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T R A N S Asian Journal of Marketing Management Research (TAJMMR)

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EVOLUTION OF ELECTRIC DRIVES

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ABSTRACT:

An important development in recent decades in technology has been the emergence of electric drives. Electric drives are essential in a number of sectors, including renewable energy systems, industry, and transportation. This chapter examines how electric drives have changed throughout time, highlighting significant innovations and breakthroughs in motor technology, control theory, and power electronics. It gives a general overview of the switch from conventional mechanical drives to electric drives while emphasizing the advantages and difficulties of this transition. It also addresses new developments and electric drive possibilities, including the incorporation of artificial intelligence and the expansion of electrification across a range of industries. This chapter provides insights into the evolution of electric propulsion and its implications for the long-term sustainability of contemporary industries.

KEYWORDS: *Drives, Electric Drives, Electrical, Energy, Motor.*

INTRODUCTION

The electrical supply system, the energy source, and the driven machine, the energy consumer, are connected by electrical drives, which transform electrical energy into mechanical energy.By offering effective, dependable, and green ways to power different mechanical systems, electric drives have transformed a number of sectors. The development of electric drives has been a wonderful journey from the early creations of simple electric motors to the complex drive systems of today.Early 19th-century scientists and innovators started investigating the possibilities of electricity as a source of mechanical power, which is when electric drives first started to take shape. Thomas Davenport's creation of the first usable electric motor in 1834 was a crucial turning point in this development. The electric drive technology was advanced thanks to Davenport's motor. Famous innovators like Nikola Tesla and Thomas Edison made substantial

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contributions to the area of electric propulsion in the late 19th and early 20th centuries. The controversy over AC vs. DC, which had a significant influence on the future of electric drives, was sparked by Edison's discovery of the direct current (DC) motor and Tesla's invention of the alternating current (AC) motor.

More effective and adaptable electric drives were created in the early to mid-20th century as a result of developments in power electronics and control systems. Transistors and thyristors, two semiconductor technologies, made it possible to regulate electric motors more precisely and adaptably. The development of changeable speed drives during this time period also made it possible to effectively manage motor speed and torque. Advancements in digital technology significantly changed the electric drive environment in the second half of the 20th century. The creation of complex motor control algorithms and intelligent drive systems was made possible by the integration of microprocessors and digital signal processors. As a result, electric drives now perform better, use less energy, and are more dependable. Recent developments in power electronics, control algorithms, and renewable energy technologies have accelerated the growth of electric drives. Electric cars are becoming more and more popular, which has sped up the development of high-performance motor drives that can provide optimum efficiency and increased range. Additionally, the overall effectiveness and sustainability of electric drives have been improved by the incorporation of energy storage technologies, such as lithium-ion batteries. Today, the desire for clean energy solutions and the spotlight on sustainability are driving the continued fast evolution of electric vehicles. The future of electric drives is being shaped by cutting-edge technologies like solid-state drives, new motor designs, and artificial intelligence-based control systems, which promise even higher efficiency, dependability, and integration with smart grid systems.

Electrical drives have emerged as a crucial element in industrial applications, as well as in transportation and consumer products, as a result of their dominant position in the energy chain flow. They have pushed technological advancement in many fields and have been the subject of countless innovations. The electricalsupplysystemandthedriven machine in the electric drives is shown in Figure 1.

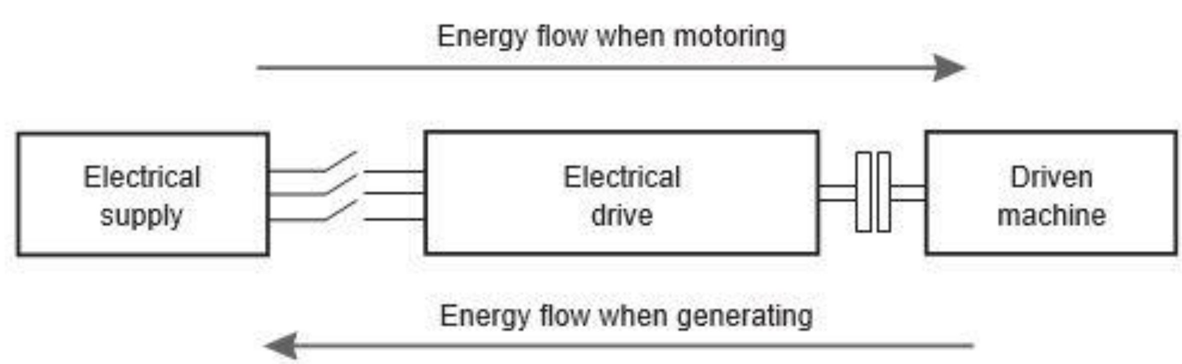

Figure 1: Electrical Drives as the Intermediary between the Electrical Supply System and the Driven Machine

The motor is the central part of any electrical drive. The early 19th century saw the discovery of the physical rules that serve as the foundation for the motor.

Discovery of the principles 1820 to 1875

Hans Christian Oerstedt observed in 1820 that a magnetic needle deflects when it is held near to a conductor carrying electricity. André Marie Ampère made his important discovery on the interplay of magnetic fields and electrical currents in the same year.These findings resulted in the creation of several "electromagnetic machines," but their practical applications were constrained by the few sources of electrical energy that were readily accessible at the time.Galvanic cells, which generate current, made it impossible to employ such "machines". They were unable to compete with the steam engine or the many varieties of gasoline or gas-powered engines.In 1831, a significant step was taken. EMF induction was discovered by Michael Faraday. This effect was used right away in generators. The dynamo was created by Werner von Siemens in 1866. This direct current generator creates a modest initial induced current using the magnetic reminisce of the magnetic poles. The excitation field created by the utilization of this induced current causes the generator to reach its maximum output. We now have the contemporary motor thanks to further improvement of these generators.

A major issue towards the end of the 19th century was providing the little amounts of energy needed for the machinery used in light industries. Because of safety concerns, steam engines could not be utilized everywhere and were expensive to maintain. As a result, gas-powered engines were often used. Dynamo machines, which had been continuously developed and improved, were the main competitors. Two electrically coupled dynamo machines made up the setup. The use of one machine as a motor and the other as a generator. The necessary electrical energy could therefore be produced at one site, transported across a greater distance, and then changed back into mechanical energy when it arrived at the area where it was needed. Mechanical energy was replaced as the transmission channel by electrical energy. Electric locomotives and city vehicles were the principal uses, although machine drives, such as those for weaving machines, were also made.

The phrase "electric motor" first appeared in a sales catalogue in 1887. The benefits of an electric motor over a steam engine and a gas motor were outlined in 1891 as follows:

1. They may be utilized in home settings, don't need a stable base, and can be installed in any direction.
2. They have a favorable efficiency and are simple to use. They can also run at quite high speeds and have variable running speeds and directions.

The three-phase squirrel-cage induction motor was created in 1889 by Michael von Dolivo-Dobrowolski. He is credited for creating the phrase "three-phase electricity." In addition, he established the first three-phase electricity transmission network in 1891, running 175 kilometers from Lauffen am Neckar to Frankfurt am Main.

For the first time, a full system made up of generators, transformers, transmission lines, and motors was shown at the International Electro technical Exhibition in Frankfurt am Main in 1891. This served as the cornerstone for the widespread adoption of electrical supply networks and electrical motors for commercial and industrial uses. The technical specifications and starting qualities of electrical motors were continually improved. Controllable electrical drives became possible with the use of resistor networks and the Ward Leonard set (a converter for changing the voltage and frequency). As a result, workshops gradually replaced their steam engines and mission systems. The machine design was no longer dependent on the energy supply provided by transmission shafts and could now be optimized to the requirements of the production process[1]–[3].

Electrical drives began to be used in many sectors of industry, including farming, trade crafts, transportation, and homes, starting about 1920. Typical drive options included DC or AC motors, together with a controller for speed control, depending on the application. Electrical drives have become much more prevalent. The development of electrical motors it took two paths: toward standardized mass goods and toward solutions that were incorporated into the driving machine. Asynchronous induction motors have increasingly being utilised in industrial settings. The early controllers, based on mercury-vapour rectifiers, were employed for variable speed applications in addition to contactor controls. Electrical drives now included power electronics.

The introduction of power semiconductors marked the beginning of the mercury-vapour rectifier's demise. Parallel to this, analogue electronic component-based controllers were created, enabling the proliferation of variable-speed drives. The comeback of DC drives was sparked by their easy controllability.

An acceleration in the development of electrical drives followed the invention of the microprocessor. Digital controllers took the place of analog ones. Continuous speed improvements allowed for the implementation of ever-more sophisticated routines. A processor-controlled digital drive was able to manage AC motors with the same control performance as a DC motor thanks to Blaschke's invention of the "field-oriented control" approach in 1971.

The integration of previously alien to the drive operations into the controller was made possible by the availability of microprocessors with growing power. The distinction between electrical drives and automation devices is less distinct nowadays. Drive systems, which are composed of low-power servo drives that are electronically coordinated, are increasingly replacing centralized drives with mechanical gears and main line shafts.

DISCUSSION

The process variables in the driven machine are controlled using the mechanical energy that the electrical drive provides. To suit the demands of the process, the mechanical energy must be changed or turned on and off. Because of this, a contemporary electrical drive has many more parts than just an electrical motor. The Functional Blocks of modernelectricaldrive is shows in Figure 2.

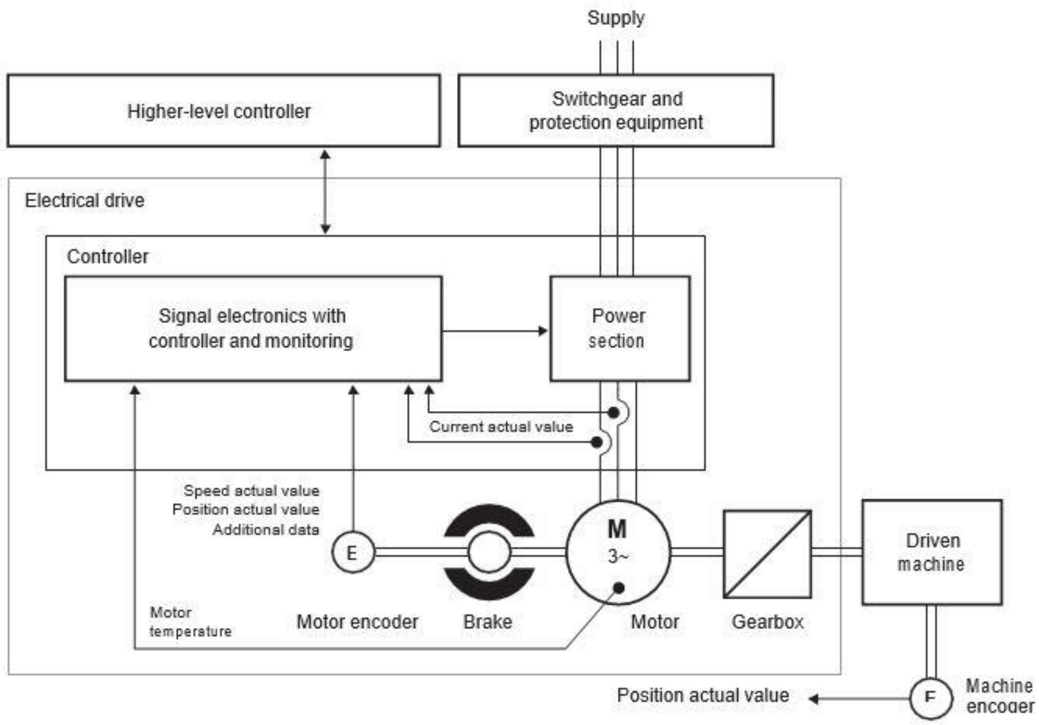

Figure 2: Functional Blocks of ModernElectricalDrive.

Additional Components of ModernElectricalDrive

1. Electric motor

Every electrical drive has an electric motor at its core. It transforms the provided electrical energy into mechanical energy, acting as an energy transformer. The energy flow is in the reverse direction during generating operation, such as while braking, when mechanical energy is transformed back into electrical energy.

2. Motor encoder

The signal electronics can access real quantities like rotating speed, speed, and location thanks to a motor-mounted encoder (motor encoder).

3. Brake

When the controller is turned off, a brake keeps the motor from moving and aids the controller in stopping it. The brake keeps the mechanical system tight even when the drive is off, which is especially important when working with hanging weights like robotic arms, elevators, and hoists.

4. Gearbox

A mechanical transformer is a gearbox. It matches the mechanical quantities—such as speed and torque that the motor supplies to those that the driven machine needs. Another responsibility is to, when required, transform a motor's circular action into a linear movement.

5. Switchgear and protection equipment

When required, switchgear and protective devices separate the electrical drive from the supply to prevent overloading the drive and supply cables. Overloading may be brought on by the driven machine itself or by a drive malfunction[4]–[6].

6. Controller

A power portion and signal electronics make up a controller:

1) The power section "portions" the electrical energy to the motor, which has an impact on the mechanical energy the motor produces. Power semiconductors are the foundation of contemporary electrical drives' power sections. These function as electrical switches, turning on and off the flow of electricity to the motor. The signal electronics may access the electrical currents and voltages that integrated measuring devices have measured.

2) The "brain" of an electrical drive is the signal electronics. In order to supply the necessary power or movement at the motor shaft, it determines the control signals for the power section. The signal electronics' many control features make this possible. The power section provides the signal electronics with the necessary electrical amount real values, whilst the motor encoder provides the necessary mechanical quantity actual values, such as rotational speed and position. A higher-level controller, to whom the real values are also sent, supplies the set point values to the signal electronics. The signal electronics handle the essential control tasks as well as protection tasks and guard against improper overloading of the power section and the motor[7]–[9].

Furthermore, improving the efficiency and dependability of electric drives has been made possible by the development of control techniques and power electronics. Precision speed and torque control has been made possible by cutting-edge control algorithms, sensor technologies, and feedback systems, leading to smoother operation and increased system efficiency. Electric drives have been more easily incorporated into a variety of applications because to developments in power electronics, such as the creation of small, effective power converters.The development of electric drives will also be fueled by the growing use of electrification in industrial applications, renewable energy systems, and transportation. The expansion of electric drives will be further aided by the continued advancement of battery technology, charging infrastructure, and smart grid integration, which will also make it possible for a cleaner and more sustainable energy ecology[10], [11].

CONCLUSION

The development of electric propulsion has made amazing strides, transforming several sectors and promoting sustainable growth. Numerous advantages have come with the switch from conventional mechanical drives to electric drives, including increased energy efficiency, less emissions, and enhanced system performance. The power and efficiency of electric drives have been greatly increased because to developments in motor technology, such as the creation of high-efficiency permanent magnet motors and the use of new materials. The performance and autonomy of electric motors may be greatly improved by combining artificial intelligence and machine learning methods. Intelligent control algorithms may improve energy efficiency and reliability by optimizing system performance, adapting to changing circumstances, and enabling predictive maintenance.

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CLASSIFICATION OF ELECTRICAL DRIVES

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ABSTRACT:

Electrical engineering's classification of electrical drives is a key component that is important to many industrial applications. An overview of the categorization techniques used for electrical drives is given in this chapter. The research examines the many classification criteria for electrical drives, such as power source, control method, motor type, and application domain. It shows the importance of each categorization strategy in the design of effective and dependable drive systems and explores its benefits and drawbacks.

KEYWORDS: *Drives, Electric Motor,Electrical Drives, Motor, Speed Drives.*

INTRODUCTION

Electrical drive classification is the process of grouping distinct electric motor drive types according to a variety of factors, including the kind of load, control methods, power source, motor characteristics, and application needs[1]. Electrical drives are an essential part of a variety of industrial, commercial, and residential applications because they are essential in turning electrical energy into mechanical energy.Depending on the viewpoint and particular needs of the system, different electrical drives may be categorized. Here, I'll provide a broad overview of the categorization system based on standard criteria:

Nature of Load:

1) Continuous Load: This load, which includes centrifugal pumps, fans, and conveyors, requires a reasonably continuous amount of torque[2].
2) Variable loads, such as those produced by machines, elevators, and robots, have torques that change over time.
3) Intermittent Load: A load that often starts and stops while operating for brief periods, such as a crane or a punch press.

Control Techniques:

1) Voltage/Frequency regulate: In induction motor drives, the voltage and frequency supplied to the motor are adjusted to regulate motor speed.
2) By independently managing the flux and torque components of the motor, flux vector control offers accurate control of both motor speed and torque.

3) Without the requirement for coordinate transformations, direct torque control (DTC) enables quick and precise control of motor torque and speed.

Power Source:

1) Drives that employ DC motors are known as DC drives. These drives need a DC power supply, which may be acquired from batteries or rectified AC.

2) Drives that employ AC motors are known as AC drives, and they may be further divided into drives that use single-phase or three-phase AC power supplies[3].

Motor Characteristics:

1) Drives for Induction Motors: Because of their durability, dependability, and affordability, induction motors are often employed. They provide excellent speed control and are appropriate for a variety of applications.

2) Synchronous motor drives provide accurate speed control and are often used in machinery like CNC machines and robots that must operate at a high level of performance.

3) Drives that use permanent magnet motors have outstanding dynamic response, are small in size, and have high efficiency[4].

Application prerequisites

1) Servo drives are used in high-precision positioning systems, including robots, CNC machines, and automated manufacturing, that need precise speed and position control.

2) Variable Frequency Drives (VFD), sometimes referred to as changeable speed drives, are frequently used for induction motor speed adjustment in a variety of applications.

Electrical drives come in a wide variety of styles and are quite versatile. As a result, categorizing them is rather challenging and can only be done by choosing certain criteria, i.e. from a particular viewpoint. A broad variety of potential driving solutions are then provided by the combination and careful selection of these parameters.

According on the following characteristics, electrical drives are categorized:

1. Speed adjustable;
2. Motor and drive controllertype;
3. Technical data.

1. Variability in speed

A drive solution is often chosen based on an application's needs for speed variability. Drives may be loosely categorized into three groups based on their speed variability:

A. Servo drives;

B. Fixed-speed drives;

C. Variable-speed drives.

1) Fixed Speed Drives

Drives that have a fixed speed are operated at that speed. They merely have the tools essential for turning on and off, as well as for overload protection. Since there is no way to change the drive's speed, the speed will fluctuate based on the load. Fans and pumps that are run directly on line by an asynchronous motor are typical applications for fixed-speed drives[5].

2) Variable Speed Drives

Drives with variable speeds can run at least two distinct speeds and have an adjustable speed. These drives contain a controller, which controls the speed in addition to an electric motor. The controller is complex and offers a variety of speed and precision options depending on the application.

i. Drives with switchable speeds enable operation at a minimum of two distinct speeds. Switchable-speed fans and pumps or traverse drives with forward and reverse functionality are a few examples of uses. Usually, asynchronous motors and the required contactor controller are employed.

ii. The speed of open-loop variable-speed drives is continually changeable. However, since there is no feedback of the actual speed, there may be load-dependent variations from the set point speed depending on the drive type. The speed control requires a controller with an electronic power section. Asynchronous motors with frequency controllers and V/f control are examples of this sort of drive.

iii. Closed-loop variable-speed drives assess the actual motor speed in addition to having a continuously changeable speed. This makes it possible to identify and fix speed deviations from the speed set point. A controller with the proper control algorithms is required to make this possible. The asynchronous motor with frequency controller and vector control is a fairly common kind of closed-loop variable-speed drive[6].

Frequencyconvertersandasynchronousmotorsforvariable-speed drives are show in the Figure 1.

Figure 1: Frequency Converters and Asynchronous Motors for Variable Speed Drives.

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3) Servo Drives

Servo drives are designed to accurately and quickly detect changes in speed. As a result, they are highly suited for complicated motion jobs that include often changing speeds. Every aspect of machine construction uses servo drives, which are usually realized using synchronous motors and servo controllers.Servo drives are shows in Figure 2.

Figure2: ControllersandMotorsforServoDrives.

2. Motor and controller types

Different motor types have emerged throughout time, each having its own advantages and disadvantages as well as preferred power ranges. Due to this and the very long lifespan of the motors themselves, almost all motor types are still in use today. A broad range of drives are produced when the diversity of controllers that are readily accessible is also taken into consideration. A taxonomy of the fundamental motor types and their potential controllers is shown in Figure 3.

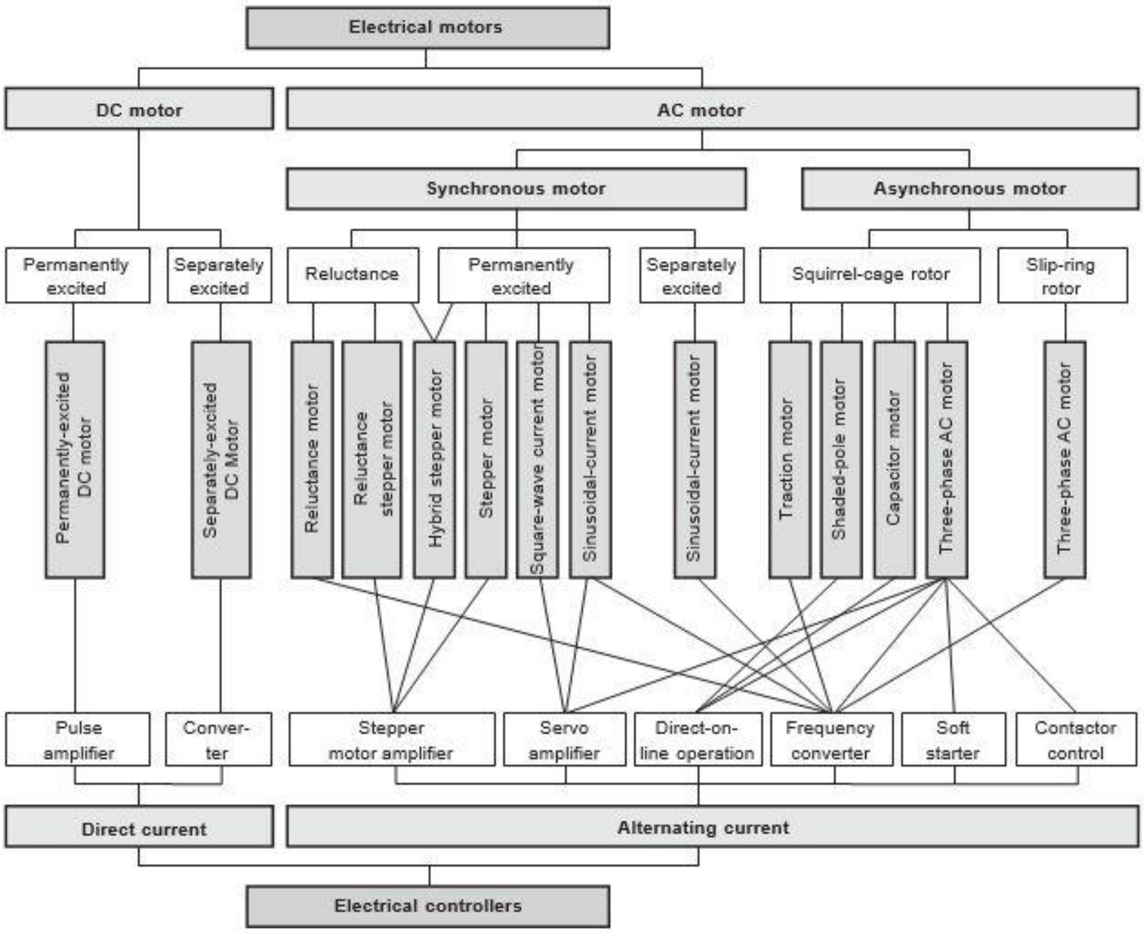

Figure 3: Classification of Electrical Drives by Motor and Controller

Drives are split into DC drives and AC drives (single-phase and three-phase) based on the motor current.

1) A DC motor is used by DC drives. Permanent magnets are used to create the magnetic field in the lower power range, while a separate excitation winding is used to create it in the higher power range. Highly dynamic pulse-controllers are employed for servo applications, whereas converters are used as the controller for variable-speed drives.

2) AC drives use motors that are powered by single- or multiple-phase AC electricity. The motor speed is significantly impacted by the motor current's frequency. While asyn-chronous motors have a mismatch between the frequency of the motor current and the rotational frequency, synchronous motors precisely match the frequency of the supply current.

The majority of drives use synchronous motors and a controller. Asynchronous motors may be run directly on the line or in conjunction with a controller. The needed speed range and the requisite precision determine the controller to be used[7]–[9].

3. Technical data

Motor data

The main selection criterion for electrical drives are the technical data. The mechanical and electrical characteristics of the motor are of utmost significance.

Rated data motor

Especially important are the graded data. They provide information about the motor at its rated operating point and may be used to contrast several motors. Nominal data is another name for rated data.

i. Motor type: specifies whether the motor is a three-phase AC motor, a single-phase AC motor, or a DC motor.
ii. Rated voltage: the maximum voltage level or range at which the motor can run continuously. For a certain time, overvoltage that fall within a specified range are allowed.
iii. Rated current: The maximum continuous operating current that a motor can handle before thermal overloading occurs. Overcurrent are permitted for a brief amount of time within a certain range.
iv. Rated power: The mechanical force that the motor produces while it is working at its rated capacity. From the provided electrical data, the electrical power consumption may be determined. The motor's efficiency may be determined if both the electrical and mechanical data are available.
v. Power factor: For single-phase and three-phase AC motors, the power factor makes it possible to compute the active power used at the rated operating point.
vi. Rated frequency: the frequency at which single-phase and three-phase AC motors' supply voltages are rated. The rated frequency for asynchronous motors is often the same as the line supply frequency, which is 50 Hz for industrial networks in Europe.
vii. Rated speed: The motor's speed at its designated operating range.
viii. Rated torque: The amount of torque a motor can produce at its rated current. This factor is particularly significant when choosing a servo motor.

Rated data controller

An appropriate controller may be discovered when a motor has been chosen based on its rated data. The controller's electrical data identifies it:

i. Rated voltage: The maximum voltage or voltage range at which the controller may be used. When choosing the controller, consideration should be given to the voltage as well as the line supply configuration (single-phase, three-phase, earthing idea).
ii. Rated current: The maximum output current the controller is capable of delivering continuously. For a brief time, many controllers permit overcurrent, such as while accelerating.

iii. Pulse frequency: the rate at which the servo and frequency controllers change the motor voltage. The drive becomes more dynamic and quieter as the frequency increases.

Mechanical design motor data

A variety of positive data are required in addition to the motor-rated statistics. They are used to match the motor to the machine being driven as well as its surroundings.

i. Construction type: outlines the motor's technical installation and mounting directions that are acceptable. The kinds of construction are outlined in international standards and are categorized as IM yzz (International Mounting) show in the Table 1.

TABLE1: EXAMPLESOFMOTORMECHANICALDESIGNCLASSIFICATION

IM	y: Shaft direction	zz: Mounting method
	B: horizontal V: vertical	Specified by either one or two digits
e.g. IM B3	Horizontal	Foot Mounting
e.g. IM B5	Horizontal	Flange Mounting

ii. Frame size (shaft height): the distance, in millimeters, between the motor's outside edge and its center shaft.

iii. Thermal class: The maximum allowable motor temperature is determined by the thermal class. Overcoming this temperature may cause the winding insulation to prematurely age and eventually fail. The thermal classifications are listed using a single capital letter and are established by international standards. Thermal class F, for instance, designates a permissible motor temperature of 140 °C on average.

System data

The system data define the open-loop and closed-loop controlled drives, which include a controller, an encoder, and a motor. They must be requested again since they are often not released by the manufacturer[10], [11] .

i. Speed range: The range within which the speed may be changed with a certain level of precision in proportion to the rated speed.

ii. Accuracy of speed and torque: difference between rated value and set point in respect to that value.

DISCUSSION

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The classification of electrical drives is a fundamental aspect of understanding and analyzing their diverse applications and functionalities. By categorizing electrical drives based on specific criteria, such as the type of power supply, control method, motor type, or intended use, researchers and engineers can gain valuable insights into their characteristics and select the most suitable drive for a given application. This classification system facilitates the systematic study and comparison of different drive technologies, enabling the development of efficient and optimized solutions across various industries, including automotive, aerospace, industrial automation, robotics, and renewable energy systems. Moreover, a comprehensive understanding of the classification of electrical drives serves as a basis for designing, modeling, and controlling these systems, contributing to advancements in energy efficiency, performance, and reliability. As technology continues to evolve, new drive classifications may emerge, further expanding the capabilities and possibilities of electrical drives in the future.

CONCLUSION

In this chapter, we understand and creating effective drive systems depend on the categorization of electrical drives. On the basis of power supply, control scheme, motor type, and application area, we spoke about categorization. The power source categorization aids in choosing the proper power conversion and control methods by differentiating between drives supplied by an AC or DC supply. The categorization of control strategies takes into account the techniques used to manage the motor's speed, torque, or position, such as voltage control, current control, or field-oriented control. Drives are categorized depending on the kind of motor being used, such as DC motors, induction motors, synchronous motors, or stepper motors, using the motor type categorization. This categorization makes it easier to choose the motor with the right qualities for a certain application.

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ELECTRO-MECHANICAL ENERGY CONVERSION

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ABSTRACT:

Electric motors, generators, transformers, and renewable energy systems all depend on the electro-mechanical energy conversion process, which is a basic procedure. The ideas and methods behind electro-mechanical energy conversion are summarized. The many electro-mechanical device types and their working theories are covered in the chapter. It also emphasizes the significance of effective energy conversion for clean and sustainable energy systems. Understanding electro-mechanical energy conversion is essential for the creation of cutting-edge technologies and for the optimum use of energy across a range of sectors.

KEYWORDS: Force, Electric Motors, Energy, Magnetic field.

INTRODUCTION

The process of transforming electrical energy into mechanical energy or vice versa is known as electro-mechanical energy conversion. To accomplish the necessary energy transformation, it includes the interplay of electrical and mechanical systems[1]. From transformers and transducers to electric motors and generators, this sector is essential to many different applications. Electrical energy is often produced, transported, and distributed in an electro-mechanical system as either alternating current (AC) or direct current (DC). Magnetic fields and electrical conductors interact to create the conversion process[2].The two primary categories of electromechanical energy conversion are:

Electrical-to-Mechanical Conversion: In this kind, electrical energy is transformed into mechanical energy. Electric motors are a typical example, where the electrical input is converted into mechanical rotation. Electric motors are extensively employed in many different applications, including robots, home appliances, transportation systems, and industrial gear[3].

Mechanical-to-Electrical Conversion: Electrical energy is transformed from mechanical energy in a process known as mechanical-to-electrical conversion. The use of generators or alternators is a classic example of mechanical-to-electrical conversion. Generators are used to generate electricity from a variety of mechanical sources, such as hydroelectric, wind, or steam turbines. When mechanical energy from various sources is captured and transformed into electrical energy for distribution and consumption, power production systems depend on this process[4].

The conversion of electro-mechanical energy relies heavily on electromagnetic induction and electromagnetism principles. According to these principles, energy is converted between electrical and mechanical forms as a result of the interaction between magnetic fields and electrical currents. Efficiency is a key factor to take into account when designing electro-mechanical energy conversion systems since conversion losses might happen. The total efficiency of the conversion may be impacted by a number of variables, including resistive losses, magnetic losses, and mechanical losses[5].

System efficiency, performance, and reliability have all increased as a result of improvements in electro-mechanical energy conversion technology. These advancements have helped to enhance the use and influence of electro-mechanical energy conversion in our contemporary society by fostering the development of renewable energy sources, electric cars, and energy-efficient appliances.We are surrounded by electric motors everywhere. Pumps in your heating system, refrigerator, and vacuum cleaner are linked to a single phase AC grid and turned on or off by a simple contactor, whereas generators at power plants are connected to a three-phase alternating current (AC) power grid. The starting motor, windshield wiper motors, and other utilities are powered by a direct current (DC) battery in automobiles. These motors use direct current and are often switched on by a relay without any control.

Numerous applications that use electric motors need for more or less sophisticated control. A fan or pump's speed may be decreased in a reasonably straightforward manner. The dynamic placement of a pull in a wafer-stepper with non-scale precision while accelerating at multiple g's is perhaps one of the trickiest. An electric crane in a port presents another hard controlled drive since it must be able to move an empty hook at high speed, move large loads up and down at moderate speeds, and make a gentle landing as near as possible to its planned ultimate position. Other uses, ranging in complexity from simpler to more complicated, include CD players, electric elevators, trains, streetcars, electric motor control in hybrid vehicles, and assembly robots[6].

A thorough grasp of how these motors interact with power electronic converters and their loads is necessary for the design and analysis of all electric drive systems. This information is in addition to knowledge of the dynamic characteristics of various motor types. These power converters are used in a variety of ways to regulate motor currents or voltages[6]. Electric drive systems have a very broad range of applications compared to other drive systems like steam engines (still used for aircraft launch assist), hydraulic engines (famous for their extreme power per volume), pneumatic drives famous for their simplicity, softness, and hissing sound, combustion engines in vehicles, or turbo-jet drives in helicopters or aircrafts:

a) Wide range of available power: actuators and drives are employed in a huge variety of applications, from microwatt-level devices like wristwatches to megawatt-level equipment like those found in steel mills, ship propulsion systems, and coal mines.

b) Since electrical drives may deliver their maximum torque at a complete stop, clutches are not necessary.

c) Electrical drives often do not need gearboxes and may provide a very wide speed range.

d) No projected oil leaks and clean operation.

e) Pumps at oil refineries and other settings with explosive gases may be operated safely.

f) Instant use: Electric drives may be turned on right away.

g) Low maintenance requirements: With the exception of the bearings, electrical drives don't need to be serviced often since there are so few parts that might wear out. As a result, electrical drives may last a very long time—typically more than 20 years.

h) Low no-load losses: Since there is no need to circulate oil to keep a drive lubricated while it is idle, little power is lost. An average drive has an efficiency level of about 85%. In rare circumstances, this might reach 98%. The drive technology is more expensive to start with the greater the efficiency.

i) When compared to combustion engines, electric drives generate very low acoustic noise.

j) Excellent controllability: electrical drives may be configured to precisely match user needs. For instance, this can have to do with reaching a certain shaft speed or torque level.

k) Four-quadrant operation the motor and brake modes may both be used in the forward or backward direction, resulting in four distinct quadrants: the forward motoring, the forward braking, the reverse motoring, and the reverse braking. Forward denotes forward motion, whereas reverse denotes reverse motion. When energy is transmitted from the power source to the shaft, or when both torque and speed have the same sign, a machine is said to be in motor mode.

What Makes High Performance Drives Special?

It is crucial to comprehend the motivations for the continual development of drives before moving on to a thorough explanation of the different drive components. For instance, when switching from a load to a controller, it's important to understand the load's characteristics, the motor's operation, and how the converter and modulator work. Last but not least, one must comprehend the control principles at play and how to incorporate the control algorithms (in software) into a microprocessor or DSP. As a result, one of the most difficult elements of working in this sector is having a thorough grasp of a very broad variety of issues. As was previously noted, the invention of electrical machinery took place more than a century ago[7]. The transition to a high-performance changeable speed drive, however, took a lot longer and is still running strong today.Below is a quick summary of the primary factors that have led to advancements in drive technology throughout the years:

a) The converter's ability to use quick and dependable power semiconductor switches. The user nowadays has access to a variety of switches to design and construct a variety of converter topologies. MOSFETs for low-voltage applications and IGBTs for medium (kW) and higher (MW) powers are the two types of switching devices most often utilized for motor drives. GCTs are furthermore offered for applications requiring medium- and high-voltage.

b) Accessibility of powerful computers for embedded (real-time) control: The controller must provide the modulator control input at a sampling rate that is generally in the range of 100 s. The computer must gather input data from sensors and user set-points throughout that period in order to apply the control algorithm and determine the control outputs for the subsequent cycle. Since the middle of the 1980s, the development of drives has been greatly aided by the availability of inexpensive, quick microprocessors or DSPs.

c) Better sensors: The user has access to a variety of dependable, affordable sensors that provide precise inputs to the controller, including LEMs, incremental encoders, and Hall-effect sensors.

d) Better simulation tools: Access to powerful "finite element" computer assisted design (CAD) software for motor design has been crucial to improving our knowledge of machines. Additionally, they have been and still are used for machine design and optimization. There are simulators with graphical user interfaces for modeling the full drive structure, including, among others, MATLAB/SimulinkXR and PLECSXR, which enable the user to examine a comprehensive dynamic model of the entire system. This implies that without having to construct the full system, one may examine novel control strategies and assess the behavior of such a system under various situations. This does not imply that putting into place real-world mechanisms is no longer necessary[8].

Experiment and simulation are never identical. It may be beneficial to improve the simulation model to include some of the discovered discrepancies when the models are unable to accurately reflect the drive system under certain circumstances. As engineers, we should be aware that drive systems are often closed-loop systems capable of tolerating (to a certain degree) parameter variations and unidentified load torques without any issues. The secret to a good simulation, to quote Einstein, is that "A simulation model should be as simple as possible, but no simpler". This implies that in order to examine extreme scenarios with respectable accuracy, the (physics-based) simulation model must include key dynamics or non-linearity that are present in the actual world system. Depending on what needs to be examined, a particular simulation model is utilized. While the overall mechanical system and the motor's response can be calculated at a hundred times larger time-step with negligible accuracy loss, as long as the power converter is regarded as a non-switching controlled voltage source, simulating pulse width modulated outputs requires a very brief simulation time-step, in the order[9]. The investigation of heat impacts on the motor is another severe case. In such instance, the only power dissipation that is of concern is the average, measured in seconds or even minutes.

1. Better materials have made it possible to create effective machines that can resist greater temperatures, providing extended application lives and low life-cycle costs. These materials include enhanced magnetic, electrical, and insulating materials.

Electrical Engineering Specialties

The effects of fields are used by electrical drives. A field describes the area where forces are applied to things or particles. The force's activity is visually represented by a field pattern. The force acts in a manner that is tangential to the field lines. The force acts more strongly the closer together the field lines are. In electrical engineering, magnetic and electric fields are significant (other fields include sound and gravity fields, for example). Electric drives make use of both fields.

Electric field

A region in which forces are exerted on electrically charged particles is referred to as an electric field. The charged particles themselves exert the forces. Positively and negatively charged particles are both types of charged particles. The charged particles in an Electric field is show in the Figure 1.

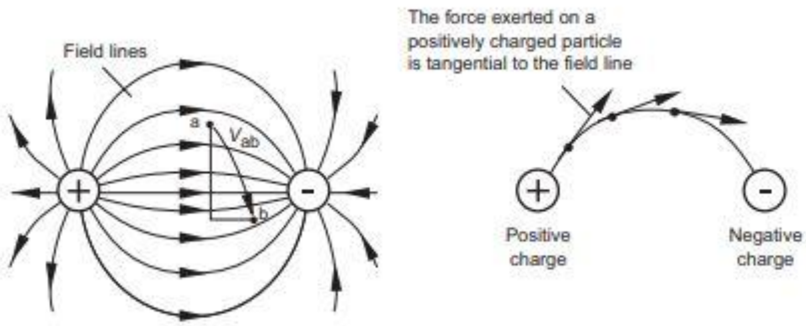

Figure 1: Anelectricfield [technicalbookspdf]

The following holds true:

1. Particles with opposite charges repel one another.
2. Particles with opposing charges are drawn to one another.

An electric current is produced when charged particles are introduced to an electric field and start to flow. The amount of charged particles that flow from point A to point B in a certain amount of time is described by the electric current. Energy is either released or absorbed, depending on how the charged particles travel.

The difference in energy of a charged particle relative to its charge at various sites in the electric field may be measured using the electric voltage, which characterizes the electric field as a whole.

Magnetic field

A magnetic field is a region where magnetic bodies are subject to forces. For instance, a magnetic needle will align itself in a magnetic field as a consequence of this. The magnetic field is show in Figure 2.

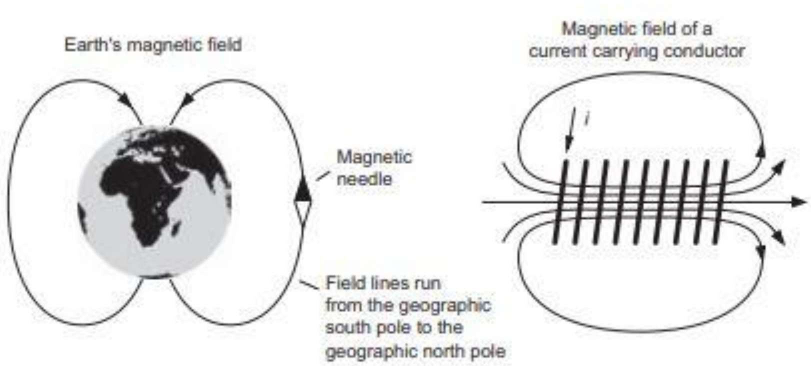

Figure 2: A magnetic field[technicalbookspdf]

Two methods may be used to create a magnetic field:

1. The magnetic field is a property of the material in the case of natural magnetism. A magnetic field surrounds certain materials, such as "hard" magnetic iron.
2. In the case of an artificial magnetic field, the magnetic field is produced by the passage of current, which may happen, for instance, in an electrical conductor. A magnetic field of this kind surrounds all conductors that carry current.

Electric motors use both magnetic field-generating effects.

Iron-based magnetic circuits are used to channel the magnetic fields in motors. The magnetic field is made as strong as feasible by minimizing air clearances and gaps. The magnetic field is enhanced by iron. Iron may be described as either "soft" or "hard" magnetically.

Only when "soft" magnetic iron is surrounded by an external magnetic field can it become magnetic on its own. Iron ceases to be magnetic if the magnetic field is eliminated, as is done, for instance, by cutting off the current that generates the magnetic field. Low magnetizing and demagnetizing losses are a result of the "soft" magnetic iron's very short hysteresis loop region. For this reason, "soft" magnetic iron must be used to build motor components exposed to shifting magnetic fields.

A persistent (retentive) magnetic field distinguishes "hard" magnetic iron. It may be used with permanent magnets. However, because there are alternative, magnetically stronger materials like samarium-cobalt (SmCo) or neodymium-iron-boron (NdFeB) that are available, "hard" magnetic iron is seldom utilized for the permanent magnets in motors.

Developing torque

Force of Lorentz

1. Force on a charged particle

The physical phenomenon that occurs when an electrical charge is transported in a magnetic field and subsequently experiences a force is of utmost significance for the operation of an electric motor. The Lorentz force is the name given to this force. Charges that are static are not affected by the Lorentz force.

2. Right-hand principle

The magnetic field's direction, the electrical charge's motion, and the resulting force are all correlated in a certain way. The angles between the three halves are all perpendicular. The three fingers of the right hand (not the left) may be used to discern each unique orientation as a visual mnemonic, as seen in Figure 3.

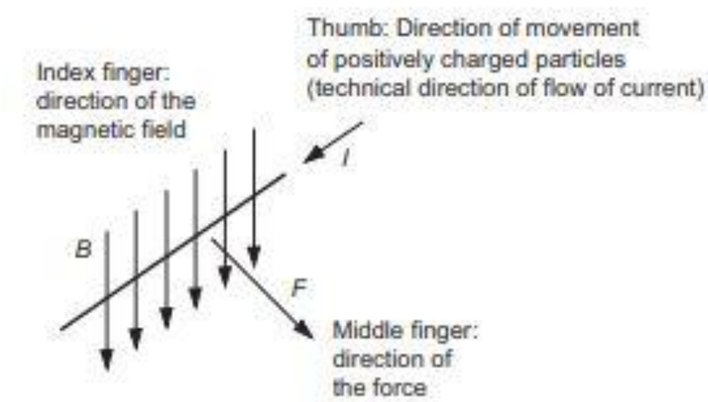

Figure 3: Theright-hand rule[technicalbookspdf]

3. Force on a current carrying conductor

The charge carriers in electrical conductors move in electric motors. The Lorentz force is felt by the charge carriers in a conductor that is conducting current when it is put in a magnetic field. The conductor receives this force impact from the charged carriers, which they are unable to escape. As a consequence, the conductor carrying the current is affected by the whole Lorentz force. The conductor will move in accordance with the applied force if it is not mechanically fixed. Electric motor torque is generated by using this phenomenon.

4. Strength of the Lorenz force

The Lorentz force's strength is proportional to

1. The magnetic field's strength, as well as
2. The quantity and rate of moving charged particles, which influences the strength of the electric current.

This brings to a close the examination of the key elements involved in an electric motor's ability to generate a significant amount of torque. Big torques and, hence, a big force effect may be produced by using powerful magnetic fields and huge currents. All electric motors utilize the Lorentz force, with the exception of reluctance motors. Reluctance motors provide torque due to the magnetic attraction between iron and electromagnets.

CONCLUSION

The effective conversion of electrical energy into mechanical work and vice versa is made possible by the electro-mechanical energy conversion process. To create and enhance diverse electro-mechanical equipment like electric motors, generators, and transformers, it is essential to comprehend electromagnetic induction and the relationship between electrical and mechanical systems. Achieving sustainability objectives and boosting the use of renewable energy sources need efficient energy conversion. We can improve the functionality of energy systems, lower energy losses, and have a less negative environmental effect by improving electro-mechanical energy conversion processes. Advancements in clean energy technology will be made possible by ongoing research and innovation in the area of electro-mechanical energy conversion, paving the way for the transition to a more sustainable and environmentally friendly future.

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FIXED SPEEDANDVARIABLE SPEEDDRIVESWITH DCMOTORS

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ABSTRACT:

In many situations where DC motors are utilized, fixed-speed and variable-speed drives are often used. This chapter gives a general overview of different drive methods and how they affect the effectiveness and performance of DC motors. In this chapter, fixed-speed and variable-speed drives' benefits and drawbacks are compared while taking energy use, speed control, and torque characteristics into account. The results help to clarify the applicability and efficiency of fixed-speed and variable-speed drives using DC motors.

KEYWORDS: *Dc Motor, Drives, Fixed-Speed Drives, Variable-Speed Drives.*

INTRODUCTION

Due to their dependability and controllability, DC motors are often employed in several industrial and commercial applications. Two popular forms of motor control systems are used: fixed-speed drives and variable-speed drives, to improve their performance and efficiency.

Fixed-Speed Drives:

The DC motor is intended to run at a consistent speed throughout operation thanks to fixed-speed drives, sometimes referred to as constant-speed drives. These drives generally consist of a straightforward control system that supplies a constant voltage or current to the motor, causing the motor shaft to rotate at a given speed.In situations where a consistent speed is necessary, such as with certain conveyor systems, pumps, and fans, fixed-speed drives are often used. These drives are uncomplicated, affordable, and simple to maintain. They don't have the adaptability to adjust to shifting load circumstances, however, or the necessity for fine-grained speed control[1].

An electric motor that runs at a constant speed independent of the load or applied voltage is referred to as a fixed-speed DC motor, sometimes known as a single-speed DC motor. These motors are often used in machinery including fans, pumps, conveyors, and certain industrial equipment when a precise speed is needed.DC motors with fixed speeds are made up of numerous essential parts. A rotor (the revolving component), a stator (the stationary component), and a commutator make up the major components. While the stator is composed of a number of coils that produce a magnetic field as electricity passes through them, the rotor is often comprised of a permanent magnet or electromagnet. The commutator, which is often a collection of copper segments, changes the coils' current direction as the rotor rotates in order to maintain rotation.

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The motor rotates when power is applied because of the interaction between the magnetic fields of the rotor and the stator coils, which creates a torque. The supply voltage, the magnetic field's intensity, and the motor's design all affect how quickly the motor rotates.Fixed-speed DC motors lack intrinsic speed control, in contrast to variable-speed DC motors, which accomplish it by using extra control methods as electronic speed controllers (ESCs) or pulse-width modulation (PWM)[2]. These motors' speeds are often fixed dependent on their construction and the supply voltage used. Fixed-speed DC motors provide several benefits in terms of dependability and ease of use. Due to the lack of complicated control systems, they are generally simple to run and maintain. Furthermore, these motors are often less expensive than more advanced variable-speed motor choices. These motors' fixed speeds, however, might be a drawback in situations when speed change is required or desired. Alternative motor types, such as DC motors with variable speeds, AC motors with VFDs, or other control methods, are often used in these situations[3].DC motor fixed-speed drives provide a number of benefits in a variety of applications. Some of the main benefits are as follows:

1. **Simple Control:** Compared to AC motors, DC motors are intrinsically easier to control. Fixed-speed drives with DC motors provide simple speed and torque control, making them appropriate for applications that don't need accurate speed regulation.
2. **Cost-Effectiveness:** Compared to AC motors, fixed-speed drives for DC motors are often more affordable. The control system's simplicity lowers the drive's overall complexity and expense.
3. **High Starting Torque:** DC motors have a high starting torque that enables them to accelerate large loads fast without the use of extra gearing or other mechanical aids. They are thus perfect for systems that must often start and stop, such conveyors.
4. **Speed Regulation:**Speed regulation is still possible with fixed-speed drives even if they lack variable speed control. This is done by using simple control techniques such altering the input voltage or connecting resistors in line with the motor. Due to this, some degree of flexibility is possible in applications that need for little speed modifications.
5. **Broad Operating Range:** Fixed-speed DC motors with a broad range of operating voltages and currents provide for flexibility in a variety of power supply situations. They are suited for usage in distant or off-grid regions where the power source may be unstable because of their versatility.
6. **Durability and Dependability:** DC motors are renowned for their extended lifespans and dependability. Compared to AC motors, they are simpler to build and have fewer moving components, which means less wear and tear. Because of this, they are dependable and economical in situations where continuous running is necessary.
7. **Regenerative Braking:** The energy produced during deceleration or braking is recycled back into the power supply system. DC motors are simply configurable for regenerative braking. Energy efficiency is made possible by this function, which also lowers the system's total energy usage.

8. Fixed-speed drives using DC motors may often be adapted into current systems with very minor adjustments. This may save time and money during installation when replacing or updating outdated equipment.

It is important to remember that the choice between fixed-speed drives with DC motors and alternative motor technologies relies on the application's particular needs. Other drive methods, including variable frequency drives (VFDs) using AC motors, may be more appropriate for applications that call for precise speed control or varied speeds.

Variable-Speed Drives:

The speed of the DC motor may be varied using variable-speed drives, sometimes referred to as adjustable-speed drives or variable-frequency drives (VFDs). These drives provide accurate speed adjustment by adjusting the voltage and frequency delivered to the motor using cutting-edge electronic control methods. In terms of energy savings, enhanced process control, and less mechanical stress on the motor and driven equipment, variable-speed drives provide a number of benefits. These drives improve energy efficiency and may result in considerable cost savings in applications like industrial automation, HVAC systems, and electric cars by adjusting the motor speed according on the load needs[4].

Torque control, regenerative braking, acceleration and deceleration ramps, and other characteristics of variable-speed drives improve the performance of individual motors and the efficiency of the whole system. Additionally, they provide remote diagnostics and monitoring, which boosts system dependability and aids in proactive maintenance. Electronic devices known as variable-speed drives (VSDs) are used to regulate the speed and torque of electric motors. They are extensively used in many industrial and commercial applications to increase motor performance, reduce energy use, and improve process control. Although several motor types, such as AC induction motors, are used in VSD systems, this introduction will concentrate on variable-speed drives for DC motors[5].

DC motors are electric motors that use the interplay of magnetic fields to transform electrical energy into mechanical energy. They are made up of a revolving component called the rotor that feels a torque in the presence of the magnetic field and a stationary component called the stator that produces a magnetic field. DC motors with variable-speed drives may have their speed precisely controlled by changing the voltage and current that are provided to the motor. This is accomplished by modulating the power provided to the motor using power electronic devices, such as transistors or silicon-controlled rectifiers (SCRs)[6].

The following are the primary benefits of employing variable-speed drives with DC motors:

1. VSDs provide smooth and precise speed control of DC motors across a broad range. They are excellent for applications requiring precise speed control, such as conveyor systems, machine tools, and robotic ones, because to their versatility.

2. VSDs allow for fine control of torque by adjusting the voltage and current sent to the motor. This is especially helpful in situations with fluctuating loads since the motor may change its torque output to suit the situation.

3. Energy efficiency: By adjusting the motor speed to the load requirements, VSDs may considerably increase energy efficiency. Energy consumption may be decreased by operating the motor at lower speeds when the load is light, leading to energy savings and lower operating expenses[7].
4. Soft starting and braking: By gently ramping up or down the motor speed, variable-speed drives provide soft starting and braking of DC motors. This lengthens the lifetime of the motor and any related equipment by reducing mechanical stress on them.
5. Process optimization is made possible by the precise control provided by VSDs for industrial operations. Manufacturers may improve quality control, boost productivity, and decrease waste by changing the motor speed in accordance with the demands of a given process.

It is important to note that, despite the industry's move toward the usage of VSDs with AC induction motors or permanent magnet synchronous motors (PMSMs) owing to their increased energy efficiency and fewer maintenance needs, VSDs for DC motors are still frequently employed today. Nevertheless, DC motors are still used in certain sectors of the economy and in a few limited circumstances because of their special qualities[8].

DISCUSSION

An overview of DC drives

Direct current (DC) is used to run it, thus the name for this class of drives. Even if the current flowing through the motor contains some ripple, the term direct current is still used.The DC motor is the essential component of a DC drive which is show in Figure 1.

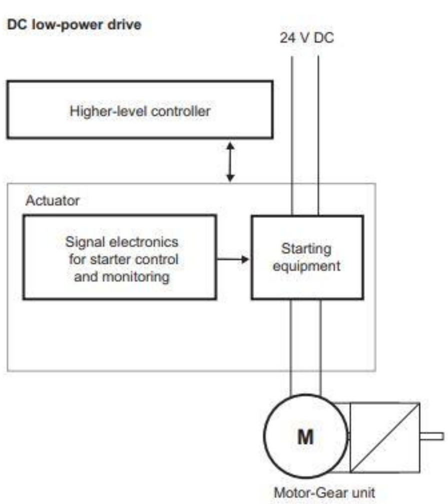

Figure 1: FunctionalblocksofaDCdrive [technicalbookspdf].

Despite AC drives gradually replacing them, DC drives are still widely used in industrial applications. They benefit from the common availability of a DC 24 V power source in practically all machines and industrial machinery in the lower power range (<500 W). Small drives that are very efficient in terms of cost may be realized using permanently excited motors and relatively basic controllers.

Comparing controlled DC drives to the price and size of AC drive controllers in the higher power range (> 100 kW) is still worthwhile. Therefore, rolling mills, cranes, and elevators still employ DC drives today. These drives provide high-quality control and monitoring capabilities. Separately referenced DC motors are employed at greater powers. Last but not least, DC drives are still used in a number of older machinery and industrial facilities. Having a solid understanding of DC drives in an industrial setting is still required since these equipment and industrial machinery must be serviced and maintained.

Generally speaking, DC generates value through excellent and simple controllability. They are thus a perfect entry point into the realm of controlled electrical drives.

The DC Motor

Current-carrying loop

The current-carrying loop is the most effective way to describe the DC motor's working principle.

A magnetic field is shown to a rotating loop. Current will flow in the loop if a DC voltage is supplied to its ends. The long sides of the loop's current flow are moving in the opposing directions. Because of this, the Lorentz force components operating on the loop's two long sides are also in opposition. A rotation of the loop is the result of these two elements. The two Lorentz force components cancel one another out once the loop is in a horizontal position. The elements of the Lorentz force operate to stop any further movement if the loop advances beyond the horizontal position. The loop is stopped, then drawn back into the horizontal position, where it stays.

Commutator

If the loop is to continue rotating without ending at the horizontal position, the direction of current flow must be switched soon after crossing this point. A commutator is used to do this purpose.

The commutator is shown in Figure 2 as a disc with two electrically separated sections. One end of the conducting loop is attached to each side. Through fixed brushes that move across the commutator's surface, the electrical connection to the DC supply is created. The brushes are set up to link to the opposite side of the commutator when the loop is in the horizontal position. In this method, both the polarity of the electrical source and the flow of current are reversed. The circular motion of the loop is now continued by the Lorentz forces.

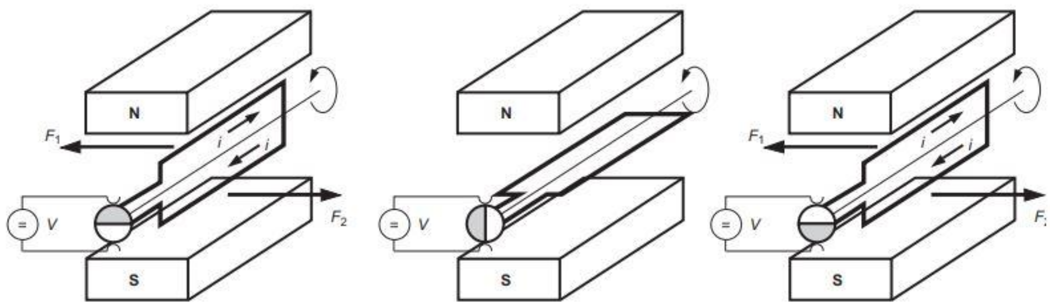

Figure 2: Function of a commutator[technicalbookspdf].

Disadvantages of the loop

The following drawbacks would be present if a DC motor were made from only one conducting loop in a magnetic field:

1. A very big current would need to flow through the conducting loop in order for extremely strong Lorentz forces, or torques, to arise. The conducting loop's conductor's cross-sectional area would need to be designed appropriately.
2. The Lorentz forces would automatically adjust and there would be no rotational movement if the current were turned on precisely when the loop is in the horizontal position. The loop would stay in place.
3. The direction of the Lorentz force is constant. As a consequence, the position of the loop itself determines how much turning force is applied to the loop. The force is at its greatest in the vertical position, and it is completely absent in the horizontal position. Accordingly, the torque operating on the loop (in the radial direction) is a sinusoidal function that varies between zero and a maximum value rather of being a constant.

Constructed differently from theoretical DC motors, actual DC motors do away with these drawbacks.

From loop to armature winding

A multi-layered armature winding consisting of insulated copper wires takes the role of the conducting loop (see Figure 4.5). Electric current cuts the magnetic field as often as the winding's number of turns as it runs through it. The Lorentz force is multiplied as a consequence.Instead of employing a single winding, several part-windings are employed to provide a more continuous torque. These part-windings are all coupled in sequence and each is positioned offset from its neighbor. The laminations of the commutator serve as the termini for the ends of the windings. Depending on where the commutator is located, a part-winding is shorted and two parallel routes made up of several part-windings are created.

Only the cross-sections of these part-windings are visible since the active winding components are going into the figure. None of the winding heads are visible. The four commutator laminations are joined to the ends of the windings. It is possible to clearly discern the associated part-windings 1-2-3-4-1 in succession. A configuration with four part-windings is shown in Figure 3.

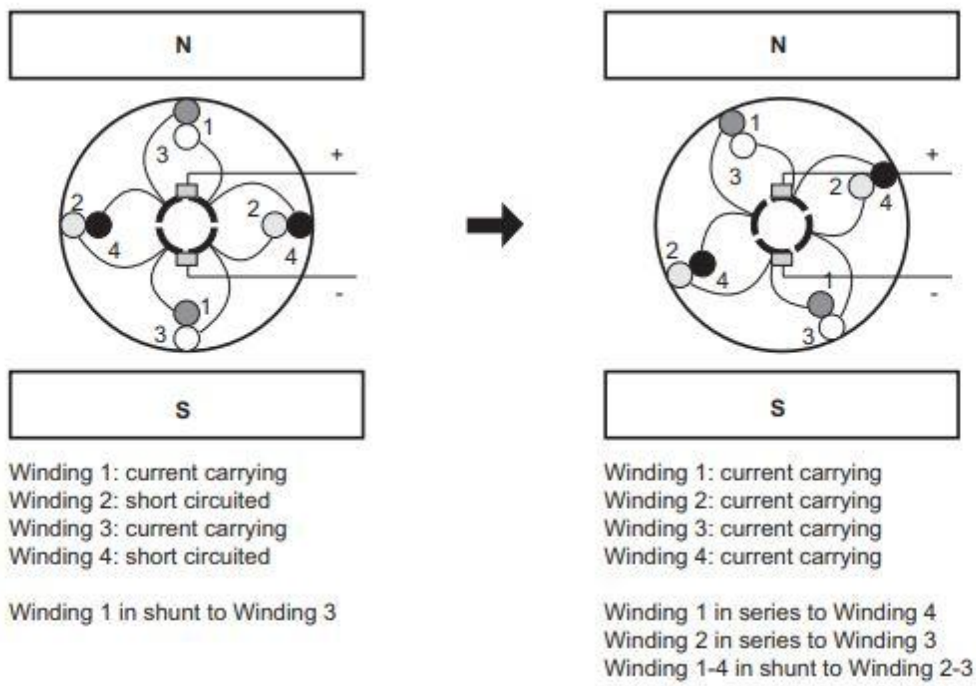

Figure 3: Current flow in the armature windings of a DC motor[technicalbookspdf]

Only the part-windings 1 and 3 conduct current when the armature is in the position seen on the left. The brushes short-circuit the commutation phase-affected windings 2 and 4. Through windings 1 and 3, the current runs parallel. The torque development is most greatly aided by both windings because of their instantaneous positions.The brushes are totally in touch with one commutator laminate if the armature is rotated farther. Windings 2-3 and 1-4 now have parallel currents flowing through them. Torque development is influenced by all windings. The torque produced by windings 1 and 3 diminishes as the loop turns while the torque produced by windings 2 and 4 increases. Last but not least, the brushes cause windings 1 and 3 to short circuit and only windings 2 and 4 to conduct electricity.

As the armature rotates farther, this process continues. Alternately, windings 1 and 3 are short-circuited, and windings 2 and 4 are as well, reversing the direction of current flow in these windings. The second winding pair continues to conduct current and produce torque when only one winding pair is commutated at a time. There is no longer a dead spot when the Lorentz forces cancel one another, as in the case of a single loop.On the basis of a fairly basic model, the graphic clearly demonstrates the functional concept; in actual DC motors, more than four part-windings are used. The torque curve is also greatly flattened in this manner. This produces a torque whose magnitude is essentially independent of the armature's position.

CONCLUSION

In a variety of applications, fixed-speed and variable-speed drives are essential for driving DC motors. Fixed-speed drives are appropriate for situations with consistent loads and where fine speed adjustment is not required since they are straightforward and cost-effective. On the other hand, variable-speed drives provide accurate speed modification and torque characteristic optimization while also providing improved control and energy economy. Fluctuating-speed drives are advantageous in situations where fluctuating loads or energy savings are required, even though they need more complicated control systems and have higher starting costs. The adaptability and efficiency provided by variable-speed drives are very advantageous to sectors like industrial automation, robotics, and electric cars. In the end, the decision between fixed-speed and variable-speed drives is based on the application's unique needs, such as load changes, speed control accuracy, and energy consumption goals. Both kinds of drives are anticipated to perform and operate more effectively in the future thanks to developments in power electronics and control systems, which will also broaden their range of applications and make it possible to use DC motors more effectively.

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FIXED-SPEEDANDVARIABLE-SPEEDDRIVESWITH ASYNCHRONOUSMOTORS

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ABSTRACT:

Asynchronous motors are often utilized with fixed-speed and variable-speed drives in a variety of industrial applications. This chapter gives a general overview of different drive systems and discusses their operating principles, benefits, and drawbacks. Asynchronous fixed-speed drives are often utilized in pump and fan applications because they need a consistent speed. Asynchronous motors with variable-speed drives, on the other hand, provide you the freedom to change the motor speed, which leads to energy savings and better process control. The performance and characteristics of the two drive systems are also compared, which also underlines the elements to take into account when choosing the best drive for a certain application.

KEYWORDS: *Asynchronous Motors, Drives, Fixed-Speed Drives, Motors, Variable-Speed Drives, Stator.*

INTRODUCTION

Functional blocks of drives with asynchronous motors

Depending on its design, the asynchronous motor, also known as an induction motor, may run on a single-phase or three-phase AC supply. It is simple to install and may be linked directly to the power supply network. It is also incredibly affordable and requires little upkeep. As a result, asynchronous motor drives are the most common kind used in industrial applications and are consequently widely used[1].The advancement of microprocessor technology allowed for the cost-effective implementation of the asynchronous motor's intricate control algorithms. As a consequence, regulated drives with asynchronous motors are now available and are similar to DC drives in terms of precision and dynamics. With a very precise gradation of control characteristics, drives with asynchronous motors span the whole bandwidth of fixed-speed and variable-speed drives. The functional blocks of asynchronous motor drives is show in Figure 1 [2].

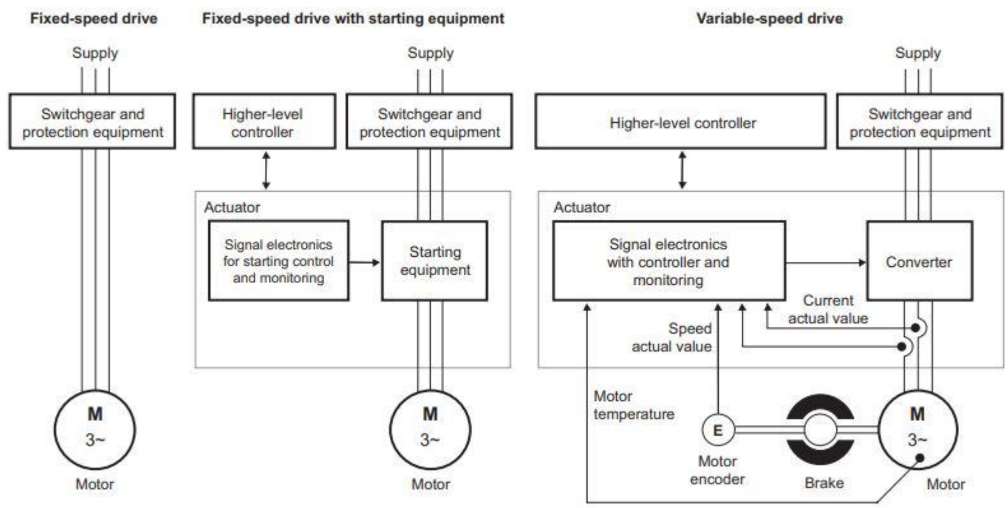

Figure 1: Shows the Functional Blocks of Asynchronous Motor Drives.

Asynchronous Fixed-Speed Drives

Asynchronous fixed-speed drives, commonly referred to as squirrel cage motors, provide a dependable and effective solution for a variety of industrial and commercial applications. The most prevalent kind of AC motors used in fixed-speed drive systems are asynchronous motors. They provide a number of benefits that make them ideal for certain applications where consistent speed operation is necessary.Asynchronous motors run at a fixed speed in a fixed-speed drive system, which is normally set by the frequency of the power supply[3]. An overview of the benefits of fixed-speed drives using asynchronous motors is given below:

1. **Cost-Effectiveness:** When compared to other motor technologies, such as synchronous motors or DC motors, asynchronous motors are often more affordable. They are easier to build and maintain because of their simplified design and construction.
2. **High Reliability:** Asynchronous motors are very dependable in continuous duty applications due to their strong and lasting architecture. The number of possible failure sites is reduced by the straightforward rotor structure that does not need brushes or slide rings.
3. **Asynchronous Motors:** Asynchronous motors come in a broad variety of sizes, from tiny motors with a fractional horsepower to massive industrial motors. They may be employed in a variety of settings, such as pumps, fans, compressors, conveyor systems, and more because to their adaptability.Asynchronous motors operate with high energy efficiency, particularly when they are working at their rated load. Because of their high-power factor, the power supply has to provide less reactive power. This effectiveness may lead to cheaper operational expenses and less energy use.
4. Asynchronous motors are easy to maintain because of their straightforward design. They don't need routine maintenance or replacement of brushes or commutators. This lowers the system's maintenance expenses and downtime.

5. Asynchronous motors have the capacity to start and accelerate the load on their own, without the assistance of extra starting processes or devices. This feature lowers upfront expenses while streamlining the control system.
6. **Broad Voltage Range:** Fixed-speed drives with asynchronous motors are appropriate for situations where there is a fluctuating power supply or voltage changes because they can operate over a broad voltage range.
7. **Power grid compatibility:** Asynchronous motors don't need sophisticated control systems to be linked to the power grid. Because they can run on a regular AC power source, they are mostly compatible with current infrastructure[4].

Although fixed-speed drives with asynchronous motors provide several benefits, it's crucial to take the application's unique needs into account. Other drive methods, such as variable frequency drives (VFDs), may be more appropriate if precise speed control or variable speed operation are required.

Variable-Speed Drives with Asynchronous Motors

Electronic devices known as variable-speed drives (VSDs) are used to regulate the speed and torque of electric motors. Despite the fact that VSDs may be used with a variety of motor types, this introduction will concentrate on how they are utilized with asynchronous motors, also referred to as AC induction motors.The most popular form of motor utilized in industrial and commercial applications is the asynchronous motor. They work on the basis of electromagnetic induction, in which the stator (stationary component) of the motor generates a rotating magnetic field that induces a current in the rotor (spinning part), creating torque[5].

Asynchronous motors equipped with variable-speed drives allow for accurate control of motor speed by modifying the frequency and voltage sent to the motor. This is accomplished by adjusting the input parameters of the motor using power electronic devices, such as insulated gate bipolar transistors (IGBTs).The following are some benefits of employing variable-speed drives with asynchronous motors:

1. **Control of speed:** A broad range of motor speed may be accurately and continuously controlled using VSDs. Applications requiring precise speed adjustment, such conveyor systems, pumps, fans, and HVAC systems, benefit from this flexibility. Energy consumption may be optimized, resulting in energy savings, by altering the speed in accordance with the load requirements.
2. Control of motor torque is made possible by variable-speed drives. In applications with fluctuating loads, the motor may modify its torque output as a result, which is very helpful. It enables more streamlined operation, improved starting and stopping control, and the capacity to adapt to rapid variations in load demand.
3. **Energy efficiency:** The motor's speed may be adjusted to fit the demands of the load by using variable-speed drives. Asynchronous motors are known to operate more effectively at lower speeds than they do at full speed. Operational at slower speeds allows for energy savings and lower operational expenses.

4. **Soft starting and braking:** By gently ramping up or down the motor's speed, VSDs make it possible for asynchronous motors to start and stop softly. By reducing mechanical stress on the motor and linked equipment, this increases their lifetime and lowers the need for maintenance.
5. **Process optimization:** Industrial processes may be optimized thanks to the precise control provided by VSDs. Manufacturers may enhance process control, improve product quality, boost productivity, and decrease waste by altering the motor speed in accordance with particular process needs.

Asynchronous motor-based variable-speed drives are becoming more and more common because of their potential for energy savings and flexibility in meeting a range of application needs. They are extensively used in a variety of sectors, including manufacturing, mining, water treatment, and others.

DISCUSSION

The Asynchronous Motor

i. The Operating Concept

Different types of asynchronous motors are used. They are categorized into single-phase and three-phase AC motors based on how many supply voltage phases there are. Squirrel-cage rotor and slip-ring rotor motors are two different types of three-phase AC motors[6]. Slip-ring rotor motors are not discussed in further detail here since they are only necessary for particular applications in the higher power range, such as wind turbines. The squirrel-cage rotor asynchronous motor is the most common kind of motor. These designs all make use of this motor type. The basic diagram of Three-phase asynchronous motor is show in Figure 2.

Figure 2: Three-phase Asynchronous Motor.

1. ***Three-phase squirrel-cage asynchronous motor***

The stator is where the asynchronous motor's winding system is located. Unlike a DC motor, a squirrel-cage asynchronous motor does not need energy to be delivered to the moving rotor via mechanical connections. As a result, it requires almost little maintenance.The stator of the three-phase asynchronous motor contains three windings, each of which is 120 degrees apart from its neighbor. The core of the rotor is a laminated core with slots. A cage made of either copper or aluminum is produced in the slots during the die-casting process. This cage is made up of bars and short-circuit end rings that link the bars at each end of the rotor electrically[6]. The cage is a network of electrical cables that have been short-circuited from an electrical perspective. In the event that the stator windings are designed to carry a sinusoidal electrical current. The three-phase AC motor stator generates a rotating magnetic field when the phase shift between the currents is 120°. The rotor cage is also penetrated by this magnetic field. The rotor bars experience an electrical voltage due to the spinning magnetic field. Current flows as a consequence of the induced voltage as the bars are short-circuited.Components of an asynchronous squirrel-cage rotor motor is show in Figure 3 [7].

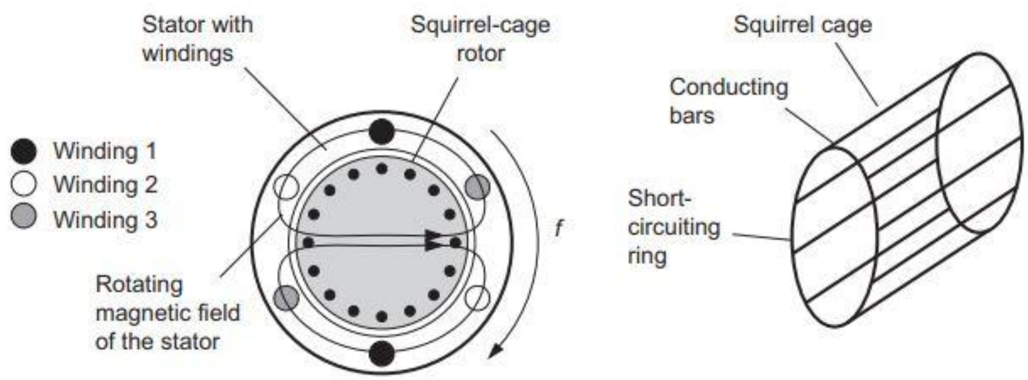

Figure 3: Components of an asynchronous squirrel-cage rotor motor [technicalbookspdf].

The magnetic field of the stator contains the current-conducting bars. As a consequence, each of the bars is subject to the Lorentz force. The forces act in combination, transmit their energy to the rotor, and produce a torque. The rotor responds by turning in a circular manner. It rotates in accordance with the stator field. But the rotor moves more slowly and does not follow the stator field synchronously. This is essential since the rotor can only create a voltage under certain circumstances, leading to current flow. The rotor's revolution is "asynchronous" with the stator field's rotation. As a result, there is a slip between the rotor's rotational speed and the frequency of the stator field. The load affects how big the slide should be. The slide is quite low when there is no load[8].

The stator field created by the three-phase winding system in the motor has both a north pole and a south pole if it conducts three-pole pairs phase current. The motor has a pole pair with a pole pair count of 1. The constructional architecture of the motor determines the number of pole pairs, or pole pair number.Motors with more than one pole pair may be created by repeating the three-phase winding system's configuration and switching the phases in sequence. Two north and two

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south poles are dispersed around the stator's circumference when the windings in this configuration conduct electricity. Two pole pairs make up the motor.An example of the setup with two pole pairs is shown in Figure 4 [9].

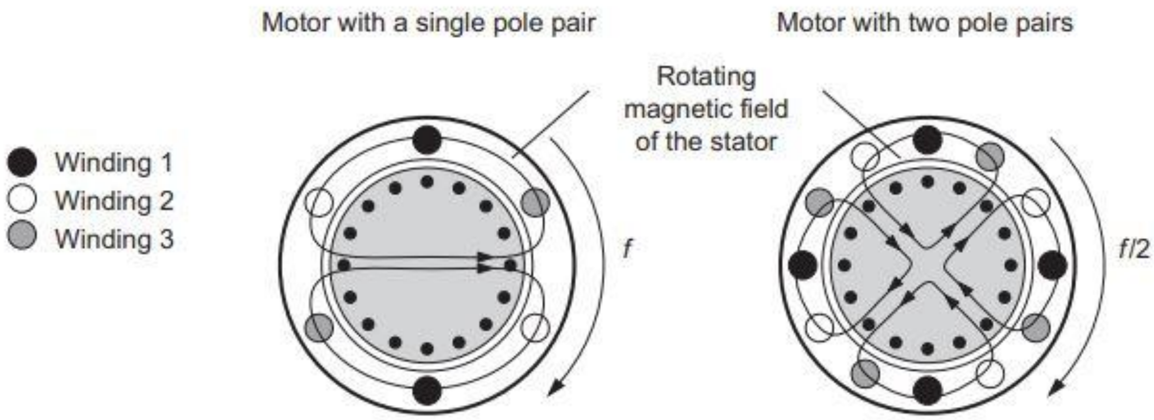

Figure 4: Arrangement of the windings for different numbers of pole pairs [technicalbookspdf].

The magnetic field of the stator advances by a complete pole division (one north and one South Pole) if the current in the stator windings cycles through a whole time period. This corresponds to a 180° mechanical rotation for a stator with two pole pairs. Even if the supply current's frequency is same, the stator field's rotational frequency has been cut in half when compared to a motor with one pole pair[10].

Synchronous speed

The motor's pole pair count (p) affects the rotating frequency of the stator field, which in turn affects the rotor's rotational speed and frequency as it asynchronously follows the magnetic field. Synchronous speed is the term for the rotational speed at which the motor's magnetic field revolves. Its connection to the supply voltage/stator current's frequency, f, is as follows:

$$n_d = \frac{60 \cdot f}{p}$$

Where the number of pole pairs p and the synchronous speed nd in 1/min are expressed. It falls off as the number of pole pairs rises. Asynchronous motors with one to four pole pairs are the most prevalent.

2. Single-phase asynchronous motor with capacitor

A single-phase AC supply may also be used to power asynchronous motors. Two stator windings offset by 90 degrees provide the spinning field in a single-phase asynchronous AC motor. The supply voltage is directly linked to one winding. An operational capacitor, also known as a running capacitor, connects the other winding to the supply voltage. Because of the capacitor, the phase current in winding 2 is time-shifted with respect to winding 1. The effect of this change in time is a rotating field. Therefore, capacitor motors are another name for single-phase asynchronous motors.

Up to around 1 kW in power, single-phase asynchronous motors are used. They may often be found in workplaces and home appliances. Only one rotational direction may be used to drive these motors.

Construction and electrical connections

Design

Three-phase asynchronous motor windings are positioned in the stator with a 120° offset. They are kept in laminations with slots. The magnetic circuit is closed thanks to the laminations. A frame made of cast iron or aluminum houses the laminations. The frame is equipped with cooling fins to enhance cooling. In the form of a laminated core, the rotor likewise consists of laminations. The slots of the laminated core have cages made of copper or aluminum cast into them.

The rotor can work at high speeds because of its straightforward construction, which makes it resistant to strong centrifugal forces. A cooling fan that is mounted on the asynchronous motor's motor shaft circulates coolant through the motor as a function of motor speed across the cooling fins. A secondary cooling fan is installed on motors that need the best cooling at low speeds. Design of an asynchronous motor is show in Figure 5.

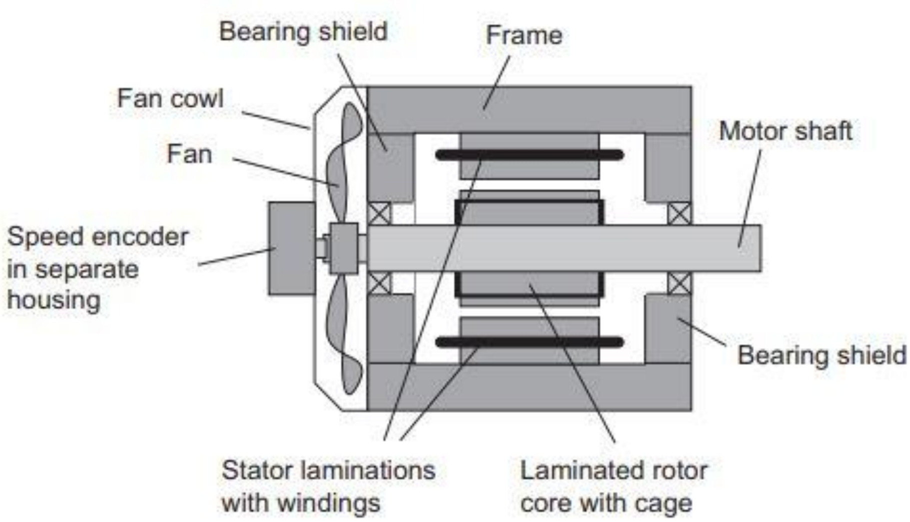

Figure 5: Design of an asynchronous motor [technicalbookspdf].

Since a speed encoder is optional, it is built-on in design. Additionally, the engine might be equipped with a brake, depending on the application. Typically, this serves as a holding brake. The motor shaft should be able to be held when the current in the windings is turned off.The

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motor's frame size and diameter increase with the amount of torque it must produce. Therefore, as torque increases, so do motor size.

Types of connection

An asynchronous motor's winding system may be created by switching its windings in either a star pattern or a delta pattern. Star and delta connection of an asynchronous motor is show in the Figure 6.

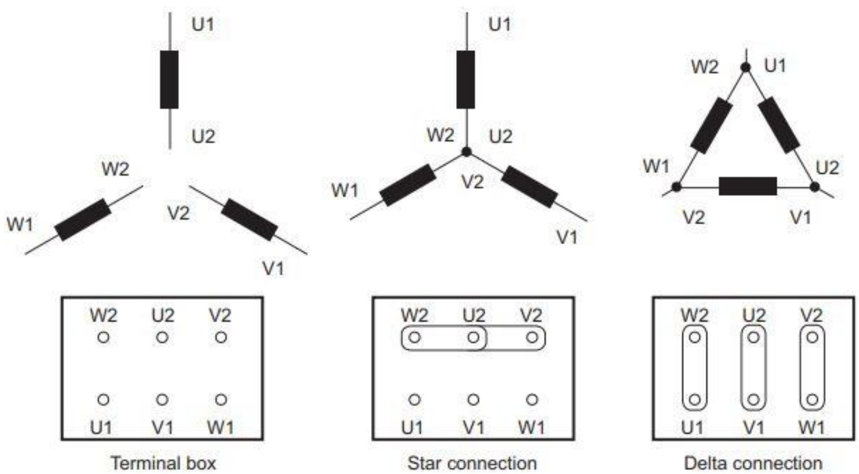

Figure 6: Star and Delta Connection of an Asynchronous Motor.

Slip

The analogous circuit diagram resembles a transformer in appearance. The secondary side is where the biggest distinction may be seen. In contrast to a transformer, where the consumer is connected to this side, an asynchronous motor shorts out the secondary side using a slip-dependent resistor. The slip s is defined as follows:

$$s = \frac{n_d - n}{n_d}$$

It depicts the difference between the synchronous speed (nd) and the mechanical speed (n) in respect to the synchronous rotational speed under the real operating circumstances. Slip lacks a unit since it is a ratio. It may be likened to the slip of a belt drive, which has more slip when the drive is loaded than when it is unloaded. S = 0 denotes the no-load situation for an asynchronous motor, whereas S = 1 denotes zero speed. The slip ranges from 0 to 1 in driving operation.Depending on the size of the motor, the slip occurs between 0.03 and 0.10 at rated working circumstances.

Controllability

A system's input parameters

From the speed-torque characteristic, the starting positions for adjusting the speed of an asynchronous motor may be found to be:

1. Varying the stator voltage Vs
2. Varying the stator frequency f
3. Simultaneously varying the stator voltage Vs and stator frequency f

Stator voltage

The speed-torque characteristic may be squeezed in the direction of the speed axis by lowering the stator voltage Vs. Reduced stalling torque allows for mild loading of the asynchronous motor. The speed seldom varies in the rated operating range (n near to nd). Therefore, the stator voltage by itself is not a viable system input for changing an asynchronous motor's speed.The stator voltage decrease is inversely proportional to the torque and stator current reductions.

Stator frequency

The speed-torque characteristic may be parallel shifted up or down by adjusting stator frequency f theoretically, this causes a significant increase in the stalling torque at lower frequencies. This is supported by careful inspection, which demonstrates that the stator's magnetic field has been enhanced greatly. However, this amplification seldom occurs because the iron circuit is saturated. A slight increase in the torque is exchanged for a significant increase in the stator current and higher thermal loading of the motor by lowering the frequency.The stator frequency f may, in theory, be used as a system input variable to change the speed of an asynchronous motor, but only if it is raised and not lowered. In this scenario, the speed rises as the stalling torque falls.

Stator voltage and stator frequency

Simultaneously when the stator voltage and stator frequency are altered simultaneously and in the same ratio, the following is taken into consideration for best performance:

$$\frac{V_s}{f} = \text{constant}$$

This method allows for the up-and-down shifting of the speed-torque characteristic without altering its form. In the rated operating range, the stalling torque and gradient of the characteristic remain unaltered. As a result, the ideal technique of adjustment for variable-speed drives with asynchronous motors is the parallel adjustment of stator voltage Vs and stator frequency f. Since the supply voltage restricts the stator voltage's maximum value, the speed n cannot be raised beyond the synchronous speed nd using this approach. As a result, the speed range is limited to n nd, which is more than enough for the majority of applications.

CONCLUSION

Asynchronous motors are crucial parts of fixed-speed and variable-speed drives, which are used in many industrial applications. For applications that demand a consistent motor speed, fixed-speed drives provide an easy and affordable option. In equipment where speed control is not essential, such as pumps, fans, and other devices, they are extensively employed. Variable-speed drives, on the other hand, allow you to change the motor speed, which results in energy savings and better process control. The unique application requirements, energy efficiency objectives, and cost considerations all play a role in determining whether fixed-speed or variable-speed drives are best for a given application. It is essential to thoroughly examine the application and weigh the advantages and disadvantages of every driving system. It is important to consider variables such the load characteristics, the required torque, and the necessity for accurate speed control.

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CLASSIFICATION OF ELECTRIC DRIVES WITH FACTOR

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ABSTRACT:

This chapter offers a categorization system for electric drives based on a wide range of variables. Electric drives are extensively employed in a variety of applications, from electric automobiles to industrial automation. Understanding an electric drive's features, performance, and appropriateness for a given application depends on how it is classified. In this chapter, we provide a categorization system that takes into account variables including power rating, control method, motor type, and ambient circumstances. By examining these variables, a methodical framework is created to divide electric drives into several classes, facilitating a better understanding and choice of suitable drive systems for various applications.

KEYWORDS: *Drive System, Electric Drives, Electric Motors, Motors.*

INTRODUCTION

In a variety of applications, such as industrial automation, robotics, electric cars, renewable energy systems, and others, electric drives are essential. They are in charge of transforming electrical energy into mechanical energy and powering different kinds of loads. It is critical to categorize electric drives according to their features, prowess, and appropriateness for various applications given the rising need for energy economy and performance improvement. The categorization of electric drives offers a methodical way to comprehend and group different drive systems according to certain criteria. Power rating, control strategy, motor type, ambient parameters, and other pertinent characteristics are some examples of these variables. Engineers, researchers, and practitioners may choose, develop, and optimize electric drives for particular applications by taking these variables into account. The categorization system enables comparisons and assessments of various drive systems based on their distinctive characteristics. It aids in determining each drive system's advantages and disadvantages as well as its suitability for a given set of operating circumstances. Additionally, the categorization system encourages uniformity and makes it easier for academics and business experts involved in the area of electric motors to communicate with one another.

The power rating is an important consideration when categorizing electric drives. The capacity of a drive system to handle various load needs is determined by its power rating. Low-power drives are better suited for smaller applications like home appliances, whereas high-power drives are often utilized in demanding applications like large-scale industrial machines. The drive system's control strategy is another thing to think about. In order to manage the motor's speed and torque, a variety of control techniques, including on-off control, proportional control, and variable frequency control, are available. The intended performance and dynamic reactivity of the drive system are factors in the control technique selection.Furthermore, a key element in the categorization process is the kind of motor utilized in an electric drive. The efficiency, torque-speed curve, controllability, and cost of various kinds of motors, including brushless DC motors, synchronous motors, AC induction motors, and DC motors, vary. When choosing the best drive system for a particular application, it is essential to understand the kind of motor being used [1].

The categorization of electric drives is significantly influenced by environmental factors as well. Drives may need to function in challenging conditions, such as excessive heat, high humidity, or corrosive atmospheres, for certain applications. To guarantee dependable and long-lasting performance, drive systems created under these circumstances need to include the proper protective methods and materials.The development of electric power systems and the creation of electric motors are at the foundation of the history of electric drives with factors. The idea of employing electric motors to power equipment initially came up in the 19th century, thanks in large part to the work of innovators like Thomas Davenport, who constructed the first usable electric motor in 1834 [2].

1. Electric motors were first used for simple tasks like running small appliances and equipment. However, as industrialization advanced, there was a greater need for more potent and effective electric drives. This resulted in improvements to power electronics, control strategies, and motor design.
2. The study of electric drives began to get increasing attention and research emphasis from the beginning of the 20th century. Engineers and scientists started looking at the different aspects that affect the functionality and properties of electric motors. Power rating, voltage and current needs, torque and speed control techniques, motor types (such as DC motors, AC motors, and synchronous motors), and ambient variables (such as temperature, humidity, and vibration) were among these considerations[3].
3. The creation of categorization methods for electric drives was made possible by the comprehension of these variables. Electric drives needed to be categorized based on their unique properties and appropriateness for various applications, researchers and industry experts concluded. By taking into account variables including power needs, control techniques, motor types, and environmental concerns, this categorization methodology sought to give a systematic framework for choosing and developing electric drives.
4. The performance and efficiency of electric drives have been increased throughout time by technological developments such as the creation of power electronics, digital control systems, and better motor designs. The categorization methods have changed to reflect these developments as the elements affecting electric drives have become increasingly complicated[4].
5. Electric drives are becoming increasingly more important due to the growth of renewable energy sources and electric vehicles. The design and selection of electric drives now heavily weigh aspects like energy economy, regenerative braking, battery management, and interaction with smart grid systems.

Electric drives with factors have a long history, dating back to the development of electric motors. The development of categorization systems has been fueled by a knowledge of variables including power rating, control strategies, motor types, and environmental conditions, allowing for improved selection and design of electric drives for a variety of applications. The industry is still developing as a result of technical breakthroughs and the rising significance of electric motors in contemporary culture[5].

DISCUSSION

Factors Impacting Electrical Drive Choice

1. The kind of electric supply whether an AC or DC source will be utilized to provide power
2. The nature of the drive whether the specific motor will drive a single machine or a collection of units.
3. Capital and operating costs
4. Maintenance is necessary.
5. Weight and space limitations
6. Location and environment
7. The kind of the load, including its inertia, whether it needs a light or heavy beginning torque, if its torque rises with speed, and whether it has a high straight-line inertia.
8. Electrical characteristics of motor: Starting characteristics, running characteristics, speed control and Braking characteristics.
9. Motor size, rating, and duty cycle: Whether the motor needs to operate constantly, sometimes, or on a variable load cycle; or whether it just has to go to the operator for a little period of time.
10. Mechanical factors

1. Including noise level, bearing type, drive transmission, and enclosure type.
2. It may not be feasible to meet all of the aforementioned factors due to practical issues.
3. In these situations, the choice of the appropriate drive is greatly influenced by the experience and knowledge background.

When choosing a motor, the following considerations must be given top priority. These elements are:

i. Mechanical load drive’s nature.
ii. Aligning the motor's speed and torque characteristics with those of the load.
iii. The load's starting circumstances.

Electric Drives Classification with Factor

Selection of electric drives

There are three categories, including

- **i.** Group drive
- **ii.** Individual drive
- **iii.** Multimotor drive

Group drive

Two or more machines are driven by a single motor. A lengthy shaft is attached to the motor. Through a belt and pulley system, all other machines are linked to this shaft. A system known as a group electric drive uses many electric motors to power a machine or a vehicle. Group electric drive distributes the power and torque across many motors rather than depending just on one for propulsion. Regarding effectiveness, efficiency, and control, this strategy has a number of benefits.

Each motor in a group electric drive system is normally coupled to a different wheel or drivetrain part. The motors may be installed in the vehicle at various points, such as one motor for each wheel or a group of motors for the front and back axles. This distribution of motors permits different driving modes like front-wheel drive, rear-wheel drive, all-wheel drive, or torque vectoring as well as more exact control over the movement of the vehicle. In a group electric drive system, complex software algorithms are often used to coordinate and regulate the motors. These algorithms constantly monitor the vehicle's performance metrics, including its speed, acceleration, traction, and tire slip, and they modify the power distribution among the motors as necessary. Efficiency, stability, and performance are all optimized by this dynamic control.

Compared to conventional single-motor systems, group electric drive systems have the following advantages:

1. **Performance improvement:** Group electric drive systems may give improved acceleration, traction, and overall performance by spreading power and torque among many motors. Together, the motors may provide more torque and offer superior control in a variety of driving circumstances.
2. **Enhanced effectiveness:** Group electric drive systems may reduce energy costs by selectively activating or disengaging motors in accordance with the needs of the vehicle. The range of the vehicle is increased and energy efficiency is improved because to this flexibility's ability to control power effectively and decrease energy losses.
3. **Redundancy and fault tolerance:** In certain group electric drive arrangements, in the event of a failure of one motor or one of its related components, the other motors can make up for the lost power and continue to operate the vehicle. This redundancy improves the system's dependability and lowers the danger of a total power outage.
4. **Enhanced control and stability:** Group electric drive systems may individually distribute torque to each motor or wheel, opening the door to sophisticated control capabilities like torque vectoring. These systems may enhance stability, handling, and maneuverability by separately managing the speed and torque of each wheel.

5. Group drive lowers the upfront cost of setting up a certain industry.
6. In electric, hybrid, and other sophisticated industrial applications, group electric drive systems are often used. Compared to conventional single-motor systems, they provide better performance, efficiency, and control, and they represent a major leap in electric propulsion technology.
7. Group drive is most cost-effective because, although not all of the motors may be operating concurrently, their combined rating may be lower than that needed to drive all of the equipment individually. Due to the investment in a single motor with a lower HP rating, costs are lower.

Disadvantages*Group drive*:

The following factors prevent the widespread usage of this kind of drive:

1. No machine can be installed exactly as we want it. Thus, layout flexibility is reduced.
2. There are few opportunities for adding more machinery to an established industry.
3. In the event that the primary driving motor develops a problem, all other motors will be shut off instantly.
4. Consequently, all systems will be idle, which is not recommended for any industry.
5. The location produces a lot of noise.
6. This kind of drive will look messy and be less safe to use because of the limitations on where additional motors may be placed.
7. Since belts and pulleys are required to link every motor, a significant quantity of energy is lost in the transmission systems. Power loss is considerable as a result.

Individual drive

Each piece of process equipment will have its own driving motor in this drive. Motion is sent from one motor to several components or mechanisms that are a part of signal equipment. For instances Lathe. One motor is utilized in the lathe to move the feed through gears, revolve the spindle, and drive the lubricating and cooling pumps[1], [6], [7].

The term "individual electric drive" describes a vehicle propulsion system in which each wheel or axle is propelled by a separate electric motor. Individual electric drive distributes the power to each wheel separately rather than utilizing a single engine or motor to move the whole vehicle. Power is normally transferred from the engine to the wheels in a standard internal combustion engine vehicle by a complicated mechanical system that includes a gearbox, driveshaft, and differentials. Individual electric drive, on the other hand, does away with the necessity for these mechanical parts by giving each wheel its own specific electric motor.A few alternative setups exist for certain electric driving systems:

1. **In-wheel motors:** In this configuration, each wheel has a motor that is built right into the wheel hub. This layout provides a space-saving and compact solution, enabling sophisticated features like regenerative braking and precise torque control over each wheel.

2. **Axle motors:** In this setup, each axle has an electric motor placed on it that drives the corresponding wheels through a mechanical connection. In electric buses and vehicles, axle motors are often utilized to power numerous wheels on a single axle.
3. **Dual-motor system:** Some electric cars use a dual-motor arrangement where each axle has its own motor, however this is not strictly speaking an individual electric drive. Better grip and handling are made possible by this configuration's all-wheel drive capabilities and separate torque management for each wheel.

Advantages of Individual drive:

Individual electric drive has a number of benefits over conventional propulsion systems, including:

1. **Performance improvement:** Independent control of each wheel enables accurate torque distribution and traction management. This enhances the car's stability, handling, and acceleration especially on rough roads.
2. **Energy efficiency:** Individual electric drive systems may optimize power supply depending on driving circumstances by separately managing the power to each wheel. This enhances both range and energy efficiency.
3. Regenerative braking is possible because to individual electric drives that let each wheel's braking torque be independently controlled. The electric motors may function as generators when the vehicle slows down, transforming kinetic energy into electricity and storing it in the battery for later use.
4. **Flexibility in design:** Individual electric drive allows for more creative freedom in vehicle design by eliminating the necessity for intricate mechanical components like a driveshaft and gearbox. This may enable more effective use of internal space as well as the investigation of novel vehicle layouts.
5. While individual electric drives have many advantages, they also present certain difficulties due to their higher complexity, weight, and expense when compared to conventional propulsion systems. Nevertheless, continual improvements in power electronics and electric motor technology are progressively overcoming these issues, making individual electric drive an increasingly realistic alternative for next electric cars.
6. The processing industry's output is very reliable in terms of consistency.
7. The impact of a single motor malfunction on overall industry output or production will be negligible.

Disadvantages of Individual drive:

Although individual electric drives provide numerous benefits, there are a few drawbacks that must be taken into account. The following are some typical drawbacks of separate drives:

1. **Cost:** When compared to centralized drive systems, implementing individual drives might be costlier. The driving unit, control system, and related components are required for each motor

separately, raising the system's total cost. Dealing with several distinct drives may also increase the expense of maintenance and troubleshooting.

2. **Space requirements:** Compared to centralized drive systems, individual drives may occupy greater space. It is necessary to physically place each drive unit close to the motor it controls, which may result in a bigger footprint and more room being needed.
3. **Complex wiring and control:** In bigger systems with many motors, managing and coordinating several independent drives may be challenging. The requirement to wire and link each drive unit to the control system necessitates more complex wiring, which raises the possibility of wiring mistakes or failures.
4. **Maintaining and troubleshooting:** Maintaining and troubleshooting might be more difficult when there are numerous separate drives. It might take a lot of effort and specialized knowledge to locate and fix problems with certain drives or motors. Additionally, if one drive malfunctions, it can affect only one motor's performance, decreasing the whole system dependability.
5. **Lack of system-level optimization:** It's possible that individual drives prevent thorough system-level optimization. By coordinating and synchronizing the action of many motors, it is possible to maximize the system's performance and energy efficiency in centralized drive systems. Since each drive functions separately, it may be more challenging to attain this degree of optimization with individual drives.
6. Control and operation might be more difficult to manage when managing several independent drives as opposed to a centralized system. To prevent conflicts and guarantee seamless operation, rigorous synchronization and monitoring are needed while starting up, shutting down, and operating numerous drives.

Multimotor Drive

For this kind of drive, many motors are offered to actuate various components of the driven system. Example: drives used in paper mills, rolling mills, and cranes. Hoisting, long travel motion, and cross travel motion in cranes are all powered by independent motors.A system in which many electric motors are used to drive a single load or carry out a particular duty is referred to as a multi-motor electric drive. To provide the necessary output or regulate different system components, these motors cooperate. Each motor is normally coupled to a different power electronic converter or an inverter in a multi-motor electric drive arrangement. A central controller or control system, which chooses the intended functioning of each motor, sends control signals to the converters or inverters.

To accomplish the intended performance, the central controller continuously checks the system's variables, such as speed, torque, or position, and modifies the individual motor inputs as necessary. This synchronized control enables accurate load adjustment, higher effectiveness, and enhanced system performance. Multi-motor electric drives may be set up in a variety of ways, depending on the particular application and specifications[8]–[10].

Typical illustrations include:

1. Multiple motors are physically connected to a single load in a parallel configuration, and each motor is given a separate set of control signals. It is often employed when redundancy is needed for fault tolerance or when the load has to be divided among the motors.
2. In a master-slave system, one motor serves as the "master" and sends commands to the "slave" motors. The slave motors help or offer extra control while the master motor typically carries the majority of the load. When precise control is necessary but load sharing is not a top priority, this arrangement is helpful.
3. In this configuration, each motor is autonomous and drives a different load or completes a separate duty. The motors may or may not share a common control system or interact with one another. This set up is typical in situations when it's necessary to handle many activities at once or where individual motor control is crucial.
4. Numerous sectors, including robotics, automotive systems, industrial automation, aerospace, and renewable energy use multi-motor electric drives. In comparison to single-motor configurations, they provide benefits such higher power density, fault tolerance, better efficiency, and superior control capabilities.

Overall, the use of many motors in an electric drive system enables more sophisticated and adaptable control, allowing for the accomplishment of challenging tasks and performance optimization in a variety of industrial and commercial applications.

CONCLUSION

We have created a systematic framework to divide electric drives into many classes by taking into account variables like power rating, control style, motor type, and environmental circumstances. This categorization system offers a thorough grasp of various drive systems and how well they fit into various applications. Engineers, researchers, and practitioners may use the suggested categorization method to choose the best electric drive system for a particular application. It offers a consistent vocabulary and structure for talking about electric drive systems, facilitating effective information exchange and field cooperation. Future studies might concentrate on enhancing and extending this categorization system while taking into account developing technology and changing market demands.

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CLASSES OF MOTOR DUTY

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ABSTRACT:

Classes of motor duty refers to a categorization system used to define the operational capabilities and limitations of electric motors in various applications. This classification framework provides valuable insights into the expected performance, durability, and thermal characteristics of motors, allowing engineers and users to select the most suitable motor for specific tasks. The concept of motor duty classes encompasses a range of factors such as duty cycle, load variation, starting and stopping frequency, and ambient conditions. Understanding these classes helps in optimizing motor selection, ensuring efficient and reliable operation, and minimizing the risk of premature failure. This abstract explores the significance of motor duty classes, highlights common duty cycle categories, and emphasizes their practical implications in engineering design and industrial applications. It also emphasizes the importance of considering motor duty classes as a vital aspect of motor specification to enhance overall system performance and longevity.

KEYWORDS: *Continuous Duty, Duty Cycle, Electric Motors, Intermittent Periodic, Motor Duty.*

INTRODUCTION

Load Conditions in Motor

The load requirements are in either of

1. Speed control
2. Torque control

The motor must be selected based on the load requirements. For instance, in a traction system, the load (traction network) requires a high beginning torque, which necessitates a high initial current value. High starting torque is provided by a series motor.The traction system should thus be powered by a series motor[1].

Classification of loads

1. Torque dependent on speed: Ex-hoists, pumping of water or gas against constant pressure.
2. Torque linearly dependent on speed: Ex- motor driving a DC generator connected to a fixed resistance load.

3. Torque proportional to square of speed: Ex- fans, centrifugal pumps, propellers
4. Torque inversely proportional to speed: Ex-milling and boring, machines [2].

Aspects of various industrial loads

Electric motors must function under three different kinds of industrial loads. They are:

1. Continuous load
2. Intermittent load
3. Fluctuating or variable load

Continuous load

The nature of the load is continuous, for example, pumps or fans need a steady supply of electricity to run [3].

Intermittent Load

1. The temperature of the motor is raised to that of room temperature by loading it briefly and then shunting it off for a long enough period of time, for instances as in a kitchen mixer.
2. The continual ON/OFF delay interval is the main cause of the electrical loss.
3. Moor loaded for a brief period of time before shutting off.
4. In this case, it may be concluded from a comparison of the two ways that the motor cannot be cooled to room temperature.
5. The motor's temperature is not raised to that of the room[4].

Classes of Motor Duty:

Various load time variations encountered into eight classes as

1. Continuous duty
2. Short time duty
3. Intermittent periodic duty
4. Intermittent periodic duty with starting
5. Intermittent periodic duty with starting & braking
6. Continuous duty with intermittent periodic loading
7. Continuous duty with starting & braking
8. Continuous duty with periodic speed changes.

Continuous duty

The capacity of an electric motor to operate continuously for long periods of time without overheating or experiencing performance deterioration is referred to as continuous motor duty. It shows the motor's capacity to run continuously, without pause or rest, under a steady load.During operation, electric motors produce heat as a result of a number of variables, including magnetic losses, mechanical friction, and electrical resistance. A motor's components may overheat if it runs constantly under strong loads without adequate cooling or rest times, which may diminish efficiency, accelerate wear, and eventually result in motor failure [5]. The maximum load or torque that the motor can withstand before overheating is represented by the continuous motor duty rating, which is normally given by the manufacturer. The most common way to quantify it is as a percentage of the motor's full-load rating. For instance, a motor with a 75% continuous duty rating may run continuously at 75% of its maximum load without experiencing any problems.

It is essential to take the continuous duty rating into account when choosing a motor for a particular application to make sure it can manage the anticipated load demands without overheating. In order to avoid overheating and guarantee dependable performance, a motor may need extra cooling devices, periodic rest breaks, or a higher-rated motor if the loads it is exposed to are more than its continuous duty rating.

Examples are Paper mill drives, Compressors, Conveyors, Centrifugal pumps, and Fans.

Short time duty

Short time motor duty is the use of an electric motor under certain circumstances when it is intended to operate for a brief period of time before being permitted to cool down. The motor works for a shorter amount of time yet at a greater power output during short time duty than it does during continuous operation. The ratio of the motor's working time to its cooling time is often used to describe the length of the short time duty cycle. For instance, S2, a typical short time duty cycle, specifies that the motor is intended to run for a certain amount of time, often given as a percentage of a 10-minute cycle, and then be left to cool down for the balance of the cycle[6].

When motors are subjected to intermittent or cyclic loads, such as when starting large equipment, powering pumps, or managing intermittent operations, short duration duty cycles are employed. These duty cycles enable the motor to operate at an appropriate operating temperature during short times of high-power demands, such as during startup or peak load situations.It's vital to remember that the motor manufacturer will often provide the precise duty cycle, length, and cooling needs for a motor's short-term employment. To guarantee safe and dependable motor functioning, it is crucial to abide by these criteria. Motor overheating, decreased efficiency, and a chance of damage to the motor windings or insulation might result from exceeding the advised duty cycle or from not providing enough cooling. It is essential to take into account aspects like the duty cycle length, cooling systems, and the motor's thermal characteristics when choosing a motor for an application with short time duty needs. To ensure best performance and endurance under these operating circumstances, motor manufacturers provide extensive specifications and recommendations for choosing motors appropriate for short-duration duty applications.Single phase/three phase induction motors, DC shunt motors, DC series motors, and universal motors are all capable of carrying out this sort of activity[6]. Examples include Crane drives, Drives for house hold appliances, turning bridges, Sluice gate drives, Valve drives, and Machine tool drives.

Intermittent periodic duty

A particular kind of duty cycle that explains how a device or system works throughout time is known as intermittent periodic duty. The equipment or system alternates between active and inactive phases, or between operating and resting periods, throughout this duty cycle. The description "intermittent" denotes that the system or equipment only works intermittently, lasting only briefly before becoming dormant. This cycle of on and off occurs repeatedly. It differs from continuous duty, in which the machine works continuously without a break[7].

Consider a motor, for instance, that is designed for intermittent periodic duty. It indicates that the motor has an operating window, such as 30 minutes, after which it must rest before being used again. The motor's designated task, such as moving a conveyor belt or spinning a fan, is carried out during its active phase. The engine is stopped when the active time is over and stays at rest until the following cycle begins. The ratio or percentage used to indicate the duty cycle of intermittent periodic duty, which compares the active time to the whole cycle time. A duty cycle of 50%, for instance, indicates that the system or device is active for 50% of the time and idle for the other 50%.It is important to note that, depending on the particular equipment or system, the duty cycle and rest intervals may change. While some devices may have longer active times and shorter rest periods, others could have short active periods and lengthy rest periods. The manufacturer will normally publish the duty cycle standards, which are crucial to take into account to ensure the equipment operates correctly and avoid overheating or damage from excessive usage.

A time of running, a period of resting, a period of beginning, and a period of braking are all included in this form of drive action. Both an operating time and a rest period are insufficient for the machine to attain its steady state temperature or cool it to room temperature. This kind of work may be done by DC shunt motors, universal motors, single phase/three phase induction motors, etc. Examples are Pressing, Cutting, and Drilling machine drives.

Intermittent periodic duty with starting

1. This is a periodic intermittent duty where the warmth caused by beginning cannot be disregarded.
2. It comprises of a beginning time, followed by running, braking, and resting periods that are too brief to attain their steady state value.
3. This sort of task may be carried out by three phase induction motors and DC series motors, DC compound motors, and universal motors. In this form of drive operation, heating due to braking is minimal.

Examples include metal cutting, drill tool drives, forklift truck drives, and mine hoist, etc.The phrase "intermittent periodic duty with starting," which is often used in electrical engineering, refers to a particular duty cycle employed with a motor or electrical device. This duty cycle alternates between periods of work and relaxation, with sporadic beginning sequences.

The breakdown of the various parts is as follows:

1. **Duty Cycle:** The duty cycle is the proportion of the device's operational or active time to its overall cycle time. When a gadget is on intermittent periodic duty, it runs for a certain amount of time before going into active mode for an additional amount of time.
2. **Intermittent Operation:** The item only performs its intended function during the active or operational portion of the duty cycle. This may include performing duties like operating a motor, producing heat, or delivering some other output.
3. **Rest Periods:** The gadget enters a time of rest or inactivity after the active phase. It doesn't use any energy or carry out any tasks during this period. The gadget can cool down, recharge, or preserve energy during the rest time.
4. **Starting Sequences:** Periodic intermittent duty devices may need a starting sequence to start up. To guarantee appropriate device startup, starting sequences may entail delivering a predetermined series of signals or giving an initial burst of power. This may be important for equipment like motors that need more complicated initialization processes or greater beginning currents.

Applications where the device's continuous operation is not necessary, would be inefficient, or are not practicable often utilize intermittent periodic duty with commencing. It provides for better energy management, lessens damage to the gadget, and lengthens its lifetime by alternately alternating active and rest times.

Intermittent periodic duty with starting & braking

1. It is impossible to overlook the heating that occurs during starting and braking during this intermittent periodic employment.
2. It comprises of a beginning phase, a running period, and too few seconds of braking and resting for the temperature to achieve its steady state value.
3. Single phase/three phase induction motors, DC shunt motors, DC series motors, DC compound motors, and universal motors may all do this sort of function.

Examples are Billet mill drive, Manipulator drive, Ingot buggy drive, Screw down mechanism of blooming mill, several machine tool drives, Drives for electric suburban trains, and Mine hoist. An operating mode or duty cycle known as intermittent or cyclical functioning of a device or system with frequent starting and braking actions is referred to as intermittent periodic duty with starting and braking. This duty cycle is often seen in a variety of machines, pieces of equipment, or systems that need to run periodically with plenty of pauses and starts[8].

Here is a list of the essential components:

1. **Intermittent Operation:** The system or gadget has phases of operation that alternate between being on and off. It could run for a certain amount of time or do a specified job before stopping.
2. **Periodic Operation:** Intermittent operation adheres to a regular cycle or pattern. It indicates that the system or equipment repeatedly performs the same set of tasks at regular intervals.

3. **Starting:** Starting describes the process of starting a system or device from a halted condition. Starting occurs regularly at the beginning of each operational cycle in intermittent periodic duty.
4. Contrarily, braking entails halting or slowing down the machine or system at the conclusion of each operational cycle. It either completely stops the instrument or slows it down at the specified pace.

Depending on the application, there may be different justifications for using intermittent periodic duty with beginning and braking.

Typical illustrations include:

1. **Motor-driven machinery:** A few machines, such conveyor systems or industrial equipment, need intermittent starting and stopping in order to function. A conveyor belt, for instance, may begin moving items, pause for loading or unloading, and then restart.
2. **Automotive applications:** In systems like engine cranking, where the engine regularly starts and stops, intermittent duty with starting and braking may be seen. Additionally, certain automobile parts, such power windows or windshield wipers, perform erratically and often start and stop.
3. **Heating, ventilation, and air conditioning (HVAC) systems:** HVAC systems may operate on an intermittent duty cycle that includes beginning and stopping. To maintain the proper temperature or airflow, the system's components, such as fans or compressors, May periodically start and stop.
4. **Robotics:** Robots often complete tasks in cycles that need repeated beginning and stopping movements. These cycles could entail picking up items, handling them, and then moving on to the subsequent job.

Continuous duty with intermittent periodic loading

1. In separately excited machines, this form of drive operation alternates between periods of operation under continuous load and periods of operation under no load with a normal voltage applied to the excitation winding.
2. Once again, the load and no load periods are insufficient to get the temperatures up to the upper limits.
3. This assignment differs from intermittent periodic duty by operating with no load rather than during a break.
4. DC compound motors, universal motors, and single-phase/three-phase induction motors are all capable of carrying out this sort of activity.

Examples are pressing, Cutting, Shearing, and drilling machine drives.

A scenario where a device or system functions continuously but sometimes encounters periods of higher or varied load is known as continuous duty with intermittent periodic loading. In other words, even if the system or device is intended to operate continuously under normal circumstances, there are some times or circumstances that momentarily raise the system's burden. Imagine that an industrial conveyor belt is driven by an electric motor that runs nonstop. In typical circumstances, the conveyor is kept moving by the motor's steady rotating force. This illustrates the ongoing obligation component. On the other hand, the motor's functioning could be interrupted by intermittent occurrences that cause momentary spikes in load. For instance, the motor has to work harder to maintain the correct speed when big things or a lot of goods are loaded on the conveyor at once. The intermittent periodic loading is represented by this.The engine may be under greater stress, use more power, and produce more heat during these times of elevated load than it would normally. When designing and choosing the motor, it is crucial to take these intermittent loading events into account to make sure it can manage the increased demand without overheating or breaking.

Continuous duty with starting & braking

1. It consists of three distinct phases: beginning, running, and electrical braking.
2. Here, the amount of downtime is minimal.
3. Induction motors that operate on one or three phases may handle this kind of task.

Examples: The main drive of a blooming mill.

An electrical motor or equipment that is built to withstand continuous, extended usage while also taking into consideration the starting and braking procedures is said to be operating on continuous duty with starting and braking. The motor must be able to endure the pressures and energy dissipation associated with frequent starting and stopping in these applications.

The breakdown of each element is as follows:

1. **Continuous Duty:** The capacity of the motor to run constantly without overheating or sustaining damage is referred to as continuous duty. Continuous-duty motors are designed to run continuously for long periods of time without requiring cooling breaks or experiencing a substantial temperature increase. They are often used in machines like pumps, fans, and conveyors where the motor must operate constantly for extended periods of time.
2. **Starting:** The process of starting the motor's rotation from a still state is referred to as starting. The beginning current, which may be many times larger than the regular operating current, is experienced by a motor when it first turns on. The motor windings, electrical components, and the power supply system are all subject to increased stress as a result of this current spike. The increased beginning current is safe to handle and endure for continuous-duty motors with starting capability.

3. **Braking:** The act of braking involves putting an end to the motor's revolution. When a motor is braked, the spinning load's kinetic energy is lost, which results in the production of reverse current or regenerative energy. If not managed appropriately, this reverse energy may cause damage to the motor and the related power supply system. In order to manage this regenerative energy, continuous-duty motors with brake capacity may either dissipate it via resistors or feed it back into the power supply system through regenerative drives or braking choppers.

In applications like cranes, hoists, elevators, and machine tools where frequent starting and stopping is necessary, continuous-duty motors with starting and braking capabilities are often employed. With their sturdy structure, effective cooling systems, and electrical safeguards, these motors are built to withstand the strains of repeated starts and stops while still providing dependable performance.

Continuous duty with periodic speed changes

1. It comprises of a time of running with a load at a certain speed and a subsequent period of running with distinct loads at speeds that are insufficient to get them both to their respective steady states.
2. Further, there is no break in this.
3. DC series motors in traction and single phase/three phase induction motors are both capable of carrying out this sort of operation.

DISCUSSION

A system or equipment that runs continuously for a lengthy period of time while experiencing periodic speed changes is referred to as continuous duty with periodic speed changes. The term "continuous duty" in this context suggests that the equipment or system is built to operate constantly with little to no pauses or interruptions. On the other hand, periodic speed changes relate to changes in a system or machine's operating speed over a predetermined period of time. Depending on the needs of the application, these speed adjustments may happen often or sporadically. A variable speed electric motor used in industrial applications is a typical illustration of continuous duty with occasional speed variations. These motors are designed to run continuously for extended periods of time while powering a variety of machines or pieces of equipment. To satisfy shifting needs or enhance performance, they may also have their speed altered frequently. For instance, the production demands of a manufacturing facility may dictate different speeds for a conveyor belt system. The conveyor belt's motor would be built for continuous duty to run continuously, but it would also have the capacity to occasionally change the speed as required. When production is at its highest, the speed may be increased; when it is at its lowest, it may be decreased[9]–[11].

CONCLUSION

In summary, classes of motor duty are essential for assuring the effective and dependable performance of electric motors in a variety of applications. These categories make it easier to choose, build, and rate motors properly by appropriately classifying motors according to their predicted workload, start-up needs, and continuous working circumstances. As a result, possible safety risks such as motor overheating and early failures are reduced. Engineers, producers, and end users may choose motors intelligently and assure the best performance and lifetime of motor-driven systems by being aware of the different classifications of motor duty.

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SELECTION OF POWER RATING OF MOTORS

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ABSTRACT:

One of the most important steps in engineering design and application is the choice of power rating for motors. It entails figuring out a motor's proper power capability depending on the demands of the system or piece of machinery it will be utilized in. In order to choose the best power rating for motors, this article outlines the variables to take into account and the approaches to use. Engineers may make sure that the motors used are effective, dependable, and able to satisfy the operational requirements of the intended application by using systematic study and assessment.

KEYWORDS: *Equivalent Current, Power Rating, Motor Selection, Motor.*

INTRODUCTION

Motors' power ratings are measurements of their capacity to produce power. It is a crucial criterion for figuring out if a motor is appropriate for a certain application. The motor's capacity to drive equipment, appliances, or any other mechanical system may be determined in large part by the power rating. Watts (W) or kilowatts (kW) are the most common units used to define a motor's power rating, which measures how quickly it can transform electrical energy into mechanical power. It displays the maximum power output that the motor is capable of producing under typical operating circumstances. The design, size, and efficiency of a motor, as well as other variables, all affect its power rating. Since they can handle bigger workloads, larger motors often have higher power ratings[1]. A motor's efficiency is another important factor in determining its power rating. A motor's ability to convert a greater portion of its electrical input power into usable mechanical power output is referred to as efficiency. It is essential to remember that a motor's power rating has to correspond to the specifications of the particular application. A motor may struggle to deliver enough power, overheat, or fail if its power rating is too low for the job at hand. On the other side, a motor with a power rating greater than what is needed may be ineffective and use more energy than is necessary [2].

In reality, motors' power ratings often come with additional details including voltage, current, speed, and torque. These standards allow engineers, designers, and users to choose the best motor for their intended applications by providing a thorough knowledge of a motor's performance characteristics. Overall, a key factor in determining a motor's performance and suitability in different industrial, commercial, and residential applications is its power rating[3]. When choosing motors, one may ensure maximum efficiency and dependable performance for a variety of applications by having a clear grasp of the power rating.The history of motor power ratings may be traced back to the invention of electric motors. The idea of power rating arose as a way to define the capacity and performance capabilities of motors in the late 19th century, when electric motors began to acquire popularity and broad usage [4].

The creation of standardized rating methods was a crucial turning point in power rating history. The International Electro technical Commission (IEC), which sets global standards for electrical technologies, including motors, was founded in 1893. The International Electro technical Commission (IEC) created a standard method of evaluating motors according to their output of power, known as the IEC frame size. This system offered a standardized method to establish the physical dimensions and power rating of motors, enabling improved compatibility and interchangeability. Power rating systems changed throughout time as motor technology improved and the need for more effective and potent motors increased. In order to offer a more thorough insight of motor performance, additional rating factors were developed. Voltage, current, effectiveness, power factor, and torque were some of these metrics [5].

Late in the 20th century, groups like the European Committee of Manufacturers of Electrical Machines and Power Systems (CEMEP) and the National Electrical Manufacturers Association (NEMA) in the United States and Europe, respectively, created their own motor rating standards. The uniformity of the power rating requirements was ensured by these standards, which also made it easier to choose and exchange different motors. Power rating systems have evolved along with improvements in motor technology and an increased focus on energy economy. In order to promote the adoption of more energy-efficient motors, modern power rating standards now often include energy efficiency classes, such as the International Efficiency (IE) classes or the NEMA Premium Efficiency levels. Today, a motor's power rating is critical in a variety of sectors and applications, from electric automobiles and HVAC systems to industrial equipment and manufacturing processes.

Power Rating for Motor's Selection

From the perspective of motor rating for different duty cycles, section 1.6 may be generally divided into the following categories:

1. Continuous duty and constant load
2. Continuous duty and variable load
3. Short time rating

Continuous duty and constant load

If the motor is operating at radians/seconds with a load torque of T N-m and efficiency is in, the motor's power rating is

$$P = \frac{T\omega}{1000} KW$$

Power rating is determined, and among commercially available ratings, the motor with the next greater value is chosen. Of course, the motor's speed must coincide with the demands of the load. Checking if the motor can provide the required starting torque is also vital[6].

Continuous duty and variable load

1. A motor's working temperature must never rise over the maximum temperature allowed since doing so may cause insulation to deteriorate and break down, reducing the motor's useful life.
2. It is customary to base motor power ratings on a reference temperature, such as 35°c.
3. As a result, the power listed on a motor's nameplate corresponds to the power that the motor can produce at 35°c ambient temperature without overheating. The duty cycle and temperature are tightly connected, and environmental elements are often included as well.
4. Heating concerns may be used to establish a machine's rating.
5. However, the starting torque and overload capability of the chosen motor should be examined.
6. This is due to the possibility that the motor chosen only on the basis of heating may not be able to satisfy the mechanical requirements of the load that it will be driving.
7. The vast majority of electric machines used in drives run constantly at a load that is constant or hardly varies.
8. If the approximate constant power input is known, choosing the motor capacity for these applications is quite straightforward.
9. Numerous applications don't know in advance how much power a motor would need, which causes a number of challenges.
10. It is important to identify the load diagram, which is a diagram showing the fluctuation of power output vs time, in order to estimate ratings for machines whose load characteristics have not been properly investigated[7].

When the load varies, the motor's temperature fluctuates continually. Because of this, choosing the motor rating for heating is challenging.

1) If the load diagram has an irregular form or a lot of steps, the analytical analysis of heating becomes quite difficult.
2) As a result of the method's lack of precision, choosing the motor capacity by examination of the load diagram becomes very challenging.

However, choosing the motor based on the lowest or maximum load would be incorrect since the motor would be overloaded in the first instance and under loaded in the second. As a result, appropriate methodologies for determining motor ratings must be used.

Methods used

The four commonly used methods are:

1. Methods of average losses

2. Equivalent current method
3. Equivalent torque method
4. Equivalent power method

A. Methods of average losses

Finding the motor's average losses Qav under the specified load diagram constitutes the procedure.

The picture depicts a straightforward power load diagram and loss diagram under changing load situations. These losses are then compared with the Q, the losses corresponding to the continuous duty of the machine when operating at its normal rating. By using the motor's efficiency curve, the losses of the motor are estimated for each section of the load diagram. The Average Load Losses is depicted in Figure 1[8].

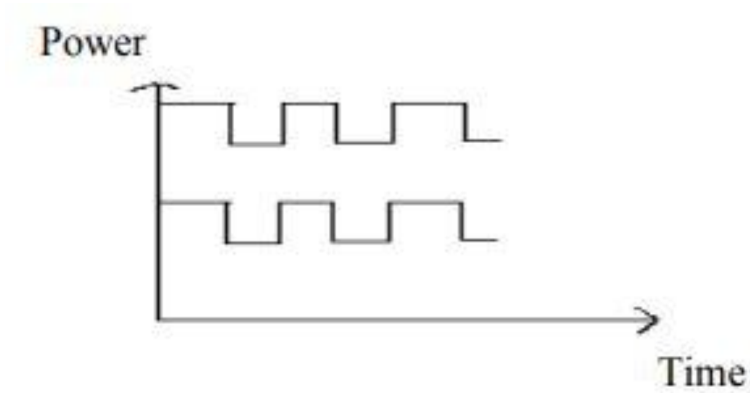

Figure 1: Average Load Losses [freebookcentre].

The average losses are given by

$$Q_{av} = \frac{Q_1 t_1 + Q_2 t_2 + Q_3 t_3 + \dots\dots\dots\dots + Q_n t_n}{t_{1+} t_2 + \dots\dots + t_n}$$

1. The motor is chosen if the two losses are equivalent or very slightly different. If the losses are significantly different, a different motor is chosen, and the computations are repeated until a motor is found that has losses that are nearly identical to the average losses.
2. It is important to confirm that the chosen motor has a suitable overload capacity and starting torque.
3. The highest temperature increase under varied load circumstances is not taken into consideration by the average loss calculation approach. The average temperature increase of

the motor throughout one work cycle may be calculated with accuracy and reliability using this approach, however.

This method's drawbacks include a laborious working environment and the frequent absence of the efficiency curve, which necessitates the use of an empirical formula that may not accurately predict efficiency.

B. Equivalent Current Method

The premise behind the equivalent current approach is that the real variable current may be substituted by an equivalent current (ieq) that results in the same motor losses as the actual current.

$$I_{eq} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + I_3^2 t_3 + ...+ I_n^2 t_n}{t_1 + t_2 + t_{3+}............+ t_n}}$$

The equivalent current is compared with the rated current of the motor selected and the conditions $I_{eq} \leq I_{nom}$ should be met. I_{nom} is the rated current of the machine.

The machine selected should also be checked for its overload capacity,

For DC motors,

$$\frac{I_{\max}}{I_{nom}} \leq 2 to 2.5 and for induction motors, \frac{I_{\max}}{nom} \leq 1.65 to 2.75$$

$I_{\max}$ = maximum current during the work cycle.

$T_{\max}$ = maximum load torque

T_{nom} = torque of the motor at rated power and speed

It becomes required to choose a motor with a higher power rating if the over load capability of the current motor is insufficient. Calculating the equivalent current could be challenging, particularly when the current load diagram is erratic. In these circumstances, the equivalent current is determined using the following equation. Equivalent Current waveform is depicted in Figure 2.

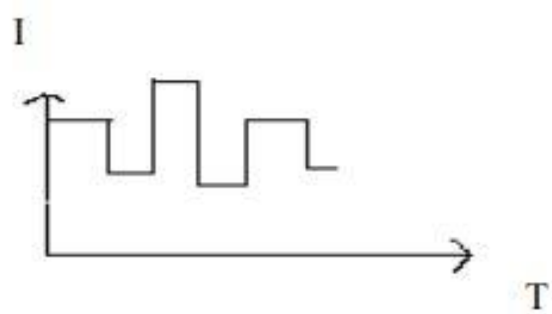

Figure 2: Equivalent Current.

For a triangular shape diagram,

$$I_{eq} = \sqrt{\frac{I^2}{3}}$$

For a trapezoidal shaped diagram,

$$I_{eq} = \sqrt{\frac{I^2 + I_1 I_2 + I_2^2}{3}}$$

The aforementioned technique enables the calculation of the corresponding current values with precision enough for practical use.

C. Equivalent torque method

Torque is exactly proportional to current under the assumption of constant flux and power factor.

$$T = \sqrt{\frac{T_1^2 t_1 + T_2^2 t_2 + \dots\dots\dots + T_n^2 t_n}{t_1 + t_2 + \dots\dots + t_n}}$$

D. Equivalent power method

Power and torque have a direct relationship in the calculation for the equivalent power method. The equivalent power is determined by the following relationship when the speed is constant or when the speed variations are minimal:

$$P_{eq} = \sqrt{\frac{P_1^2 t_1 + P_2^2 t_2 + \dots\dots\dots + P_n^2 t_n}{t_1 + t_2 + \dots\dots\dots + t_n}}$$

Short time rating of motor

An electric motor with rated power Pr that is continually exposed to its rated load achieves the allowable temperature increase over time. The same motor may handle higher load for a brief period of time if it is being utilized for short-term duty without raising the motor's maximum allowable temperature. Short time motor rating is show in Figure 3.

$$\theta = \theta_m(1 - e^{\frac{N}{\tau}}) \qquad \theta_m = \theta_m^{'}(1 - e^{-\frac{N}{\tau}})$$

Figure 3: Short Time Motor Rating.

Where ϴ = operational period at rated load

The highest temperature that a motor operating on a short time rating is permitted to attain while operating continuously at that rating is denoted by the symbol ϴm.

The motor's maximum allowable temperature increase while it is operating continuously at its continuous rating is ϴm'.

If it is assumed that the increase in temperature is proportionate to losses equal to the motor's rated output.

$$\frac{\theta_m^{'}}{\theta_m} = \frac{W_x}{W_r} = \frac{1}{(1 - e^{-\frac{N}{\tau}})}$$

The motor's ratings will correspond to its losses.

Losses for continuous rating are as follows if Px is the short-term load and Pr is the motor's continuous rating:

$$W_r = W_{const} + W_{cu}$$

$$W_x = W_{const+}(\frac{P_x}{P_r})^2 W_{cu}$$

The ratio of $\frac{P_x}{P_r}$ can be determined.

CONCLUSION

In this chapter, we have learnt that motor's power rating is a challenging undertaking that calls for careful consideration of several variables. These variables include the system's operating specifications, the load characteristics, the environment, and safety laws. Engineers can establish the proper power capacity for a motor by using a methodical approach and doing in-depth investigation. Oversizing a motor may result in excessive expenses and inefficiencies while under sizing a motor can cause performance problems and early failure. In order to guarantee that the motor performs dependably and effectively for the duration of its planned lifetime, it is crucial to choose the best power rating. To further limit energy usage and lessen environmental effect, advances in motor technology and the availability of energy-efficient solutions should be taken into account. Engineers may improve the overall performance and sustainability of their systems or equipment by using appropriate motor selection procedures.

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AN OVERVIEW OF THE ELECTRICAL MACHINES

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ABSTRACT:

This chapter gives a general overview of the numerous electrical machine types that are often used in commercial and household settings. DC machines, induction machines, and synchronous machines are the primary kinds covered. Each type's operating principles, distinguishing traits, and uses are described. Also outlines the benefits and drawbacks of each machine type, assisting readers in developing a thorough awareness of their unique capabilities and limits. The choice and design of electrical machinery for certain purposes may be aided by this knowledge.

KEYWORDS: *Electrical Machines, Dc Machines, Induction Machines, Synchronous Machines.*

INTRODUCTION

Electrical machinery is equipment that transforms electrical energy into mechanical energy or the other way around. They are essential components of many different industries, transportation networks, electricity production, and other purposes. Electrical devices come in a variety of forms, each with a distinct function. Devices that transform electrical energy into mechanical energy are known as electric motors. They are extensively used in electric cars, pumps, fans, industrial gear, and appliances. Further divisions into different kinds of electric motors include:

1. **Alternating Current (AC) Motors:** Alternating Current (AC) motors produce a revolving magnetic field by using alternating current. Induction motors, synchronous motors, and permanent magnet motors are a few examples.
2. **Direct Current (DC) Motors:** Direct Current (DC) motors rotate by using direct current to create a magnetic field that interacts with the motor's armature. Stepper motors, brushless DC motors, and brushed DC motors are a few examples.
3. **Generators:** Electrical equipment known as generators transform mechanical energy into electrical energy. Portable generators, wind turbines, and power plants all often use them. Additionally, generators may be categorized according on the kind of energy input they utilize, including:
4. **Alternating current (AC) generators**, usually referred to as alternators, create this kind of power. They generate voltage in the stator windings using a revolving magnetic field.
5. **Direct Current (DC) Generators:** DC generators generate power using a direct current. Typically, they use brushes and a commutator to transform mechanical energy into electrical energy.

6. **Transformers:** Using electromagnetic induction, transformers move electrical energy between two or more electrical circuits. They are used for impedance matching, power distribution, and voltage conversion. Transformers may be broadly divided into.
7. **Step-Up Transformers:** Typically employed in power transmission and distribution systems, step-up transformers raise the voltage from the input side to the output side.
8. **Step-Down Transformers:** Frequently used in power supply and electrical appliances, step-down transformers lower the voltage from the input side to the output side.
9. Electrical devices known as alternators create alternating current (AC) power. They are generally used in power production applications, including as internal combustion engines and wind turbines, and automobile charging systems.
10. **Synchronous condensers** are synchronous devices used in electrical power systems for reactive power support, voltage stability, and power factor correction. They are made to control voltage levels and increase the stability of the power system.

Evolution of Electrical Machines:

The development of numerous machine kinds to satisfy certain needs and technical breakthroughs has considerably advanced the area of electrical machines throughout time. An outline of the development of electrical machines is shown below:

1. Direct Current (DC) machines were among of the first kinds of electrical machinery. Among them are DC motors and DC generators, which transform electrical energy into mechanical energy and mechanical energy into electrical energy, respectively. Early electrical power systems and industrial applications made extensive use of DC equipment.
2. Asynchronous machines, usually referred to as induction machines, rose to prominence in the late 19th century. They work using the electromagnetic induction theory. Induction motors are strong, dependable, and often utilized in many different applications, such as transportation, HVAC systems, and industrial machines.
3. Synchronous Machines: Synchronous machines have a fixed speed that is coordinated with the power system's frequency. They include synchronous motors, which find employment in industries where consistent speed operation is necessary, and synchronous generators, which are often used in power plants to create energy.
4. Transformers: In electrical power systems, transformers are crucial components. They work by transferring electrical energy across various voltage levels using the electromagnetic induction technique. Transformers have been essential for the effective transfer of energy and adjustment of voltage throughout the transmission and distribution of electrical power.
5. Electronically commutated machines, commonly referred to as brushless machines, have grown in favor in recent years. They do away with the necessity for mechanical commutators and brushes that are present in conventional machines. Due to their increased efficiency, dependability, and controllability, brushless DC motors and permanent magnet synchronous motors are often utilized in applications including electric cars, appliances, and industrial automation[1]–[3].

6. Stepper motors are specialized motors that are made to move in precise steps or increments. They are often used in robotics, 3D printing, and CNC machine applications where precise positioning and control are necessary.
7. Switched Reluctance Machines: To produce torque, switched reluctance machines (SRMs) rely on the magnetic reluctance concept. Due to its straightforward design, high torque-to-inertia ratio, and potential for high-speed operation, they have attracted interest as a possible substitute for conventional machines. SRMs are used in a variety of fields, including as industrial automation, aerospace, and automotive systems.
8. Emerging Technologies: New classes of electrical machines have been created recently as a result of developments in materials, electronics, and power electronics. Examples include improved electric motors of different types, magnetically levitated machines, and superconducting machines. These innovations are designed to increase productivity, decrease size and weight, and open up new possibilities for advanced robotics, transportation, and renewable energy.

The demand for greater economy, dependability, environmental sustainability, and technical developments are driving the ongoing evolution of electrical equipment. To satisfy the changing needs of diverse sectors and contribute to a more electric and sustainable future, new materials, control methods, and production processes are being investigated.

DISCUSSION

A special issue of Energies is devoted to the design and use of electrical machines. Authors from several research institutions offer the findings of their scientific studies on electrical devices in this special issue. The most crucial elements of both the industrial and commercial realms are electrical machinery. They are at the center of the new industrial revolution that has been sparked by the advancement of renewable energy and electro mobility. To match the useful lifetime of power electronics in complex system applications and to compete in a market under constant pressure to deliver the highest performance standards, today's electric motors must meet the strictest requirements for reliability, availability, and high efficiency.Today, it is feasible to construct electric machines and full drive systems that are quicker and more affordable owing to the use of extremely efficient numerical algorithms operating on powerful computers. The creation of ever-more complicated motor designs and topologies is also made possible by advancements in material science and technology.The "Design and Application of Electrical Machines" Special Issue's objective is to further the development of electrical machines. The purpose is to illustrate a range of electrical machine-related challenges that are well-known. This enables us to reach a far larger population of scientists and engineers than other extremely monothematic issues (accessible primarily to specialist readers).Here, researchers discuss the findings of their studies on the development and use of various electric devices. Electrical machines include: linear drives for transportation; new design methodologies for electrical machines; optimization of electrical machines; electrical machines for EVs and HEVs; power electronics used in electrical machines; supply and control of electrical machines; and new technologies, materials, devices, and systems for electrical machines[4]–[6].

It was decided to publish the original findings of study, modeling, design, construction, and testing of contemporary electrical machines in this Special Issue, "Design and Application of Electrical Machines".

Electrical machines are classified as AC machines and DC machines.

Types of DC machines

1. DC Generator
2. DC Motor

Types of AC machines

1. Transformers
   i. Single phase Transformers
   ii. Three phase Transformers
2. Alternators
3. Synchronous motor
4. Induction motor
   i. Single phase Induction Motor
   ii. Three phase Induction Motor

Many different businesses and sectors use electrical machinery, which include motors and generators. Here are a few typical uses for electrical devices:

1. Electric motors are widely employed in industrial machinery to power equipment such as pumps, compressors, fans, conveyors, machine tools, and other tools. For a broad variety of production operations, they provide dependable and effective power.
2. Transportation: A variety of types of transportation depend heavily on electric devices. In order to provide clean and effective propulsion, electric motors are utilized to drive the wheels of electric cars (EVs) and hybrid electric vehicles (HEVs). They are also used for propulsion in trams, trains, and subway systems.
3. Home Appliances: Many domestic appliances, including refrigerators, washing machines, vacuum cleaners, dishwashers, air conditioners, and fans, include electric motors. They support the essential mechanical operations and improve the practicality and effectiveness of these gadgets.
4. Electric generators are essential parts of renewable energy systems, such as wind turbines and hydroelectric power plants. These generators help to generate electricity sustainably by converting mechanical energy from wind or water into electrical energy.
5. Power Generation and Distribution: Power plants employ large-scale electric generators to generate energy. These generators are commonly powered by steam turbines or gas turbines.

They transform mechanical energy into electrical energy, which is subsequently transmitted through the power grid to residences, commercial buildings, and industrial facilities.

6. Robotics and automation: In the manufacturing, assembly, and logistics sectors, electric motors are the fundamental component of robotic systems and automation machines, enabling precise and controlled movement for robotic arms, actuators, and robotic systems.
7. Aviation and aerospace: A variety of aerospace applications, such as aircraft propulsion systems, actuation systems, landing gear mechanisms, and auxiliary power units, use electrical machines. Satellites and other spacecraft also employ electric motors for attitude control and other purposes.
8. Electric motors are used in a variety of medical devices and apparatus, including ventilators, MRI scanners, surgical robots, infusion pumps, and artificial limbs. They support the functioning, accuracy, and control of these essential medical devices.
9. Electric motors are used in entertainment and consumer electronics products including cameras, projectors, audio systems, and gaming consoles. They also provide electricity to consumer devices like remote-controlled toys, drones, and electric toothbrushes.
10. These are just a few instances of the many uses for electrical machinery. Electric motors and generators are vital components in many sectors due to their adaptability, effectiveness, and controllability, which enables different technological developments and enhances the quality of our everyday lives.

Electric machines have many benefits.

1. Efficiency: Electric equipment with high levels of efficiency include motors and generators. They can efficiently transform electrical energy into mechanical energy (motors) or vice versa (generators), saving money and having a less negative effect on the environment.
2. Environmental friendliness: Unlike combustion engines, electric machines don't produce any greenhouse gases or other pollutants while they're operating. As a result, they are more eco-friendly and help to create a cleaner, greener energy system.
3. Integration of Renewable Energy: Renewable energy sources including sun, wind, and hydropower are compatible with electric machinery. They can effectively transform the energy from these sources into useful electrical power, making it easier to integrate and use renewable energy sources in the grid.
4. Electric machines provide fine control over speed, torque, and position, enabling flexible and accurate operation in a variety of applications. Variable Speed: Electric machines also enable variable speed. Efficiency is increased, wear and tear is decreased, and energy consumption may be optimized thanks to variable speed control.
5. Compact and Lightweight: Compared to other kinds of machines, electric machines may be constructed to have a high power-to-weight ratio, which makes them small and light. This qualifies them for uses like electric cars and portable electronics where weight and space are important considerations.

Negative aspects of electric machinery

1. Beginning Cost: Compared to other kinds of machines, electric machines often have a greater beginning cost. This is mainly because of the complexity of their designs, the need for power electronics, and the necessity for control systems. The prices have, however, been decreasing over time due to technological breakthroughs and economies of scale.
2. Dependence on Power Source: In order to function, electric devices need a steady and dependable power source. Backup power systems or energy storage solutions could be required in situations where power outages or variations are frequent, increasing system complexity and expense.
3. Limited Energy Storage Capacity: Electric machinery, particularly motors, lack the ability to store energy by nature. To store and release energy as required, they need external energy storage devices like batteries or capacitors. The whole system may become more complicated and costly as a result.
4. Cooling and Heat Dissipation: During operation, electric machines produce heat that must be efficiently removed in order to avoid overheating and retain peak performance. It may be necessary to use adequate cooling systems, such as fans or liquid cooling, which increases complexity and maintenance needs.
5. Electric machinery may produce electromagnetic interference (EMI), which can impair the functionality of neighboring electronic equipment or communication networks. To reduce EMI and guarantee compatibility with other equipment, appropriate shielding and mitigation measures must be put in place[7]–[9].

CONCLUSION

For engineers and other professionals working in the area of electrical engineering, it is vital to comprehend the many kinds of electrical machines. Electric cars and industrial equipment both employ DC machines because they provide superior speed control. Because of their high dependability and affordability, induction machines are ideal for many industrial and domestic applications, including pumps and fans. Due to its capacity to maintain constant speed and power factor, synchronous machines are generally employed for high-power applications like power generation and big industrial systems. Engineers may choose and develop electrical machines for particular applications by taking into account the operating concepts, traits, benefits, and drawbacks of each machine type. The creation of more efficient and dependable electrical machines is being fueled by ongoing technological developments, which will increase their potential uses and advantages in the future.

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AN OVERVIEW OF THE DC GENERATORS

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ABSTRACT:

Direct current (DC) generators are electro-mechanical systems that transform mechanical energy into electrical power. They are essential for a number of applications, including as electric mobility, industrial operations, and power production. An overview of DC generators, including their design, operation, and essential components, is given in this chapter. The many kinds of DC generators are also covered, along with their benefits and drawbacks. The report also emphasizes the significance of routine maintenance and troubleshooting methods to guarantee the best performance and lifetime of DC generators.

KEYWORDS: DC Generators, Direct Current, Generators, Electro-Mechanical Devices, Motors.

INTRODUCTION

An instrument for electro-mechanical energy conversion is a DC machine. DC machines can be divided into two categories: DC motors and DC generators. In contrast to a DC motor, which transforms DC electrical power into mechanical power, a DC generator transforms mechanical power into DC electrical power[1]. A DC motor is utilized in applications where a broad range of speeds and good speed regulation are necessary, such as in electric traction systems, while an AC motor is almost often used in the industry to convert electrical power into mechanical power. Generator and dc motor architecture is essentially identical[2]. A very safe method of using the generator is used. There is therefore the open construction style. The generator is used in a very secure manner. Consequently, there is the open construction style. However, because the motor is utilized in an environment where it is exposed to dust and moisture, it needs enclosures that are, for example, dustproof, fireproof, etc., as needed. Despite being a significant source of DC electricity, the battery has a limited capacity to run any devices[3]. Large amounts of DC electricity are necessary for various applications like electroplating, electrolysis, etc. As a result, DC generators are employed to provide power in these locations.

Evolution of DC generators:

DC generators have a long history that begins in the early 19th century, when researchers and creators started delving into the concepts of electromagnetism and electrical power production. Here is a quick rundown of the significant turning points in the development of DC generators:

1. **Discover of Electromagnetic Induction (1831):** English scientist Michael Faraday established the groundwork for the creation of electricity with his discovery of the

electromagnetic induction phenomena. According to Faraday's experiments, a magnetic field change may cause an electric current to flow through a nearby conductor.

2. The dynamo was developed between 1832 and 1833 by French instrument maker Hippolyte Pixii, who created the first functional machine known as the "Pixii machine" or the "magneto." It was made up of a coil of wire that generated alternating current (AC) and a revolving magnet.
3. **The Gramme Machine's invention (1870):** The dynamo was significantly improved by Zenobe-Theophile Gramme, a Belgian electrical engineer, who created the "Gramme machine." Direct current (DC) may be generated by it thanks to a ring armature with several coils. The Gramme machine served as the model for contemporary DC generators[4].
4. Engineers furthered the development of DC generators by creating the compound-wound generator in the late 19th century. In order to provide a more consistent output voltage, this kind of generator included both series and shunt winding topologies[5].
5. Late 19th to early 20th century improvements in generator performance: Over time, engineers concentrated on improving the performance and efficiency of DC generators. Better armature designs, superior insulating materials, and more effective commutation techniques led to the development of more dependable and powerful generators.
6. In the late 19th and early 20th centuries, industrial power generation began to take off: DC generators were crucial in the creation of industrial power networks as the need for energy increased. They produced power for illumination, motors, and several industrial uses[6].
7. Alternating current (AC) systems were used in the late 19th and early 20th centuries. The transition to AC power systems was made possible by Nikola Tesla's development of the AC generator and improvements in AC transmission technology. Compared to DC, AC has a number of benefits, including the capacity to transfer electricity further and at greater voltages. The use of DC generators in power generating declined as a result of this change.

DC generators continue to be used in a variety of contexts, including battery charging, traction systems, and specialized industrial operations, despite the fall in their use in power systems. The historical advancements in DC generators cleared the path for the creation of increasingly complex electrical devices and systems and set the groundwork for the larger area of electrical power production[7].

Basic structure of Electrical machines:

The Stator and Rotor are the two primary components of a rotating electrical or DC machine. An air gap separates the stator and rotor from one another. The machine's fixed outer frame is known as the stator. The internal component of the machine is the rotor, which is free to rotate. Ferromagnetic materials are used to create the stator and the rotor. Both the outer and inner peripheries of the rotor and stator have slots carved into them. In the slots of the stator or rotor, conductors are inserted. Windings are created by connecting them together. The Armature windings are the windings in which voltage is induced. the winding that a current is routed through to create the main flux is called field winding.

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Despite the fact that AC machines make up a much higher proportion of electrical equipment in use, D.C. machines are still very important for industry. The main benefit of a DC machine, and especially a DC motor, is that speed can be controlled precisely. No AC motor makes this claim of a benefit. However, DC generators are less popular than they once were since rectifiers are mostly utilized to obtain direct current from an AC source when it is needed. However, a knowledge of DC generators is crucial since they provide as a logical introduction to DC motor behavior. In fact, a lot of DC motors used in industry briefly double as DC generators. This chapter will cover a variety of topics of DC generators[8].

Electromechanical System in Simplified Form is shown in Figure 1:

• Energy Distribution can be express as follows given below:

WE = total energy supplied by the electric source

WM = total energy supplied by the mechanical source

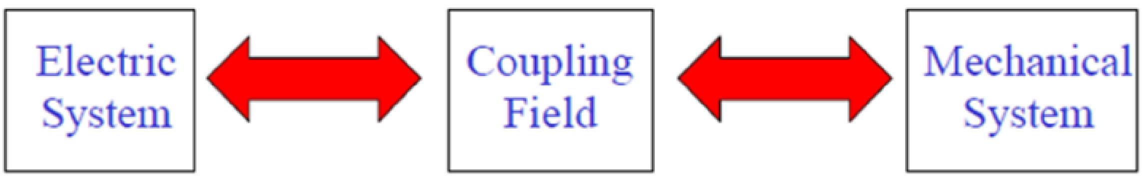

Figure 1: Electromechanical System.

WE = We + Wel + Wes

Wm = Wm + Wml + Wms

DISCUSSION

DC Generator

An electrical device known as a dc generator turns mechanical energy into direct current electricity. The idea behind this energy conversion is the creation of dynamically generated EMF.

i. Construction of DC Generator:

Without making any structural alterations, a DC generator can function as a DC motor, and the opposite is also true. Therefore, a DC machine can be broadly defined as a DC generator or a DC motor. These fundamental constructional aspects apply equally to the building of a DC motor. A straightforward 4-pole DC machine's construction details are shown in the below diagram. The stator and rotor are the two fundamental components of a DC machine. The following list of a DC machine's fundamental components is provided. The construction of DCGenerator is show in Figure 2.

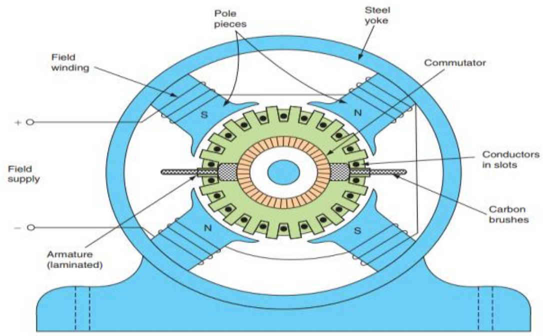

Figure 2: Construction of DC Generator.

There are various sections that which motor is divided, they are as follows as:

1. Yoke: A DC machine's yoke is its outside frame. Steel or cast iron make up its construction. It not only gives the entire assembly mechanical strength, but it also conveys the magnetic flux generated by the field winding.

2. Poles and pole shoes: Bolts or welding are used to attach the poles to the yoke. They are attached to pole shoes and carry field winding. Pole shoes have two functions: first, they support field coils, and second, they evenly distribute flux in the air gap.

3. Field winding: Copper is typically used to make them. Each pole has a field coil that has been previously wrapped, positioned there, and connected in series. They are constructed with a wound pattern that, when energized, north and south are formed become alternate.

4. Armature core: The rotor of a DC machine is the armature core. It has slots to carry the armature winding and is cylindrical in shape. To minimize eddy current losses, the armature is constructed from thin, circular steel discs that have been laminated. It might have air ducts for the axial air flow needed for cooling. The shaft is keyed to the armature as shown in the Figure 3.

Figure 3: Armature core.

5. Armature winding: Typically, an armature slot holds a former wrapped copper coil. The armature conductors are separated from one another and the armature core by an insulation layer. Either the lap winding method or the wave winding method can be used to wind an armature. In most cases, double layer lap or wave windings are used. In an armature with a double layer winding, there will be two distinct coils in each slot.

6. Commutator and brushes: Using a commutator-brush setup, the armature winding is physically connected. In a dc generator, a commutator's job is to collect the current produced in the armature conductors. In contrast, a DC motor's commutator aids in supplying current to the motor's forward conductors. A copper set of insulated from one another segments makes up a commutator.Graphite or carbon are typically used to make brushes. As the commutator rotates, they rest on the segments and slide along them, maintaining physical contact and collecting or supplying the current. Commutator is shown below in the given Figure 4.

Figure 4: Commutator.

Working principle of DC generators:

According to Faraday's equations of electromagnetic induction, an EMF is induced in a conductor whenever it is exposed to a magnetic field that is changing. The induced EMF's magnitude can be determined using the dc generator's induced EMF equation. The induced current will flow along the conductor's closed path if one is present. The armature conductors are spun into the electromagnetic field created by the field coils in a DC generator. As a result, the conductors in the armature produce an electromagnetically induced EMF. Induced current's direction is determined by Fleming's right-hand rule.

The direction of induced current shifts anytime the conductor's motion direction shifts, according to Fleming's right hand rule. Think about a conductor travelling upward at the left and an armature spinning in the opposite direction. The motion of that specific conductor will change from upward to downward when the armature has completed one-half of its revolution. Every armature conductor will therefore have alternating current flow. You may see how the induced current's direction alternates in an ar mature conductor by looking at the above figure. However, when the current is reversed with a split ring commutator, the connections of the armature conductors also change. The result is that the terminals get unidirectional current as shown in the Figure 5.

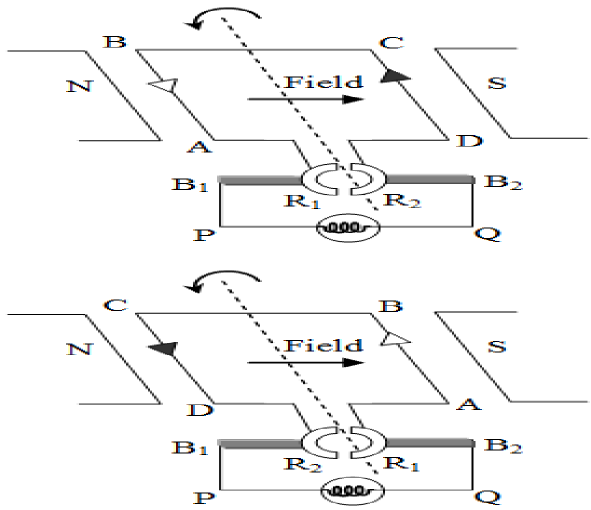

Figure 5: Illustrating the diagram of DC generator.

Therefore, the necessary components of a generator are as follows:

(a) a magnetic field

(b) conductor or a group of conductors

(c) Motion of conductor w.r.t. magnetic field.

Application of DC generators

DC generators are used in a variety of sectors and disciplines. Applications that are often used include:

1. DC generators are used in power plants to generate energy. For the purpose of converting mechanical energy into DC electrical power, they may be connected to turbines or engines. This power production may be used as a source of energy for small-scale applications, a backup power source, or in rural places.
2. DC generators are used in industrial processes where a steady and dependable DC power source is necessary. They are used in regulated DC power-dependent production procedures such as metal smelting, electroplating, electrochemical reactions, and other activities.
3. Electric transportation: Historically, the charging infrastructure for electric vehicles (EVs) has used DC generators. They provide the necessary DC power so that the batteries in the car may be charged. However, it's important to remember that contemporary EVs mostly use AC motors and inverters as opposed to DC generators.

4. DC generators are used to charge batteries in a variety of applications, including marine boats, recreational vehicles, off-grid solar systems, and portable power sources. They provide a dependable DC power supply for maintaining and charging battery banks.
5. Applications requiring a steady and continuous DC power source, such as welding and cutting, employ DC generators. They provide accurate and effective operation by supplying the required current for arc welding and cutting operations.
6. For studies and equipment testing that need a DC power supply, DC generators are used in research labs and testing facilities. They provide a regulated and flexible power source for carrying out different technical and scientific investigations.
7. In distant or off-grid telecommunication systems, such as cell towers situated in locations without access to a reliable grid power source, DC generators are employed. To power communication equipment, they provide a constant supply of DC power.
8. DC generators are often used into hybrid power systems, which couple a backup generator with renewable energy sources (such solar or wind). When renewable energy production is limited or when systems fail, they provide a dependable power supply.

CONCLUSION

In this chapter we have covered the basic introduction of DC generator and working principle and construction of DC generator, types of DC and it focused on important parts and components of a DC generator. Due to their capacity to transform mechanical energy into DC electrical power, DC generators are essential tools in a wide range of industries and applications. Their design and operation make them useful for a variety of power production systems and electric cars since they generate electricity effectively. Engineers and technicians may choose the best generator for a particular application and maximize its performance by being aware of the essential parts and different kinds of DC generators. DC generator lifetime and dependability are dependent on routine maintenance and problem-solving. The efficiency and dependability of DC generators are anticipated to be improved by ongoing technological breakthroughs, thereby increasing their uses in the future.

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AN OVERVIEW OF THE TYPES OF DC GENERATOR

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ABSTRACT:

Direct current (DC) generators are electrical devices that transform mechanical energy into electrical energy. Based on their design and operation principles, they are divided into numerous categories and find use in a variety of industries. This chapter gives a general overview of the many kinds of DC generators, including individually excited generators, shunt-wound generators, series-wound generators, and compound-wound generators. Each variety is ideal for certain uses and has its own distinctive qualities. Selecting the best generator for a specific application requires a thorough understanding of the many kinds of DC generators.

KEYWORDS: *Compound-Wound Generator, Dc Generator, Shunt-Wound Generator, Series-Wound Generator, Separately Excited Generator.*

INTRODUCTION

DC generators are electromechanical devices that transform mechanical energy into electrical energy. They are sometimes referred to as dynamos or generators. Direct current (DC) is the output they produce, which implies the current only travels in one direction. There are many different kinds of DC generators, each having unique properties and uses. Here is a description of a few of the popular kinds of DC generators:

Separately Excited DC Generator: A separate DC power source is used to supply the field winding in a separately excited DC generator. The magnetic field required for the production of electricity is created by the field winding. By changing the field current, the output voltage and current may be managed[1].

Self-Excited DC Generator: The field winding of a self-excited generator does not need to be powered externally. Instead, the initial magnetic field is produced by residual magnetism in the iron core of the generator. Three more categories are used to categorize self-excited generators:

1. **Series DC Generator:** In a series generator, the armature winding and field winding are linked in series. The consequence is a high output voltage with poor stability since the full current flows through both windings. Applications needing strong starting torque, such electric traction systems, are suited for series generators.
2. **Shunt DC Generator:** Shunt generators have the field winding and armature winding linked in parallel (shunt). Better voltage control is made possible by the field winding only drawing

a part of the total current. Shunt generators are often employed in situations where a consistent voltage is necessary, such as in the delivery of electricity to homes and businesses

3. **Compound DC Generator:** Compound generators feature a series field winding and a shunt field winding. A balance between the characteristics of series and shunt generators is offered by this combination. Compound generators may also be divided into two categories:
   i. **Cumulative Compound Generator:** As the load rises, the shunt field winding and series field winding work together to produce a greater output voltage.
   ii. **Differential Compound Generator:** To regulate voltage and improve stability, the series field winding opposes the shunt field winding[2].

These are the main kinds of DC generators that are often used in a range of applications. The decision is based on elements like the need for voltage control, the characteristics of the load, the beginning torque, and the needs of the particular application. Each kind has benefits and drawbacks of its own.

Types of DC generator:DC generators fall into one of three categories: self-excited, independently excited, or permanent magnet generators, depending on how the field is generated. The field coils in the first kind are activated by permanent magnets whereas those in the individually stimulated type are excited by an external force. An additional generator that is powered by a self-excited DC generator also has its own field coils. Because it is not widely used in the industry, the permanent magnet field is not included in the figure for the various kinds of DC generators.Types of DC generator can be described as they are shown in below Figure 1 [3].

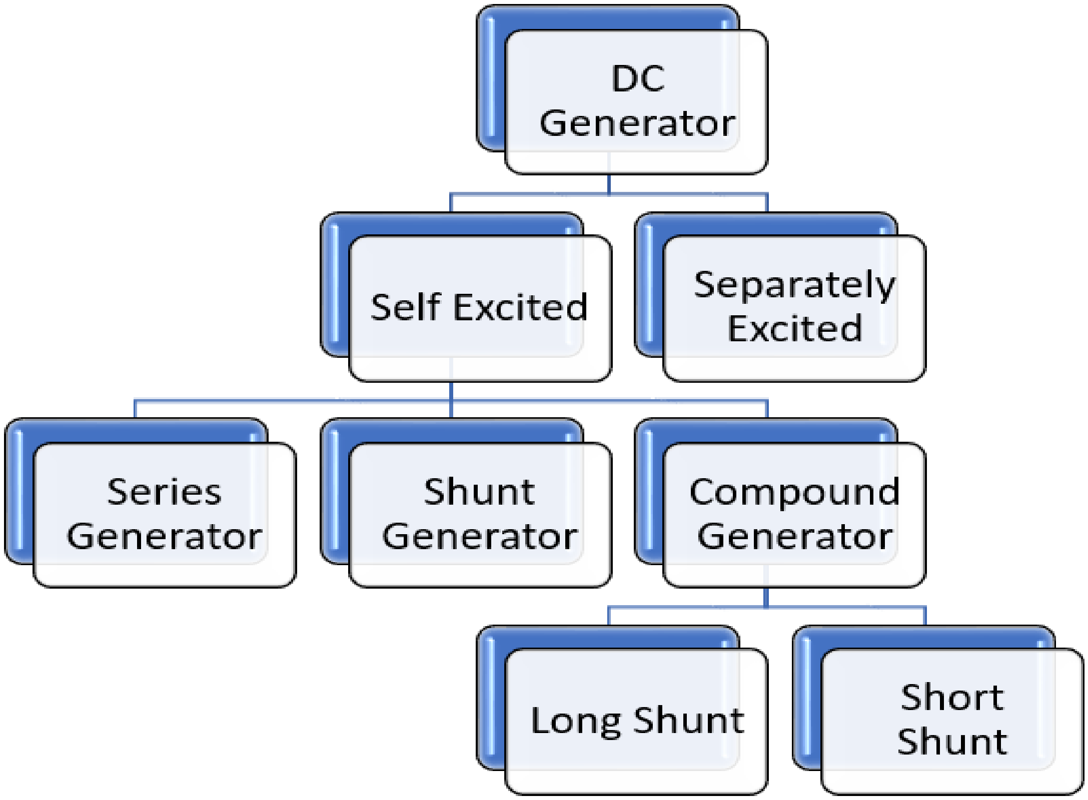

Figure 1: Types of DC generator.

Permanent magnets DC generators

A permanent magnet DC generator is the most fundamental kind of generator since it generates flux in the magnetic circuit using permanent magnets. An armature is surrounded by one or more permanent magnets. This kind of generator cannot generate a lot of power due to its design and is not employed in industrial applications[4]. Permanent magnet DC generators are often used in compact applications, such dynamos in bicycles. The amount of voltage generated when a wire crosses a magnetic field varies on the number of wire loops and the field's rotating speed, as is widely known. The amount of voltage also depends on the angle formed by the magnetic flux and the moving surface. An absolute quantity of sinusoidal voltage is produced by the voltage changing with the rotation of each loop from zero to its highest value as a function of angle. As the number of loops at different angles rises, the voltage stabilizes at its maximum value.The fundamental design of a permanent magnet DC generator is show in Figure 2 [5].

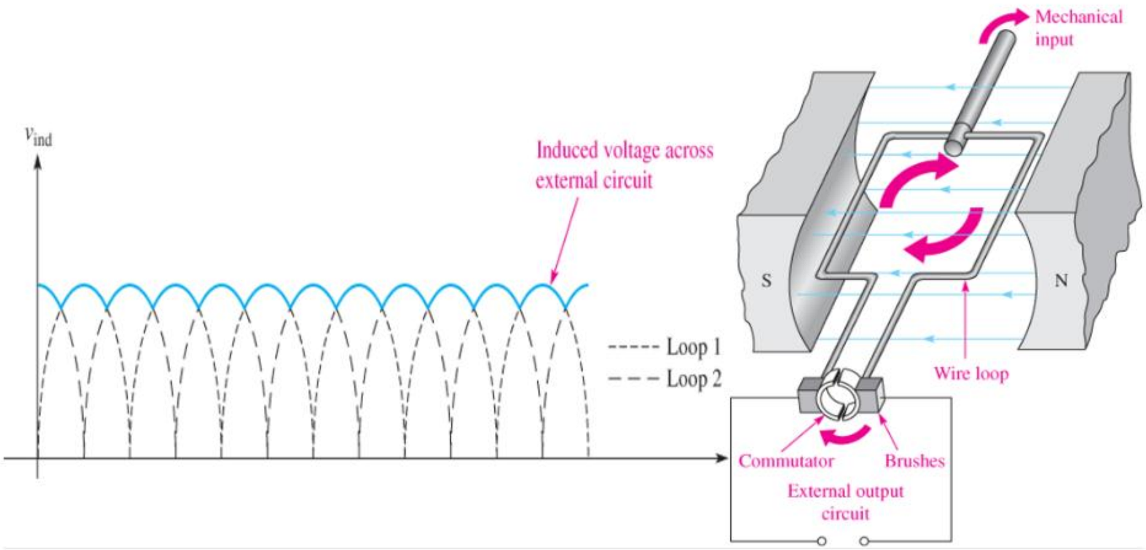

Figure 2: Permanent magnetic DC generators.

Separately Excited DC Generators

This method uses an external DC source, such as a battery, to power the field magnets. A larger EMF and voltage in the output can be produced as the rotation speed rises. Figure shows the circuit diagram for the independently excited DC generators. The symbols are as follows:

I_L = the current at the Load

I_a = Armature current

E_g = Generated EMF

V = The voltage at the terminal

The generated power and the delivered power to the external force can be calculated as show in Figure 3:

Ia = Il = I

V=IRa

Pg=Eg×I

Pl=VI

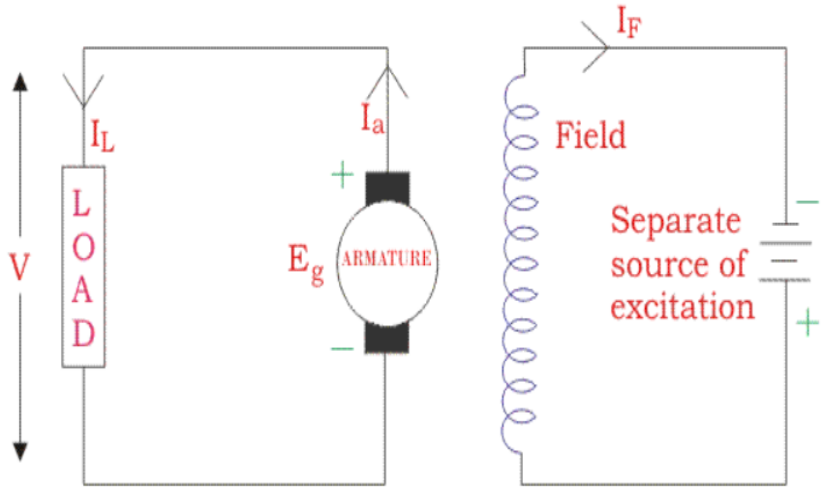

Figure 3: Separately Excited DC Generators.

Self-Excited DC Generators

In self-excited DC generators, the field coils are internally connected to the armature, and the field magnets are driven by their own internal current. The poles are always in flux as a result of residual magnetism. As the armature spins, a little amount of current is produced, and this current passes through the field coils with the load to amplify the pole flux. As the pole flux increases, the current and EMF grow, and the accumulative process continues until excitation is needed [6]. Based on the field coils and their placement, self-excited DC generators are divided into the following categories:

1. Shunt Wound Generators
2. Compound Wound Generators
3. Series Wound Generators

1. Shunt Wound DC Generators

The armature conductors and the field windings are connected in parallel to activate the generator. The magnetic field required for the excitation of the generator is produced by the insulated current-carrying coils, referred to as field windings. Due to residual magnetism in the poles, the field windings of a shunt generator have the same voltage as the generator's terminals, but the voltage's actual value fluctuates with the load and its speed. The following is the circuit schematic for this type:

Where:

V = Terminal voltage

E_g = Generated EMF

I_{sh} = Current flowing through the shunt field

I_a = Armature current

I_L = Load current

R_{sh} = Shunt winding resistance

R_a = Armature resistance

The Shunt Wound DC Generators circuit is show in Figure 4:

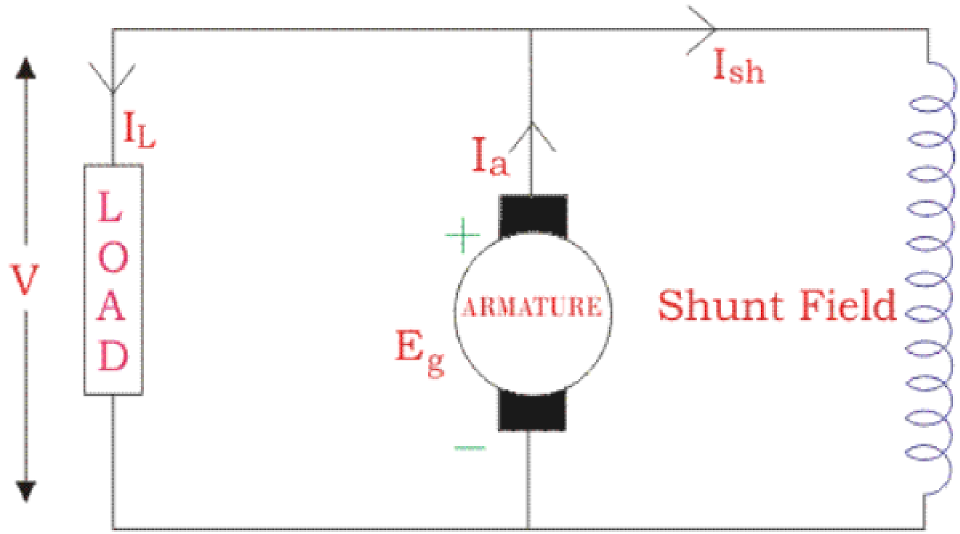

Figure 4: Circuit diagram of the Shunt Wound DC Generators [geeksforgeeks].

In this, when armature current is equal to the sum of shunt current and load current

Ia= Ish +Il

The most effective power for the load would be available when the IL is at its highest value. Therefore, it is preferable to maintain a minimal shunt current. Therefore, maintaining a high shunt resistance is reasonable.

Ish = V \ Rsh

V = Eg - IaRa

- The power generated and the electricity sent to the load are:

  Pg = Eg x Ig.

  Pl = V x Il

2. Series Wound DC generators

The field winding and armature wires are coupled together in series in series-wound generators. The circuit diagram for this generator is shown in the circuit schematic in Figure below. The current flowing through the field coil and the load are both constant. Field windings are produced with few turns and thick wires for low electrical resistance. The circuit schematic diagram for series wound DC generators are shown in Figure 5:

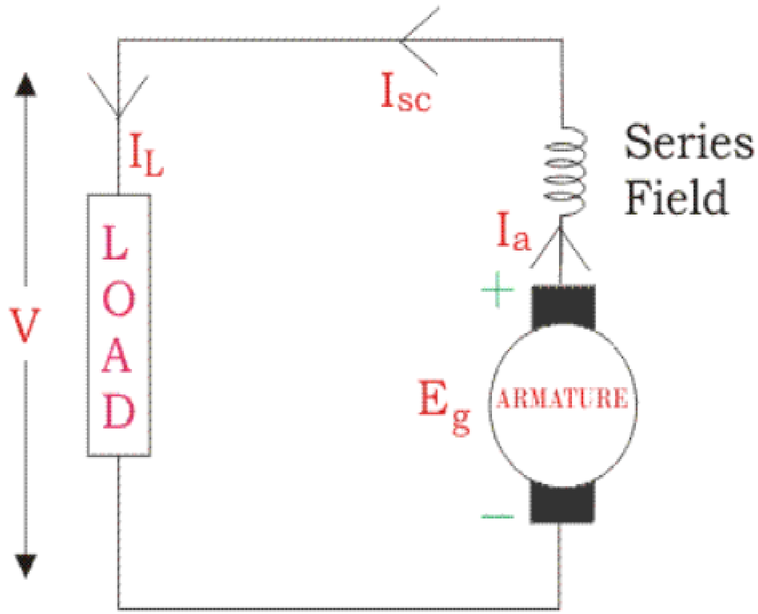

Figure 5: Circuit diagram of the series-Wound DC Generators.

Let's consider the following equations by explained below:

Ia=Il=Isc=I

V=Eg– I^2 ×Ra

The power Generated and the power delivered to the load are given below:

Pg= I x Eg

Pl=I x V

3. Compound Wound DC generators

In the shunt type, the output is proportional to the inverse of the load current, but in the series wound type, the output voltage and EMF are dependent on the load current. There are compound wound generators that mix series and shunt to overcome the shortcomings of each. The compound wound generators' circuit uses both series and shunt field wounding. Short shunt compound wound generators and long shunt compound wound generators, as well as series and parallel windings, are two distinct kinds of generators that work with the armature [7].

i. **Long shunt compound wound DC generators:** The shunt windings are parallel with both the series field and armature in long shunt compound DC generators. The following is the circuit schematic for this type as shown in Figure 6:

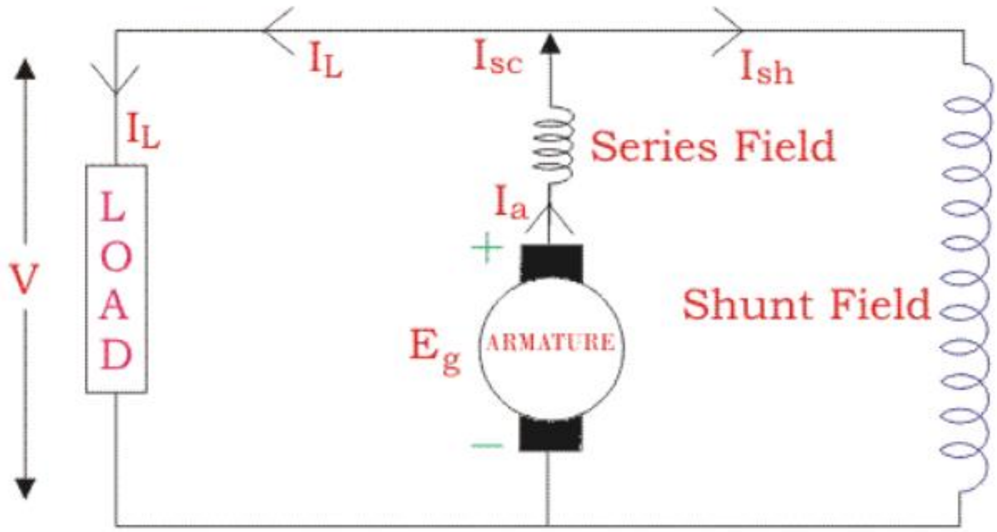

Figure 6: Long Shunt Compound wound DC Generators.

The currents in the circuit are:

Ish = V / Rsh

Ics = Il+ Ish

Ics = Ia

The voltage of the load is equal to:

V= Eg – Ia x (Ra- Rsc)

The power Generated and the delivered power to the load are given below:

Pg= IG x Eg

Pl= IG x V

ii. **Short shunt compoundwound DC generators:** As seen in the following image, an armature is parallel to the shunt field windings of short type as show in Figure 7:

The currents in this systems are:

- Isc = Il
- Ish = V + Isc x Rsc / Rsh
- Ia = Isc + Il

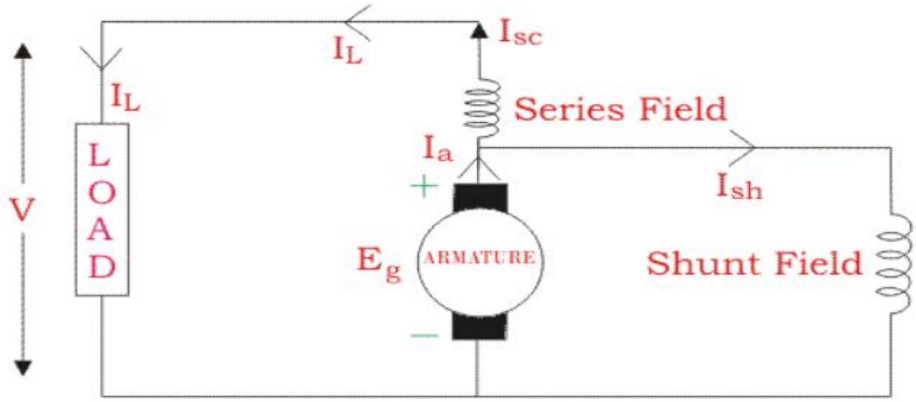

Figure 7: Short shunt compound wound DC generators.

The voltage of the load, load power, and the generated power are given below:

V= Eg – IaRa- IscRsc

Pl= IG x V

Pg= IG x Eg

EMF EQUATION OF A DC GENERATOR: Let us calculate the equation of DC generator by using the following parameters as given below:

Ø = flux/pole in Wb (weber)

Z = total no. of armature conductors

P = no. of generator poles

A = no. of parallel paths in armature

N = rotational speed of armature in revolutions per min. (rpm)

E = EMF induced in any parallel path in armature

Now,

Avg. emf generated per conductor= $\frac{d\O}{dt}$ volts

and flux cut per conductor in one revolution= dØ= Ø.P (Wb)

no. of revolutions per second (speed)= N/60

∴ time for one revolution = dt = 60/N

∴ emf generated / conductor = $\frac{d\O}{dt} = \frac{P\O N}{60}$ volts

but generated emf (Eg) will be equal to generated emf in any parallel path

∴ Generated emf (Eg) = $\frac{P\O N}{60} \frac{Z}{A}$ volts

Now, for simplex wave wound generator
no. of parallel paths = A = 2

∴ Eg= $\frac{P\O N Z}{120}$ volts

and, for simplex lap wound generator
no. of parallel paths = A = no. of poles = P

∴ Eg= $\frac{P\O N}{60} \frac{Z}{P}$ volts

This is known as the EMF equation of DC generator given above.

The output voltage is maintained by balancing the two fields so that the rise in the series field just offsets the drop in the shunt field. Figure illustrates this by displaying the voltage characteristics of generators that are series-, shunt-, and compound-wound as shown in Figure 8.

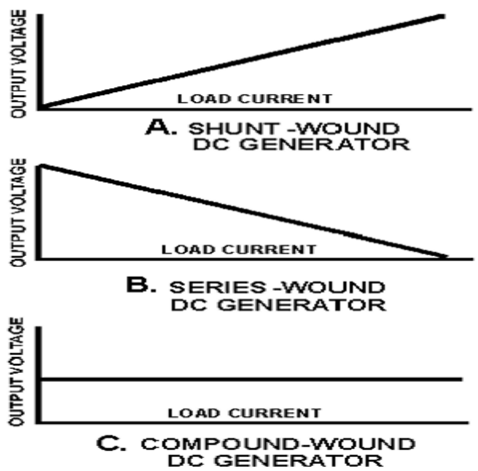

Figure 8: Voltage output characteristics of the series-, shunt-, and compound-wound dc generators.

As you can see, a compound-wound generator produces a consistent output voltage under a variety of load circumstances by balancing the effects of the two fields (series and shunt). Curves in reality are rarely, if ever, as flawless as they appear.

DISCUSSION

The discussion section delves deeper into the types of DC generators and provides a comprehensive analysis of their characteristics, advantages, and limitations. This analysis aids in understanding the suitability of each generator type for different applications and load conditions.The first type of DC generator explored is the separately excited generator. This generator relies on an external power source to supply the field winding, creating the necessary magnetic field. Separately excited generators offer excellent voltage regulation capabilities and are highly suitable for applications where precise and stable voltage output is required. However, they are more complex in design and require an additional power source, making them less efficient in terms of overall system cost.Self-excited generators, on the other hand, utilize their own armature winding to generate the magnetic field required for operation. This type is further classified into three subtypes: series-wound, shunt-wound, and compound-wound generators. Series-wound generators are characterized by connecting the field winding in series with the armature winding. They offer high starting torque and are suitable for applications requiring a substantial initial power surge. However, they have limited voltage regulation capabilities and are prone to voltage fluctuations under varying load conditions.Shunt-wound generators, in contrast, connect the field winding in parallel to the armature winding. This configuration provides better voltage regulation and stability, making them ideal for applications with varying loads. Shunt-wound generators are widely used in industrial and commercial settings due to their reliability and consistent performance.Compound-wound generators combine the characteristics of both series and shunt-wound generators. They consist of both series and shunt field windings, allowing for enhanced voltage regulation and increased power output. Compound-wound generators are commonly used in applications where a balance between starting torque and voltage stability is required.Another type of DC generator gaining popularity is the permanent magnet generator (PMG). These generators utilize permanent magnets to generate the magnetic field, eliminating the need for separate field windings. PMGs offer compact designs, high efficiency, and lower maintenance requirements compared to other generator types. They are particularly suitable for small-scale applications, portable devices, and renewable energy systems.The discussions presented in this paper highlight the diverse range of DC generator types available and their respective advantages and limitations. Selecting the appropriate type of DC generator is crucial for achieving optimal system performance and efficiency. Factors such as voltage regulation requirements, starting characteristics, load conditions, and compatibility with renewable energy sources should be carefully considered when choosing a DC generator for a specific application[8]–[10].

CONCLUSION

In this chapter we have covered the basic introduction of DC generator and it focused on important parts and components of a DC generator. We have learnt about the EMF equation of DC and also the characteristics of shunt, series and compound generators. The numerous kinds of DC generators often utilized in electrical systems have been covered in this chapter. Due to its consistent voltage output, shunt-wound generators are often utilized for general-purpose applications. Series-wound generators are appropriate for uses that call for a lot of beginning torque, including electric traction. Compound-wound generators are appropriate for applications needing both voltage control and strong starting torque because they combine the qualities of shunt-wound and series-wound generators.

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AN ELABORATION OF THE DC MOTORS

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ABSTRACT:

Due to their simplicity, efficiency, and controllability, DC motors are used extensively in a variety of applications. An overview of DC motors is given in this chapter with particular attention paid to their kinds, properties, and uses. The structure, commutation strategies, and operating modes of DC motors are all examined. The benefits and drawbacks of DC motors in comparison to other kinds of motors are also covered. While DC motors have benefits like strong starting torque and speed control, they also have drawbacks including the need for routine maintenance and the existence of brushes in brushed motors, which may eventually wear out.

KEYWORDS: Commutation, DC motors, Direct Current, Motors.

INTRODUCTION

Direct current motors, often known as DC motors, are frequently utilized to convert electrical energy into mechanical motion in a variety of industries and applications. They are a common option in many systems because of their reputation for being straightforward, controllable, and efficient operation. DC motors are an essential component of many commonplace products, whether they're powering domestic appliances, robots, industrial gear, or electric cars.Magnetic fields and electric current interacting are the fundamental idea underlying a DC motor[1]. A force is applied to a current-carrying conductor when it is put in a magnetic field, which causes the conductor to move. This idea is used to generate rotational motion in a DC motor. The armature of the motor, which is made up of wire coils, receives a direct current to create a magnetic field. The armature and linked shaft rotate as a consequence of the interaction between this magnetic field and the stator's fixed magnetic field. Compared to other motor types, DC motors provide a number of benefits. One important benefit is their strong starting torque, which enables them to be used in situations requiring swift acceleration or large loads[2]. Furthermore, DC motors have outstanding speed control capabilities that enable exact motor speed regulation in accordance with application requirements. Several approaches, including as pulse width modulation, voltage control, and current control, may be used to accomplish this control.

DC motors come in a variety of designs, including brushless and brushed models. Brushless DC motors utilize electronic commutation, while brushed DC motors use brushes and a commutator to regulate the direction of the current flow within the motor. Particularly when compared to brush DC motors, brushless DC motors have seen tremendous growth in popularity because of its improved efficiency, lower maintenance requirements, and longer lifetime[3].Although ac motors are utilized the majority of the time, DC motors are utilized for a variety of purposes.A rotating magnetic field is created when the coils are turned on and off sequentially. This field interacts with the various fields of the stator's stationary magnets to produce torque, which causes the stator to rotate[4]. DC motors are able to transform electrical energy from direct current into mechanical energy through rotation, which can then be used for object propulsion thanks to these fundamental operating principles. In many ways, this amazing piece of electrical equipment has changed how we live, similar mechanisms were developed by a large number of people, as is the case with all significant innovations. In the United States, Thomas Davenport is widely regarded as the inventor of the first electric motor. He was also, without a doubt, the first to patent an electric motor that could be used in 1837[5].

Nevertheless, Davenport was not the first to create an electric motor; by the time Davenport submitted his patent, many European innovators had already created more potent variations. Frank Julian Sprague created the first usable DC motor in 1886, and as a result, the first motorized trolley system and electric elevator were created in 1887 and 1892, respectively. Sibrandus Strating and Christopher Becker were the first to use an electric motor to power a tiny model automobile in 1835, making history in the process. Moritz Jacobi had shown a motor in 1834 that was three times more powerful than the one Davenport would go on to patent. Sprague's invention of the DC motor was a key achievement that gave rise to a number of applications that changed the character of manufacturing and industry.

Industrial fans, pumps, machine tools, household appliances, power tools, automobiles, and a wide range of drives all make use of electric motors. As you can see, electric watches also have tiny motors. As a generator, electric motors can also be used to recover energy lost through friction and heat. Both linear and continuous rotation are supported by the electric motor. Nowadays three-phase synchronous motor is usable in highly dynamic applications and electrical devices. In 1887, the synchronous motor was first developed by Friedrich August. Nowadays we can see that use of motors is increasing day by day and it will be very beneficial in any field. DC motors use magnetic fields that occur from the electrical generated, which powers the movement of a rotor fixed within the output shaft

. The output torque and speed depend upon both the electrical input and the design of the motor. The term ‘DC motor’ is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power from minor motors in toys and appliances to large mechanisms that power vehicles, pull elevators and hosts, and drive steel rolling mills.

What is DC motors?

A sort of electric machine that transforms electrical energy into mechanical energy is a direct current (DC) motor. Direct current (DC) motors take electrical power and turn it into mechanical rotation. DC motors move a rotor positioned within the output shaft using magnetic fields produced by electrically generated energy. The electrical input and the motor's design both affect the output torque and speed. Any rotating electrical device that transforms direct current electrical energy into mechanical energy is referred to as a "DC motor." DC motors come in a variety of sizes and powers, from tiny ones found in toys and appliances to massive ones used to power machinery like cars, steel rolling mills, and elevators [6].

Principle of DC Motor:

A machine that converts dc power into mechanical energy is known as dc motor. The principle of motor based on the fact that "when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of the force is given by Fleming's left hand rule[7].

Construction of DC motor:

The Construction diagram of DC motor is shown in Figure 1.

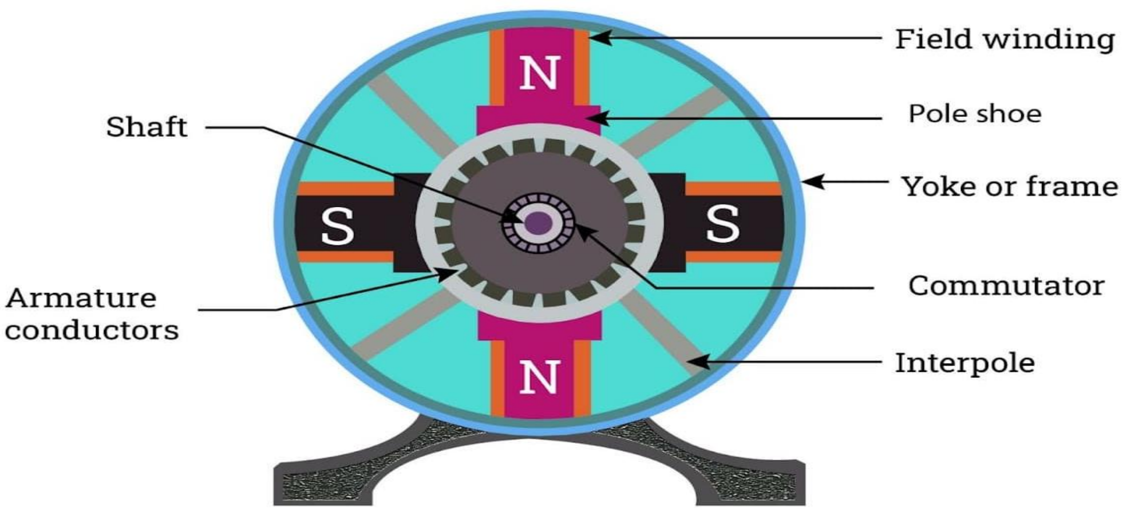

Figure 1: Construction of DC motor [electrical4u].

There are six important construction parts of a simple motor:

- **Yoke or frame:**The yoke is the hollow cylinder of cast or rolled steel that serves as the DC motor's outer frame. The field pole core is supported by the yoke, which also serves as a protective cover for the machine and also it provides a route for the field winding's magnetic flux.
- **Magnetic field winding:**The machine's stationary component is the DC motor's magnetic field system. It is the primary source of the motor's magnetic flux. It consists of a field winding wound around an even number of pole cores that are bolted to the yoke. The pole shoe serves two purposes: first, it provides the field coils with support and secondly by increasing its cross-sectional area, it reduces the resistance of the magnetic circuit.To reduce eddy current loss, the pole cores are made of thin sheet steel laminations that are insulated from one another. The field coils are connected in series with one another so that the north and south poles change when current flows through them.
- **Armature core:** The DC motor's armature core rotates between the field poles and is mounted on the shaft. The armature conductors are inserted into slots on its outer surface. Soft steel laminations that are tightly clamped together and insulated from one another make

up the armature core. The laminations are mounted on a spider in large machines, whereas they are keyed directly to the shaft in small machines. The eddy current loss is reduced by using the laminated armature core as shown in Figure 2.

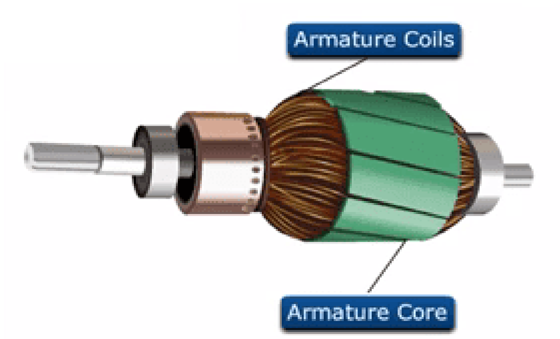

Figure 2: Armature core [electrical4u].

- **Armature winding:**The armature core's slots are filled with insulated conductors. The connections between the conductors are correct. The term "armature winding" refers to this connected arrangement of conductors. Wave winding and lap winding are the two types of armature windings that are utilized.
- **Commutator and Brushes:** The mechanical rectifier known as a commutator transforms the direct current that is supplied to the motor by the DC source into alternating current that is carried by the armature winding. Copper segments in the shape of wedges make up the commutator, which is separated from the shaft and each other by mica sheets. The ends of the armature coils are connected to each segment of the commutator.The current from the DC source is injected into the armature windings by means of the brushes, which are mounted on the commutator. The carbon brushes are supported by a metal box known as the brush holder. With the help of springs, the commutator's pressure on the brushes can be changed and kept constant. Carbon brushes and a commutator carry the current from the external DC source to the armature winding. The diagram shown below shows the commutator and brushes in Figure 3 [8].

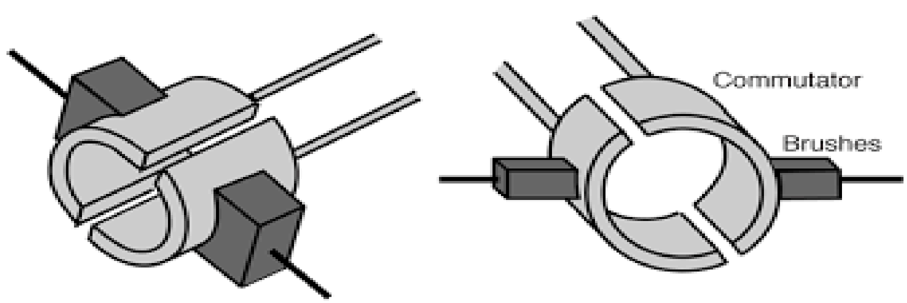

Figure 3: Commutator and Brushes [electrical4u].

Working of DC motor

Let's understand a DC motor with two poles, as depicted in the figure given below. The field coils are excited, resulting in the formation of alternate N and S poles, and a current flows through the armature windings when the DC motor is connected to an external DC supply as shown in Figure 4.

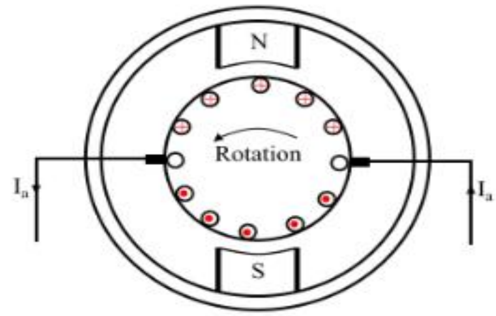

Figure 4: Working of DC motor [electrical4u].

While all of the armature conductors at the N pole carry current in one direction, all of the conductors at the S pole carry current in the opposite direction. A mechanical force is exerted on each conductor because it is subjected to a magnetic field and is carrying a current. Applying Fleming's left hand rule reveals that the armature tends to move in an anticlockwise direction due to the force exerted on each conductor. The torque that causes the armature to rotate is the result of the combined force exerted on each conductor. The conductor's current is reversed and influenced by the next pole of the opposite polarity when the conductor moves from one side of a brush to the other. The direction of force exerted on the conductor remains unchanged as a result. As a result, the motor is reversing its course.

Benefits of DC Motors

The strong speed control capabilities of DC motors make it possible to make exact modifications to satisfy particular needs. By altering the voltage or using pulse width modulation (PWM) methods, speed may be readily controlled.

1. **Strong Starting Torque:** DC motors have a strong starting torque, which makes them perfect for applications that need to accelerate quickly or overcome an initial resistance. Electric cars, conveyor systems, and robots all benefit greatly from this characteristic.
2. **Structure that is basic and robust:** Compared to other motor types, DC motors have a comparatively basic structure and fewer moving components. Their simplicity makes them more dependable and durable, requiring less upkeep and lowering the likelihood of mechanical failure.
3. **Reversible operation:** By switching the polarity of the power source, DC motors may simply alter the direction of their revolution. They are excellent for applications that need bidirectional motion, such as elevators and winches, because to their reversible function.
4. **High efficiency:** DC motors often convert a significant amount of electrical energy into mechanical energy. This effectiveness aids in lowering energy losses and decreasing power usage.

DC motor disadvantages include:

1. **Commutation Problems (Brushed DC Motors):** Conventional brushed DC motors use a commutator and brushes to transfer current, but these components may deteriorate with time, necessitating regular maintenance and replacement. Brushes also produce sparks and electrical noise, which restricts their usage in several applications.
2. **Complex Control for Brushless DC Motors:** More complex control electronics, such as sensors and electronic commutation systems, are needed for brushless DC motors (BLDC). The initial cost and complexity of control algorithms may both rise as a result of this complexity.
3. **Limited Speed Range:** Compared to certain other motor types, DC motors have a comparatively small maximum speed range. Commutation and mechanical restrictions may limit their performance at high speeds.

DC motor applications include:

1. **Industrial Machinery:** Due to their controllability and durability, DC motors are widely used in a wide range of industrial applications, including conveyor belts, pumps, fans, and machine tools.
2. **Robotics:** Due to its precise speed control, great torque, and small size, DC motors are often used in robotic systems. They are included into the grippers, locomotion, and arms of robots.
3. **Electric Vehicles:** DC motors, particularly brushless DC motors, are often utilized for propulsion in electric vehicles (EVs). For enhanced performance and increased energy economy, they provide great torque at low speeds and effective control.
4. **HVAC Systems:** The use of DC motors for air circulation, blower operation, and variable speed control results in energy savings and enhanced comfort in heating, ventilation, and air conditioning (HVAC) systems.
5. Appliances, toys, and portable tools are just a few examples of the consumer electronics products that use DC motors. The power operations including cooling, vibration, and spinning.
6. **Renewable Energy Systems:** To convert the produced energy into electrical power or to move the equipment for optimum efficiency, DC motors are utilized in renewable energy systems like wind turbines and solar tracking systems.

Overall, DC motors have several benefits, such as speed control, strong starting torque, simplicity, and efficiency, which make them suited for a variety of applications in various systems and sectors. However, the unique needs and limitations of the application at hand should be taken into account while choosing the motor type.

CONCLUSION

In this chapter we learn about the basic introduction of DC motors and construction and working of DC motors. DC Motors play a vital role in today's engineering and technology, a DC motor is used for various purpose and it proves to be very useful for the electrical technology. DC motors are adaptable devices with a broad variety of uses in many systems and sectors. They are excellent for a variety of applications, including robotics, automation, electric cars, and industrial machines, thanks to their straightforward design and controllability. A DC motor's operation is based on the interplay of magnetic fields and current flow, which produces rotational motion. Different kinds of DC motors, such as brushed and brushless DC motors, have different construction and commutation techniques. Through suitable design and control techniques, the properties of DC motors, such as speed control, torque, and efficiency, may be customized to meet particular needs. Despite these drawbacks, DC motors continue to be essential in a variety of applications, and continuous technological improvements are further enhancing their performance and dependability.

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AN ELABORATION OF THE TYPES OF DC MOTORS

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ABSTRACT:

This chapter gives a general overview of the numerous DC (Direct Current) motor types that are often used in a variety of applications. Due to their simplicity, controllability, and efficiency, DC motors are extensively used in a variety of sectors, robotics, the automobile industry, and other disciplines. Brushed DC motors, brushless DC motors, permanent magnet DC motors, shunt DC motors, series DC motors, and compound DC motors are among the kinds addressed. Each type's traits, benefits, and drawbacks are analyzed in order to gain understanding of how well suited they are for various applications.

KEYWORDS: *Dc Motors, Shunt Dc Motors, Series Dc Motors, Compound Dc Motors.*

INTRODUCTION

Because they are straightforward, controllable, and efficient, DC (Direct Current) motors are often utilized in a variety of industries and applications. These motors use the interplay of magnetic fields to transform electrical energy into mechanical energy. Different kinds of DC motors have been developed as a result of the wide variations in the design, working theories, and uses of DC motors [1]. Brushed DC motors, brushless DC motors, permanent magnet DC motors, shunt DC motors, series DC motors, and compound DC motors are some of the several kinds of DC motors. Each kind has distinctive qualities and is appropriate for various situations depending on elements such required torque, speed control, cost, and efficiency.

The most fundamental form of DC motors uses brushes and a commutator to create motion. Conversely, brushless DC motors do not need brushes, leading to increased efficiency and less maintenance. Enduring magnet Permanent magnets are used in the manufacturing of DC motors to provide great torque and efficiency. Shunt DC motors are more efficient at low loads but have worse speed control. Series DC motors have a high torque but need external regulation to keep them in good condition. Compound DC motors strike a compromise between speed control and torque by combining the characteristics of both shunt and series motors[2].

Engineers may choose the right DC motor for their unique needs by carefully considering the design, workings, and applications of these several kinds of DC motors. Researchers may also pinpoint DC motor technology advancement and innovation opportunities[3].

DC motors have a long history that starts in the early 19th century when researchers and innovators first started experimenting with electromagnetic. The basis for the development of electric motors was provided by Hans Christian's discovery of electromagnetic in 1820 and Michael Faraday's subsequent invention of the electric generator in 1831. Thomas Davenport, an

American blacksmith, created the first useful DC motor in 1834. In Davenport's motor, a spinning magnetic field was produced by a battery-powered electromagnet, which in turn rotated a rotor. Even though his motor was somewhat primitive, it showed how electrical energy can be transformed into mechanical motion[4].

DC motors saw a number of advancements in the decades that followed. The Gramme machine, a crucial development in motor design, was created in 1873 by Belgian electrical engineer Zenobe Gramme. The Gramme machine operated more smoothly and efficiently because to the employment of a ring armature with several windings and a commutator.The separate development of the brush and commutator system by Zenobe Gramme and Ernst Werner von Siemens in the late 19th century marked another significant turning point in the history of DC motors. This innovation made it possible to manufacture DC motors that were useful and profitable for businesses[5]. A continuous rotation of the motor was made possible by the employment of brushes and commutators, which allowed the conversion of alternating current (AC) to direct current (DC).

The technology of DC motors continued to progress throughout the 20th century. Permanent magnets were added to motor designs to increase efficiency and replace electromagnets. Permanent magnet DC (PMDC) motors were created as a result, and they are now used in a variety of industries, such as robotics, industrial automation, and automobiles. Brushless DC (BLDC) motors have been made possible in recent years by the rise of solid-state electronics and improvements in semiconductor technology. Compared to brush DC motors, BLDC motors are more efficient, more controllable, and need less maintenance. In place of mechanical brushes and commutators, these motors use electronic commutation systems[6].

DC motors continue to be essential in many applications today. DC motors are used to power a variety of equipment and systems, ranging from modest hobbyist projects to big industrial machines. For improved performance and energy savings, current motor technology research and development focuses on boosting efficiency, boosting power density, and integrating smart control systems.

Types of DC motor: In today's engineering and technology, a DC motor, also known as a direct current motor, can be used for many different things. DC motors are found in everything, from automobiles to electric shavers. Different kinds of DC motors are used for different kinds of applications to cover this wide range as shown in Figure 1 [7].

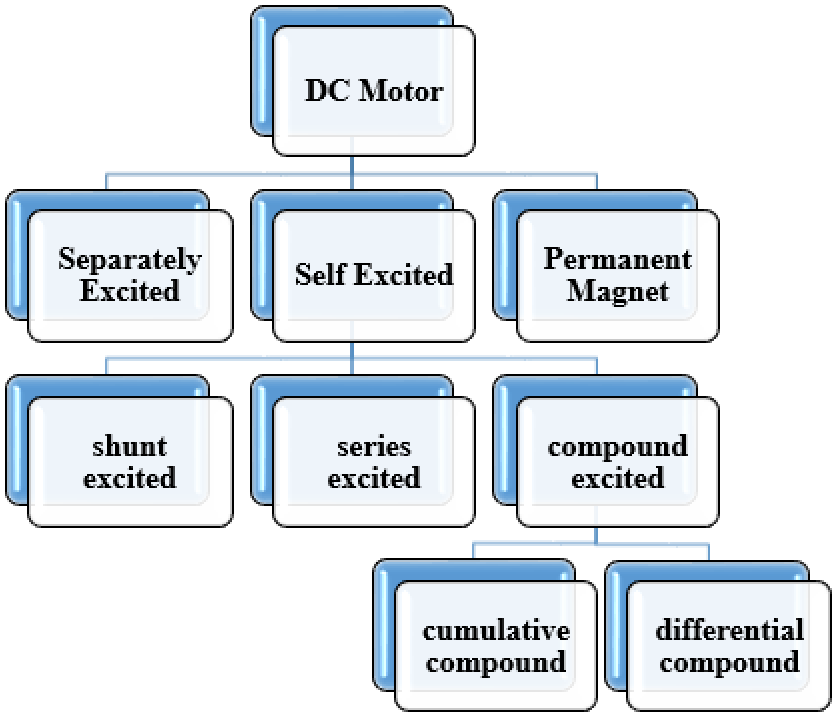

Figure 1: Different types of DC motor

There are following different types of DC motor:

A. Permanent Magnet DC Motors

B. Separately-Excited DC Motors

C. Self-Excited DC Motors

1. Series Wound DC Motor

2. Shunt Wound DC Motor

3. Compound Wound DC Motor

Permanent Magnet DC Motors

A constant magnet DC motors are DC motors in which permanent magnets provide the majority of the field flux. This particular kind of DC motor just needs one external DC supply source to power the armature. Toys and other small-scale applications often use DC permanent magnet motors. Permanent magnet can be shown in the given Figure 2 [8].

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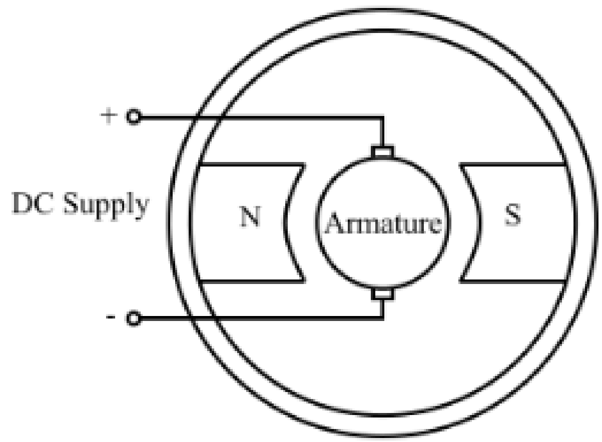

Figure 2:Permanent Magnet DC Motors [electrical4u]

Separately-Excited DC Motors

The main field winding of a separately excited DC motor is excited by an external DC supply. A doubly-excited motor, the separately-excited dc motor requires two DC supply sources—one for the armature and another for the field winding's excitation as shown in Figure 3.

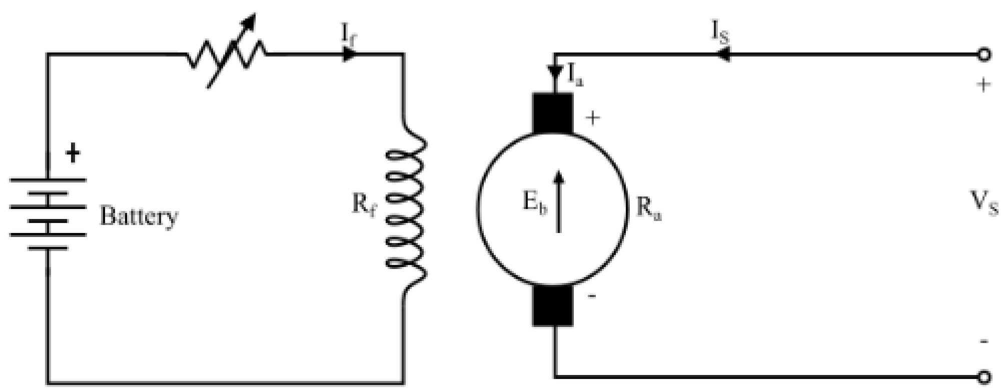

Figure 3:Separately-Excited DC Motors [electrical4u]

Here,

Armature current, Ia = Is

The Supply voltage, Vs = Eb + IaRa

The developed Electric power in armature is given as = Eb x Ia

Self-Excited DC Motors

This can be broken down into the following sections as given below because the shunt winding is connected to the armature winding in series or parallel, either partially or completely.

1. Series Wound DC Motor

A series-wound DC motor is one in which the field winding and the armature winding are connected in series because the entire armature current is carried by the series field winding. As a result, the series field winding should have a low resistance due to the small number of turns of thick wire. Because it is connected in series to the armature winding in this instance, the entire armature current flows through the field winding. For better comprehension, the self-excited dc motor that is wound in series is depicted in a diagram. The speed of a series wound dc motor varies with load. Additionally, this is its primary operational distinction from a shunt wound dc motor. The Series Wound Self-Excited DC Motor is shown in Figure 4[9].

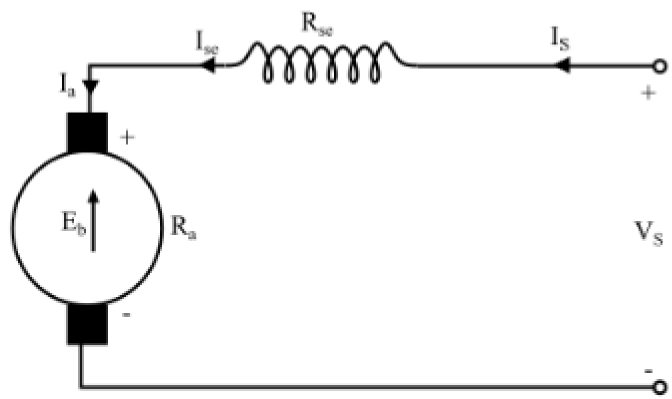

Figure 4:Series Wound Self-Excited DC Motor [electrical4u]

Here,

Armature current, Ia = Ise

The voltage supply of series wound DC, VS = Eb + IseRse + IaRa = Eb + Ia(Ra+Rse)

Applications of series-wound DC motor: The variable speed of the series DC motors means that their speed is low at high torque and vice versa. Despite this, the motor travels at a dangerously high speed even when only lightly loaded. The starting torques of the series motors are high. As a result, they are utilized in the following contexts:

a) It is used in elevators, electric traction systems, cranes, and other devices requiring a significant starting torque.

b) It is used in situations where the load is subject to significant fluctuations and the speed needs to be automatically adjusted to meet load requirements.

c) Additionally utilized in vacuum cleaners, hair dryers, sewing machines, and air compressors.

2. Shunt Wound DC Motor

The field winding and the armature winding are connected in parallel in a shunt wound DC motor. In a shunt wound motor, the field winding is connected in parallel with the armature. The

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shunt field windings are designed to have high resistance, i.e., a large number of turns of fine wire, so that the shunt field current is relatively smaller than the armature current.

The armature current and the current that flows through the shunt field winding are not the same thing. Shunt field windings are constructed to generate the required MMF by means of a relatively large number of high-resistance wire turns. As a result, the armature current is significantly larger than the shunt field current. The Shunt Wound DC Motoris show in Figure 5.

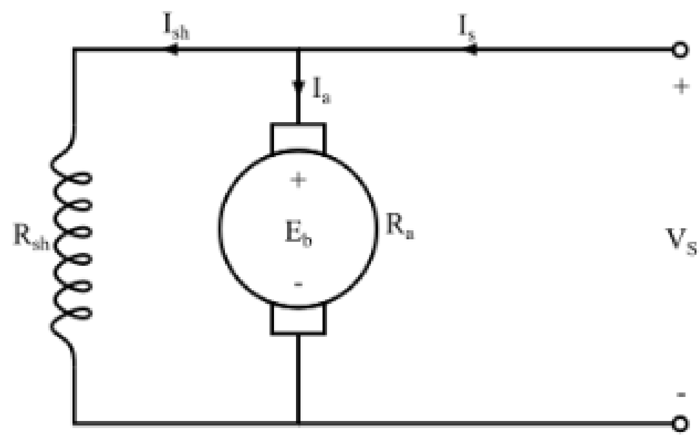

Figure 5:Shunt Wound DC Motor [electrical4u]

Because they are connected in parallel to the armature winding as depicted in the figure, the field windings in this instance are exposed to the entire terminal voltage. The shunt wound dc motor has a constant speed because the mechanical load on the output does not change its speed. It falls under the Self-excited DC Motor category[10].

Here,

The Armature current, Ia = Is − Ish

The current in the Shunt field in shunt DC motor, Ish = VsRsh

The voltage is supplied by Shunt DC motor, Vs = Eb + IaRa

Applications of Shunt DC motor:

Shunt motors operate at a constant speed. As a result, the following applications call for their use:

a) It is applicable in a situation in which speed must remain constant from no load to full load.

b) It is utilized in boring mills, lathes, drills, sharpeners, spinning and weaving machines, and so on.

3. Compound Wound DC Motor

Combining both the series field and the shunt field creates a compound wound DC motor. The compound excitation characteristic of a DC motor is produced by combining the functional traits of the shunt and series excited DC motors. The compound wound self-excited DC motor, sometimes referred to as the compound wound DC motor, has connections between the field winding and the armature winding in both series and parallel.

Combining the operational characteristics of the shunt and series-excited dc motors results in the compound excitation characteristic of a dc motor. The field winding is connected to the armature winding in both series and parallel in the compound wound self-excited dc motor, or simply the compound wound dc motor as shown below in Figure 6.

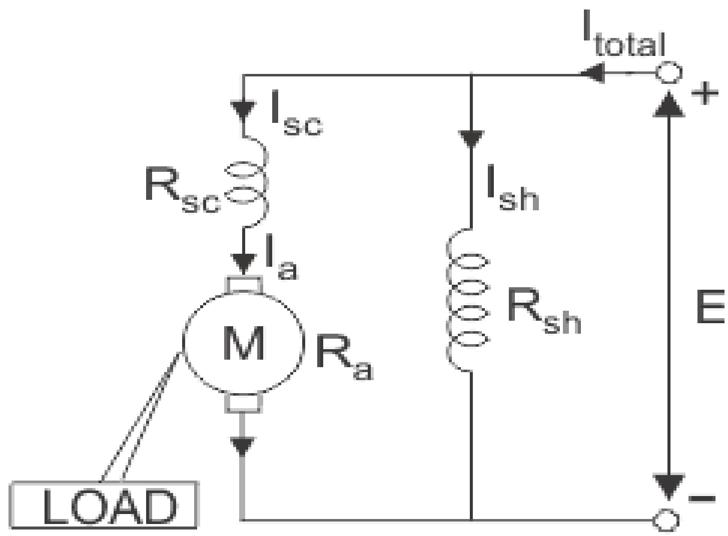

Figure 6:Compound Wound DC Motor [electrical4u]

Depending on the nature of the compounding, the compounded dc motor can excite in two ways.

Cumulative Compound DC Motor:

Shunt field flux helps the main field flux produced by the main field connected in series to the armature winding in a cumulative compound DC motor.

$$\Phi \text{ total} = \varphi \text{ series} + \varphi \text{ shunt}.$$

Differential compound dc motor:

A differential compound dc motor has shunt and series windings arranged in such a way that the effect of flux from the main series field winding is lessened by the shunt field flux. Since the net flux produced in this instance is less than the initial flux, its application is limited.

$$\Phi \text{ total} = \varphi \text{ series} - \varphi \text{ shunt}$$

Depending on the arrangement, the cumulative compound and differential compound dc motors can be **short shunt** or **long shunt**.

i. **Short Shunt compound DC Motor:**

If the armature winding is only parallel to the shunt field winding and not the series field winding, the motor is also known as a short shunt type compound wound dc motor. A short shunt DC motor is nothing more than a pair of parallel arms. DC shunt motors are used in devices that require speed control, as depicted in Figure 5.

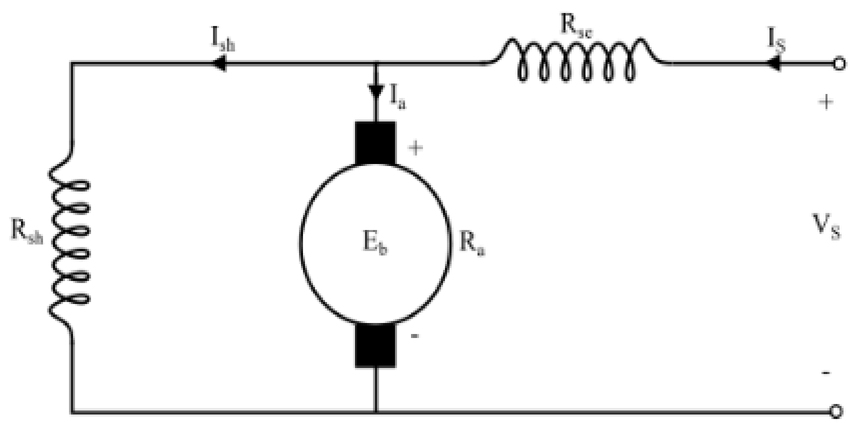

Figure 7: Short Shunt compound DC Motor [electrical4u]

ii. **Long Shunt compound DC Motor:**

If the shunt field winding is parallel to both the armature winding and the series field winding, then it is referred to as a long shunt type compounded wound dc motor or simply long shunt dc motor. Its primary application is in centrifugal pumps, which produce constant flux.The motor is referred to as a long-shunt compound motor when the shunt field winding is connected parallel to the series combination of the armature winding and the series field winding as shown in the Figure 8.

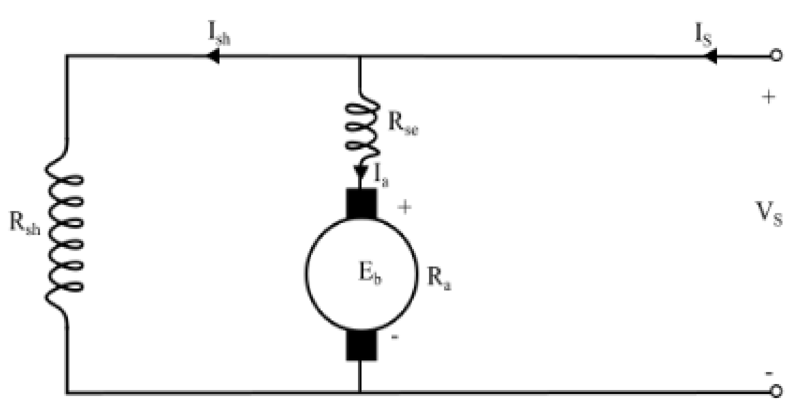

Figure 8:Long Shunt compound DC Motor [electrical4u]

A compound motor is referred to as a cumulative compound motor when both the series field flux and the shunt field flux are moving in the same direction. On the other hand, a differential compound motor is referred to when both the series field flux and the shunt field flux are moving in the opposite direction. The magnetic flux produced by the shunt field winding is always greater than that produced by the series field winding in compound DC machines (motors or generators).

Applications of compound excited DC motor:

Due to their poor torque characteristics, differentially-compound motors are rarely utilized. However, applications requiring constant speed and sudden application of heavy loads, such as presses, reciprocating machines, and shears, utilize cumulatively-compound motors.

Commutation in a DC Motor

To exert unidirectional force (or torque) on a motor's armature conductors, the conductors under any pole must always carry the same current. In a dc motor, the commutator and brush gear reverse the current flowing through a conductor as it moves from one side of a brush to the other.

Voltage Equation of Motors

Calculate the voltage equation in a DC motor, as follows given below:

Let's consider the following parameters:

V = the applied voltage

Eb = back EMF

Ra = armature resistance of DC motor

Ia = armature current Since back EMF

Eb acts opposite to the applied voltage V, the net voltage across the armature circuit is V- Eb.

The armature current Ia is given by: Ia = V- Eb / Ra --------------- (1)

V = Eb + IaRa ------------ (2)

The equation 2 is known as voltage equation of the DC motor.

Condition for maximum power:

Because V and Ra are fixed, the motor's mechanical power is dependent on the armature current. dPm / dIa should be zero for maximum power. As a result, the motor generates the most mechanical power when operating backwards is equivalent to half the voltage applied.

So, Pm = Eb x Ia

dPm / dIa = 0

$$\frac{dP_m}{dI_a} = V - 2I_aR_a = 0$$

$$I_aR_a = \frac{V}{2}$$

$$V = E_b + I_aR_a = E_b + \frac{V}{2} \qquad \therefore \qquad E_b = \frac{V}{2}$$

CONCLUSION

In this chapter we learn components or parts of DC motors and we learn about the basic types of DC motors and characteristics of DC motors. Motors play a vital role in today's engineering and technology; a DC motor is used for various purpose and it proves to be very useful for the electrical technology.Every motor type has distinctive qualities and is appropriate for a particular application. Although simple and inexpensive, brushed DC motors need regular maintenance since they employ brushes. Brushes are not required with brushless DC motors, which increases efficiency and dependability. Shunt DC motors are efficient at low loads yet provide strong speed control. Series DC motors have a high torque but need external regulation to keep them in good condition. Compound DC motors strike a balance between speed control and torque by combining the qualities of both shunt and series motors.

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AN OVERVIEW OF THE CHARACTERISTICS OF SERIES, SHUNT AND COMPOUND DC MOTORS

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ABSTRACT:

This paper aims to explore the characteristics of three commonly used types of DC motors: series, shunt, and compound. DC motors are widely employed in various industries and applications, and understanding their unique features and performance is crucial for efficient design and operation. The study delves into the distinct operating principles and construction of each motor type, highlighting their individual advantages and limitations. Additionally, key characteristics such as speed regulation, torque-speed curves, starting torque, and field control methods are discussed in detail, providing valuable insights for engineers and researchers working with DC motor systems. Through a comprehensive analysis, this paper enhances the understanding of series, shunt, and compound DC motors, aiding in their appropriate selection and utilization in diverse industrial settings.

KEYWORDS: *Dc Motors, Series Motor, Shunt Motor, Compound Motor, Torque-Speed Characteristics.*

INTRODUCTION

Due to their adaptability and dependable performance, DC motors are used extensively across a broad range of industries and applications. Series, shunt, and compound motors are three popular kinds of DC motors, each having specific features and benefits. It's essential to comprehend these motors' features in order to choose the best motor type for a certain application [1]. A series DC motor is advantageous for applications with high beginning loads due to its strong starting torque. It is made up of a field winding and an armature winding that are linked in series to allow the same current to pass through both windings. The series motor, however, lacks speed control and is susceptible to speed change while operating with various loads.

Shunt DC motors, on the other hand, provide effective speed control and run at a generally steady speed. There is a separate field winding attached to the armature winding in parallel (shunt). Shunt motors are renowned for their capacity to run continuously under a variety of loads. It is often utilized in situations that need for precise speed control and has a modest beginning torque.The properties of both series and shunt motors are combined in the compound DC motor[2]. There are two field windings in it: a parallel field winding and a shunt field winding that are coupled in parallel with the armature winding. A balance between beginning torque and speed management is offered by the compound motor. Compared to a series motor, it provides better speed control and more beginning torque than a shunt motor. Here, we mostly covered the characteristics of series, shunt, and compound motors[3].A DC motor's performance is determined by the relationship between its speed, torque, and current in the armature. These correlations are visually depicted as curves, which are referred to as the characteristics of DC motors. These characteristics show how the DC motor behaves under different load levels. DC motors are used for a number of things, even though ac motors are used the bulk of the time. The consecutive turning on and off of the coils produces a revolving magnetic field[4]. The stator rotates as a result of the torque created by the interaction between this field and the different fields of the stator's stationary magnets. These basic working principles enable DC motors to convert electrical energy from direct current into mechanical energy via rotation, which may subsequently be employed for object propulsion. This incredible piece of electrical technology has significantly altered how we live, and as with many important breakthroughs, numerous individuals have created mechanisms comparable to it[5].

When the series field flux and the shunt field flux of a compound motor are both travelling in the same direction, the compound motor is referred to as a cumulative compound motor. However, when both the series field flux and the shunt field flux are traveling in the opposing directions, a differential compound motor is mentioned. In compound DC machines (motors or generators), the magnetic flux generated by the shunt field winding is always larger than that generated by the series field winding[6]. Electric motors are used in industrial fans, pumps, machine tools, home appliances, power tools, cars, and a broad variety of drives. Electric timepieces, as you can see, also include tiny motors. Electric motors may be utilized as generators to recuperate energy lost to heat and friction. The electric motor is capable of supporting both linear and continuous rotation.Today, we can see that the usage of motors is growing daily and will be quite helpful in any industry. DC motors move a rotor positioned within the output shaft using magnetic fields produced by electrically generated energy. The electrical input and the motor's design both affect the output torque and speed[7]. Any rotating electrical device that transforms direct current electrical energy into mechanical energy is referred to as a "DC motor." DC motors come in a variety of sizes and powers, from little ones found in toys and appliances to massive ones used to power machinery like cars, elevators, and steel rolling mills.

The following are the Characteristics of a DC motor:

The relationship between the speed, torque, and current in the armature of a DC motor indicates its performance. These relationships are represented graphically in the form of curves, which are known as DC motor characteristics. The DC motor's behavior under various load conditions is demonstrated by these characteristics[8].

The three most important characteristics of a DC motor are:

A. Torque and armature current characteristics:

A DC motor's armature torque (a) and armature current (Ia) are plotted on a graph. It is also known as the DC motor's electrical characteristics.

B. Speed and Armature Current Characteristics:

The Characteristics of Speed and Armature Current as discussed when a DC motor's speed (N) and armature current (Ia) are plotted on a graph. This characteristic curve is mostly used to choose a motor for a specific use[8].

C. Speed and Torque Characteristics:

A DC motor's speed-torque characteristics are the graph that shows the relationship between the speed (N) and the armature torque (a). It is also known as the DC motor's mechanical characteristics.

Characteristics of DC Shunt Motor:

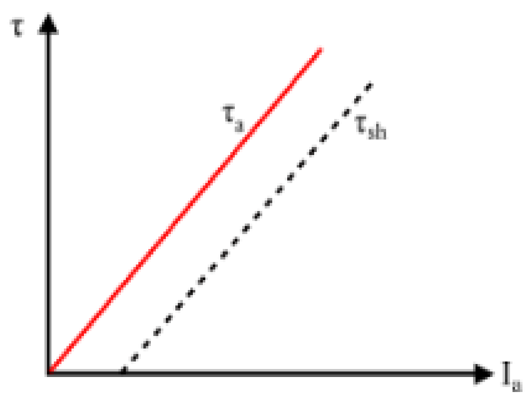
Shunt motors are constant flux machines because their field winding is directly connected across the supply voltage, which is assumed to be constant. This means that their magnetic flux remains constant.

i. **Torque and armature current characteristics (Ta / Ia):** It shows the curve between armature torque and armature current of a dc motor.It is also called as electrical characteristics of the DC motor. A DC motor's armature torque is directly proportional to the flux and armature current, as shown in the figure given below.

$Ta \propto \varphi Ia$

If talking to the shunt motor, flux is also fixed, then

$Ta \propto Ia$



Ta- Ia Characteristics

As a result, the DC shunt motor's torque and armature current characteristics are represented in the figure as a straight line passing through the origin. The armature torque, as shown by the dotted line, is greater than the shaft torque in the above figure. It is evident from the characteristics that a significant current is required to initiate a heavy load. As a result, heavy loads should not cause the shunt motor to start[9].

The back EMF equation for dc motor is Eb = PNZ /60A = V– Ia Ra.

Therefore,

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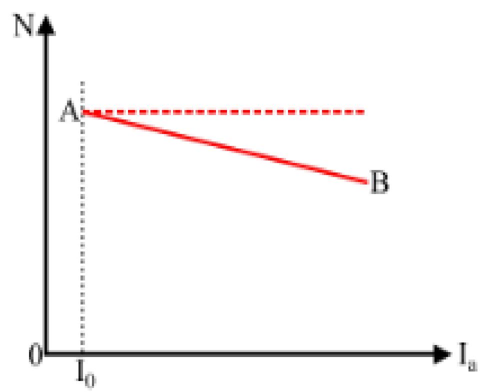
$$N = \frac{V - IaRa}{\phi PZ} 60A = \frac{K(V - IaRa)}{\phi}$$

ii. **Speed and armature current characteristics (N / Ia):** It is the graph plot between speed and armature current.

$N \propto Eb$

$\because Eb = V - IaRa$

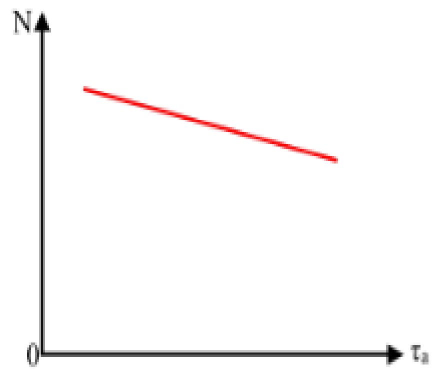
$\therefore N \propto (V - IaRa)$



Characteristics (N / Ia)

Under normal operating conditions, the back EMF and flux of a DC shunt motor are constant. As a result, the dotted line indicates that the speed of a shunt motor will remain constant in relation to the armature current. Back EMF and flux, on the other hand, decrease as load increases due to changes in armature reaction and resistance, respectively. Despite the fact that the flux decreases more rapidly than the back EMF, motor speed decreases slightly with load as line AB is shown in the above figure [10].

iii. **Speed vs torque characteristics (N / Ta):** It is the graph plot between speed and armature torque. It is clearly showing the speed of the shunt motor reduces as the load torque increases as shown in the given below figure.



Characteristics (N / Ta)

a) The torque generated and speed of a dc shunt motor at different armature currents may be seen from the aforementioned two features of a dc shunt motor.

b) If these data are displayed, a graph showing how changes speed as torque is built is produced.

c) Due to the fact that the torque is inversely proportional to the armature current, this curve matches the speed Vs current characteristics.

Characteristics of DC Series Motor:

The field winding of a DC series motor is connected in series with the armature, carrying the entire armature current in a DC series motor. The armature current also rises in tandem with the motor's shaft load. As a result, when the armature current rises, so does the flux in a series motor.

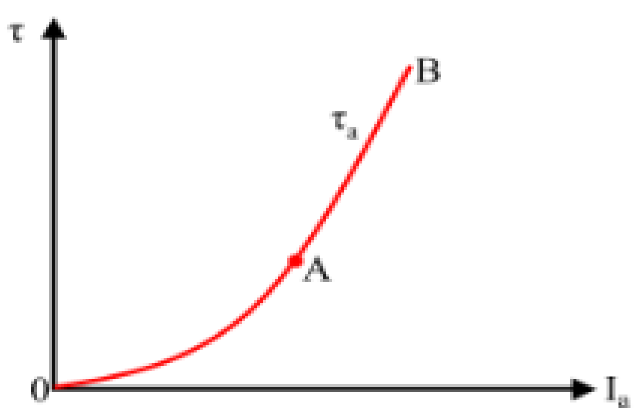
i. Ta and Ia Characteristics:

In a DC motor, characteristics is given below in the figure,

Ta ∝ φIa

Magnetic saturation, φ∝Ia; so that Ta ∝Ia^2

After magnetic saturation φ is becomes constant so that Ta ∝ Ia



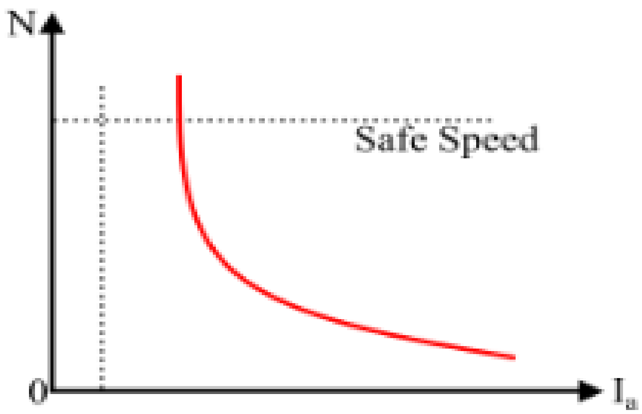
ii. **N / Ia characteristics:** The speed of a DC series motor can be calculated by,

N∝Ebφ;

Where,Eb=V−Ia(Ra+Rse)

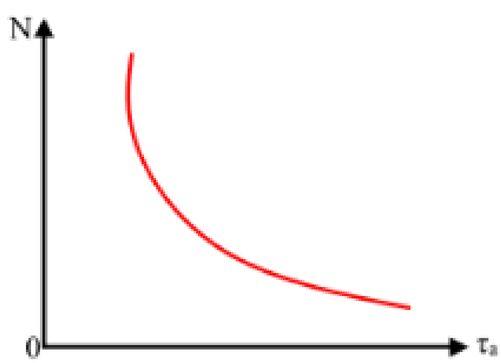
The back EMF decreases due to the ohmic reduction in armature and series field resistances while the flux increases as the armature current increases. Despite the fact that under normal working circumstances the resistance loss is minimal, as indicated;

N∝1/φ∝1/ Ia;Up tosaturation point of magnetic



iii. **Speed and torque characteristics (N / Ta):**

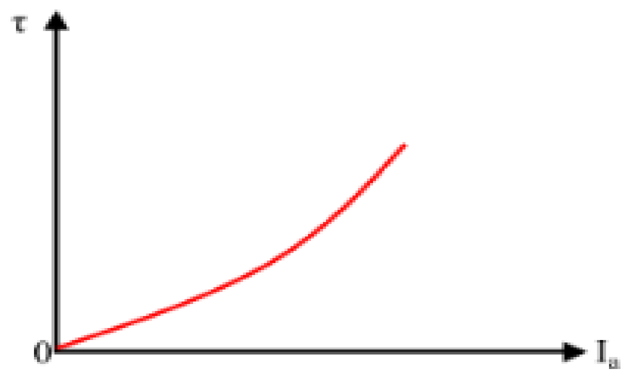
DC series motor's speed-armature current and torque-armature current characteristics can be used to determine its speed-torque characteristics as follows: For a given value of Ia, deduce a from the curve of the torque-armature current and N from the curve of the speed-armature current. A point (Ta,N) on the speed-torque curve will result from this. Determine the speed and torque values (T1, N1), (T2, N2), and so on by repeating this procedure for various armature current values.The speed and torque characteristics of a DC series motor can be seen in the figure when these points are plotted on the graph.



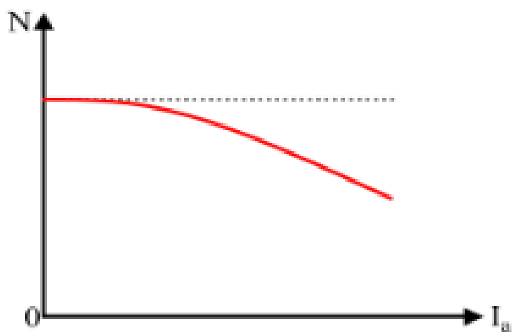
The flux and armature current are extremely small at no load. As a result, the speed rises to a dangerously high level, which has the potential to harm the machine. As a result, a series motor shouldn't be started with no load at all.

Characteristics of Compound wound DC Motor:

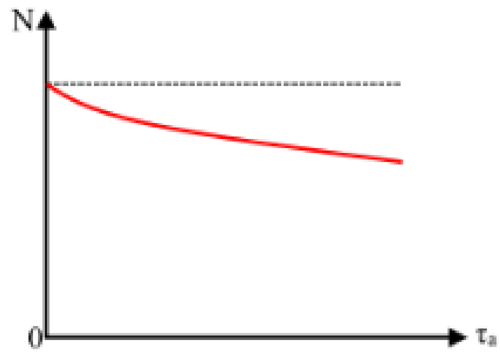
i. **Ta and Ia Characteristics:** The series field goes up when the armature current goes up, but the shunt field stays the same. Consequently, the armature torque and overall machine flux both rise as shown in figure below.



ii. **N and Ia characteristics:**The flux per pole goes up when the load goes up and so does the armature current. As a result, as the load increases, the motor's speed decreases. As a result, a cumulative compound motor lacks control over speed as shown in given below figure.



iii. **N / Ta characteristics:** A cumulative compound motor has more torque than a shunt motor for the same armature current, but less torque than a series motor as shown in the given figure.



DISCUSSION

The characteristics of series, shunt, and compound DC motors play a significant role in their performance and application. Series DC motors exhibit high starting torque and are suitable for applications requiring heavy initial loads. However, their speed regulation is poor, making them unsuitable for precision control. Shunt DC motors, on the other hand, offer good speed regulation and are commonly used in applications requiring constant speed. They provide a wide range of operating speeds and are relatively simple to control. Compound DC motors combine the advantages of both series and shunt motors. They possess the high starting torque of series motors and the speed regulation capabilities of shunt motors. The compound motors can be further classified into cumulative compound and differential compound, depending on the connection of the field windings. Cumulative compound motors provide enhanced starting torque and are used in applications where the load may increase during operation. Differential compound motors offer improved speed regulation and find application in situations where the load may decrease during operation. Understanding the unique characteristics of each motor type enables engineers to select the most suitable motor for specific applications, optimizing performance and efficiency.

CONCLUSION

In this chapter we learn about the characteristics of series, shunt and compound of DC motors and we learn about the basic types of DC motors. Series, shunt, and compound DC motors all have unique qualities that make them suited for various uses. The shunt motor is appropriate for applications requiring accurate speed control because it provides strong speed regulation and runs at a reasonably steady speed. It can sustain speed with varied loads and has a modest beginning torque. The compound motor strikes a balance between starting torque and speed management by combining the qualities of both series and shunt motors. Compared to a series motor, it provides better speed control and more beginning torque than a shunt motor. Industries that need both a strong starting torque and speed management often use compound motors. Engineers can choose the best motor type for certain applications by having a thorough understanding of the properties of series, shunt, and compound DC motors. This improves performance and efficiency. DC motors may get better and have a wider range of uses as a result of future research and technical developments.

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AN OVERVIEW OF THE ELECTRIC BRAKING OF DC MOTORS

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ABSTRACT:

An essential feature of DC motors is electric braking, which enables them to slow down or stop in an efficient and safe manner. This chapter examines the different strategies and methods used for DC motor electric braking. This addresses dynamic braking, plugging, and regenerative braking, outlining each technique's benefits and drawbacks. Additionally, it offers a thorough study of the crucial elements, including motor design, load parameters, and control methods, that affect how well electric braking works. The importance of electric braking in improving motor performance, energy economy, and overall system safety is emphasized in the paper's conclusion.

KEYWORDS: *Dynamic Braking, Electric Braking, Plugging, Regenerative Braking.*

INTRODUCTION

Electrical braking is typically used in situations where a motor-driven unit needs to be stopped precisely or its deceleration speed needs to be appropriately controlled. Applications requiring frequent, quick, accurate, or emergency stops call for electrical braking. Electrical braking makes it possible to stop smoothly without causing passengers any problems [1]. Although ac motors are utilized the majority of the time, DC motors are utilized for a variety of purposes.A rotating magnetic field is created when the coils are turned on and off sequentially. This field interacts with the various fields of the stator's stationary magnets to produce torque, which causes the stator to rotate. DC motors are able to transform electrical energy from direct current into mechanical energy through rotation.Applications requiring frequent, quick, accurate, or emergency stops call for electrical braking[2]. Electrical braking makes it possible to stop smoothly without causing passengers any problems.

Electric braking keeps the speed within safe limits as a loaded hoist is lowered. In any other case, the drive or machine's speed will reach dangerous levels. Electric braking is used to keep a train's speed within the safe limits when it descends a steep gradient. In situations where active loads are present, electrical braking is more frequently utilized. Mechanical brakes can provide the same amount of braking force as electric brakes do. Mechanical or electrical braking can quickly bring a motor that is running to a stop. Mechanical break shoes are used to apply the mechanical braking. As a result, the brakes' physical condition and surface influence mechanical braking's smoothness. Electric braking can be used to brake a motor smoothly[3].

Industrial fans, pumps, machine tools, household appliances, power tools, automobiles, and a wide range of drives all make use of electric motors. As you can see, electric watches also have tiny motors. As a generator, electric motors can also be used to recover energy lost through friction and heat[4]. Both linear and continuous rotation are supported by the electric motor. The term 'DC motor' is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power from minor motors in toys and appliances to large mechanisms that power vehicles, pull elevators and hosts, and drive steel rolling mills.It may be necessary to quickly stop the motor or change its direction of rotation in some situations[5]. Frictional braking can be used to bring the motor to a stop. The operation of frictional braking has the following disadvantages. It is unable to be controlled, reliant on the braking surface, and far from smooth.

Electrical braking of DC Motor:

Electrical braking is typically used in situations where a motor-driven unit needs to be stopped precisely or its deceleration speed needs to be appropriately controlled. Applications requiring frequent, quick, accurate, or emergency stops call for electrical braking. Electrical braking makes it possible to stop smoothly without causing passengers any problems.Electric braking keeps the speed within safe limits as a loaded hoist is lowered. In any other case, the drive or machine's speed will reach dangerous levels. Electric braking is used to keep a train's speed within the safe limits when it descends a steep gradient[6]. In situations where active loads are present, electrical braking is more frequently utilized. Mechanical brakes can provide the same amount of braking force as electric brakes do.

Types of electric braking:

There are three different kinds of electric braking:

1. Dynamic or rheostatic braking
2. Reverse current braking, counter current braking, or plugging
3. Regenerative braking

Regenerative Braking

1. Although it is still linked to the supply, the motor acts as a generator during regenerative braking, when the speed is higher than the synchronous speed.
2. Mechanical energy is converted into electrical energy, some of which is sent back to the system, while the remainder is converted to heat in the winding and bearing.

Dynamic Braking

This technique of breaking involves disconnecting the motor from the power source, switching the field connections, and connecting the motor in series with a variable resistance R.

Plugging

1. The motor's polarity may be changed to reverse the motor's spin in order to perform the plugging action.

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2. This may be done in dc motors by changing the polarity and in ac motors by altering the phase sequence.

1. Plugging or Reverse Current Braking:

The armature terminals or supply polarity of a separately excited or shunt motor when running are reversed during Plugging or Reverse Current Braking. As a result, when the plug is plugged, the induced voltage Eb and the supply voltage V, also known as back EMF, will interact in the same manner. As a result, the effective voltage across the armature will be almost twice as high as the supply voltage when the plug is plugged in (V + Eb). High braking torque is produced as a result of the armature current being reversed. To maintain a safe operating current, the armature is connected in series to an external current limiting resistor. The motor tends to run in the opposite direction due to the armature connections being reversed in this method. The applied voltage V and the back EMF Eb begin to act in the same direction as a result of the armature terminals being reversed, which results in an increase in the total armature current[6].

To restrict the current flowing through the armature, a variable resistor is attached across it. This is true for both series wound and shunt procedures.Plugging generates higher braking torque than rheostatic braking. This method is often used to control elevators, machinery, printing presses, and other equipment.The plugging process is made possible by switching the motor's polarity. The phase order of the starting winding and dc machines determines the polarities of the field or armature terminals. The direction of rotation of the magnetic field and the motor are reversed, producing the braking torque by switching any two supply connections. The generated electromagnetic torque causes the rotor to quickly halt. In each case, the device is operating like a motor. This kind of braking is also known as current braking and reverse current braking[7].

A series motor's armature or field terminals are flipped over for braking. However, field terminals and armatures cannot be reversed simultaneously. The reverse operation of both terminals will only result in normal operation.The braking torque is not zero at the zero speed. When the motor is used to stop a load, it must be disconnected from the supply and running at or close to zero speed. The motor will accelerate in the opposite direction if it is not disconnected from the supply mains. Centrifugal switches are used to disconnect the supply. Because both the power supplied by the source and the power supplied by the load are wasted in resistance, the method of braking known as "plugging" or "reverse current braking" is insufficient[8].

Applications of Plugging

The most commonly use of Plugging is for the following purposes listed below:

i. It is used for regulatoring elevators
ii. It is used in Rolling Mills
iii. Used for Printing Presses
iv. Used for Machine tools work.

2. Dynamic or Rheostatic braking of DC Motor

When the DC motor is disconnected from the supply mains in Dynamic Braking, a braking resistor Rb is connected across the armature. The motor now generates the braking torque and functions as a generator. A kinetic energy is stored in the mass of an electric motor as it rotates. If the motor is disconnected from the power source, it will continue to rotate for some time until all of the kinetic energy is lost through rotational losses. The braking is more rapid the faster the kinetic energy is dissipated.

The motor is connected in two ways in Dynamic Braking for the purpose of braking. First, the separately excited or shunt motor can be connected as a flux-controlled separately excited generator. The second method involves connecting the field winding parallel to the armature to a self-excited shunt generator, when it is in the motoring mode of operation.

Because an external braking resistance Rb is connected across the armature terminals for electric braking, this method is also referred to as rheostatic braking. When the motor is acting as a generator, the kinetic energy stored in the machine's rotating parts and the connected load is converted into electric energy during electric braking. In the armature circuit resistance Ra and braking resistance Rb, the energy is lost as heat. A variable resistor called a rheostat is connected across the supply in DC shunt motors. The armature is disconnected from the supply. The supply is left connected across the field winding. Evidently, the machine begins to function as a generator as the armature is now driven by inertia. The braking effect is controlled by varying the resistance connected across the armature. As a result, the machine will now feed the current to the connected rheostat, and heat will dissipate at the rate of I^2R.

The diagram of Dynamic Braking of DC Shunt Motor is shown below in given figure, when motoring mode is on. The braking process is sluggish when self-excitation is used. As a result, the machine is connected in self-excitation mode when quick braking is required. In order to keep the current at a safe level, the field and a suitable resistance are connected in series. Because all of the generated energy is lost as heat in the resistance, the Dynamic or Rheostatic Braking method is insufficient for braking.

3. Regenerative braking

In regenerative braking, the driven machinery's kinetic power or energy is returned to the mains power supply. When the load on the motor has a very high inertia, such as in electric trains, regenerative braking is used. It goes without saying that the armature current Ia, and consequently the armature torque, will be reversed when the applied voltage to the motor is decreased to less than the back EMF Eb. Thus, speed decreases. Regeneration is the process by which power is returned to the line when the generated EMF is greater than the applied voltage then the machine is acting as a DC generator. As speed continues to decrease, back EMF Eb also decreases until it falls below the applied voltage and the armature current again moves in the opposite direction of Eb.

When the motor is continuously excited by a driven load or machinery, it can perform this type of braking at a speed higher than the no-load speed.The motor armature current moves in the opposite direction when the back EMF Eb of the motor exceeds the supply voltage V. The machine now begins to function as a generator, supplying the source with the generated energy. If the motor is connected as an independent excited generator, regenerative braking can also be performed at very low speeds. As the speed decreases, the motor's excitation increases, resulting in the satisfaction of the two equations presented below.

$$E_b = \frac{nP\varphi Z}{A} \quad \text{and} \quad V = E_b - I_a R_a$$

On increasing excitation, the motor does not reach saturation.The shunt and separately excited motors make it possible to perform regenerative braking. Braking is only possible in compound motors with weak series compounding**.**While still connected to the supply, the motor acts as a generator during the regenerative braking process. In this instance, the synchronous speed is lower than the motor speed.

Electrical energy is produced when mechanical energy is converted into electrical energy. Some of this electrical energy is returned to the supply, while the remaining energy is stored neatly in the electrical machine's windings and bearings. When overdriven by the load, the majority of electrical machines move smoothly from the motoring region to the generating region as shown in the Figure 1.

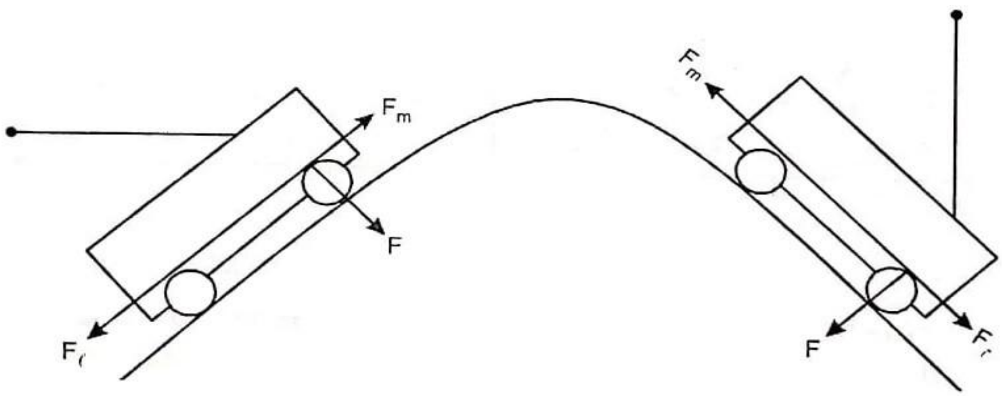

Figure 1: Regenerative braking [geeksforgeeks].

Regenerative braking in action, as depicted in the figure above. A trolley bus is being driven uphill and downhill here by an electric motor. In the upward direction, the gravity force can be divided into two components. One is parallel to the road surface Fl and the other is perpendicular to the load surface F. The parallel force pulls the motor down the hill.

To propel the bus uphill, the motor must exert a force Fm opposite to Fl if we disregard the rotational losses. In the first quadrant of the figure, this operation is depicted. The load torque Tl is opposite the motor torque Tm in this instance, but the speed and motor torque are both moving in the same direction. The mechanical load receives power from the motor.

Speed-Torque Characteristics of Regenerative Braking:

When the motor's speed exceeds the synchronous speed, regenerative braking occurs. Regenerative braking is the name given to this baking technique because the supply receives power from the motors, which act as a generator. The primary requirement for regenerative braking is that the rotor must rotate at a speed greater than that of synchronous rotation; only then will the motor function as a generator, causing the direction of current flow in the circuit to reverse and braking to occur as shown in the graph between speed vs torque in Figure 2.

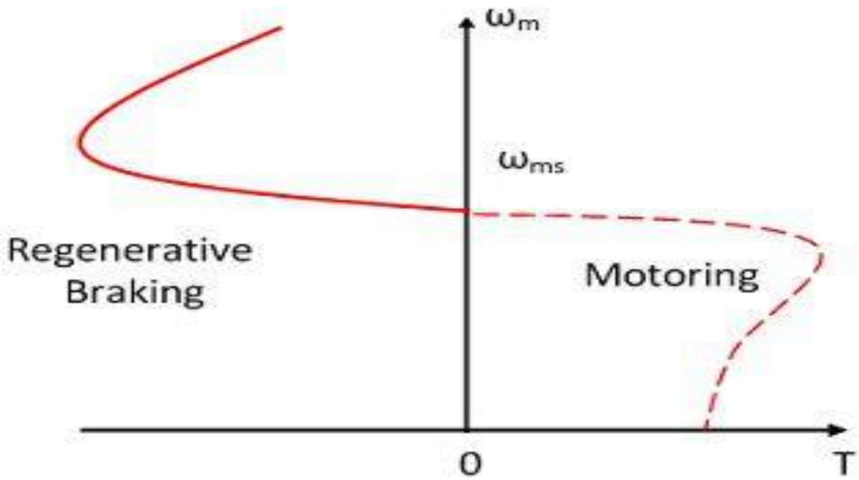

Figure 2:Speed-Torque Characteristics of Regenerative braking[geeksforgeeks].

Applications of Regenerative braking

i. When frequent braking and driving at a slower speed are required, regenerative braking is often used.
ii. Holding a descending load of high potential energy at a constant speed is its greatest application.
iii. The speed of motors driving loads like electric locomotives, elevators, cranes, and hoists is controlled by regenerative braking.
iv. The motor cannot be stopped with regenerative braking. It is used to regulate motor driving speeds above the no-load speed.

Regeneration only works if the back EMF Eb is higher than the supply voltage. If this happens, the armature current goes in the opposite direction and the mode of operation shifts from motoring to generating.

Regenerative Braking in DC Shunt Motors

Under the armature current at the normal operating condition is given by the equation shown below:

$$-I_a = \frac{V - E_b}{R_a}$$

The back EMF exceeds the supply voltage when the load is lowered by a crane, hoist, or lift, causing the motor speed to exceed the no-load speed. As a result, the armature current Ia turns negative. The equipment begins to function as a generator now.

Regenerative Braking in DC Series Motors

As the DC Series Motor's speed is raised, the armature current and field flux drop. The back EMF Eb cannot be bigger than the source voltage. Regeneration is feasible in a DC series motor because the field current is limited by the armature current. Regeneration is necessary in applications where DC series motors are often utilized, such as traction and elevator hoists. For instance, a constant speed may be necessary for an electro-locomotive traveling down the incline. It is necessary to slow down hoist drives when their speed exceeds hazardous levels.

Regenerative braking is often accomplished by connecting a DC series motor as a shunt motor. Because the field winding has a low resistance, a series resistance is added in the field circuit to maintain the current within a safe range.

Compare Electrical and Mechanical Braking

When an electric drive is unplugged from the power source, the driving motor's speed progressively drops until it hits zero. The word "braking" is a general term for a set of operating circumstances for electric motor systems. It involves swiftly halting the electric motor, stabilizing the motor shaft, maintaining the proper speed, and limiting the motor's speed.

During the braking process, the energy might alter the direction of its flow between the load and the source. The device then functions as a generator, sending the energy back to the power source. The braking method of an electric drive system has a significant impact on its whole operating cycle. The efficiency and accuracy of braking procedures typically determine the output and quality of produced items. There are typically two types of braking strategies:

1. **Mechanical braking**
2. **Electrical braking**

Mechanical braking:

According to the simplest concept of mechanical braking, the frictional force between the spinning parts and the brake drums creates the required brake. Mechanical components including brake linings, brake shoes, and brake drums are essential. This kind of brakes need regular maintenance. The diagram shown below shows the construction of mechanical braking in Figure 3

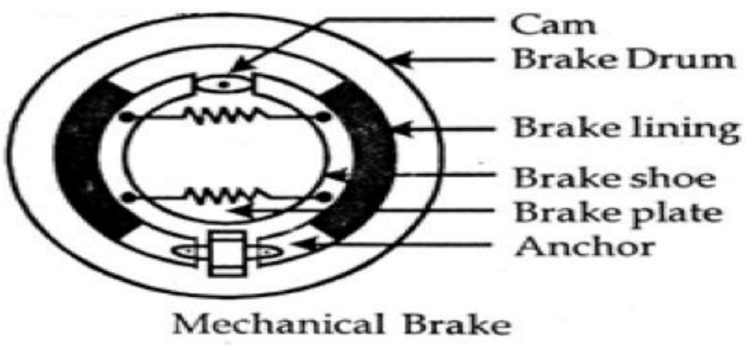

Figure 3: Mechanical braking [geeksforgeeks].

Electrical braking:

The motor is made to function as a generator while using electric braking. A negative slip and torque are thus produced (braking torque). By appropriately altering the motor's electrical connections, this is accomplished. For safety reasons, the drive's braking system, whether it be mechanical or electric, electric braking should be designed to bring the motor to a complete stop at the designated time and place.

The following factors may necessitate electric braking:

i. The load torque will be the sole opposing torque in the event that a motor operating at a certain speed is disconnected from the input supply. After the kinetic energy stored in its inertia has been released, the motor will come to a stop. The motor takes a long time to come to a stop when either the load torque is low or the inertia is high. Using electric braking, additional opposing torque must be introduced to reduce stopping time in applications that necessitate frequent stops.

ii. In order to avoid accidents, quick emergency stops are necessary in some crucial applications like traction. The majority of the time, electric braking is used to make quick and very smooth stops.

iii. If the motor does not provide braking force, the drive speed will reach dangerous levels in some applications with active loads. For instance, when a loaded hoist is being lowered in a hoist application, the motor should exert braking force to maintain the safe speed. Similar to electric traction, a braking force is required to maintain a train's safe speed when traveling down a steep gradient.

iv. If the motor does not provide braking force, the drive speed will reach dangerous levels in some applications with active loads. For instance, when a loaded hoist is being lowered in a hoist application, the motor should exert braking force to maintain the safe speed. Similar to electric traction, a braking force is required to maintain a train's safe speed when traveling down a steep gradient.

TABLE 1: COMPARE ELECTRICAL AND MECHANICAL BRAKING.

Mechanical Braking	Electrical Braking
It is Less effective.	It is highly effective method.
Friction wastes the energy of the rotating parts into heat.	The rotating parts' energy can be turned into electrical energy that can be used or returned to the mains.
It requires brake lining replacement and adjustment on a regular basis. They are easily damaged and worn.	It necessitates very less maintenance due to the absence of mechanical pieces of equipment.
The brakes may not be extremely smooth depending on the circumstances.	The brakes are very smooth and do not snag.
The system is held in place by applying this brake.	It is unable to generate holding torque. For it to work, electricity is needed.
In mechanical braking, we required a Brake drum, brake shoes, and brake linings, etc. for higher performance.	In some types of brakes, equipment with a higher rating than the motor rating may be required.

Electric braking is more effective and requires less upkeep than mechanical braking. However, electrical and mechanical transients can be stressful when braking. As a result, the braking system must be designed to operate safely and effectively.

CONCLUSION

In this chapter we learn about the basic introduction of electric braking of DC motors and. electric braking is essential to the reliable and effective running of DC motors. Motors may successfully slow down and stop while using methods like dynamic braking, regenerative braking, and plugging. This reduces energy waste and wear on mechanical braking systems. Through regenerative braking, the motor may transform kinetic energy into electrical energy, which can then be used again immediately or saved for later. Dynamic braking allows for controlled slowing by releasing surplus energy as heat via external resistors. For a quick deceleration, plugging entails inverting the motor connections to provide an opposite torque. Electric brake technology will continue to progress as a result of more in-depth study and development in this area, which will provide motor systems that are more efficient and dependable.

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EFFECT OF BRAKING ON SHUNT, SERIES AND COMPOUND DC MOTORS

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ABSTRACT:

This chapter examines how braking affects compound, series, and shunt DC motors. A key component of motor control is braking, which allows spinning equipment to decelerate quickly. The goal of the research is to examine how braking impacts the functionality, effectiveness, and general operation of these three classes of DC motors. Various metrics, including braking torque, power dissipation, and temperature increase during braking, were measured experimentally via experiments. The findings give suggestions for the best braking techniques and insights into the braking characteristics of each engine type.

KEYWORDS: *Braking, Compound Dc Motor, Shunt Dc Motor, Series Dc Motor.*

INTRODUCTION

Due to their dependability, simplicity, and controllability, DC motors are often utilized in a variety of industrial applications. In order to stop spinning equipment quickly, braking is a crucial component of motor control. Motor designers and control engineers are quite interested in how braking affects various kinds of DC motors, such as shunt, series, and compound motors [1]. There are several ways to stop an object, including mechanical or electrical braking systems or a hybrid of the two. It is essential for improving motor management techniques and maintaining safe operation to understand how braking impacts the performance, efficiency, and general behavior of DC motors, regardless of the braking mechanism used. In situations where speed control and stable torque characteristics are needed, shunt DC motors are often employed[2]. They are made up of an armature winding and a parallel field winding. Regenerative braking, which involves the motor acting as a generator to transform the kinetic energy of the revolving rotor into electrical energy, may be introduced via braking in shunt motors. It is possible to store this regenerative energy in an external energy storage device or to feed it back into the power source. Analysis is required to determine how regenerative braking affects the motor's performance, efficiency, and power dissipation [3].

On the other hand, series DC motors are renowned for their strong starting torque and features of changing speed. The field winding and armature winding are linked in series in series motors. Dynamic braking is used to stop series motors by connecting a resistor across the armature terminals and dissipating the motor's kinetic energy[4]. Although the dynamic braking system provides quick deceleration, it also generates a lot of heat and wastes a lot of electricity. To avoid overheating and maintain safe operation, it is essential to comprehend the thermal behavior

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and power dissipation during series motor braking.Shunt and series motor characteristics are combined in compound DC motors. Both a parallel and a series field winding are present. Depending on the respective contributions of the two field windings, the braking behavior of compound motors falls between that of shunt and series motors. Compound motors' braking performance and efficiency may be improved by analyzing their braking characteristics and maximizing the field winding design.

Electric Braking

There are three types of electric braking namely,

1. Rheostatic or Dynamic braking
2. Plugging or counter current braking or reverse current braking
3. Regenerative braking

1. Electric braking of DC shunt motors

a. Dynamic braking in DC shunt motor

The armature is detached from the supply and linked across a variable resistance R in this braking technique. The dynamic braking in DC shunt Motor is show in Figure 1.

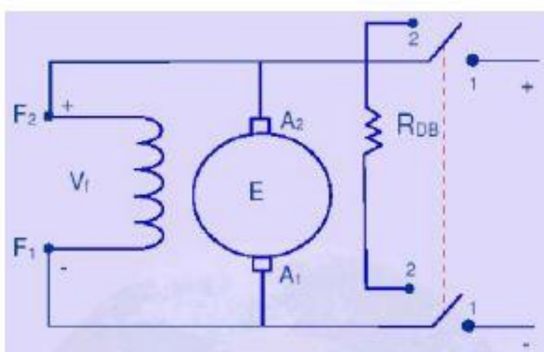

Figure 1: Dynamic Braking In DC Shunt Motor.

The field winding is retained intact and linked across the supply. By changing the series resistance R, the braking effect may be managed.

In DC shunt motors, dynamic braking has various benefits, such as:

1) Dynamic braking allows the motor to decelerate quickly, enabling swift stopping or controlled speed decrease. The motor's kinetic energy is dissipated to provide the braking action by a linked brake resistor, which causes a rapid reduction in rotational speed.

2) Simple and Economical: When compared to other braking methods, dynamic braking is a very simple and economical procedure. The brake circuit may be turned on with only a switching mechanism and a braking resistor. The system's simplicity makes it simple to install and maintain, which lowers total expenses.

3) Energy Dissipation: When a spinning motor is dynamically stopped, its kinetic energy is transformed to thermal energy and dissipated by the brake resistor. There is no longer a need for extra braking systems or external energy storage systems because of this energy dissipation. Additionally, it stops the engine from coasting or freewheeling to guarantee a swift and controlled stop[5].

4) Control Accuracy: Dynamic braking enables accurate control of the motor's deceleration rate. The brake resistor's resistance value may be changed to fine-tune the braking torque, allowing for a regulated and gentle deceleration. This degree of control is especially useful in situations when precise slowing or halting is necessary.

5) Reduced Mechanical Wear and Tear: The mechanical wear and tear on the motor and other brake components is reduced by dynamic braking. There is less strain on the motor's working elements because, unlike mechanical braking systems, there is no physical contact or friction involved in the braking process. As a result, the motor needs less maintenance and lasts longer.

6) Improved Safety: Dynamic braking increases overall motor control system safety by delivering a quick and controlled deceleration. It helps the engine to stop effectively and reliably, reducing mishaps or damage brought on by errant or protracted coasting. Dynamic braking's quick reaction guarantees that the engine stops in the right amount of time, improving safety in crucial applications[6].

b. Counter current braking or plugging in DC shunt motor

i. By reversing connections to the armature terminals, this type of breaking causes the motor to pull in the other direction.

ii. V and Eb start operating in the same direction throughout the circuit as a result of the reversal of armature connections.

iii. The armature connections must be reversed while a resistor is added to the circuit to restrict the armature current to a safe level.

iv. Plugging provides greater braking torque than rheostat braking.

For printing presses, elevators, rolling mills, and machine tools, this technique is often utilized. The Counter current braking or plugging in DC shunt motor is show in Figure 2.

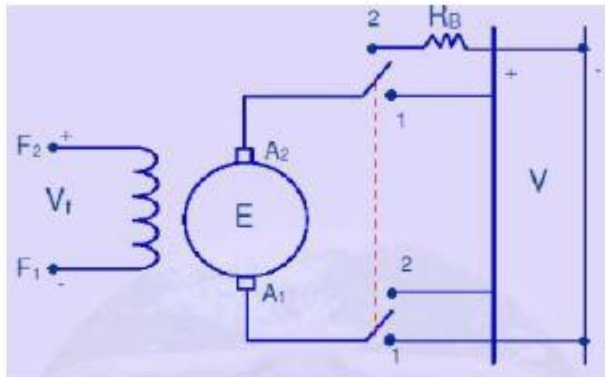

Figure 2: Counter current braking or plugging in DC shunt motor

c. ***Regenerative braking in DC shunt motor***

In DC shunt motors, regenerative braking is a method used to recover and redistribute energy that is generally lost as heat during braking. A DC shunt motor may generate electrical energy and feed it back into the power supply system when it is used as a generator. The regenerative braking in DC shunt motor is show in Figure 3 [6].

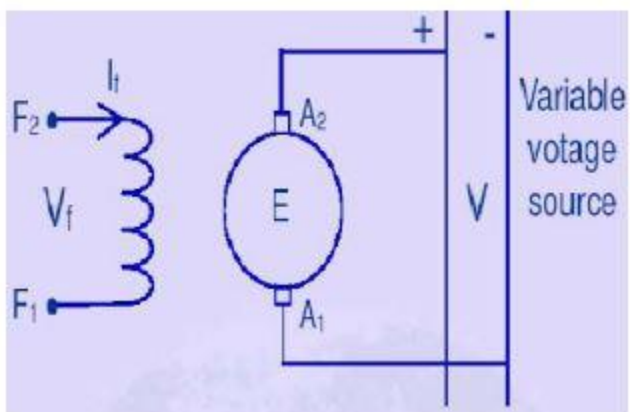

Figure 3: Regenerative braking in DC shunt motor

Regenerative braking in a DC shunt motor operates as follows:

i. **Normal Operation:** The armature and field windings of the motor are electrified during normal operation, which involves the delivery of electrical power to the motor. The motor does the needed work by converting electrical energy into mechanical energy, which rotates the motor shaft.

ii. **Braking Operation:** The power supply to the armature is cut off or switched around when the motor has to slow down or stop. In addition, a resistor or another load is connected in parallel with the field winding. The motor may function as a generator thanks to this set up.

iii. **Electrical Energy Production:** The mechanical energy of the spinning shaft is transformed into electrical energy when the motor shaft slows down. The reverse electromotive force (back EMF) is a voltage produced by the armature windings, which are now functioning as a generator. The back EMF varies in direct proportion to the motor's rotational speed.

iv. **Energy Recovery:** The electrical energy produced is often pumped back into the power grid. It may sometimes be saved for later use in a battery or capacitor. Regenerative braking increases system efficiency by collecting and recycling this energy and lowering the amount of energy lost as heat.

v. **Speed Control:** Regenerative braking generates back EMF, which opposes the direction of the applied voltage and lowers the speed of the motor. The braking torque may be regulated, enabling a smooth deceleration, by modifying the field current or the load resistance.

Electric cars, elevators, and conveyor systems are just a few examples of equipment that often uses regenerative braking in DC shunt motors. It has benefits including energy efficiency, less mechanical brake wear, and the capacity to collect and redistribute energy that would otherwise be lost during braking[5].

2. Electric braking of DC series motors

a. Dynamic braking in DC series motor

a) The motor is attached to a dynamic braking resistance RDB during dynamic braking and is cut off from the supply.

b) It should not be necessary to cut off the field's supply. The armature continues to spin because of the inertia and rotation that occurs during driving mode.

c) The existence of the field and the rotation cause an emf to be generated. The braking resistance is current-driven by this voltage. This current is flowing in the opposite direction to that in which it was flowing before to the connection modification[7].

The dynamic braking in DC series motor is shown in Figure 4.

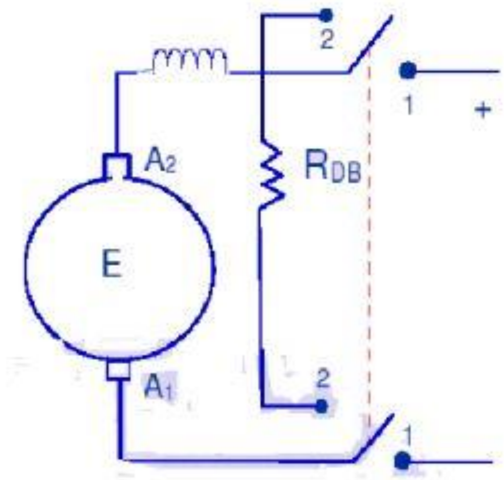

Figure 4: Dynamic braking in DC series motor.

b. Counter current braking or plugging in DC series motor

In this braking technique, the armature's connections are switched around, and a variable resistance R is connected in series with the armature as show in Figure 5.

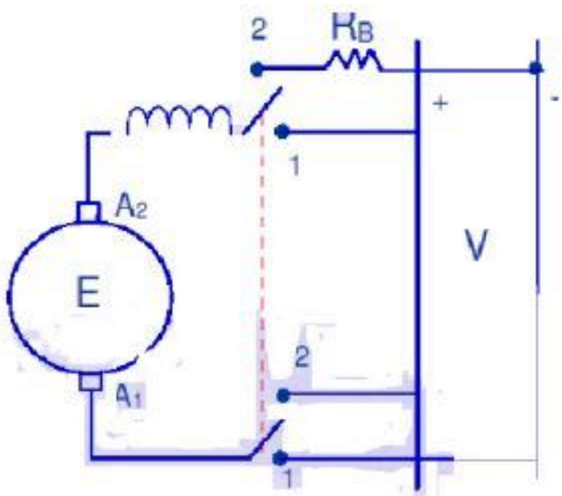

Figure 5: Counter current braking or plugging in DC series motor.

c. Regenerative braking in DC series motor

Regenerative braking is not feasible in a DC series motor without the required adjustments since reversing Ia will flip the field, and therefore Eb.

However, traction motors with certain configurations employ this technique.

Regenerative braking is a useful braking method in a variety of applications because it has multiple benefits for DC series motors. Several benefits are as follows:

1) Energy Efficiency: Regenerative braking's capacity to collect and repurpose the energy generally lost as heat during braking is one of its main benefits. The power obtained by turning mechanical energy into electrical energy may be used immediately or saved for later use. As a consequence, energy waste is decreased and energy efficiency is increased.

2) Regenerative braking aids in reducing energy consumption, which may result in cost savings in situations when there is a lot of braking or acceleration. Less energy must be provided from outside sources when it is recovered and used as opposed to being lost as heat, possibly resulting in decreased running expenses.

3) Extended Battery Life: Regenerative braking is a key factor in prolonging battery life in electric and hybrid cars powered by DC series motors. Regenerative braking enables the motor to act as a generator and replenish the car's battery when the vehicle slows down or stops. This lessens the need for external charging and aids in keeping the battery at a higher level of charge, extending its life[8].

4) Heat Reduction: When braking, regenerative braking produces less heat than conventional braking techniques. In situations where extreme heat might harm components or hinder performance, this can be useful. Regenerative braking lessens the need for heat dissipation and eases the burden on brake systems by collecting and reusing energy.

5) Environmental Benefits: Regenerative braking's ability to save energy makes it more environmentally friendly and sustainable. Regenerative braking lessens the environmental effect of the system or vehicle by cutting down on energy waste and dependency on external power sources.

6) Controlled Deceleration: The deceleration process may be controlled precisely and smoothly using regenerative braking. A regulated and steady deceleration is possible because to the adjustable and controllable back electromotive force (back EMF) that is created. This enhances the braking operation's general safety and comfort[9].

3. Electric braking of DC Compound motors

The series and shunt fields are both present in the DC compound motor.

- **i.** Regenerative braking
- **ii.** Dynamic braking
- **iii.** Counter braking

1) The orientation of the armature and the series field are switched during the compound motor's regenerative braking function.

2) In order to prevent the motor from demagnetizing, the motor's series field winding is shunted as soon as the speed reaches Wo.

3) As a result, the straight line represents the speed-torque characteristics of regenerative braking.

4) The compound motor's dynamic braking is comparable to the shunt motor's dynamic braking.

5) The motor's armature is separated from the supply during dynamic braking and linked across the braking resister; only the shunt field winding is stimulated.

6) The field flux is hence constant.

7) The compound motor's countercurrent braking is comparable to that of the series motor. The effect of series field winding is responsible for this.

DISCUSSION

The discussion on compound DC motors revealed several important findings. Firstly, the compound DC motor is a versatile and efficient device widely used in various industrial applications. Its unique design combines the characteristics of both series and shunt DC motors, resulting in enhanced performance and increased torque capabilities. This makes it suitable for applications requiring high starting torque, such as elevators, cranes, and hoists. Furthermore, the discussion highlighted the different types of compound DC motors, namely cumulative compound and differential compound motors. Cumulative compound motors have a series field winding aiding the shunt field winding, while differential compound motors have a series field winding opposing the shunt field winding. Each type offers distinct advantages and can be selected based on the specific requirements of the application. Additionally, the discussion addressed the control and speed regulation of compound DC motors. The compound DC motor's speed can be regulated by controlling the armature voltage, field flux, or both, depending on the motor's configuration. The availability of various control methods, such as rheostatic control, flux control, and armature voltage control, allows for precise speed adjustment and efficient operation. Moreover, the discussion emphasized the significance of proper maintenance and protection measures for compound DC motors. Regular inspection, cleaning, and lubrication of the motor components are crucial to ensure optimal performance and prolong the motor's lifespan. Furthermore, protective devices, such as overload relays and thermal sensors, are essential to prevent damage caused by excessive current or temperature. The discussion on compound DC motors highlighted their versatility, efficiency, and wide range of applications. The different types of compound DC motors, methods of speed regulation, and maintenance considerations were explored. Understanding these aspects is essential for engineers and technicians involved in the design, operation, and maintenance of compound DC motors in various industrial settings.

CONCLUSION

Braking provides a significant quantity of regenerative energy into shunt DC motors, which may be returned to the power source or stored in an external energy storage device. This regenerative braking system boosts energy efficiency and lessens power loss while slowing down. To avoid overloading or damage, it is important to pay close attention to the voltage and current restrictions of the motor and its related components. Dynamic braking, a distinct braking feature of series DC motors, involves connecting a resistor across the armature terminals to release the kinetic energy of the motor.Compound DC motors include features of both series and shunt motors, and their braking behavior falls in the middle of the two. The relative contributions of the shunt and series field windings determine the braking torque and power dissipation.

Compound DC motors' braking performance may be improved by carefully adjusting the field winding design.

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AN ELABORATION OF THE TRANSFORMERS

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ABSTRACT:

Transformers have become a potent class of machine learning models for applications like natural language processing. Transformers were first developed for machine translation, but they have subsequently revolutionized a number of fields, including sentiment analysis, question answering, and text production. This chapter gives a general review of transformers while examining its design, education system, and uses. We examine important elements, emphasizing their function in collecting long-range dependencies and contextual information, such as self-attention processes and positional encoding.

KEYWORDS: *Ideal Transformers, Magnetic Flux, Transformers, Winding.*

INTRODUCTION

Hasbro, an American toy corporation, and Takara Tomy, a Japanese toy manufacturer, are the creators of the Transformers media brand. The main characters are the valiant Autoboots and the evil Decepticons, two opposing extra-terrestrial robot groups with the ability to change into other forms, including vehicles and animals. Toys, animation, comic books, video games, and movies are all part of the series. It was one of the highest-grossing media franchises ever as of 2011, bringing in more than 2 trillion ($25 billion) in revenue. The Transformers toy line, which included transforming mecha toys from Takara's Diaclone and Micro Change toylines renamed for Western markets, launched the series in 1984. The Transformers animated television series and the corresponding comic book series, which include separate Japanese, British, and Canadian spin-offs, are both referred to as "Generation 1" in this context.

Sequels followed, such as the Beast Wars TV series and the Generation 2 comic book, each of which established its own mini-universe. With Dreamwave Productions in 2001 and IDW Publishing in 2005, Generation 1 characters had two reboots; a third will begin in 2019. The tale has been retold in multiple forms based on various toy lines during and beyond the 20th century. The first was the Robots in Disguise series, which was followed by three programs (Armada, Energon, and Cybertron), together known as the "Unicron Trilogy" and taking place in the same world[1]. The Transformers: Animated series included ideas from the G1 continuity, the 2007 live-action feature, and the "Unicron Trilogy," while a live-action film series debuted in 2007, again separate from earlier iterations. In an effort to lessen the flood of reboots, the "Aligned Continuity" was developed throughout the majority of the 2010s. Transformers: Cyber verse made a return in 2018, this time in a new, original version.Tonka's GoBots were once a distinct and rival brand that debuted in 1983, but when Tonka was acquired by Hasbro in 1991, they became part of their intellectual property. The world featured in the Challenge of the GoBots cartoon series and its follow-up movie, GoBots: Battle of the Rock Lords, was afterwards established retrospectively as an alternative reality inside the Transformers multiverse [2]–[4].

Transformers: Generation 1 (1984–1993)

The characters from the Transformers franchise who first debuted between 1984 and 1993 are referred to as Generation One. The 1980s Japanese toy brands Micro Change and Diaclone are where The Transformers first appeared. They displayed robots that could change into common cars, gadgets, or weapons. Hasbro collaborated with Takara and acquired the Micro Change and Diaclone toys. Hasbro engaged Marvel Comics to construct the history; editor-in-chief Jim Shooter penned the overarching plot while author Dennis O'Neil was tasked with inventing the characters. Shooter picked Bob Budiansky to design the characters since he was dissatisfied with O'Neil's work (even if O'Neil came up with the moniker "Optimus Prime").

Shji Kawamori, the creator of the Japanese mecha anime series Macross (which was turned into the Robotech franchise in North America), was primarily responsible for designing the Transformers' mecha. While working on the Diaclone and Macross series in the early 1980s (such as the VF-1 Valkyrie in Macross and Robotech), Kawamori came up with the concept of morphing mechs; his Diaclone mechs eventually served as the inspiration for Transformers. The main idea behind Generation One is that Optimus Prime, Megatron, and their best warrior’s crash land on ancient Earth in the Ark and the Nemesis before emerging in 1985, when Cybertron is speeding through the Neutral zone as a result of the conflict. The Marvel comic was once a part of the main Marvel Universe, with Spider-Man and Nick Fury cameos, cameo appearances a trip to the Savage Land, and more.

Around the same period, the Transformers television series debuted. It was created by Sunbow and Marvel Productions, then Hasbro Productions, and from the beginning it was in conflict with Budiansky's backstories. The TV episode depicts the Autobots searching for fresh sources of energy and crash landing as the Decepticons launch their assault. The Autobots were seen by Marvel as having destroyed a rogue asteroid that was heading for Cybertron. In the TV series, Shockwave supports Megatron and keeps Cybertron at a standstill while he is away, while in the comic book, he tries to seize control of the Decepticons. The beginnings Budiansky had imagined for the Dinobots, the Decepticon turned Autobot Jetfire (referred to on TV as Skyfire), the Constructicons (who unite to become Devastator), and Omega Supreme would all be drastically different in the TV series. The Creation Matrix, which gives robots life, is something Prime controls, as is made clear early on in the Marvel comic. The two-part episode The Key to Vector Sigma from the second season featured the ancient Vector Sigma computer, which had the same initial function as the Creation Matrix (creating the Transformers), as well as its keeper Alpha Trion.

The Transformers: The Movie, a 1986 movie that takes place in the year 2005, was adapted from the animation. The "Autobot Matrix of Leadership" was first seen in this movie when a mortally wounded Prime gave it to Ultra Magnus. However, when Prime passed away, he dropped the matrix, which Hot Rod later picked up and turned into Rodimus Prime. Galvatron is created as a result of Unicron, a planet-eating transformer, who is afraid of Megatron's strength.

Bombshell or Skywarp also transforms into Cyclonus, Thundercracker becomes Scourge, and two other Insecticons becoming Scourge's hunters, the Sweeps. In the end, Rodimus Prime defeats Unicron and destroys the Matrix. To keep up with American reprints, the weekly comic book in the UK interspersed original content, and The Movie contributed a lot of fresh content. With cinematic spin-offs featuring the time-traveling Galvatron, author Simon Furman continued to broaden the continuity. Leonard Nimoy as Galvatron, Scatman Crothers as Jazz, Casey Kasem as Cliffjumper, Orson Welles as Unicron, and Eric Idle as the commander of the Junkions (Wreck-Gar, though he isn't given a name in the film) all had cameo appearances in the movie. Lion sang the Transformers theme song, while "Weird Al" Yankovic contributed a song to the soundtrack.

The Quintessons' usage of Cybertron as a factory was made known in the third season, which came after The Movie. Their robots begin to revolt, and eventually the laborers transform into Autobots and the troops become Decepticons. (Note: This seems to go against the history described in the show's first two seasons.) The Autobots are the ones that create transformation. At the end of the third season, Optimus Prime is revived by popular demand and the show concluded with a three-episode plot arc. However, a freshly made OVA, Scramble City, was added to the Japanese broadcast of the series before whole new series were created to continue the plot, omitting the American series' 1987 conclusion. The Headmasters, Super-God Masterforce, Victory, and Zone were among the titles that had a lengthy Japanese run. They were then reissued in illustrated magazine form as Battlestars: Return of Convoy and Operation: Combination. Marvel kept developing its continuity when the TV show came to an end. Although it took place in the present, it emulated The Movie by murdering Prime and Megatron. Grimlock assumes control of the Autobots as their new commander.The short series The Transformers: Headmasters, which further broadened the focus to include the planet Nebulon, and a G.I. Joe crossover also occurred. It paved the way for Prime to be revived as a Powermaster in the main title.

The mythos kept expanding throughout the United Kingdom. In order to serve his physical body, the planet Cybertron, and battle his archenemy Unicron, Primus was revealed to be the creator of the Transformers. The female Autobot Arcee also made an appearance, despite the comic book's claim that the Transformers had no sense of gender. Her history describes how the Autobots created her in an effort to dispel sexism claims made by humans. Megatron's deputy Soundwave likewise breached the fourth wall in the letters section, denouncing the cartoon continuity as a false portrayal of history. The UK's version of G.I. Joe, Action Force, also included a crossover.When Furman took over the American comic book, which showed Megatron as still being dead, he rescanned it to show a clone of Megatron instead.The UK comic ran for 332 issues and numerous annuals until being superseded by Dreamwave Productions later in the 20th century. The U.S. comic ran for 80 issues till 1991.The whole G1 series was made available in 2009 by Shout! Factory in a 16-DVD box set dubbed the Matrix of Leadership Edition. They also made available the same material as separate seasons[5]–[7].

A transformer is a passive part that transfers electrical energy between circuits, whether they are single circuits or numerous circuits. The electromotive force (EMF) across any additional coils wrapped around the same core changes in response to changes in the current flowing through any one of the transformer's coils, which causes changes in the magnetic flux in the transformer's core. Without a metallic (conductive) link between the two circuits, electrical energy may be transported between different coils. The 1831 discovery of Faraday's law of induction defines the induced voltage effect in any coil as the result of a fluctuating magnetic flux around the coil.Transformers are used to adjust the AC voltage levels; these transformers are classified as step-up or step-down types depending on whether they raise or decrease the voltage level. Additionally, transformers may be employed to connect the stages of signal-processing circuits and to provide galvanic isolation between circuits. For the transmission, distribution, and use of alternating current electric power, transformers have been crucial ever since the first constant-potential transformer was created in 1885. Transformer designs come in a variety of shapes and sizes for use in electronic and electric power applications. Transformers come in a variety of sizes, from RF transformers with a volume of less than one cubic centimeter to devices used to link the electrical grid that weigh hundreds of tons.

Ideal Transformer

A perfect coupled, lossless, linear transformer exists. Perfect coupling indicates that there is no net magnetomotive force and that the core magnetic permeability and winding inductance are both indefinitely high (i.e. ipnp − isns = 0).

The transformer core, which is also ringed by the secondary winding, is subject to fluctuating magnetic flux due to variable current in the transformer's main winding. This fluctuating flux at the secondary winding causes the voltage or electromotive force in the secondary winding to fluctuate. Transformer operation is based on an electromagnetic induction phenomena, and Lenz's law states that the secondary current created by this phenomenon produces a flux that is equal to and in the opposite direction of the flux produced by the main winding. The main and secondary windings are both able to pass through the magnetic flux because the windings are encircled by a core with indefinitely high magnetic permeability. The transformer currents flow in the directions shown when the primary winding and secondary winding are linked to a voltage source and a load, respectively, and the core magnetomotive force cancels to zero as shown in the Figure 1.

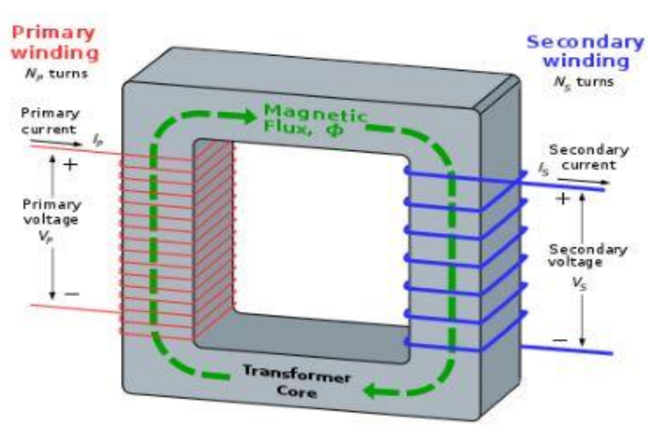

Figure 1: Ideal Transformer and Induction Law.

According to Faraday's law, a voltage is induced in each winding proportionate to its number of windings since the same magnetic flux flows through both the main and secondary windings in an ideal transformer. The winding turns ratio and the transformer winding voltage ratio are same.The voltage ratio and winding turns ratio of an ideal transformer are both inversely proportional to the corresponding current ratios, which is a realistic estimate for a typical commercial transformer. The turns ratio squared times the load impedance of the secondary circuit creates the load impedance for the main circuit. The circuit diagram of ideal transformer is show in Figure 2.

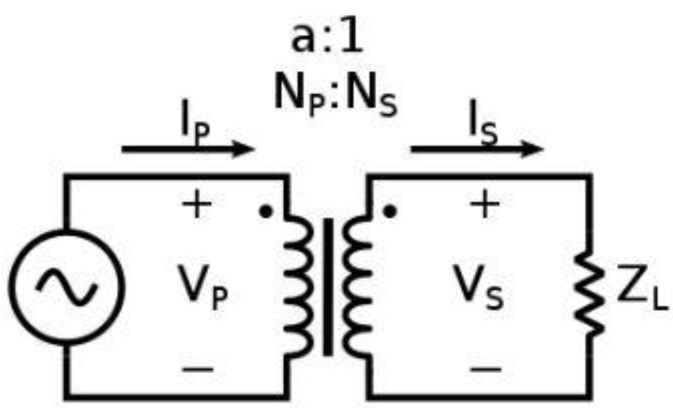

Figure 2: Ideal transformer connected with source VP on primary and load impedance ZL on secondary, where 0 < ZL < ∞.

Real transformer

Deviations from ideal transformer

The following fundamental linear characteristics of actual transformers are ignored by the ideal transformer model:

Core losses, also known as magnetizing current losses, consist of eddy current losses caused by joule heating in the core and hysteresis losses caused by nonlinear magnetic phenomena in the transformer core. These losses are proportional to the square of the applied voltage to the transformer. In contrast to the ideal model, a real transformer's windings include non-zero resistances and inductances linked to: Joule losses brought on by resistance in the main and secondary windings Primary and secondary reactive impedance is caused by leakage flux that eludes the core and only goes through one winding. Parasitic capacitance and self-resonance owing to the dispersion of the electric field, which is analogous to an inductor. Typically, three different types of parasitic capacitance are taken into account, and closed-loop equations are presented.

1. A layer's capacitance between neighboring turns;
2. Between neighboring layers' capacitance;
3. Between the core and the layer or layers next to the core, capacitance;

The ‘real' transformer model's equivalent circuit, depicted below, does not contain parasitic capacitance since adding capacitance to the transformer model is difficult and seldom tried. Comparing open-circuit inductance, or the inductance of a primary winding while the secondary circuit is open, to a short-circuit inductance, or the inductance when the secondary winding is shorted, allows one to quantify the capacitance effect.

Leakage flux

According to the ideal transformer model, the main winding joins all the turns on all the other windings, including itself. In reality, some flux travels via routes that go away from the windings. This flux is known as leakage flux, and it produces leakage inductance in series with the transformer windings that are mechanically connected. With each cycle of the power supply, leakage flux causes energy to be alternately stored in and released from the magnetic fields. Although it does not immediately result in a power loss, poor voltage regulation prevents the secondary voltage from being precisely proportionate to the main voltage, especially when a large load is present. As a result, transformers are often built with very low leakage inductance.

Long magnetic pathways, air gaps, or magnetic bypass shunts may be purposefully included into a transformer's design to reduce the amount of short-circuit current it will deliver in situations when more leakage is required. Leaky transformers may be used to safely handle loads that occasionally short-circuit, such as electric arc welders, or to provide loads that display negative resistance, such as electric arcs, mercury- and sodium-vapor lamps, and neon signs. In particular, audio-frequency transformers in circuits with a DC component running in the windings employ air gaps to prevent saturation. A storable reactor uses the core's saturation to manipulate alternating current.When operating transformers in parallel, understanding leakage inductance is also helpful. It can be shown that two transformers would share the load power proportionate to their individual ratings if their % impedance and related winding leakage reactance-to-resistance (X/R) ratios were equal. The impedance tolerances of industrial transformers, however, matter a lot. Additionally, various capacity transformers have varying impedances and X/R ratios[8], [9].

DISCUSSION

The transformers is a renowned and beloved franchise that has captured the imagination of audiences around the world. Combining science fiction, action, and intricate storytelling, these iconic robots in disguise have become cultural icons since their inception. With their ability to transform into various vehicles and weaponry, the Transformers captivate fans of all ages, providing an exciting blend of technology, adventure, and the enduring struggle between good and evil. The franchise has expanded beyond its original animated series and toys, spawning successful live-action films, comic books, video games, and animated spin-offs. Through their captivating narratives and dynamic characters, the Transformers have left an indelible mark on popular culture, transcending generations and continuing to enthrall fans with their epic battles, complex relationships, and enduring themes of heroism and loyalty. Whether you are a dedicated fan from the early days or a newcomer to this extraordinary world, the Transformers' appeal remains as strong as ever, offering a timeless tale of robotic wonders and the eternal fight for justice.

CONCLUSION

The science of natural language processing and machine learning has substantially improved thanks to Transformers, in our opinion. They have advanced to the forefront of several applications because to their capacity to model long-range interdependence and gather contextual information via self-attention processes. Transformers, including BERT, GPT, and Transformer-XL, have shown astounding proficiency in jobs like emotion analysis, text production, and language translation. The requirement for extensive training data, processing power, and eliminating biases in language models are still issues. The development of more effective architectures, investigation of unsupervised learning strategies, and advancement of fairness and transparency in Transformer models should be the main areas of future study. Transformers have enormous promise for improving the comprehension and processing of human language, provided that innovation and cooperation are sustained.

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AN ELABORATION OF THE INDUCTION MOTORS

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ABSTRACT:

Due to their durability, simplicity, and affordability, induction motors are often employed in a broad range of industrial and commercial applications. An overview of induction motors, including their design, manufacture, and performance characteristics, is given in this chapter. The stator, rotor, and electromagnetic fields, as well as other important induction motor components and operating concepts, are covered. The effects of efficiency, power factor, and torque on motor performance are also discussed. Additionally, prevalent induction motor types including wound rotor and squirrel cage motors are examined. This chapter's overall goal is to provide readers a thorough grasp of the workings and characteristics of induction motors.

KEYWORDS: *Induction Motors, Motors, Phase Induction, Rotor, Squirrel Cage, Stator.*

INTRODUCTION

The most popular kind of electric motors in a variety of commercial and industrial settings are induction motors. They are renowned for being straightforward, dependable, and economical. Machines, pumps, fans, compressors, and many more equipment are all powered by induction motors. For engineers, technicians, and anybody else dealing with electric motors, it is crucial to comprehend the fundamentals of induction motors. Electromagnetic induction is the basic idea underlying induction motors. A revolving magnetic field is produced when an alternating current (AC) is supplied to the stator windings. A magnetic field is produced by the rotor's currents being induced by this spinning magnetic field. The rotor rotates as a consequence of the interaction between the revolving magnetic field of the stator and the induced magnetic field of the rotor, producing mechanical work[1]–[3].

The stator and the rotor are the two primary components that make up an induction motor. A laminated core and insulated windings make up the stator. The AC power source is linked to these windings, which creates the revolving magnetic field. On the other hand, the rotor may be either a wound or a squirrel cage rotor. The wound rotor features windings that are externally linked to resistors or other external devices, in contrast to the squirrel cage rotor, which has laminated iron cores and conducting bars that are shorted at both ends. A few benefits of induction motors are their excellent dependability, little maintenance needs, and ruggedness. They do not need commutators or brushes, which are typical parts of other kinds of motors that are prone to wear and need constant maintenance. Induction motors are also renowned for their efficiency, particularly when working at or close to their rated load. Efficiency, power factor, torque, and speed control are just a few of the variables that affect how well induction motors function. Aims have been made to increase motor control abilities, decrease energy usage, and improve motor efficiency. These developments have produced more effective motors and variable frequency drives (VFDs), allowing for more accurate speed control and better motor performance.

The workhorses of many industries, induction motors provide dependable and economical mechanical power. Their ease of use, durability, and high efficiency are factors in their widespread usage. Engineers and technicians may efficiently build, run, and repair these motors by being aware of their principles and features, which will help to create dependable and efficient industrial operations.

Background of Induction Motors:

François Arago, a French scientist, proposed the presence of rotating magnetic fields in 1824. These rotations were known as Arago's rotations. Walter Baily showed the first rudimentary induction motor in 1879 by manually turning switches on and off.Otto Blathy, a Hungarian engineer, created the first single-phase AC induction motor without a commutator, which he utilized to power his creation, the electricity meter. Galileo Ferraris and Nikola Tesla separately developed the first AC commutator-free polyphase induction motors, with the former demonstrating a functional motor model in 1885 and the latter in 1887. In October and November 1887, Tesla submitted applications for US patents; some of these applications were accepted in May 1888. Ferraris' study on his AC polyphase motor, which outlined the principles of motor functioning, was published in April 1888 by the Royal Academy of Science of Turin. Tesla presented three different types of four-stator, four-pole motors to the American Institute of Electrical Engineers (AIEE) in May 1888. The first type had a four-pole rotor that formed a non-self-starting reluctance motor, the second type had a wound rotor that formed a self-starting induction motor, and the third type was a true synchronous motor with a separately excited DC supply to the rotor winding.

In 1888, George Westinghouse, who was then working on an AC power system, bought a US patent option on Ferraris' induction motor design and licensed Tesla's patents. Tesla worked as a consultant for one year as well. C. F. Scott, a Westinghouse employee, was tasked with helping Tesla and eventually took over Westinghouse's induction motor research. Mikhail Dolivo-Dobrovolsky created the cage-rotor induction motor in 1889 and the three-limb transformer in 1890 while steadfastly advocating for three-phase advancement. Additionally, he said that Tesla's motor was impractical due to two-phase pulsations, which led him to continue working on three-phase systems. Westinghouse built its first usable induction motor in 1892 and a series of polyphase 60 hertz induction motors in 1893, however these early Westinghouse motors had wound two-phase rotors until B. G. Lamme created a revolving bar winding rotor.Induction motors with three phases were first developed by the General Electric Company (GE) in 1891. A cross-licensing deal for the bar-winding-rotor design, subsequently known as the squirrel-cage rotor, was struck by General Electric and Westinghouse in 1896. In order to indicate the 90o rotation operator in the analysis of AC issues, Arthur E. Kennelly was the first to fully realize the relevance of complex numbers (using j to denote the square root of negative one).

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The induction motor Steinmetz equivalent circuit is a widely used analytical model that was considerably improved by GE's Charles Proteus Steinmetz for the use of AC complex variables.A 100-horsepower induction motor today has the same mounting dimensions as a 7.5-horsepower motor in 1897 thanks to advancements in induction motor technology brought about by these breakthroughs and discoveries.An induction motor is one with simply amortize windings. Most of the time, an induction motor is the least expensive electrical equipment in terms of construction. An electromagnetic field is generated into the rotor when the spinning magnetic field of the stator cuts the stationary rotor, according to the induction motor's working principle. In commercial, residential, and industrial contexts, induction motors are by far the most prevalent. It is an AC motor with three phases. Induction Motor is depicted in Figure 1.

Figure 1: Induction Motor.

These characteristics define it:

1. Simple and durable design
2. Low cost and little upkeep
3. Excellent reliability and enough skill
4. Does not need a separate starting motor and cannot be coordinated.

Stator and Rotor are the two main components of an induction motor.

Stator

The stator is constructed from a variety of stampings that include spaces for three-phase windings. It has a certain number of poles for winding. The windings are separated by 120 degrees geometrically. Squirrel cage rotors and wound rotors are the two types of rotors used in induction motors. The machine doesn't need any DC field current to operate. Rotor voltage is not physically linked by wires, but is instead induced in the rotor windings.

Rotor

The revolving component of the electromagnetic circuit is called the rotor. The squirrel cage rotor is the most prevalent form of rotor. The rotor is made up of a cylindrical laminated core with parallel slots for the conductors that are axially positioned. A copper, aluminum, or alloy bar is kept in each slot. It is commonly indicated that the rotor of three-phase induction motors acts as an anchor. The anchor form of the rotors utilized in very early electrical equipment serves as the inspiration for this term. Although the rotor performs this function in three-phase induction motors, the magnetic field would stimulate the anchor's winding in electrical equipment.The physical stator of an induction motor is identical to that of a synchronous machine, but the rotor development is different. An induction motor may be used as a generator or a motor. However, they are mostly used as induction motors[4]–[6].

There are two types of Induction Motors:

1. Single-phase Induction Motor
2. Three-phase Induction Motor

Single-phase Induction Motor

A single-phase induction motor cannot start on its own. The primary winding of a motor that is coupled to a single-phase power source is carrying an alternating current. It seems sense that the engine that costs the least and requires the least repair will be used the most often. Since they don't start on their own, they may be classified into many sorts depending on how they begin. They are capacitor, dual phase, and shaded pole motors. Again, there are three types of capacitor motors: permanent, capacitor start, and capacitor run. Below is a picture of a permanent capacitor motor.

The start winding of these motors may contain a centrifugal switch or a series capacitor. Because of the main winding impedance, when the supply voltage is applied, the current in the main winding trails the supply voltage. And depending on the impedance of the starting mechanism, the current in the start winding follows or follows after the supply voltage.The phase difference created by the angle between the two windings is enough to create a rotating magnitude field that generates a beginning torque. A centrifugal switch on the motor shaft opens and disconnects the beginning winding when the motor achieves 70% to 80% of synchronous speed.

Types of Single-Phase Induction Motor

Four different kinds of single-phase induction motors are categorized, including Split Phase, Capacitor Start, Capacitor Start & Capacitor Run, and Shaded Pole Induction Motor.

1. Split Phase Induction Motor

Resistance Start Motor is another term for a split-phase induction motor. This kind of motor has a stator and a rotor with a single cage, and the stator has two windings—a beginning winding and a main winding. These two windings are shifted in space by 90 degrees. While the main winding has a very low resistance and a strong inductive reactance, the beginning winding has less inductive reactance and a higher resistance.This kind of motor is more affordable and suitable for simply starting loads when the beginning frequency may be limited. Because of its lower starting torque, this motor cannot be used for drives that need more than 1 KW. Washing machines, floor polishers, AC fans, mixer grinders, blowers, centrifugal pumps, drilling & lathe machines are just a few of the uses for split-phase inductor motors.

2. Capacitor Start Induction Motor

A 1-phase motor having a stator and rotor with a single cage is known as a capacitor start induction motor. This motor's stator primarily consists of two windings, a primary winding and an auxiliary winding. Starting winding is another term for an auxiliary winding. These two windings may be arranged individually at 90 degrees in space for building a motor. Where frequent starts are required, such as with larger inertia loads, capacitor start induction motors are employed. Conveyors, pumps, machine tools, and compressors are all driven by this kind of motor. It is used in refrigerators and AC compressors.

3. Capacitor Start & Capacitor Run Induction Motor

The operating theory of a capacitor-run induction motor is the same as that of a capacitor-start induction motor. We are aware that a single-phase induction motor cannot start on its own since the magnetic field it produces is not rotational in nature. Induction motors thus need phase difference to produce a rotating magnetic field. The resistance is required to produce a phase difference in a split-phase induction motor, however with these motors, the capacitor will do so.

It is true that the voltage is controlled by the current that flows through the capacitor. Two windings, such as the main and the beginning, are present in capacitor start and capacitor start capacitor run type motors.Due to a link in the capacitor's beginning winding, the current it supplies bends the applied voltage in a certain direction. These two motors are employed mostly in grinders, conveyors, compressors, air conditioners, etc. because of their strong starting torque.

4. Shaded Pole Induction Motor

This is a self-starting, single-phase induction motor that allows one of its poles to be shaded using a copper ring, commonly known as a shaded ring. This ring in the motor serves as a secondary winding's primary purpose. This kind of motor can only turn in one direction, and it is not feasible to move the motor in backward. This motor has very large power losses, a poor power factor, and potentially very low induced starting torque. Due to its tiny size and low power ratings, this motor has a low efficiency. Due to its cheap cost & ease of starting, shaded pole induction motors are used in tiny devices like fans & relays.Hairdryers, exhaust fans, table fans, air conditioners, cooling fans, refrigerators, record players, projectors, tape recorders, and photocopying equipment all utilize this motor. These motors are also used to start 1-phase synchronous timing motors and electronic clocks.

Applications of Single Phase Induction Motor

The single phase induction motor has several uses in both industrial and home settings and is often employed in low-power applications. And a few of them are listed below.

1. Pumps
2. Compressors
3. Small fans
4. Mixers
5. Toys
6. High-speed vacuum cleaners

7. Electric shavers
8. Drilling machines

Three-Phase Induction Motor

These motors start themselves without the need of a centrifugal switch, a capacitor, or any other starting mechanism. In commercial and industrial settings, three-phase AC induction motors are often employed. These come in two varieties: slip ring and squirrel cage motors. Due to their robust structure and simple design, squirrel cage motors are often employed. External resistors are necessary for slip ring motors to have a high starting torque. Industrial and household appliances employ induction motors because they are very inexpensive, have a robust design that requires little maintenance, and just need power to run the stator.

Types of 3 Phase Induction Motor

The stator and the rotor are two crucial parts of a three-phase induction motor. The stator serves as the motor's fixed component while the rotor rotates. The load is attached to the shaft of this motor. Over the stator, three-phase armature winding is possible. Once this winding is supplied with balanced 3-phase current, the air gap may provide a consistent amplitude rotational magnetic field.

The load current is carried by this armature winding, which is coupled to the three-phase power source. Based on how they are built, these motors are divided into two categories: wound and squirrel cage rotor.

1. Squirrel Cage Induction Motor

The building of a squirrel cage induction motor is quite straightforward. The rotor of this motor has several slots on the exterior perimeter and a cylindrical core that may be laminated. These slots are twisted at certain angles and are not similar. These grooves help prevent magnetic locking between the rotor's and stator's teeth so that smooth operation and minimal humming noise may be accomplished. In lieu of the rotor winding, these motors use bar-shaped rotors that are made of copper, brass, or aluminum[7]–[9].

In this kind of motor, the rotor's winding consists of an aluminum bar that is fastened into partially closed rotor slots alongside uninsulated copper. These conductors are short-circuited at both ends of the motor via an end ring made of a related substance. This kind of induction motor is referred to as a squirrel cage induction motor since the rotor it uses is comparable to a squirrel cage.

2. Wound Rotor or Slip Ring Induction Motor

The wound rotor motor is another name for the slip-ring induction motor. This motor has a laminated cylindrical core in the rotor. There are various gaps around the outside, same like the squirrel cage. One inserts the rotor winding into the slots. The insulated windings in the wound rotor are coiled on top of the rotor in a manner similar to that of the stator. In the STAR paradigm, the winding of this rotor may be linked and dispersed equally. Through the slide ring, the three terminals of this STAR connection may be removed. This explains why this motor is referred to as a slide ring induction motor.

Why Does a Three-Phase Induction Motor Self Start?

Three single-phase wires with a 120° phase difference make up a 3-phase motor. Therefore, the rotating magnetic field also has a phase difference, and the rotor will revolve as a result. For instance, if phase 'a' is magnetized, the rotor will move toward phase 'a' if we think of phases a, b, and c as three separate phases. 'B' will get magnetized in the following second phase, which will then magnetize the rotor and lead to phase 'c'. The rotor will continue to revolve in this manner.

Why 1-Phase Induction Motor is not Self Starting?

A single phase supply causes a one-phase induction motor to produce a pulsing magnetic field rather than a rotating one. A conductor's current supply creates a flux that may be divided into two halves, each of which rotates at a constant speed in the opposite direction. As a result, the net flux, the current flowing in the induced conductors of the rotor, and the torque all become zero. A single-phase induction motor is not self-starting as a consequence.

This motor may be briefly changed into a 2-phase motor during beginning in order to solve this problem and make it self-starting. As a result, in addition to the primary winding like the beginning winding, the one-phase motor's stator is provided. These windings are thus spread out along the 1-phase supply. It is possible to design the windings such that there is a significant phase difference between the currents in the two stator windings. This motor functions as a two-phase motor as a result. The two currents provide a spinning flux that enables the single-phase motor to start on its own.

Benefits of an Induction Motor

The following diagram illustrates the benefits that the induction motor has as a result of its design and the method that electric power is delivered. And now let's quickly review them.

1. **Low Cost:** In comparison to synchronous and DC motors, induction machines are considerably inexpensive. The induction motor's understated design is to blame for this. Because AC line power can be connected quickly, these motors are widely chosen for fixed speed applications in industrial, commercial, and residential settings.
2. **Low Maintenance Cost:** Unlike synchronous and dc motors, induction motors need no maintenance. An induction motor's construction is fairly straightforward, and since maintenance is likewise straightforward, it has a minimal maintenance cost.
3. Operation is made easy by the absence of an electrical connection that supplies power to the rotor; instead, current is generated by the movement of the transformer performed on the rotor owing to the low resistance of the spinning coils. Self-starting motors include induction motors. As a consequence, less work may be required for upkeep.
4. **Speed fluctuation:** The induction motor's speed fluctuation is almost constant. When transitioning from no load to rated load, the speed normally only changes by a few percent.

5. **Strong Starting Torque:** The induction motor's strong starting torque makes it beneficial for tasks where the load is applied before the motor starts. In contrast to synchronous motors, 3-phase induction motors will have self-starting torque. Single-phase induction motors, on the other hand, lack self-starting torque and need some auxiliaries to turn.
6. **Durability:** An induction motor's durability is another key benefit. It is hence the best machine for a variety of tasks. As a consequence, the motor lasts for many years without needing any repairs or maintenance.

Due to all these benefits, induction motors are used in many industrial, household, and other applications.

Disadvantages of Induction Motor

The following are some drawbacks of induction motors.

1. The power factor is quite low and it uses a lot of electricity when there is a light load. As a result, there may be significant copper loss, which lowers efficiency under light load conditions.
2. The initial torque of the squirrel cage induction motor is not small.
3. This motor has an unchanging speed, hence it cannot be used in situations where varied speed is required.
4. It's difficult to manage the motor speed.
5. This motor has a significant starting inrush current, which initially results in a drop in voltage.

DISCUSSION

Induction motors are a widely used and fascinating piece of technology. These motors have become the backbone of numerous industries and applications, powering a vast array of devices and machinery. Known for their efficiency, durability, and versatility, induction motors are essential components in both household appliances and heavy industrial equipment. One of the most intriguing aspects of induction motors is their working principle. They operate based on the principle of electromagnetic induction, wherein a rotating magnetic field is created within the motor. This rotating magnetic field induces currents in the rotor, generating the necessary torque for rotational motion. This concept allows induction motors to operate without the need for direct electrical contact, making them highly reliable and resistant to wear and tear. Induction motors come in various types and designs, catering to specific needs. The most common types include squirrel cage and wound rotor motors. Squirrel cage motors are simpler in construction, with rotor bars shaped like a squirrel cage, while wound rotor motors have external electrical connections to the rotor windings, offering additional control and flexibility. The benefits of induction motors are numerous. They are known for their high efficiency, converting electrical energy into mechanical energy with minimal losses. This efficiency is particularly advantageous in industries where large amounts of power are required, as it helps reduce energy consumption and operating costs. Moreover, induction motors are robust and require minimal maintenance, making them suitable for continuous operation in demanding environments. They can withstand high temperatures, voltage fluctuations, and mechanical stress, ensuring reliable performance and longevity. Induction motors also offer precise control over motor speed and torque, allowing for smooth acceleration and deceleration. This feature is crucial in applications that require precise control, such as in industrial automation and HVAC systems and induction motors are a remarkable technology that has revolutionized various industries. Their efficiency, durability, versatility, and precise control make them an indispensable component in countless devices and machinery. As technology continues to advance, induction motors are likely to evolve further, driving innovation and powering the world around us[10]–[12].

CONCLUSION

Induction motors are essential in a wide range of industrial and commercial applications. An overview of the main features of induction motors, including their construction, performance characteristics, and operating theories, has been given in this work. To maximize the efficiency and dependability of induction motors, one must have a thorough understanding of how they function. The performance of the motor is affected by a number of variables, including efficiency, power factor, and torque. To ensure efficient and dependable motor operation, efforts should be made to increase efficiency, boost power factor, and optimize torque characteristics. Different induction motor designs, such squirrel cage and wound rotor motors, each have unique benefits and uses. For a particular application, choosing the right motor type is essential for achieving the best performance and lifespan. Generally speaking, induction motors remain the workhorses of many sectors, and continuous research and development efforts strive to further enhance their effectiveness, dependability, and performance characteristics.

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AN ELABORATION OF THE STARTING OF DC MOTORS

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ABSTRACT:

There are many uses for DC motors, from consumer electronics to industrial equipment. It's essential to comprehend how DC motors start in order for them to run well. The beginning mechanisms are discussed in this chapter, along with the various approaches used and the variables affecting starting performance. It goes through the importance of beginning torque, back EMF, and armature response in the motor's first spin. Additionally, the effects of different beginning methods, including electronic soft starters, decreased voltage starting, and direct-on-line starting, are investigated. The goal of the study is to improve knowledge of DC motor starting and provide guidance in choosing the best starting strategy for certain applications.

KEYWORDS: *DC Motors, Motor, Motorstarter, Starting Current, Starter.*

INTRODUCTION

A device used to start and accelerate a DC motor is known as Stator. A controller is a device for starting, controlling, reversing, and stopping the DC motor. The DC motor draws a lot of current when it starts, which damages the motor. The heavy current is reduced and the system is shielded from damage by the starter[1].A motor starter is a safe electrical device for starting and stopping a motor. The motor starter, like a relay, turns the power on and off, but unlike a relay, it also protects against low voltage and overcurrent. A motor starter is a safe electrical device for starting and stopping a motor. The motor starter, like a relay, turns the power on and off, but unlike a relay, it also protects against low voltage and overcurrent[2].

The primary purpose of a motor starter is to protect a motor from low voltage and overcurrent, to safely start a motor, stop a motor, and reverse its direction.A device used to start and accelerate a motor is called a starter. A controller is a device for starting, controlling, reversing, and stopping the DC motor[3]. The DC motor draws a lot of current when it starts, which damages the motor. Although ac motors are utilized the majority of the time, DC motors are utilized for a variety of purposes.A rotating magnetic field is created when the coils are turned on and off sequentially. This field interacts with the various fields of the stator's stationary magnets to produce torque, which causes the stator to rotate. Industrial fans, pumps, machine tools, household appliances, power tools, automobiles, and a wide range of drives all make use of electric motors[4].

As you can see, electric watches also have tiny motors. As a generator, electric motors can also be used to recover energy lost through friction and heat. Both linear and continuous rotation are supported by the electric motor. Nowadays we can see that use of motors is increasing day by day and it will be very beneficial in any field. DC motors use magnetic fields that occur from the electrical generated, which powers the movement of a rotor fixed within the output shaft. The output torque and speed depends upon both the electrical input and the design of the motor. The term 'DC motor' is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy[5].

Starting Of DC Motors

A device used to start and accelerate a DC motor is known as Stator. A controller is a device for starting, controlling, reversing, and stopping the DC motor. The DC motor draws a lot of current when it starts, which damages the motor. The heavy current is reduced and the system is shielded from damage by the starter.A motor starter is a safe electrical device for starting and stopping a motor. The motor starter, like a relay, turns the power on and off, but unlike a relay, it also protects against low voltage and overcurrent.A motor starter is a safe electrical device for starting and stopping a motor[6]. The motor starter, like a relay, turns the power on and off, but unlike a relay, it also protects against low voltage and overcurrent.The primary purpose of a motor starter is to protect a motor from low voltage and overcurrent, to safely start a motor, stop a motor, and reverse its direction.Starter can shown below in the given Figure 1.

Figure 1: Starter Used for DC Motors.

DISCUSSION

Starting methods of DC Motors:

The fundamental operational voltage equation for a DC motor is given as E = Eb + IaRa, and consequently, Ia = (E - Eb) / Ra. However, the back EMF Eb = 0 when the motor is at rest. As a result, the starting armature current can be expressed as Ia = E / Ra. Because the armature resistance is typically very low around 0.5ohm in practical DC machines, a significant current flows through it during startup[7]. The armature circuit could be damaged by this significant current are as follows:

1. Fuses and armature winding and/or commutator brush arrangement damage may result from this excessive starting current.
2. Due to the fact that torque is directly proportional to the armature current, a very high starting torque will be generated. This high starting torque may result in a significant centrifugal force, which may cause the armature winding to be thrown off.
3. The terminal voltage of other loads connected to the same source might drop.

Due to the large rotor's inertia, a large DC motor will accelerate slowly. As a result, the level of high starting current was maintained for quite some time as the back EMF was gradually increased. This could result in severe damage[8]. A suitable DC motor starter must be used to avoid this. However, using a contactor or a switch to connect very small dc motors to the supply, they can be started immediately. Because of the small rotor inertia, they quickly gain speed, so it doesn't hurt. Due to the rapid rise in the back EMF, the large starting current will quickly diminish in this instance.

Need of starters for DC Motors:

Starting an induction motor requires a motor starter. It is because of the low impedance of its rotor. The slip of the induction motor, which is the difference in speed between the rotor and stator, affects the rotor impedance. The slip is inversely correlated with the impedance. The impedance of the induction motor is at its lowest and it draws a significant amount of current known as inrush current because the slip of the motor is at its maximum at standstill (rest position). The air gap that separates the rotor and stator is magnetized by the high inrush current, resulting in an EMF in the rotor winding[9]. To generate torque in the rotor, this electromagnetic field causes an electrical current to flow through the rotor winding. The motors slip decreases and its current consumption decreases with increasing rotor speed.There is no back EMF in the dc motor. The armature current is controlled by the circuit's resistance when the motor starts. The armature has a low resistance, so when the motor is at a standstill and the full voltage is applied, the armature current becomes extremely high, causing damage to the motor's components.

At the beginning, the armature circuit experiences additional resistance as a result of the high armature current. When the machine speeds up, the circuit is cut off from the machine's starting resistance. A motor's armature current is determined by:

$$I_a = \frac{V - E}{R_a} \; \ldots\ldots\ldots \; (1)$$

As a result, Ia is dependent on E and Ra if V remains constant. The armature remains stationary when the motor is turned on for the first time. As a result, Eb, the back EMF, is also zero. The following equation describes the initial starting armature current Ias:

$$I_{as} = \frac{V - 0}{R_a} = \frac{V}{R_a} \; \ldots\ldots\ldots\ldots \; (2)$$

Because a motor's armature resistance is extremely low, typically less than one ohm. As a result, the current starting armature Ias would be quite large. The difference (V – E) continues to decrease as the motor speed increases, resulting in an increase in the back EMF. As a result, the motor's armature current gradually decreases until it reaches its stable speed and the corresponding back EMF. The armature current reaches the desired level under this circumstance. As a result, it has been discovered that the armature resistance is aided in limiting the current that flows through the armature by the back EMF.

Due to the large starting current encountered when the DC motor is started. Except for very small DC motors, an additional resistance must be connected in series with the armature when the motor starts. The motor's safe value is maintained by adding this additional resistance, which also limits the motor's starting current until it reaches its stable speed. As the motor's speed increases and the back EMF increases, the series resistance is divided into sections that are cut out one at a time. When the motor's speed reaches its normal value, the extra resistance is removed.The normal rated full load current is 5-8 times higher than the high inrush current. Therefore, a current of this magnitude can harm or burn the motor's windings, rendering the machine useless, and it can result in a significant drop in supply line voltage, which can harm other appliances connected to the same line.We use a starter that limits the initial current for a short time at startup to protect the motor from such high currents. Once the motor reaches a certain speed, the normal power supply to the motor is resumed. During normal operation, they also offer protection against fault conditions like low voltage and overcurrent [10].

How does a motor starter work?

A starter is a control device that can manually or automatically switch the motor. It is used to safely make or break the contacts of electrical motors to turn them ON or off. For smaller motors, the manual starter is used because the lever must be manually moved to the ON or OFF position. The fact that these starters need to be turned on after power goes out is a drawback. In other words, each ON or OFF operation necessitates manual control. This operation may occasionally result in high currents flowing through the motor winding, which could burn the motor. Because of this, it is not recommended in most situations when automatic starters or other motor starters with protection are used.As again we discussed, the motor's ON/OFF operation is controlled by electromechanical relays and contactors in automatic starters. The contactor coils are energized and produce an electromagnetic field when current flows through them, pulling or pushing the contacts to connect motor windings to the power supply.

Motors can be turned ON and OFF with the help of the start and stop pushbuttons that are connected to the starter and motor. Pushing the stop button will de-energize the contactor coils, allowing them to be de-energized. The motor is turned off as a result of the contactor contacts returning to their normal position as a result of the spring arrangement. The motor won't start automatically unless we manually start it by pressing the "start push button" in the event of a power failure or manual shutoff. The operation of an ON/OFF DOL motor starter is depicted in the following diagram given above.

Types of Motor Starters Based on Starting Methods & Techniques:

An induction motor can be started in a variety of ways in businesses. Here are some of the methods utilized in motor starters before we get into the different kinds of motors.

1. **Full Voltage or Across the Line Starter:** These types of starters connect the motor directly to the power line, supplying the entire voltage. Due to their low power ratings, these starters' motors do not cause a significant voltage drop in the power line. They are utilized in a situation in which motors have low ratings and must operate in a single direction.
2. **Full Voltage Reversing Starter:** By switching any two phases, a three-phase induction motor can have its direction reversed. Two mechanically interlocked magnetic contactors with switched phases for forward and reverse direction make up this kind of starter. It is used in a situation where contactors are used to control a motor that must run in both directions.
3. **Multispeed Starter:** Multispeed Starter Changing the AC supply frequency or the number of poles is required to alter the speed of an AC motor. These kinds of starters operate the motor at a few predetermined speeds depending on the application.
4. **Reduced Voltage Starter:** The most common method of starting a motor is to reduce the voltage at the motor's start in order to cut down on the inrush current, which can damage the motor's windings and cause a significant drop in voltage. High-powered motors require these starters.

Types of starters available for induction motors are:

1. **Full voltage direct online starting**
   a. DOL starter
2. **Reduced voltage starting Stator control**
   a. Star-Delta starter
   b. Auto transformer starter

3. Rotor resistance starter

There are many different kinds of motor starters, but most of them fall into two categories.

A. **Manual Starter:** This kind of starter works by hand and doesn't need any experience. The motor that is connected to it can be turned OFF and ON with a push button. A mechanical switch is part of the button's mechanism, causing the circuit to break or cause the motor to start or stop.Additionally, they offer overload protection. However, these starters lack LVP, or low voltage protection, which prevents the circuit from being damaged in the event of a power outage. Because the motor restarts when power is restored, it can be dangerous for some applications. As a result, a low-power motor makes use of them. A manual starter known as the Direct On-Line (DOL) starter features overload protection.

B. **Magnetic Starter:** Magnetic starters are the most prevalent kind of starter, and high-power AC motors typically make use of them. Similar to a relay that uses magnetism to make or break the contacts, these starters operate electromagnetically.It includes protection against low voltage and overcurrent as well as a lower and safer voltage for starting. The magnetic starter automatically interrupts the circuit when there is no power. It includes an automatic and remote operation that does not involve the operator, in contrast to manual starters.

Direct Online Starter (DOL)

The simplest motor starter is the Direct Online (DOL) Starter, also known as a Direct Online Starter. This type of starter connects the motor directly to the power supply. It consists of an overload relay to prevent overcurrent and a magnetic contactor to connect the motor to a supply line. Safe motor start requires no voltage reduction. As a result, the starter motor is rated at less than 5 hp. The motor can be started and stopped with just two simple push buttons.

The coil that pulls the contactors together to close the circuit is energized when the start button is pressed. Additionally, pressing the stop button breaks the circuit by pushing the contactor's coil apart and de-energizes it. Any kind of switch—rotary, level, float, etc.—can be used to turn the power supply ON or OFF. Even though this starter does not provide a safe voltage for starting, the overload relay prevents overheating and overcurrent. The coil of the contactor is energized by the overload relay's typically closed contacts. The contactor's coil is de-energized and the circuit is severed when the relay trips as depicted in the given Figure 2.

The advantages of the DOL Motor Starter include:

1. Its low price and straightforward design.
2. It is very simple to use and comprehend.
3. Due to the high starting current, it provides high starting torque.

The Disadvantages of the DOL Motor Starter include:

1. The power line's voltage dips as a result of the high inrush current, which can damage the windings.
2. Heavy motors should not use it because it can shorten a motor's lifespan.

Figure 2: DOL Motor Starter.

Rotor Resistance or Slip Ring Motor Starter

The full voltage motor starting method is utilized by this kind of motor starter. It is also known as a slip ring motor starter because it only works with slip ring induction motors. Through the slip ring, external resistances are connected to the rotor in a star combination. The torque is increased and the rotor current is limited by these resistors. The starting stator current decreases as a result of this. Power factor is also improved because resistors are only used to start the motor and are removed once it reaches its maximum speed.Rotor Resistance or Slip Ring Motor Starter is shown in Figure 3.

TheAdvantages of rotor resistance or slip ring motor starter include:

1. Using full voltage, it provides a low starting current.
2. The motor can be started under load thanks to its high starting torque.
3. This method raises the power factor.
4. It offers numerous speed control options.

TheDisadvantages of rotor resistance or slip ring motor starter includes:

1. The rotor is more costly and weightier
2. It only works with slip-ring induction motors.

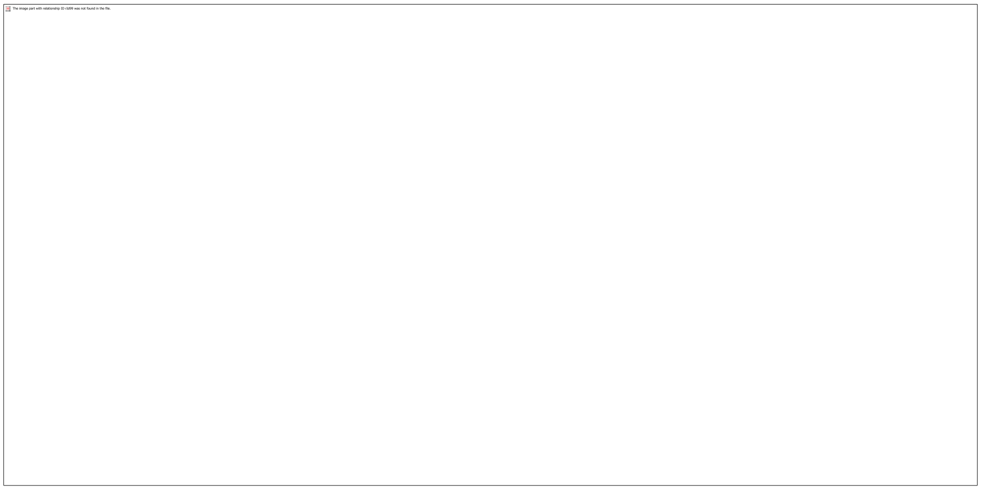

Figure 3: Rotor Resistance or Slip Ring Motor Starter.

Autotransformer Starter

An autotransformer serves as a step-down transformer in these motor starters, lowering the voltage that is applied to the stator during the starting stage. It can be connected to delta- and star-connected motors in the same way.

Each motor phase is connected to the secondary of the autotransformer. The autotransformer's multiple tapings only provide a small portion of the rated voltage. The relay is positioned at the start position, or tap point, providing a reduced startup voltage. To increase the voltage in accordance with the motor's speed, the relay switches between the tap points. It finally connects it to the full recommended voltage. It provides a higher voltage for a particular starting current than other methods of reducing voltage. It contributes to the improvement of the starting torque as shown in the given below Figure 4.

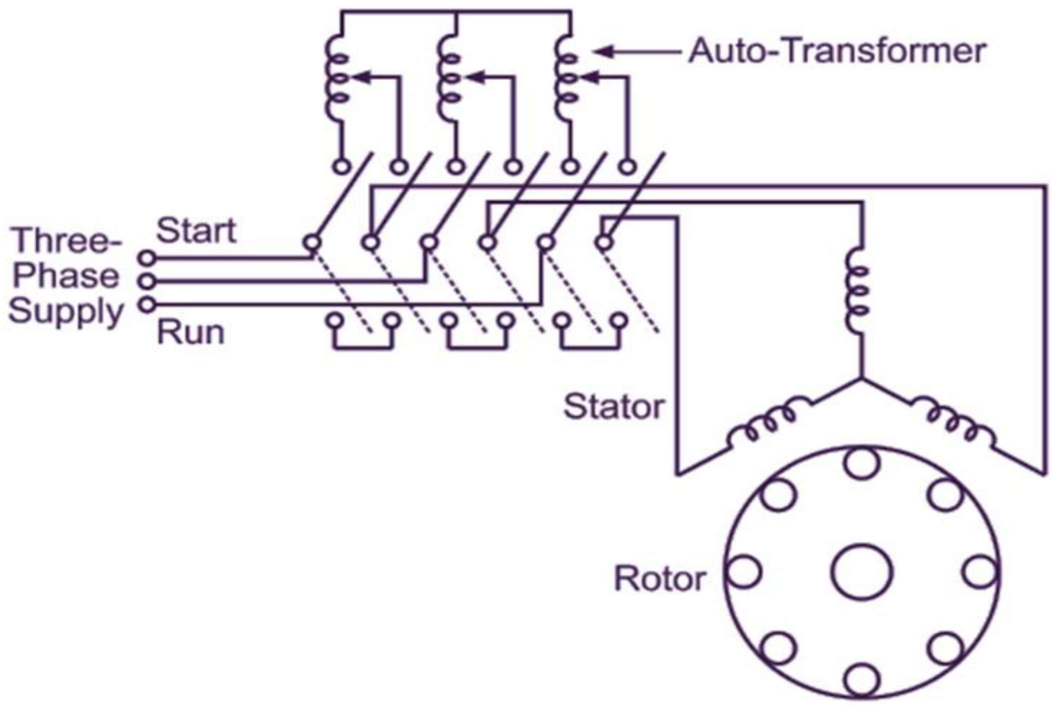

Figure 4: Autotransformer Starter.

TheAdvantages of autotransformer starter include:

1. It gives you more torque for starting.
2. It is used to start large motors that have a lot of load on them.
3. It also lets you control the speed manually.
4. Additionally, it provides starting characteristics flexibility.

TheDisadvantages of autotransformer starter include:

1. Such a starter takes up too much space due to the autotransformer's size.
2. Compared to other starters, the circuit is complicated and relatively expensive.

Star Delta Starter

In industries that deal with large motors, this is yet another common starting method. To start a three-phase induction motor, the windings are switched between a star and a delta connection. A triple pole, double throw relay is used in star to start the induction motor. In a star connection, the starting current and torque are both reduced by one-third of their normal rated values, and the phase voltage is decreased by a factor of one-third.A timer relay changes the stator windings' star connection to the delta connection as the motor accelerates, allowing full voltage to flow through each winding. The motor operates at its maximum speed as shown in Figure 5.

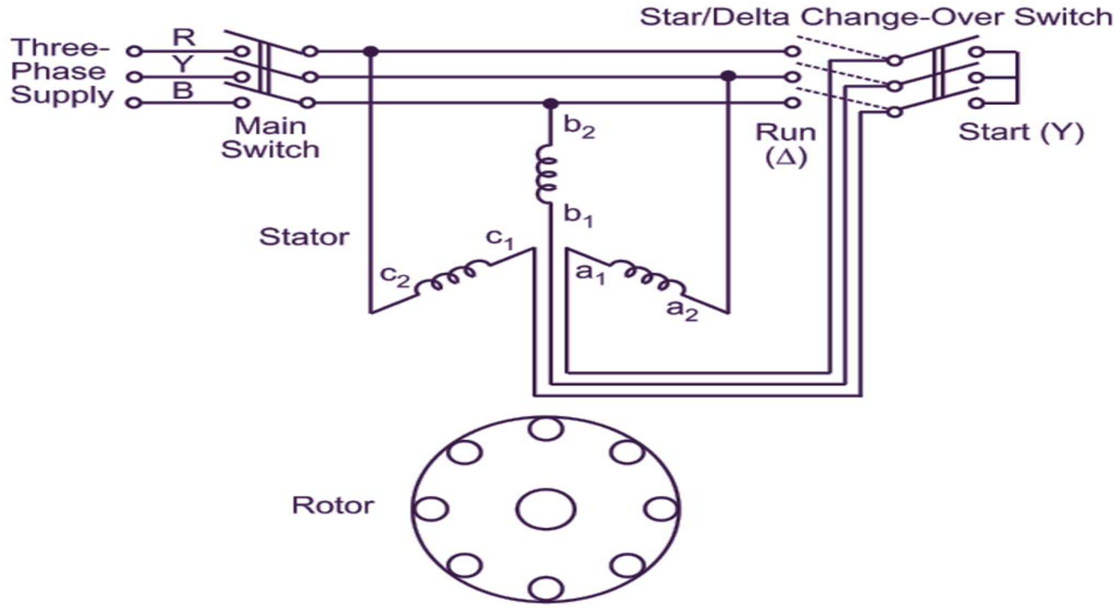

Figure 5: Star Delta Starter.

TheAdvantages of Star delta starter include:

1. It has a low surge current.
2. It is inexpensive, and also does not need to be maintained.
3. Large induction motors are started with it.
4. It works best for accelerating for a long time.

TheDisadvantages of Star delta starter include:

1. There are additional wire connections, so it works on delta-connected motors.
2. It has low starting torque that can't be kept up.
3. Starting characteristics offer only a very limited amount of adaptability.
4. When switching from star to delta, there is a mechanical jerk.

Soft Starter

The voltage reduction method is also used by the soft starter. The induction motor's voltage and starting current are controlled by means of semiconductor switches like TRIAC. Variable voltage is provided by using a phase-controlled TRIAC. The TRIAC's firing or conduction angles can be changed to change the voltage. To provide lower voltage, the conduction angle is kept as low as possible. Increasing the conduction angle gradually raises the voltage. The induction motor operates at its rated speed when the maximum conduction angle is reached. The full line voltage is applied to it.The torque, current, and starting voltage all rise gradually and smoothly as a result. As a result, there is no mechanical jerk and the machine runs smoothly, which extends its lifespan as shown in the given below Figure 6.

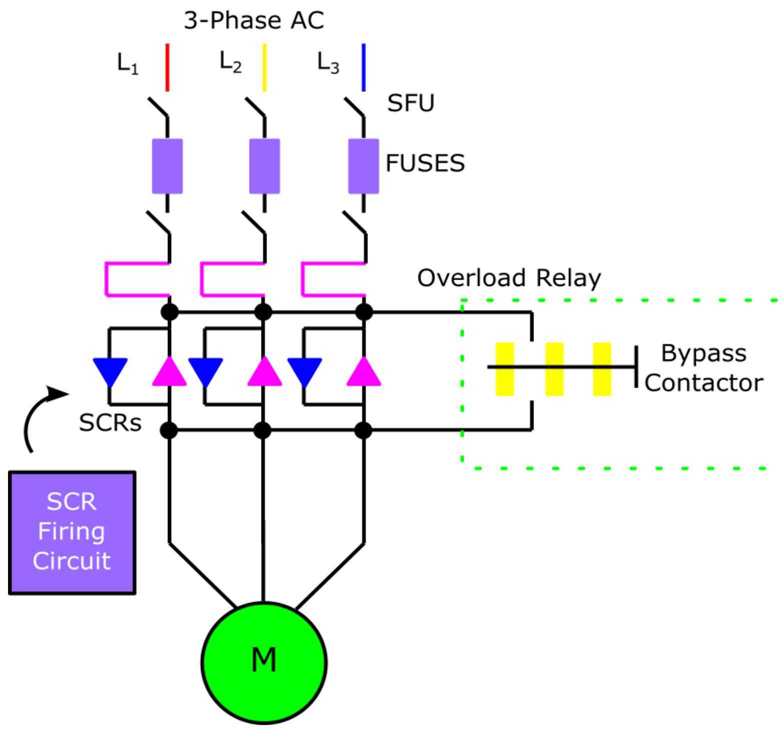

Figure 6: Soft Starter.

TheAdvantages of Soft starter include:

1. It provides smooth acceleration with no jerks and better control over the starting current and voltage.
2. The system's power surges are reduced as a result.
3. Increases the system's lifespan, improves efficiency, and eliminates the need for routine maintenance.
4. It is small in size.

TheDisadvantages of Soft starter include:

1. It is more expensive than another starter.
2. The energy degenerate in the form of heat.

DISCUSSION

The starting of DC motors is a crucial aspect in their operation, playing a pivotal role in their efficiency and performance. When a DC motor is initially powered on, the starting process sets the motor's rotor in motion, enabling it to generate the necessary torque to overcome inertia and initiate rotation. Various techniques are employed to initiate the starting process, including direct-on-line (DOL) starting, star-delta starting, and the use of starters such as rheostatic or electronic controllers. These techniques control the current and voltage supplied to the motor during the starting phase, preventing excessive current surges and ensuring a smooth acceleration. Proper motor starting not only extends the motor's lifespan but also minimizes stress on the electrical system. Understanding the starting mechanisms of DC motors is crucial for engineers and technicians involved in designing, operating, and maintaining these motors, as it allows for optimized motor performance and improved overall system reliability.

CONCLUSION

In this chapter we learn about the basic introduction about starters and how to start DC motors and why we need to start the motors. Later we focused on the types of starters and on what basis starters are classified. The performance and operation of DC motors depend greatly on how well they start. Exploring the benefits and disadvantages of the various beginning techniques, such as direct-on-line starting, decreased voltage starting, and electronic soft starters, was done. Direct-on-line starting is straightforward and reliable, although it may produce a lot of inrush current. Star-delta beginning or autotransformer starting are examples of reduced voltage starting systems that reduce inrush current but may also cause voltage dips and increase complexity. Electronic soft starters may be more expensive and sophisticated, but they give precise control and lessened mechanical stress when starting.

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AN OVERVIEW OF THE SYNCHRONOUS MOTORS

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ABSTRACT:

Due to its ability to operate efficiently and at a consistent speed, synchronous motors are electric devices that are often utilized in a variety of industrial applications. The working theory, design, and salient features of synchronous motors are covered. The chapter also examines the benefits and drawbacks of synchronous motors and offers some real-world examples. Additionally, synchronous motor types and control strategies are briefly covered. Overall, the purpose of this chapter is to provide a thorough overview of synchronous motors, highlighting their significance and promise in the area of electrical engineering.

KEYWORDS: *Motor, Magnetic Field, Rotor, Synchronous Motor.*

INTRODUCTION

The rotation of the shaft in a synchronous electric motor is synchronized with the frequency of the supply current in steady state; the rotation period is precisely equal to an integral number of AC cycles. Electromagnets, which serve as the motor's stator in synchronous motors, produce a magnetic field that spins in time with the oscillations of the current[1]. The second synchronized revolving magnet field is produced by the rotor's permanent magnets or electromagnets, which rotate at the same rate as the stator field. If both the rotor and the stator of a synchronous motor are powered by independently excited multiphase AC electromagnets, the motor is said to be doubly fed.

The two AC motor types that are most often utilized are synchronous and induction motors. Since the synchronous motor does not depend on current induction to create the magnetic field of the rotor, it spins at a speed that is locked to the line frequency. In contrast, the induction motor needs slip: in order to induce current in the rotor winding, the rotor must revolve a little bit more slowly than the AC alternations. Small synchronous motors are used in timing applications like synchronous clocks, appliance timers, tape recorders, and precision servomechanisms where the motor needs to run at a precise speed; the speed accuracy is that of the power line frequency, which is meticulously controlled in big interconnected grid systems [2].

Synchronous motors come in a range of sizes, from self-excited fractional horsepower to large industrial sizes. Most synchronous motors in the fractional horsepower range are used in applications requiring accurate constant speed. These devices are often employed in analog electric clocks, timers, and other gadgets that demand accurate time. The synchronous motor serves two crucial purposes at larger industrial scales with increased power. First off, it is a very effective way of turning AC energy into labor. Additionally, it offers power-factor adjustment by operating at leading or unity power factors[3].

Due to its distinct features and effective functioning, synchronous motors are a class of electric devices that are often utilized in a variety of industrial applications. They are essential for maintaining consistent speed and delivering precise control in a variety of sectors, including as transportation, manufacturing, and power production. Synchronous motors spin at a speed that is exactly synchronized with the frequency of the alternating current (AC) power source, as opposed to asynchronous motors, which run at rates that are slightly slower than the synchronous speed. The interaction of the magnetic fields of the revolving stator and rotor, which results in a constant speed of operation, allows for this synchronization[4].

Synchronous motors are advantageous in certain applications due to their many benefits. They are energy-efficient options for different industrial processes because of their great efficiency, which allows them to transfer electrical energy into mechanical energy with little loss. Additionally, synchronous motors may enhance the electrical system's power factor, which lowers energy consumption and optimizes power transmission.

Electrical engineers and other experts in fields requiring precise control, consistent speed, and great efficiency must have a solid understanding of synchronous motors. Engineers may choose wisely when it comes to the installation, upkeep, and optimization of synchronous motors by obtaining knowledge of their operating principles and uses.One benefit of synchronous motors is that they can operate at unity power factor because the magnetic field of the machine can be created by the direct current in the field winding, which reduces the amount of current required from the stator windings. The stator windings' heating and losses are reduced by this circumstance[5].

By adjusting the field current, the power factor of the stator's electrical input may be directly managed. The stator current changes to include a component to account for this over magnetization if the field current is raised over the level necessary to maintain the magnetic field. A total stator current that is in phase with the stator voltage will occur, giving the power system the reactive volt-amperes, it needs to magnetize other devices linked to it, such transformers and induction motors. To improve the overall power factor of the electrical loads in a manufacturing facility and prevent higher electric supply rates from being assessed for low power-factor loads, a big synchronous motor may be operated at such a leading power factor.

The main use of three-phase synchronous motors is in industrial settings where leading power factor performance is important and there is a significant, generally stable mechanical load—typically more than 300 kilowatts. Synchronous machines often cost more than induction machines below this power level. A shaft-mounted rectifier with a spinning transformer or generator or, in the case of bigger motors, an externally controlled rectifier via slip rings may provide the field current.

Self-starting would not be possible with a synchronous motor that merely had a field winding supplying direct current. Its rotor would suffer an oscillating torque of zero average value at any speed other than synchronous speed when the spinning magnetic field continually passed the more slowly moving rotor. To increase beginning torque to the rotor, a short-circuited winding like that of an induction motor is often added. In order to protect the field winding from high induced voltage, the field winding is often short-circuited before the motor is started, either with full or decreased stator voltage, and brought up to around 95% of synchronous speed. The rotor then pulls into synchronism with the rotating field once the field current is delivered.

Because of its added ability to dampen down any oscillation that can be brought on by rapid changes in the load on the rotor while in synchronism, this additional rotor winding is sometimes referred to as a damper winding. The angle by which the rotor field lags the stator field must be changed in order to adapt to variations in load, which necessitates temporary changes in instantaneous speed. These result in the induction of currents in the damper windings, creating a torque that works to counteract the speed shift. Similar to how huge induction motors are protected, so are synchronous motors. Both the stator and the field windings can detect temperature, which may be utilized to turn off the electricity. Due to the significant heating that occurs during beginning, timers are typically placed to prevent multiple starts within a short period of time[6].

Motors and generators are now widely used in the electrical systems we utilize for household, commercial, and industrial purposes. New kinds of these electrical devices are being developed in response to the desire for systems that use less energy and are more energy efficient. The Power factor is the fundamental calculation element for the dependability of motors and generators. It is determined by the applied power to necessary power ratio. Typically, the power factor is used to determine the overall amount of electricity utilized at factories and enterprises. Power factor should thus always be kept at 1. But when reactive power in these devices increases, power factor falls. Numerous techniques are used to keep the power factor at unity. One of them is the idea of synchronous motors.

Synchronous motor

Synchronous motors are defined as "AC Motors in which, at steady state, shaft rotation is in synchrony with the frequency of applied current." The synchronous motor functions like an AC motor, except in this case, the total number of shaft revolutions is equal to an integer multiple of the applied current's frequency.

The synchronous motor does not operate using induction current. Unlike induction motors, these motors use multiphase AC electromagnets on the stator, which creates a rotating magnetic field. The rotor in this case is made of a permanent magnet, which spins in synchrony with the frequency of the current given to it and the spinning magnetic field[7].

Design of Synchronous Motors

The synchronous motor's primary parts are the rotor and stator. Keybars and circumferential ribs are fastened to the wrapper plate on the stator frame in this instance. To support the machine, footings and frame mounts are used. DC field windings are excited using slip rings and brushes. For 6 pole applications, cylindrical and round rotors are used. When a greater number of poles are needed, salient pole rotors are employed. The synchronous motor and synchronous alternator have identical construction.

Synchronous Motor Operating Theory

The interplay between the magnetic fields of the rotor and the stator is what makes synchronous motors work. The stator is powered in three phases and has three phase windings. As a result, the stator winding generates a three-phase rotating magnetic field. The rotor is provided a DC supply.The stator and the rotor are the two main parts of an electric motor. Induction motor stators are built similarly to synchronous motor stators. A synchronous alternator's construction is similar to that of a synchronous motor. With the exception of wound-rotor synchronous double fed electric machines, the stator frame incorporates wrapper plate. Keybars and circumferential ribs are fastened to the wrapping plate. Frame mounts and footings are needed in order for the machine to support its own weight. Three phases make up the synchronous stator winding. It has a three-phase supply, and the rotor has a direct current supply.

Brushes and slip rings are necessary for DC stimulated motors to connect to the excitation supply. A brushless exciter may be used to activate the field winding. Up to six poles are utilized with cylindrical, round rotors, sometimes referred to as non-salient pole rotors.

A salient pole rotor is employed in various machines or when a lot of poles are required. In the majority of synchronous motor designs, the field winding rotates around a stationary armature. Compared to DC motor types where rotating armatures are employed, this architecture provides a benefit. The rotor synchronizes its rotation by entering the revolving magnetic field created by the stator winding. The frequency of the current that is provided now determines the motor's speed.

The frequency of the applied current regulates the speed of the synchronous motor. One may determine a synchronous motor's speed by using the formula

$Ns=60f/P=120f/p$

Where,

p = overall number of poles per phase and,

f = frequency of the AC current (Hz),

P = is the total number of pole pairs in a phase.

The motor desynchronizes if a load that is larger than the breakdown load is applied. The benefit of being able to control rotational direction is provided by the three phase stator winding. The direction of rotation cannot be determined in the case of a single-phase winding, and the motor may start in any way. Starting arrangements are required for these synchronous motors in order to regulate the direction of rotation.

Starting Methods of Synchronous Motor

The large-sized synchronous motors cannot self-start due to the rotor's moment of inertia. This inertia of the rotor prevents a rotor from synchronizing with the magnetic field of the stator as soon as power is introduced. Therefore, the rotor needs some extra assistance to synchronize.

The huge motors that provide the necessary torque for acceleration use induction winding. Pony motors are employed with extremely big motors to speed the machine while it is not loaded. Motors that are controlled electronically may accelerate even from zero speed by varying the stator current frequency. When the rotor's moment of inertia and the mechanical load are as tiny as desirable, extremely small motors may start without the need of any starting mechanisms.

Types of Synchronous Motor

There are two kinds of synchronous motors, depending on how the rotor is magnetized:

1. Non-excited.
2. Direct current Excited.

1. Non-excited Motor

The external stator field of these motors magnetizes the rotor. There is a permanent magnetic field within the rotor. The rotor is made of high-retentive steel, such as cobalt steel. These are categorized as hysteresis, reluctance, and permanent magnet motors.

1) Permanent Magnet Synchronous Motors

A permanent magnet and steel are both employed in the design of the rotor in permanent magnet synchronous motors. Since the rotor of these motors always has a magnetic field, induction winding cannot be utilized to start them. serving as motors for gearless elevators. A continuous magnetic field is produced by permanent magnets placed in the rotor of a permanent-magnet synchronous motor (PMSM). In order to create a spinning magnetic field (as in an asynchronous motor), the stator contains windings coupled to an AC current source.

The rotor poles lock to the revolving magnetic field at synchronous speed. PMSMs resemble brushless DC motors in many ways. Although neodymium magnets are the most popular, research into ferrite magnets was sparked by the price of neodymium magnets rapidly fluctuating. Due to ferrite magnets' intrinsic properties, these machines' magnetic circuits must be able to concentrate the magnetic flux, which often necessitates the usage of spoke type rotors. When compared to neodymium machines, ferrite magnet machines have a lesser power density and torque density. Since 2000, PMSMs have been used as gearless elevator motors.

A variable-frequency drive is often required to start a PMSM. Some, referred to as line-start or self-starting, however, integrate a squirrel cage in the rotor for beginning. Due to the absence of slip, they are often employed as more efficient alternatives to induction motors, although care must be taken to ensure that synchronous speed is attained and that the system can survive torque ripple during beginning.

Direct torque control and field-oriented control are often used to regulate PMSMs. However, these techniques have issues with stator flux ripples and rather high torque. These problems are best handled by predictive control and controllers based on neural networks.

Permanent Magnet Synchronous Motors is show below in Figure 1.

Figure 1: Permanent Magnet Synchronous Motors

2) Reluctance Motor

The rotor of a reluctance motor is composed of a steel casting with protruding tooted poles. Rotor poles are smaller than stator poles to reduce torque ripples. include squirrel cage winding, which gives the rotor beginning torque. used for instrumentation purposes.

Solid steel cast rotors with protruding toothed poles are the feature of resistance motors. In order to reduce torque ripple and prevent the poles from aligning simultaneously a position where torque cannot be produced—there are typically fewer rotor than stator poles. The magnetic circuit's reluctance is lowest when the poles are parallel to the stator's (spinning) magnetic field, and it is larger as the angle between them increases. This generates torque that forces the rotor to align with the stator field's closest pole. The rotor is "locked" to the revolving stator field at synchronous speed. The rotor poles often have squirrel-cage windings incorporated in them to give torque below synchronous speed since this cannot start the motor. Since the rotor "pulls in" and locks to the stator field as the machine achieves synchronous speed, it initially operates as an induction motor.

Ratings for reluctance motor designs vary from a few watts of fractional horsepower to roughly 22 kW. Small reluctance motors are often employed in instrumentation applications because of their low torque. Motors with several horsepower and a moderate torque are built with a squirrel cage and toothed rotors. All of the motors in a drive system are capable of running at the exact same speed when coupled with a changeable frequency power source. The frequency of the power source influences the motor's operating speed.

3) HysteresisMotors

Self-starting motors are hysteresis motors. The rotor in this instance is a smooth cylinder composed of cobalt steel, which is magnetically hard and high coercivity. These pricey motors

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are utilized in applications where accurate constant speed is necessary. often used as servomotors.

The cylindrical rotor of a hysteresis motor is solid, smooth, and made of high coercivity, magnetically "hard" cobalt steel. Due to its extensive hysteresis loop and high coercivity, this material cannot be magnetized in the opposite direction without a strong magnetic field. Each little volume of the rotor experiences a reversing magnetic field as a result of the revolving stator field. Hysteresis causes the phase of the magnetization to move more slowly than the applied field phase. As a result, the rotor's magnetic field axis trails the stator field axis by a constant angle, causing torque as the rotor attempts to "catch up" with the stator field. Each rotor particle receives a reverse magnetic field at the "slip" frequency that pushes it through its hysteresis loop, causing the rotor field to lag and producing torque as long as the rotor is moving slower than synchronous speed. A 2-pole low reluctance bar construction makes up the rotor. The rotor magnetizes and aligns with the stator field when it nears synchronous speed and slip decreases to zero, which causes the rotor to "lock" to the revolving stator field. The lag angle of the hysteresis motor generates continuous torque from starting to synchronous speed since it is speed independent. As a result, it can start on its own and does not need an induction winding, however many designs include a squirrel-cage conductive winding structure in the rotor to increase torque at startup. Hysteresis motors are generally produced as servomotors and timing motors, with sub-fractional horsepower ratings. Hysteresis motors, which are more costly than reluctance-type motors, are used in applications requiring accurate constant speed.

2. DC Current Excited Motor

Here, the DC current delivered directly via slip rings is used to activate the rotor. Additionally, rectifiers and AC induction are employed. These are often enormous, more than one horsepower, etc.DC currentExcited Motor is show in below Figure 2.

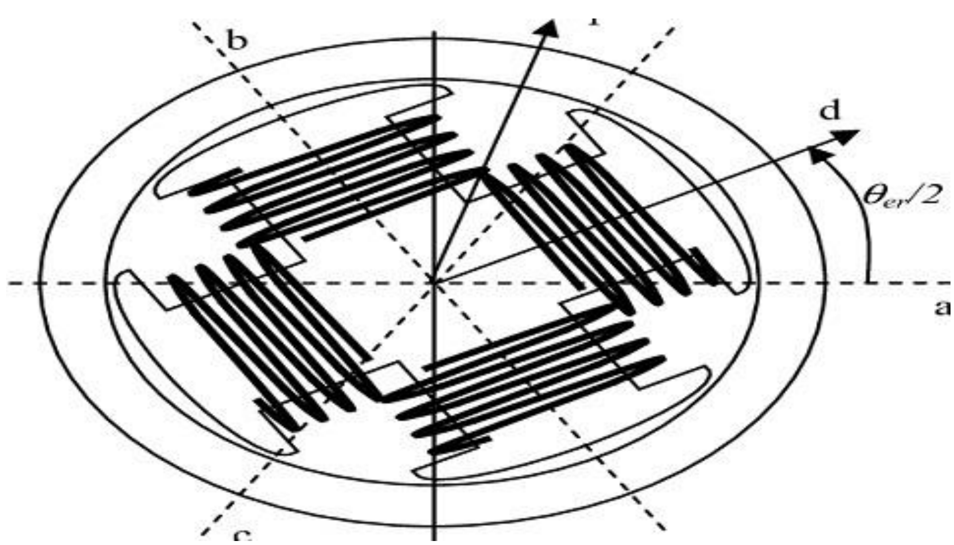

Figure 2: DC Current Excited Motor

Application of Synchronous motors:

Electric motors known as synchronous motors run at a constant speed that is coordinated with the frequency of the power supply. Due to their distinctive qualities and benefits, these motors are used in a variety of sectors. Here are a few typical uses for synchronous motors:

1. Alternators, usually referred to as synchronous generators, are used in power plants to transform mechanical energy into electrical energy. Turbines, such as steam or gas turbines, power these generators to create energy. For large-scale power production, synchronous generators are recommended because they can be synced with grid frequency and provide steady power output.
2. Synchronous motors are used in a variety of industrial machinery, including compressors, pumps, fans, and conveyors. These motors are appropriate for applications requiring precise speed control in high-power and high-torque systems. For example, synchronous motors are often employed in cement plants, paper mills, and mining activities.
3. Synchronous motors are used in robotics and automation systems because of their ability to precisely regulate speed. Robotic arms, CNC machines, and other motion control systems that need precise positioning and synchronization may all be driven by them. In these applications, synchronous motors offer dependable and constant performance.
4. HVAC Systems: Heating, ventilation, and air conditioning (HVAC) systems employ synchronous motors. They are used in machinery including cooling towers, pumps, and air handling systems. Synchronous motors are appropriate for HVAC applications because they provide effective operation, improved power factor correction, and accurate speed control.
5. Synchronous motors are used in the propulsion systems of electric vehicles (EVs). These motors provide good torque characteristics, a small size, and great efficiency. They can sustain speed under variable loads and generate quick torque, which improves the overall performance and energy economy of electric cars.
6. Synchronous generators are often used in wind turbines to transform the energy of the wind into electrical energy. The wind turbine blades and the synchronous generator's rotor are connected directly. Wind turbines' synchronous generators provide reliable power production, grid synchronization, and easier integration of renewable energy sources.
7. Synchronous motors are used in aerospace applications, primarily in aircraft systems, according to the aerospace industry. They may be found in a number of aircraft subsystems, including the actuation, hydraulic, and fuel pumps. Synchronous motors provide trustworthy and accurate control in aeronautical settings.

DISCUSSION

The synchronous motor is a type of electric motor that operates at a constant speed, perfectly synchronized with the frequency of the alternating current (AC) power source. It offers several advantages over other types of motors, making it a popular choice in various applications. One key advantage is its high efficiency, which results in reduced energy consumption and lower operating costs. Additionally, synchronous motors provide excellent power factor correction, leading to improved overall power system efficiency. These motors are also known for their precise control capabilities and stable operation, making them ideal for applications that require accurate speed and position control, such as robotics, industrial automation, and aerospace. Moreover, synchronous motors are often preferred in situations where high torque is needed at low speeds, making them suitable for heavy-duty industrial machinery. With their numerous benefits and versatility, synchronous motors continue to play a significant role in various industries, driving technological advancements and enhancing operational efficiency[8]–[10].

CONCLUSION

Synchronous motors are useful electrical devices that provide a variety of benefits in terms of speed regulation, efficiency, and power factor correction. They are often utilized in industrial settings where exact control and steady speed are essential. A thorough review of synchronous motors, including information on their manufacture, operating mechanism, and distinguishing features, has been presented in this study. High efficiency, an enhanced power factor, and higher performance in high-power applications are all benefits of synchronous motors. They do, however, have several disadvantages, such as a greater initial cost and the need for external stimulation. However, synchronous motors are used in many other industries, such as power generating, manufacturing, and electric vehicle propulsion. It has been briefly covered how to regulate synchronous motors, emphasizing how crucial exact control is for getting desired performance. Overall, synchronous motors are important in the field of electrical engineering, and future research and developments in this subject will help to increase their effectiveness and broaden their range of applications.

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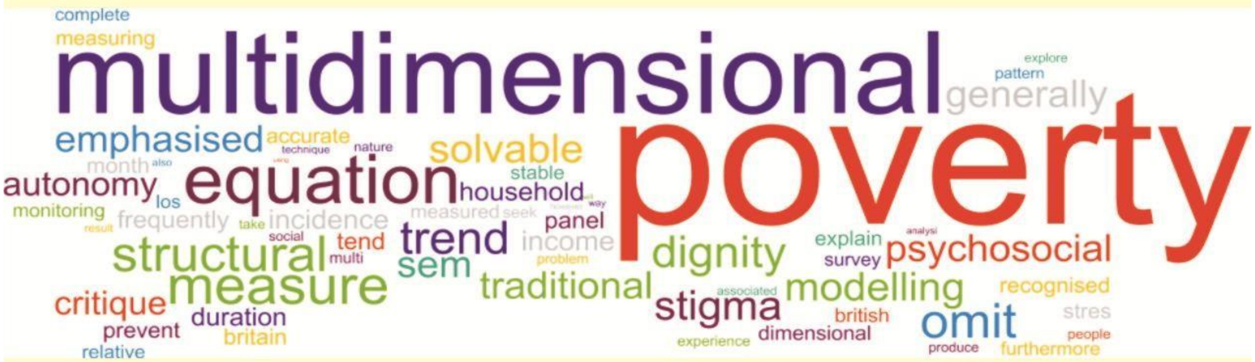

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