March 2023

ELECTRICAL DEVICES & SYSTEMS

Edited By

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CIIR Research Publications

Contents

Preface

People rely on electricity frequently, and knowing the fundamental parts of an electrical system may help you restore service when the power goes out due to a storm, a tripped breaker, or any issue with an electrical circuit. It's crucial to understand who is in charge of what aspect of your electricity service. The line part of your service, which includes everything up to the attachment point on your home, is handled by the utility provider. The area after that is referred to be the load side, and everything there is within your control. The flow of electrons is a source of energy that results in electricity. We can accomplish work by guiding these electrons via a circuit. The output of electricity may be mechanical work, heat, light, or magnetism.

Modern domestic equipment heavily relies on electricity. Turf equipment nearly primarily uses 12-volt electrical systems in modern times. The starting, lighting, and ignition systems are among the demands placed on the electrical system. Electrical circuits supervise certain machine activities and regulate machine functioning. Through a variety of safety circuits, they improve both the operation as a whole and the safety of the operator. Electrical gadgets provide novel approaches to controlling the machine's functionality and functioning. All of the components required to deliver electrical power, such as poles, overhead and subterranean wires, transformers, and other apparatus, make up an electric system.

Devices that functionally depend on electric energy (AC or DC) to power their essential components are known as electric(al) devices. (electric motors, transformers, lighting, rechargeable batteries, control electronics). When compared to conventional mechanical systems, which rely on various power sources like fuels or human physical strength, they may be seen as being superior. Electronic devices are a specific kind of electrical equipment in which the creation of mechanical forces is less common than the processing of data. Electric devices that emphasize physical effort are sometimes known as electromechanical devices in order to more clearly distinguish between the two kinds. The confluence of the two sciences is highlighted by mechatronics.

Electrical engineering is the study of electronic and electric equipment, as well as the design, upkeep, and power supply of such devices. The bulk of electric appliances in homes are fixed and rely on electrical infrastructure, particularly electric outlets, rather than tiny electric generators or batteries, whether rechargeable or not, because of their high power consumption. Electric gadgets and their power consumption patterns are now the focus of smart metering because of their reliance on electric power sources and generally well-evolved power infrastructures.

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CHAPTER 1

INTRODUCTION TO ELECTRIC VEHICLE

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Currently in its third century of development, electric vehicle technology is expected to grow quickly in the years to come. Modern high-speed trains are competitive with air travel in terms of trip speed over shorter land distances, and electric trains are frequently employed. Compared to air travel, they utilise less than 10% of the fuel per passenger kilometre. Although internal combustion engine cars have seen more economic success, electric cars are now being manufactured on a commercial scale because to advancements in battery technology. The usage of electric road cars is projected to increase in the next years due to future battery advances [1]–[3].

Airport staff carriers and golf buggies are two examples of small electric vehicles that have become commonplace. Electric bicycles are one of the quickest methods to navigate congested cities and are growing in popularity. The usage of electric cars has the potential to have significant positive effects on the environment, particularly when the electricity is produced from sources like nuclear power plants or highly efficient, contemporary producing stations. Benefits to the environment include no exhaust pollution near the cars, less reliance on fossil fuels, and lower total carbon emissions.

Electric cars are becoming more and more significant because, in addition to reducing noise and pollution, they may also be used to lessen the reliance of transportation on oil, provided that the power is produced from sources other than oil. Carbon emissions may be decreased by using electric automobiles. The energy for electric cars must be provided from non-fossil fuel sources, such as nuclear and alternative energy, in order to create zero carbon dioxide emissions.

The worst-case scenario is that, with our present consumption rates, there will only be enough oil for 40 years. In reality, however, as supplies become more scarce, prices will skyrocket and ultimately, the use of oil and other fossil fuels will become unprofitable, leading to an increase in oil conservation as demand declines. Coal and other fossil fuels may also be used to make oil. Since this method of producing oil has historically been thought to be around 10% more costly, production from coal is now beginning to break even.

Even if there is more coal than oil remaining and more than 100 years of coal available, it is still a limited resource. Concerns about global warming are continuing to grow. When fossil fuels are used, carbon dioxide is released into the atmosphere, which is blamed for global warming. This is thought to cause a variety of issues, such as climate change and rising sea levels, which have the potential to damage many coastal towns across the globe. In contrast to road transportation, which is just recently at the stage where vehicle manufacturers are beginning to mass-produce electric automobiles, electric trains are well established and extensively utilised. Electric road cars are not as common as tiny electric vehicles utilised in specialised sectors, such as electric bicycles, wheelchairs, and golf buggies. The huge success of internal combustion (IC) engine cars, which typically have significantly longer ranges and are relatively simple to refill, has not been experienced by electric road vehicles [4]–[6].

After Michael Faraday published his findings in 1821, electric motors were created. British scientist William Sturgeon created the first direct current electric motor with a commutator that could turn machines in 1832. The scientist Robert Davidson constructed the first electric locomotive known to exist in 1837, and it was powered by non-rechargeable batteries. Later, Davidson created a bigger locomotive that was shown in 1841 at the Royal Scottish Society of Arts Exhibition.

In 1895, a 4 mile (6.4 km) section of the Baltimore Belt Line in the USA became the first major line to be electrified. In St. Petersburg, Russia, in 1880, the first electric trams or trolley vehicles were deployed on an experimental basis. The Gross-Lichterfelde Tramway, built by Siemens & Halske AG, was the first regular electric tram service, and it entered operation in Lichterfelde, a Berlin suburb, in May 1881. The Blackpool Tramway, the country's first electric street tramway, debuted on September 29, 1885. Trams had been a common form of transportation at the start of World War One. In 1910, a tram may be seen in London.

The first trolleybus was operated on April 29, 1882, by Dr. Ernst Werner in a neighbourhood of Berlin. In 1901, the first passenger-carrying trolleybus in history ran in the German town of Bielathal, close to Dresden. In Britain, Leeds and Bradford saw the introduction of trolleybuses in 1911. Before batteries could be effectively employed in commercial free-ranging electric cars, it took a half-century following the introduction of the first electric vehicles.

Through the 20th century, electric trains improved steadily utilising both DC and AC systems. Because they need less upkeep for the engine and the track, electric trains are the favoured choice of railroad corporations. Trams and trolleybuses lost their economic viability and mostly went out of use as a result of the widespread adoption of IC motor vehicles and cheap, plentiful oil.

Electric trains, which could draw power from supply rails or overhead lines and did not depend on batteries, were more successful than electric road cars, which were never able to match them. Since the beginning of the 20th century, electric cars have been used for a variety of purposes, even though they generally did not perform well in comparison to other road vehicles at the time. Electric cars offer a few benefits over those with internal combustion engines, most notably the fact that they don't emit any exhaust into the air around them and that they are naturally silent. Because of this, electric vehicles are perfect for places like warehouses, inside buildings, and on golf courses where noise and pollution are unacceptable.

Mobility aids for the elderly and physically challenged are one typical use for battery/electric drives; in fact, in Europe and the USA this sort of vehicle is one of the most popular forms of electric car. It may be driven on sidewalks, through stores, and within a variety of structures. A range of 4 miles (6.4 km) is often more than enough, although larger ranges are feasible.

Electric cars are often linked to environmental advantages and energy savings. These advantages include a decrease in carbon emissions, a decrease in dependency on oil and other fossil fuels, and a reduction in localised pollution from the cars themselves. A detailed awareness of the consequences on the environment is required when thinking about the adoption of electric cars. Significant energy savings are possible when using electric cars to replace less energy-efficient forms of transportation. An excellent illustration is switching from flying to using an electric train, which consumes far less energy per passenger mile. Another example would be to promote the usage of electric trams instead of cars. Electric cars reduce energy use while replacing internal combustion engines, provided the electricity is generated by an effective grid system employing cutting-edge power plants. When a percentage of the power is produced by nuclear or other carbon-free energy sources, it will also further cut carbon emissions.

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CHAPTER 2

TYPES OF ELECTRIC VEHICLES

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An electric vehicle, often known as an electric drive vehicle, propels itself using one or more traction motors. An electric vehicle may be self-contained with a battery, solar panels, or a generator to convert fuel to energy, or it may be fueled via a collector system by electricity from sources outside the vehicle. Road, rail, surface, and underwater vehicles, electric aircraft, and electric spacecraft are all examples of EVs. EVs first appeared in the middle of the 19th century, when electricity was one of the most popular forms of motor vehicle power. They offered a degree of comfort and convenience of use that gasoline automobiles of the day were unable to match. Although the internal combustion engine has dominated motor vehicle propulsion for over a century, other vehicle types, such railways and smaller vehicles of all kinds, continue to be propelled mostly by electric power. Due to advancements in technology and a greater emphasis on renewable energy sources, EVs had a renaissance in the twenty-first century. A vehicle that relies on one or more electric or traction motors for propulsion is known as an electric drive vehicle (EV) or simply an electric vehicle. Different vehicles have varying levels of electrification. A scale from 0 (conventional car) to 1 (full electric vehicle) is used to categorise EVs [1]–[3].

The BEV-AEV

High capacity batteries and an electric motor are used in the All Electric Vehicle (AEV) or Battery Electric Vehicle (BEV) for propulsion. It lacks an internal combustion engine, a fuel cell, or a gasoline tank, and instead relies only on the electricity from its battery pack. The car must be plugged into a charging station in order to replenish its batteries. The Mercedes-Benz B-Class Electric and the Chevrolet Spark are examples of this.

The HEV/PHEV

The second kind is a hybrid electric vehicle (HEV), which physically combines an internal combustion engine (ICE) for usage outside of metropolitan areas with an electric motor (EM) operating at low speeds for in-city travel [4]–[6]. The EM ceases when ICE mode is engaged, and batteries begin to charge using an alternator powered by the same ICE that is fitted. The Plug-in Hybrid Electric Vehicle (PHEV), which is an improvement for the HEV, has a new battery charging mechanism that can be supplied externally.

When the batteries are exhausted and the driver cannot take a stop for recharge, the combustion engine kicks in as a backup. In lieu of the previous Panamera Hybrid, Porsche has introduced the new Panamera Plug-in S E-Hybrid, which offers improved vehicle performance and driving responsiveness.

REEV

Extended Range Electric Vehicles (EREV or REEV) are the primary third kind; with this design, just an electric motor powered by large-capacity batteries is used to propel the vehicle. A little engine-generator unit keeps these batteries charged. Its low fuel consumption less than two litres per 100 kilometers provides a greater autonomy and travel range.

FCEV

Fuel Cell Electric Vehicles (FCEV) have been created in addition to these three primary categories to accomplish great distances. Its onboard electric motor is powered by a fuel cell technology. FCEVs utilise hydrogen fuel stored onboard and oxygen in proton exchange membrane fuel cells, also known as polymer electrolyte membrane (PEM) fuel cells.

SEV

An electric vehicle that is mostly or entirely powered by solar energy is known as a solar electric vehicle (SEV). Solar energy is directly turned into electric energy by photovoltaic (PV) cells found in solar arrays put on top of vehicles. All or a portion of the SEV's propulsion, electronics, communication, navigation, security, and other auxiliary functions are powered by converted solar energy as this is the only available source [2]. Sensors aid the driver in a manner similar to that of traditional automobiles. The information received here enables tracking of the vehicle's energy use, solar energy collection, and other characteristics. A battery pack may be added to SEVs to help assure continued operation at night or during shaded days, extending the users' autonomy.

Practically, SEV may be dependable in certain applications when the vehicle is used seldom but is parked in the sun for most of the day, such as golf carts, single-track vehicles, or specialised target; International contests known as Solar Race Challenges are being held to further the study of solar-powered vehicles. The most impressive solar racing cars include the German Power Core Suncruiser, the Japanese Kaitu II, and the Australian eVe. Commercially, auxiliary power units for various EVs, particularly PHEV applications, are made using photovoltaic modules. Assuring optimum use and regeneration of the overall energy in the vehicle is a major problem for the energy management system (EMS) in an electric vehicle. The control strategy must choose how much power is distributed among various energies regardless of the number of sources, the powertrain arrangement, or the time or vehicle speed. It is necessary to decide how to distribute extra power between the RESSs and between the fuel converters when there are two storage systems or two fuel converters available. Two considerations impose restrictions on these choices.

In the near future, it will be crucial to combine various energy sources and powertrains in the best possible way, as well as to carry out an accurate and robust power management control algorithm, in order to build a dependable and affordable EV while protecting the environment and making wise use of our limited resources. In order to improve our comprehension of the basic performance issues with vehicle systems, several various strategies have been put forward. But each control approach has pros and cons when compared to the other control techniques. Our future research will be focused on boosting power management supervisory level, taking use of today's commendable accomplishments and attempting to optimise a multi power source management in BEVs and HEVs as a first step in developing PMC algorithms.

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CHAPTER 3

AC AND DC MOTORS

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Alternating current is needed for the AC motor to spin. Using electromagnetic induction, this motor transforms alternating electricity into mechanical power. The stator and rotor are the two components of an AC motor that are most crucial.

AC motor

When the motor's rotor rotates and the stator is still. Most AC motors are either single-phase or three-phase. The three-phase AC motor, which is mostly utilised in industry, provides large amounts of power. The single-phase AC motors used in low power applications. The single-phase AC motor is a compact device that performs a number of tasks. The majority of household equipment, including refrigerators, fans, washing machines, and mixers, utilise single-phase AC motors [1]–[3].

DC Motor

A DC motor is one that transforms DC electricity into mechanical power. It is powered by DC current. A DC motor's fundamental operating principle is that when a current-carrying conductor is put in a magnetic field, a force applied to it causes it to create torque.

Armature and Stator are the two major components of a DC motor. The armature is its spinning component, while the Stator is their stationary component.

Types of AC motor

There are three basic categories for AC motors: Synchronous Motor

Asynchronous or Induction Motor

Linear Motor

1. Synchronous Motor

The synchronous motor converts the alternating current into mechanical power at the specified frequency. This motor's speed is in rhythm with the AC frequency. These motors rely heavily on a three-phase supply. In this, the motor speed refers to the constant speed at which the motor produces an electromotive force [4]–[6].

The current flowing through the stator and rotor are too fast for an air gap to exist. Consequently, it offers greater rotational precision. These motors may be used in automation, robotics, and other fields because to their great rotational precision.

The synchronous motor is divided into two categories:

(i) Reluctance Motor

The reluctance motor is a kind of single-phase synchronous motor with a structure similar to an induction motor.

This motor has a rotor that resembles a squirrel cage and a stator that has sets of windings, including an auxiliary winding and a primary winding. The extra windings are particularly helpful in providing level functioning at a steady pace.

These motors are often employed in signal generators, recorders, etc., which calls for the right synchronisation.

(ii) Hysteresis Motor

The hysteresis motor has a constant air gap and no DC excitation mechanism. In order to carry out the necessary work, this motor's rotor generates eddy current and hysteresis. A motor's operation is dependent on its design and whether it receives a single-phase or three-phase power source.

Similar to other synchronous motors, these motors provide highly constant speed and very smooth operation. Because of this motor's low noise output, it is used in devices like sound players and audio recorders and other devices that call for soundproof motors.

2. Induction Motor

Asynchronous speed is the speed at which an induction motor or an asynchronous motor operates. It converts electrical energy into mechanical power using electromagnetic induction.

There are two kinds of induction motors based on rotor structure. They are phase wound and squirrel cage induction motors. The induction motor is divided into single-phase and three-phase induction motors according to the supply phases.

(i) Squirrel Cage Rotor

The motor's rotor resembles a squirrel cage. The inner part of this, which is attached to the output shaft and resembles a cage, this rotor lessens the rotor's magnetic locking and buzzing sound.

(ii) Phase Wound Rotor

This rotor is a variant of a three-phase induction motor that is intended to provide strong torque for loads with high inertia while using very little current. It is sometimes referred to as slip ring motors.

(iii) A single-phase induction motor

A single-phase induction motor is one that use electromagnetic induction to transform single-phase AC electric energy into mechanical power.

(iv) Three-phase Induction Motor

A three-phase induction motor is a device that transforms three-phase alternating current (AC) electric energy into mechanical power.

3. Linear Motor

A linear motor is an electric motor that has had its stator and rotor unrolled. Instead of the circular torque, it generates a linear force throughout its length (force). The majority of the time, linear motors are employed in actuators and on sliding doors.

Types of DC motor

The DC motor has several varieties, as shown in the chart, depending on how it is built and how it is connected to the electrical system.

1. Separately Excited DC Motor

The separate DC source is used in this motor to excite the DC windings. The motor's armature windings are powered by a separate DC source, which creates the flux.

2. Permanent Magnet DC Motor

A permanent magnet DC motor is a kind of motor that generates field flux using a permanent magnet (PMDC).

The PMDC motor has excellent speed management and offers higher beginning torque. However, because to their limited torque, they are usually used in low horsepower applications like air conditioners, wipers, and car starters.

3. Self-Excited DC Motor

Self-excited DC motors are those in which the field winding is either connected in series with the armature winding or parallel with it. In light of this, the self-excited DC motor is categorised as:

- Series-wound DC motor

The field winding and armature of the series-wound DC motor are connected in series.

- Shunt Wound DC motor

The field winding of the shunt wound DC motor is connected in parallel to the motor's armature. The shunt-wound motor provides excellent speed control. The field winding of this motor may be individually energised or coupled to the same source as the armature.

- Compound Wound DC motor

The field winding is connected to the compound wound rotor in both parallel and series. Depending on the kind of compounding, there are two different methods of excitation for a DC motor with a compound winding. Cumulative compound DC motor: In this motor, the main field flux generated by the series winding is assisted by the shunt field flux produced by the shunt winding.

Differential Compound DC Motor In this, we can state that the motor's primary series winding's impact is lessened by the shunt field flux.

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CHAPTER 4

MOTORS IN ELECTRIC VEHICLES

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Electric vehicles are not new to the globe, but with to technical advancements and growing attention to pollution management, they now have the reputation of being the form of transportation of the future. An electric motor serves as the primary component of an electric vehicle (EV), which takes the place of internal combustion engines. Different kinds of electric motors may now be employed in electric vehicles thanks to the quickly evolving fields of power electronics and control systems. High starting torque, high power density, excellent efficiency, etc., are desirable qualities in electric motors used in automotive applications [1]–[3].

The demand for electric vehicles is rapidly rising these days. Instead of internal combustion engines, EVs utilise batteries and electric motors. The electric vehicle (EV) motor must have certain characteristics, such as high starting torque, high power density, high efficiency, simple controllability, minimal maintenance, etc. Electric cars employ a variety of motor types, including brushless DC motors, permanent magnet synchronised motors (PMSM), induction motors, and DC motors.

Due to brushes and commutation, the DC series motor, which was formerly employed for traction applications, cannot be operated by electric vehicles (EVs). The induction motor has a low starting torque under fixed circumstances, necessitates a complicated inverter circuit, and is challenging to operate. The PMSM is utilised for high performance, much like the BLDC, but it is more expensive and requires complicated regulation. Compared to other motor types, BLDC motors are less expensive and yet provide the necessary characteristics. Every kind of motor's control network has to be upgraded due to the development of power electronics and drives.

A brushless DC electric motor, sometimes referred to as a synchronous DC motor or an electronically commutated motor (ECM or BL motor), is a synchronous motor that uses a direct current (DC) electric power source. Similar to a brushed DC motor, a BLDC motor operates on a similar concept. According to the Lorentz force law, a current-carrying conductor receives a force anytime it is exposed to a magnetic field [4]–[6]. The magnet will feel a force that is equal to and opposite to the response force. The permanent magnet rotor follows the magnetic fields created by switching DC currents to the motor windings, which essentially cause them to revolve in space. To regulate the motor's speed and torque, the controller modifies the phase and amplitude of the DC current pulses.

A replacement for the mechanical commutator (brushes) used in many traditional electric motors is this control system. The mechanical commutator connections in brushless DC motors are replaced with an electronic servo system. In order for the electromagnets to produce torque in one direction, an electronic sensor senses the angle of the rotor and controls semiconductor switches, such as transistors, to switch current through the windings, either reversing the direction of the current or, in some motors, turning it off, at the proper angle. Brushless motors have less friction and a longer lifespan since the sliding contact is no longer there; the lifespan of their bearings is the sole factor limiting how long they may operate.

Permanent magnets spin a fixed armature in a conventional brushless motor, which solves the issue of how to provide current to a moving armature. The commutator assembly of the brushed DC motor is replaced with an electronic controller, which continuously adjusts the phase to the windings to keep the motor moving. Instead of employing a commutator method, the controller conducts a comparable timed power distribution using a solid-state circuit.

The motor's creation ushered in the industrial revolution, which is what we are now living in. A variety of motor types have been produced throughout time, but they may typically be divided into two groups: AC motors and DC motors. There is a collection of DC motors available for usage with various gadgets. However, two different kinds of DC motors are often used in industrial applications. In the first kind, the requisite air gap flux is provided by a permanent magnet, but in the second type, the magnetic flux is produced by a current flowing through the field coil of a static pole structure. A BLDC motor is a particular kind of DC motor that does not utilise a brush for transportation but rather an electronic process system.

The synchronous BLDC motor typically consists of a permanent magnet and a trapezoidal back EMF waveform. The present trend demonstrates the widespread usage of high performance BLDC motor technology for variable speed drives in electric car motors and other worldwide industrial applications. These motors' control circuits are what they really rely on. Since these motors depend on their control circuit, it might be difficult for researchers to create a high-performance circuit.

The BLDC motor structure for tuning control project selection, simulation, and soon. A difficult job, the design structure of a BLDC motor relies on a number of variables, including project selection, modelling, simulation, etc. There have been several cutting-edge control ideas put out in relation to the BLDCmotor's speed architecture. The main characteristics of a traditional PI controller algorithm are its simple design, which makes it extensively utilised for regulating systems, and its simply modifiable, steady functioning.

The area of automated ship steering systems, developed from the early 1920s forward, saw the first theoretical study and practical implementation of PID. As a result, it was extensively employed in first pneumatic and subsequently electronic controllers for automated process control in the industrial sector. A proportional-integral-derivative controller, also known as a three-term controller or PID controller, is a feedback-based control loop mechanism that is often used in industrial control systems and a broad range of other applications that call for constantly modulated control.

A PID controller constantly calculates an error value e(t) as the difference between a desired setpoint (SP) and a measured process variable (PV), thus the name. The controller then makes a correction based on proportional, integral, and derivative terms (denoted P, I, and D, respectively). Simply put, the controller determines the P, I, and D actions and multiplies each parameter by the error, or E, which is equal to SP-PV in direct acting, as was previously described. After that, the Control Variable is created by summing all parameter computations.

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CHAPTER 5

OVERVIEW OF MOTOR TYPES

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In place of internal combustion engines (ICE), which have dominated transportation for more than a century, electric vehicles (EVs) are growing in popularity as a green alternative. Electric vehicles (EVs) run on a battery-powered motor. Different motor types are used in EVs. This page provides an overview of the widely used EV motor types from the inside out.

EVs have traction motors that can transmit torque to the wheels. DC motors and AC motors are the two main categories of electric motors.

EV applications may make advantage of either kind. DC motors are reliable and easy to regulate. Both brushed and brushless DC motor versions are possible. The technology behind brushed DC motors is well established and offers cheap cost, great torque at low speed, and simple speed control [1]. For traction motors, these characteristics are crucial. However, brushed DC motors are not often utilised in electric vehicles (EVs) owing to their drawbacks, which include their size, poor efficiency, and need for regular maintenance because of the brush and collector construction. DC motors without brushes are much more efficient. These motors do away with the brushes in favour of an electronic commutator/inverter. When compared to DC motors, AC motors have superior dependability, fewer maintenance, and regenerative capabilities, which allows braking energy to be transferred back to the batteries [2]–[4].

The battery weight of an EV is directly influenced by the motor and electronics efficiency since lost power must be made up for. The battery has to provide 1% extra power for every 1% decrease in efficiency (meaning more batteries). The electrical motor specs have a direct impact on the performance of the EV. The traction motor's torque-speed and power-speed characteristics govern how well the motor performs [5].

Important elements in these curves are grade ability and maximum speed. To enable effective starting and acceleration, the needed motor grade ability necessitates strong torque at low speed. High power at high speed and a broad speed range in the constant power area are required of the EV motor. For a smooth start and uphill driving, the constant torque working area is crucial at low speeds. On flat terrain, the maximum EV speed is determined by the constant power region. As soon as the base speed is reached, the motor achieves its rated power limit, and its torque starts to decline in direct proportion to the square of speed. In the range from base speed to maximum motor speed, the constant power area begins after base speed. When choosing the right EV motor type, this range, which varies across motor types, is a crucial consideration. Additionally, the appropriate control drives may be used to modify the motor's operating range.

It might be difficult to choose the right acceleration performance and broad speed range for an EV motor since they must be balanced in the constant power zone. The power needed for acceleration performance decreases with an increase in the constant power zone. The need for more torque increases, affecting the size of the motor and its eventual cost. We want an EV motor to have the following characteristics:

- high effectiveness
- powerful at the moment

- a quick torque response
- greater power density
- High acceleration at little cost
- Robustness

We'll now examine how these characteristics compare in the various motor types.

DC motor

Robust design and easy control are the two greatest benefits of DC motors in EVs. DC motors have suitable torque-speed characteristics that enable them to produce high torque at low speed. Their primary drawbacks are their size, poor performance, expensive maintenance requirements, low dependability, and slow speed due to friction between the brushes and collectors. Brushless DC motors and brushed DC motors are the two kinds of DC motors. Due to developments in power electronics, the latter are being repressed more and more.

PM BLDC motors, also known as permanent magnet brushless DC motors, employ permanent magnets rather than rotor windings. They are more efficient than inductive motors because they do not account for rotor losses. Due to the stator field's thinning of the permanent magnet field in PM BLDC motors, this area of operation at constant power is brief. Since EVs need a broader constant power zone, conduction angle control may be used to increase this so that the speed range can reach three to four times the base speed. The permanent magnets also prevent a high motor torque. High temperature has a severe impact on magnets, reducing remaining flux density and consequently motor torque capability. The two greatest drawbacks of this kind of motor are mechanical forces and magnet costs. Because the magnets may break as a result of the greater centrifugal forces brought on by faster motor rotation, there may be safety concerns.

Induction Motor (IM)

This motor type is widely used in EVs because to its simple design, excellent dependability, robustness, ease of maintenance, cheap cost, and functioning in a variety of environmental situations. A key safety benefit for EVs is the ability of IMs to spontaneously de-excite in the event of an inverter breakdown. Industrial standardisation governs the field-oriented vector control of IMs. IMs' drawbacks include a somewhat lower efficiency (as compared to PM motors), greater power losses (due to increased cage losses), and a comparatively low power factor. The speed range may be increased in the constant power operating zone by taking advantage of the weakening of the flux. Additionally, the use of twin inverters might expand this area. By carefully designing the motor, rotor losses may also be decreased.

Permanent Magnet Synchronous Motor PMSMs, like BLDCs, feature permanent magnets in the rotor. PMSMs feature a sinusoidal back electromotive force (EMF), which is in contrast to the trapezoidal back EMF waveform of BLDC motors. Because of their straightforward design, excellent efficiency, and high power density, they are suited for use as traction motors (common in hybrid vehicles, EVs, and buses). Compared to IMs, PMSM motors are more efficient. The disadvantages of this kind include expensive prices, eddy current loss in PMs operating at high speeds, and a reliability risk due to the potential for magnet breakage.

Surface-mounted and internal permanent magnet synchronous motor drives are the two different types of PMSM motors. IPM motors outperform SPM motors in terms of performance, but their complicated construction is a drawback.

Reluctance motor with switch (SRM)

SRMs have the advantage of having a high torque component, making them useful in a variety of applications, including wind energy, gas turbine engine generator starting systems, and high-performance aerospace applications. Additionally, they are durable, easy to regulate, highly efficient, have a large constant power operating zone, are fault tolerant, and have good torque-speed characteristics, which are all benefits in EVs. Since SRMs don't have brushes, collectors, or magnets, maintaining them is extremely easy and efficient, and their cost is quite low.

Because there are no magnets, the issue with mechanical forces is resolved, allowing the motor to run at a high speed. There are no copper losses in the rotor since the motor's windings are not employed, keeping the rotor temperature lower than with other motor types. The phases are not coupled, so SRM motors may keep running even if one of them disconnects. Rotor inertia is lower in SRMs than in other motor types. Increased vibration and acoustic noise are this motor type's disadvantages. Furthermore, the structure of the salient-pole rotor and stator results in significant torque ripple. Sensor-less control is possible due to the high rotor inductance ratio. High speeds are possible because to proper motor design's large constant power operating zone. SRMs feature a torque/power speed characteristic that is suited for EV applications.

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CHAPTER 6

CONCEPT OF BLDC MOTOR

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DC motors are known as BLDC motors. It does not supply current using brushes, as the name would imply. The coils are attached to the stator rather than the rotor in this motor. As a result of the rotor's permanent magnet nature, brushes and commutators are not required since it runs without current. The outside influences the amount of current going to the fixed coils. A BLDC motor rotates due to the permanent magnet, which is accomplished by switching the magnetic fields produced by the surrounding stationary coils. Changing the amount and direction of current flowing into these coils will change the spin [1], [2].

The expense of maintenance is decreased since there are no brushes and hence fewer brushes need to be replaced as often. The speed and location of a Brushless DC motor may be controlled to a very high degree. An advantage of brushless DC motors over brushed DC motors is their longer lifetime [3], [4]. The lack of brushes reduces sparking, and the possibility of burnout from sparking problems is minimal. Robotics and medical applications are ideally suited for brushless DC motors since they have a high torque to speed ratio. The Brushless DC motor has a minimised heating problem since it does not have an electromagnet.

Controlling

One must manage the timing and flow of current into the coils of a BLDC motor in order to spin it. Having just to connect the positive and negative leads to the power supply, brushed motor control is straightforward. But for a BLDC motor to operate, a certain input power is needed depending on where the rotor is located. One must manage the timing and flow of current into the coils in order to spin the BLDC motor.

The motor's three coils will be denoted by the letters U, V, and W. By repeatedly switching the flux, the revolving magnetic field produced by the coils is kept in motion by the permanent magnet always following it. For the resulting flux to continue moving and create a spinning field that pulls on the rotor magnet continuously, the energising of U, V, and W must thus be turned on and off continuously.

Hall Sensors

In order to control BLDC motors, the coil flux's directionality is continuously changed. The rotor is made to rotate because the permanent magnets on the rotor are constantly chasing the revolving magnetic field. The position of the rotor (magnet) must be synchronised with the control of BLDC motors, which often include sensors to determine this position. If current is applied without first knowing the rotor's location, the rotor can start rotating the incorrect way. This issue may be avoided by using sensors [5].

Three hall sensors monitor the rotor's position every sixty degrees, and they regulate the current input to the motor to spin it in accordance with that information. The sensor's main job is to translate the actual location and state of the motor shaft into an equivalent electrical signal that the controller circuit can use. The decoder block uses information from the hall sensors to produce the sign of the reference current signal vector for the back electromotive force (BEMF).

A universal three-phase power converter that is made up of up to six power switches coupled in a bridge configuration is implemented by the Universal Bridge block. A BLDC motor needs an AC-like voltage waveform to run properly, hence an inverter circuit is employed to convert the DC power supply voltage into an equivalent AC supply voltage.

To provide three-phase voltage concurrently for a full-bridge design power converter, a three-phase BLDC motor utilises six electronic switches. There is a rotor position for each switch, and this position will be used to set the switching order. Selectable options in the dialogue box include the power switch type and converter settings.

DC motor performance may be improved by using a controller circuit, which is very necessary. A number of controller circuits and algorithms are used for this. The PID controller, however, is the one for the BLDC motor that is most appropriate of the bunch. Three circuit blocks, known as the proportional, integral, and derivative blocks, make up the majority of the PID controller. As their names indicate, each circuit block is utilised to carry out various mathematical calculations.

Automatic controller gain adjustment is possible with PID controller tuning using a Simulink model of the control system. Among the tools for model-based tuning is PID Tuner, which enables interactive PID gain tweaking while monitoring pertinent system responses to confirm performance. A linearization of your plant model is how PID Tuner operates by default. When dealing with models that are not linearizable, PID gains may be adjusted in relation to a plant model that is derived from simulated or actual response data.

Powergui

The Powergui block launches a graphical user interface (GUI) that shows all state variables as well as the steady-state readings of the observed current and voltages (inductor currents and capacitor voltages). In order to start the simulation from any beginning circumstances, you may change the initial states using the Powergui block. It enables initialization of three phase networks with machines and load flow calculation.

If you include Impedance Measurement blocks in your model, the Powergui block will additionally provide impedance vs frequency charts. If you have the Control System Toolbox, the Powergui block may create a state-space model (SS) of your system and launch the LTI Viewer for time- and frequency-domain responses.

It is a field-effect transistor (FET with an insulated gate) known as a metal-oxide-semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET) in which the voltage controls the conductivity of the component. To switch or amplify signals, it is used. Electronic signals may be amplified or switched using materials whose conductivity changes in response to the amount of applied voltage. The use of MOSFETs in digital and analogue circuits has recently surpassed that of BJs (bipolar junction transistors). Due to its almost infinite input impedance, MOSFETs are very helpful in amplifiers since it enables the amplifying device to almost completely amplify the incoming signal. The key benefit is that, in comparison to bipolar transistors, it takes practically minimal input current to regulate the load current.

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CHAPTER 7

ADVANTAGES AND DISADVANTAGES OF BRUSHLESS DC MOTOR

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An electrical motor is a device that transforms electrical energy into mechanical energy via the rotation of a shaft called the rotor. Most electric motors work by having current flow through a conductor when it is put in a magnetic field. Due to the left-hand rule in videography, a force will be applied to the conductor as a consequence of this, and the direction of the force may be determined.

DC motors come in a variety of forms, but the brushless DC motor and the brushed DC motor are the two most used. Between the permanent magnets known as the stator in a brushed DC motor is a conducting material called the rotor. The rotor spins in the direction of the left-hand rule when force is applied to it by the passage of current via the armature winding. The rotor rotates 180 degrees as a result of this. With the aid of commutators and brushes, the direction of current is reversed, allowing the rotor to be rotated a full 360 degrees. The motor continues to rotate and the current direction also continues to reverse after each half revolution, producing a full 360-degree rotation [1]–[3].

On the other hand, with a brushless DC motor, the stator is an electromagnet and the rotor is a permanent magnet. Contrary to brushed DC motors, carbon brushes do not change the current's direction to allow for 360-degree rotation; instead, the current is regulated by an electronic controller. This not only offers a solution for the problem of ongoing Maintenance caused by the need to replace carbon brushes owing to deterioration, but it also offers high-resolution speed control and precision [4]–[6].

Benefits of a Brushless DC motor

Compared to conventional brushed DC motors, brushless DC motors offer several benefits. Below, a few of the benefits are explained in more detail:

Due to the absence of carbon brushes, brushless DC motors need less frequent brush replacement, which lowers maintenance expenses.

Because electronic control allows for fine-grained control over the speed and position of the motor, brushless DC motors perform and operate more efficiently than brushed DC motors. The lifetime of brushed DC motors is around six times lower than that of brushless DC motors.

Brushes may produce a lot of sparks, which might cause a brushed DC motor to burn out completely or have a limited lifespan. There are minimal risks of burnout due to sparking problems with brushless DC motors since there is no spark problem. Due to their tiny, compact diameters and excellent torque-to-weight ratio, brushless DC motors are well suited for a variety of robotics and medical applications including robotic arms and legs.

When compared to other motors with the same ratings, brushless DC motors operate quite quietly. Similar to other motors, brushes in this one are in constant contact, which causes noise and sparking while they are in touch. Therefore, when it is necessary to prevent electrical noise, brushless DC motors are used.

The current electronic commutation system replaces the conventional mechanically based commutation system, providing more control and reducing the likelihood of failure owing to the wear and tear previously mentioned. Brushless DC motors are suited for operation at low or no load because they have low no-load current compared to other types of motors.

In contrast to brushed DC motors, which can only provide maximum torque at a single moment in the rotation, brushless DC motors can deliver maximum torque constantly throughout rotation. The brushed motor needs a significantly larger magnet than the brushless DC motor does for the same torque rating. As a consequence, a brushless DC motor with a very high torque rating is extremely tiny and compact. For precise torque and speed control, brushless DC motors may be equipped with feedback controls. This results in improved efficiency, lower power consumption, and longer battery life when the motor is utilising multiple batteries. The presence of an electromagnet in the motor's core causes brushed DC motors to heat up and take longer to cool down. However, the brushless DC motor has no magnetic in the core, which eliminates the heating problem.

Brushless DC motor disadvantages

Brushless DC motors have a few drawbacks compared to traditional motors, just as in all other devices. Although brushless DC motors often perform better than brushed DC motors, they also have a few drawbacks, which are detailed below.

As opposed to conventional motors, which employ a low-cost mechanical commutation setup requiring brushes, brushless DC motors are relatively more expensive. The cost of the electronic controller further raises the setup cost. During low-speed spinning, a brushless DC motor experiences very tiny vibration. However, at high speeds, vibrations are reduced.

Because brushless DC motors naturally vibrate at a frequency that is higher than that of the human body or of plastic components, resonance phenomena can develop from this natural frequency matching or approaching that of the body or the plastic parts. However, resonance may be reduced by modification, and resonance is a typical phenomenon in many brushless DC motor-based systems.

The positive terminal is connected to the positive wire, the negative terminal is linked to the negative wire, and the motor begins to revolve. Brushed DC motors are simple to use and have simple wiring. Due to the use of electronic control and its connection to all of the electromagnets in brushless DC motors, however, the wiring and operation of the motor are not as straightforward.

In comparison to brushed DC motors, brushless DC motors are more expensive. There are very tiny vibrations when the Brushless DC motor is running at low speeds. Due to the use of electronic control and its connection to all electromagnets, brushless DC motor operation and wiring are more complex.

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CHAPTER 8

INTRODUCTION TO ELECTRICAL MOTORS

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We are aware that the basic purpose of a motor is to convert energy from one form to another, such as electrical to mechanical. Depending on the source of power, such as AC or DC, different types of motors may be categorised. Under these AC & DC motors, several types of motors are available, including induction motors, reluctance motors, DC shunt, PMDC, stepper, synchronous, etc. Overviews of several induction motor types and how they operate are included in this page. As a result of operating at a lower speed than synchronous speed, this motor—also known as the most widely used AC motor—is also known as an asynchronous motor. The rotational magnetic field's speed within the stator is what is being referred to as synchronous speed in this context [1]–[3].

The magnetic field of the stator winding acts as the source of electromagnetic induction in an induction motor, also known as an asynchronous motor, to provide the electric current required for the rotor to generate torque. An induction motor may be produced without any electrical connections to the rotor. For induction motors, rotors of the wound type and the squirrel-cage type are both acceptable.

Three-phase squirrel-cage induction motors are often used as industrial drives because they are affordable, reliable, and self-starting. Single-phase induction motors are used to power several tiny loads, such as household items like fans. Induction motors have typically been used in fixed-speed applications, but when coupled with variable-frequency drives, they are increasingly used in variable-speed applications (VFD). VFDs provide especially large energy savings opportunities for present and future induction motors in applications requiring centrifugal fans, pumps, and compressors with variable torque. Squirrel-cage induction motors are widely used in applications for fixed-speed and variable-frequency drive [4], [5].

François Arago, a French physicist, initially presented the idea of rotating magnetic fields in 1824. This idea is sometimes referred to as Arago's rotations. By manually turning switches on and off, Walter Baily demonstrated what the first rudimentary induction motor was really in 1879. The first single-phase AC induction motor without a commutator was created by Hungarian engineer Ottó Bláthy, who also invented the electricity metre.

The first AC commutator-free polyphase induction motor was created independently by Galileo Ferraris and Nikola Tesla, both of whom did it in 1885 and 1887, respectively. Tesla applied for US patents in October and November 1887, and some of his ideas were subsequently recognised in May 1888. The Turin Royal Academy of Science released Ferraris' report on his AC polyphase motor in April 1888, outlining the fundamentals of motor working. Tesla's technical paper A New System for Alternating Current Motors and Transformers was sent to the American Institute of Electrical Engineers (AIEE) in May 1888. He discussed three different kinds of four-stator, four-pole motors in it: one with a four-pole rotor that creates a non-self-starting reluctance motor, another with a wound rotor that creates a self-starting induction motor, and the third with a genuine synchronous motor.

While working on the creation of an alternating current power system in 1888, George Westinghouse leased Tesla's patents in addition to purchasing a US patent option on Ferraris' induction motor concept. Tesla also spent a year working as a consultant. A Westinghouse employee named C. F. Scott was sent to help Tesla before eventually taking over Westinghouse's induction motor research. While adamantly supporting three-phase progress, Mikhail Dolivo-Dobrovolsky developed the three-limb transformer and cage-rotor induction motor in 1889 and 1890, respectively. He said that Tesla's motor couldn't be employed in practical applications due to the two-phase pulsations, which prompted him to continue developing three-phase systems. Even though Westinghouse produced its first practical induction motor in 1892 and a number of polyphase 60 hertz induction motors in 1893, up to B. G. Lamme's invention of the rotating bar winding rotor, these early Westinghouse motors had wound two-phase rotors.

Induction motors with three phases were created for the first time by the General Electric Company in 1891. (GE). General Electric and Westinghouse signed a cross-licensing deal for the bar-winding-rotor design, which was later referred to as the squirrel-cage rotor, in 1896. The importance of complex numbers was first fully realised by Arthur E. Kennelly, who used j to stand for the square root of -1 in the analysis of AC problems. Charles Proteus Steinmetz of GE made significant improvements to an analytical model that is now known as the induction motor Steinmetz equivalent circuit for the utilisation of AC complex variables.

100-horsepower induction motors now have the same mounting dimensions that 7.5-horsepower motors did in 1897 as a result of these findings and advancements.

Induction motors, often known as asynchronous motors, are typical AC electric motors. An induction motor uses its stator winding's rotating magnetic field to electromagnetically induce the electric current necessary to produce torque into the rotor. The rotor of an induction motor may be coiled or enclosed in a squirrel cage, depending on the application.

The name itself indicates that the induction process is at work here. When power is applied to the stator winding, a magnetic flux is produced in the stator as a result of current flowing through the coil. Because of how the rotor's winding is arranged, each coil shorts out. The flux from the stator cuts off the short-circuited coil in the rotor. The rotor coils will start to conduct current as soon as they are short-circuited, according to Faraday's electromagnetic induction law. Another flux is produced within the rotor as a result of current flowing through the rotor coils. The two fluxes at this time are rotor flux and stator flux. The rotor flux will trail the stator flux in magnitude. The rotor will experience a torque as a consequence, and it will start to spin in the direction of the rotating magnetic field. This is the principle on which both single-phase and three-phase induction motors function.

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CHAPTER 9

DIFFERENT TYPES OF INDUCTION MOTORS

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Induction motors come in primarily two varieties. Based on the power source that induction motors are supplied, this categorization is made. The two most common varieties of induction motors are single-phase and three-phase models. A single-phase induction motor and a three-phase induction motor, as their names suggest, are linked to a single phase of an AC power supply and a three phase of an AC power supply, respectively [1]–[3]. These two primary classes each have various subdivisions. Induction motors may be divided into four different categories for single-phase models and two for three-phase models [3], [4].

Different Single-Phase Induction Motor Types

The four varieties of single-phase induction motors are split phase, capacitor start, capacitor start capacitor run, and shaded pole based on the way they are built and how they are started. We will go into further detail about each of these categories of single-phase induction motors in the sections that follow.

Split Phase Induction Motors

One more winding, known as the auxiliary winding or beginning winding, exists in addition to the stator's primary winding of a single-phase induction motor. Series connections are made between the centrifugal switch and the auxiliary winding. When the motor speed gets up to 75 to 80 percent of the synchronous speed, this switch is supposed to shut the auxiliary winding off from the main circuit. The running winding, you may understand, is inductive, however we need to establish a phase distinction between the two windings. If the beginning winding has a large resistance, this is feasible. Split-phase induction motors have an angle at which the beginning and main currents are separated. As a split-phase induction motor, this device so received its name [5], [6]. The initial current and torque of this kind of motor are both quite modest. As a result, these motors may be found in a variety of devices, including air conditioning fans, centrifugal pumps, washing machines, grinders, and lathes.

Capacitor Start and Capacitor Start Capacitor Run Induction Motors

These two kinds of induction motors are essentially identical in terms of manufacturing and operation. As a result of the non-rotating nature of the magnetic field created, single-phase induction motors are not self-starting. Phase difference is required for a rotating magnetic field in induction motors.

Split-phase induction motors use resistance to create the phase difference, while capacitor start and capacitor start capacitor run induction motors use capacitors to do the same. It is a known fact that the voltage follows the current through the capacitor. The main winding and the beginning winding are two of the windings used in induction motors that use capacitors for both their start and run.

The capacitor will have a contact when the beginning winding is present, which will cause the applied voltage to be somewhat behind the capacitor's current flow. Due to their high starting torque, these two types of induction motors are used in a variety of devices, including air conditioners, compressors, conveyors, grinders, and more.

Shaded Pole Induction Motors

The salient or projecting poles are visible if you look at the stator of the single-phase shaded pole induction motor. The copper ring's inductive field shades these prominent poles. Two uneven parts of these poles separate them. Known as the shaded region of the pole, the smaller section conducts the copper ring. Because shaded pole motors have low starting torques and are reasonably priced, they are often used in tiny appliances like hair dryers, toys, record players, small fans, electric clocks, and more.

Different Types of Three-Phase Induction Motors

The rotor winding of three-phase motors is used to categorise them into two groups. Squirrel cage and slip ring are the two subcategories.

Squirrel Cage Induction Motor

This kind of induction motor is known as a squirrel cage induction motor because of the way its rotor looks similar to the form of a squirrel's cage. Such rotors have a fairly simple construction. The rotor features a laminated cylindrical core and several slots on the outside of the core. There are differences between the slots, and they are angled in various directions.

The magnetic locking between the rotor and stator teeth may be avoided by having skewed slots. Smooth functioning and a decrease in humming noise are produced by these slots and their skewed form. Rather of having rotor windings, the squirrel cage motors use bar-based rotors. Aluminium, brass, or copper are the materials used to make these bars. There are no slide rings or brushes in this kind of rotor. So, this sort of motor's structure is more streamlined and durable.

Motors with a wound rotor or a slip ring

Wound rotor motors, or slip-ring induction motors, are also used. The cylindrical, laminated core of the rotor is its main component. There are a few slots on the outside border, similar to squirrel cage motors. Slots are used to hold the rotor winding. In slip-ring induction motors, the rotor winding is wound such that it has an identical number of poles as the stator winding's poles.

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CHAPTER 10

SINGLE PHASE INDUCTION MOTOR

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For home and industrial applications, single-phase motors are more desirable than three-phase induction motors. Only one kind of supply is accessible due to utility reasons. The three-phase induction motor hence cannot be utilised in this kind of application. A single phase induction motor is comparable to a three phase squirrel cage induction motor, with the exception that the stator of the single phase motor has two single phase windings mounted on it (as opposed to the three phase motor's single winding), and the cage winding rotor is housed inside the stator and rotates freely thanks to bearings that are mounted on the motor shaft [1]–[3].

Use of single-phase motors as opposed to three-phase motors is often justified for two reasons.

1. Due to the relatively low power needs of individual load items, single phase a.c. is often delivered to rural regions, offices, and most homes for economic reasons.

2. The motor and its branch circuit's financial situation.

• Single phase electricity and a single phase motor are often the most cost-effective ways to provide fixed loads with power that don't need more than 0.5KW. Single phase motors are widely used in fans, refrigerators, vacuum cleaners, washing machines, other kitchen appliances, tools, blowers, centrifugal pumps, small agricultural appliances, and other devices because they are straightforward to build, dependable, affordable, and easy to repair. For the reasons listed above, several motors with relatively low ratings—often fractional KW ratings—are produced for single phase ac operation at conventional frequencies. The fact that the overall number of fractional kilowatt motors in use today significantly outnumbers the entire number of integral kilowatt motors of all kinds gives an idea of how many of these motors are in existence [4]–[6].

Single-phase induction motors

Applications and Drawbacks

Applications: Single phase induction motors are widely used in industry, notably in the fractional horsepower sector. They are often used for electrical drive in situations where a three-phase supply is not easily accessible for low power, constant speed equipment including machine tools, residential appliances, and agricultural gear.

- Toys, hair dryers, vending machines, and other products employ single phase induction motors with capacities ranging from 1/400 kW to 1/25 KW.
- Vacuum cleaners, portable tools, and kitchen appliances all often employ universal motors.

Because of their many drawbacks and inability to be employed in situations where three-phase machines may be used, these machines are rarely used for huge powers, even if they are suitable for tiny outputs. Single-phase induction motors' principal drawbacks include:

For a given frame size and temperature increase, their power is only half that of a three-phase motor.

- There is less power factor with them.
- less effective
- No starting torque is built into these motors.
- Greater in cost compared to three-phase motors of the same power.
- A little overflow capacity.

How to build a single phase induction motor

A very simple and durable design characterises single phase induction motors. In the slots drilled all the way around the inner perimeter, the stator is wound evenly. Low resistance exists in the stator conductors, and they are wound in what is Also situated on the stator is the starting winding. The stator slots contain a lot of inductance since this winding has a high resistance and is buried deep within. Every time, a squirrel cage style rotor is used.

In real life, auxiliary wires are inserted into the top layers of the stator slots to temporarily transform a single phase motor into a two phase motor. Linked in series with the auxiliary winding is a centrifugal switch. When the rotor accelerates to roughly 75% of its rated speed, the switch's purpose is to turn off the initial winding. When a motor uses a capacitor to start it, the beginning winding circuit also contains an electrolytic capacitor with the appropriate capacitance value. It is possible to flip the polarity of just the beginning winding thanks to a configuration that joins the primary stator winding and auxiliary (or starting) winding in parallel. For the rotor to rotate in a different direction, this is required.

Single-phase induction motor workings

It is simple to demonstrate that single phase induction motors are intrinsically non-self-starting. Take into account an induction motor operating in one phase with a stationary rotor. Let the stator winding be wired to a single phase a.c. source (it is assumed that there is no starting winding). Put two poles on the stator's winding. A constant current called alternating current runs through the stator winding when the power source for the stator is turned on. A fluctuating flux is created as a result. By bridging the air gap, this flux connects to the conductors of the rotor. EMFs are induced in the rotor conductors using electromagnetic induction. Induced currents flow through the rotor bars because the rotor creates a closed circuit.

A torque is created as a result of the interplay of the flux provided by the stator and the induced currents from the rotor. It is obvious that if all of the rotor conductors in the top half are under the same stator N pole, the stator S pole will be under the same stator conductors in the bottom half. As a result, the bottom half of the rotor is acted upon by an equal torque that tends to spin it in the opposite direction from that applied to the top half of the rotor. The net driving torque is zero because the two equal and opposing torques cancel each other out. Because of this, the rotor doesn't move. As a result, the starting torque of the single phase motor is insufficient. No matter how many stator poles there are or what direction the stator winding faces, this logic is valid. At rest, the rotor is subjected to zero net torque. However, if the rotor is moving in any direction when the supply to the stator is turned on, it can be shown that the rotor produces higher torque in that direction. The rotor would accelerate in that direction as a result of the net torque having a non-zero value and having an effect.

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CHAPTER 11

INSULATED GATE BIPOLAR TRANSISTOR

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The Insulated Gate Bipolar Transistor, commonly known as an IGBT for short, is a bipolar transistor that combines the advantages of a MOSFET with a normal bipolar junction transistor, making it the perfect semiconductor switching device. The IGBT transistor combines the best characteristics of these two popular types of transistors—the high input impedance and quick switching times of a MOSFET with the low saturation voltage of a bipolar transistor—to create a new kind of transistor switching device that can handle sizable collector-emitter currents with essentially no gate current drive [1]–[3].

Before the invention of the IGBT, power MOSFETs and power BJT were often used in power electronic applications. The IGBT is a relatively recent technology in the field of power electronics. The pros and drawbacks of each of these technologies were similar. While the Power BJT had poor switching performance, a low input impedance, secondary breakdown, and current regulation, it also had good conduction properties. Similarly, our voltage controlled PMOSFETs exhibited high input impedance, great switching properties, and at higher ratings, troublesome parasitic diodes and poor conduction characteristics. Low switching times are a result of PMOSFETs' unipolar structure, but as the voltage rating rises, so does the ON-state resistance [4]–[6].

IGBTs were launched somewhere in the early 1980s and quickly gained popularity among power electronic engineers due to their excellent qualities, filling the demand for a device that combined the best features of PMOSFETs and Power BJTs. IGBTs have output properties that are similar to Power BJTs and input characteristics that are similar to PMOSFETs, hence their symbols are a combination of the two parent devices' symbols. IGBT has three terminals: Gate, Collector, and Emitter. IGBT's emblem may be seen in the image below.

Power electronics applications needing high dynamic range control and low noise may benefit from the IGBT, particularly those using three-phase drives and pulse width modulated (PWM) servos. Additionally, it is applicable to Switched-Mode Power Supplies (SMPS), Uninterruptible Power Supplies (UPS), and other power circuits with high switch repetition rates. IGBTs have lower levels of audible noise and improved dynamic performance. In resonant-mode converter circuits, it works equally well. Low conduction loss and low switching loss optimised IGBTs are offered.

Positives and Negatives of IGBT

Advantages

- The benefits of both BJT and MOSFET are shared by IGBT as a whole.
- Higher voltage and current handling capacities are available.
- The input impedance is rather high.
- With relatively little voltage, it can switch currents that are quite high.
- It has zero input current and minimal input losses since it is voltage-controlled.
- The gate drive circuitry is easy to use and inexpensive.

- It is simple to switch between ON and OFF by supplying positive voltage and zero or slightly negative voltage, respectively.
- On-state resistance is very low.
- Because of its high current density, the chip size is reduced.
- Compared to MOSFET and BJT, it has a larger power gain.
- It switches more quickly than a BJT.

Disadvantages

- It switches more slowly than a MOSFET.
- It can't conduct in backward since it is unidirectional.
- It is incapable of blocking larger reverse voltage.

More expensive than BJT and MOSFET.

The PNPN structure, which resembles a thyristor, causes latching issues. IGBTs have two terminals: collector (C) and emitter (E), which are used to conduct current, and a gate (G), which is used to operate the IGBT. The biassing between the Gate-Emitter terminals and the Collector-Emitter terminals underlies how it operates.

In order to maintain a positive voltage difference between the collector and emitter, the collector-emitter is linked to Vcc. Reverse bias develops at junction j2, whereas forward bias develops at junction j1. There isn't any electricity at the gate right now. No current will pass between the collector and emitter due to reverse j2, keeping the IGBT off.

Applying a gate voltage VG that is greater than the emitter will cause negative ions to amass directly below the SiO2 layer owing to capacitance. As the VG rises beyond the threshold voltage in the upper P-region, more charges will finally coalesce into a layer. This layer creates an N-channel by shortening the N+ and N- regions.

From the N+ area into the N- drift zone, electrons from the emitter flow. While the P+ region in the N- drift zone is where the holes from the collector are injected. The drift region's conductivity increases and current begins to flow because there are too many electrons and holes there. IGBT turns on as a result.

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CHAPTER 12

TYPES OF SWITCHES

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The purpose of a switch is to stop the passage of current across a circuit. An electrical circuit may be completed or interrupted by a switch, to put it simply. To turn on and off a device, every electrical and electronic application requires at least one switch. So switches are a component of the control system; control action is not possible without them. By shutting its contacts, a switch may transition between being totally ON and entirely OFF (by opening its contacts). A switch closes off one channel for current to flow when its contacts are closed, causing the load to use up the power coming from the source [1]–[3].

Switches: Types

In essence, there are only two sorts of switches. They include:

- Electronic
- Mechanical

A physical act such as moving, pushing, releasing, or contacting the contacts of a mechanical switch is required to turn it on.

Instead of requiring physical touch to operate a circuit, electronic switches may be used. By semiconductor action, they are turned on.

Mechanical Switches

Mechanical switches can be categorised into different types based on a number of different characteristics, including the way they are activated (manual, limit, and process switches), the number of contacts (single contact and multi contact switches), the number of poles and throws (SPST, DPDT, SPDT, etc.), the way they operate and are built (push button, toggle, rotary, joystick, etc.), the state they are in (momentary and locked switches), and more [4]–[6].

Switches are divided into the following sorts according to the number of throws and poles. The pole's value is the maximum number of independently switchable power circuits. The majority of switches are single, double, or triple pole, depending on how many poles they contain in their construction.

The quantity of throws indicates the variety of states through which electricity may flow via the switch. The majority of switches are made with either one or two throws, and are referred to as single throw switches and double throw switches, respectively.

Single Pole Single Throw Switch (SPST)

One input contact and one output contact make up the fundamental ON and OFF switch in this device. It may turn the load on (ON) or off (OFF) by switching a single circuit. Both usually open and normally closed configurations are possible for SPST connections.

Double-Throw Single-Pole Switch (SPDT)

A single input contact and two output contacts make up the three terminals of this switch [7]. It has two ON positions and one OFF position, according to this. These switches serve as a changeover in the majority of circuits, connecting the input to one of two available outputs.

A typically open contact is one that connects when the switch is turned on, whereas a normally closed contact is one that is by default connected to the input.

Electronic Switches

As a result of the lack of actual moving elements and therefore of physical connections, electronic switches are often referred to as solid state switches. Like motor drives and HVAC equipment, the majority of appliances are controlled by semiconductor switches. In today's consumer, industrial, and automotive markets, a variety of solid state switch types in various sizes and ratings are available. To name a few of these solid state switches, there are transistors, SCRs, MOSFETs, TRIACs, and IGBTs.

Typical Features of Switching

Switching Perfectly Power switch operation should always be as near to the ideal scenario as feasible. According to device characteristics, a semiconductor device needs the following characteristics to function as an optimal switch:

- The device may carry an unlimited amount of current while it is in the conduction state (also known as forward or reverse current).
- There is no cap on the device-voltage (sometimes referred to as forward or reverse blocking voltage) while the device is in the nonconduction condition (off-state).
- No on-state voltage drop while in the conduction state.
- The gadget may operate at any pace while changing modes; there is no rising or fall time constraint.
- There is no energy lost.
- Its functioning is controlled with minimum power.
- It is really trustworthy.
- Both the size and weight of it are little.

It is affordable and requires minimal upkeep. One may attain an infinite working frequency with no switching delays since there is no power loss during either the switching or the conduction phases, yielding a 100% efficiency. In essence, the perfect switch is one that is 100% efficient, has limitless speed, and can handle any amount of electricity. It should be mentioned that finding semiconductor-switching devices that can virtually, in all actuality, function as perfect switches for a variety of applications is not unexpected.

Practical Switch

These switching and conduction properties apply to the real switch:

- Restricted power handling abilities, i.e. restricted conduction current while the switch is in the on-state and restricted blocking voltage when the switch is in the off-state.
- Due to the finite turn-on and turn-off durations, there is a limited switching speed. This restricts the gadget's top operating frequency.
- There are finite forward voltage drop and reverse current flow (leakage) while the device is in the on-state, respectively, and there are finite on-state and off-state resistances.

- The practical switch endures power losses during switching transitions, conduction loss, and in the on and off states as a result of features 2 and 3 above (known as switching loss).

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CHAPTER 13

DIGITAL SIGNAL PROCESSING (DSP)

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In our everyday lives, signals play a significant role. Signals are any sort of information carrying media. An information-containing single-valued function of one or more independent variables is referred to as a signal. As a physical quantity that changes with time, place, or any other independent variable, a signal is also described in this way. A signal may be seen in either the time domain or the frequency domain. One well-known indication is human voice. Signals may also include electric current and voltage. A signal may rely on one or more independent factors. A signal may depend on time, temperature, place, pressure, distance, and other factors. One-dimensional signals are those that rely on only one independent variable, whereas two-dimensional signals are those that depend on two independent variables. A system is defined as an object that processes an input signal to produce an output signal. Another way to think of a system is as a collection of components or building blocks that are linked together and generate an output in response to an input signal. The relationship between two or more signals is one of cause and effect [1]–[3].

The precise relationship between the input x (n) and the output y (n) is determined by the system's real physical structure, which also defines the output for each input. Systems may be multi-input and multi-output or single-input and single-output systems. Signal processing is a technique for removing information from signals, and it is dependent on the signal's type and the sort of information it conveys. As a result, signal processing is concerned with expressing signals in mathematical terms and extracting information from the signal by using algorithmic procedures. Analog signal processing cannot compete with the numerous benefits of digital signal processing. Here are a few of these: The exact values of digital signals are not necessary for the functioning of digital circuitry. Changes in component values are less noticeable in digital circuits. Additionally, they are less subject to temperature changes, ageing, and other outside factors [3]–[5].

Digital signal processors (DSP) take digital versions of real-world signals such as speech, audio, video, temperature, pressure, or location and mathematically alter them. Mathematical operations like "add," "subtract," "multiply," and "division" may be completed fast with a DSP. The information that a signal contains must be processed before it can be displayed, examined, or changed into another signal type that could be useful. Analog goods in the real-world sense and modify signals like sound, light, temperature, and pressure. The real-world signal is then converted using converters, such an analog-to-digital converter, into the digital representation of 1s and 0s. Following this, the DSP assumes control by gathering and processing the digital data. The digital information is then sent back into the actual world for use. It does this in one of two ways: either digitally, or analogly, using a digital-to-analog converter. This is all happening really quickly.

Computers may utilise the data from a DSP to operate many devices, including home entertainment systems, security, telephones, and video compression. Signals may be compressed to enable faster and more effective transmission from one location to another (e.g. teleconferencing can transmit speech and video via telephone lines). Additionally, signals may be improved or modified to increase their quality or give information that humans cannot perceive (e.g. echo cancellation for cell phones or computer-enhanced medical images). Real-world signals may be handled in their analogue form, but digital signal processing offers the benefits of high speed and precision.

The term "digital signal processing" (DSP) refers to a broad range of signal processing procedures that are carried out using digital processing, such as that provided by computers or more specialised digital signal processors. The digital signals that are processed in this way are a series of numbers that stand in for samples of continuous variables in domains like time, place, or frequency. A pulse train, which is commonly produced by the switching of a transistor, is how a digital signal is represented in digital electronics.

Subfields of signal processing include digital signal processing and analogue signal processing. Sonar, radar, and other sensor array processing, spectral density estimation, statistical signal processing, digital image processing, data compression, video coding, audio coding, image compression, signal processing for telecommunications, control systems, biomedical engineering, and seismology, among other applications, are just a few examples of DSP applications.

Linear or nonlinear operations may be used in DSP. The time, frequency, and spatio-temporal domains may all be used to execute nonlinear signal processing, which is strongly connected to nonlinear system identification. The use of digital computing in signal processing offers various benefits over analogue processing in a variety of applications, including data compression and error detection and correction in transmission. Additionally essential to digital technology, including wireless communications and digital telephony, is digital signal processing. DSP may be used with both streaming and static (stored) data.

Although there are numerous benefits to signal processing in the digital realm, there are some disadvantages as well. Analog-to-digital and digital-to-analog converters, as well as the corresponding reconstruction filters, are necessary for "pre" and "post" processing in digital processing. The digital system becomes more sophisticated as a result. Additionally, digital methods are constrained by frequency.

While analogue processing methods may be implemented using passive devices that do not use power, digital systems are built utilising active devices that do. Active components are also less dependable than passive ones. The benefits of digital processing methods, however, often exceed the drawbacks in many situations. Hardware for DSPs is also becoming cheaper all the time. As a result, the applications for digital signal processing are expanding quickly.

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CHAPTER 14

INDUCTION MOTOR AND ITS COMPONENTS

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Because of its simplicity in manufacture, durability, and affordability, induction motors are the electrical motors that are used the most often. Due to its flexibility in configuration for a wide range of power ratings, induction motors are used in more than 90% of industries, usually as electrical drives. Although they are adaptable and durable, they are prone to frequent catastrophic failures. Since these errors might result in considerable production and financial losses, early detection and correction are essential. The prevention of fault growth and failure of other, more important components is achieved by identifying healthy components beforehand and isolating them. due to the massive need for motors in industry. Automated maintenance has thus been tried on several occasions. Electromechanical relays were utilised in the past to conditionally monitor electrical machines. These relays, however, work slowly and result in considerable power losses due to the mechanical components used [1]–[3]. The Stator and Rotor make up the bulk of an induction motor.

Stator

Several stampings that have spaces for three-phase windings make up the stator. A certain number of poles are twisted into it. The geometric division of the windings is separated by 120 degrees. Induction motors employ squirrel cage and wound rotors, two different types of rotors. The machine may be operated with no DC field current. Instead of being physically linked by wires, the rotor windings generate the rotor voltage.

Rotor

The component of the electromagnetic circuit that rotates is known as the rotor. Squirrel cage rotors are the most prevalent kind of rotor. The rotor consists of a laminated cylindrical core with parallel slots for the conductors that are axially positioned. Copper, aluminium, or alloy bars are stored in each slot. Many times, an anchor is also suggested for the rotor of three-phase induction motors. The anchor-shaped rotors that were utilised in some very early electrical devices are the inspiration for this name. Although the rotor performs this function in three-phase induction motors, in electrical equipment the anchor's winding is induced by the magnetic field.

With a different rotor development, an induction motor has a physical stator that is identical to a synchronous machine's. Both a motor and a generator may operate on an induction motor. They are mostly used as induction motors, on the other hand. The electromagnetic induction obtained by the motor's rotor due to the rotational magnetic field of the stator winding is the basis for the induction motor's operating principle, which states that torque must be generated.

Types of Induction Motors

Three-phase induction motors and single-phase induction motors are the two categories into which induction motors fall. A single-phase induction motor is linked to an AC power source, as suggested by its name, but a three-phase induction motor may be connected to an AC power source with three phases. Again, there are many classifications that these induction motor types fall under. In comparison to three-phase, single-phase is divided into four categories [4]–[6].

Single-phase Induction Motor

It is not possible to start a single-phase induction motor by oneself. The primary winding transmits an alternating current when the motor is coupled to a single-phase power source. It makes sense to use the type engine with the lowest cost and least maintenance requirements the most often. Due to the fact that they do not start on their own, they may be divided into several sorts. These motors include capacitor, dual phase, and shaded pole types. Capacitor motors come in three different varieties: permanent, capacitor start, and capacitor run. As shown here, the permanent capacitor motor.

A series capacitor and/or a centrifugal switch may be included in these motors' start windings. Because of the main winding's impedance, when the supply voltage is applied, the main winding's current trails behind the supply voltage. Additionally, depending on the impedance of the starting mechanism, current in the start winding either precedes or follows supply voltage. In order to create a rotating magnitude field and a beginning torque, the angle between the two windings must be large enough. Upon reaching 70% to 80% of synchronous speed, a centrifugal switch on the motor shaft opens and disconnects the beginning winding.

Single-phase Induction Motor Types

Split Phase, Capacitor Start, Capacitor Start & Capacitor Run, and Shaded Pole Induction Motor are the four categories under which single-phase induction motors fall.

Split Phase Induction Motor

Alternatively referred to as a Resistance Start Motor, a split-phase induction motor comprises two phases. The stator of this kind of motor has two windings, the beginning winding and the main winding, and the rotor has a single cage. They are rotated by 90 degrees in relation to one another. Low inductive reactance and high resistance are present in the initial winding, but very little resistance and high inductive reactance are present in the main winding.

This kind of motor is more affordable and suited for loads that start easily when the beginning frequency may be limited. Because it has a lower beginning torque, this motor is not suitable for drives that need more than 1 KW. The most common machines that use split-phase inductor motors are washing machines, floor polishers, AC fans, mixer grinders, blowers, centrifugal pumps, and drilling and lathe equipment.

Capacitor Start Induction Motor

An induction motor with a capacitor start is a single-phase device that features a stator and rotor with a single cage. Two windings, the primary winding and an auxiliary winding, are primarily present in the stator of this motor. The term "beginning winding" may also be used to refer to an auxiliary winding. These two windings may be set up in a motor's design at 90-degree angles to one another.

Capacitor Start & Capacitor Run Induction Motor

The working theory of capacitor start and run induction motors is same. Due to the fact that the magnetic field produced by a 1-phase induction motor is not rotational in nature, we are aware that it is not self-starting. Induction motors need phase difference in order to produce a rotating magnetic field. While a resistance is required in a split-phase induction motor to provide a phase difference, with these motors, a phase difference is produced by the capacitor. Undoubtedly, the voltage is influenced by the current that is passing through the capacitor. The main & beginning windings are two of the windings in capacitor start and capacitor start capacitor run type motors. There is a link in the capacitor's beginning winding, which causes the current it supplies to flow through it at an angle as it directs the applied voltage. They are mostly utilised in grinders, conveyors, compressors, air conditioners, etc. since these two motors have a strong starting torque.

Shaded Pole Induction Motor

Using the copper ring, also known as the shaded ring, one of the poles of this self-starting, one-phase induction motor may be shaded. This ring serves the same purpose as a secondary winding in the motor. Such a motor can only rotate in a single direction, and it is not capable of moving backward. This motor has very large power losses, a poor power factor, and very low beginning torque that may occur. Due to its compact design and low power ratings, this motor performs poorly. Because it is inexpensive & quick to start, the shaded pole induction motor is used in tiny appliances like fans & relays. This motor is utilised in photocopying equipment as well as hair dryers, exhaust fans, table fans, air conditioners, cooling fans, and refrigeration units. Aside from starting synchronous timing motors, these motors are also utilised to start electronic clocks.

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CHAPTER 15

ENCODER AND DECODER

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In digital electronics, encoder and decoder are combinations of logic circuits. One significant distinction between these two terminologies is that the encoder outputs binary information, whilst the decoder receives it. Let's examine how encoder and decoder vary from one another. A data signal may be transformed into a message that can be read by a control device using an encoder. Or, to put it another way, encoders are combinational circuits that transform binary input into N output lines. A decoder is a combinational circuit that transforms binary data into 2N output lines [1]–[3].

A digital circuit known as an encoder carries out the opposite function of a decoder. The output lines of an encoder generate binary code that corresponds to the input value and have n input lines and 2n output lines. An encoder is a tool, algorithm, or piece of software that transforms information from one code (format) to another. Security, speed, uniformity, and space conservation are the key goals of the encoder. They may produce a multibit output code and receive one or more inputs [4]–[6].

Encoders and decoders are crucial components in digital electrical projects. It is used to transform data from one form to another. In communication systems like telephony and networking, where data is sent from one end to the other, they are often utilised frequently. In a similar manner, it is used in the digital world to facilitate the placement of data with codes and subsequent transfer of that data. The coded data are gathered from the code at the receiver's end and processed for display. What an encoder is, how it works, and what it's used for are all covered in this article.

A circuit, a transducer, or a device is an encoder. The encoder will change the format of the data, for example, electrical signals to counters or a PLC. Position, count, speed, and direction are all determined by the encoder's feedback signal. The commands are sent to certain functions via the control devices. A circuit known as a decoder is used to convert a code into a series of signals. Because it has the opposite of encoding, the name itself informs the decoder. Designing the decoders is extremely straightforward.

How the Encoder Works

Mechanical, magnetic, resistive, and optical methods are among those used most often to generate the signal in encoders. The encoders will provide feedback utilising optical sensing that uses light interruption. The disc code, which has opaque lines, will not block the LED's light from passing through it. The opaque lines on the code disc block the LED's light beam if the encoder shaft begins to rotate. This will produce pulse signals, and if a light source is available, the light will be ON; otherwise, it will be OFF. In order to build the necessary function, the signals are first transmitted to the counters or controller.

Table of Encoder Truth

Logic gates like an OR-gate are used in the design of the decoders and encoders. There are several kinds of encoders and decoders, such as 4, 8, and 16, and the truth table of the encoders relies on the specific encoder the user selects.

A decoder is a piece of technology that transforms digital signals into analogue signals. It only permits one input line and generates several output lines. The decoders are used in several communication initiatives that include two-device communication. The decoder accepts N-inputs and produces N-outputs of 2 power. For instance, if we provide two inputs, a 4 by 2 decoder will result in four outputs.

A combinational circuit in a decoder transforms binary data from n input lines to a maximum of 2n output lines. The decoder may have less than 2n outputs if the information that is n-bit coded contains unused combinations. Each set of inputs asserts a different output. Other code converters, such the BCD-to-seven segment decoder, also go by the moniker decoder. One output line is active at a certain tie. A parallel binary number is used as the input to a decoder, which is used to determine if a certain binary number is present there. The output shows if a certain number is present or absent at the decoder input.

Table of Truth for Decoder

Logic gates like AND gates are used in the construction of the encoders and decoders. There are several decoder kinds, such as 4, 8, and 16, and the truth table of the decoder relies on the specific decoder the user selects. The truth table of a 4-bit decoder will be discussed in the paragraphs that follow.

For converting codes, it is used. In the analogue decoder, for example, analogue to digital conversion also serves as a means of data delivery. Decoders are utilised as address decoders in CPU memory location identification and may be used to reduce the impact of system decoding for high performance memory systems. Decoders are mostly used in logical circuits, data transport, and the creation of half adders and full adders, two types of basic digital logic.

Different I/O devices may be chosen for the microprocessor.

- To activate the LED segments and show the decimal number, binary data is decoded.
- Different banks of memory may be chosen for a microprocessor memory system.
- Because the decoder output will be triggered sequentially when the decoder inputs originate from a counter that is being continuously pulsed, the decoder may be utilised as sequencing or timing signals to turn the device on or off at certain times.
- It is utilised anytime a set of outputs, or an entire group of outputs, has to be triggered only when a certain set of input signals occurs.
- It is possible to use the switching function often with less integrated circuits.

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PUBLISHER
M/S CIIR RESEARCH PUBLICATIONS
B-17, SECTOR-6, NOIDA,
UTTAR PRADESH, INDIA.
201301
EMAIL: INFO@CIIR.IN

March 2023
ISBN 978-81-962236-8-7