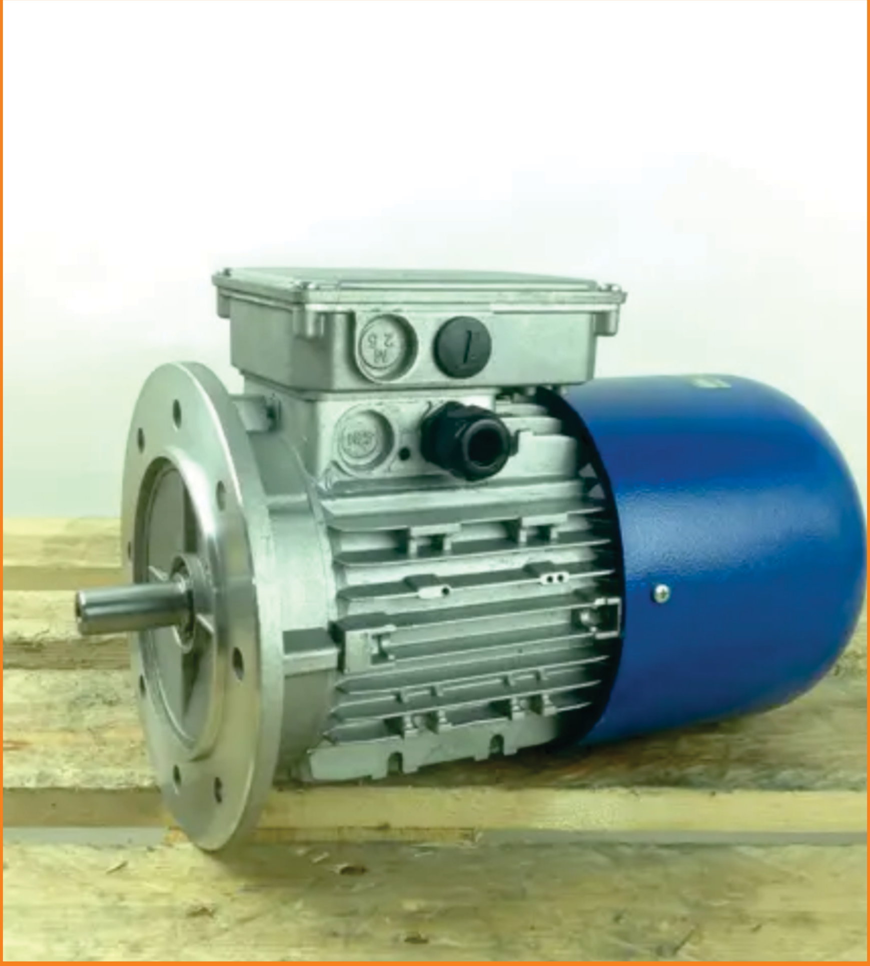
ELECTRIC MOTOR DRIVE



Dr. V Joshi Manohar
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CONTENTS

CHAPTER 1

AUTOMOTIVE INDUSTRY AND ELECTRIFICATION

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The automotive industry is going through a fundamental change that could alter the market and the competitiveness.The battery electric vehicle (BEV) has the potential to overtake internal combustion engine vehicles as the dominant design, marking the first significant shift since such vehicles gained that status in the late 1920s.The transition from ICEVs to BEVs has already seen new competitors for established automakers arise, spurred on by changes in public policy, innovation, and consumer demand. In this white paper, it is argued that the ICEV era has come to an end. However, not all pure-play BEV enterprises will be successful. Some established companies like General Motors, which is emphasized in this report—have now made a commitment to an all-electric future, investing not only to survive the industry's transformation but also to take advantage of it as a chance to become stronger[1], [2].

Previous waves of BEV adoption have stagnated for a variety of reasons, including supply and demand-related variables, business strategies, consumer concerns, and regulatory pendulum swings, the last of which has resulted in inertia and the survival of the fossil-fuel regime. But it is possible to make this into a positive cycle that accelerates the spread of BEVs. Many believe that the switch to BEVs will result in a repetition of the changes that have already taken place in other industries, notably the digital ones. As a pioneering disruptive force that currently thrives as a pure-play BEV start-up, Tesla has earned a position that other new, comparable companies are fast emulating[3], [4].

The established automakers, whose reliance on ICEVs outweighs their meagre number of (perhaps token) BEV models, and whose agility is in doubt, are expected to lose market share to these new entrants, according to many. These massive bureaucratic vestiges from a previous century would quickly decline as a matter of course. This anticipated trend is supported by Tesla's astounding valuation, which is more than the sum of most other established automakers.This viewpoint ignores one crucial fact and one demonstrable premise. The enormity of the BEV transition issue is beyond what Tesla and other new entrants can overcome in the amount of time required to bend the emissions curve, and this is the key reality. Take into account that roughly 100 million automobiles are produced and sold annually by the worldwide auto industry. Before the COVID disruptions in 2019, 2 million, or 2% of all vehicle sales, were BEVs. Tesla is acknowledged for its lofty aspirations and optimistic timetables for achieving them: The business declared a 2030 objective of 3 TWh of battery cell production, split equally between automobiles and energy, at its shareholder meeting in 2020.1 In the best case scenario, assuming 75 kWh/vehicle, this would be the equivalent of 20 million vehicles annually, or nearly 20% of worldwide automobile sales. In less than ten years, Tesla would grow to be twice as big as the biggest automakers in the planet.

In 2019, Volkswagen sold 10.8 million vehicles, Toyota sold 10.7 million, NissanRenault-Mitsubishi sold 10.1 million, General Motors sold over 9 million, Hyundai/Kia sold almost 8 million, and Ford sold about 6 million.Even if Tesla is able to achieve this improbable growth curve—and even if other BEV start-ups succeed in gaining traction and scale the total volume of BEVs produced by these pure-play companies would not be sufficient to bend the curve on transportation-related carbon emissions to the extent that is required by policymakers and, increasingly, by the general public. Additionally, the average lifespan of a car among all owners is currently longer than 12 years. The installed base of ICEVs, which in the U.S. numbers about 250 million, won't change rapidly despite an infusion of new BEV models vying for buyers due to high longevity in the car park that is, among all vehicles in service. It seems clear that the current ICEV companies will continue to play a significant role in the supply of personal mobility for many years to come[5], [6].

All of which brings us to the demonstrable truth that these established automakers, or original equipment manufacturers (OEMs), are well capable of and completely motivated to play a key role in the transition to BEVs. After all, they have developed great talents as global supply chain managers and system integrators of complicated multi-technology products. They also have a proven track record of effectively integrating new technologies, sometimes through internal "make" processes but more frequently through "buy" processes from knowledgeable suppliers that are governed by contracts. OEMs spend a lot of money on research and development (R&D) on new technologies, such as battery chemistries and electric drive trains, because they need to "know more than they make"2 in order to manage product development and suppliers. This puts them in a good position to influence the characteristics of an eventual dominant BEV design. Last but not least, OEMs have a well-established structural.

Position as guarantors of vehicle quality and safety by their responsibility for meeting regulatory standards and their legal liability for product failures. That gives them yet another advantage: preserving a large share of the value in the increasing mobility sector. From this perspective, the essential second act of the electrification transformation, now beginning, will be ushered in by recent OEM commitments to a rapid scale-up of BEVs. These enterprises will, in other words, contribute to the quicker realization of Tesla's aim "to accelerate the world's transition to sustainable energy." So the narrative of incumbents slipping away, so typical in digital transitions, does not reflect the facts and requirements of this sector's electrification.

The winner-take-all dynamics common to digital disruptions aren't probable in this transition, either. Incumbent OEMs already possess many of the competencies and complementary assets needed to design, build, sell, and maintain BEVs. Many BEV components overlap with those in ICEVs and, even when vehicles are redesigned to enable electrification (with lighter weight, less rolling resistance, less draw on the battery), these remain well within OEM capabilities, meaning less start-up advantage over incumbents. Despite ongoing manufacturing overcapacity and comparably low profit margins, the global automotive industry has also shown to be steadfastly resistant to consolidation. This, coupled with economic and political forces, will keep numerous OEMs in the game.

Nevertheless, not all conventional OEMs will be able to make the shift to the new era of powered mobility. The difficulty of managing a legacy business while investing in a new dominant design is indeed daunting, and politicians, investors, and consumers will all be watching to see which firms emerge as leaders. Not all OEMs or start-ups will be able to draw in enough money or talent, and if they fall behind in the race to create enticing BEVs, they will either collapse fast or have their assets taken over by others. After a period of ferment, a new set of leading enterprises will emerge.

A combination of new BEV-only businesses and former ICEV OEMs,Several competitors seeking to move towards BEV leadership, among them VW, Toyota, and Ford, and it spotlights General Electric as a potential leader in this transition.The question of whether BEVs will in fact replace other transportation-related decarburization technologies is more difficult to forecast.bvBEVs presently lead as most effective for the most rapid bending of the emissions curve, and that lead could grow if new battery chemistries, for example, solid-state, soon reach large-scale commercialization. Crucially, the reliance of BEVs with charging makes it imperative that investments into the extension of charging infrastructure rise dramatically and for charging access to be prioritized for public investment in difficult-to-serve places.Ultimately making progress on emissions reductions is an all-hands-on-deck project that will involve many actors and many different technologies, including “last gasp” enhancements in internal combustion engines for higher efficiency; dual-drive-train hybrids, including plug-ins; and hydrogen-based fuel cells. Strategies that depend less on BEVs and more on these alternatives including, notably, Toyota’s current approach can’t be dismissed altogether at this moment.

To critics who question that incumbent firms can handle a big technological transition when faced with start-ups and disruptive technologies, history provides ample examples of these firms’ capabilities that proven effective in both old and new technology regimes. There are also many examples of agility displayed by such companies when they have been faced with upstart competition. Of bigger issue in the electrification of mobility is whether incumbents will actively assist the other actors and policies as necessary to meet the aspirational targets that bend the emissions curve lower. Investors and consumers will do well to examine OEMs’ direct actions, particularly those involving progress towards stated goals, as well as their political activities—for instance, a company potentially undercutting those direct actions by paying deference to fossil-fuel interests.

This research builds the assertion that virtuous cycles to accelerate the BEV transition are more achievable now than they have been at any previous period in history. BEV demand continues to exceed estimates. Newly announced BEVs can sell out on the first day of bookings. In many cases, the reason is clear: BEVs can simply be better for customers. Driving can be quicker, quieter, cleaner, and more enjoyable. Current and upcoming BEV platform architectures provide innovation in terms of safety, form, and function as cars. They may, for instance, have a wider front crumple zone, a lower center of gravity, and more interior space, which reduces the chance of rollover. Through their batteries, BEVs might offer power to a jobsite or replace generators that supply electricity to residences during a power outage[7], [8].

After recently passing electricity generating, the U.S.'s greatest source of carbon emissions is currently transportation(Figure 1.1). Meanwhile, the electricity generation industry has witnessed the greatest emissions drop due to shifts in energy source first a move from coal towards gas, and now an increasing amount of renewables. Thus, three factors increasing transportation emissions, declining emissions from electricity generation, and the gradual switchover of transportation to electricity are responsible for this change in rank order. While electrification of transportation is picking up now, it has been slow due to limitations on both the supply and demand sides of the energy equation: battery cost and range and a low number of products on the supply end and minimal charging infrastructure along with consumer reluctance due to cost and range concerns on the demand side. Over the past 50 years, transportation emissions have more than doubled, with road-based vehicles accounting for over 80% of that growth. The current car park will continue to grow at a strong rate globally, especially in emerging economies, according to projections (i.e., all cars in operation) to roughly double by 2040. As the impact of carbon emissions is not restricted by geography, these transport driven increases threaten to overwhelm emissions-reduction accomplishments elsewhere.

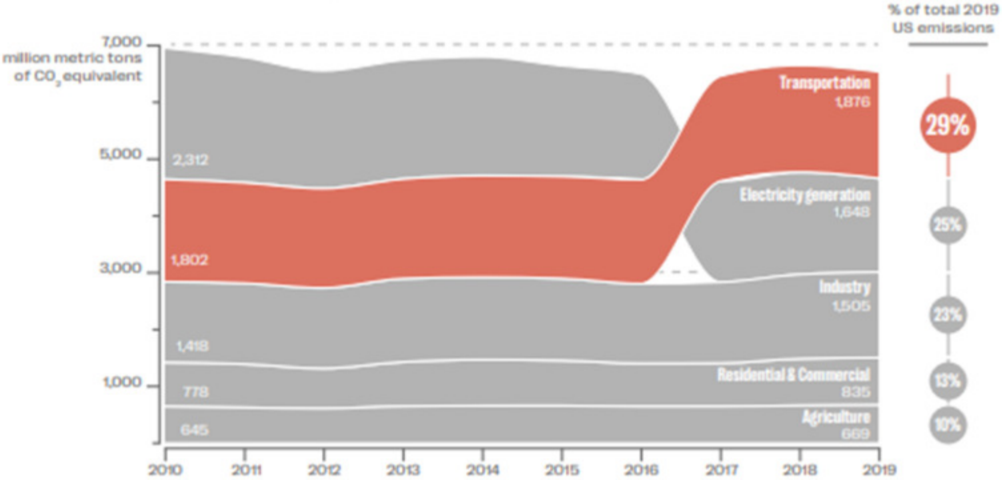

Figure 1.1: Represent the Transportation Is the Leading Source of Greenhouse Gas Emissions in the US.

Transportation will therefore be the industry most directly accelerating the speed of climate change and, specifically, global warming, if current trends continue. Policy objectives at the national, regional, and international levels are progressively being established with the idea of limiting the increase in global temperatures, and they are currently accelerating industrial transformation at a faster pace than they have in the previous 20 years. Firms and investors may overlook these changes at their own peril. Instead they should position themselves well by redefining how best to pursue economic benefits in this context.

A recent analysis by David Victor, issued in collaboration with Engine No. 1 in conjunction with its campaign to influence ExxonMobil's policy, makes a solid case that we are reaching the end of the fossil fuel era. To underline important findings from Victor's report, days are numbered for the longtime consensus favoring continuous increase in oil and gas consumption. The market capitalization of key players reflects this fact: Since 2010, the top four oil and gas companies' market cap has decreased by more than half while the largest green-energy supply companies all electric—have quadrupled theirs. Estimates of projected demand for oil are higher. Wide-ranging than ever, with several credible estimates looking for dramatic declines in that demand in the next decade, notably in the 2020 BP and Shell forecasts (See Figure 1.2.) The possibility for demand implosion increases the risk of continuous investment in new sources of oil and gas, and that could result in significant stranding of assets.Climate change can't be fixed with any one technical fix. The solution lies not in the post-extraction, post-processing remedies of the past for instance, scrubbers applied after coal-fired electricity generation nor in the ambitious and as-yet unproven technologies of the future, such as carbon sequestration. Carbon dioxide (CO_2) is an issue of accumulation, and its negative impacts can only be effectively addressed if we minimize future additions to the store of CO_2 now existing in the atmosphere[9], [10].

Climate change is drawing more public and policy attention and concern now than ever before, and this is encouraging a reframing for energy industries: that pursuing a future supply of fossil generates is now less important than reducing excessive demand of oil and gas and switching to alternative low emissions technologies.

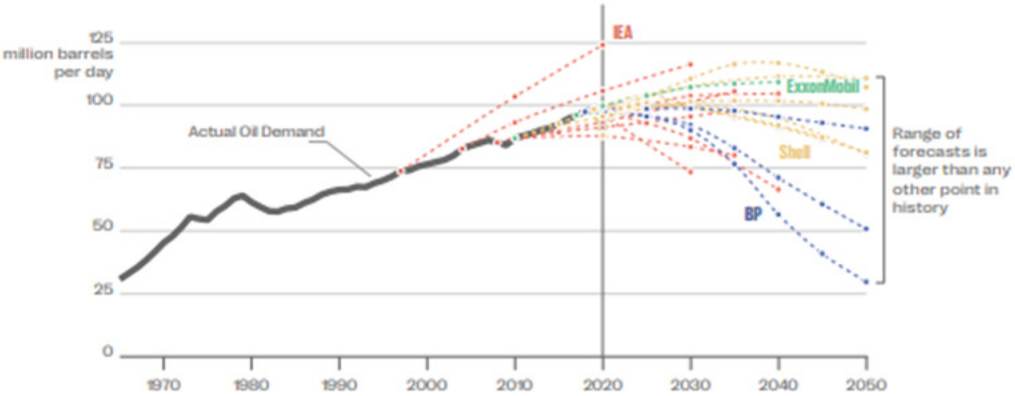

Figure 1.2: Represents the Rising Uncertainty Around the Future of Oil Demand.

According to technology historians, the dominating design for the mass-produced vehicle emerged around the year 1927.By that time, the components of the prevalent mode of transportation of the day an enclosed metal body, wheels, suspension, a steering wheel, brakes, a transmission that controlled the transmission of power to the wheels, and an internal combustion engine were all in place. By that point, ICEVs had essentially defeated electric vehicles in a race between competing power-train designs (despite the friendship between Henry Ford and Thomas Edison), thanks in large part to a sharp decline in petrol prices and the development of the electric starter. As soon as a dominant design was established, funding poured into expanding ICEV-related R&D, production, and supply chains, and the sector consolidated from hundreds of start-ups to an oligopoly of enormous automakers.

We are at a favorable period when rivalry between power-train designs is active once again, causing turmoil for the automotive industry and the larger mobility sector. The BEV is generally seen as the first significant change since ICEVs acquired that status in the late 1920s and as having the potential to become the next dominant design. As in that previous era (when vehicles competed against horses and carriages, railways, and streetcars), the battle now is not between a brand-new technology and more established modes of personal movement. Instead, it is a battle between a vast ecosystem of ICEV producers, fossil fuel suppliers, and a gasoline-based refueling infrastructure on the one hand, and an emerging ecosystem of BEVs that will resemble classic cars in many ways but use an entirely new drive-train and power source that necessitates a completely new fueling infrastructure on the other.

Electric Cars and the Automotive Industry

There's a significant likelihood that in the near future, the market for automobiles will be dominated by electric vehicles, given the public's steady acceptance of electric vehicles and the growing concern about climate change. Electric vehicle sales rose by 27% between 2016 and 2017, indicating that the shift is already underway, although slowly, even if it will take some time for electric cars to fully dominate the market. The automobile industry is changing in many ways due to the transition to alternative energy, and this development is underlining the need for more modifications as our use of cars continues to evolve.

Concerns have been raised about the accessibility of electric cars for those with disabilities. It is a prevalent misconception that electric cars' ability to operate quietly especially at low speeds is an unanticipated advantage. However, as their usage spreads, people are discovering that these vehicles endanger blind and inattentive pedestrians as well as other vulnerable groups. The National Highway Traffic Safety Administration of the United States Department of Transportation has recently recommended that electric cars be louder as a safety measure because it has determined that the danger connected with quiet vehicles is significant enough to warrant action. We will probably see several beneficial improvements as a consequence of the automotive industry's ongoing transformation and the increase in the number of individuals switching to electric automobiles. The annual recycling of automobiles, which generates over $65 billion for the American economy, may rise if we switch to alternative energy.

We will start to rid the roadways of high-emission vehicles and replace them with vehicles that won't contribute as much to climate change as soon as more people recycle their old and inefficient petrol guzzlers. Hopefully, this modification can be implemented in time to stop future environmental harm. As alternative energy moves up the priority list for governments and individuals, the effect of electric vehicles on the automobile sector may become more abrupt than we anticipate. Americans' perspectives are already changing, and as the issue of climate change grows more imminent, the car sector is set to undergo even more adjustments. Hopefully, these revolutionary changes will result in better environments and cleaner air for coming generations.

In light of current sales of electric vehicles, compare these figures. Global BEV sales in 2019 were 1.7 million, or around 2 percent of all sales, increasing the total number of BEVs on the market to 7.2 million.with approximately 1 million sales, or 57% of worldwide sales, China was the world's biggest BEV market in 2019. This represents an increase of approximately two times the 23 percent market share of BEVs in Europe and 4 times the 14 percent market share in the United States. Despite a downturn in vehicle sales caused by COVID in 2020, BEV sales increased to more over 4% of worldwide sales, bringing the total number of BEVs on the market to over 10 million. Sales in the EU will finally exceed those in China in 2020 as a result of tighter pollution regulations and more incentives for buying.

Analysts offer various interpretations of the growth rates of BEV sales. Yearn-year percentage growth figures can seem impressive but may be less so when we recognize that for many years the denominator of annual sales alternated between shrinking and growing. That said, no one disputes that the relative level of remains very low when compared with those of ICEVs. Plus, despite the influx of new BEV models seeking buyers, high longevity in Due to the endurance of ICEVs, the existing supply won't change very rapidly cars and a life expectancy of more than 12 years.Numerous studies highlight the stark difference between present BEV and ICEV sales, and using a variety of forecasting techniques, they investigate the diffusion pattern required to achieve considerable market growth and subsequently emissions reduction in the next decades. Several obstacles to [BEV] diffusion exist, including low consumer acceptance, high vehicle costs, and a lack of refueling infrastructure, according to a recent simulation-based report. As a result, sophisticated strategies and policies will be required to achieve a [BEV] market transition that is both ecologically and economically sustainable. Investors seem to be placing their bets on BEV inventors as the group most likely to lead this transformation and get through these obstacles, judging by the recent market excitement for Tesla and other BEV start-ups. This wager, however, may be exposed as magical thinking based on an incorrect assessment of the difficulty of the task. Instead, from a system-level view on the switch from ICEVs to BEVs, promoting full-on participation of incumbent automakers in hastening the electrification of mobility is now the most crucial objective (Figure 1.3).

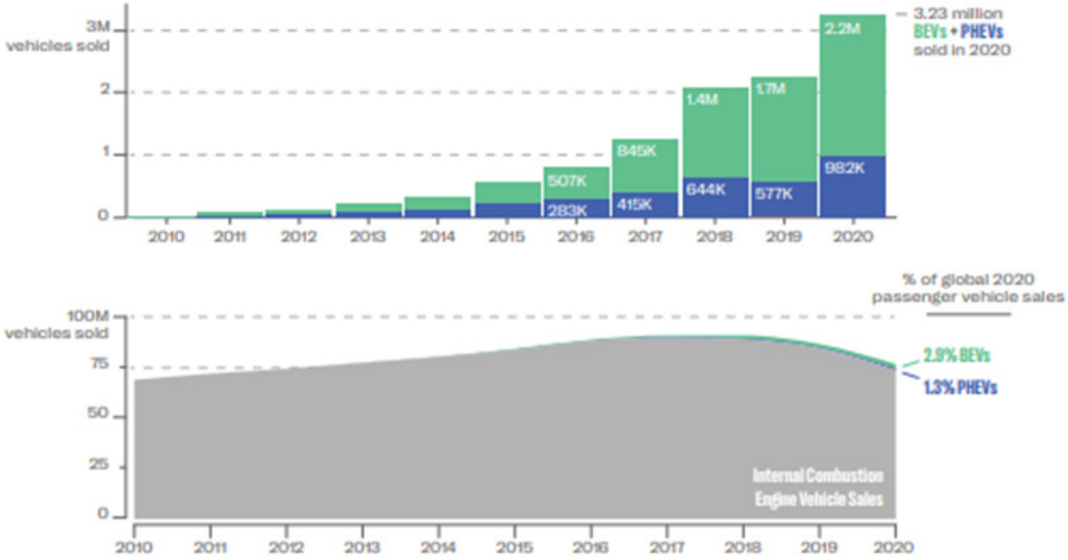

Figure 1.3: Represent the Battery Electric Vehicle Sales Rise in China and Europe with US Lagging Behind.

The longevity of cars and a lifetime that exceeds 12 years, the existing supply of ICEVs (approximately 250 million in the U.S.) won't shift very soon. Numerous studies highlight the stark difference between present BEV and ICEV sales, and using a variety of forecasting techniques, they investigate the diffusion pattern required to achieve considerable market growth—and subsequently emissions reduction in the next decades. Several obstacles to [BEV] diffusion exist, including low consumer acceptance, high vehicle costs, and a lack of refueling infrastructure, according to a recent simulation-based report. As a result, sophisticated strategies and policies will be required to achieve a market transition that is both ecologically and economically sustainable. Investors seem to be placing their bets on BEV inventors as the group most likely to lead this transformation and get through these obstacles, judging by the recent market excitement for Tesla and other BEV start-ups. This wager, however, may be exposed as magical thinking based on an incorrect assessment of the difficulty of the task. Instead, from a system-level programs view on the switch from ICEVs to BEVs, promoting full-on participation of incumbent automakers in hastening the electrification of mobility is now the most crucial objective.

Distributor of BEVs over the globe. Tesla most definitely doesn't seem to be in a monopolistic position. Tesla established a 2030 goal of 3 TWh of battery cell manufacturing, divided 50/50 between electricity and automobiles, during its 2020 shareholder meeting. In the best case scenario, at 75 kWh per car, this is the equivalent of 20 million vehicles annually, or nearly 20% of worldwide automobile sales. In less than ten years, Tesla would grow to be two or three times bigger than the biggest manufacturers in the world, which is not impossible but is implausible. Elon Musk would be more likely to succeed in electrifying transportation if Tesla's rivals increased both BEV production and demand at the same time. "Tesla's goal is to accelerate the emergence of sustainable transportation, and I'd prefer the other manufacturers go fully electric as soon as possible," he said in 2014.31 Many of Tesla's supporters whether they are owners, investors, or just fans have this perspective on the company's objective. According to a Financial Times article about Tesla's earnings report for the quarter ending the enterprise's mission is not to take away everyone's market share, but to spur the adoption of sustainable transportation and energy production, which is only possible with many active and successful market participants."32 It's probable that some customers, with diverse tastes and when presented with a variety of choices, may forego Tesla and opt for BEV cars provided by conventional OEMs (Figure 1.4).

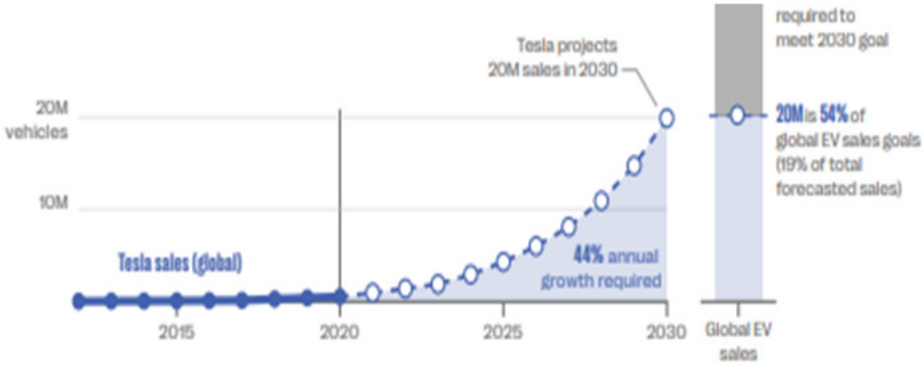

Figure 1.4 Tesla's Optimistic Sales Projections Fall Short of Global EV Goals.

Profound understanding of the many diverse technologies and enormous numbers of components required for a staggeringly complex product that must appeal to customers in both practical and emotional aspects in today's vehicles. R&D, product development, supply-chain management, manufacturing, sales and distribution, marketing, brand management, post-sales services (financing, insurance, maintenance), and use-based services (GPS, internet connectivity, concierge services) are all functional areas in which these capabilities exist.OEMs have maintained the majority of value in the automobile industry even though suppliers provide between 50 and 75 percent of a vehicle's value because they "know more than they make.The system-integration skills of OEMs, which are hard to duplicate, and their sustained source of competitive advantage are more valuable than any of the individual parts of the car.

Due to OEMs' extensive experience serving as the guarantors of quality and safety in their capacity as the bearers of regulatory obligations and the bearers of product responsibility, this share of value also endures.One of Tesla's less-noticed accomplishments, but one that has been essential to its present high valuations, has been its ability to understand how to use all of the conventional automaker's resources. Notably, Tesla reversed direction and acquired its competence as an OEM by growing vertical integration that is, by performing a rising number of things internally after first outsourcing essential activities.

Investors often have doubts about conventional OEMs switching to BEVs because they think that these firms' former sources of competitive advantage would become obsolete as a result of a change in the preeminent design. However, these system-integrator characteristics are potentially even more useful for BEVs than for ICEVs.Many think that BEVs are less complicated than ICEVs since they have fewer components, which may have an impact on both supply chains and aftermarket service needs. The fact that there are even more interdependencies between functional subsystems in BEVs than in ICEVs, which benefits conventional OEMs, is a fact that is often disregarded.38 Additionally, these businesses have shown that they can integrate BEV manufacturing in mixed-model assembly facilities alongside ICEV production very well.

Traditional OEMs are scale masters, and as the BEV industry expands, this skill will become more crucial. Indeed, as stated above, scaling success for both Tesla (and other BEV pure-play start-ups) and the automakers who dominated the ICEV period is the only realistic way to meet 2030 emissions objectives, either worldwide or in the U.S.

It also follows this trend for today's OEMs to progress towards complete vertical integration of battery design and manufacture, or towards quasi-integration via partnerships. Tesla apart, startups are less able to coerce such agreements, have less prior technical expertise (or "absorptive capacity"40), are less able to compete on an equal technical footing, and are less equipped to oversee the integration of batteries into the rest of the car.It is challenging for incumbents to run legacy companies built on technologies that are close to their end of life, invest in new technologies, and compete with startups that can devote all of their attention to the newest technologies. Many incumbents failed to make this shift throughout the history of digital technology, and many of them were really unaware of the threat to their current economic model.

What has changed with the switch from ICEVs to BEVs In the next part, we emphasize three key distinctions that are compatible with the explanation above and provide instances thereof:

1. Due to their position as "know more than they make" system integrators, traditional OEMs have been doing R&D on BEVs for many years and have amassed a significant amount of intellectual property (IP) in the form of patents and trade secrets.

2. These OEMs have the ability to learn about new technologies and components, even if they lack previous experience, and to incorporate that new knowledge, as they have done in the past with several other new components based on new technologies. Examples include airbags, "drive by wire" mechanical system software controls, aluminum and magnesium body components, and airbags.

3. Despite the basic differences in the drive train components, such as the power source, motor, and transmission, ICEVs and BEVs will share components in the majority of vehicle subsystems. Many vehicle subsystems must be built differently for BEVs; for example, tires must have less rolling resistance and HVAC systems must use less power; nonetheless, these are evolutionary changes that conventional OEMs can completely grasp while still doing their typical system integrator duties.

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CHAPTER 2

ELECTRICAL GRID SYSTEMS

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Large central producing stations were linked to a chain of distribution centers that directly supplied customer demand through a high-voltage (HV) transmission system in the conventional electric power grid. The majority of generating stations were steam plants that burned fossil fuels and hydro turbines that powered high inertia turbines to generate electricity. Local and regional grids gave way to a vast, linked network that was controlled by coordinated operational and planning processes as the transmission system evolved from them. Peak demand and energy use increased at predictable rates, while technological advancements occurred in a mostly clear-cut operational and regulatory framework.

The bulk power grid has seen significant technical advancements during the last 100 years. With the constant introduction of new technology, such as more efficient and ecologically friendly producing sources, the power grid has been improved. Power electronics in the form of flexible alternating current transmission infrastructure (FACTS) and HV direct current (HVDC) as well as improvements in computerized grid management techniques for planning, real-time operations, and maintenance. Demand response and energy-efficient load management techniques. Every year, the pace of change in the electric power sector increases[1], [2].

Drivers for Change

The high pace of change in the electric power system is being driven by public policy, economics, and technology advancements. The power system moves closer to its objective of producing dependable energy from more affordable and clean resources. The electrical power system has quickly made the switch to the new two-way power flow arrangement and is still developing (Figure 2.1).

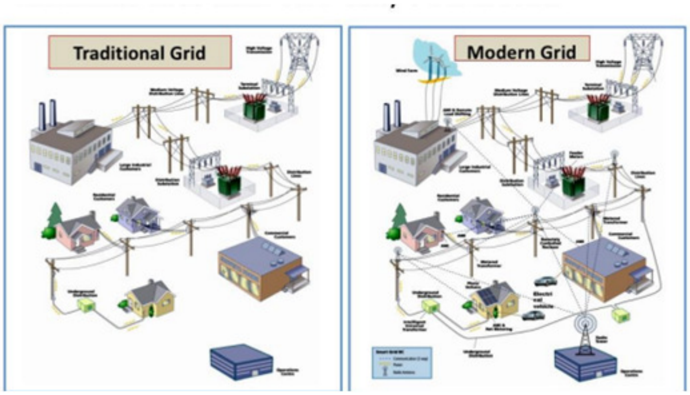

Figure 2.1 Represent the Transition from a traditional to new electrical grid with two-way power flow.

Wholesale electric markets were developed as a result of the reregulation of the electric power industry in the US and other countries. Competition decreased consumer prices, moved risk from ratepayers to investors, and promoted quick innovation. Significant changes in the fuel mix of generating stations led to the switch from inefficient coal- and nuclear-fired combined cycle units to effective natural-gas-fired combined cycle units as a result of the development of markets and environmental legislation. The wholesale electric markets and government initiatives to subsidies or otherwise support demand response, energy efficiency, and renewable resource utilization are in conflict. In spite of this, the economics of these technologies have improved, and their use has led to reduced consumer prices and increased environmental sustainability. The emergence of retail access and even distribution marketplaces is one recent trend that increases customer choice and corporate prospects while complicating grid management. The electric power business is still undergoing transformation as a result of regulatory reform[3], [4].

The technical revolution was aided by the regulatory revolution. More customer options that can be controlled locally, or from afar automatically are made possible by the Internet of Things (IoT), which also permits changes in consumer expectations and behavior. Initially, the distribution infrastructure was created and planned to handle peak demand while also passively delivering electricity via radial infrastructure.But nowadays, a lot of customers are turning more and more on the grid to help them manage their own production and demand as well as act as a backup provider in case their locally sourced generation isn't accessible. Customers are becoming prosumers and expecting to get surplus in increasing numbers.

Without any limitations on their output, and get payment for redistributing their power to the grid. Customers nonetheless continue to depend on the system to provide electricity when they need it. The functioning of the distribution system has been significantly altered by these conflicting interests. The digital revolution is also seen in the much improved monitoring and control technology used in the conventional power system. Innovative analytical methods have also given grid operators a faster understanding of the issue. Smart inverters for photovoltaic (PV) systems that can actively communicate with the distribution system are one example of innovative technology that has emerged as a result of advances in material science and controls.

Both performance and cost have been improved as a consequence of innovations in solar, wind, and energy storage. The cost of solar panels has decreased as a result of rising sales and technical advancements. A number of U.S. states, including California and New York, as well as nations like Germany, Spain, and Australia, have ambitious plans to increase the use of distributed energy resources (DERs) and renewable power in the next years. Regulations like net-zero metering may be utilized to promote the expansion of PV systems. Net-zero metering encourages the installation of PV panels by owners while allowing users to sell excess energy to the grid. However, even users that have a net-zero footprint often utilize grid electricity at night and on overcast days since they depend on the distribution system's availability. Unfortunately, since the expansion and upkeep expenses of the distribution system are included into the rate base, the net-zero metering policy forces customers who do not have solar panels to subsidies those who do. As a result, consumers who use the old grid more often pay a disproportionately higher part of the infrastructure expenditures. Since PV panels are often placed by customers that are financially better situated, this impact is aggravated even more[5], [6].

For instance, Nevada, which has one of the greatest solar radiation resources in the country, has a strict renewable portfolio standard (RPS) that calls for the production of 25% renewable energy by 2025, as well as incentives that are meant to encourage the use of renewable energy.Additionally, Nevada has favored the development of power buying agreements to satisfy the RPS objectives due to the highly competitive cost of utility-scale solar. Nevada has modified its net energy metering program to lessen incentives for brand-new rooftop solar plants in response. Florida, on the other hand, rejected the rooftop solar amendment that would have increased energy costs for rooftop solar consumers in order to finance utility infrastructure. These illustrations of several solar power strategies highlight the necessity for regulators to consider how to charge for using the grid. For solar power installations to succeed and expand, new strategies that address both energy consumption and distribution system infrastructure costs are required.

The supply of natural gas in the United States has been one of the key factors, since a large portion of the new power plant capacity built over the previous 20 years depends on natural gas to produce electricity. The large retirement of coal and nuclear power facilities, which are thought to be less efficient than natural gas, was a trend that followed this one. The recent Staff Report to the Secretary on Electricity Markets and Reliability from the U.S. Department of Energy (DOE) (see https://energy.gov/sites/prod/files/2017/08/f36/Staff%20Report%20on%20Electricity%20Markets%20and%20Reliability_0.pdf) suggested that all energy sources be priced at their true costs; as a result, the proliferation of solar powered by incentives may slow down[7], [8].

RPSs and locations with good conditions for renewable energy production (such California, New Jersey, New York, and Hawaii). At the same time, it is anticipated that cutting down on subsidies won't have a substantial influence on solar and wind's ability to compete with gas since utility-scale solar has already reached parity with natural gas in regions with abundant wind and solar resources. These instances are from the USA. However, tremendous caution must be used in every electrical system in the globe to ensure that the adoption of renewable technologies and the switch to alternative fuel sources do not jeopardize the stability and resilience of the electric grid. Given the different environmental rules and economic factors, the global power sector must reliably produce its energy while ensuring that this transformation does not adversely impact the dependability and resilience of the electric power system.

Grid Modernization Needs

How much should be spent in the grid as more and more DER systems service loads without using the grid for lengthy periods of time is a crucial topic in accomplishing these objectives. If the transmission and distribution (T&D) grid is not accessible or able to provide backup for renewable power intermittent, it may possibly have a detrimental impact on the dependability and safety of supplying electrical power demands. It is vital to increase the T&D system's capacity to host and support the usage of DERs, as their penetration levels rise.DER proliferation and grid modernization are undoubtedly connected, but none is necessary for the other. Utilities like Commonwealth Edison (COMED) and CenterPoint, which provide services in areas where DER penetration is just beginning, have successfully carried out grid modernization initiatives to increase grid reliability, resiliency, and system efficiency, as well as to meet rising customer service expectations and replace ageing infrastructure that is at the foundation of their systems. For instance, since 2012, COMED Energy Infrastructure Modernization Act, which calls for the installation of 4 million smart meters and 2,600 smart switches, has prevented more than 4.8 million consumer disruptions. It will also be easier to adapt to a new paradigm with a high penetration of DERs thanks to this modernized infrastructure.

Utilities operating in jurisdictions like California and Hawaii actively encourage DER deployment to meet RPS objectives and quickly transition to a modernized distribution grid. Additions to grid modernization infrastructures and systems should be viewed as necessary investments since an even greater adoption of DERs is unavoidable given the planned achievement of grid parity by distributed generation in these markets. This will allow the regular operation of current and future distribution systems.

The Grid of the Future

Achieving grid parity will be difficult for the electric power sector. A cleaner environment is made possible by the effective integration of variable energy sources, but it also raises problems such a greater need for control, ramping, and reserves. Applications of HVDC and FACTS provide performance improvements, but they might make network management and planning more difficult. The large-scale expansion of energy efficiency and demand using inverter-based technologies, including applications of electric mobility vehicles, exacerbates the requirement for network management. The distribution system will need to adapt in order to function with electricity flowing in two ways, as opposed to the one direction it previously did, due to the growth of demand energy resources and demand response. Micro grids provide dependability and resilience but also dramatically alter the network's physical characteristics[9], [10].

Although the distribution of the electrical power system is increasing and will continue to increase, it is crucial to remember that the interconnected grid of today first existed as a collection of scattered grids.To increase grid cost-efficiency, dependability, service quality, and safety, interconnected grids were developed. The essential advantages of a linked grid persist even as dispersed renewable resource deployment become more straightforward due to technological improvements. The current grid is fairly dependable, but customers will need even more dependability in the future, including resilience during significant weather or security incidents. As part of the overall development strategy to balance supply and demand uncertainties and risks with a variety of different resources, the integration of DERs and distributed grids can improve the efficiency in which the existing grid is used. This will ensure resilient, flexible, and safe power delivery to consumers. Furthermore, paradigms of the electric power industry will be impacted by creative modifications to the regulatory environment. Rates that are only dependent on energy sales will fall off quickly. Traditional utilities will evolve into power suppliers that provide services like distributed resource installation, gathering consumers who engage in wholesale electric markets, and setting up backup energy on demand.

The growth of wind and solar energy constitutes a considerable shift from the current resource balance. Both generate emission-free energy at steadily declining capital costs. The total variability experienced by the whole power system is decreased by the greater installation of these resources across large regions. Modern designs decrease maintenance costs while increasing the effectiveness and lifespan of wind and solar resources. The growth of resources as a whole is facilitated by significant advances in controls that improve voltage and frequency responses. New solar, onshore wind, and offshore wind technologies are all developing quickly.

Transmission Innovation

Since the growth of renewable resources often takes place distant from load centers, higher transmission transfer restrictions may be necessary. However, the transmission system is exposed to a broad variety of operating circumstances due to the changeable nature of both solar and wind resources, as well as changing demand. New technologies provide more flexible operation and better use of scarce rights-of-way.Since the growth of renewable resources often takes place distant from load centers, higher transmission transfer restrictions may be necessary. However, the transmission system is exposed to a broad variety of operating circumstances due to the changeable nature of both solar and wind resources, as well as changing demand. New technologies provide more flexible operation and better use of scarce rights-of-way.

Transmission Structures

Reducing costs and making the placement of transmission circuits easier may both be accomplished by making greater use of new and existing rights-of-way. In the past, adding higher voltage facilities to replace older transmission circuits allowed for more power to be transferred over a given area. Recent patterns suggest that switching lengthy ac lines to HVDC might be a cost-effective fix. Installing the following is one of many more recent techniques for enabling greater power transfers across constrained rights-of-way.

Compact structural designs, which allow for larger voltages, better levels of surge impedance, and improved thermal capacities. Improved ampacity new kinds of overhead wires ecologically pleasant and simpler to install subterranean cables that are self-contained or even superconducting. Technology for dynamic line rating, particularly those used to incorporate wind farms. Environmental restrictions must be met by transmission infrastructure. New techniques for coexisting peacefully with wildlife, notably birds that build their nests on towers, make site selection and reliable operation easier. Low-cost designs with high-strength conductors minimize the number of spans per mile, which also lessens their negative aesthetic effects.

Substation Equipment

Applications make greater use of the available area and transmission infrastructure because to the significant advancements in substation technology. Substation costs and detrimental environmental effects have decreased because to new materials and inventive designs. There is no longer a need for Sulphur hexafluoride, a very strong greenhouse gas, to be used in new gas-insulated substations. Reliability, which is becoming more crucial for an ageing infrastructure, may be improved and current facilities can be used more effectively with the help of performance monitoring. New surge arrestor designs are used to safeguard equipment and increase its lifespan.

Distribution Innovation

Utilities are using sophisticated automation techniques in distribution systems including fault localization, isolation, and service restoration (FLISR) to increase dependability. SCADA systems provide real-time monitoring and control of automation schemes like FLISR, which are required to increase dependability cost-effectively. The insight and flexibility required for operations may be included into distribution automation to assist the activation of DERs.Modern DER facilities, including energy storage systems, that use "four quadrant" smart inverters have the ability to provide very inexpensive voltage support and management of voltage variations on the distribution system. To fully understand the influence on utility reactive power needs, particularly as PV penetration rises, further study and related standards are required. The absence of a business strategy to reimburse DER owners for the additional cost of the smart inverter may further hinder adoption.

The IOT is essential for providing distribution networks and DERs with more detailed visibility and monitoring. Consumer privacy and security are top design priorities. Tools for thorough modeling, simulation, and analysis are required, and low-voltage distribution grids must be included into typical distribution system models. Increased real-time and near-real-time distribution system monitoring (using, for example, GPS synchronized measurements) is essential, but so is the capacity to identify and avert any service interruptions and disturbances brought on by DER operation.

Changing inertia and system impedance may drive more circuit breaker replacements and increase the need for adaptive protection and control schemes. Adaptations at the bulk power level will be required to replace inertial and governor response from conventional synchronous generators. Fast inverter-based resources, especially storage, can respond in just a few cycles and be used to responautonomously to rate of change of frequency as a pseudo-inertia response and to frequencydeviation with a droop to emulate speed governors. When coupled with high-speed communications and control and synchro phasor applications, their response could conceivably be coordinated system wide to enhance stability.Grounding requirements notably dealing with harmonics and other power quality difficulties induced by large inverters, may develop. This is more likely to become a concern for big industrial clients or in future micro grids.

The variety of short circuit availability (high and low) implies adaptive control and protection designs become increasingly crucial. In general, protective settings will have to be constantly and automatically updated as operating circumstances change, especially with greater penetration levels of DERs. Dynamic modification is only feasible with current microprocessor-based relays. Advanced protection and control techniques should be assessed for different circumstances such as the following:

1. A change in operating circumstances of a feeder such as generation and load changes including reverse power flow and back feeding
2. A change in circuit topology according to the distributing automation scheme □ the ability to swiftly clear the issue and restore consumers

3. fault detection and clearance in the grid-connected and islanded modes
4. A tolerance to change in fault current capacity owing to the existence of power electronic based DERs.

Solid-state voltage regulators and transformers are technologies that may assist manage changes in the grid owing to the increased penetration of DERs. Energy storage provides the capacity to decrease renewable DER fluctuation and increase T&D utilization and economics. It is acknowledged that “shared applications” the various usage of the same energy storage device is crucial to attaining the highest economic potential from the technology.Regulatory hurdles and old paradigms have been solved in some jurisdictions and need to be addressed at others to allow the adoption of these technologies and their most effective usage. Storage may not fall into one of the traditional categories (such as generating, load, T&D, consumer, and transportation) or follow recognized norms for that asset type. It is uniquely equipped to perform services across asset classes, such as the Battery Energy Storage System (BESS) facility in Tehachapi. Storage is possibly a new asset class of its own, but new regulatory regimens and market regulations may be required.

Energy storage and other DER technologies capable of quick reaction to control signals provide the promise of giving the capabilities to regulate the variability of renewable DERs both locally on the distribution system and in the power system overall. However, procedures for effectively incorporating DERs in grid ancillary and balancing services have yet to be completely established. The business mechanisms that make this appealing to the markets, utilities, and DER owners are still under debate. Legacy planning and operations analytics and methods do not accommodate for energy storage in general or sub optimally. This slows down utility uptake and comprehension.

Electrical Transportation Innovation

Electric transportation shows considerable potential for lowering dependency on oil and our carbon footprint. Electrical transportation systems may assist enhance the livability, workability, and sustainability of "smart cities." Electrical transportation encompasses electric trains and electric vehicles (EVs) as well as allowing electrical corridors to convey people and commodities.Specifically addressing EVs, studies have shown that the initial purchase of an EV is likely to inspire more in the same area, which may lead to the creation of clusters and may overload the local distribution system transformers. Distribution system capacity enhancements, in conjunction with solutions based on DERs and sophisticated load management, are able to mitigate these overloads.

Furthermore, although EV discharging back to the grid, widely known as vehicle-to-grid, is still undesirable from an automotive original equipment manufacturer standpoint owing to the effect on battery life, there is still the possibility for the EV to offer local backup power to the user. This could become both a selling feature for sophisticated EV chargers, particularly in combination with PV and household energy storage, and a new problem for interconnection standards. This operational mode is not yet extensively investigated, and its influence on utility standards, interconnection, etc., remains uncertain (the nature of standards likely will be similar to backup generation or islanded PV operation).

Micro grid Innovation

Micro grids have existed for years on university campuses, military bases, and large industrial sites and at various critical the infrastructure locations where combinations of the economics of Distributed Generation (DG) and demand response, the need for very high reliability, and research objectives all led to their development. Today, the micro grid idea is considered as an option to enhance resiliency, enable the DER integrat6ion, and offer efficient energy supply to distant or remote areas.Larger micro grids develop and execute complex scheduling and control systems that can optimize their energy use, production, and grid sales and purchases during the day. As micro grid systems become increasingly linked with smart buildings and smart charging systems for EVs, their flexibility and complexity will only rise. When a significant school, business park, or residential community desires to construct a micro grid but does not control HV distribution, the utility must become a partner in its establishment. This may involve the engineering and design, and even the ownership, of parts of the control and connectivity systems.

Pilot projects for this model exist worldwide, but business models established inside tariff systems, as well as clear regulations regarding asset ownership, privacy, responsibility, etc.

Integrated T&D Planning

For decades, the planning nor operations of T&D systems were independent tasks with little or no integration and interaction. The distribution planning engineers delivered the anticipated bus loads to the transmission planners, and the distribution SCADA engineers may pass on bus load data to transmission. Transmission seldom gave information to distribution, since distribution planning and operations analytics always believed that the transmission system was an infinite bus (i.e., fixed voltage) behind an equivalent impedance representing primarily the distribution substation transformer.

As the unpredictability of distribution system net demand grows, improved coordination and information transfer is necessary. For example, the independent system operator (ISO) can no longer rely on simple load prediction bus allocation factors to estimate bus net loads but must be able to forecast PV production. More crucially, the utilization of DERs to deliver aggregated energy supply to the T&D system and associated services to the wholesale markets will be more lucrative. It of that information will move back and forth through the distribution system operator (DSO), but it will also need to pass directly to bulk power system stakeholders. For example, the DSO may aggregate ancillary services offered by DERs, but the ISO will demand direct visibility for certain auxiliary and reliability services such as regulation for both control reasons and performance calculations and settlements. Current thinking and budgeting for the DSO typically still reflects the original T&D divide. However, in a future electric sector when high renewables and DER penetration are the norm, the transmission operator will be impossible to optimize schedules and dispatch without considering the implications on the distribution system, and vice versa. Integrated wholesale/distribution market operations will become a prerequisite.

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CHAPTER 3

COMBUSTION IN SI ENGINES

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Fuel and air are mixed before entering the combustion chamber in conventional SI engines. When the mixed gas enters the engine cylinder, it mixes with the residual gas and is compressed by the piston during the compaction process. When SI occurs at the spark plug near the end of the compression cycle, combustion begins. This is the first step in the combustion process, known as inflammation. The mixed gas releases its energy through rapid lame development and propagation after being initiated by sparking (inflammation). The development and propagation of lames differ from cycle to cycle. This is why the in-cylinder conditions, such as pressure, temperature, and species concentration, as well as space distributions, differ significantly. The speed of lame propagation is largely determined by the concentration of unburned mixture; that is, the higher the unburned mixture density, the faster the lame propagates. In a SI engine, however, the lame front is roughly circular due to relatively homogeneous unburned petrol distributions[1], [2].

Typically, combustion occurs near the TDC at the end of the compression cycle. Proper combustion timing is critical for combustion efficiency. When combustion occurs before TDC, the piston pushes the mixed gas, reducing the kinetic energy of the piston. When combustion occurs after TDC, the peak in-cylinder pressure delays, and thus the work transfer from the petrol to the piston is reduced. Thus, combustion timing cannot be too early or too late, and optimal combustion timing exists. Maximum brake torque is the torque produced by optimal combustion timing (MBT).

The combustion process of SI engines may be classified into three major regions:

(1) Ignition and flame development.

(2) Flame propagation.

(3) Flame termination.

Flame development is commonly regarded the consumption of the first 5% of the air-fuel combination (other sources use the first 10%). During the flame development stage, ignition occurs and the combustion process commences, but very little pressure increase is apparent and little or no useful work is generated (Figure 3.1). Just nearly all usable work generated in an engine cycle is the consequence of the flame propagation stage of the combustion process. This is the phase when the majority of the fuel and air mass is consumed (i.e., 80-90%, depending on how defined)[3], [4]. During this

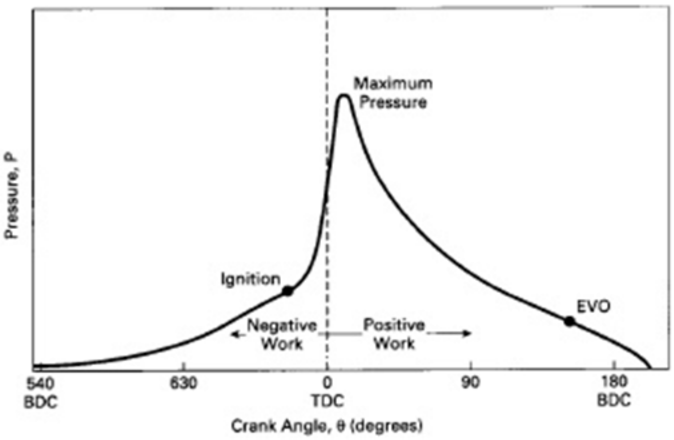

Figure 3.1: Represents the combustion storage.

Time, pressure in theexpansion stroke. The last 5% (some sources say 10%) of the air-fuel mass which burns is defined as flame termination. During this period, pressure rapidly falls and combustion ceases. In an SI engine, combustion ideally consists of an exothermic subsonic flame flowing through a premixed homogenous air-fuel combination. The spread of the flame front is considerably boosted by produced turbulence, swirl, and squish inside the cylinder. The correct mix of fuel and operating parameters is such that knock is avoided or practically prevented[5], [6].

Combustion in Ci Engines

After the fuel injection, which typically occurs near the end of the compression cycle, combustion occurs with the several crank angles delay in CI engines. At high pressure, the fuel is delivered and atomized into the combustion chamber. The fuel is vaporized and mixed with the air in the chamber after injection. Diesel fuel reaches its ignition point and begins to ignite spontaneously when subjected to high pressure and temperature during fuel injection. After ignition, the unburned fuel/air mixture will continue to burn for the duration of the expansion cycle. Because combustion occurs spontaneously and at multiple points in CI engines, the process is much more complex than in SI engines and is affected by fuel properties, mixture homogeneity, and the shape of the engine chambers.Because CI engines use auto ignition, the time between the combustion initiator (fuel injection timing) and the ignition timing is critical. In CI engines, this is referred to as ignition delay. Empirical estimates of ignition delay as a function from in pressure and temperature are as follows:

$$\tau_d = Ap^{-n} \exp\left(\frac{E_a}{RT}\right)$$

Where d denotes the ignition delay R is the gas constant; E_a is the apparent activation energy for the gas auto ignition process. A and n are constant parameters linked to the concentration of fuel and other species.

Emissions

The exhaust gases from SI engines (gasoline engines) contain nitrogen oxides (NOx), which include nitrogen oxide (NO) and nitrogen dioxide (NO_2), carbon monoxide (CO), and unburned (or partially burned) hydrocarbons (HC). Nitrogen oxide emissions in CI engines (diesel engines) are the same as in SI engines. Hydrocarbons and specific emissions are more significant in diesel engines than in SI engines. The carbon monoxide level in diesels is lower than in SI engines**.**

Nitrogen Oxides

The chemical reactions between atmospheric nitrogen and oxygen produce the vast majority of nitrogen oxides. Several factors contribute to the formation of nitrogen oxides. The peak complete combustion is the most critical factor. In general, the higher the peak combustion temperature, the more likely the production of nitrogen oxides. The oxygen concentrations in the air/fuel mixture are also important. The fuel/air, burned gas fraction, exhaust gas recirculation rate, and spark timing/fuel injection timing, in particular, will heavily influence the above two factors and thus influence nitrogen oxide production.

Fundamentals of Power Electronics

Power electronics is a technology that controls and converts electric power by combining contributions from electronic, magnetic, and electrochemical components. Power electronics are used to convert and transport energy and power, whereas analogue and digital electronics are used to transmit and transform data and information. Peter Cooper Hewitt invented the first power electronics system in 1902. A mercury arc rectifier was used to convert alternating current (ac) to direct current (DC). Modern power electronics began with the invention of the first transistors at the end of the 1940s. Since then, the performance of designed converters has been consistently improved due to advancements in components such as switching devices, magnetic materials, and cold plates, to name a few[7], [8].

Power electronics is the technology that allows electrical energy to be managed. Electric traction motors focus on providing mechanical power to the wheels of an electric vehicle. The energy used to power the motors comes from an electrochemical energy source (battery, ultra-capacitor) or is generated by the engine. To operate a motor, energy must be transferred from an onboard source(s) to the motor. This energy must be converted in a controlled manner in order to generate a rotating magnetic field in the motor that matches the load requirements. Power electronic systems enable all of these phases (transfer, transformation, and control). Power converters (dc-dc, ac-dc, and dc-ac) are used in vehicles to convert electrical power and manage the power low. This power outage can occur from the battery to the wheels (both directions), from the grid to the battery (both directions), or from the engine to the cell or wheels.

It introduces the basics of a switch-mode DC-DC converter. Electrical circuits and steady-state operation of the most popular converters are introduced, as are semiconductor devices. The following section is about switch-mode ac-dc converters. Single-phase and three-phase inverters, as well as the faint heartbeat (PWM) method,the third section goes over the fundamentals of ac-dc rectifiers. In single-phase and three-phase configurations, both uncontrolled and controlled rectifiers are introduced. The final section goes over design recommendations for power converters[9], [10].

AC–Dc Converter Use in Modern Electrified Vehicle

A DC-DC converter generates a controlled dc output from any input dc voltage. In other words, using a DC-DC converter allows you to convert a dc input voltage into a different voltage for the DC output. The input voltage can be stepped up or stepped down depending on the converter used (Boost, Buck, and Buck-Boost). A dc-dc converter converts unregulated rectified voltage into a controlled dc-voltage in applications like electricity generation (e.g., wind turbines) or domestic applications. The output voltage is selected based on the application (540 or 28 V in aerospace systems, 225-650 V in hybrid vehicles, and so on). A high-voltage battery is typically used as the vehicle's electrical energy source in an electrified vehicle. Depending on the type of vehicle, this battery can be sized differently. The larger the battery capacity, the more electrical energy that can be stored and used to power the vehicle. The battery is directly connected to the traction inverter in some vehicles (Toyota Hybrid System I, Fiat 500e). In this configuration, battery output is imposed on the drive system, which can be a constraint in some cases because it limits the performance of the electric motor (especially in terms of maximum speed). Other configurations (Toyota Hybrid System II: Camry 2007, Prius 2010) use a dc-dc converter between the battery and the traction inverter to avoid this. To obtain the required dc-bus voltage, the dc-dc converter steps up the battery voltage.

The step-up dc-dc converter, for example, allows the Prius 2010 to use three different dc-link voltages. By adjusting this value, the drive system's performance and efficiency can be modified. Furthermore, the use of a dc-dc converter allows for greater flexibility in system design; different battery packs with varying voltage ratings could be used for the same motor.Another use for a dc-dc converter in an electric vehicle is the implementation of an auxiliary power unit to power the low-voltage 12-V (or 48 V) dc grid. This dc grid powers all of the vehicle's electronic components (air-conditioning system, microprocessor, lights, etc.). First, their steady-state operation will be presented.The following section provides an overview of switching devices used in power electronics. It contains the fundamental information and details needed to explain how switching dc-dc, ac-dc, and dc-ac converters work. Readers interested in learning more about switching devices and how they work are encouraged to consult. The mathematical models required to perform dynamic analysis and converter parameter selection are then presented.

Steady-State operation of Switch-mode DC–DC Converter

The term "switch" refers to the fact that a switch-mode dc-dc converter contains at least one switching device. This device is a semiconductor component that allows a current to flow through it (on state) or not (off state). The semiconductor's state (on and off) is either determined by an electric circuit (e.g., diode) or controlled by a periodic gate signal u, which is defined by its duty cycle d over a time period T. (e.g., MOSFET and IGBT). The value of d represents the average value of u over the period T. A dc-dc converter's steady-state operation corresponds to the expression of the input/output currents and voltages. It specifies the converter's root main square (RMS) output voltage based on the RMS input voltage and duty cycle. In this section, it is assumed that all converters operate in continuous conduction mode (CCM). This implies that the inductor's current is always greater than zero.

Electrical Circuit

The electrical circuit of a three-phase inverter. It is made up of three parallel legs connected to a dc voltage source. Each leg's midpoint corresponds to one of the converter's three outputs. The three phases of the motor are connected in Y configuration and are connected to the middle point of each leg in motor drive application, a three-phase inverter is made up of six bidirectional switches, such as MOSFETs or IGBTs, connected by an antiparallel diode. The electrical characteristics of the switches are identical to those of the single-phase configuration. Similarly to the single-phase inverter, the two switches on one leg cannot be closed at the same time. The dc-voltage source is short-circuited if this occurs.

Single-Phase Full-Wave Rectifier

A full-wave rectifier is capable of converting an alternating input voltage to a unipolar output voltage. Once the requirements for turning the switch ON are met, this circuit allows the positive half-cycle of the input waveform to pass. This configuration is capable of delivering an alternate path to rectify the input waveform, that is, invert it to maintain the same polarity at the output, during the negative half-cycle. This circuit is inherently more efficient than its half-wave counterpart because it generates the output dc voltage using both the positive and negative portions of the input voltage rather than every other half-cycle. The converter's operation will be demonstrated only for the purely resistive case. The case corresponding to the RL load, on the other hand, can be determined using a similar analysis method to the one presented for the single-phase half-wave inverter.

Bridge versus Center-Tapped Transformer Configurations

Alternate configuration for full-wave rectification using a center-tapped transformer. When the transformer's point A is positive in relation to the center tap C, diode D1 is forward-biased and conducts. Point B of the transformer, on the other hand, is positive with respect to C during the negative half-cycle. Diode D2 is currently biased forward. Current lows through the pile Z in the same direction in each case. During both half-cycles, the output is unipolar. The subsection that follows briefly discusses some of the benefits and drawbacks of the two rectifier topologies.

Power Module Selection

Many manufacturers, including Powerex, Inineon, Semikron, and International Rectifier, to name a few, offer various power modules. When you look through their catalogue which notice that the same type of component is offered in a variety of voltage and current ratings, as well as different packaging’s. All of the proposed power modules differ in terms of forward voltage, line losses, and thermal impedance of their packaging. The goal of this section is to provide input for choosing the best power module for a specific application.The first step in selecting a proper power module is to perform a similar analysis to the one presented to identify the electrical characteristics required for the switch to be selected. The voltage rating of the component is the first piece of information to obtain from this (other than the type of microelectronics required). Due to voltage overshoot that can occur during the switch's turn-off phase due to stray inductance of circuitry, it is recommended to select a power module rated for twice the voltage specified by the circuit's operation. Then, depending on how the switch is used, the current rating of the power module must be respected. However, simply considering the current rating is insufficient.

Every power module is, in fact, rated for a maximum junction temperature. If the junction temperature exceeds the maximum specified by the manufacturer, the device is damaged and will most likely fail. The junction temperature of a power module is determined by the current flowing through the device as well as the system's thermal properties. This means that the maximum current a switch can handle varies depending on the packaging or heat sink used. To ensure that a module is being used properly, ensure that the maximum power loss (Ploss) dissipated by the semiconductor in the considered application, as well as the thermal properties of the system (packaging, heat sink), do not result in a junction temperature higher than the maximum allowed for the module.

Aside from voltage, current, and switching frequency, power device compactness, ease of installation (wiring and heat sink), ease of maintenance (replace parts if damaged), thermal properties, and cost are all important factors in switching device selection. The goal is to create a switching device with a small footprint, easy heat dissipation, simple maintenance, and a low cost. In reality, however, these conditions are diametrically opposed. A compact relay can heat up faster than a standard-size device.

As a result, the power rating of a compact switching device is typically lower. Due to heat dissipation constraints, a compact design with embedded systems may not be possible if the power rating is too high. Multiple power switches are frequently integrated into a compact power module. If one of the switches fails, the entire module must be replaced. The compact module with switches is less expensive than the sum of multiple single switches. However, the compact module's potential maintenance fee is higher than that of single switches. Three different popular IGBT module package types and their corresponding circuit symbols. The detailed comparison using different IGBT packages to form the same power-rating inverter it should be noted that each packaging has advantages and disadvantages and can meet the needs of various applications.

Semiconductor Power Modules

The power sources for different electronic subsystems are managed by semiconductor power modules, which are electronic devices. Aerospace, automotive, motor control, and power generation are among the industries in which semiconductor power modules are used. Power modules are another name for them. Diodes, rectifiers, and Insulated Gate Bipolar Transistors (IGBTs) are often used in their construction.In infrastructure systems, electricity is transferred from a distributed power bus to each point-of-load (POL) by use of step-down (buck) regulators. Step-down converters are able to change a voltage source (usually 5V to 25V or greater) into a lower regulated voltage (generally 0.5V to 5V). They also convert a voltage from an input source to a lower output voltage. A difficulty for system power supply design engineers arises from the use of 20–40 point-of-load (step-down) converters in more contemporary infrastructure systems, each with a distinct need for output voltage and output current. Many designers are exploring employing power modules rather than conventional discrete POL designs to address the issue of building the power sub-system for these systems.

A crucial aspect of the design is choosing the output capacitor. The power supply's load transient performance is determined by the output capacitance. To reduce voltage overshoot and ripple at a step-down converter's output, output capacitance is necessary. Insufficient output capacitance results in poor load transient performance or instability, and low output capacitance combined with high equivalent-series resistance (ESR) in the output capacitor results in excessive voltage ripple. Typically, during design, the maximum permitted output voltage overshoot and ripple are set. You must thus add an output capacitor with sufficient capacitance and a low ESR in order to comply with the ripple criteria for a step-down converter circuit.

The power supply's input capacitor is used to lower ripple voltage at the input and suppress noise at the input. The amount of the input ripple voltage is affected by a number of variables, including load current, duty cycle, and switching frequency. Directly at the regulator's input, ceramic capacitors lessen the magnitude of ripple voltage. The very low ESR required to decrease ripple voltage amplitude is only found in ceramic materials. To function properly, these capacitors must be positioned near to the regulator input pins.

The total efficiency of the buck converter will be determined by the careful selection of the upper and lower MOSFETs. The total efficiency will be impacted by switching losses and the power MOSFETs' on-resistance. To guarantee that the design meets the stability standards over the specified operating circumstances, the compensating components must be carefully chosen. The positioning of the external components may also impact how well the power supply works. In order to reduce noise and increase system effectiveness, designers must adopt the best possible layout. For every power rail, the complete operation must be carried out again. The procedure must be carried out 20 times if the system has 20 point-of-load power rails, which may rapidly become a difficult undertaking for a power subsystem designer.

Use of a Power Module

When choosing a power module, system designers will weigh cost, design effort, and performance. Designers may decide to utilize a discrete regulator for systems with 1–5 power rails in order to save costs and fulfil the deadline for going to market. The design of the power sub-system, however, gets difficult and demands a lot more design work as the number of power rails and current rating rise. Designers may choose to employ a power module solution to address this issue. The cost of ownership of a distinct design will be taken into account by designers. The bill of materials (BOM) cost plus the time spent designing and testing the design by the power designer make up the cost of ownership. For discrete designs, extra costs include manufacturing and assembly charges as well as potential redesign revisions. How many of the building parts of the discrete architecture may be integrated into a power module. The PWM controller, power MOSFETs, inductor, and compensation network are all included in the package as part of a power module. To finish a design, the designer often simply has to choose the input and output capacitors.

To meet the demands of infrastructure systems, Renesas provides a broad spectrum of digital and analogue point-of-load power modules. Renesas power modules are entire DC/DC power sub-systems. These modules shorten design cycles, save costs, and free up board space thanks to their industry-leading power technology. With high current operation and high power density without the need for an external heat sink or fan, Renesas's optimized thermal packaging technology offers superior thermal performance while lowering system costs.

Vicor has developed a competence for power modules that includes product design, manufacture, simulation, and tool selection. Vicor is able to help power systems designers deploy high-performance power delivery networks (PDNs) quickly and easily, from the power source to the point-of-load (PoL), for end systems spanning numerous industries, including (automotive, AI/data centre, defense and aerospace, LED lighting, etc.). With a methodology that also offers other power system benefits like a smaller power system footprint, high efficiency, and a quicker time to market, this modular power component approach represents a new standard within the power industry. It addresses the growing power needs of contemporary, high-performance end systems.

The need for power modules

The networks that distribute power to various end units in many sectors are now developing quickly. Since the power needs for these many systems varied greatly from one another, a modular power component technique must be used with the greatest amount of flexibility.

Vicor offers a variety of modular power solutions, such as:

1. Modules for AC-DC and DC-DC
2. 50W to more than 50kW of power
3. a few amps to 1,000A+ in current
4. voltages between 0.1 and 1,000 volts
5. Converters and regulators, both isolated and not isolated
6. converters with preset and regulated ratios

In addition to the aforementioned, there are many control elements including telemetry, compensation, and programmability, as well as any possible industry/safety certifications.A thorough power module strategy is required to accommodate various PDNs in various sectors with an optimized solution. Utilizing power modules is consistent with the advantages of mass customization. Offering distinctive PDNs that are optimized for various end systems while taking use of standard design and manufacturing processes is made possible by mass customization. Faster time-to-market, dependability, reduced technological risk, and cost control are further benefits of common, scalable design and manufacturing processes.

The networks that distribute power to various end units in many sectors are now developing quickly. Since the power needs for these many systems varied greatly from one another, a modular power component technique must be used with the greatest amount of flexibility. Vicor offers a variety of modular power solutions, such as:

The following are the major components of this power module approach:

Modular power component design technique the end designer's ability to choose, configure, optimize, and supply a unique power administration network made up of several power modules. Power module design – power modules are manufactured through a standard manufacturing method and may be readily customized by utilizing:

1. Topologies for flexible power switching and control systems.
2. Packaging that can be customized and scaled.

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CHAPTER 4

TORQUE PRODUCTION

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The force that may cause an item to revolve along an axis is measured as torque. In linear kinematics, force is what drives an object's acceleration. Similar to this, an angular acceleration is brought on by torque. As a result, torque may be thought of as the rotating counterpart of force. The axis of rotation is a straight line along which an item rotates. Torque in physics is only a force's propensity to spin or twist. Torque is referred to using a variety of terms, including moment and moment of force. The moment arm or lever arm is the measurement of the separation between the point of exerting force and the axis of rotation.If there is an air-gap, the equation used to compute the force on the conductor may no longer be valid. The answer to this observant question is that the Weld formed by the current-carrying conductors on the rotor will undoubtedly affect the original Weld (i.e. the Weld existing when no current was flowing in the rotor conductors). But, in the majority of motors, the force on the conductor may be computed appropriately by multiplying the current by the 'initial' Weld. This is incredibly lucky in terms of estimating the force, but it also has a logical sense to it. For example, we would not anticipate any force on the current-carrying conductor if there was no externally imposed Weld, even if the current in the conductor will create its own Weld (upwards on one side and downwards on the other). Hence, because we only acquire a force if there's an external Weld, it seems that all of the force must be attributed to that Weld alone[1], [2].

When we cons6der the action and response principle, the second issue emerges. Since there is a torque on the rotor, there must be an equal and opposite torque also on stator; so, we could question whether the process of torque creation can be depicted using the same assumptions that we used to acquire the rotor torque. Indeed, there is always an equal and opposite torque on the rotor, which is why it is typically vital to secure a motor. Torque is created on the stator in certain machines (for example, the induction motor. The combination of the air-gap FLUX density and the generator currents produces torque on the stator in the same manner as the FLUX density produces torque on the rotor. With other motors (for example, the D.C. motor we've been studying), there is no straightforward physical explanation that can be used to calculate the torque on the stator, but it is equal and opposite of the force on the rotor.

The Final question refers to the resemblance between the setup shown and the Weld patterns created, for example, by electromagnets employed to lift automobile carcasses in a salvage yard. With the high force of attraction that lifting magnets can generate, shouldn't we anticipate a high radial force between the stator pole and the iron body of the rotor? And, assuming there is, what prevents the rotor from being dragged over to the stator. Again, the affirmative answer is that there is a radial force due to magnetic attraction, just as there is in a lifting magnet or relay, though the mechanism by which the magnetic Weld exerts a pull as it enters iron or steel is completely different from the 'BIl' force we have been looking at so far.The force of attraction per unit area of pole-face comes out to be equal to the square of the radial FLUX density, and with typical airgap FLUX densities of up to 1 T in motors, the force per unit area of rotor surface works out to be about 40 N=cm 2. This implies that the overall radial force may be extremely large: for example, the force of attraction on a short pole-face of just 5 10 cm is 2000 N, or about 200 Kg. This force adds nothing to the motor's torque and is just an unwanted by-product of the 'BIl' mechanism we use to generate torques on the rotor conductors[3], [4].

In most machines, the radial magnetic force beneath each pole is much greater than the tangential electromagnetic force on the rotor conductors, and thus tends to drag the rotor onto the pole, as the question indicates. Nevertheless, the majority of motors are built with an even number of poles evenly distributed around the rotor, and the FLUX density in each pole is the same, such that the resulting force on the whole rotor is, in principle, zero. In reality, even minor eccentricities cause the Torque to be stronger under the poles in which the air-gap is less, resulting in an imbalanced pull and loud running and premature bearing wear.

Magnitude of torque

Returning to our original topic, gives the force on each conductor, and it follows that the total tangential force F is determined by the FLUX density created by the Weld wrapping, the number of conductors on the rotor, the present in each, and the length of the rotor. The resulting torque or couple1 (T) is proportional to the rotor radius (r) and is given by

$$T = Fr$$

The beauty of slotting

The air gap would have to be at least comparable to the wire diameter, and the conductors would have to be fastened to the rotor in order for the turning force to be transmitted to it. The oldest motors were constructed in this manner, with string or tape used to connect the conductors to the rotor.However, a large air-gap introduces unwanted high-reluctance into the magnetic circuit, necessitating a large number of turns and a high current to achieve the appropriate Flux density only in air-gap. This causes the Weld winding to grow quite large and to use a lot of electricity. The early (nineteenth-century) pioneers quickly came up with the concept of partly sinking the conducts on the rotor into grooves cut parallel to the shaft, with the goal of reducing the air-gap so that the exciting windings may be smaller. This worked incredibly well because it offered a more positive place for the rotor windings, allowing the force on them to be passed to the rotor body.

Soon after, the conductors were recessed into deeper and deeper slots until they no longer stood proud of the rotor surface and the air-gap could be made as narrow as was compatible with the necessity for mechanical clearances between the stator and the rotor. The new ‘slotted' machines performed well, and its pragmatic designers were undeterred with rumblings of dissatisfaction from skeptical theorists.Almost all of the FLUX would now flow via the teeth's appealing low-reluctance channel, leaving the wires exposed to the slots' extremely low leakage FLUX density. They reasoned that since the conductors would only be subjected to a very low FLUX density, little or no 'BIl' force would be created on them[5], [6].

The sceptics were correct in that the FLUX did XOW down the teeth; yet, there was no doubting that motors with slotted rotors generated the same torque as those with air-gap conductors, given that the average FLUX densities at the rotor surface were the same. The search for an explanation preoccupied some of the leading thinkers long after slotting became the norm, but eventually it became theoretically possible to verify that the total force remains the same as it would have been if the conductors were actually in the FLUX, but almost all of the tangential force now acts on the rotor teeth rather than the conductors themselves.

This is really encouraging news. By inserting the conductors into slots, we simultaneously minimize the resistance of the magnetic circuit and transfer the force from the conductors to the sides of the iron teeth, which are strong and capable of transmitting the generated torque to the shaft. Another advantage is that the insulation surrounding the conductors no longer needs to convey circumferential forces to the rotor, making its mechanical qualities less important. Seldom do preliminary tests with one goal provide positive results in practically every other significant area.

But, there are some issues. To maximize torque, we'll want as much current as possible flowing through the rotor conductors. Certainly, we will work the copper at the greatest feasible current density (usually between 2 and 8 A=mm 2), but we will also want to maximize the cross-sectional area of the slots in order to accommodate as much copper as possible.This will drive us towards broad slots and, as a result, small teeth. Nevertheless, since the Flux must flow radially along the teeth, making the teeth too thin will cause the iron in the teeth to saturate, resulting in a poor magnetic circuit. There is also the option of raising the depth of the slots, yet this can't be done too far since the center area of the rotor iron, which must transfer the FLUX from one pole to another, would get depleted and saturate at what influences the torque that can be achieved from a given rotor size, as well as how speed affects power output[7], [8].

Specific Loadings and Specific Output

At the critical air-gap zone, design compromise is unavoidable, and designers must continuously exercise their talents to strike the optimal balance between the convicting demands on space made by the FLUX (radial) and the current (axial).As with most engineering design, norms evolve as to what can be accomplished in respect to certain machine sizes and kinds, and motor designers often work in terms of two factors, the specific magnetic loading and the specific electric loading. As we shall see later, these settings have a direct impact on the motor's output.The specific magnetic loading (B) is the average of the magnitude of the radial FLUX density throughout the rotor's whole cylindrical surface. The average FLUX density is always smaller than the FLUX density in the teeth due to the slotting, but in order to compute the magnetic loading, we imagine the rotor as smooth and calculate the average density by dividing the total radial FLUX from each 'pole' by the surface area beneath the pole.

The axial current per meter of circumferential on the rotor (typically indicated by the symbol (A), the A standing for Amperes) is the specie electric loading. The axial current in a slotted rotor is concentrated in the conductors within each slot, but just to calculate A, we imagine the total current being distributed uniformly around the circumference (in a manner similar, but with the individual conductors under each pole represented by a uniformly distributed 'current sheet'). For example, suppose we find Wave slots, each carrying a flow of 40 A, beneath a pole with a circumferential width of 10 cm.Several variables influence the values that may be used in motor design, but the specific magnetic and electric loadings are restricted by the qualities of the components (iron for the FLUX, and copper for the current), as well as the cooling system used to eliminate heat losses. Since the saturation characteristics of most core steels are comparable, the specific magnetic loading somehow doesn't vary considerably from machine to machine.

Nevertheless, depending on the method of cooling employed, the specific electric loadings vary quite a little.

Despite the low resistivity of the conductive materials, heat is created by the flow of current, thus the current must be controlled to a value that does not harm the insulation due to an excessive temperature increase. The larger the electric loads, the more efficient the cooling system. For example, if the motor is completely enclosed and lacks an internal fan, the density in the copper must be substantially lower than in a comparable motor with a fan to supply a constant flow of ventilation air. Similarly, windings that have been entirely saturated with varnish may be worked considerably harder than those that are surrounded by air, since the solid body of enveloping varnish offers a far better thermal channel for heat to go to the stator body. Overall size also influences permitted electric loads, with bigger motors often having larger values than small ones. In reality, the crucial thing to remember is that, unless an unusual cooling system is used, most motors (induction, D.C. etc.) of a given size have about the same specification loadings, independent of type. As we shall see later, this implies that motors of equal size have comparable torque capacities. This truth is not frequently acknowledged by users, yet it is always important to remember[9], [10].

Torque and motor volume

In light of the above reasoning, we may calculate the total tangential force by first for a rotor surface area of width w and length L. The axial current showing with in width w is provided by I 14 wA, and because all of this current is exposed to the radial FLUX density B on average, the tangential force is supplied by B W6L. Since the surface area is WL, the force per unit area is B A. The average tangential stress across the rotor surface is expressed by the sum of the two specific loadings.To calculate the total tangential force, multiply the total force by the area of the curved surface of the rotor, and to get the total torque, multiply the total force by the radius of the rotor. As a result, the total torque for a rotor of diameter D and length L is given by

$$T = (\overline{B}\,\overline{A}) \times (\pi DL) \times D/2 = \frac{\pi}{2}(\overline{B}\,\overline{A})D^2L$$

This is an incredibly significant equation. Since the term D2L is proportional to the rotor volume, we can show that the torque from any motor is proportional to the rotor volume for given values of the specific magnetic and electric loadings. We may pick between a long thin rotor and a short fat rotor, but once the rotor area and certain loadings are specified, we have effectively computed the torque.It is important to note that we have not concentrated on any one kind of motor, but have tackled the issue of torque output from a very broad perspective. In essence, our findings reflect the fact that all motors are built of iron and copper, and the only difference is how these components are disposed of. We should also recognize that in reality, the total volume of the motor is more essential than the volume of the rotor. Yet, we discovered that, regardless of motor type, there is a pretty tight connection between total volume and rotor volume for motors of comparable torque. As a result, we can make the bold but typically correct claim that the total volume of an engine is defined by the torque it must generate. There are exceptions to this rule, but it is incredibly helpful as a general guideline in motor selection. Having shown that torque is proportional to rotor volume, I must now shift our attention to the issue of power production.

Specific output power importance of speed

When deriving a power expression, people who are more experienced with linear rather than rotational systems may find a quick detour useful. The work piece or energy in the SI system is the Joule (J). A joule is the work done by a charge of one newton travelling one meter in its own direction. As a result, the work (W) by a force F moving a distance d is given by:

$$W = F \times d$$

With F in newton's and d n meters, W is plainly in newton-meters (Nm), indicating that a newton-meter is equal to a joule. In rotary systems, it is easier to think in terms of torque and angular distance rather than force and linear distance, yet they are inextricably related as we can see when a tangent force F is applied at a radius r from the rotational axis. The torque is easily defined as

$$T = F \times r.$$

Assume the arm rotates over an angle u, resulting in a circumferential distance traversed by the force of r u. The force's job is then assigned byin a linear system, work equals force times distance; in a rotary system, work equals torque times angle. Since torque is measured in newton-meters and angle in radians (which is equal to zero), the units of work done are Nm or Joules, as predicted. Obviously drive the motor at the greatest conceivable speed to produce the highest possible specific output for given values of the specific magnetic and electric loadings. The apparent drawback of a tiny high-speed motor and gearbox is that the acoustical noise (both from the motor and from the power transmission) is greater than with a bigger direct drive motor. When noise levels must be kept low (as in ceiling fans), a direct drive engine is chosen, despite its bigger size.

Energy Conversion Motional E.M.F

Turn away from discussions of what defines a motor's overall capabilities and examine the behavior of a rudimentary linear machine, which, despite its evident simplicity, captures all of the essential electromagnetic energy conversion processes that occur in electric motors. How the process of converting energy from electrical to mechanical energy is neatly described in an 'equivalent circuit,' from which all major characteristics of motor behavior can be anticipated. This circuit will answer issues such, and "What determines the stable speed and current. The issue of motional E.M.F, which is discussed next, is central to such concerns.

We've previously seen how force (and so torque) is generated when current-carrying conductors are exposed to a magnetic Weld. The force is determined by equation, which demonstrates that the force will be constant as long as the FLUX density and current stay constant. We can observe that the force is independent of whether the conductor is fixed or moving. On the other hand, comparable movement is required for the creation of mechanical output power (as opposed to torque), and as we have seen, output power is supplied by the equation P 14 TV. We shall now show that the existence of relative motion between the conductors and the Weld necessarily introduces ‘motional a.m.,' and that this motional E.M.F is critical in characterizing the energy conversion process.

Elementary motor stationary conditions

It is made up of an active length l conductor that may move horizontally perpendicular to a magnetic Flux density B. It is assumed that the conductor has a resistance (R), a direct current (I), and travels at a velocity (v) perpendicular to the Weld and the current A string is attached to the conductor and passed across a pulley to support a weight, with the tension in the string serving as a mechanical 'load' on the road. Friction is believed to be non-existent.We don't have to be concerned about the many tricky logistics of building such a machine, not least how we'll keep electrical connections to a moving conductor. The crucial thing is that, although this is a fictitious setup, it accurately replicates what occurs in a real motor and helps us to obtain a good grasp of how genuine machines work act before confronting considerably more complicated arrangements by examining the conductor's electrical input power.

For the sake of this discussion, assume that permanent magnets supply the magnetic Weld (B). After the Weld has been created (when the magnet was first magnetized and set in position), no further energy is required to maintain the Weld, which is fortunate given that an inert magnets is incapable of continually providing energy. As a result, none of the energy required in obtaining mechanical output from this primitive ‘motor' originates from the magnet. This is critical: the Weld system, whether powered by permanent magnets or 'exciting' windings, serves solely as a catalyst in the energy conversion process and provides nothing to mechanical output power.While the conductor is maintained stationary, the force exerted on it, accomplishes no work, therefore no mechanical output power is required, and the only electrical input power required is that necessary to move the current through the conductor. Since the conductor's resistance is R and its current is I, the voltage that must be provided to the ends of the rod from an external source is V1 14 IR, and the electrical input power is V1I or I 2R. All of the electric input power will appear as heat within the conductor under these circumstances, and the power balance may be described by the equation.

Equivalent Circuit

In circuit terminology, the conductor resistance and motional E.M.F indicate what is occurring in the conductor (albeit in fact, the E.M.F and resistance are dispersed, not lumped as distinct elements). The voltage V on the left represents the externally applied resource that generates the current (the old-fashioned battery symbol is intentionally used to distinguish the applied voltage V from the induced E.M.F E). We can see that the induced motional E.M.F is revealed to be opposing the applied voltage in the ‘motoring' situation have been discussing. Using Kirchhoff V's law, we derive the voltage equation as follows (Figure 5.1):

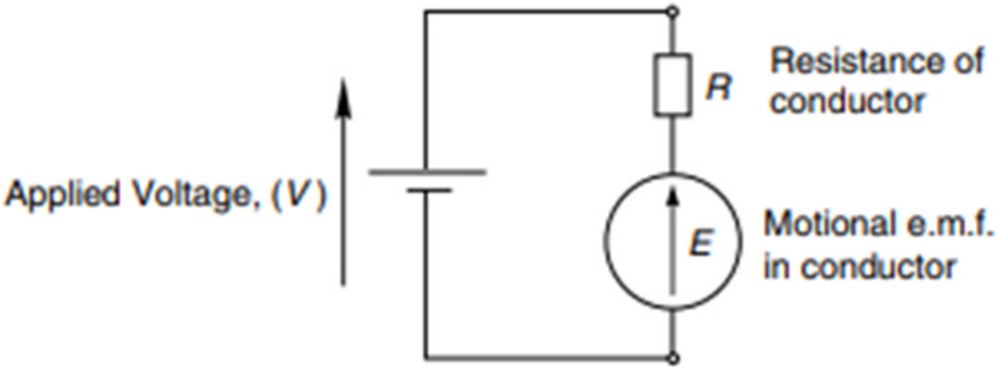

Figure 5.1: Represent the Equivalent circuit of primitive D.C motor.

It is worthwhile to investigate what may be learnt from these equations since, this basic elementary ‘motor' encompasses all of the important characteristics of actual motors. Lessons learned at this level will be important later, when we examine how real motors operate.If the applied voltage V is less than the E.M.F E, the current will be positive, and electrical power will flow from the source, resulting in driving motion. If E is greater than V, the current will XOW return to the source, and the wire will operate as a generator. This intrinsic capacity of electrical energy converters to switch from driving to producing without user intervention is a highly valued attribute. Our basic setup is basically a machine that can function as both a motor and a generator.

Another thing to keep in mind is that mechanical power is just the motional E.M.F multiplied by the current. This outcome is, once again, generally applicable and readily recalled. We may have to be a little more cautious if the E.M.F and current are not simple D.C. numbers, but the essential notion will always remain true.

Lastly, it goes without saying that in a motor, we want as much of the electrical input power as possible transferred to mechanical output power and as little as possible converted to heat in the conductor. Since the output power is EI and the heat loss is I 2R, we can see that ideally, EI should be considerably more than I 2R, or E should be much greater than IR. In the analogous circuit, this indicates that the motional E.M.F (E) accounts for the bulk of the supplied voltage V, and only a little portion of the supplied voltage is utilized to overcome the resistance.

Motoring condition

Motoring indicates that the conductor is moving in the same direction as the electromagnetic force (BI) and at a speed that is less than the applied voltage V. Thus far, we've assumed that the load is constant, such that under steady-state circumstances, the current remains identical at all speeds, with the voltage increasing with speed to account for the motional E.M.F This was a useful strategy for determining steady-state power relationships, but it is seldom representative of actual operation. We now consider how the moving conductor will act when the applied voltage V is constant, since this correlates more closely to the usual working of a real motor.The next part will certainly be more involved than the previous one since we will analyses how the motor grows of one speed to another, as well as what occurs under steady-state circumstances. The study of the transient behavior of our basic linear motor, as in other fields of dynamics, introduces extra factors such as the conductor mass (corresponding to the inertia of a genuine rotary motor) that are missing from steady-state considerations.

Behavior with no mechanical load

The only force acting on the conductor is that created by its own electromagnetic field. Our major focus will be in what determines the constant speed of the primitive motor, though we have to first investigate what occurs when the voltage is first applied.When the voltage V is supplied to a stationary conductor, the current will quickly grow to a value of V/R since there is no motional E.M.F and the only factor that restricts the current is the resistance.

Strictly speaking, we should account for the effect of inductance in slowing the increase of current, but we will omit it here for the sake of simplicity. Since the resistance is low, the current is strong, and a high force is created on the conductor. As a result, the conductor will accelerate at a rate equal to the force acting on it divided by its mass.When it accelerates, the motional E.M.F Increases in proportion to the speed. When the motional E.M.F opposes the applied voltage, the current falls reducing the force and therefore the acceleration, but the speed continues to grow. As long as there is an accelerating force, i.e. current in the conductor, the speed will grow. According to equation 1.21, the current will eventually decrease to zero when the speed reaches a level where the motional E.M.F equals the applied voltage. As a result, the speed and current fluctuate, both curves have the exponential form characteristic of systems driven by a first-order deferential equation. The finding that the steady-state current is zero is consistent with our prior discovery that the steady-state current is determined by the mechanical load (in this instance zero).

We can see that in this idealized case (with no load applied and no friction forces), the conductor will continuing to move at a constant speed since there is no acceleration because there is no net force acting on it. Of course, no mechanical power is created since we assumed there is no opposing force on the conductor, and no input power is produced because the current is zero. The only difference between this hypothetical state and the so-called 'no-load' condition in a motor is that a motor will have some friction (and hence draw a modest current), but we have assumed no friction to simplify the explanation.

Although no power is required to keep the frictionless and unloaded conductor moving once it is up to speed, we should note that during the whole of the acceleration phase the applied voltage was constant and the input current fell progressively, so that the input power was large at First but tapered-ova as the speed increased. Throughout the run-up period, energy was continuously provided from the source; part of this energy is lost as heat in the conductor, but most of it is stored as kinetic energy, which, as we shall see later, may be recovered.

An ingenious self-regulating system is clearly at work here. While the conductor is stationary, a strong force acts on it, but as the speed increases to its goal value, the force tapers-oV, corresponding to the back E.M.F being equal to the applied voltage. Returning to the motional E.M.F formula, we can derive an expression for the no-load speed (vo) by equating projected applied voltage and the back E.M.F, which provides

$$E = V = Blv_0, \text{ i.e. } v_0 = \frac{V}{Bl}$$

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CHAPTER 5

PRIMITIVE MOTOR

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Primitive Reflexes

Primitive reflexes are reflexive, stereotypical motions that originate in the brainstem and don't involve the cortices (thinking). They are necessary for the fetus' survival, development, and growth throughout the first several months of life. But when the brain's higher, more complex center's start to grow, these rudimentary reflexes start to bother us and need to be suppressed for optimal neurological organization of the brain to emerge.Primitive Reflexes may obstruct social, scholastic, and motor learning if they are kept beyond the first year of life (at the latest). In essence, our perception of and reaction to our environment that is, conscious life may be altered. Disorder, and other neurodevelopmental problems still maintain some of their rudimentary reflexes, which contributes to their symptoms and degree of dysfunction. Each reflex is linked to one or more of the following sensory processing systems: vestibular, proprioceptive, interceptive, auditory, taste, tactile, and/or olfactory. A kid or person may thus have impairment in one or more of the sensory processing systems if preserved. This may result in sensory processing disorder, as the name suggests[1], [2]

Electric motors are so prevalent in daily life that we almost every stop to think about them. For instance, when we turn on an electric drill, we implicitly assume that it will run quickly up to the proper speed. We do not wonder how the drill determines what speed it should operate at, or how the power drawn from the supply drops to a very low level once it has reached the desired speed. The power consumed from the mains increases when we put the drill to work and decreases automatically when we want, all without our assistance.The simple motor, which is nothing more than a configuration of steel laminations and copper coils, is undoubtedly a brilliant energy converter that deserves careful examination. Gaining a fundamental grasp of the motor's operation will enable us to see both its advantages and disadvantages, as well as how the addition of additional electrical controls might improve the motor's already exceptional performance[3], [4].

Different types of compositional components for movement are possible. Overall kinematics, force interactions with the environment, underlying body dynamics, and impedance regulation are all components of motor activities. These in turn rely on the ways in which muscles are controlled and activated. When should we start looking for compositional MPs in the area of motor neuroscience? MPs have been examined by several writers on various levels. MPs have been classified as kinetic elements (force-based, such as viscoelastic force-field primitives and their associated muscle synergies, kinematic elements (i.e., patterns of motion without regard to force or mass, such as strokes or cycles, or neural drive circuits. The most fundamental MPs must be useful as compositional elements in each of these contexts because the nervous system appears to organize both the executed motion and prepare the contingent acts and corrections needed for any common or unexpected perturbations in any complex body motion. To put it another way, the fundamental MPs must be sufficient building blocks to quickly construct the kinematic, kinetic, impedance, and contingent response aspects of a complete both kinematic and kinetic components are presumably included in our current computational knowledge of motor control. It is still challenging to combine the kinetic/synergy and kinematic MP frameworks into a single compositional method. In all domains, as will be explained below, investigations that significantly improve our knowledge of movement are still ongoing. According to the mechanical relationships between them, I treat the kinetic MPs as the basic building blocks and the kinematic MPs as more developed here, although a satisfactory union of the two in motor neuroscience is ultimately required.

Storage, Handling and Preparation of Coal

Fuel storage and subsequent treatment are necessary because of the uncertainty surrounding its supply and transportation. Stocking coal has drawbacks of its own, such as inventory buildup, space limitations, quality degradation, and possible fire dangers. Oxidation, wind, and carpet loss are some other small losses connected to coal storage. A coal's 1% oxidation has the same impact as coal's 1% ash content, while wind losses might make up between 0.5% and 1.0% of the overall loss.Keeping carpet loss and loss from spontaneous combustion to a minimum is the major objective of effective coal storage. Carpet loss results from the development of a soft carpet made up of coal, dust, and dirt. On the other hand, if temperature gradually rises in a coal heap due to oxidation, coal in storage may spontaneously burn.

The following are the steps that would aid in decreasing carpet losses:

1. Creating a solid surface on which to lay coal.

2. Creating typical storage compartments out of brick and concrete.

Coal handling techniques in the processing industry vary from manual to conveyor systems. It would be wise to handle coal as little as possible to prevent additional fines production and segregation effects.Propane and butane make up the majority of LPG, with a little amount of propylene and butylene and some lighter C_2 and heavier C_5 fractions. The LPG spectrum includes butane (C_4H_8), propane (C_3H_8), normal and iso-butane (C_4H_{10}), and propane (C_3H_6).

LPG may be characterized as those hydrocarbons that, at normal atmospheric pressure and temperature, are gaseous but can be condensed to a liquid condition by the application of moderate pressures. They are kept and transported under pressure as liquids even though they are often utilized as gases since it is more convenient and manageable. When liquid LPG evaporation occurs, nearly 250 times as much gas is produced.The main fuel used to generate electricity in thermal power plants is coal. In India, coal-fired power stations provide the majority of the nation's electricity. Depending on the distance and accessibility of different modes of transportation, coal is transported from coal blocks or mines to these power plants by belt conveyors, rail, or ship. The coal is then dumped in a coal yard and piled up for storage[5], [6]. A healthy focus has to be placed on its bulk storage and appropriate treatment in order to generate electricity at the highest possible efficiency. For optimal combustion, coal preparation before putting it into the boiler is essential. Large and irregular coal lumps may result in the following issues:

1. Inadequate combustion and furnace temperature.
2. An increase of ash that hasn't burned.
3. A decrease in thermal effectiveness

Crushed coal ensures efficient combustion and turns into a cost-effective asset for power production in thermal power plants after it has been reduced in size by crushing and pulverizing.Butane and propane are each around 1.5 times as heavy as air in terms of density, making LPG vapor thicker than air. Therefore, the vapor may seep down the ground and into drains, dropping to the lowest one of the surroundings, where it might ignite far from the leak's source. Vapour will gently disperse in quiet air. Even little amounts of the liquefied gas may escape and produce massive volumes of vapor and air combination, which poses a significant risk. All LPGs must be odorized in order to help in the identification of air leakage. Where LPG is kept, there has to be enough ground level ventilation. LPG cylinders shouldn't be kept in basements or cellars since these spaces lack ground-level ventilation.

Behavior with a mechanical load

The back E.M.F should be equal to the applied voltage, and the ideal scenario is one in which the term IR in equation 1.19 is insignificant. The steady-state speed would thus be exactly proportional to the input voltage and independent of the load, giving us a perfect machine with an efficiency of 100%.The size of the machine affects how closely we can simulate the ideal circumstance stated above in real life. Small motors, like those used in wristwatches, are terrible because their motional E.M.F is extremely low and much of the supplied voltage is consumed by overcoming conductor resistance. As a result, these motors are considerably better at creating heat than mechanical output power. Small machines, like those found in hand tools, perform much better when the motional E.M.F makes up around 70–80 percent of the applied voltage. Industrial machines are significantly more efficient since even the biggest ones (of several hundreds of kW) only consume one or two percent of the supplied voltage to overcome resistance.

General Properties of Electric Motors

The principles of electromagnetism control all electric motors, and the limitations imposed by the materials (copper and iron) used to create them are basically the same for all electric motors. Therefore, it shouldn't come as a surprise when we discover that all motors, regardless of kind, have several essential characteristics.The most important concepts to remember are consequently listed below, each with a short remark. Experience shows that users who keep these fundamental concepts in mind will find it easier to comprehend why one engine seems to be superior to another and will feel much more confident when given the challenging job of evaluating the advantages and disadvantages of competing motors.Any motor will produce greater power if its electric circuit is operated more vigorously, or if the current is permitted to grow. The windings' permitted temperature increase, which varies depending on the kind of insulation, is often the limiting factor. The permitted temperature increase is 100 K for class F insulation (the most popular), and 125 K for class H insulation. Therefore, assuming the cooling stays the same, adopting the better-grade insulation alone might result in a larger output. Alternately, if the cooling system is enhanced, with a given insulation, the output may be raised. For instance, a throughventilated motor may provide up to double the output power of an otherwise equivalent but completely enclosed machine.In comparison to small motors, big motors typically have a substantially larger specific electric loading and a somewhat higher specific magnetic loading. Together, these two elements provide the greater specific torque[7], [8].

In contrast to motors of more than, let's say, 100 kW, which have efficiencies over 95%, extremely tiny motors (such as the 1% in a watch) are intrinsically highly inefficient. The causes of this scale effect are complicated, but they may be traced back to the fact that in big electromagnetic devices, the resistance volt-drop component can be made relatively modest, but in tiny ones, the resistance becomes the dominating term.

Kron's Primitive Model

Any type of motor's speed control is crucial because it enables the motor user to limit the speed to the necessary or required speed to complete a particular task. We must first comprehend and have knowledge about induction motors before talking about induction motor drives. Induction motors are self-starting, constant speed, three-phase or single-phase ac motors, to put it simply. Induction motors are referred described as having a constant speed because, in most cases, they do so dependent on the frequency of the power source and the number of windings. The speed of induction motors could not previously be adjusted to suit the situation.

Due to this drawback, despite the fact that they had benefits over dc motors, their usage was restricted. However, variable speed induction motor drives have been created as the field of drivers has advanced as a result of the availability of thyristors, power transistors, IGBTs, and GTOs. Despite being more expensive than DC drives, AC drives are replacing them due to their benefits.

In contrast, DC motors are simpler to regulate than AC motors. However, AC single phase or AC three phase power is what is commonly accessible for all industrial purposes. Therefore, there is a tremendous need for a universal speed controller that can change its configuration in response to demand and supply situations while still managing regulated speed control for both AC and DC.

The different varieties vary from one another in how these windings are excited and how they are organized. Generalized theory of electrical machines, often known as two-axis theory of electrical machines, is the result of efforts to harmonise the disparate approach of rotating electrical machines. In order to deal with all spinning electrical machinery in a systematic way using tensor analysis, Gabriel Kron created Park's Two Axis equations. Generalized theory of electrical machines is the name given to Kron's comprehensive analysis of spinning electrical machines.

Reconfigurable computing is another significant aspect that drives RUC research. Reconfigurable computing is a kind of computer architecture that processes data using extremely flexible high-speed computing fabrics like field-programmable gate arrays (FPGAs), which combines some of the software's flexibility with hardware's high performance. The ability to significantly alter both the control flow and the data stream itself sets employing FPGAs apart from using conventional microprocessors. The ability to modify the hardware while it is running by "loading" a new circuit onto the reconfigurable fabric is the primary distinction between bespoke hardware, or application-specific integrated circuits (ASICs), and the former. A computer with a common CPU and a variety of "reconfigurable" components was Gerald Estrin's idea. The primary processor would manage how the reconfigurable hardware behaved. The hardware might be changed after the work was completed to do another task. As a consequence, a hybrid computer architecture was created, combining the speed of hardware with the flexibility of software[9], [10].

DC Motor

In the past, low-speed elevators were powered by AC-2 motors via the use of a worm gearbox. However, DC motors were used for high-speed elevators. Because DC motors often have more starting torque than AC motors, this is the case. A magnetic flux, f, is generated around the stator poles as a result of DC passing through the corresponding field windings. On the rotor's surface, there are conductors that have additional DC current flowing through them, creating an armature magnetic flux of An all the way around the pole. There is always an angle between f and A because of the way they are organized; they never coincide with one another. This interaction between the two magnetic fluxes results in a torque that is dependent on the intensity of each flux and the angle at which they are separated. This interaction is often characterized by repulsion.

Power source for the commutator, the brush, and then the rotor winding. The renowned Fleming 'left hand motor rule' can be used to determine the force acting on the rotor conductor: the first finger of the left hand points in the direction of the field flux produced by the stator, the middle finger points in the direction of the current flow along the rotor conductor, and the thumb points in the direction of the force produced as a result.

It should be observed that both the field flux from the stator and the armature flux from the rotor stay largely unaltered with the aid of the revolving commutator. As a result, the torque is constant.The stator windings of a DC motor may be powered in essentially two different ways, but the rotor flux is provided using the same fundamental idea. The older technique, known as the Ward-Leonard or motor-generator (MG) set included manually coupling a DC generator with a three-phase inductor motor. The induction motor rotates at a very steady pace. By altering its field current, the generator may change the DC supply voltage. The drive's DC motor receives the variable supply voltage. Rotation speeds increase with voltage, and vice versa. This kind of drive is suitable for high-speed lift applications since it has a high beginning torque.

ACVV and Variable-Frequency (ACVVVF) Drive

Despite the fact that an ACVV drive may alter the pace at which a lift operates and needs less maintenance than a DC drive, there are three significant drawbacks. The speed control range is very limited. The load torque ought to be much less than the maximum torque allowed by the rated voltage supply, second. Third, because of the significant energy waste, it is not resource conservative. As a result, since 25 years ago, ACVVVF drives have dominated the market to the point that it is now difficult to get AC-2, DC, and ACVV drives.

The supply's voltage and frequency are both modified. The torque-speed curves of a typical With certain exceptions, V/f is often maintained constant for the curves on the left side, which correspond to lower voltages, V, and frequencies, f. Say a lift, the load torque is rather constant if, for instance, the rated three-phase voltage is 480 V and the rated frequency is 60 Hz, with a V/f of around 8. When the V or f keeps rising, the speed rises along with it until the rated value is reached. This speed control model is excellent. The drive's circuit diagram is seen in Figure 8. A converter initially converts the typical three-phase supply into DC on the DC bus, where it is then further converted back into AC by the inverter, which comes with free adjustment in V and f. Power diodes are utilized in the converter, while insulated-gate bipolar transistors are often employed in the inverter.

The lift control system must attempt to stop the lift when it is descending with a vehicle load that is heavier than the counterweight load. The motor is currently feeding energy back to the inverter and DC bus. Due to the directional nature of the power diodes, this energy could not return to the three-phase supply and had to be dissipated. The brake resistor is crucial for using the energy required to ensure that the whole drive is working securely. This raises safety issues and is unfavorable in terms of energy saving.

Therefore, "regenerative braking" is a well-known concept so that energy may be returned to the power grid in a new way. Under a steady-state, low-speed, open-loop scenario, the operating principle, known as "scalar control," is effective for controlling speed. "Open loop" in this context refers to the absence of speed feedback, which is always necessary for lift functioning, rather than the presence of current feedback control.

In terms of size, weight, inertia, price, and speed, induction motors outperform DC motors, but DC motors are easier to regulate. Flux vector control of such an ACVVVF drive is required if accurate dynamic closed-loop control offering gentle acceleration and deceleration, as well as extremely low speed levelling, etc., is required. The fundamental concept behind "flux vector control" is a set of mathematical transformations that reduce a three-phase system's electrically separated voltages and currents to a two-phase system's electrically separated voltages and currents. These are known correspondingly as direct-axis vectors and quadrature-axis vectors. The two phases no longer interact and may be managed separately since they are now perpendicular to one another. One vector is in charge of the flux component, which is comparable to the field created by the stator in a DC motor, and another is in charge of the torque component, which is comparable to the armature field created by the rotor in a DC motor.

In a three-phase system, everything that changes on one phase has some effect on the other phases unless a completely balanced state can be maintained. As a result, the "scalar control mode" necessitates constant balancing. This makes it simple to establish torque control using "flux vector control" with quick adjustments. There are two subcategories under this category: direct torque control and field-oriented control.

Hybrid Motor

Even when flux vector control is used with an induction motor, the rotor magnetic field must still be generated by the stator magnetic field, which causes a slower and weaker reaction. The torque-to-motor size ratio may be significantly improved if the rotor magnetic field can be created autonomously rather than via the use of a brush and commutator as in a DC motor.

The permanent-magnet synchronous motor (PMSM) uses this technology. Permanent magnets are used in lieu of the rotor windings or bars in these motors, which has the following benefits: Lower rotor inertia; Elimination of copper loss; Increased power density and efficiency; Possibility of a bigger air gap due to higher coercive force densities; Elimination of copper loss There are, of course, drawbacks as well, including the following: Reduced rotor field flux control flexibility High cost of permanent magnets with high flux density Deterioration of magnetic properties with time Loss of magnetization when operating temperature is above Curie point.

The magnetic moments are perfectly aligned inside magnetic domains in ferromagnetic materials at temperatures lower than the Curie threshold. A temperature above that causes such alignment to eventually disintegrate. Despite these drawbacks, they are nonetheless becoming more and more common in current lift applications because to their high torque-to-size and torque-to-weight ratios and the potential for cost savings by substituting artificial metals for rare-earth ones. Axial-field motors may also be created by properly arranging the permanent magnets. The magnetic fields in traditional motors are often perpendicular to the rotor's axis of rotation.Axial-field motors have incredibly thin fields because they are all parallel to the axis of rotation. They are thus ideal for applications without machine rooms.

The brushless DC (BLDC) motor is another form of permanent-magnet motor, however this type is not often utilized in the lift business. An average energy savings of at least 25–30% may be achieved by replacing a conventional motor with a PMSM one of the same rating. It is impractical to utilize conventional motors for applications requiring extremely high speeds, such as 15 mps (3,000 fpm) or beyond, therefore PMSM becomes the sole option.

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CHAPTER 6

FORCED AND NATURAL COMMUTATION

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Commutation

The two kinds of commutation methods Natural Commutation and Forced Commutation are depending on where the commutation voltage is located.

Natural Commutation

1. When a positive half-cycle ends, the anode current passes through zero and an instantaneous reverse voltage is applied across the SCR if the SCR is connected to an AC source.
2. So that the current is stopped and the thermistor junctions have time to recharge.
3. These are needed in order to turn the SCR OFF.

Forced Commutation

1. DC circuits lack an intrinsic current zero that would disable the SCR.
2. The forward current in such circuits must be pushed to zero using a circuit outside the circuit in order to commutate the SCR; thus, the phrase forced commutation.

Thyristors are used in inverters in two separate ways.In the first case, when the inverter is used to power an essentially passive alternating current load, such as an inductor, each thyristor must be fitted. includes its own auxiliary ‘forced commutating' circuit, whose job it is to push the current through the thyristor to zero when it is time to turn 0V. The commutating circuits are highly complicated, and large capacitors are necessary to store the energy used for commutation.As a result, force-commutated thyristor converters are often large and costly. They were formerly the only option, but they are now mostly outdated, having been supplanted by MOSFET, IGBT, or GTO variants[1], [2].

When the A.C side of the bridge is linked to a three phase V (i.e. low source impedance) mains supply, thyristors may also be used to invert power from D.C to A.C this is the standard 'controlled rectifier' setup described before. In this situation, the active mains voltages naturally drive the currents in the thyristors to zero, enabling the thyristors to commutate or turn 0V automatically. As we shall see when we look into D.C motor drives, this way of operation remains crucial.

Matrix converters

Each of the converters we've looked at so far has been designed with a specific function in mind (e.g., rectifying alternating current to obtain direct current), but they all have one thing in common: they all use sequentially operated swapping devices to link the output terminals to the supply terminals. The switching components (transistors, thyristors, and diodes) in all of these circuits can only conduct current in one way, limiting the circuit's capacity to function with reverse power flow: for certain circuits, such as the basic diode rectifier, reverse power XOW is not feasible at all.

The ideal power-electronic converter would convert power in either direction between different schemes of any voltage and frequency, including direct current, and would not need any intermediary step, such as a direct current connection. In theory, this may be accomplished using an array of switches that enable any one of a set of input terminals to just be linked to any one of a set of output terminals at any one time. Not surprisingly, such converters are referred as matrix converters[3], [4].

The operation is best understood by supposing that the input voltage is that of a sinusoidal three-phase mains system, and that we know precisely what each incoming row voltage will be at any given time.Assume we want to create a three-phase harmonic output with a specified voltage and frequency. We know what voltage we want, say, between lines A and B, and we know what voltages are present between the three eagerly. Thus we turn on whatever pair of A and B switches links us to the two input lines whose voltage is closest to the required output line-to-line voltage at the moment, and we stick with it until it gives us the greatest approximation to what we want. The switching pattern changes when we use a different combination of switches to connect to a more suitable pair of input lines.

A little thought will reveal that, because there are only three different incoming line-to-line voltages to choose from at any given time, we cannot expect to synthesize a decent sinusoidal waveform with this type of discrete switching, despite the fact that this is the approach taken to derive a lowfrequency output in the cycloconverter drive. To get a good estimation to a sinusoidal waveform, we must apply chopping, which involves quickly switching on and off and modulating the output voltage amplitude. This implies that the switches must be able to operate at significantly higher frequencies than the basic output frequency, making switching loss a critical factor.To be able to transfer power in either way (such that the words input and output no longer have distinct meanings), the switches must be capable of transmitting current in both directions. Matrix converters are not yet significant in the drives market due to the lack of single affordable devices with this bi-directional current capability, but their development is attracting attention, and they look likely to emerge as improved control strategies and bi-directional switching devices become more practicable[5], [6].

Inverter Switching Devices

It does not really matter what type of switching device is used inside the inverter as far as the user is concerned, but it is probably helpful to mention the four most important families of devices in current use so that the terminology is familiar and the symbols used for each device can be recognized. The common characteristic of all four devices is that they can be turned on and off using a low-power control signal, i.e. they are self-commutating. As previously stated, the ability to switch on or 0V on demand is critical in any inverter that supplies a passive load, such as an induction motor. Each gadget is briefly explained here, along with a general indication of its most probable spectrum of applicability. Since there is significant overlap between competing technologies, it is impossible to be dogmatic and say which technology is superior, and the reader should not be shocked if one company produces a 5 kW inverter using MOSFETs while another utilizes IGBTs. The whole power electronics industry is still evolving:

additional technologies (such as those based on silicon carbide) have yet to appear on the driving scene.

The integration of the drive and protection circuitry into the same package as the switches is a continuing trend (or devices). This clearly leads to significant simplification and cost savings in the building of the whole converter.

Bipolar junction transistor (BJT) (of the two types, npn and pnp) has been extensively employed in inverters for drives, primarily in applications reaching up to a few kilowatts but several hundred volts.

The main (load) current flows into the collector (C) and out of the emitter (E), which is indicated by the arrow on the device symbol. Bipolar junction transistors were the first to be utilized for power switching. Only the npn version flow), a modest current must flow from the base (B) to the emitter When the base-emitter current is zero, the collector-emitter circuit's resistance is extremely high, and the device is switched 0V.Since the 1980s, power MOSFETs have mostly replaced BJTs in drive inverters. The MOSFET, like the BJT, is a three-terminal device that comes in two varieties: n-channel and p-channel[7], [8].

The n-channel is the most common and the primary current (load) flows into the drain (D) and out of the source (S). (Confusingly, in this situation, the load current flows in the opposite direction of the arrow on the sign.) The gate source voltage controls the MOSFET, as opposed to the base current, which controls the BJT.To switch on the gadget, the gate-source voltage must be comfortably above a few volts. When the voltage is first supplied to the gate, currents flow in the parasitic gate-source and gate-drain capacitances, but after these capacitances have been charged, the input current to the gate is insignificant, resulting in a low steady-state gate drive power. The parasitic capacitances must be emptied and the gate-source voltage must be retained below the threshold level in order to turn the device 0V.

The main benefit of the MOSFET is the fact that it's a voltage-controlled device that needs very little power to keep it turned on. As a result, the gate drive circuitry is simpler and less expensive than the base-drive circuitry of an analogous bipolar device. The downside of the MOSFET is that the effective resistance of the drain source is larger in the 'on' state than in an identical bipolar device, hence leakage current is higher and the device is less efficient as a power switch. MOSFETs are employed in medium- and low-power inverters ranging from a few kilowatts to a few kilowatts, with voltages often not surpassing 700 V.

Gate turn-off thyristor (GTO)

The GTO is activated by a current pulse in the gatecathode circuit, much like a normal thyristor. Nevertheless, unlike a standard thyristor, which cannot be switched on or off by gate action, the GTO may be turned on or off by a negative gate-cathode current. Like in a normal thyristor, the primary (load) current XOWS from anode to cathode.The dual arrowed routes on the gate lead show that both forward and reverse gate currents are used to regulate the gate. In American literature, instead of the two arrows, a single gate led with a short crossbar is utilized. The gate drive needs are more than for a normal thyristor, and the on-state performance is lower, with a forward voltage drop of about 3 V compared to 1.5 V, but these are the trade-offs for the increased flexibility. Since the GTO has far greater voltage ratings (up to 3 kV and 2 kA) than the other three devices, it is employed in high-power inverters.

Converter Waveforms and Acoustic Noise

The waveforms illustrated), like most textbooks, are what we would expect to observe under perfect circumstances. It makes sense to focus on these ideal waveforms in order to obtain a fundamental knowledge, but we should be aware that what we see on an oscilloscope may be very different. We have seen that the switching process is the basis of power electronics, thus it should come as no surprise that in actuality, switching is seldom performed in such a clear-cut manner as we had thought. Typically, there will be some type of high-frequency oscillation or 'ringing' seen, especially on the transmission voltage after each switching transition. This is due to the effects of stray capacitance and inductance: it ought to be anticipated during the design stage, and efforts should be made to minimize it by Wtting'snubbing' circuits at suitable locations in the converter. Nevertheless, total suppression of all transient phenomena is seldom economically beneficial, thus the user should not be startled if vestiges of transient phenomena may be seen in the output waveforms.

Acoustic noise is another issue that may concern visitors. Most power electronic converters make whining or buzzing noises at frequencies corresponding to the switching frequency's fundamental and harmonics; however, when the converter is used to feed a motor, the sound from the motor is generally much louder than the sound from the converter itself. These noises are difficult to define in words, but they often vary from a large hum to a piercing whistle. They fluctuate in strength depending on the size of the converter and the load, and to a skilled ear, they may provide a decent indicator of the motor and converter's health.

Cooling Of Power Switching Devices

Thermal resistance

Implementing a switching strategy the power loss in the switching devices is negligible in relation to the power throughput, resulting in a high eYciency for the converter. Yet, practically all of the heat generated in switching devices is emitted in the active area of the semiconductor, which is quite tiny and would overheat and breakdown if not sufficiently cooled. As a result, it is critical to guarantee safety even under the most difficult working circumstances. Implementing a switching strategy the power loss in the switching devices is negligible in relation to the power throughput, resulting in a high efficiency for the converter. Yet, practically all of the heat generated in switching devices is released in the active area of the semiconductor, which is quite tiny and would overheat and breakdown if not sufficiently cooled. It is thus critical to guarantee that the temperature of the active junction within the device does not exceed the safe threshold even under the most difficult operation circumstances.

Examine what happens to the temperature of the device's junction area when we start from a cold (i.e. ambient) temperature. Use the gadget in such a way that its average power dissipation stays constant. When the junction temperature increases at first, part of the heat created is transmitted to the metal casing, which stores some heat as its temperature rises. Heat then XOWS into the heat sink, which starts to warm up, and heat begins to XOW to the ambient air. The temperatures of the junction, casing, and heatsink increase until an equilibrium is established, at which point the overall rate of heat loss to ambient temperature equals the power dissipation within the device.

The total 'thermal resistance' between the junction within the device and the surrounding medium therefore determines the final steady-state junction temperature (usually air).Thermal resistance is often represented in degrees Celsius per watt (C/W), which directly reflects how much temperature increase occurs in the steady state for every watt of dissipated power. As a result, for a given power dissipation, the greater the thermal resistance, the higher the temperature increase, therefore to reduce the temperature rise of the device, the total thermal resistance between it and the surrounding air must be as low as feasible[9].

The device designer tries to reduce thermal resistance between the semiconductor junction and the device's casing, and offers a wide metal mounting surface to reduce thermal resistance between the case and the heatsink. The converter designer must provide adequate thermal contact between the device and the heatsink, which is often accomplished by a bolted connection extensively smeared with heat-conducting material to fill any tiny spaces, and must design the heat sink to minimize thermal resistance to air (or in some cases oil or water).

Heatsink design is the only true opportunity to significantly reduce overall resistance, and it entails careful selection of the material, size, form, and orientation of the heatsink, as well as the related air-moving system (see below).The metal mounting surface (or surfaces in the case of the popular hockey puck packaging) might be electrically 'live' due to the excellent heat route between the junction and the device's casing. This is difficult for the converter designer since placing the device directly on the heatsink renders it unsafe. In order to eliminate short-circuits, many independent separated heatsinks may be necessary. The devices may be electrically separated from the heatsink using thin mica spacers, but the thermal resistance is significantly enhanced.

To avoid the 'live' issue, gadgets are increasingly being packed as ‘modules' with an electrically insulated metal foundation. The packages comprise transistor, diode, or thyristor combinations from which different converter circuits may be created. Several modules may be installed on a single heatsink that does not need to be segregated from the enclosure or cabinet. They are available in ratings suited for converters ranging from a few hundred kilowatts to hundreds of kilowatts, and the range is growing. This advancement, along with a shift to fan-assisted cooling of heatsinks, has resulted in a considerable decrease in overall size of entire converters, with a current 20 kW drive converter perhaps being the size of a compact briefcase.

Arrangement of heatsinks and forced air cooling

The overall surface area, surface quality, and air XOW are the primary parameters that influence a heatsinks thermal resistance. Most converters use aluminum sheet heat sinks with numerous Function to improve effective cooling surface area and reduce resistance, as well as a machined face or faces for device installation. Heatsinks are often vertically positioned to facilitate natural air circulation. Surface finish is critical, with black anodized aluminium generally 30% better than brilliantrev/min. They are mostly used for directly cooling circuit boards and have the benefit of being able to adjust the speed via voltage fluctuation, allowing for a trade-0V among noise and volume XOW.

Conventional D.Sc. Motors

Until the 1980s, the traditional (brushed) D.C. machine was the automated option for speed or torque control, and despite a diminishing market share that reflects the shift to inverter-fed induction motors, considerable numbers remain in operation. Steel rolling mills, railway traction, and a broad variety of industrial drives, robots, printers, and precise servos are all examples of applications. The range of power outputs is likewise large, ranging from several megawatts at the top to just a few watts at the bottom, but all share the same fundamental construction 1, with the exception of a few very low-performance ones used in toys. The motor has two independent circuits. The smaller pair of terminals connect to the Weld windings, which encircle each pole and are generally connected in series: in the steady state, all input power to the Weld windings is dissipated as heat and is not converted to mechanical output

power. The 'power' or 'work' current is sent to the brushes through the main terminals, which make sliding contact with the armature winding on the rotor. The supply to the Plate is distinct from that to the armature, thus the term "separately stimulated."

A D.C motor may be designed for any desired supply voltage, just like any other electrical machine, although for a variety of reasons, rated voltages lower than roughly 6 V or much higher than 700 V are uncommon. The lower limit derives from the brushes which create an inevitable volt-drop of about 0.5-1 V, and it is obviously not good practice to allow this 'wasted' voltage to become a significant percentage of the supply voltage. At the other end of the spectrum, insulating the commutator segments to resist greater volts becomes prohibitively costly.

The role and functioning of the commutator will be addressed later, however it is important to note that brushes and commutators may be problematic at high speeds. Tiny D.C motors with hundreds of watts of power may operate at speeds of up to 12 000 rev/min, although the bulk of medium and large motors are typically built for speeds of less than 3000 rev/min.Power-electronic drives, which receive power from alternating current mains and convert it to direct current for the motor, are increasingly being used. Since mains voltages are often standardized (e.g., 110 V, 220-240 V, or 380-440 V, 50 or 60 Hz), motors are designed with rated voltages that correspond to the range of D.C outputs from the converter.

It is fairly typical for a motor of a particular power, speed, and size to be offered at a variety of voltages. In theory, all that has to be done is change the number of turns and wire size used to make up the machine's coils. A 12 V, 4 A motor, for example, might be readily converted to run on 24 V by wrapping its coils with twice as many twists of wire with half the cross-sectional area of the original. At 24 V, the full speed would be the same as it was at 12 V, and the rated current would be 2 A rather than 4 A. The input and output power would be constant, and the exterior look would be identical, with the exception of the terminals being somewhat smaller.

Historically, direct current motors were classified as shunt, series, or individually excited. Moreover, motors were often referred to as "compound-wound." These descriptions originate from before the emergence of power devices, and a strong linkage developed, attaching one or more 'kind' of D.C machines to a certain application. There is no essential difference between shunt, series, and independently excited machines; the designations just reflect how the Weld and armature circuits are linked. But, the terms remain, and we shall return to them later. But first, we must grasp how the fundamental machine works, so that we may comprehend what the different historic phrases represent, and so observe how current practice is used to attain the same aims.

Although the number of poles in an alternating current machine is critical in determining speed, the number of poles in a direct current machine is unimportant to the user. It turns out that using two or four poles in small or medium size D.C. motors is more economical than using more (e.g. ten or twelve or even more) in large ones, but the only difference to the user is that the 2-pole type will have two brushes at 1808, the 4-pole will have four brushes at 908, and so on. In the sake of simplicity.The armature is a collection of identical coils coiled in slots on the rotor that make up the primary (power) circuit. Current flows into and out of the rotor through carbon "brushes" that make sliding contact with the "commutator," which is made up of insulated copper segments set on a cylindrical former. (The word "brush" comes from early efforts to build sliding contacts using bundles of wires linked together in the same manner as willow twigs are bundled together in a witch's broomstick. Unsurprisingly, these crude brushes quickly wore grooves in the commutator.)

The commutator's purpose is covered more below, however it is important to note that all electrical energy that is to be transformed into mechanical output must be delivered into the motor through the brushes and commutator. Considering that a rising sliding electrical contact is involved, it is not unexpected that the commutator must be maintained clean, and the brushes and their related springs must be cleaned on a regular basis to guarantee trouble-free operation. Brushes, of course, wear out, but if correctly adjusted, they may endure for thousands of hours. If all goes well, the brush debris (in the form of graphite particles) will be carried away by the ventilating air: any dust buildup on the insulation of a high-voltage motor's windings risks short circuits, while debris on the commutator itself is dangerous and can lead to disastrous 'Passover' faults.

The axial length of the commutator is determined by the amount of current it must manage. Small motors typically have one brush on each side of the commutator, so the commutator is quite short; however, larger heavy-current motors may have many brushes mounted on a common arm, each with its own brush box (in which it is free to slide) and all the brushes on one arm connected in parallel via their Flexible copper leads or 'pigtails'. The length of a commutator may then be compared to the armature's 'active' length (i.e. the section holding the conductors exposed to the radial FLUX.

Function of the commutator

With D.C armatures, many different winding configurations are employed, and it is neither beneficial nor essential for us to dig into the nitty-gritty of winding and commutator design. They are better left to motor designers and mechanics. All we need to do is concentrate on what a well-designed commutator-winding does, which, despite its seeming complexity, can be expressed fairly simply. Current enters the rotor via one brush, flows through all of the rotor coils in the directions, and exits through the other brush. The brush's first point of contact with the armature is through the commutator segment or segments on which it is pressing at the time (the brush is usually wider than a single segment), but because the contact points between the individual coils are made at each commutator segment, the current actually passes through all the coils via all the commutator segments in its path through the armature.

All conductors under the N pole carry current in one direction, whereas all conductors under the S pole carry current in the other way. As a result, all conductors under the N pole will feel a downward force (proportional to the radial FLUX density B and the armature current I), whereas all conductors beneath the S pole will experience an equivalent upward force. Hence, a torque is created on the rotor, with the magnitude corresponding to the product of the Flux density and the current. In actuality, the FLUX density beneath the pole will not be fully uniform, therefore the force on some of the armature conductors will be larger than on others. Nonetheless, it is simple to demonstrate that the total torque created is given by

$$T = K_T \Phi I$$

Where F is the total FLUX generated by the Generator and KT denotes a constant for a specific motor. Since FLUX is constant in the majority of motors, we can see that motor torque is exactly proportional to armature current. This relatively simple finding suggests that if a motor is needed to provide constant torque at all velocities, we merely need to maintain a constant armature current. As will be shown later, standard drive packages frequently offer this capability. We can also see from equation that the torque direction may be changed by reversing the armature current (I) or the Flux (F). We clearly utilize this when we want the engine to reverse and sometimes when we want regenerative braking.

The astute reader may rightly question the claim made above that the torque will be constant regardless of rotor position. However, if the rotor is turned just a few degrees, one of the Wave conductors shown as being under the pole will move out into the region where there is no radial Flux before the next one moves under the pole. The torque be lowered if there are just four have conductors providing force instead of have conductors producing force.

The answer is affirmative, and most motors utilize numerous more coils than to reduce this undesirable variance of torque. Smooth torque is, of course, desirable in most applications to eliminate vibrations and resonances in the transmission and load, and it is required in machine tool drives where uneven cutting may degrade the quality of Finish if the torque and speed are not constant.In general, the more coils (and commutator segments) there are, the better, since the ideal armature would have a pattern of current on the rotor that approximated to a 'current sheet' rather than a sequence of discrete packets of current. If the number of coils was fixed, the rotor would appear the same in every position, and the torque would be perfectly smooth. This is obviously not feasible, yet it is roughly approximated in most D.C. motors. Large motors, which may have a hundred or more coils and hence very little ripple in their output torque, have a greater number of slots for practical and economic reasons.

Operation of the commutator

Returning to the commutator's operation, and focusing on a specific coil, we see that for half a revolution - while side is under the N pole and side b is under the S pole - the current must be optimistic inside a and negative in side b in order to produce a positive torque. During the remaining half revolution, when side a lies beneath the S pole and side b is under the N pole, the current must flow in the other direction through the coil in order for it to continue producing positive torque. This current reversal occurs in each coil as it travels across the interplay axis, with the coil being'switchedround' by the action of the commutator moving under the brush. When a coil reaches this condition, it is said to be undergoing commutation, and the corresponding coil in is depicted with no current to signify that its current is shifting from positive to negative. The simplified reveals the core of the current-reversal process.

Interpoles (or compoles) are used to increase commutation and hence reduce sparking. These supplementary poles are situated halfway between the main Weld poles. Interposes are often not needed in permanent magnet motors since the lack of stator iron adjacent to the rotor coils results in much reduced armature coil inductance. The interpoles aim is to create a motional electromotive force. in the commutating coil in such a way that the required reversal of current is accelerated and sparking is avoided. The E.M.F necessary is determined by the current (armature current) that must be commutated as well as the rotational speed.

There is no motional E.M.F produced in the armature while it is immobile. As the rotor revolves, the armature cut the radial magnetic Flux and produce an E.M.F while the rotor rotates, an alternating E.M.F is induced in each individual coil on the armature. For example, if the rotation is clockwise, side a will move upward through the Flux, generating an E.M.F directed out-of-the plane of the paper. At the same time, the'return' side of the coil b will be moving downwards, generating the same magnitude of E.M.F but directing it into the paper. As a consequence, the resulting E.M.F in the coil will be double that in the coil-side, and this E.M.F will stay constant for almost half a rotation, during which time the coil sides are cutting a constant Flux density. The E.M.F will be 0 for a relatively brief period while the coil is not cutting any Flux, and then the coil will begin to cut through the Flux again, but now each side is under the opposite pole, therefore the E.M.F will be in the other direction. The resulting E.M.F waveform in each coil is a rectangular alternating wave, with amplitude and frequency proportional to rotational speed.

Since the coils on the rotor are coupled in series, we would witness a significant alternating E.M.F across any specific pair of diametrically opposing commutator segments. The fact that the induced voltage in the rotors is alternating may surprise you, given that we are discussing a D.C. motor rather than an A.C. motor. But, whatever concerns we may have should be alleviated when we question what we will observe in terms of induced E.M.F when we 'look in' at the brushes. The brushes and commutator effect a stunning alteration, returning us to the comforting world of D.C. The first thing to notice is that the brushes are not moving, this implies that, even if each brush's segment is constantly replaced by its neighbor, the circuit connecting the two brushes always has the same number of coils and the same orientation with regard to the poles. As a consequence, the E.M.F at the bristles is constant (rather than alternating).

The magnitude of the E.M.F depends on where the brushes are arranged around the commutator, but they are always located at the location where they constantly ‘see' the peak value of the alternating E.M.F produced in the armature. The commutator and brushes in effect may be seen as as mechanical rectifier, converting the alternating E.M.F in the rotating reference frame to a direct E.M.F in the stationary reference frame. It is an incredibly creative and effective gadget, with the only significant limitation being that it has a mechanical system, and therefore prone to wear and tear. We observed before that a high number of coils and commutator segments were required to create smooth torque, and we discovered that the same principles apply to the smooth of the generated E.M.F.

The E.M.F will have a visible ripple overlaid on the mean D.C. level if there are just a few armature coils. The more coils we use, the smaller the ripple and the better the D.C. we generate. The little ripple that we unavoidably get with a finite number of segments is seldom an issue with motors used in drives, but it may sometimes cause problems when a D.C. machine is employed to produce a speed control signal in a closed-loop system.

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CHAPTER 7

EQUIVALENT CIRCUIT AND MOTOR DRIVE

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D.C Motor steady-state characteristics

From the user's perspective, the amount to which speed declines when load is added, as well as the fluctuation in speed with applied voltage, are generally the first concerns that must be addressed in order to evaluate the motor's appropriateness for the work at hand. The data is often communicated in the form of steady-state characteristics, which show how the motor operates after any transient effects (produced, for example, by a quick change in load) have faded away and circumstances have returned to normal. Steady-state features are typically much simpler to anticipate than additional context, and they can all be determined from the basic equivalent circuit for the D.C. machine[1], [2].

Behavior when loading

Get the load at a certain speed. Certain loads, such as a basic drum type hoist with a constant weight upon that hook, need the same torque regardless of speed, however the torque required changes with speed for the majority of loads. The torque required for a fan, for example, varies approximately with the square of the speed. We can find the steady-state speed easily by finding the intersection of the two curves in the torque-speed plane if we know the torque/speed characteristic of the load and the torque/speed typical of the motor. The torque generated by the motor is precisely equal to the torque required to maintain the load spinning at point X, therefore the motor and load are in equilibrium and the speed stays constant. At all lower speeds, the motor torque will be greater than the load torque, resulting in a positive net torque and motor acceleration. When the speed approaches X, the acceleration decreases until the speed is stable at X.

At speeds greater than X, the motor's driving torque exceeds the braking torque exerted by the load, resulting in a negative net torque and the system decelerating until it finds equilibrium at X. This is an intrinsically stable example, in that if the speed is disturbed for whatever cause from point X, it will always return there when the disturbance is removed.Moving on to the derivation of the torque/speed characteristic of the D.C. motor, we can clearly utilize the preceding example to demonstrate issues. By first computing the back E.M.F at full load, we can derive the full-load speed for V 14 500 V[3], [4].

These computations lead to two crucial conclusions. For starters, the speed decrease with load is negligible. This is quite desirable for most applications since all we have to do to maintain practically constant speed is establish and maintain the right armature voltage. Second, a delicate equilibrium between V and E is exhibited. Since the current is proportional to the difference between V and E even slight changes in either V or E cause disproportionately significant changes in the current. A 4% decrease in E leads the current to climb to its rated value in the example. As a result, the divergence between V and E must be controlled to prevent excessive currents (which cannot be allowed in a thyristor supply, for example). This topic will be revisited when ephemeral performance is investigated.

A sample family of torque ripple for the motor explained above. As previously stated, no-load speeds are exactly proportional to applied voltage, with the slope of each curve being governed by armature resistance: the lower the resistance, the less the speed declines with load. These operational qualities are appealing since the speed may be easily adjusted by simply adding the appropriate voltage.When motors are driven continuously at full current (i.e. full torque) even at extremely low speeds, where natural ventilation is weak, a cooling issue is to be anticipated. This working situation is regarded relatively usual in converter-fed motor drive systems, and motors are thus equipped as standard with a tiny air-blower motor[5], [6].

Which are devices that transform electrical energy into mechanical power. Yet, the D.C. motor, like other electrical devices, is intrinsically capable of acting as a generator, transforming mechanical power into electrical power. While the vast majority of motors will spend the most of their working career in driving mode, there are certain applications, such as rolling mills, that need regular reversing and others that demand quick braking. In the first situation, the motor is programmed to return the stored kinetic energy towards the supply system each time the rolls must be reversed, while in the latter case, the energy may also be returned to the supply or discharged as heat in a resistor.

These transitory modes of operation are best defined as'regeneration,' since they solely entail the recovery of energy supplied by the motor. Continuous generation is, of course, achievable with a D.C machine if we have a mechanical power source, such as an internal combustion (IC) engine. In the last case, we observed that when the unloaded machine was attached to a 500 V supply, it operated at 1040 rev/min, at which time the back E.M.F was approximately 500 V and only a minor positive current was flowing. When we added mechanical stress to the shaft, the steady-state speed decreased, lowering the back E.M.F and raising the armature current until the motor torque equaled the opposing load torque and balance was reached. We discovered that the lower the armature resistance, the less the speed reduction with load.

If, instead of delivering opposing (load) torque, we utilize the IC engine to provide torque in the other direction, i.e. attempting to raise the speed of the motor, the motional E.M.F will be larger than the voltage level (500 V).This indicates that current will flow from the D.C. machine to the power supply, resulting in a power Flow reversal. When the motor speed (current) is equal to and opposite to the torque produced by the IC engine, stable generating conditions are attained. In the example, the full-load present is 20 A, hence the E.M.F must be delivered to push this current through its own resistance and surpass the supply voltage.

If the mechanical load on the motor's shaft grows, the speed decreases and the armature current increases until torque equilibrium is attained and the speed returns to steady. If the armature voltage is at its maximum (rated) value and the mechanical load is increased until the current meets its rated value, we are obviously at full-load, i.e. we are working at full speed (defined by voltage) and full torque (determined by current). The maximum current is determined at the design stage and represents the maximum amount of heating of the armature conductors.Obviously, increasing the load on the shaft will cause the current to surpass the safe amount, causing the motor to overheat. Yet this begs the question, "Could the motor offer more and more power output if it weren't for the issue of overheating, or is there a limit? Maximum. The mechanical output power is the product of torque and speed, and we can see that when either the load torque or the speed is 0, the power will be zero (i.e. the motor is stationary). There must be a maximum between these two zeroes, and it is simple to demonstrate that the maximal mechanical power occurs at half the no-load speed. This working situation, however, is only feasible in very tiny motors: in the majority of motors, the supply simply would not be able to produce the extremely high current necessary.

To calculate the theoretical maximum power, we may apply the maximum power transfer theorem (from circuit theory) to the analogous circuit. Since we assume D.C circumstances, we may neglect the inductance. If we consider the armature resistance R to be the source resistance V, the theorem states that in order to transmit maximum power to the load (represented by the motional E.M.F on the right side), we must make the load 'look like' a resistance equal to the source resistance, R. When the applied voltage V splits evenly, half of it is dropped across R and the other half is equal to the E.M.F E[7], [8].

(As previously indicated, the condition E 14 V=2 corresponds to the motor operating at half its no-load speed.) The current at maximum power is V/2R, while the mechanical output power (EI) is supplied by V2/4R.The maximum output power expression is pleasantly easy. We could have anticipated the maximum power to be affected by other motor characteristics, but it is purely dictated by the armature voltage and resistance. For example, a 12 V motor with an armature resistance of 1 V cannot potentially generate more than 36 W of mechanical output power. Of course, at maximum power circumstances, the overall eYciency is only 50% (since an equivalent amount of power is burnt as heat in the armature resistance), and we should emphasize that only very tiny motors can ever be driven continuously in this condition. It is merely of academic interest for the overwhelming majority of motors since the current (V/2R) will be much too high for the supply.

Power Electronic Converters for Motor Drives

Power converter circuits used with motor drives, producing D.Cor A.C outputs and operating on a D.C (battery) supply or the usual A.C mains. The treatment is not meant to be comprehensive, rather should serve to highlight the most crucial elements that are shared by all types of drive converters.Although there are many different types of converters, all of them, with the exception of very low-power ones, use some form of electronic switching. The requirement for a switching strategy is stressed in the first scenario, where the effects are thoroughly examined. We will see that switching is required to achieve high-eYciency power conversion, but that the ensuing waveforms are invariably less than optimal from the motor's perspective.The examples were selected to demonstrate typical usage, therefore the most widely used switching devices (e.g., thyristor, transistor are shown for each converter. Many different switching devices may be useful in many circumstances thus we should not label a given circuit as being the sole domain of a single device.

General arrangement of drives

The converter's job is to draw electrical energy from the mains (at whatever voltage and frequency is required to generate the specified mechanical output. Except for the smallest converters (such as a simple diode rectifier), most converters have two different sections. The first stage is the power stage, which transfers energy to the motor, and the second is the control section, which regulates the power flow. Control signals, in the form of low-power analogue or digital voltages, instruct the converter on what it should do, while additional low-power feedback signals measure what is actually happening. The goal output is maintained by comparing the demand and feedback signals and modifying the output accordingly. The simple system has only one input representing the desired speed and one feedback signal indicating actual speed, but as we will see later, most drives will include additional feedback signals. Almost all drives use closed-loop (feedback) control, therefore readers who are unfamiliar with the fundamental principles may find the Appendix useful at this point[9], [10].

The fact that power electronic converters have extremely limited energy storage capacity is a feature shared by most electrical systems. This means that any abrupt change in the power supplied to the motor by the converter must be rejected by an abrupt increase in the power drawn from the supply. In most circumstances, this is not a severe issue, but it does have two disadvantages. To begin, a sudden increase in current drawn from the supply will result in a brief reduction in supply voltage due to the effect of the supply impedance. These voltage "spikes" will cause unwanted distortion for other users on the same power source. Second, there may be an unavoidable delay before the source can provide additional power. For example, with a single-phase mains supply, there can be no abrupt rise in power supply from the mains at the time when the mains voltage is zero, because instantaneous power is necessarily 0 at this point in the cycle because the voltage is itself zero.

It would be preferable if a significant quantity of energy could be stored within the converter itself, allowing short-term energy demands to be satisfied promptly, avoiding fast fluctuations in power drawn from the mains. Unfortunately, this is simply not economic: most converters contain a modest store of energy in their smoothing inductors and capacitors, but the amount is insufficient to sufficiently buffer the supply from anything other than very short-term Punctuations.

Voltage control – D.C Output from D.C Supply

To keep things simple, we'll start with the challenge of managing the voltage across a 2 V resistive load fed by a 12 V constant-voltage source like a battery. Three distinct approaches, with the circle on the left representing an ideal 12 V D.C source and the tip of the arrow denoting the positive terminal. Although this configuration is not exactly the same as if the load were a D.C motor, the results are nearly identical.Method (a) employs a variable resistor (R) to absorb the fraction of the battery voltage that is not required at the load. It gives smooth (although manual) control over the entire range of 0 to 12 V, but power is lost in the control resistor. To reduce the load voltage to 6 V, for example, the resistor (R) must be adjusted to 2 V, so that half of the battery voltage is dropped across R. The current will be 3 amps, the load power will be 18 watts, and the power dissipated in R will be 18 watts as well. Overall power conversion eYciency (i.e. useful power provided to the load divided by total power from the source) is a dismal 50%. When R is increased further, the efficiency declines even further, approaching 0 as the load voltage approaches zero. As a result, this type of control is unsuitable for motor control, especially in low-power applications such as miniature racing cars.

Method (b) is similar to Method (a), except that instead of a manually operated variable resistor, a transistor is utilized. The transistor is connected in series with the voltage source and the load resistor via its collector and emitter connections. The transistor is a variable resistor, but it is a very unique one in that the effective collector emitter resistance may be changed over a wide range by the base-emitter current. Because the base-emitter current is normally relatively modest, it can be adjusted using a low-power electronic circuit.

The main advantage of the chopper circuit is that no power is wasted, resulting in a 100% eYciency. When the switch is turned on, current flows through it, but the voltage across it is zero due to its low resistance. As a result, the power dissipated in the switch is zero. Similarly, when the switch is in the 'V' position, the current through it is zero, therefore even if the voltage across the switch is 12 V, the power dissipated in it is also zero.

The obvious disadvantage is that the load voltage cannot be considered 'good' D.C.: it comprises of a mean or 'D.C' level with a superimposed 'A.C.' component. Given that we want the load to be a D.C. motor rather than a resistor, we must consider if the pulsating voltage will be acceptable. Fortunately, the answer is yes, as long as the chopping frequency is sufficiently high. We will see later that the motor's inductance causes the current to be much smoother than the voltage, which means that the motor torque fluctuates much less than we might expect, and the mechanical inertia of the motor Filters the torque ripples so that the speed remains almost constant, at a value governed by the chopped waveform's mean (or D.C.) level.

A mechanical switch would obviously be inappropriate, and could not be expected to last long when pulsed at high frequency. As a result, an electronic power switch is used instead. The bipolar junction transistor (BJT) was the first of many devices used for switching, hence we'll start by looking at how such transistors are used in chopper circuits. If we select a different device, such as a metal oxide semiconductor Weld effect transistor (MOSFET) or an insulated gate bipolar transistor (IGBT), the exact arrangements for turning on and off the device will be divergent.

Transistor chopper

A transistor is evocatively a controllable resistor, which means that the resistance between collector and emitter is proportional to the current in the base-emitter junction. To simulate the operation of a mechanical switch, the transistor must be capable of providing either infinite resistance (corresponding to an open switch) or zero resistance (corresponding to a closed switch). Both of these ideal states are not achievable with a real transistor, but they can be closely approximated.When the base-emitter current is zero, the transistor is 'V'. Its resistance will be very high when viewed from the main (collector emitter) circuit. Under this 'cut-V' condition, regardless of the voltage (VCE) between the collector and emitter, only a very small current (IC) can flow from the collector to the emitter. As a result, the power dissipated in the device will be negligible, providing an excellent approximation to an open switch. A base-emitter current is required to turn the transistor fully "on." The required base current is determined by the prospective collector-emitter current, i.e. the current in the load. The goal is to keep the transistor ‘saturated,' so that it has a very low resistance. In the, if the transistor's resistance is very low, the current in the circuit will be nearly 6 A, so we must ensure that the base-emitter current is sufficiently large to keep the transistor saturated when IC 14 6A.

To keep a bipolar transistor (BJT) in the saturation region, the base current should be around 5-10% of the collector current: in the example with the full load current of 6 A showing, the base current might be 400 mA, the collector-emitter voltage might be say 0.33 V, giving an on-state dissipation of 2 W in the transistor when the load power is 72 W. The power conversion efficiency is not as high as it would be with a perfect switch, but it is adequate. It is worth noting that the on-state base-emitter voltage is really low, which, when combined with the low base current, indicates that the power is low.

A D.C. motor may be designed for any desired supply voltage, just like any other electrical machine, although for a variety of reasons, rated voltages lower than roughly 6 V or much higher than 700 V are uncommon. The lower limit derives from the brushes which create an inevitable volt-drop of about 0.5-1 V, and it is obviously not good practice to allow this 'wasted' voltage to become a significant percentage of the supply voltage. At the other end of the spectrum, insulating the commutator segments to resist greater volts becomes prohibitively costly.

The role and functioning of the commutator will be addressed later, however it is important to note that brushes and commutators may be problematic at high speeds. Tiny D.C. motors with hundreds of watts of power may operate at speeds of up to 12 000 rev/min, although the bulk of medium and large motors are typically built for speeds of less than 3000 rev/min.

Historically, direct current motors were classified as shunt, series, or individually excited. Moreover, motors were often referred to as "compound-wound." These descriptions originate from before the emergence of power electronics, and a strong linkage developed, attaching one or more 'kind' of D.C. machines to a certain application. There is no essential difference between shunt, series, and independently excited machines; the designations just reflect how the Weld and armature circuits are linked. But, the terms remain, and we shall return to them later. But first, we must grasp how the fundamental machine works, so that we may comprehend what the different historic phrases represent, and so observe how current practice is used to attain the same aims.

We should emphasise here that, although the number of poles in an alternating current machine is critical in determining speed, the number of poles in a direct current machine is unimportant to the user. It turns out that using two or four poles in small or medium size D.C. motors is more economical than using more (e.g. ten or twelve or even more) in large ones, but the only difference to the user is that the 2-pole type will have two brushes at 1808, the 4-pole will have four brushes at 908, and so on. In the sake of simplicity, we will focus on the 2-pole version, however there is no important difference in terms of working characteristics.

A D.C. motor may be designed for any desired supply voltage, just like any other electrical machine, although for a variety of reasons, it is uncommon to find rated voltages lower than roughly 6 V or much higher than 700 V. The lower limit is caused by the brushes (see below), which generate an inevitable volt-drop of about 0.5-1 V, and it is obviously not good practice to allow this 'wasted' voltage to become a significant percentage of the supply voltage. On the other end of the spectrum, insulating the commutator parts to resist greater volts becomes prohibitively costly.

The commutator's role and operation will be covered later, however it is important to note that brushes and commutators may be problematic at high speeds. Tiny D.C motors with hundreds of watts of power may operate at speeds of up to 12 000 rev/min, although most medium and large motors are intended for speeds of less than 3000 rev/min. Motors are increasingly being equipped with power-electronic drives, which collect power from alternating current mains and convert it to direct current for the motor.

Since mains voltages are often standardized (e.g., 110 V, 220-240 V, or 380-440 V, 50 or 60 Hz), motors are built with rated voltages that correspond to the range of D.C. outputs from the converter it is common for a motor of a particular power, speed, and size to be offered at a variety of voltages. In theory, all that is required is a change in the number of turns and wire size used to make up the machine's coils. A 12 V, 4 A motor, for example, may simply be converted to run on 24 V by wrapping its coils with twice as many twists of wire with half the cross-sectional area. At 24 V, the full speed would be the same as it was at 12 V, and the rated current would be 2 A instead of 4 A. The input and output power would remain constant, and the exterior look would remain identical, with the exception of the terminals being somewhat smaller.

D.C. motors were traditionally classified as shunt, series, or individually excited. In addition, motors were often referred to as "compound-wound." These descriptions are from before the introduction of power electronics, when there was a strong linkage that linked one or more 'kind' of D.C machines with a certain application. There is no essential difference between shunt, series, and independently excited machines; the designations just reflect how the Weld and armature circuits are coupled. Yet, the words endure, and we shall return to them later. But first, we must grasp how the fundamental machine works so that we may comprehend what the different historic phrases represent and, as a result, see how current practice is used to attain the same goals.

We should emphasize here that, although the number of poles in an alternating current machine is critical in determining speed, the number of poles in a direct current machine is of little value to the user. It turns out that using two or four poles in small or medium size D.C motors is more economical than using more (e.g. ten, twelve, or even more) in large ones, but the only difference to the user is that the 2-pole type will have two brushes at 1808, the 4-pole will have four brushes at 908, and so on.

Operation of the commutator

The coil-side an in the left-hand drawing is beneath the N pole and carries positive current since it is linked to the darkened commutator segment, which is supplied from the top brush. Side an is therefore subjected to a Flux density oriented from left (N) to right (S) in the drawing, resulting in a downward force. This force will be constant as long as the coil-side is beneath the N pole. Side b, on the other hand, has negative current but also resides in a Flux density oriented from right to left, resulting in an upward push. As a result, there is an anti-clockwise torque on the rotor.

As the rotor is turned to the right, the current in both sides is reversed since side b is now provided with positive current through the unshaded commutator section. The force direction on each coil side is inverted, which is precisely what we want to keep the torque clockwise. The torque is constant except for a brief time when the coil is outside the influence of the Flux and experiencing commutation (current reversal).

It should be noted that the preceding discussion is meant to demonstrate the idea at hand, and the sketch should not be taken too literally. The commutator arc in a true multi-coil armature is considerably smaller than that illustrated in, and only one of the many coils is reversed at a time, thus the torque stays practically constant regardless of the rotor position.

The fundamental difficulty in getting excellent commutation stems from the armature coils' internal inductance and the related stored energy. As previously stated, inductive circuits resist changes in current, so if a current reversal has not been completed by the time the brush moves over the commutator section in issue, there will be a spark at the brush's trailing edge. Some sparking is acceptable in tiny motors, but in medium and large wound-Weld motors, small extra stator poles called asInterpoles (or compiles) are used to increase commutation and hence reduce sparking. These supplementary poles are situated halfway between the main Weld poles. Interpoles are often not needed in permanent magnet motors since the lack of stator iron adjacent to the rotor coils results in much reduced armature coil inductance.

The interpoles' aim is to create a motional E.M.F in the commutating coil in such a way that the required reversal of current is accelerated and sparking is avoided. The E.M.F required is proportional to the current (armature current) that must be commutated as well as the rotational speed. To attain the right E.M.F, the armature current is passed via the coils on the Interpoles, making the Flux from the interpoles proportionate to the armature current. As a result, the interpole coils are made up of a few turns of thick conductor that are permanently connected in parallel to the armature.

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CHAPTER 8

MOTIONAL E.M.F

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Induction is the mechanism by which any change in magnetic flux causes an emf to be produced that opposes the change. One of the main factors that induces induction is motion. For instance, moving a magnet towards a coil causes an emf, and moving a coil towards a magnet causes a comparable emf. This section focuses on motion in a magnetic field that is stationary with respect to the Earth and creates what is colloquially referred to as motional emf. The Hall effect is one instance of motional emf, and it has previously been discussed. The magnetic force F = qvB sin that opposing charges feel while passing through a magnetic field causes them to move in opposing directions and results in an emf = Blv. We saw that the Hall effect has uses, such as determining B and v. We shall now discover that motional emf may be employed as a power source and that the Hall Effect is a subset of the larger phenomena of induction. In a uniform magnetic field B, a rod is transported down a pair of conducting rails that are separated from one another by a distance l at a speed v. The rails are coupled to a resistor R that is also stationary with respect to B. Anything from a light bulb to a voltmeter might serve as the resistance. Take into account the space that the moving rod, rails, and resistor encompass. This region is perpendicular to B, and as the rod advances, the region grows. This results in an increase in the magnetic flux contained by the rails, rod, and resistor. According to Faraday's law of induction, an emf is generated when flux changes[1], [2]

.Base speed and field weakening

Continuing to our discussion of motor operating characteristics, the speed corresponding to full armature voltage and full present (i.e. the rated full-load situation) is known as base speed when the Variable Flux is at its maximum value. By selecting a suitable armature voltage, the motor may run at any speed up to base speed and at any torque (current) up to the specified amount. The shaded area Oban =represents the whole Flux zone of operation, which is also known as the torque-speed plane's 'constant torque' region. In this sense, 'continuous torque' means that the motor can produce its entire rated torque at any speed below base speed. It is important to note that the phrase constant torque does not imply that the motor will create constant torque, but rather that the motor may produce constant torque if necessary: as we have seen, the mechanical load applied to the shaft defines the steady-state torque produced by the motor.

The torque is at its greatest (rated) value when the current is at its maximum because mechanical power is defined as torque times speed, power output along ab is proportional to speed, and maximal power corresponds to point b. Both the current and the voltage are at their full rated values at point b.Nevertheless, the gain in speed comes at the sacrifice of available torque, which is proportional to Flux time’s current. The current is limited to the rated value, therefore halves the Flux doubles the speed but reduces the maximum torque to half the rated value). It is worth noting that at point e, both the armature voltage and current are at their full rated levels, implying that the power is at its peak, as it was at point b. Because the power remains constant throughout the curve through B and E, the shaded area to the right of the line BC is known as the 'constant power' zone. Weld weakening is obviously only suitable for applications that do not require full torque at high speeds, such as electric traction[3], [4].

The maximum allowed speed in weak Weld circumstances must be controlled (to prevent excessive sparking at the commutator) and is often specified on the motor rating plate. For example, a marking of 1200/1750 rev/min indicates a base speed of 1200 rev/min and a maximum speed with Weld weakening of 1750 rev/min. The maximum speed seldom surpasses three or four times the base speed, depending on the motor design.

To summarize, the following controls the speed: The Flux is at its maximum below base speed, and the speed is determined by the armature voltage. At every speed, full torque is accessible. Above base speed, the voltage output is at (or near) maximum, and the Flux is lowered to increase speed. The greatest torque available decreases proportionally to Flux.

To determine a motor's appropriateness for a specific application, compare the torque-speed characteristic of the projected load with the operating diagram for the motor: if the load torque requires operation beyond the shaded areas, a bigger motor is plainly required.

Lastly, if we lower the Flux to zero, the no-load speed becomes in white, according to equation (3.9). This is doubtful; after all, we've seen that the Weld is required for the motor to function, therefore it seems odd to think that removing the Weld completely will increase the speed to infinity. The reason is found in the assumption that "no-load" for a genuine motor equals "zero torque."

If we could create a motor with no friction torque, the speed would actually increase as the Coefficient Flux was lowered to zero. Nevertheless, as we dropped the Flux, the torque per ampere of armature current became smaller and smaller, thus in a real machine with friction, the torque produced by the motor will eventually equal the friction torque, limiting the speed. Therefore, open circuiting the Weld winding is quite dangerous, especially in a big empty motor. There may be enough ‘residual' magnetism left in the poles to generate significant accelerating torque, resulting in a run-away situation. Weld and armature circuits are usually linked such that if the Weld fails, the armature circuit switches off immediately[5], [6].

Armature reaction

In addition to the purposeful Weld-weakening outlined above, the Flux in a D.C machine can be weakened by an effect known as "armature reaction." Armature response, as the name indicates, refers to the influence that the armature MMF has on the Flux in the machine: in small machines, it is minimal, but in big machines, the undesired Weld weakening induced by armature reaction is Sufficient enough merit extra design mechanisms to prevent it. A thorough discussion would be far too long for most users, therefore a quick explanation is offered for completeness.

The mechanism of armature response is best understood by glancing and noticing that the MMF of the armature conductors operates along the axis defined by the brushes, i.e. the armature MMF acts in quadrature to the main Flux axis that runs down the stator poles. Because of the large air spaces that the Flux has to cross, the reluctance in the quadrature direction is high, so despite the fact that the rotor MMF at full current can be very large, the quadrature Flux is relatively small; and because it is perpendicular to the main Flux, the average value of the latter would not be expected to be affected by thequadrature Flux, even though part of the path of the reaction Flux

A similar issue was addressed with regard to the basic machine. It was explained there that while calculating the electromagnetic force on a conductor, it was not required to account for the Flux created by the conductor itself. Without the nonlinear phenomenon of magnetic saturation, the armature reaction Flux would have no effect on the average value of the main Flux in the machine: the Flux density on one edge of the pole-pieces would be increased by the presence of the reaction Flux, but decreased by the same amount on the other edge, leaving the average of the main Flux unchanged. If the iron in the main magnetic circuit is already saturated, the presence of the rotor MMF will cause less of an increase on one edge than it does a drop on the other, resulting in a nett reduction in main Flux.

We already know that decreasing the Flux causes an increase in speed, thus in a machine with significant armature reaction, when the load on the shaft is raised and the armature total current to create greater torque, the Weld is concurrently lowered and the motor speeds up. Although this is not a real example of instability, it is not considered acceptable. Additional windings fitted into slots in the pole-faces and linked in series with the armature are common in large motors. These 'compensating' windings generate an MMF that is diametrically opposed to the armature MMF, decreasing or eliminating the armature response effect[7], [8].

Transient Behavior

It would be improper, for example, to attempt to start any but the smallest D.C. motors by merely turning on the rated voltage. the rated voltage is 500 V and the armature resistance is 1 V. At rest, the back E.M.F is zero, hence the starting current is 500 /1 14 500 A, or 25 times the rated current! The thyristors in the supply converter would be destroyed (and/or the fuses would be blown). Obviously, the initial voltage we must apply is significantly lower than 500 V; and if we wish to limit the current to the rated amount (20 A in the case), the voltage required is 20 1, i.e. just 20 V. The back E.M.F grows as the speed increases, and to maintain the entire current V must also be ramped up so that the divergence between V and E remains constant at 20 V. Of course, when the current is maintained under control, the motor does not accelerate nearly as quickly as it would if we had turned on maximum voltage and let the current run wild. But, this is the price we must pay to preserve the converter.Similar current-surge difficulties arise when the load on the motor is rapidly increased, as this causes the motor to slow down, resulting in a drop in E. In some ways, we welcome the decrease in E since it causes an increase in current required to provide the additional load; nevertheless, we only want the current to rise to its rated value; beyond that point, we must be prepared to cut V to prevent an excessive current.

Dynamic behavior and time-constants

The use of the terms ‘surge' and’ sudden' in the preceding explanation would have undoubtedly given the impression that changes in motor current or speed might occur instantly, whereas in reality a right period is always required to effect changes in both. As the current varies, so does the stored energy in the armature inductance, and when the speed changes, so does the rotational kinetic energy stored in the inertia. For each of these changes to occur in zero time, a pulse of in white power would be required, which is plainly impossible. Theoretical study of the transient dynamics of the D.C. computer system is simpler than for any other form of electric motor, but it is still outside the scope of this paper. Yet, it is worth summarizing the main characteristics of the dynamic behavior and emphasizing the fact that all transitory changes are defined by only two temporal constants.

The first (and most essential from the standpoint of the user) is the electromechanical time-constant, which regulates how the speed settles to a new level after a disturbance such as a change in armature winding or load torque. The second is the electrical (or armature) time-constant, which is often considerably shorter and regulates the rate of change of armature current immediately after an armature voltage change[7].

When the motor is running, we may modify two 'inputs' at once: the applied voltage and the load torque. When one of these is altered, the motor goes through a transitory phase before settling into its new steady state. It turns out that if we disregard the armature inductance (i.e. assume the armature time constant is zero), the transient period is characterized by first-order exponential responses in speed and current. Except for the very biggest motors, this assumption holds true. When we looked at the basic linear motor in, we got a similar result. For example, if we changed the armature voltage of a frictionless and unloaded motor from V1 to V2, the speed and current would change. Because the applied voltage is suddenly greater than the back e.m.f, there is an immediate increase in current (note that we have ignored inductance); the increased current produces more torque and thus the motor accelerates; the rising speed is accompanied by an increase in back e.m.f so the current begins to fall; and the process continues until a new steady speed is reached corresponding to the new voltage. The steady-state current is zero in this example because we assumed no friction or load torque, but the form of the transient response would be the same whether there had been an initial load or if the load had been quickly altered.

If the original gradient of the current-time graph is extrapolated, it crosses the final value after one time constant. In theory, the response takes as in wh6ite period to settle, but in practice, the transient is usually over in four or Wave time constants. The transient response is fairly good: because when voltage is increased, the current quickly increases to supply more torque and begin the acceleration, but the growing torque is progressively reduced to ensure that the new goal speed is reached gently. Because the systems is first-order, no oscillatory response with overshoots is recommended. Analysis reveals the relationship between the number constant and the motor/system features.

Shunt, Series And Compound Motors

When variable-voltage supplies became widely available, most D.C. motors were forced to run on a single D.C. supply, usually of constant voltage. As a result, the armature and Weld circuits were designed to link in either parallel (shunt) or series. As we will see momentarily, the operating properties of shunt and series machines differ greatly, and hence each kind tends to claim its own niche: shunt motors were deemed suitable for constant-speed applications, but series motors were (and still are) extensively utilized for traction applications.In some ways, it's a shame that these historical patterns of association have become so entrenched. The truth is that a converter-fed individually excited motor, free of any limitation between Weld and armature, can perform everything a shunt or series motor can, and more; therefore it's improbable that shunt and series motors would have ever been common if variable-voltage supplies had always been available. Both shunt and series motors are handicapped in contrast to the individually excited motor, and it would be well to consider their oft-stated advantages with this in mind. The working properties of shunt, series, and compound (a combination of both) motors are discussed further down, but first we need discuss the physical differences. On a basic level, these sums

The motor was simply connected to the power source. When the motor gains speed, the beginning resistance decreases, and the current decreases as the back E.M.F climbs from its initial value of zero. The operator controls the resistance in a manual starting, but in an automated starter, the motor armature voltage or current is monitored and the resistance is shorted out in predefined steps[9], [10].

Consider what occurs if the supply voltage fluctuates for whatever reason, and the simplest scenario to consider is when the motor is running light, in which case the back E.M.F will virtually match the supply voltage. If we drop the supply voltage, intuition could lead us to expect a decrease in speed, but instead two opposite effects occur, leaving the speed practically constant.If the voltage is cut in half, for example, both the Filament current and the armature voltage are cut in half, and assuming the magnetic circuit is not saturated, the Flux is likewise cut in half. The new stable value of back E.M.F must be half its previous value, but because we now have half as much Flux, the speed remains constant. The maximum output power will, of course, be lowered, because the power available at full load (i.e. full current) is proportional to the armature voltage. Of course, if the magnetic circuit is saturated, a small reduction in applied voltage may result in a very small drop in Flux, in which case the speed will decline in proportion to the voltage drop. This discussion explains why, in general, the shunt motor is not suited for operating below base speed.

Universal motors

In terms of numbers, the series commutator motor's major application area is in portable power tools, food mixers, hoover cleaners, and so on, where the supply is A.C rather than D.C. These motors are sometimes referred to as 'universal' motors since they may be powered by either a D.C. or an A.C. source.At first glance, it's difficult to realize that a D.C. machine can run on alternating current. Nevertheless, because the Weld Flux in a series motor is set up by the current that also flows in the armature, reversal of the power will be accompanied by reversal of the magnetic Flux, guaranteeing that the torque stays positive.When the motor is coupled to a 50 Hz supply, the (sinusoidal) current will change direction every 10 sec, and the torque will peak 100 times per second. Nonetheless, the torque will always be unidirectional, and the speed Fluctuations will be imperceptible due to the smoothing effect of the armature inertia. Series motors for alternating current are always constructed with a completely laminated structure (to prevent eddy current losses caused by the pulsing Flux in the magnetic circuit) and are meant to run at high speeds, such as 8-12 000 rev/min at rated voltage. Commutation and sparking are harsher than when working on alternating current, and output powers are rarely larger than 1 kW. The benefit of high speed in terms of power output per unit volume, and the universal motor is arguably the greatest common illustration of how high power can be attained with a compact size by designing for high speed. Until recently, the universal motor was the only relatively inexpensive means to reap the benefits of high speed from mono alternating current supply.

Competing compact alternating current machines, such as induction and synchronous motors, were limited to maximum speeds of 3000 rev/min at 50 Hz (or 3600 rev/min at 60 Hz), and hence could not compete in terms of power per unit volume. The development of high-frequency inverters has increased the possibility of higher specification outputs from induction motors, but the universal motor remains the dominant force in tiny low-cost applications because to the massive investment made over many years to create them in large numbers.Speed control of tiny universal motors is simple when a triac (in effect, a pair of thyristors linked back to back) is matched in series with the A.C supply. The voltage delivered to the motor may be changed to give speed control by adjusting the Wring angle, and therefore the fraction of each cycle for which the conducts. This method is commonly used for electric drills, fans, and other similar devices. If torque control is necessary (as with hand power tools), the current instead of the voltage is regulated, and the speed is governed by the load.

Compound motors

Both field coils supply the appropriate magnetic flux, which connects with the armature coil and produces the torque needed to allow rotation at the correct speed. As we can see, a compound wound DC motor is primarily made by combining a shunt wound DC motor with a series wound DC motor to attain the best of both kinds. The DC series motor has a large starting torque, but the shunt wound DC motor has a highly efficient speed regulation feature.As a result, the compound wound DC motor strikes a balance between these two characteristics, offering an excellent mix of precise speed management and high beginning torque. Though its starting torque is lower in comparison to that of a DC motor, and its speed control is not as effective as that of a shunt DC motor. The overall characteristics of a DC shunt motor sit halfway between these two extremes. Study our electrical MCQs to understand more about motors.

It is feasible to produce motors with a wide range of intrinsic torque-speed characteristics by arranging for some of the Required MMF to be delivered by a series winding and some to be provided by either a shunt winding. In fact, most compound motors have the majority of their Weld MMF delivered by a shunt Weld winding, therefore they perform similarly to shunt connected motors. The series winding MMF is relatively tiny and is used to trim the torque-speed curve to fit a certain load requirement.The motor is said to be 'cumulatively compounded' when the series Weld is coupled in such a way that its MMF strengthens the shunt Weld MMF. When the load on the motor grows, the higher armature current in the series Circuit leads the Flux to rise, increasing the torque per ampere but causing a larger reduction in speed than a simple shunt motor. The motor is said to be differentially compounded' if the series Weld winding opposes the shunt winding. In this scenario, increasing the current weakens the Flux, reduces the torque per ampere, but produces in a lower loss in speed than in a basic shunt motor. Differential compounding can thus be utilized in situations when it is critical to keep as close to constant speed as feasible.

Four-Quadrant Operation and Regenerative Braking

The simplicity with which the individually stimulated D.C. motor may be operated is its charm. To begin, the applied voltage determines the steady-state speed, thus we can make the motor operate at any desired speed in either direction by simply providing the proper magnitude and polarities of the armature voltage. Second, the torque is proportional to the armature current, which is determined by the difference in voltage between the applied voltage V and the back E.M.F E. We may therefore vary the amount to which the applied voltage is larger or less than the back E.M.F to make the machine generate positive (motor racing) or negative (generating) torque. An armature voltage controlled D.C. machine is therefore naturally capable of 'four-quadrant' operation, referring to the numbered quadrants of the torque-speed plane.Appears simple, but experience has shown that drawing the picture correctly requires a clear brain, thus it is important explaining out the main aspects in detail. A thorough comprehension of this figure is helpful in understanding how controlled-speed drives work.

Full speed regenerative reversal

The applied armature voltage is assumed to be V, and because the motor is unloaded, the no-load current is extremely tiny and the back E.M.F is almost equal to V. Finally, we'll need an armature voltage of V to for the motor to operate at maximum speed in reverse. But we can't just invert the applied voltage; if we did, the armature current would be provided by (V E) =R, which would be disastrously high. (The motor may accept it for the brief time it would persist, but the power supply would not).All we need to do is change the voltage such that the current is always confined to the rated value and flowing in the correct direction. Because we want to decelerate as quickly as possible, we must attempt to keep the current negative and at rated value (i.e. 100%) during the deceleration phase as well as the run up to full speed in reverse. This produces consistent torque throughout, resulting in continuous deceleration (and subsequent acceleration) and uniform speed change. To begin, the applied voltage must be decreased to less than the rear E.M.F., and then linearly scaled down with time so that the divergence between V and E remains constant, hence maintaining the current constant at its rated value.

Dynamic braking

By wasting the kinetic energy of a motor and load in a resistor rather of restoring it to the supply, a simpler and less evocative way of braking may be produced. A variant of this technique is used in lower-cost electronic power converter drives that lack the ability to return power to the mains. When the motor is to be turned off, the power to the armature is disconnected and a resistor is connected across the magnetic circuit brushes. The E.M.F of the motor drives a (negative) current through resistor, and the negative torque causes deceleration. As the speed decreases, so do the E.M.F., current, and braking torque. As a result, at low speeds, the braking torque is very small. Finally, all of the kinetic energy is transformed to heat by the motor's internal and exterior resistance. Using a low resistance allows for very rapid initial braking (or even simply short-circuiting the armature). For its simplicity, dynamic braking is still frequently employed in traction, however most modern rapid transit projects utilize the more energy-efficient regenerative braking technology.

Toy Motor

The motors used in model automobiles, railroads, and other vehicles are built differently than those covered thus far, largely to save money. They also operate at high speeds, therefore smooth torque is unimportant. The rotor, which is formed from laminations with a limited number (usually three or Wave) of multi-turn coils in extremely large ‘slots,' is straightforward to produce, as is the commutator, which has few segments. To complete the magnetic circuit, the Weld system (stator) consists of radially strong magnetic ceramic magnets with a steel backplate.The rotor obviously displays considerable saliency, and three extremely big projections that contrast sharply with the rotors we looked at before, when the surface was almost cylindrical. Even when there is no current in the rotor coils, it is simple to envisage that the stator magnets will pull one or both of the rotor saliencies into alignment with a stator pole, causing the rotor to lock in any of six states.

The stator is a permanent magnet that does not move on the exterior of a DC motor. The rotor is the moving portion on the inside. In this case, the rotor is analogous to the nail in our previous example, and the stator is analogous to the horseshoe magnet. When direct current (DC) power is applied to the rotor, it generates a transient electromagnetic field that interacts with the stator's permanent magnetic field. The commutator's duty is to maintain the field's polarity switching, which retains the rotor spinning. This generates the torque required to generate mechanical power.Two tabs hold the nylon end cap in place. As the motor rotates, the brushes within the end cap transmit electricity from the battery to the commutator. Because brushes wear out and must be replaced, current DC motors are often brushless.

The rotor and commutator are held in place by the axle. In this scenario, the rotor is made up of three electromagnets. The armature of this motor is a stack of thin metal plates with thin copper wire wound around every single one of the three rotor poles. Each wire's two ends (one for each pole) are connected to a terminal, and each of the three terminals is hooked to one plate of the commutator.

Rotor, Commutator and Brushes

The commutator and the brushes are responsible for "flipping the electric field" in an electric motor which use in how the commutator (in green) and brushes (in red) work together to allow current to pass to the electromagnet while simultaneously flipping the direction of electron flow at precisely the appropriate time. The commutator's contacts are linked to the axle of the electromagnet and spin with it. The brushes are just two bits of springy metal or carbon that make contact with the commutator's contacts (Figure 9.1).

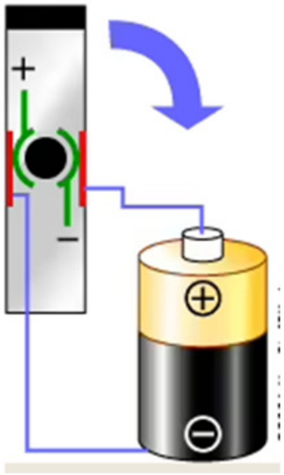

Figure 9.1 represent the commutator (in green) and brushes n red).

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CHAPTER 9

D.C MOTOR DRIVES

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A power modulator or amplifier that integrates with a controller and a DC motor is called a DC motor drive. It transforms the low current into a high current that is suitable for the motor after taking the low current. The high current torque, which is 400% more than the rated continuous torque, is also provided by the DC motor drive. Rolling mills, paper mills, mine winders, hoists, machine tools, traction, presses for print, textile mills, excavators, and crane are a few of the significant industries that use DC motor drives[1], [2].

The thyristor D.C. drive continues to be an essential speed-controlled industrial drive, particularly if the increased maintenance cost associated with D.C. motor brushes (vs. induction motor) is acceptable. The regulated (thyristor)rectifiergenerates a variable low-impedance 'D.C.' voltage. for the motor armature, allowing speed control.Before the 1960s, the only method to acquire the variable-voltage D.C supply required for speed control of an industrial D.C motor was to create it using a D.C generator. An induction motor drove the generator at fixed speed, and the generator's Frequency was changed to alter the produced voltage. The motor/generator (MG) set might be located apart from the D.C motor, and multi-drive sites (for example, steelworks) would have enormous halls filled with MG sets, one for each variable-speed motor on the plant.

'Ward Leonard' drives needed three machines (all of the same power rating), which was excellent business for the motor maker. They were briefly replaced by grid-controlled mercury arc rectifiers in the 1950s, but these were quickly replaced by thyristor converters, which covered lower first cost, greater efficiency (usually over 95%), smaller size, lower maintenance, and quicker reaction to changes in set speed. The downsides of recited supplies are that the waveforms are not pure D.C the converter's overload capability is relatively restricted, and a single converter cannot regenerate.

Motor current waveforms

Operation from a single-phase (2-pulse) converter for simplicity, although same findings apply to the 6-pulse converters. The voltage (VA) given to the motor armature is normally as, where the exact form and average value depend on the Wring angle.The voltage waveform is made up of a mean D.C. level (VDC) and a superimposed pulsing or ripple component, which we may refer to as Vac. The mean voltage VDC may be changed by adjusting the Wring tilt, which also affects the ripple (i.e. VAC).The smoothing effect of the armature inductance is critical for successful motor operation: the armature acts as a low-pass filter, blocking the majority of the ripple and resulting in a more or less constant armature current. To be effective, the armature time constant must be longer than the pulse duration (half a cycle with a 2-pulse drive, but only one sixth of a cycle with a 6-pulse drive). This requirement is satisfied by all 6-pulse drives and many 2-pulse drives. Overall, the motor behaves similarly to if it were powered by an ideal D.C. source (though the I 2R loss is higher than if the current was perfectly smooth)[3], [4].

The no-load speed is determined by the applied voltage (which is determined by the converter's Wring angle); there is a small drop in speed with load, and as previously stated, the average current is determined by the load, for example, the voltage waveform in (a) applies equally to the two load conditions represented in (b), where the upper current waveform corresponds to a high value of load torque and the lower corresponds to a much lighter load, with the speed being nearly the same in both cases. (The small speed difference is due to IR, as it is worth noting that the current ripple does not change with load; only the average current does. In general, we can say that the speed is determined by the converter Wring angle, which is a very satisfactory state because we can control the Wring angle with low-power control circuits and thus regulate the drive speed.

The current waveforms are called 'continuous' because there is never a time when the current is not flowing. This 'continuous current' situation is the standard in most drives, and it is extremely desired since the average voltage from the converter is dictated only by the Wring angle and is independent of the load current only under continuous current circumstances. With, we can see why this is so. Assume that the motor is connected to the output terminals and draws a continuous current. The current will Flow into the motor from T1 and return to the mains through T4, thus the armature is effectively switched across the supply and the armature voltage is equal to the supply voltage, which is considered to be ideal, i.e. it is independent of the current drawn, for half of a full cycle. The motor current flows from T2 and returns to the supply via T3 for the other half of the time, so the motor is hooked up to the supply again, but this time the connections are reversed. As a result, once the ring angle is set, the average armature voltage and thus, to a first approximation, the speed - are defined.

The speed will settle at point A, with the average armature currents and voltages at full (rated) levels. When the load is lowered while the current remains constant, the predicted modest increase in speed occurs until point B is attained. The current is poised to reach the discontinuous phase at this moment. Every additional drop in load torque results in a completely disproportionate - if not terrifying - rise in speed, particularly if the load is lowered to zero when the speed reaches point C.We can enhance these essentially weak features in two ways. To begin, we may add more inductance in series with the armature to smooth out the current waveform and reduce the possibility of discontinuous current. The effect of increasing inductance is by the dotted lines. Second, may move from a single-phase converter to a three-phase converter, which provides smoother voltage and current waveforms.

When the converter and motor are used in a closed-loop control system, the user should be ignorant of any flaws in the intrinsic motor/converter characteristics since the control system automatically adjusts the Wring angle to reach the desired speed at all loads. In the case of Figure 4.4, for example, the user is only concerned with the shaded zone, and the fact that the motor is theoretically capable of operating unloaded at the high speed corresponding to point C is solely of academic interest.

Single-converter reversing drives

Build a fully controlled converter powering a permanent magnet motor, and demonstrate how the motor can be regenerative braked from full speed in one direction and then driven up to full speed in the other way. We discussed this method in general at the conclusion, but here we look at how to do it with a converter-fed drive. To be clear, all the user needs to do in reality is shift the speed reference signal from full forward to full reverse: the control system in the drive converter takes care of the rest. The converter delay angle will be minor when the motor is moving at full speed forward, and the converter output voltage V and current I will both be positive.

To brake the motor, the torque must be reversed. The only way to do this is to reverse the direction of the armature current. Since the converter can only produce positive current, we must reverse the armature connections using a mechanical.A witch or contactor (Before running the contactor, the armature current is lowered to zero by reducing the converter voltage, removing the need for the contactor to interrupt current.) While the motor is still spinning in the positive direction, the back E.M.F stays unchanged; however, the motional E.M.F is now shown to be helping the current, and so the converter must provide a negative voltage V that is just a bit less than E to maintain the current within boundaries. This is accomplished by positioning the delay angle between 908 and 1808. The maximum allowable negative voltage will typically be somewhat less than the maximum positive voltage; this limitation derives from the necessity to maintain a margin for current commutation between thyristors. The converter current is still positive, but the converter voltage is negative, and power is therefore flowing back to the mains. The system is in quadrant at this point, and the motor is decelerating due to the negative torque. When the speed decreases, E decreases, and so V must be gradually lowered to maintain the current at its maximum amount. The activity of the current-control loop, which is detailed later, does this automatically.

To run up to speed in the reverse direction, the current (i.e. torque) must be maintained negative, but as the back E.M.F changes sign (when the motor reverses), the converter voltage becomes positive and larger than E, as illustrated . The converter then rectifies, and power is delivered into the motor, putting the system in quadrant three. Because of the delay imposed by the mechanical reversing switch, which may easily amount to 200-400 m/sec, schemes employing reversing contactors are not suited when the reversing time is crucial. Field reversal methods work similarly, but reverse the Weld current rather of the armature current. Because of the comparatively large time constant of Weld winding, they are considerably slower.

Double-converter reversing drives

When complete four-quadrant operation and quick reversal are required, two anti-parallel converters are utilised, the motor is supplied with positive current by one converter and negative current by the other. The bridges are managed such that their D.C voltages are almost identical, ensuring that any D.C circulating current is modest, and a reactor is put between the bridges to restrict the flow of ripple currents caused by the two converters' differing ripple voltages. Instead, the reactor may be avoided by running just one converter at a time. Only until the Wring bursts have been eliminated from one converter and the armature current has dropped to zero can the switchover take place. As an inherent element of the drive, appropriate zero-current detecting circuitry is supplied, so that the two converters act as if they were a single ideal bidirectional D.C source to the user.Potential customers should be informed that a simple single converter can only operate in one quadrant. If regenerative braking is necessary, either Weld or armature reversing contactors must be used, or a double converter must be utilized if quick reversal is required. All of these things raise the purchasing price[5], [6].

Power factor and supply effects

The supply power factor of a converter-fed D.C. drive is extremely low when the motor is working at high torque (i.e. high current) or low speed (i.e. low armature voltage), and is less than unity even at base speed and full load (Figure 10.1). This is because, as illustrated, the supply current waveform lags behind the power supply waveform by the delay angle a (for a 3-phase converter).

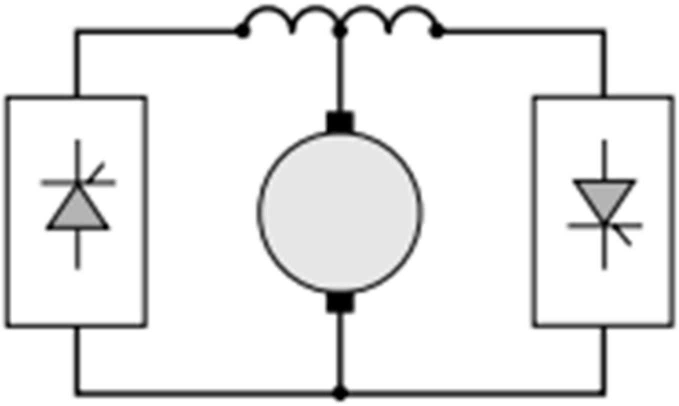

Figure 10.1 Represent the Double-converter reversing drive.

It is critical to emphasize that even while the converter is inverting, the supply power factor is constantly trailing. Because there is no way to avoid low power factor, users of large drives must be prepared to supplement their existing power factor correcting devices as needed.Harmonics in the mains output current can cause a wide range of interference issues, and supply authorities typically impose statutory limits. Walters may be required for large drives (say, hundreds of kilowatts) to prevent all such limits from being exceeded[7], [8].

Control arrangements for D.C. Drives

The so-called two-loop control is the most typical configuration, which is utilized with only slight alterations from tiny drives of 0.5 kW up to massive industrial drives of several megawatts. An inner feedback loop controls the current (and hence the torque) while an outside loop controls the speed. When position control is required, an additional outer position loop is introduced. A two-loop system for a thyristor D.C. drive, although the key elements are the same in a chopper-fed drive. After that, the simpler layouts employed in low-cost tiny drives are explained.The talk is based on analogue control and is confined to the elements that the user has to be aware of and comprehend. In fact, after a drive has been commissioned, the user only has access to a few potentiometer changes (or presets in the case of a digital control). Although most of them are self-explanatory (e.g. maximum speed, minimum speed, acceleration and deceleration rates), others are not (e.g. 'current stability, “speed stability,' 'IR comp'.) and must be explained.

To understand how a two-loop strategy works in general, consider what we would do if we were operating the motor manually. For example, if we observed the tach generator and discovered that the speed was lower than desired, we would want to supply more current (and hence torque) to induce acceleration, thus we would increase the armature voltage. Yet, we would have to proceed with caution due to the risk of producing an excessive current due to the delicate balance that occurs between the back E.M.F ., E, and applied voltage, V. To prevent blowing up the thyristor stack, we would undoubtedly want to keep an eye on the ammeter at all times, and as the speed neared the goal, we would cut down the current (by reducing the applied voltage) to avoid overshooting the set speed. Such actions are carried out automatically by the drive system, which we shall now investigate.

a conventional drive system with speed and current regulation. The major objective of the control system is to provide speed control, therefore the speed reference signal on the left is the 'input' to the system, and the output is the motor speed (as measured by the tachogenerator TG) on the right. The total performance of this closed-loop system is strongly reliant on the quality of the feedback signal, in this instance the speed-proportional voltage produced by the tachogenerator. As a consequence, it is critical to guarantee that the tacho is of good quality (such that its output voltage does not change with ambient temperature and is ripple-free), and the cost of the tacho is frequently a significant part of the entire cost.

A speed error indicates that acceleration is required, which means torque, i.e. more current. The speed controller (more precisely characterized as a speed-error amplifier amplifies the speed error, and the output serves as the reference or input signal to the integral control system. Since the inner feedback loop is a current-control loop, when the current reference rises, so does the motor voltage level, delivering more torque and commencing acceleration. As the speed increases, the speed error decreases, and the current and torque decrease to achieve a smooth approach to the goal speed.This 'electronic current limiting' element is by far the most critical safety aspect of any drive. That implies that if the motor abruptly stalls due to a load seizing (causing the back E.M.F to decrease rapidly), the armature voltage will immediately decline to a very low value, restricting the current to its maximum permissible level.

When configuring a drive, the first thing we should strive for is a solid current loop. In this sense, 'good' indicates that the steady-state motor current should match the current reference accurately, and that the transient reaction to step changes in the current reference should be rapid and properly damped. The integral term in the current-error amplifier satisfies the first of these conditions, while the second is provided by careful selection of the amplifier derivative controller and time constant. In terms of the user, the 'current stability' adjustment allows him to optimize the transient response of the current loop.

Torque control

For applications requiring the motor to run with a constant torque regardless of speed (e.g., line tensioning), we may omit the outer (speed) loop and just provide a current reference signal straight to the current controller (often through the 'torque ref' connector on the control board). Since torque is directly proportional to current, the current controller in effect is also a torque controller. We may need to account for increasing torque with a transient 'inertia correcting' signal, although this is normally accomplished with a potentiometer change or digital preset.In the current-control mode, the current stays constant at the given value, and the steady operating speed is dictated by the load. If the torque reference signal was set to 50%, for example, and the motor was initially at rest, it would accelerate with a steady current of half the rated amount until the load torque equaled the motor torque. if the motor was operating without any load, it would accelerate fast, the applied voltage ramping up such that it was always greater than the back E.M.F by the amount required to push the specified current into the armature. Ultimately, the motor would reach a speed (a bit faster than usual 'full' speed) at which the converter output voltage had hit its upper limit and it was no longer able to sustain the set current: the motor speed would then stay constant.

An 'excellent' speed controller will have 0% steady-state error and a well-damped response to step changes in the requested speed. The integral component in the PI control accounts for the need of zero steady-state error, whilst the transient response is determined by the derivative controller and time constant settings. The'speed stability' potentiometer allows the user to fine-tune the transient speed response.

It should be noted that obtaining a good transient response is often considerably simpler with a regenerative drive, which has the capacity to give negative current (i.e. brake torque) if the motor overshoots the required speed. Since a non-regenerative drive cannot provide negative current (unless equipped with reversing contactors), the only option if the speed exceeds the objective is to drop the armature current to zero and wait for the motor to decelerate naturally. This is insufficient, and each effort must be designed to prevent controller settings that cause the desired speed to be exceeded.

As with any closed-loop approach, issues arise when the feedback signal is lost while the system is running. If the tacho feedback was lost, the speed amplifier would quickly saturate, resulting in full torque being delivered. The speed would then increase until the converter output voltage reached its maximum. To prevent this, many drives have tacho-loss detecting circuitry, and in certain instances, armature voltage feedback (see later section) takes over automatically in the event of tacho failure.While operating above base speed, drives that employ Weld-weakening to widen the speed range provide automated provision for regulating both armature voltage and Weld current. Normally, the Weld current is maintained at maximum power until the armature voltage reaches around 95% of the rated value. When a faster speed is required, the additional armature voltage delivered is followed by a corresponding decrease in the Weld current, such that when the armature voltage hits 100%, the Weld current is at the safe operating value. This is referred as 'spillover Weld weakening.

Armature voltage feedback and IR compensation

In low-power drives when accurate speed-holding is not required and expense is limited, the tacho-generator is omitted and the input power is employed as'speed feedback' instead. The performance is plainly inferior to that of tacho-feedback because, although the steady-state no-load speed is related to armature voltage, the speed decreases as the load (and therefore armature current) grows. That the loss in speed with load was caused by the armature resistance volt-drop (IR), and that the drop in speed may be compensated for by increasing the applied voltage according to the current. In the drive circuit, an adjustment labelled 'IR comp' or simply 'IR' is given for the user to tune to fit the specific motor. The compensation is seldom ideal since it cannot account for temperature variations in resistance or effects of armature response; still, it is better than nothing.

Chopper-fed D.C. Motor drives

A chopper-type converter is often used when the supply is D.C. (for example, in a battery car or a rapid transit system). The fundamental functioning of a single-switch chopper was reviewed, and it was shown that the average output voltage could be changed by regularly switching the battery voltage on and off at variable intervals.The main difference between a thyristor-controlled rectifier and a chopper is that the former always flows via the supply, whilst the latter only flows from the supply terminals for a portion of each cycle.A single-switch chopper based on a transistor, MOSFET, or IGBT can only give positive voltage and current to a D.C motor, limiting it to quadrant 1 driving. When regeneration and/or quick speed reversal is necessary, more sophisticated circuitry is required, incorporating two or more power switches and therefore increasing cost. There are many different circuits used, and it is not possible to go into detail here, but it should be noted that the chopper circuit only provides an output voltage in the range 0 E, where E is the battery voltage, so this type of chopper is only suitable if the motor voltage is less than the battery voltage. When the motor voltage exceeds the battery voltage, a ‘step-up' chopper is utilized with an extra inductance as an interim energy storage.

Torque speed characteristics and control arrangements under open-loop condition

Since the mean armature voltage stays constant while the armature current is continuous, the speed only marginally decreases with load. Nevertheless, when the armature current is irregular (which is most probable at high speeds and low loads), the speed declines V quickly as the load grows because the mean armature voltage falls. Discontinuous current may be prevented by connecting an inductor to the armature or increasing the chopping frequency, but when closed-loop speed control is used, the control loop masks the unwanted events of discontinuous current.The control philosophy and arrangement for a chopper-fed motor are the same as for a converter-fed motor, with the obvious distinction that the chopper's mark-space ratio, rather than the Wring angle, is utilised to adjust the output voltage.

D.C Servo drives

When the armature current is continuous the speed declines only lightly with load, since the mean armature voltage stays constant. However when the armature current is discontinuous (which is most often at high speeds and low load) the speed decreases 0V quickly when the load grows, since the mean armature voltage falls as the load increases. Discontinuous current may be prevented by placing an inductor in series with the armature, or by boosting the chopping speed, but when closed-loop speed control is applied, the undesired effects of discontinuous current are hidden by the control loop. The control philosophy and arrangements for a chopper-fed motor are the same as for the converter-fed motor, with obvious exception that the mark–space ratio of the chopper is utilized to alter the output voltage, rather than the Wring angle.

Servo drives are used in DC motor control systems to amplify command signals and deliver electric currents to servo motors. They are critical to the efficient generation of motion with the optimal velocity, location, and/or torque for a given application. DC servo drives are continually working to optimize performance based on data from a sensor inside the servo motor. They guarantee that each DC motor can adjust to a broad range of performance-related factors in real time. DC servo drives, in particular, provide accurate position and speed control inside closed loop systems of brushed or brushless DC motor control systems. These drives extend the life of the motor.

Electrical drives are the types of systems that are used to regulate the motion of electrical machines. In other terms, electrical drive refers to a drive that makes use of an electric motor. Any main source of energy may be used by the electrical drive, including diesel or gasoline engines, gas and steam turbines, steam power, hydraulic motors, even electrical motors. The mechanical energy required by the drive with motion control is provided by this prime mover. Electrified Drives. Electromechanical devices called electric drives are used to regulate the motion for electrical machinery. Given that it makes motion control optimization simple, it is regarded as a crucial part of equipment used in a variety of industrial operations. The mechanism that manages the motor's spinning shaft is said to be complex. A typical drive system consists of one or more electric motors and a mechanism for regulating the motor shaft's velocity. The working (or driven) machine, energy transmission device, and electric motor are the main elements of electric drives.

Concept of Electric Drives

B.S. Iakobi first developed the idea of electric driving in 1838 in Russia. Electric drives were first used in industry in the year 1870, but they are now widely used in a variety of applications. Motion control is well-known to be used in both residential and commercial applications. Drives are a special system that are integrated in order to provide the necessary motion and maintain smooth control. Electric drives are made up of an electric motor, an energy-transmitting device, and a working machine, as we've previously covered. The electric motor provides the necessary energy for the desired motion to occur. Whereas an energy transmitting device is utilized to transport the provided power to the driven machine therefore for operation to occur. The intended manufacturing process that must take place inside the system is handled by the driven and working equipment. Pumps, food mixers, and other operating devices are a few examples. As a result, we can state that an arrangement is considered to be an electric drive if it includes an electric motor together with regulating and energy-transmitting components. A motion control scheme is mostly provided by electric drives, which transform electricity into mechanical energy to impart motion to various devices.

Parts of Electrical Drive

The power modulator, the motor, this same controlling unit, and the sensor units are the essential components of electrical drives.

Power Modulator

The source's output power is controlled by the power modulator. It regulates the power flowing from the generator to the motor in order for the motor to convey the speed-torque characteristics needed by the load. Excessive current is taken from the source during transitory actions like starting, stopping, and speed reversal. This increased current flow might overwhelm the source or result in a voltage drop. The power modulator limits the source and power flow as a result. When an induction motor was employed and the energy source is DC, the voltage modulator transforms the energy into AC in order to meet the needs of the motor. Additionally, it decides whether the engine will be in driving or braking mode.

Control Unit

The power modulator, typically functions at low voltage and power levels, is controlled by the control unit. The power modulator is also controlled by the control unit as needed. Additionally, it creates the instructions for the motors and power modulator's protection. An instruction signal from such an input to the control module that modifies the drive's operating temperature.

Sensing Unit

It detects certain driving parameters like motor speed and current. It was primarily necessary for closed loop functioning or protection.

Power Source

This device is in charge of giving the system the power it needs to perform the required task.

Power Converter or Controller the following tasks are carried out by this unit:

This component is in charge of transforming the electrical energy provided as input into a form that can power the motor (generally mechanical energy). The power controller regulates the amount of power input that the motor is capable of handling. In essence, this management is required because the system's power determines the torque-speed characteristics that the load needs. This device assists in regulating the current to preset levels during transient system activities like starting, braking, etc. such that voltage overloads or dips may be avoided. Power converters come in a variety of sorts, and we have created a distinct resource on them.

Control Unit and Sensor Unit

Under closed-loop operation, this device controls the power converter in accordance with the inputs supplied and the feedback signal acquired from the load. In order to have the right operating conditions, the control unit basically collaborates with both the sensor unit, which still measures the voltage or current signal providing feedback. The sensing component is in charge of detecting the motor's current or speed. It offers closed-loop functioning in addition to protection.

Electric Motor

The applied energy is mostly converted into mechanical motion through this. The majority of the DC motors used in electric drive systems were slip ring induction motors, which are employed in series, shunt, as well as compound form. In certain instances, stepper motors but rather brushless DC motors are also employed.

Load

In accordance with the torque/speed properties of the system, such as those of the pumps, machines, etc., the load that is a component of the system is described. In respect of torque-speed characteristics, both electric motor and load perform in harmony.

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CHAPTER 10

HEATING AND COOLING CURVES OF ELECTRICAL DRIVES

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A precise forecast of electrical drive heating and cooling curves Because of the complicated geometrical forms and the usage of heterogeneous materials, rising within an electrical motor is highly challenging. The assumption that the machine is a homogenous body allows for the creation of a straightforward thermal model of a device since the conductivities of different materials do not vary significantly. Even if it is imprecise, such a model is sufficient for a drive engineer for whom the sole responsibility is to choose the motor rating for a specific operation while making sure that the temperature within various motor body components does not go over the safe limits[1], [2]. Given that the machine is thought to be a homogenous body:

P1: Heat produced in joules/second or watts.

P2 = Heat dissipated towards the cooling medium, expressed in joules per second or watts.

W is the machine's active component weight in kilograms.

H stands for specific heat, measured in joules per kilogram me per degree Celsius.

A = Cooling surface, m2, and d = heat transfer coefficient or specific heat dissipation, in joules/sec/m2/°C.

= Mean temperature increase, in degrees Celsius.

Allow the machine's temperature to increase by d throughout the time interval dt. Since,

$$\text{Heat absorbed in the machine} \\ = \text{Heat developed inside the machine} \\ - \text{heat dissipated to the surrounding cooling medium}$$

$$Whd\theta = p_1 dt - p_2 dt$$

$$p_2 = \theta dA$$

Substituting and rearranging the terms.

$$C\frac{d\theta}{dt} = p_1 - D\theta$$

$$C = Wh$$

$$D = dA$$

D is the heat dissipation constant throughout watts/°C, and C is the machine's thermal capacity in watts/°C. Convection is the primary mechanism for heat dissipation. D typically has values between 40 and 600 W/m2/°C. There is a resolution to the first order differential equation.

$$\theta = \theta_{ss} + Ke^{\frac{-t}{\tau}}$$

$$\theta_{ss} = \frac{p_1}{D}$$

$$\tau = \frac{C}{D}$$

Continuous with integration by replacing the temperature increase at time t = 0, K is obtained. Has a solution whenever the initial temperature increase is 1.

$$\theta = \theta_{ss}\left(1 - e^{\frac{-t}{\tau}}\right) + \theta_1 e^{\frac{-t}{\tau}}$$

The machine's heating (or thermal) time constant is called as, which has the dimension of time τ. where t = ∞, θ = θss. Thus, ss is indeed the machine's steady state temperature when it's heated constantly by power P1. At this temperature, the whole amount of heat generated by the machine is released into the environment. When the machine's temperature rises to a value of 2, let the load be removed. Heat loss will decrease to a low value P′1 and the motor's cooling process will start. Let D′ represent the new heat dissipation constant value. If the load was thrown off when the timer starts, then.

$$C\frac{d\theta}{dt} = p_1' - D'\theta$$

The speed of cooling air changes with motor speed for self-cooled motors when a cooling fan is installed on the motor shaft, changing the cooling time constant τ′. At a standstill, the cooling time constant was substantially greater than it is while moving. As a result, the motor has always been equipped with a separate forced cooling system in high efficiency, medium, especially high power variable speed drives, as shown in Figure 11.1.

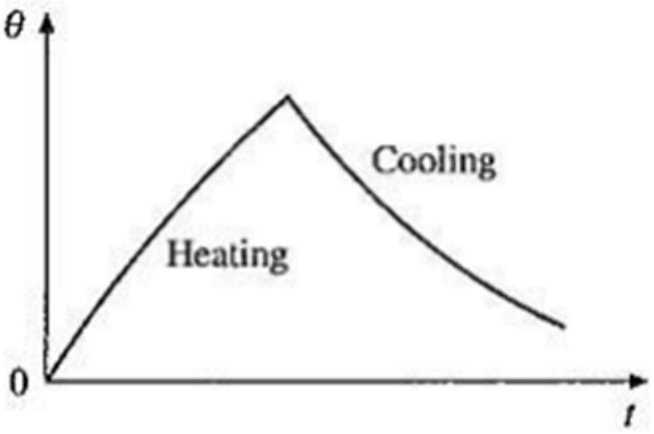

Figure 11.1: Illustrates the heating and cooling curve in terms of time.

The increase in motor temperature over time during electrical drive heating and cooling curves. In comparison to electrical and mechanical frequency components, a motor's thermal time constant is much bigger. Thermal time constants may range from a few minutes to a few hours, unlike electrical and mechanical frequency components, which typically have ranges of 1 to 100 MS and 10 ms to 10 s, respectively[3], [4].

Classification of Electrical Drives

These are often broken down into three categories, including group drive, individual drive, but also multi-motor drive. These drives are also divided into other categories depending on the many factors that are described. According to their stage of development, electric drives are typically divided into three groups: group, individual, and multi-motor electric drives

Group Drive

A system is referred to as a group drive or shaft drive if many groups of mechanisms or machines were arranged on one shaft and powered or operated by a single motor. Different related mechanisms may operate at different rates. As a result, the shaft has many stepped pulleys with belts for connecting to different loads. Due to the possibility that not all linked loads will be present at once, this sort of drive allows for the employment of a single machine for whom the rating is less than the total of any and all connected loads. Even though the cost of a shaft with stepped pulleys might appear excessive, this makes the drive affordable.

Due to the following drawbacks, this approach is seldom utilized in contemporary drive systems and has only historical importance. The drive's efficiency is poor as a result of losses that occur in various transmission mechanisms. If the motor has to be serviced or repaired, the whole drive system must be turned down. The shaft determines where the mechanical apparatus being driven is located, and there is minimal room for arrangement. Operating the system is not particularly secure. There is a lot of noise when work is being done.

Individual Drive

A drive is referred to as an individual drive if just one motor is employed to power or activate a specific mechanism and it completes all tasks associated with this load. One machine, for instance, may be able to handle all the tasks involved in running a lathe. Transmission devices can be needed if these processes must be carried out at various rates. Over numerous operations, efficiency may decline as a result of power loss. It is sometimes feasible to combine the drive motor and the driven load into a single unit[5], [6].

Multi-motor Drive

Each function of the mechanism was handled by a different driving motor in a multirotor drive. The system has a number of unique drives, which are each utilized to run a different mechanism. Complex machine tools, mobile cranes, rolling mills, etc. all use this kind of drive. Each process may be carried out under ideal circumstances while using automatic control techniques.

Torque Equation of Motor Load System

In most cases, a motor uses a transmission system to move a load (a machine). While the motor always rotates, the load also may spin or move in a different direction. If the load is composed of several pieces, the load's speed may vary from the motors, and some of those parts may spin while others may move in a translational motion. Therefore, it is more practical to depict the Torque Equation of Motor Load System using an analogous rotating system, as illustrated in Figure 11.2.

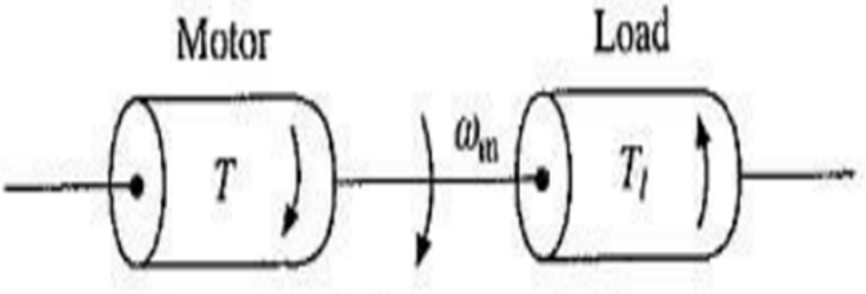

Figure 11.2: Illustrates the equivalent motor load system.

The following notations are used:

J = kgm, referred to as the polar moment of inertia of the motor-load system.

ωm = Motor shaft's instantaneous angular velocity, expressed in rad/sec.

T is the instantaneous, in N-m, value of the produced motor torque.

T1 = Instantaneous load (resisting) torque, expressed in N-m, applied to the motor shaft.

Friction and motor wind age torque are included in the load torque.

The following basic torque equation could be employed to define the Torque Equation for Motor Load System:

$$T - T_t = \frac{d}{dt}(J\omega_m) = J\frac{d\omega_m}{dt} + \omega_m\frac{dJ}{dt}$$

Equation may be used for motors with variable inertia such mining winders, reel drives, and industrial robots. (dJ/dt) = 0 for drives having constant inertia. Therefore,

$$T = T_l + J\frac{d\omega_m}{dt}$$

A load torque T1 as well as a dynamic torque J(dm/dt) balance out the torque produced by the motor. Given that it only appears during transient activities, the torque component J(dm/dt) is known as the dynamic torque.

Depending according to whether T is more than or less than T1, the drive will accelerate or decelerate. So order to compensate for the drive inertia during acceleration, the motor needs provide not simply the load torque in addition to an extra torque component, J (dm/dt). To provide acceptable acceleration in drives with high inertia, including such electric trains, this same motor torque must be much greater than the load torque. Motor torque should indeed be kept as high as feasible in drives that need quick transient reaction, and the torque equation for motor system analysis and design should indeed be built with as little inertia as possible. The kinetic energy represented by (J2 m/2) is used to store the energy connected with the dynamic torque J (dm/dt). Dynamic torque J (dm/dt) has a negative number during deceleration. As a result, it uses stored kinetic energy to sustain driving motion while assisting the motor's created torque T[7], [8].

Intermittent Periodic Duty with Starting

It denotes a series of similar duty cycles, each comprising of a beginning phase, a period of operation with constant load, as well as a rest period. As shown in Figure 11.3 , the working periods are too brief for thermal equilibrium to be reached within a single duty cycle. This sort of motor function is often used in mine hoists, drives for metal drilling and cutting tools, etc.

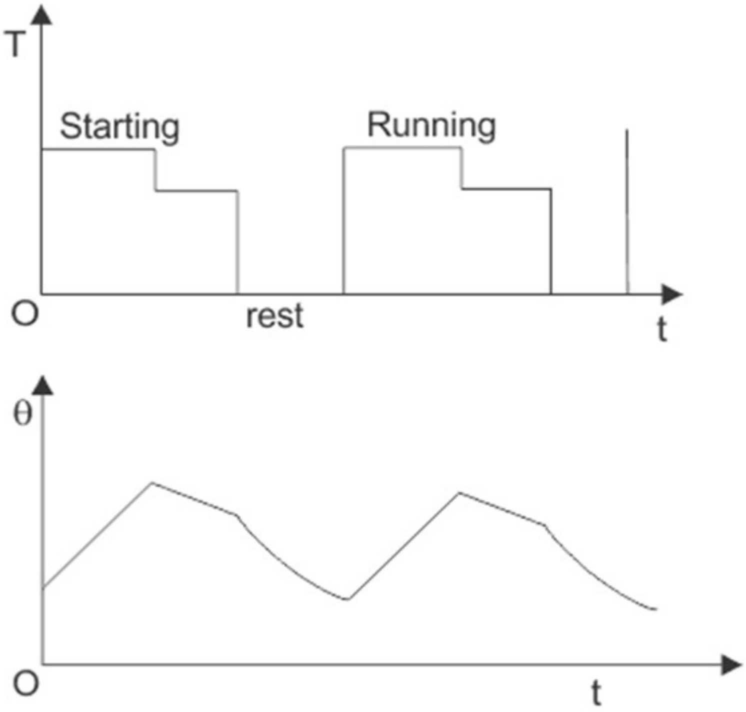

Figure 11.3: Illustrates the Intermittent Periodic Duty with Starting.

Intermittent Periodic Duty with Starting and Breaking

Heat losses during beginning and braking can indeed be disregarded during this intermittent periodic employment. As a result, it consists of a beginning phase, a time of operation with something like a constant load, a period of electrical braking, as well as a period of rest, with the working and resting periods being too brief to reach the corresponding steady state temperatures. Numerous instances of this responsibility include the drives for mine hoists, manipulators, ingot buggy's, blooming mill screw down mechanisms, several machine tool drives, including electric commuter train drives. Figure 11.4 shows that in certain drives, heat loss during braking and starting cannot be disregarded. These approaches are employed throughout billet mill drive, manipulation drive, mine hoist, etc[9]–[11]. The corresponding durations include beginning period, operation period, braking period, then resting period, but all of these times are too short to reach the relevant steady state temperatures.

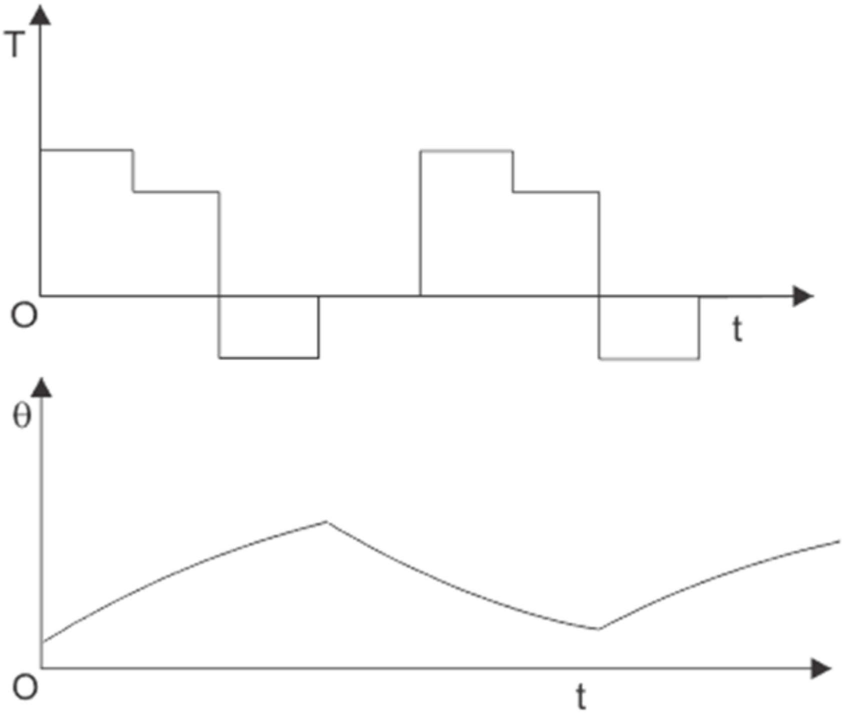

Figure 11.4 : Illustrates the Intermittent Periodic Duty with Starting and Breaking[12]**.**

Continuous Duty with Intermittent Periodic Loading

It comprises of regular duty cycles with normal voltage throughout the excitation coil that alternate between periods of operation under a constant load and periods of operation under no load. Once again, the load duration and also no load period were too short to allow the desired temperatures to be reached. In contrast to intermittent periodic duty, this kind of motor duty in motor machines alternates between periods of operating at a constant load and periods of running with no load as opposed to periods of rest. Machine drives for pressing, cutting, shearing, as well as drilling are a few examples. It comprises of regular duty cycles having normal voltage throughout the excitation coil that alternate between periods of operation under a constant load with periods of operation under no load. Once again, the load duration and also no load period were too short to allow the desired temperatures to be reached. In contrast to intermittent periodic duty, this kind of motor duty involving electrical drives alternates between periods of operating at a constant load and periods of running with no load as opposed to periods of rest. Machine drives for pressing, cutting, splitting, and drilling are some examples.

Continuous Duty with Starting and Braking

Consists of repeated duty cycles with no rest periods between the periods of beginning, operating at a constant load, and electrical braking. An example is the primary drive of a blossoming mill.

Continuous Duty with Periodic Speed Changes

Consist of a periodic duty cycle with two operating periods that are too brief for the corresponding steady-state temperature and pressure to also be reached: one operating period at a certain load and speed, and the other operating at quite a different speed and load. Additionally, there is no downtime.

Types of Electrical Drives

Depending on the different parts of the drive system, electrical drives may be categorized. The drives may now be divided into three categories based on design: single-motor drive, group motor drive, as well as multi motor drive. The simplest sort of drive is the single motor type, which is often used in simple metalworking, home appliances, etc. Due to several complexity, group electric drives were utilized in contemporary businesses. Heavy industries and other applications requiring many driving units, such as rail transportation, employ multi-motor drives. From the different angle, these drives may be divided into two categories: reversible drives and non-reversible drives. This mostly relies on the driving system's capacity to change the flux's orientation.

Parts of Electrical Drives

The fundamental circuit layout and pieces of a drive also demonstrate the fact that certain components, such as the load, motor, power modulator, control unit, and supply, are fixed in a drive. These devices are referred to as driving system components. Now, loads may be of several sorts, with distinct circumstances and needs that are covered later. But first, let's talk about the other four components of electrical drives: the motor, power modulator, source, and control unit. There are several kinds of electric motors. Shunt wound, series wound, compound wound, as well as permanent magnet DC engines are the four categories into which DC motors may be categorized. Induction motors as well as synchronous motors are the two kinds of AC motors. There are now two kinds of synchronous motors: permanent magnet and round field. Additionally, there are two kinds of induction motors: wound and squirrel cage. Stepper motors and switching reluctance motors are also regarded as components of the drive system in addition to all of the above.

Electric motors come in a variety of forms, and each one is employed for a unique purpose. Induction and synchronous motors have often been only used in situations where a fixed or constant speed has been the sole requirement whenever electrical drives were less common. DC motors were used in applications requiring variable speed drives. However, as is well known, induction motors with equivalent ratings to DC motors offer a number of benefits, including lighter weight, cheaper cost, smaller volume, and less limitation on maximum voltage, speed, and power ratings. Because of these factors, induction motors are quickly replacing DC motors. Induction motors are also more mechanically robust and need less upkeep. When synchronous motors are taken into account, winding field and permanent magnet synchronous motors outperform induction motors on terms of full load efficiency and power factor, although synchronous motors are larger and more expensive than induction motors for the same reason rating.

Brushless DC motors were comparable to synchronous permanent magnet motors. They are used in servo applications and have become a reliable substitute for DC servo motors since they lack drawbacks like the commendation issue. In addition to this, switching reluctance motors are utilized for speed control and stepper motors are employed for position control.

Power Modulators

To regulate electrical drives, there exist devices that modify the kind or frequency of the power in addition to its intensity. In general, there are three categories of power modulators: converters, variable impedance circuits, and switching devices.

Power converter in Electric Drive

The power converter circuits for use with motor drives, offering either D.C. or A.C. outputs, and operating from either a D.C. (battery) supply or from the standard A.C. mains. The approach is not meant to be thorough but rather to draw attention to the key features that all drive converter types have in common. Despite the wide variety of converter designs, all save the extremely low-power ones rely on some kind of electronic switching. The first scenario, where the effects are thoroughly discussed, emphasizes the necessity to adopt a switching strategy. They shall see that switching is crucial for achieving high-efficiency power conversion, but also that the waveforms that follow are always not the best for the motor.

The examples were selected to reflect actual usage, therefore the most popular switching devices, such as transistors and thermistors, are shown for each converter. We shouldn't label a certain circuit as being the only domain of a certain device since in many situations, a variety of switching devices may be useful. The converter's function is to provide the motor with electrical energy from either the mains at the voltage and frequency required to produce the specified mechanical output. There are often two separate pieces to a converter, with the exception of the simplest converter (such a straightforward diode rectifier).

The energy lows travel to the motor via the first stage, known as the power stage, and through the second stage, known as the control stage, that either controls the power lows. Whereas other low-power feedback signals are employed to assess what is actually occurring, control signals, which take the form of low-power analogue and digital voltages, instruct the converter about what it should be doing. The goal output is maintained by analyzing the feedback and demand signals and modifying the output appropriately. The straightforward configuration in only has one input for the intended speed one and feedback signal for the actual speed, but as we shall see later, most drives include additional feedback signals. Nearly all drives use closed-loop (feedback) control, thus it may be good for readers who are not acquainted with the fundamentals to read the Appendix at this point.

Power electronic converters have extremely low energy storage capacity, which is a trait they share with the majority of electrical systems. This implies that any abrupt change in the power the converter delivers to the motor must be accompanied by an abrupt rise in the power required from the supply. Although this is often not a significant issue, it does have two negatives. First off, because of the impact of the supply impedance, a rapid rise in the current pulled from the supply will result in a brief reduction in the supply voltage. These voltage "spikes" will seem to other users on the same source as unwanted distortion. Second, before the supplier can provide more power, there can be a forced delay. There cannot be a rapid rise in the power supply from the mains at the time when the mains voltage is zero, for example, with a single-phase mains supply. It would be preferable if a significant quantity of energy could be stored within the converter itself. This way, any immediate energy needs could be satisfied, preventing sudden swings in the power used from the mains. The majority of converters do have a tiny energy reserve stored in their smoothing inductors and capacitors, but the quantity is insufficient to buffer the supply enough to protect it from anything other than extremely brief variations. Unfortunately, this is just not economically feasible.

AC to DC Converters

DC motors have been around for over a century. In actuality, the first electric motors were created and engineered to run on direct current electricity. Despite the fact that AC motors are more often utilized in industry for high speed operation (above 2500 rpm) than their DC counterparts due to their being smaller, lighter, cheaper, and practically maintenance-free, the latter are nevertheless used. They have a broad speed range, strong speed regulation, beginning and accelerating torques beyond 400% of rated, less sophisticated management, and are often less costly drives, which are the reasons behind this. DC motors are still employed in a variety of applications today, including the manufacturing and processing of pulp production, the textile industry, the propulsion of electric vehicles (EVs), and modes of public transportation including the TRAM (trolley) and METRO. Power electronics, such as controlled rectifier fed (thermistor-fed) DC drives and chopper-fed DC drives, are often used to operate these motors. These devices have been a mainstay of industrial applications due to their simplicity, ease of use, dependability, and affordable price.

One of the most crucial components in power electronics are AC to DC Converters. This is due to the fact that many practical applications rely on these transformations. AC-DC converters are the electrical circuits that convert alternating current (AC) input in and out of direct current (DC) output. They are utilized in applications of power electronics when a sine-wave AC voltage at 50 or 60 Hz has to be converted into a DC output. Rectification is the process of converting AC current to DC current. There at load end connection, the rectifier transforms the AC supply into the DC supply. In a similar vein, transformers are often employed in Figure 1 to modify the AC source to lower the voltage level for a wider operating range.

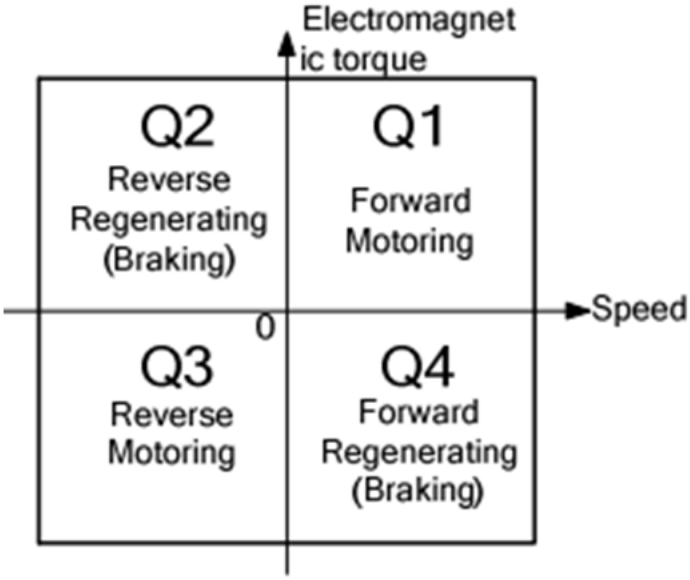

Figure 11.5: Illustrates the Quadrants of operation of a DC motor.

The manner that DC motor drives handle the energy produced when the DC motor brakes may be used to classify these drives. There are non-regenerative and regenerative DC drives throughout industry, according to this viewpoint. The most prevalent kind of DC drives used nowadays are non-regenerative ones. They have one-way control over motor torque and speed. The direction of rotation of the motor armature as well as the controller output polarity are both reversed with the inclusion of an electromechanical (magnetic) armature reversing solenoid valve or manual switch (units rated 2 HP or less). Torque and rotational orientation are same in both scenarios. Regenerative DC drives, sometimes referred to as four-quadrant drives, are able to adjust the motor's torque direction as well as its speed and direction of revolution.

The ability of the drive to transform the mechanical energy of a motor and linked load towards electrical energy that is returned (or "regenerated") to the AC power supply is referred to as regenerative. The drive performs as a typical non-regenerative unit while it is running in the first and third quadrants, in which both the motor rotation as well as the torque are moving in the same direction. Only during the second and fourth quadrants do regenerative drives exhibit their distinct properties. The motor torque opposes the motor rotation's direction within those quadrants a regulated braking or decelerating force. Rapid transitions between driving and braking modes are possible with high performance regenerative drives, which can also adjust the motor's rotational direction. In essence, a regenerative DC drive is two synchronized DC drives combined into a single unit. The first and fourth quadrants are covered by one drive, while the third and second quadrants are covered by the other.

Uncontrolled AC to DC Converters

Uncontrolled rectifiers make use of a diode's unidirectional nature. The rectified output current and voltage with uncontrolled rectifiers depend on the applied inputs. While using AC to DC converters using diodes for conversion, the output voltage level can indeed be changed. The basic ability of the PN junction diode can operate as a closed switch forward when biased and not as an open switch while reverse biased is the basis for the functioning of diode rectifier circuits. Regardless of the uncontrolled rectifier type, such as half-wave or full-wave rectifiers, the basic principles of circuit functioning remain the same. For single-phase and three-phase applications, half-wave and full-wave rectifier designs are both suitable.

Full-wave AC to DC converters generate DC from both and negative half-cycles, in contrast to uncontrolled half-wave AC to DC converters, which use one diode and convert just positive half-cycle AC to DC. Center-tap rectifiers and bridge rectifier diodes are the two kinds of full-wave AC to DC converters that employ two and four diodes, correspondingly. Ripple-free DC output is desired from AC to DC converters using diodes. Large capacitor filters were attached to the DC side providing ripple-free DC voltage. For the purpose of calming the pulsing DC, the capacitor charges periodically discharges. The capacitor charges towards the input voltage peak, draws a significant amount of current during the half-cycle peak, and then discharges. In unregulated AC to DC converters,

The current flow might be zero for a limited period of time, and the current obtained from the mains supply becomes severely skewed. Poor power factors, electrical energy waste, and excessive harmonic components are all results of the distortions. The usage of straightforward diode AC to DC converter circuits was restricted nowadays despite their low cost due to strict harmonic requirements. Another approach to categories DC motor drives is based on the kind of converter that is used to regulate the speed and torque of the DC motor. Controlled Rectifier-Fed (Thyristor-Fed) DC Motor Drive is the term employed when a controlled bridge rectifier (one or three phase) is employed. If a DC to DC converter is employed, the appropriate category is known as Chopper Fed DC Motor Drive.

Phase-Controlled AC to DC Converters

The amount of DC voltage with uncontrolled AC to DC converters depends on the maximum voltage and frequency at which the applied voltage. Diodes are replaced by silicon-controlled rectifiers (SCRs) or thyristors within circuits for controlled AC to DC converters. SCRs in AC to DC converters enable adjustment of the conducting voltage's phase or conduction time. Anode, cathode, & gate are the three pins that make up an SCR's three terminals. SCR-based phase-controlled AC to DC converters behave similar diode rectifiers when the gate is activated (or fired) at the applied AC input voltage's 0° phase angle. The anode to cathode voltage would have to be positive for the SCR to conduct however when the gate is activated. The SCR's conduction may be managed by starting the gate triggered between 0° and 180° amplitude of the input AC voltage. Controlled DC is produced as a result of variations in the average output DC voltage caused by SCR firing. Traction systems, electrochemical reactions, magnet power supply, high voltage DC transmission, including DC motor drives all employ phase-controlled AC to DC converter circuits. Printed circuit panels are used to create AC to DC power converters, regardless of controllability. A gate drive circuit (control circuit) with sufficient isolation from either the converter circuit is necessary for phase-controlled AC to DC converters (power circuit). Cadence provides the appropriate PCB design software for creating power and control circuits for household, business, and industrial power semiconductor purposes.

AC regulators

Auto transformers or tap change transformers are utilized in this step-less control of output voltage achieved by firing angle control shown Figure 11.5 to generate variable that have the same frequency from such a source of fixed AC voltage.

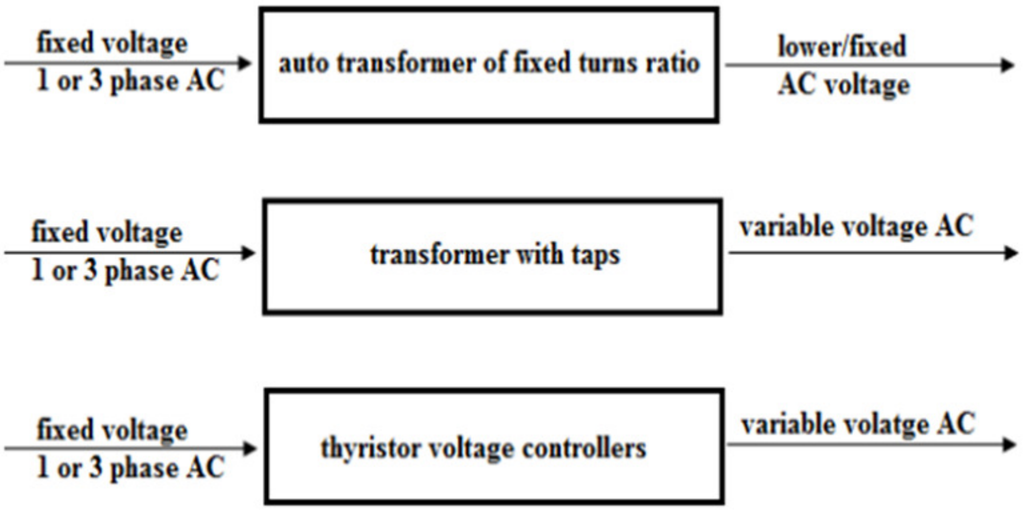

Figure 11.5: Illustrates the schematic process of AC regulator.

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CHAPTER 11

INTRODUCTION TO CHOPPER

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The output voltage of a chopper could be adjusted separately by adjusting the duty ratio of a machine of low power signal from either the control unit in Figure 12.1. Choppers are employed to obtain variable, it varies from the fixed DC, and is designed utilizing semiconductor devices including such power transistor IGBT's, GTO's, authority MOSFET's, and thyristors.

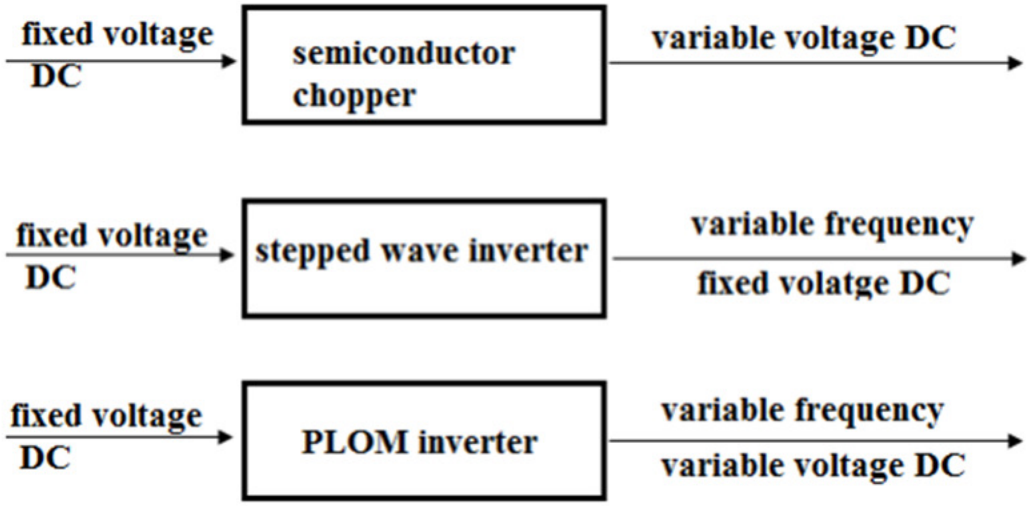

Figure 12.1: Illustrates the schematic process of chopper fed drive.

Inverters:

When controlling AC mains, inverters are used to transform a fixed voltage DC source into a variable frequency AC supply. Output voltage and current must be monitored in addition to frequency variance. This can be done by having to import a chopper between both the fixed voltage DC source and the inverter or by feeding the inverter from an AC-DC converter[1], [2].

Cycloconverter:

Cycloconverter use thyristors and thus are controlled using firing angles obtained from a low - powered controlled device to convert fixed voltage and frequency AC into variable voltage and variable frequency AC.By adjusting the circuit's resistance or impedance, variable impedance circuitry are used to regulate speed. However, low cost DC as well as ac drives utilize these regulating techniques. Two or more stages may be handled either manually or automatically using contactor assistance. AC motors employ inductors to reduce the beginning current. Motors and electrical drives employ switching circuits to provide smooth operation while also safeguarding the equipment from errors. These circuits are employed to switch a motor's operating quadrant while the motor is running. Furthermore, these circuits are used to run the motor and drives in a preset order, to provide interlocking, and to cut the motor away from the main circuit in the event of any exceptional circumstances or defects. 1 phase and 3 phase sources are both possible. The most typical kind of electricity delivered in India, for both household and commercial use, is 50 Hz AC power. The maximum speed of synchronous motors that are given a 50 Hz supply is 3000 rpm; high frequencies supplies are required for greater speeds. Low- and medium-powered motors are supplied with 400 V, and larger ratings such as 3.3 kV, 6.6 kV, 11.5 kV, etc. are also available.

Classification of Parallel resonant DC-link inverter

In order to address problems that arise throughout the resonant DC-link, the bus resonance network has sometimes been modified to minimize the clumping factor, which also lowers switch pressures. New topologies have been introduced as a result. They may be lowered voltage, actively clamped, or passively clamped[3], [4].

Passive clamped DC-link

Inert clamp In order to create a DC-link, an auxiliary circuit is added, mostly made up of passive components (coupled-inductor), as well as a diode is attached to the DC-bus. In this method, the clamp level is established by removing energy from either the LC resonance tank. The energy that was acquired is returned to the source of power. On the other hand, enough extra energy may be stored within the inductor to ensure that the voltage waveform of a DC-link has a zero-crossing position. As a result, this method reduces the peak voltage strains on the DC-link.

Active Clamped DC-Link

As shown in Figure 12.2, the active clamped DC-link idea was first put out in [88]. While the average DC-link voltage remains equal to the source voltage Vdc, the clamping device SC helps to recover the charge stored in the capacitor Cc. The resonance inductor Lr must have a suitable starting current flowing through it in order for the clamping circuitry to sustain the succeeding resonance cycle. But you may do this by precisely regulating the moment when the clamped switching device Sc is turned off. As a result, the DC-link short-circuit is prevented at the moment of zero crossing, eliminating the dead-time interval. By precisely adjusting the clamping switch Sc, the clamp voltage Vcc may be maintained without the need of an additional DC-power source.

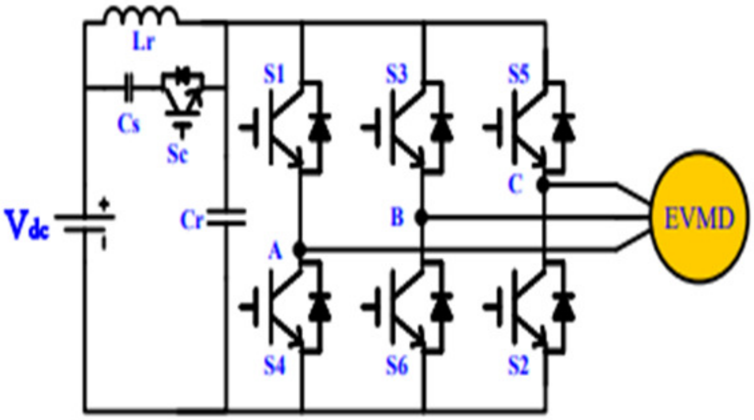

Figure 12. 2 : Illustrates the Active Clamp Resonant DC-Link Inverter (ACRDCLI) Topology for EV Motor Drive.

Disadvantages of the active clamped resonant DC-link

Also because current magnitude depends on the ratio of the clamp voltage to the voltage supply (i.e., k = VCC/VDC), a high ratio of di/dt occurs in each switching cycle. The presence of a high (di/dt) value encourages the EMI. K affects the DC-link frequency fluctuation, which increases the load current's harmonic content. The extra active clamp circuit increases real power loss in the DC-link and complicates the resonant network. Additionally, it will be harder to accurately manage the voltage at the DC-link[5], [6].

Reduced Voltage DC-Link

Figure 12.3 shows the lower voltage notion that was put out. Additionally, the loss calculations has been described. This design combines the fundamental parallel resonant DC-link architecture with two extra resonant components (Lh and Ch). The resonant switch Sr is activated throughout each switching cycle to provide gentle switching circumstances again for inverter power switches. But the resonance frequencies of the two resonant network components (Lr, Cr) and (Lh, Ch) are chosen to ensure that the resonance frequency of the first network (Lh, Ch) is about three times that of second network (Lr, Cr)[7], [8].

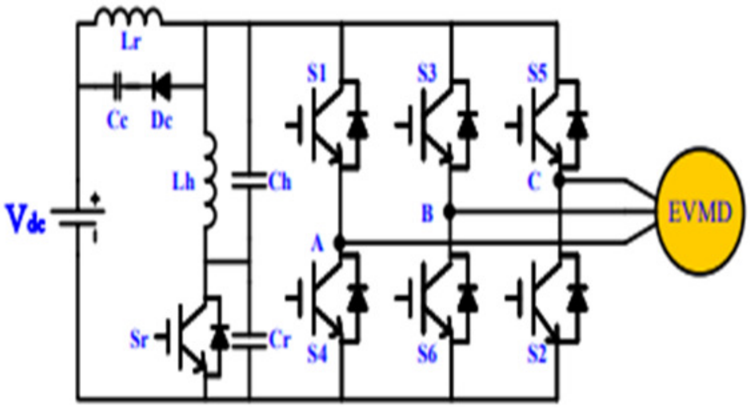

Figure 12.3: Illustrates the reduced voltage resonant DC-link inverter (RVRDCLI) for EV motor drive.

The decreased voltage resonant DC-link has certain drawbacks. Two pairs of resonant components make up the circuit. Due to the complexity of this circuit design, a complex control circuit is required, such as a current estimation system that calculates the starting current inside the resonant main inductor all throughout course of each resonant period.

Load Resonant PWM DC-AC Inverters

For these DC-AC inverters, a new configuration of LC passive elements was introduced. The extraction of resonance converter control parameters that used the state graph is provided as a generalized method. Loading resonance Series-load resonant (SLR) as well as parallel-load resonant (PLR) inverter kinds are subcategories of DC-AC inverters. In the (SLR) topologies, the three-phase bridge works with the inverter bridge to supply a square-wave voltage to something like a resonant network that is coupled in series. As a result, the load is coupled to the resonant network either series, parallel, or in a partial mesh topology that includes parallel/series and multi-resonance. The resonant network that's also coupled to the inverter in parallel receives a square-wave-shaped current from the inverter in the (PLR) topologies. In this situation, the load may also be present parallel to or in series with both the resonant tank. An LC resonant network is attached to the load-side through series, parallel, or a combination of series and parallel in load resonant DC-AC inverters. As a consequence, the switching components of the inverter bridge may reach ZVS or ZCS soft switching circumstances.

Soft Switching

Topologies for DC-AC a resonant high-frequency circuit was added to the traditional hard-switching circuit architecture in soft-switching topologies. In Figure 1, the soft-switching converters are being shown in 12.4, energies in DC-AC converter topologies, the location of the resonant network in relation to the load, three-phase inverters, and DC-link determines the kind of converter. The attained resonant conditions determine the features of the switching device waveform (ZVS or ZCS) (parallel or series). This may be clarified further as follows.

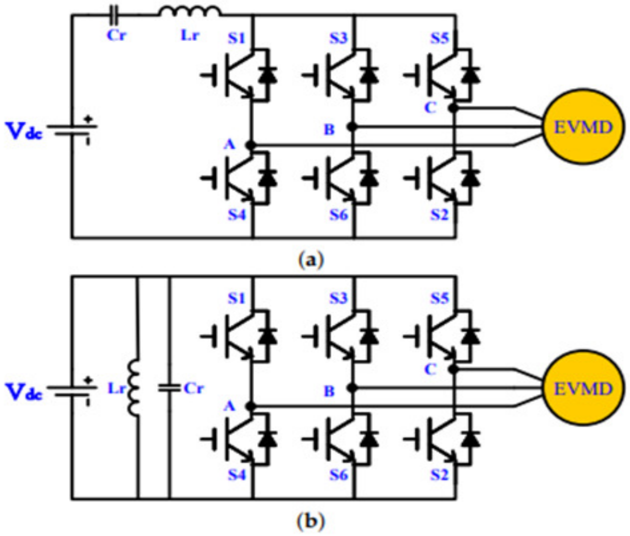

Figure 12.4: Illustrates the Resonant AC-link inverter for EV motor drive. (a) Series resonant AC-link, (b) Parallel resonant AC-link.

Resonant Link DC-AC Inverters

The resonant components are positioned between the DC power supply and the inverter three-phase bridge with resonant DC-AC inverters. To provide a gentle switching state, the resonant networks is used to regularly drive the current or voltage of the DC-link down to zero just at point of switching. The resonant link DC-AC inverters may be split into two basic types: resonant AC-link and resonant DC-link, depending on the arrangement of a resonant network as well as gate-pulse switching time.

Resonant AC-link

For the DC-AC inverter three-phase bridge, the AC-link waveforms might be either alternating current or interchanging voltage to generate ZCS or ZVS situations, respectively. Bidirectional power switches should be used moving forward. A series resonance-based resonant AC-link was described. It was investigated how to drive induction motors using a parallel resonant AC-link. An alternative approach to power conversion within distribution networks was described using a high-frequency link-based technology. In the input DC-bus is a resonant circuit with just an LC high-frequency connection. The resonant AC-link inverter circuit's primary drawbacks are its extensive use of semiconductor components and complex management system. They are divided into two groups: parallel-resonant AC links and series-resonant AC connections. Series resonant components inside an AC-link may generate sinusoidal current waveforms, whereas parallel resonant components may generate sinusoidal voltage waveforms.

Resonant DC-link

Unidirectional power switches may be installed in the DC-AC inverter three phase bridge together with ZVS or ZCS soft switching circumstances due to the DC-biased fluctuation waveform of both the DC-link resonance. Between both the Dc supply and the inverter were resonant networks. However, a number of improved soft-switching inverter circuit complexity have been created, and they may be divided into two groups: parallel and series resonant DC link inverters. Series resonant DC-link, first Figure depicts the series resonant DC-suggested link's operating principle. Every resonance cycle requires that the components of the resonant circuit retain an equal amount of energy. Oscillations may then happen as a result of input or motor load variations.

The series resonance DC-link must have a capacitive output. These capacitors should be located at the output in the event of an inductive load. ZCS soft-switching is used to turn on and off the inverter switching components for a series resonant DC-link. On the other hand, a number of multilevel inverters have been proven using this idea. In contrast towards the forced commutation PWM scenario, switching SCRs at high frequencies is more appropriate in this case. The series resonant DC-link is advantageous for high-power and high-dynamic-performance applications, including such EV motor drives, due to these properties. The main drawbacks of a series of resonant DC-links include difficulties in the management circuit and high-link irregular/regular current peaks.

Parallel Resonant DC-link

Parallel resonant DC-link theory. The load in this circuit may be replaced by a VSI. As a result, a resonant voltage in the DC-link emerges, allowing for the gentle switching of the inverter power switches. Voltage strains that are more than double the voltage of the DC source harm semiconductor switches. The cost of both the power circuit as a whole rises when high rated voltage switches are used. On the basis of this idea, a new circuit were put into place. The suggested resonant inverter also isn't promising despite having a little different topology from that which has been explored since it exceeds the circuit components (Figure 12.5).

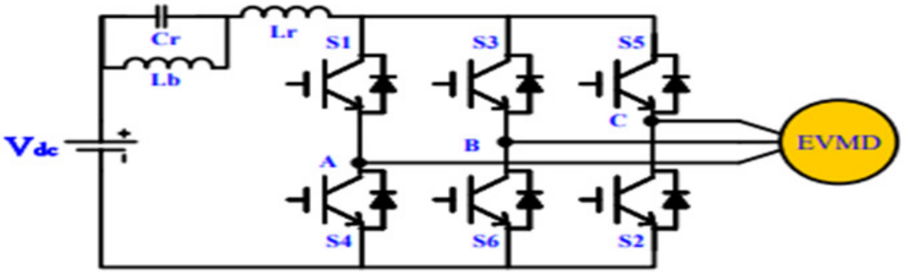

Figure 12.5: Illustrates the Series Resonant DC-link Inverter (SRDCLI) Topology for EV Motor Drive.

Quasi-Resonant

Each switching phase or cycle in quasi-resonant (QR) inverters, as seen in Figure 1, has two intervals: overall non-resonating interval and the resonating interval or period. A little portion of the switching interval is represented by the resonance interval. The resonance networking is started to enable a quiet switching operation again for length of the resonant interval. Zero-voltage soft-switching (ZVS) or zero-current soft-switching might be used in this situation as the soft switching (ZCS). Nevertheless, PWM soft-switching converter circuits have successfully used this concept. The basic cells, which are applicable to a broad variety of topologies, were thought to represent many sorts of resonant switching devices

In contrast, since so many switches are needed when this idea is used directly to DC-AC conversions, the resultant topologies will be quite complex. The zero-voltage soft-switching idea has served as the foundation for the introduction of other QR soft-switching topologies. For modelling quasi-resonant inverters, the averaging approach was developed. With high-power QR PWM inverters, the use of IGBT-GTO concatenated switches results in greater performance. Refs. It suggested QR topologies depending on ZVS with PWM control. Anywhere at modulation index, the selected control system executes a PWM operation. Some of the drawbacks of the PWM approach include the need for extra switches and excessive modulation. The space-vector-modulation (SVM) approach was explored by the authors in order to address such issues. By adjusting the time-ratio and maximizing the generated waveforms and minimizing harmonics, this SVM approach minimizes the amount of switches while preventing the challenging over-modulation index (Figure 12.6).

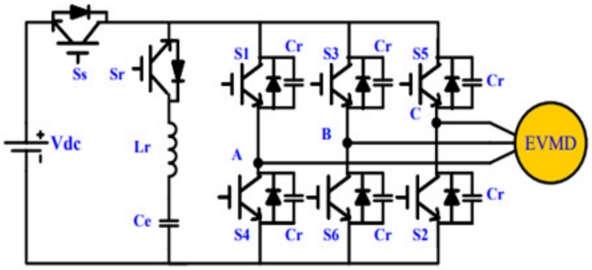

Figure 12.6: Illustrates the Three-phase quasi-resonant DC-AC inverter topology for EV motor drive.

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CHAPTER 12

MAGNETIC CIRCUITS IN MOTORS

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Magnetic circuit, closed channel to which a magnetic field, depicted as lines of magnetic flux, is restricted. In contrast to an electric circuit through which electric charge flows, nothing really flows in a magnetic circuit. In a ring-shaped electromagnet with a tiny air gap, the magnetic field or flux is nearly totally contained to the metal core and the air gap, which together create the magnetic circuit. In an electric motor, the magnetic field is primarily contained to the magnetic pole pieces, the rotor, the air gaps between the rotor and the pole pieces, and the metal frame. Each magnetic field line produces a full unbroken circle. All the lines combined create the overall flow. If the flux is split, such that part of it is limited to a region of the gadget and part to another, the magnetic circuit is termed parallel. If all the flux is contained to a single complete loop, as in a ring-shaped electromagnet, the circuit is termed a series magnetic circuit.

The answer to this observant question is that the Weld formed by the current-carrying conductors on the rotor will undoubtedly affect the original Weld (i.e. the Weld existing when no current was flowing in the rotor conductors). But, in the majority of engines, the force on the conductor may be computed appropriately by multiplying the current by the 'initial' Weld. This is incredibly lucky in terms of estimating the force, but it also has a logical sense to it. , for example, we would not anticipate any force on the current-carrying conductor if there was no externally imposed Weld, even if the current in the conductor will create its own Weld (upwards on one side and downwards on the other). Hence, because we only acquire a force whenever there is an external Weld, it seems that all of the force must be attributed to that Weld alone[1], [2].

When we consider the action and response principle, the second issue emerges. Since there is a torque on the rotor, there must be an equal and opposite torque on the stator; so, we could question whether the process of torque creation can be depicted using the same assumptions that we used to acquire the rotor torque. Indeed, there is always an equal and opposite torque just on stator, which is why it is typically vital to secure a motor. It is simple to understand that torque is created on the stator by the interaction of the air-gap Flux density and the stator currents, just as torque is produced on the rotor by the interaction of the Flux density and the rotor currents. With other motors (for example, the d.c. motor we've been studying), there is no straightforward physical explanation that can be used to calculate the torque on the stator, but it is equal and opposite to the torque on the rotor.

The resemblance between the setup shown and the Weld patterns created, for example, by electromagnets employed to lift automobile carcasses in a salvage yard. With the high force of attraction that lifting magnets can generate, shouldn't we anticipate a high radial force between the stator pole and the iron body of the rotor? And, assuming there is, what prevents the rotor from being dragged over to the stator.

Again, the affirmative answer is that there is a radial force due to magnetic attraction, just as there is in a lifting magnet or relay, though the mechanism by which the magnetic Weld exerts a pull as it enters iron or steel is completely different from the 'BIl' force we have been looking at so far.

The force of attraction per unit area of pole-face comes out to be equal to the square of the radial Flux density, and with typical airgap Flux densities of up to 1 T in motors, the force per unit area of rotor surface works out to be about 40 N=cm 2. This implies that the overall radial force may be extremely large: for example, the force of attraction on a short pole-face of just 5 10 cm is 2000 N, or about 200 Kg. This force adds nothing to the motor's torque and is just an unwanted by-product of the 'BIl' mechanism we use to generate tangential force on the rotor conductors.

In most machines, the radial magnetic force beneath each pole is much greater than the tangential electromagnetic force on the rotor conductors, and thus tends to drag the rotor onto the pole, as the question indicates. Nevertheless, the majority of motors are built with an even number of poles evenly distributed around the rotor, and the Flux density in each pole is the same, such that the resulting force on the whole rotor is, in principle, zero. In reality, even minor eccentricities cause the Torque to be stronger under the poles where the air-gap is less, resulting in an imbalanced pull and loud running and premature bearing wear[3], [4].

The beauty of slotting

If the conductors were installed on the rotor iron's surface, the air gap would have to be at least equal to wire diameter, and the conductors would have to be fastened to the rotor in order to impart their turning force to it. The oldest motors were constructed in this manner, with string or tape used to connect the conductors to the rotor.

However, a large air-gap introduces unwanted high-reluctance into the magnetic circuit, necessitating a large number of turns and a high current to achieve the appropriate Flux density in the air-gap. This causes the Weld winding to grow quite large and to use a lot of electricity. The early (nineteenth-century) pioneers quickly came up with the concept of partly sinking the conductors on the rotor into grooves cut parallel to the shaft, with the goal of reducing the air-gap so that the exciting windings could be smaller. This worked incredibly well because it offered a more positive place for the rotor conductors, allowing the force on them to be passed to the rotor body.

Soon after, the conductors started to be recessed into progressively deeper slots until they no longer stood proud of the rotor surface and the air-gap could be made as narrow as was compatible with the necessity for mechanical clearances between the rotor and the stator. The new'slotted' machines performed well, and their pragmatic designers were undeterred with rumblings of dissatisfaction from skeptical theorists.

The search for an explanation preoccupied some of the leading thinkers long after slotting became the norm, but eventually it became theoretically possible to verify that the total force remains the same as it would have been if the conductors were genuinely in the Flux, but almost all of the tangential force now acts on the rotor teeth rather than the conductors themselves.

This is really encouraging news. By inserting the conductors into slots, we simultaneously minimize the resistance of the magnetic circuit and transfer the force from the conductors to the sides of the iron teeth, which are strong and capable of transmitting the generated torque to the shaft. Another advantage is that the insulation surrounding the conductors no longer needs to convey tangential forces to the rotor, making its mechanical qualities less important. Seldom do preliminary tests with one goal provide positive results in practically every other significant area.

But, there are some issues. To maximize torque, we'll want as much current as possible flowing through the rotor conductors. Certainly, we will work the copper at the greatest feasible current density (usually between 2 and 8 A=mm 2), but we will also want to maximize the cross-sectional area of the slots in order to accommodate as much copper as possible[5]–[7].

This will drive us towards broad slots and, as a result, small teeth. Nevertheless, since the Flux must flow radially along the teeth, making the teeth too thin will cause the iron in the teeth to saturate, resulting in a poor magnetic circuit. There is also the option of raising the depth of the slots, but this cannot be done too far since the center area of the rotor iron, which must transfer the Flux from one pole to another, would get depleted and saturate. In the next part, we'll look at what influences the torque that can be achieved from a given rotor size, as well as how speed affects power output.

Specific loadings

At the critical air-gap zone, design compromise is unavoidable, and designers must continuously exercise their talents to strike the optimal balance between the convicting demands on space made by the Flux (radial) and the current (axial).As with most engineering design, norms evolve as to what can be accomplished in respect to certain machine sizes and kinds, and motor designers often work in terms of two factors, the specific magnetic loading and the specific electric loading. As we shall see later, these settings have a direct impact on the motor's output.The specific magnetic loading (B) is the average of the magnitude of the radial Flux density throughout the rotor's whole cylindrical surface. The average Flux density is always smaller than the Flux density in the teeth due to the slotting, but in order to compute the magnetic loading, we imagine the rotor as smooth and calculate the average Flux density by dividing the total radial Flux from each 'pole' by the surface area beneath the pole[7], [8].

The axial current per meter of circumference on the rotor (typically indicated by the symbol (A), the A standing for Amperes) is the specific electric loading. The axial current in a slotted rotor is concentrated in the conductors within each slot, but to calculate A, we imagine the total current being distributed uniformly around the circumference (in a manner similar to that shown in Figure 1.12, but with the individual conductors under each pole represented by a uniformly distributed 'current sheet'). For example, suppose we find Wave slots, each carrying a current of 40 A, beneath a pole with a circumferential width of 10 cm.

Several variables influence the values that may be used in motor design, but the specific magnetic and electric loadings are restricted by the qualities of the materials (iron for the Flux, and copper for the current), as well as the cooling system used to eliminate heat losses.Since the saturation characteristics of most core steels are comparable, the specific magnetic loading does not vary considerably from machine to machine. Nevertheless, depending on the method of cooling employed, the specific electric loadings vary quite a little.Despite the low resistivity of the copper conductors, heat is created by the flow of current, thus the current must be controlled to a value that does not harm the insulation due to an excessive temperature increase. The larger the electric loads, the more efficient the cooling system. For example, if the motor is completely enclosed and lacks an internal fan, the current density in the copper must be substantially lower than in a comparable motor with a fan to supply a constant Flow of ventilation air. Similarly, windings that have been entirely saturated with varnish may be worked considerably harder than those that are surrounded by air, since the solid body of encompassing varnish offers a far better thermal channel for heat to go to the stator body. Overall size also influences permitted electric loads, with bigger motors often having larger values than small ones.

In reality, the crucial thing to remember is that, unless an unusual cooling system is used, most motors (induction, D.C, etc.) of a given size have about the same specification loadings, independent of type. As we shall see later, this implies that motors of equal size have comparable torque capacities. This truth is not frequently acknowledged by users, yet it is always important to remember.

Torque and motor volume

In light of the above reasoning, we may calculate the total tangential force by first for a rotor surface area of width w and length L. The axial currentflowing in the width w is provided by I 14 wA, and because all of this current is exposed to the radial Flux density B on average, the tangential force is supplied by B Wal L (from equation 1.2). Since the surface area is wL, the force per unit area is B A. The average tangential stress across the rotor surface is expressed by the product of the two specific loadings. 6To calculate the total tangential force, multiply the total force by the area of the curved surface of the rotor, and to get the total torque, multiply the total force by the radius of the rotor.

This is an incredibly significant equation. Since the term D2L is proportional to the rotor volume, we can show that the torque from any motor is proportional to the rotor volume for given values of the specific magnetic and electric loadings. We may pick between a long thin rotor and a short fat rotor, but once the rotor volume and certain loadings are specified, we have effectively computed the torque.It is important to note that we have not concentrated on any one kind of motor, but have tackled the issue of torque output from a very broad perspective. In essence, our findings reject the fact that all motors are built of iron and copper, and the only difference is how these components are disposed of. We should also recognize that in reality, the total volume of the motor is more essential than the volume of the rotor. Yet, we discovered that, regardless of motor type, there is a pretty tight connection between total volume and rotor volume for motors of comparable torque. As a result, we can make the bold but typically correct claim that the total volume of a motor is defined by the torque it must generate. There are exceptions to this rule, but it is incredibly helpful as a general guideline for motor selection[9], [10].

Multilevel DC-AC Inverters (MLIs) Topologies

In the creation of multilayer inverters for EV motor drives, establishing a soft-switching operation is indeed a difficult problem. However, multilevel inverters may provide a number of unique benefits that primarily benefit EVs. To be more precise, they are suitable for high rating motor drives and sufficient for BEVs where floating DC power sources seem to be logically attainable. They also produce nearby-sinusoidal voltage waveforms with nothing but frequency components, smaller harmonic contents throughout the output current and voltage, decreased power losses, almost no EMI, and reduced power losses. The drawbacks of the conventional two-level inverter (TLIs), as mentioned in the preceding section, may be avoided. As a result, the development of multilayer inverters for EVs may be greatly sped up. MLI circuit configurations may generate multilevel AC output waveforms. There are two types of multilevel DC-AC inverter topologies: traditional and cutting-edge.

Classical Multilevel DC-AC Inverter (MLI) Topologies

It is vital to comprehend traditional MLI topologies that have since been documented in recent literature, in order to better appreciate the current developments in MLI topologies. Three alternative fundamental MLI topologies diode-clamped MLI, flying capacitors MLI, and cascaded H-bridges MLI are often constructed. The many multilevel inverter types are outlined:

Diode-Clamped Multilevel Inverter

Topology The topology of a Diode-Clamped Multilevel Inverter (DC-MLI). High-voltage grid applications are another use for PV technology, which also powers variable-speed motor drives throughout additional to the DC-bus. Figure 13.1 shows a three-phase, three-level Diode-Clamped-MLI architecture. The DC-bus voltage, which has been divided into five divisions and is clamped by one of the two additional diodes across four DC bus capacitors, is shared between each of the three-phase converter outputs. C1 through C4 are the capacitors. The voltage from across switch is clamped by the two diodes to a level that is half that of the DC-bus voltage. The neutral point of a inverter is made up of the center points of capacitors C2 and C3, as well as the output voltage contains five voltage values relating towards the neutral point. Through a variety of switches linked in series and controlled at such a low-frequency control, the near AC (multilevel/staircase) output voltage signal was created from certain inner input voltages.

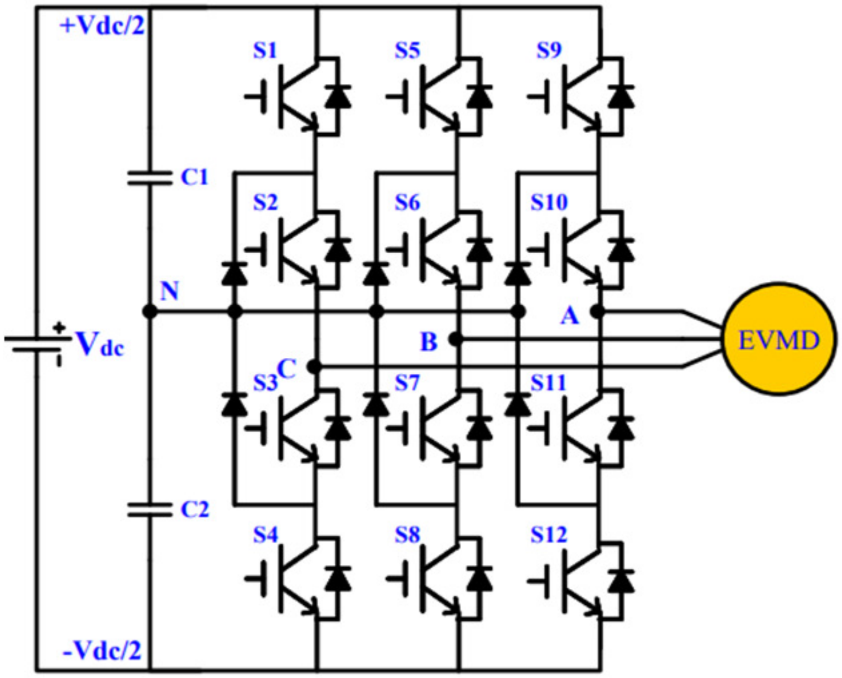

Figure 13.1: Illustrates the three-phase three-level diode-clamped multilevel inverter (DC-MLI) for EV motor drive.

The LC components expand in both volume and weight. The semiconductor switches are subjected to extreme voltage and current strains while being coupled to the resonant components in the same power transfer channel. The quality factor (Q) of a resonant network needs to be as high as feasible to provide a broad range of output voltages and also to lessen the output harmonic distortion.

Resonant Transition DC-AC Inverters

Resonant changeover the three kinds of DC-AC inverters listed below may be categorized using the resonant transition approach. Resonant snubber, soft-transition, and quasi-resonant.

Soft-Transition

As demonstrated in Figures 13.2 and 13.3, soft-transition approaches such as zero-voltage transition (ZVT) inverters with zero current transition (ZCT) inverters have been published in the literature. Whenever the auxiliary resonant circuit is turned on, the load plus DC bus in the ZVT inverter both create a parallel resonance network, but in the ZCT inverter, they create a series resonance network. The ZCT inverter, meanwhile, does not constitute a dual of the ZVT inverter. With ZVT and ZCT, correspondingly, all of the switching devices of an inverter-bridge throughout soft transition inverters were switched on and off. But in the ZVT inverter architecture, every diode and auxiliary switch is subject to ZCS turn-on and turn-off, but in the ZCT inverter, the diodes including auxiliary switching in the inverter bridge are almost ever turned off at levels close to the load current. This idea of soft-transition PWM was put forward (STPWM). More soft-transition structures have already been reported as a result of this perception. With the exception of how long the switching transient lasts, this architecture operates similarly to a traditional PWM converter. This configuration has the drawback of requiring a large number of parts, including a diode-bridge and three resonant inductors.

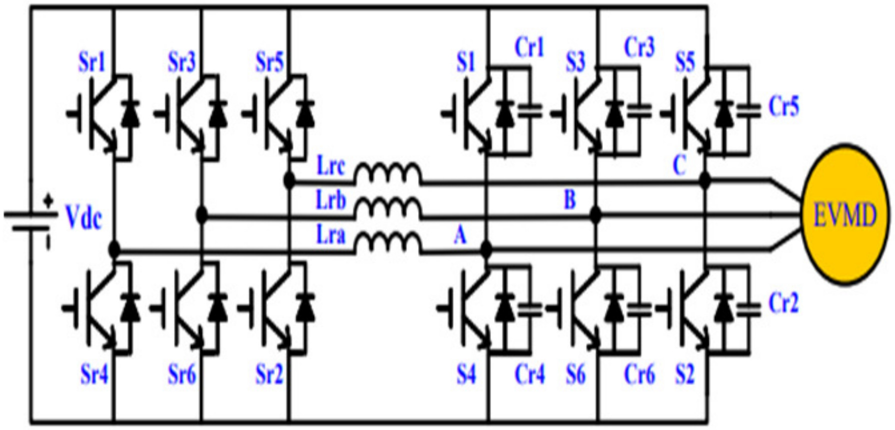

Figure 13.2 : Illustrates the Three-phase zero voltage transition (ZVT) inverter topology for EV motor drive.

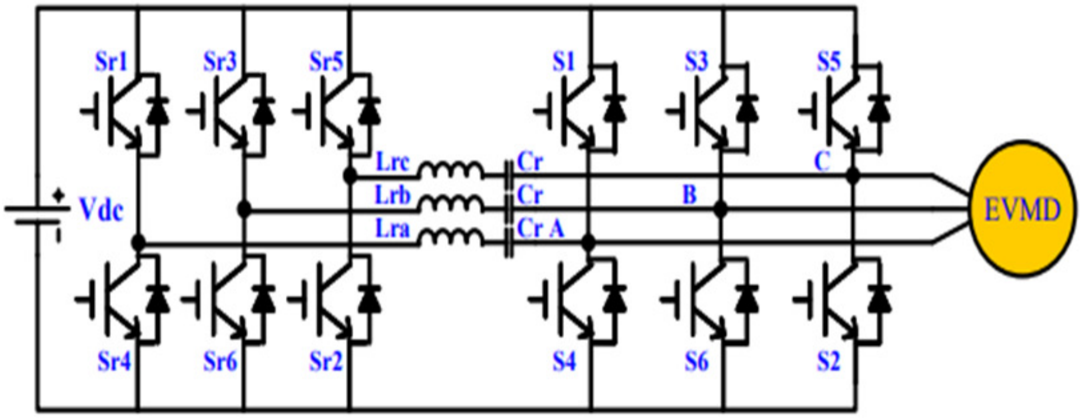

Figure 13.3: Illustrates the three-phase zero-current transition (ZCT) inverter topology for EV motor drive.

Resonant-Snubber

As shown in Figure 13.4, the straightforward resonant snubbers (RS) concept is discussed. In this configuration, the switching device is paralleled with a resonant capacitor to achieve zero-voltage switching turn-off, and the extra switch is connected to a resonant inductor to achieve zero-voltage switching turn-on. It is referred to as an auxiliary resonant snubber (ARS) inverter as just a result. The ARS inverter was created with electric propulsion in mind. To function in soft-switching circumstances, resonating snubber capacitors, auxiliary power switches, and resonating inductors were employed. This inverter has the benefit of enabling ZVS soft switching for all semiconductor devices, while ZCS soft switching also is possible for all auxiliary switches. Additionally, the parasitic inductance as well as stray capacitance are utilized as resonant components. Utilizing soft-switching vector control will further reduce the power losses of the associated extra circuit.

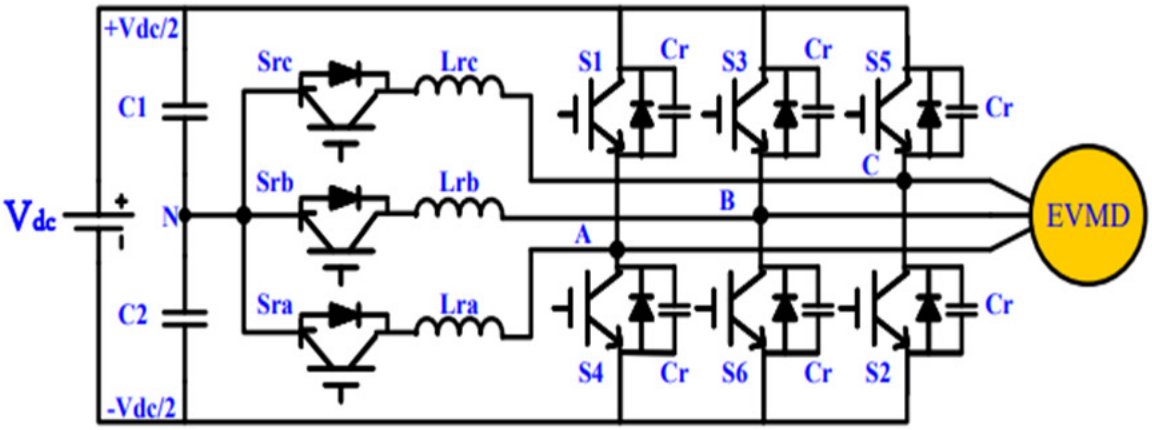

Figure 13.4: Illustrates the three-phase resonant snubber (ZVT) DC-AC inverter topology for EV motor drive.

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CHAPTER 13

POWER RELATIONSHIPS CONDUCTOR

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The ability of a material to carry electricity or heat is referred to as conductivity. A conductor conducts electricity because it provides little or no resistance to the movement of electrons, resulting in an electrical current flow. Metals, metal alloys, electrolytes, and even certain nonmetals, such as graphite and liquids, such as water, are often strong electrical conductors. One of the greatest electrical conductors is pure elemental silver. Other excellent electrical conductors are as follows:

1. Copper
2. Steel
3. Gold
4. Silver
5. Platinum
6. Aluminum brass

Assume that the conductor is travelling at a constant velocity (v) in the direction of the electromagnetic force that is driving it. What current must flow through the tube, and what voltage must be put across its ends? To begin, we recognize that the conductor's constant velocity indicates that the mass (m) is going upward at a constant pace, i.e. it is not accelerating. As a consequence of Newton's rule, there must be no resultant force acting on the mass, hence the string tension (T) must equal the weight (mg). Similarly, since the conductor is not moving, its net force must be zero. Since the string produces a braking force (T), the electromagnetic force (BIl) must be equal to T. When these circumstances are combined, the result is

This is the same equation we derived under stationary circumstances, and it emphasizeshow the mechanical stress determines the steady-state current. As we design the analogous circuit, we must accept that one of the electrical variables (current) is dictated by the mechanical load in the steady-state. Mechanical work is performed as the mass rises at a steady pace because the bulk's potential energy rises. The moving conductor is responsible for this task. The mechanical output power is equal to the rate of work, which is equal to the force (T 14 BIl) multiplied by the velocity (v)[1], [2].

Since it has the same resistance and current, the power wasted as heat in the conductor is the same as it was while stationary. The electrical input power to the conductor must continue to provide this heat loss, but it must also supply the mechanical output power. We don't know what voltage will have to be applied yet, so we'll call it V2. The power-balance equation is currently known as the electrical input power equation (V2I) 14 rate of heat generation in conductor mechanical output power.

Motoring indicates that the conductor is moving in the same direction as the electromagnetic force (BIl) and at a speed that is less than the applied voltage V. Thus far, we've assumed that the load is constant, such that under steady-state circumstances, the current is the same at all speeds, with the voltage increasing with speed to account for the motional E.M.F this was a useful strategy for determining steady-state power relationships, but it is seldom representative of actual operation. We now consider how the moving conductor will act when the applied voltage V is constant, since this correlates more closely to the usual working of a real motor[3], [4].

The next part will certainly be more involved than the previous one since we will analyses how the motor grows from one speed to another, as well as what occurs under steady-state circumstances. The study of the transient behavior of our basic linear motor, as in other fields of dynamics, introduces extra factors such as the conductor mass (corresponding to the inertia of a genuine rotary motor) that are missing from steady-state considerations.

Behavior with no mechanical load

In this part, we assume that the hanging weight has been removed and that the only force acting on the conductor is that created by its own electromagnetic field. Our major focus will be in what determines the constant speed of the primitive motor, but we must first investigate what occurs when the voltage is first applied.When the voltage V is supplied to a stationary conductor, the current will quickly grow to a value of V/R since there is no motional E.M.F and the only factor that restricts the current is the resistance.(Strictly speaking, we should account for the effect of inductance in slowing the increase of current, but we will omit it here for the sake of simplicity.) Since the resistance is low, the current is strong, and a high force is created on the conductor. As a result, the conductor will accelerate at a rate equal to the force acting on it divided by its mass.

When it accelerates, the motional E.M.F increases in proportion to the speed. When the motional E.M.F opposes the applied voltage, the current falls reducing the force and therefore the acceleration, but the speed continues to grow.As long as there is an accelerating force, i.e. current in the conductor, speed will rise. The current will eventually decrease to zero when the speed reaches a level where the motional E.M.F equals the applied voltage. As a result, the speed and current fluctuate, as seen in Figure 1.16: both curves exhibit the exponential form that characterizes the response of systems driven by a first-order deferential equation. The finding that the steady-state current is zero is consistent with our prior discovery that the steady-state current is determined by the mechanical load (in this instance zero)[5], [6].

We can see that in this idealized case (with no load applied and no friction forces), the conductor will continue to move at a constant speed since there is no acceleration because there is no net force acting on it. Of course, no mechanical power is created since we assumed there is no opposing force on the conductor, and no input power is produced because the current is zero. The only difference between this hypothetical state and the so-called 'no-load' condition in a motor is that a motor will have some friction (and hence draw a modest current), but we have assumed no friction to simplify the explanation.

Although no power is required to keep the frictionless and unloaded conductor moving once it is up to speed, we should note that the applied voltage was constant throughout the acceleration phase and the input current fell progressively, so the input power was large at first but tapered-oV as the speed increased. Throughout the run-up period, energy was continuously provided from the source; part of this energy is lost as heat in the conductor, but most of it is stored as kinetic energy, which, as we shall see later, may be recovered.Assume that we immediately connect the string holding the weight to the primitive linear motor at its no-load speed, resulting in a steady force (T 14 mg) opposing the velocity of the conductor. Since there is no current in the conductor at this point, the only force acting on it is T. As a result, the conductor will begin to slow down. Yet, when the speed decreases, the back E.M.F becomes less than V, and current begins to flow into the conductor, providing an electromagnetic driving force. The greater the decrease in speed, the greater the current, and hence the greater the force created by the conductor. When the force generated by the conductor equals the load (T), the deceleration stops and a new equilibrium situation is established. The conductor's speed will be lower than when no load is applied, and it will now provide continuous mechanical output power, i.e. serve as a motor[7], [8].

Since the electromagnetic force on the conductor is exactly proportional to the current, the steady-state current is, as previously stated, directly proportional to the applied load. If we investigated the transitory behavior statistically, we would discover that the decrease in speed followed the same Worst-order exponential response as we saw during the run-up period. As a load is added, the speed slows just enough to enable sufficient current to flow to provide the force necessary to balance the load, demonstrating the self-regulating feature once again. We couldn't ask for a greater performance, and the conductor does it without our assistance. Closed-loop control system readers will presumably recognize that the reason for this exceptional performance is because the primitive motor has intrinsic negative speed feedback through the motional E.M.F Referring to equation 1.21, we see that the current is directly proportional to the difference between V and E, and inversely proportional to the resistance. As a result, the bigger the load (and hence the steady-state current) for a given resistance, the greater the needed divergence between V and E, and thus the lower the steady running speed, also shows that the greater the resistance of the conductor, the slower it moves when a given load is applied. In contrast, the lower the resistance, the better the conductor's ability to maintain its no-load speed in the face of applied force is much desired for the majority of applications.

We finish our investigation of performance while loaded by investigating how the Flux density influences behavior. Given that the electromagnetic force is proportional to the Flux density as well as the current, we can calculate that the current needed to create a given force will be greater with a weak Flux than with a strong one. As a result, since there is always an upper limit to the current that the conductor can safely carry, the maximum force that can be created varies in direct proportion to the Flux density, with a low Flux resulting in a low maximum force and vice versa. This emphasizes the significance of using maximum Flux density wherever feasible.Another downside of having a low Flux density is that the loss in speed to obtain a given force is disproportionately big when we move to a lower Flux density. We can demonstrate this by assuming that we desire a certain force and thinking about how we can do it first with full Flux and then with half Flux. With full Flux, there will be a decline in speed, causing the motional E.M.F to fall enough to permit the requisite current. Nevertheless, with half the Flux, for example, twice as much current is required to generate the same force. As a result, the motional E.M.F must decrease by twice as much as it did with full Flux. Yet, since the Flux density is now only half as high, the speed loss must be four times as severe as it was with full Flux. As a result, the half Flux'motor' exhibits a load characteristic with a load/speed gradient four times as floppy as the full-Flux one[9], [10].

In each of these circumstances, the no-load rate is the same. The half-Flux motor plainly has a lower capacity to maintain the specified speed when a load is added and tempted to believe that increasing the speed by lowering the Flux results in improved performance, but we can clearly demonstrate that this is not the case. For example, halves the Flux doubles the no-load speed for a given voltage, but when the load is increased until the rated current is flowing in the conductor, the force created is only half, and therefore the mechanical power remains the same. We're exchanging speed versus force in effect, and there's no chance of receiving anything for free.

Relative magnitudes of V and E, and efficiency

We always desire machines with great efficiency. To obtain high eYciency, the copper loss (I 2R) must be modest in comparison to the mechanical power (EI), which implies that the resistive volt-drop in the conductor (IR) must be tiny in comparison to either the induced E.M.F (E) or the applied voltage (V). In other words, we want the 'useful' motional E.M.F to account for the majority of the applied voltage rather than the wasteful volt drop in the wire. Since the motional E.M.F is proportional to speed and the resistive volt drop is related to conductor resistance, we can see that a successful energy converter needs a low conductor resistance and a fast speed.

This indicates that the speed will have more than doubled, as planned. The electrical input power has increased to 80 watts, the mechanical output power has increased to 72 watts, and also the copper loss remains at 8 watts. The efficiency has now reached 90%, demonstrating that the energy conversion process improves at faster speeds.The ideal scenario is one in which the term IR in equation 1.19 is insignificant, resulting in a back E.M.F equal to the applied voltage. The ideal machine would thus have an eYciency of 100%, with the steady-state speed being exactly proportional to the input voltage and independent of the load.

In reality, the size of the machine determines how close we can get to the ideal condition stated above. Small motors, such as those used in wristwatches, are terrible because much of the applied voltage is used up in overcoming conductor resistance, and the motional E.M.F is quite small: tiny motors are far better at creating heat than mechanical output power. Smaller machines, such as those used in hand tools, perform far better, with motional E.M.F accounting for around 70-80% of the applied voltage. Industrial machines are much superior: the biggest (of several hundreds of kW) need just one or two percent of the input voltage to overcome resistance, resulting in very high efficiencies.

Power Electronics

One of the most important applications of power electronics is motor drives. The two key issues here are a) the construction of appropriate converter topologies and b) the control of the power converter and the drive. Power ratings range from a few tens of watts in consumer applications to many megawatts in industrial drives. Control of motor drives is one of the key topics of study in power electronics since solutions must be adequate for the power level. In this field, five articles have been published. Behera and Das present Direct Torque Control (DTC), an enhancement in the control approach for induction motors. To identify the next switching state of the inverter controlling the motor, the basic DTC approach employs hysteresis controllers for motor torque and flux. The authors recommend including a dither signal in the hysteresis blocks to decrease torque ripple and acoustic noise. Nandi investigated the influence of time and spatial harmonics on sensor less control systems for slip ring induction motors and recommended solutions for improved speed estimation. Murugan et al present the design of a brushless DC (BLDC) motor drive for power assisted steering in cars. Aside from the primary propulsion motor, there are a variety of auxiliary uses in traction and automotive applications that need electrical control and activation**.**

Power electronic converters used in power systems may enhance numerous elements of system functioning. High Voltage Direct Current (HVDC) power transmission and Static Var Compensators are two common uses nowadays. Active filters based on switching power converters are also widely used to enhance power quality at the distribution and sub transmission levels. The Flexible AC Transmission Systems (FACTS) idea has been presented and is awaiting of the

(SSSC)Such real-time models

They are critical because they may be used in real-time simulations of systems to develop control methods for converters and investigate the influence on the power system.

Key characteristics of electrical conductors

The following are important characteristics of an electrical conductor.

1. It allows electrons or ions to travel freely through it.
2. It has a zero electric field inside, allowing electrons or ions to travel.

The electric field outside the conductor is perpendicular to the conductor's surface. It has a charge density of zero, which ensures that positive and negative charges cancel each other out and that free charges exist exclusively on the surface.

Conductors also have low resistance and good heat conductivity. A conductor in a magnetic field also does not retain energy. Finally, both conductor ends have the same potential. When the potential difference at one end of the conductor is adjusted, electrons begin to flow from one end to the other.

Working of conductors

Solids have a valence band and a conduction band, according to band theory in solid-state physics. There must be no energy gap between a material's valence band and conduction band for it to conduct electrical current. As a result, in conductors, these bands overlap, enabling electrons to pass through the material even with a low voltage supplied. Because the outside electrons in the valence band are only weakly linked to the atom, applying a voltage, an electromotive force, or a temperature action excites them and causes them to migrate from the valence band to the conduction band.

These electrons may flow freely wherever in the conduction band, resulting in an abundance of electrons in this band. These electrons move in a zigzag pattern rather than in a straight path. As a result, their velocity is referred to as drift velocity, or Vd. Electrons clash with atoms of the material or other electrons inside the conductor's conduction band due to this drift velocity. When there is a potential difference in a conductor between two points, electrons move from the lower potency point to the higher potency one. Electricity and electrons move in opposing directions. In this case, the conductor material provides just a little resistance.

Resistors, semiconductors and superconductors

A resistor is a substance that conducts electricity somewhat well but not as well as a conductor. A resistor is a mixture of carbon and clay combined in a specified ratio to generate a continuous, predictable resistance to electric current.Semiconductors are excellent conductors in certain situations but poor conductors in others. Both electrons and so-called holes (electron absences) serve as charge carriers in a semiconductor. Silicon, germanium, and other metal oxides are examples of semiconductors.The vibration of conductor molecules increases as temperatures rise. This disrupts the smooth passage of electrons, lowering the material's conductivity. Furthermore, increased temperatures cause bonds in conductor molecules to break, releasing electrons. This reduces the material's capacity of carrying an electrical current through it by leaving it with fewer electrons.

Types of conductors

Electrical conductors are classed as one of two types based on their ohmic response:

1. Conductors with ohmic resistance.
2. Conductors that are not ohmic.

Ohmic conductors always obey Ohm's law, which states that the voltage applied is proportionate to the current flowing. Aluminum, copper, and silver are a few examples. Thermistors and light-dependent resistors, or photo resistors, are examples of nonohmic conductors that do not obey Ohm's law.

Electrical conductor applications

Conductors have a wide range of uses, including the following:

Aluminium, an excellent conductor of heat and electricity, is widely utilized in the production of cooking items. It is also utilized in food storage and preservation foils. Iron, a powerful conductor of heat, is employed in the production of automobile engines. Conductors are also used in car radiators to direct heat away from the engine.Insulators are also employed in a variety of everyday applications. Rubber, for example, is used to make fire-resistant clothes and footwear. Plastic is widely used in electrical products to protect consumers from electrocution. Insulators also protect people from fire and noise. Conductors have a wide range of uses, including the following:

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CHAPTER 14

POWER ELECTRONIC CONVERTERSFOR MOTOR DRIVES

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Power electronics is an area of electrical engineering that deals with power conversion and control utilising semiconductor power switches. A worldwide panel of more than 40 specialists wrote this book, which gives an overview of contemporary electrical power converters and systems, as well as their applications. Multilevel, multi-input, modular, matrix, soft-switching, and Z-source converters, switching power supply, and smart power electronic modules are among the topics discussed. Permanent magnet synchronous motor and induction motor drives are examined, as well as wind, solar, and automobile energy systems, shipboard power systems, the power grid, distributed generation and microgrids, uninterruptible power supply, and wireless power transmission. Power electronic system advanced control is also investigated.

The power converter circuits utilized with motor drives, offering D.C. or A.C. outputs and operating on a D.C (battery) supply or the normal A.C. mains. The approach is not meant to be thorough, but rather to emphasize the most critical characteristics that apply to all kinds of drive converters.While there are many different kinds of converters, all of them, with the exception of extremely low-power ones, use some sort of electronic switching. The requirement for a switching strategy is emphasized in the first scenario, where the effects are thoroughly examined. We shall see that switching is required to accomplish high-efficiency power conversion, but that the ensuing waveforms are always less than optimal from the motor's perspective.

The examples were selected to demonstrate normal usage, therefore the most widely used switching devices (e.g., thyristor, transistor) are presented for each converter. Several different switching devices may be useful in many circumstances (see later), thus we should not label a certain circuit as being the sole domain of a single device. Before delving into specific circuits, it's a good idea to look at a typical drive system as a whole.The resistance between collector and emitter of a transistor is effectively controlled by the current at the base-emitter junction. To simulate the behavior of a mechanical switch, the transistor must be capable of providing either infinite resistance (corresponding to an open switch) or zero resistance (corresponding to a closed switch). Both of these ideal states are not achievable with a real transistor, although they may be roughly approximated[1], [2].

The transistor is effectively a controlled resistor, which means that the resistance between collector and emitter is proportional to the current in the base-emitter junction. To simulate the behavior of a mechanical switch, the transistor must be capable of providing either infinite resistance (corresponding to an open switch) or zero resistance (corresponding to a closed switch). While none of these ideal states is achievable with a real transistor, they might be roughly approximated.

The power needed to drive the transistor is far less than the power switched in the collector-emitter circuit. To switch the transistor in the regular pattern clearly need a base current waveform that goes on and off at regular intervals, and we may question how we generate this 'control' signal. The base-drive signal is often generated by a low-power oscillator (built from logic gates or on a single chip) or a microprocessor. Depending on the primary switching transistors base circuit power needs, it may be feasible to supply it straight from the oscillator; if necessary, additional transistors are interposed between the main device and the signal source to give the requisite power implication.

Just as we must choose mechanical switches based on their role, we must utilize the appropriate power transistor for the work at hand. In particular, we must guarantee that when the transistor is turned on, we do not exceed the safe current, or otherwise the device's active semiconductor area would be damaged by overheating. And we must ensure that the transistor can resist any voltage that arises across the collector-emitter junction while it is '0V'. If the safe voltage is exceeded, the transistor will fail and remain permanently "on."

A sufficient heatsink will be required, when the transistor is turned on, some heat is created, and at low switching rates, this is the principal source of undesirable heat. Yet, with large switching rates, ‘switching losses may be significant.The heat released during the right time it takes for the transistor to go from on to 06V or vice versa is referred to as switching loss. The base-drive circuitry will be designed to transition as quickly as possible, but in fact, it will seldom take less than a few microseconds. During the 'on' phase of the switch, for example, the current will be increasing while the collector-emitter voltage will be decreasing towards zero. As a result, the peak power achieved might be rather high before decreasing to the comparatively low onstate value. Of However, since the process is so rapid, the total energy produced as heat each time the gadget changes is little[3], [4].

As a result, if the switching rate is minimal (say, once per second), the switching power loss is negligible in compared to the on-state power.Nevertheless, at high switching rates, when the time required to perform the switching is equivalent to the on time, switching power loss may quickly become dominating. Switching rates in drives range from hundreds of hertz to low tens of kilohertz: Higher frequencies would be preferable in terms of supply smoothness.

D.C. From A.C. – controlled rectification

The great majority of drives of all sorts are powered by constant voltage 50 or 60 Hz mains, and practically all mains converters include a rectifier that converts alternating current to a rudimentary form of direct current.A basic (uncontrolled) diode rectifier is sufficient when a constant-voltage (i.e. unvarying average) 'DC.' output is needed. A controlled rectifier is used when the mean D.C. voltage must be regulated (as in a D.C. motor drive to achieve varied speeds). Several other converter configurations based on diode and thyristor combinations are available, but we will concentrate on 'fully-controlled' converters in which all rectifying devices are thyristors. They are often seen in contemporary motor drives.

The following questions pique the user's interest: How is the output voltage regulated? What does the output voltage of the converter look like? Is it an issue if the voltage is not pure d.c.? How does the output voltage range relate to alternating current mains voltage?

We can answer these questions without delving too far into the converter's inner workings. This is fortunate, since comprehending all of the intricacies of converter functioning is beyond our expertise.On the other hand, knowing the nature of the regulated rectification process is beneficial in understanding the restrictions imposed by the converter on drive performance But, before answering the preceding questions, it is evident that the thyristor must be introduced.When forward voltage is provided, the thyristor continues to block forward current until a tiny current pulse is injected into the gate-cathode circuit to turn it on, or 'Wre' it. Once the gate pulse is delivered, the primary anode-cathode current quickly builds up, and once it reaches the 'latching' level, the gate pulse may be withdrawn and the device remains 'on'.Once formed, no gate signal may stop the anode-cathode current. Only when the anode-cathode current has been lowered to zero and has stayed at zero for the turn-oV time (usually 100-–– 200ms in converter-grade thyristors) can the no conducting condition be restored.While conducting, a thyristor behaves similarly to a closed switch, with a forward drop of only 1 or 2 V across a large range of current. Despite the modest voltage drop in the 'on' state, heat is dissipated, and heatsinks, perhaps with fan cooling, are frequently required. Devices must be chosen with consideration for the voltages to be blocked as well as the r.m.s. and peak currents to be carried. Their overcurrent capacity is quite restricted, and devices in drives are often required to tolerate up to twice full-load current for just a few seconds. To prevent against high fault currents, special fuses must be Wtted[5], [6].

The reader may be questioning why we need the thyristor since we covered how a transistor may be utilised as an electrical switch in the previous section. On the surface, the transistor looks to be superior to the thyristor since it may be turned off while the current is flowing, but the thyristor will stay on until the current through it is decreased to zero by external means. The fundamental argument for using thyristors is because they are less expensive and have greater voltage and current ratings than power transistors. Moreover, the circuit configuration of rectifiers is such that the thyristor is not required to interrupt the flow of current, therefore its failure to do so is not a drawback. In However, there are other circuits (such as the next section on inverters) where the devices must be able to switch 0V on demand, in which case the transistor has an advantage over the thyristor.

As previously stated, motor loads are inductive, and we have shown that the current in an inductive load cannot change instantly. As a result, we may anticipate the converter's behaviour with an inductive load to differ from that with a resistive load, where the current might vary instantly.

The realization that the mean voltage for a particular Wring angle may be affected by the type of the load is a terrifying idea. What we mean is that after having fixed a delay angle, we may define the output voltage waveform independent of the load (a). We'd then know what value of a to use to get any specified mean output voltage. In practice is that once we have fixed a, the mean output voltage with a resistive–inductive load is not the same as with a purely resistive load, and therefore we cannot give a simple general formula for the mean output voltage in terms of a. This is obviously very undesirable: for example, if we had set the speed of our unloaded d.c. motor to the target value by adjusting the Wring angle of the converter to produce the correct mean voltage, the last thing we would want is for the voltage to fall as the load current drawn by the motor increases, causing the speed to fall below the target.Thankfully, it turns out that once there is sufficient inductance to keep the load current from going to zero, the output voltage waveform for a given a becomes independent of the load inductance. This is known as 'continuous current,' and fortunately, many motor circuits have sufficient self-inductance to produce continuous current.

But, with the resistive load, the output voltage was never negative, while we now observe that the output voltage may go negative for brief periods of time. This is because the inductance smoothes out the current such that it never falls to zero. As a consequence, one pair of thyristors is always conducting, therefore the load is always directly linked to the power source, and the load voltage is always made up of chunks of the supply voltage.It is not immediately clear why the current shifts over (or 'commutates') from the first pair of thyristors to the first pair when the latter are Wred, so a quick study at the behaviour of diodes in a similar circuit configuration may be useful at this point. Consider the configuration depicted in which has two voltage sources (one time-varying) that feed a load through two diodes. What decides which diode conducts, and how does this affect the load voltage.

It is sometimes proposed (especially by individuals with a light-current background) that a resistor may be employed to smooth the output voltage, as is typical practice in low-power D.C supplies. While this works well at reduced power, capacitors are not utilized with controlled rectifiers that feed motors for two reasons.To begin, as will be demonstrated later, it is not required for the voltage to be smooth since the current directly affects the torque, and as previously stated, the present is always considerably smoother than the voltage due to inductance. Second, the power levels in most drives are such that extremely large and costly capacitors would be necessary to store enough energy to smooth out the rectified voltage[7], [8].

Firing circuits

The gate drive circuitry is simple and inexpensive since the gate pulses are only of low power. Often, a single integrated circuit (chip) comprises all of the circuitry required to generate gate pulses and synchronize them with the necessary delay angle (a) with regard to the supply voltage. To prevent direct electrical connections between the high voltages in the main power circuit and the low voltages in the control circuits, gate pulses are often connected to the thermistor through tiny pulse transformers. Most converters additionally incorporate 'inverse cosine-weighted' Wring circuitry, which implies that the Wring circuitry is weighted in the inverse cosine direction.

GM executives have also been quite clear in stating that these goals are “aspirational” and can’t be achieved without supportive public policies and the embrace of BEVs by consumers. Investors should also take this broader perspective. To reiterate a central argument from above, investors will benefit from traditional automotive OEMs becoming leaders in BEVs as a means of achieving more rapid scaling of mobility electrification. Investors also benefit when these OEMs offer proactive support to complementary private sector and government moves rather than having a compliance-only attitude. Time will tell whether GM—and other contending OEMs—will lean into this proactive role.

When important clients want it. Large, bureaucratic companies are capable of starting and finishing technologically challenging innovations, even ones that need for whole new skill sets. When the new technology was required to fulfil the expectations of current consumers, we notice that established enterprises have led their sectors in producing crucial competence-destroying technologies, but sometimes at tremendous expense.

Silicon Controlled Rectifier

The Silicon Controlled Rectifier (SCR) is a three-pin device with three fundamental terminals: anode, cathode, and gate. The gate terminal is the control terminal for anode-cathode voltage application. Silicon is often utilised because to its low leakage current. The polarity of the voltages provided to the cathode and anode determines whether the device is in forward or reverse bias, while the gate voltage determines the SCR's conduction. In other words, when forward bias is provided to the SCR after applying the correct positive gate voltage, the device begins to conduct and is shut off only when the current through the device is less than the holding current. As a result, the SCR may be utilised as a switch[9], [10].

Types of SCR firing

There are two forms of shooting in general

Zero Voltage Cross Over firing: The zero-crossing control mode (also known as quick cycling, integral cycle, or burst firing) functions by turning the SCRs on only when the sinusoidal voltage's instantaneous value is zero. The phase angle is altered, i.e. the application of gate pulses delays by a particular amount of time, and conduction is regulated (Figure 15.1 and Figure 15.2).

At the right times, firing circuits should provide trigger pulses for the thyristor. Electrical isolation is required between the firing circuits and the thyristor. A pulse amplifier or an optoisolator is used to do this.

R-Firing circuit

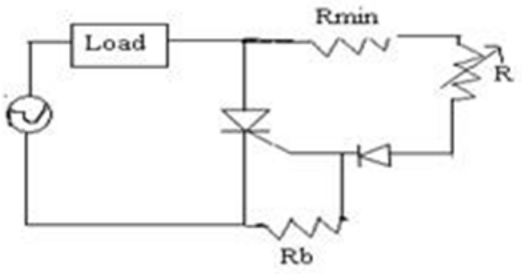

Figure 15.1 Represent the R- firing circuits.

RC firing circuit:

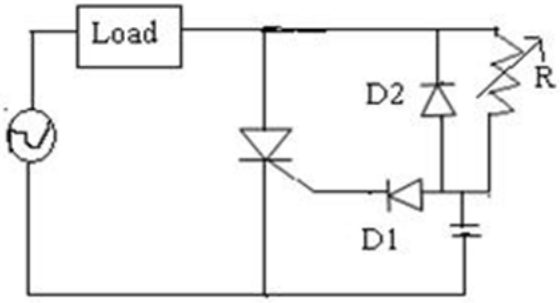

Figure 15.2 Represent the RC Firing circuit.

Firing Angle:

The firing angle is the amount of degrees from the start of the cycle when the SCR is turned on. Any SCR would begin to conduct at a certain point on the alternating current source voltage. The firing angle is defined as the specific location. The higher the voltage delivered to the load, the sooner in the cycle the SCR is gated ON (Figure 15.3).

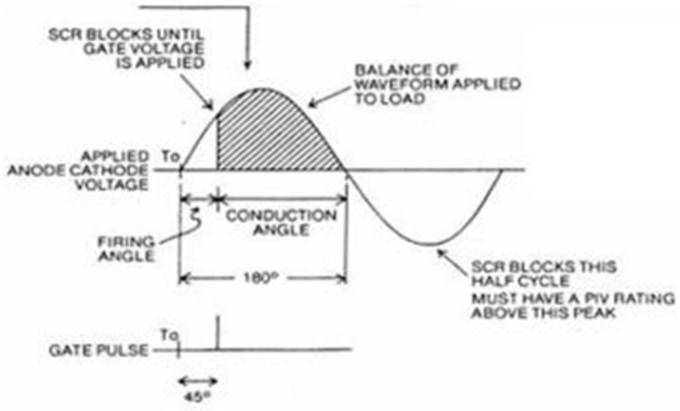

Figure 15.3 Represent the SCR controlled Rectifier.

Firing Angle Control

By adjusting the delivery of power to the SCR, ring angle control may be employed in applications such as managing the speed of fan motors and the intensity of a bulb. The firing angle is controlled by altering the time at which Gate pulses are applied to the SCR. The voltage to the SCR's Gate terminal may be applied at a time determined by the remote input.

Controlling the firing angle essentially means managing the point on the AC signal waveform at which the SCR will be activated, or, in a nutshell, determining the time corresponding to the AC signals waveform at which the SCR gate will be fed DC supply voltage. Normally, an opt isolator is used to activate an SCR. Normally zero-crossing detectors or opt isolators with zero-crossing detectors may be utilized for a basic power application circuit when no power control is needed, triggering the SCR solely at the zero crossing levels of the AC waveform. In other applications requiring power management, the gate is triggered by pulses, and the firing angle is changed to control the switching of the SCR and hence the power of the SCR.

Firing angle control may be utilized in applications like managing the speed of fan motors, adjusting the intensity of a bulb, by controlling the application of power to the SCR. The firing angle control is performed by adjusting the time of application of Gate pulses to the SCR. The voltage to the Gate terminal of the SCR may be applied at a specified time chosen by the remote input. Basically by regulating the firing angle implies managing the point on the AC signal waveform when the SCR is going to be triggered or in other words, the time corresponding to the AC signal waveform when the SCR gate is going to be provided DC supply voltage. Normally to activate an SCR we utilize opt isolator. For a basic power application circuit, where no power management is needed, generally zero-crossing detectors or opt isolators with zero-crossing detectors may be used, by which the SCR is activated only at the zero crossing levels of the AC waveform. For other applications including power regulating application, the gate is activated using pulses and the firing angle is modified appropriately to control the switching of the SCR and consequently the power of the SCR.

A back to back SCR connection is used to provide AC power to the load throughout both half cycles of the AC signal. Two opt isolators are connected to each SCR. After being engaged by an opt isolator during the first half cycle of the AC signal, one of the SCRs conducts, enabling current to flow through the load. During the second half cycle, another opt isolator activates another SCR connected in the opposite direction to the other SCR, enabling current to flow to the load. As a consequence, the load gets alternating current power throughout both half cycles.

In this configuration, an opt isolator with an LED and a TRIAC is utilized to trigger the SCR. When pulses are sent to the LED, light falls on the TRIAC, causing it to conduct and enabling the opt isolator output pulses to be transferred to the SCR. The approach involves changing the frequency of surrounding pulses to control the rate at which pulses are applied. A microcontroller is used to provide pulses to the opt isolator in response to the push button input. The number of of times the push button is pressed determines the amount of delay in the application of pulses. For instance, hitting the push button once causes the Microcontroller to delay the pulse application by 1ms. As a consequence, both the angle at which the SCR is engaged and the distribution of AC power to the load are controlled.

Triggering of Thyristors or SCR Triggering

The SCR, sometimes known as the thyristor, is a kind of semiconductor device that is specifically intended for use in high-power switching applications. This gadget can only be used in switching mode and works as a switch. When the SCR is activated into transmission by its gate terminal, it will continually provide current. When constructing an SCR or Thyristor circuit, extra attention should be paid to the circuit's activation. The operation of the whole area of the SCR circuit is mostly determined by how it is triggered. This page describes several techniques of SCR triggering, SCR switch ON methods, and Thyristor triggering. There are several triggering mechanisms accessible depending on various things such as temperature, voltage, and so on. After being engaged by an optoisolator during the first half cycle of the AC signal, one of the SCRs conducts, enabling current to flow through the load. During the second half cycle, another optoisolator activates another SCR connected in the opposite direction to the other SCR, enabling current to flow to the load. As a consequence, the load gets alternating current power throughout both half cycles.

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SCR Triggering Methods

Forward Voltage Triggering

This triggering mechanism is mostly used to enhance the voltage between the anode and cathode. As a result, the width of the depletion layer may be extended, which raises the accelerating voltage of minority charge carriers at the J2 junction. This may also result in an avalanche breakdown of the J2- junction at a forward break over-voltage.

At this point, the silicon-controlled rectifier may switch to conduction mode, resulting in a large current flow with a lower voltage drop. The forwarding voltage drop across the SCR is 1 to 1.5 volts throughout the triggering condition. This approach cannot be employed in practice because it demands an extraordinarily high anode voltage to the particular cathode. When the voltage exceeds the break over-voltage, it provides extraordinarily large currents. This might damage the thyristor. As a result, in most cases, this kind of SCR triggering technique cannot be employed.

Temperature Triggering

This form of triggering is mostly caused by certain conditions. It may raise unexpected reactions, and the findings must be recorded as an aspect of any design technique. Temperature triggering of thyristors happens primarily when the voltage across the J2 junction, as well as leakage current, may raise the temperature of the junction. When the temperature rises, the leakage current rises with it.

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