SPEED CONTROL OF ELECTRIC VEHICLES USING ADAPTIVE PID CONTROLLER

A Project Report Submitted in Partial Fulfillment of the Requirements for the award of Degree of

Bachelor of Technology

in

Electrical and Electronics Engineering

Submitted by

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Approved by AICTE, Accredited by NBA & NAAC with 'A' Grade
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CERTIFICATE

This is to certify that the project report entitled **SPEED CONTROL OF ELECTRIC VEHICLES USING ADAPTIVE PID CONTROLLER** is being submitted by

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In partial fulfillment for the award of the Degree of Bachelor of Technology in Electrical and Electronics Engineering to the Jawaharlal Nehru Technological University Gurajada, Vizianagaram is a record of bonafide work carried out under my guidance and supervision.

The results embodied in this project report have not been submitted to any other Institute or University for the award of any Degree.

Project Guide **Head of Department**

External Examiner

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We consider it as a privilege to thank all those people who helped us a lot for the successful completion of this project work entitled **"SPEED CONTROL OF ELECTRIC VEHICLES USING ADAPTIVE PID CONTROLLER".**

We sincerely express our whole hearted gratitude to **Mrs. K. Aswini, Assistant Professor** for his technical guidance, constant encouragement and support incarrying out the project work.

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INSTITUTE

VISION

Producing globally competent and quality technocrats with human values for the holistic needs of industry and society.

MISSION

- Creating an outstanding infrastructure and platform for enhancement of skills, knowledge and behaviour of students towards employment and higher studies.
- Providing a healthy environment for research, development and entrepreneurship, to meet the expectations of industry and society.
- Transforming the graduates to contribute to the socio-economic development and welfare of the society through value-based education.

Department of Electrical and Electronics Engineering

VISION

To be a hub for imparting knowledge, skills, and behavior for exemplary contributions in the field of Electrical and Electronics Engineering.

MISSION

- To impart Technical Education through the state-of-the-art infrastructure facilities, laboratories and instruction.
- To inculcate industry-oriented learning through industrial visits, internships, projects at Industries, MOUs, to make students’ technically skills oriented.
- Creating conducive environment for higher education, employment and entrepreneurship through quality education, professional skills and research.
- To promote societal commitment among students by inculcating moral and ethical values.

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

PEO1: Graduates shall have strong foundation in core and allied Electrical and Electronics Engineering, in sciences and mathematics, to become globally competent in designing, modeling and critical problem solving.

PEO2: Graduates shall involve in research activities in the field of electrical and electronics engineering through lifelong learning and provide solutions to engineering problems for sustainable development ofsociety.

PEO3: Graduates shall have good communication skills and socio-ethical values for getting employmentor higher studies by excelling in competitive examinations and be able to work in supportive and leadership roles.

Department of Electrical & Electronics Engineering

PROGRAM OUTCOMES (POs)

PO1: Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO2: Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3: Design & Development: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations

PO4: Investigations: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5: Modern Tools: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6: Engineer & Society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7: Environment & Sustainability: Understand the impact of the professional engineering solutions insocietal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and normsof the engineering practice

PO9: Individual & Team Work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10: Communication Skills: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11: Project mgt. & Finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manageprojects and in multidisciplinary environments

PO12: Life Long Learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

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PSO1: Capable of design, develop, test, verify and implement electrical and electronics engineering systems and products.

PSO2: Succeed in national and international competitive examinations for successful higher studies andemployment.

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Department of Electrical & Electronics Engineering

PROJECT COURSE OUTCOMES

1. Apply the Concepts of Electrical Engineering to analyze the ideas of Students and Design thePhysical / Simulation model.
2. Enable Students to work as an individual and in Diverse Teams.
3. Identify the state of the art in the Fields of Electrical Engineering through Literature Survey andImplement the ideas using Modern Tools.
4. Design and Develop models that are useful for the Society by following Research Ethics andValues.
5. Improve Writing and Presentation Skills of Students so as to enable the Work done by them toget Published.

CO Vs PO & PSOs MAPPING

COs	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	3	3	3	2	3	1	-	3	3	3	3	3	3	1
CO2	3	3	3	2	2	1	-	-	3	2	3	2	3	1
CO3	3	3	3	2	3	2	-	1	2	2	2	2	3	1
CO4	3	3	3	3	2	2	1	3	2	2	2	2	3	2
CO5	3	3	3	2	2	1	-	-	3	2	2	2	3	1
CO*	3	3	3	2	2	1	1	2	3	2	2	2	3	1
Overall POs & PSOs mapped: PO1, PO2, PO3, PO4, PO5, PO6, PO7, PO8, PO9, PO10, PO11, PO12, PSO1, PSO2														

CONTENTS

ABSTRACT

Electric vehicles (EVs) are broadly utilizing for their High Efficiency, high torque, low volume and gained significant attention due to their potential for reducing carbon emissions and reliance on fossil fuels. To maximize the performance and efficiency of EVs, precise speed control is crucial. This analysis presents the design and implementation of an Adaptive Proportional-Integral-Derivative (PID) controller for the speed regulation of an Electric Vehicle using MATLAB Simulink. The proposed Adaptive PID controller aims to enhance the performance of traditional PID controllers by dynamically adjusting its parameters based on the system's characteristics. The adaptation mechanism allows the controller to automatically tune its gains to optimize the closed-loop system's response, ensuring robust and efficient speed control across a range of operating conditions. The Adaptive PID controller is then designed to regulate the speed of the Electric Vehicle by adjusting the control signals in real-time. Simulation will demonstrate the effectiveness of the Adaptive PID controller in achieving precise and rapid speed control of the Electric Vehicle. This analysis highlights the fast time response in terms of transient response, settling time, and disturbance rejection. The adaptive nature of the controller ensures robust operation in the face of parameter variations and uncertainties in the motor system. This research contributes to the understanding of control strategies for electric vehicles, which is crucial for achieving energy-efficient and reliable electric transportation. The findings can be used to enhance the design and implementation of speed control systems in electric vehicles, ultimately promoting their adoption and sustainability in the automotive industry.

INDEX TERMS: Electric Vehicles, Speed Control, Adaptive PID Controller, MATLAB Simulation, Control System Design.

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CHAPTER - 1

INTRODUCTION

1.1 OVERVIEW

Presently, the industrialized world is growing very quickly and the requirement for accuracy and unbending nature has become a significant prerequisite. Various applications require accuracy and are fit for surviving issues. In driving, from a variety of motors, BLDC motors have been broadly utilized in mechanical, restorative hardware, vehicles, aviation, hard circle drive, as the benefits of BLDC are extraordinary execution, advance and lower assurance in power factor.

In the direction of recent years, with their promising presentation in different applications in both the military and regular citizen fields, unmanned aeronautical vehicles (UAVs) have stood out for researchers to control procedures. The UAV is described by its minimal effort, high portability, simple to structure and simple to keep up, and the capacity to work in perilous and dull situations to spare human life. These highlights give a promising option in contrast to different not controlled military and regular citizen applications. As of late, DC electronic motors assume a significant position in UAV rotor control. One of the fundamental preferences of an electric motor is its effortlessness of controlling the speed and its speed of movement. These days, BLDC motors are generally utilized in electronic vehicles, on the fields that the nonattendance of a brush/ transport gathering decreases hearing sharpness and improves productivity and torque. A well-known magnet brushless DC motor (PMBDCM) is mainstream and utilized BLDC motor utilized as a variable speed drive framework for mechanical, car, aviation and computerization applications.

1.2 LITERATURE REVIEW

From the last few years, a lot of research work has been done in the speed control strategies of electrical vehicles using various Modern control Techniques.

Segu Yaswanth Vamsi Kumar, Mounika Mukku, Vimala Kumari, Anush Gudidh (2023) : Electrical vehicles (EVs) will be the transportation system's future when it overcomes some disadvantages like battery life., charging stations., and speed control limitations. In EV., the brushless DC motor is often used because of its high torque and high efficiency. however., it's difficult to control the speed of the DC motor. This paper presents the speed control of an EV by using different controlling methods such as PID (Proportional-Integral-Derivative)., Fuzzy-PID., and ANFIS (Adaptive-Neuro Fuzzy Inference System) controllers. The comparison of the results of all three techniques is discussed in this paper. From the results of the simulation., it can be noticed that the PID-Fuzzy offers better speed control than the conventional PID and augmenting ANFIS with PID gives better results than the PID-Fuzzy and PID alone.

M. Rif'an, F. Yusivar and B. Kusumoputro (2017): In this paper author implements adaptive PID controller Based on Additional Error of an Inversed-Control Signal to solve the problems of non-linearity, parameter variations and load excursions that occur in BLDC motor drive systems. The performance of the traditional PID controller-based speed control method is compared with the model reference-based speed control for BLDC motor drive system using MATLAB software.

Z. Hou, W. Wang, G. Zhang and C. Han (2017): In this paper author presents a mixed-initiative motion control strategy for multiple quadrotor aerial vehicles. The proposed approach incorporates formation specifications and motion-planning commands as well as inputs by a human operator. More specifically, we consider a leader–follower aerial robotic system, which autonomously attains a specific geometrical formation, by regulating the distances among neighbouring agents while avoiding inter-robot collisions. The desired formation is realized by a decentralized prescribed performance control strategy, resulting in a low computational complexity implementation with guaranteed robustness and accurate formation establishment. The multi-robot system is safely guided towards goal configurations, by employing a properly defined navigation function that provides appropriate motion commands to the leading vehicle, which is the only one that has knowledge of the workspace and the goal configurations. Additionally, the overall framework incorporates human commands that dictate the motion of the leader via a teleoperation interface. The resulting mixed-initiative control system has analytically guaranteed stability and convergence properties. A realistic simulation study, considering a team of five quadrotors operating in a cluttered environment, was carried out to demonstrate the performance of the proposed strategy.

M. V. Rajkumar, G. Ranjhitha, M. Pradeep and M. F. Kumar (2017): The aim of this paper is to provide a system for the speed control of a Brushless DC motor (BLDC) fed inverter with the electric vehicle. The fuzzy logic technique is used to estimate the speed of the BLDC motor under variable and fixed condition of the back EMF. Finally, the speed can be controlled by using Proportional-Integral (PID) Controller with the help of fuzzy based estimation of the speed and rotor position. In order to Compare PI controller, PID and fuzzy controllers provide better speed response and having zero steady state error. Resonant inverter is used for DC-AC conversion with current resonance. The inverter used to regulate voltage and fed into the BLDC motor through a motor driver circuit.

M. Mahmud, S. M. A. Motakabber, A. H. M. Z. Alam, A. N. Nordin (2020): This paper describes the design of the BLDC motor control system using in using MATLAB/SIMULINK software for Proportional Integral Derivative (PID) algorithm that can more effectively improve the speed control of these types of motors. The purpose of the paper is to provide an overview of the functionality and design of the PID controller. Finally, the study undergoes some well-functioning tests that will support that the PID regulator is far more applicable, better operational, and effective in achieving satisfactory control performance compared to other controllers.

J. X. Shen, Z. Q. Zhu, D. Howe and J. M. Buckley (2005): In this paper A simple adaptive fuzzy logic control algorithm, in which the speed-error threshold may be either fixed or self-tuned, is proposed. Simulations and measurements on vector-controlled permanent-magnet brushless AC drives confirm that the proposed adaptive fuzzy logic control results in an excellent speed-control performance and robustness to parameter variations, while current harmonics are reduced. Its performance is compared with that which is achieved when conventional fuzzy logic and PI speed control are employed.

1.3 RIDE QUALITY OF ELECTRIC VEHICLES

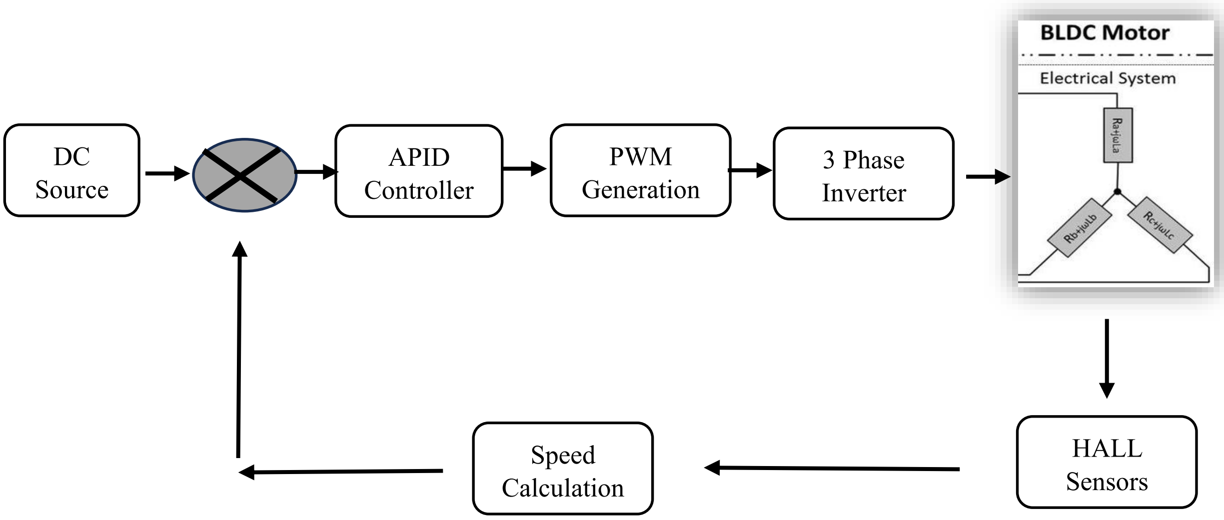
In recent years, with the wide spread of internal-combustion engine vehicles (ICEVs) all over the world, the environment and energy problems are going severely. Therefore, the development of next-generation vehicles such as hybrid vehicles (HVs) and electric vehicles (EVs) has been focused. Especially, EVs have attracted great interests as a powerful solution against the problems. EVs are automobiles which are propelled by electric motors, using electrical energy stored in batteries or another energy storage device. Electric motors have several advantages over ICEs:

- Energy efficient. Electric motors convert 75% of the chemical energy from the batteries to power the wheels—ICEs only convert 20% of the energy stored in gasoline.

- Environmentally friendly. EVs emit no tailpipe pollutants, although the power plant producing the electricity may emit them. Electricity from nuclear-, hydro-, solar-, wind-powered plants causes no air pollutants.
- The input/output response is faster than for gasoline/diesel engines. It is said that the motor torque response is 2 orders of magnitude faster than that of the engine. E.g., if engine torque response costs 500 ms, the response time of motor toque will be 5 ms.
- The torque generated in the wheels can be detected relatively accurately. For engine, the output torque varies along with the temperature and revolutions, even it has high-nonlinearity. Consequently, the value of torque is too difficult to be measured accurately. However, the value of motor torque is surveyed easily and accurately from the view of current control.
- The motor can be made small enough, then the vehicles can be made smaller by using multiple motors placed closer to the wheels. The drive wheels can be controlled fully and independently. E.g., it becomes easily achievable to control the differences of driving force developed between the left and right wheel.

From these good points of EVs, we can realize the superior running of vehicle with the good ride quality by using appropriate speed control. Such superior speed control is very useful for autonomous vehicle and some types of autonomous vehicle can also be applied, for example, PRT (Personal Rapid Transit) and so on.

1.4 BLOCK DIAGRAM



1. **Input DC Source:** This is initial Power Source that provides direct Current (DC) to the System. This power coming from the battery that we have charged in the Electric Vehicle through the external power source.
2. **APID Controller:** An adaptive PID controller is an advanced control algorithm that dynamically adjusts its parameters in response to changes in system behaviour. Unlike traditional PID controllers with fixed gains, adaptive PID controllers continuously update their gains based on real-time feedback from the system. This adaptability enables them to maintain optimal performance even in the face of varying operating conditions, parameter uncertainties, and disturbances.

   In this first iteration it will be no proper feedback came from the motor and hall sensors due to starting of the Electric vehicle. Later on, next Iteration it takes take the speed calculation values from the block dynamically adjust the parameters in response to changes in system behaviour.
3. **PWM Generation:** Pulse Width Modulation (PWM) is a widely used technique in electronics and control systems for achieving variable power outputs, controlling the speed of motors, regulating the brightness of LEDs, and numerous other applications. This essay explores the principles behind PWM generation, its applications across different industries, and the advancements shaping its future.

   It results the power input to the motor to vary the speed of the vehicle and other parameters. It also reduces Harmonics which occurs in the system.
4. **3 Phase Inverter:** A three-phase inverter is a device that converts DC power into three-phase AC power. It consists of semiconductor switches, typically insulated gate bipolar transistors (IGBTs) or metal-oxide-semiconductor field-effect transistors (MOSFETs), arranged in a bridge configuration. The three-phase inverter operates by switching these semiconductor devices in a sequence that generates three-phase AC output voltages.

   The most common configuration for three-phase inverters is the six-switch topology, comprising three pairs of switches. Each switch pair is connected to one of the three phases of the AC output. By modulating the switching states of these switches using pulse width modulation (PWM) techniques, the inverter can control the magnitude and frequency of the output voltages.
5. **BLDC Motor:** The inception of BLDC motors traces back to the mid-20th century, but it was advancements in semiconductor technology that spurred their widespread adoption. BLDC motors feature a rotor with permanent magnets and a stator with multiple windings. Commutation is achieved through electronic switches, typically MOSFETs or IGBTs,

controlled by a motor drive circuit. Sensors such as Hall effect sensors or encoder feedback provide rotor position information, enabling precise control of motor speed and torque.

6. **Hall Sensors:** Hall sensors utilize the Hall effect, a fundamental principle in physics discovered by Edwin Hall in 1879, to measure magnetic fields. When a magnetic field is applied perpendicular to the direction of current flow in a conductor, a voltage potential develops across the conductor, perpendicular to both the current flow and the magnetic field. This Hall voltage is proportional to the strength of the magnetic field and can be measured using Hall effect sensors.

   Hall sensors typically consist of a semiconductor material with a narrow conducting strip, through which current flows. When a magnetic field is present, the Hall voltage is generated perpendicular to the direction of current flow. By measuring this Hall voltage, Hall sensors can determine the strength and polarity of the magnetic field, enabling various sensing applications.

7. **Speed Calculation:** This Block will compare the speed output with the speed reference that we had given to the system. In this system we have given the reference RPM of 3000 RPM.

1.5 OBJECTIVES

- Develop a robust adaptive PID controller tailored for speed control applications in electric vehicles. This involves understanding the dynamics of electric vehicle propulsion systems and designing adaptive control algorithms capable of adjusting PID parameters in real-time to accommodate varying operating conditions and system uncertainties.
- Construct a comprehensive mathematical model of the electric vehicle propulsion system, including the motor, power electronics, and mechanical components.
- Implement algorithms for online parameter identification and adaptation within the adaptive PID controller. Utilize sensor data, such as motor speed, vehicle velocity, and battery voltage, to continuously estimate system parameters and dynamically adjust PID gains to optimize speed control performance and efficiency.

CHAPTER - 2

INVERTERS & PULSE WIDTH MODULATION (PWM)

2.1 INTRODUCTION

The converters which convert the power into ac power popularly known as the inverters. The application areas for the inverters include the uninterrupted power supply (UPS), the ac motor speed controllers, etc.

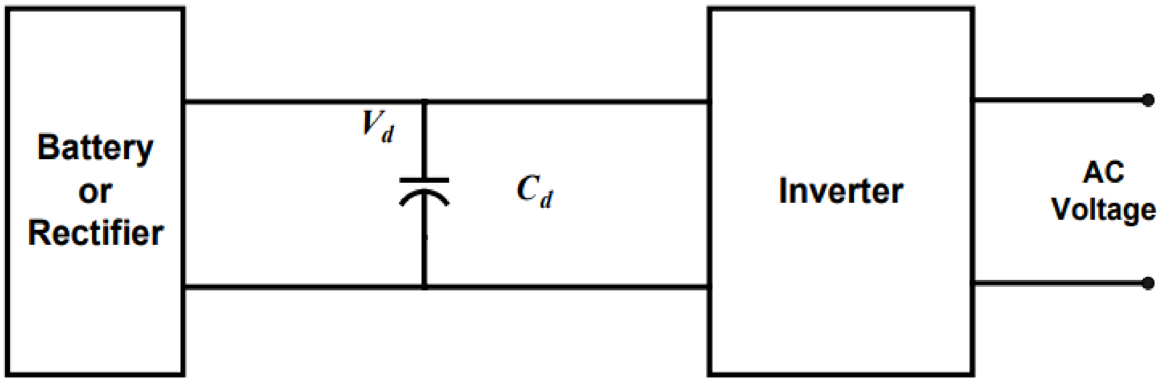


Fig 2.1 Block Diagram of an Inverter

The inverters can be classified based on a number of factors like, the nature of output waveform (sine, square, quasi square, PWM etc), the power devices being used (thyristor transistor, MOSFETs IGBTs), the configuration being used, (series. parallel, half bridge, Full bridge), the type of commutation circuit that is being employed and Voltage source and current source inverters.

The thyristorised inverters use SCRs as power switches. Because the input source of power is pure DC in nature, forced commutation circuit is an essential part of thyristorised inverters. The commutation circuits must be carefully designed to ensure a successful commutation of SCRs. The addition of the commutation circuit makes the thyristorised inverters bulky and costly. The size and the cost of the circuit can be reduced to some extent if the operating frequency is increased but then the inverter grade thyristors which are special thyristors manufactured to operate at a higher frequency must be used, which are costly. Thus, for example, the primary source of input power may be utility ac voltage supply that is converted to dc by an ac to dc converter and then 'inverted' back to ac using an inverter. Here, the final ac output may be of a different frequency and magnitude than the input ac of the utility supply.

2.2 SINGLE PHASE HALF BRIDGE INVERTER

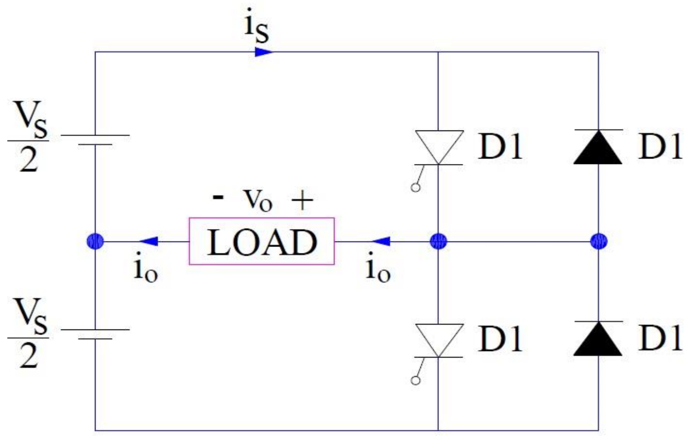


Fig 2.2 Single phase Half Bridge DC-AC inverter

The analysis of the DC-AC inverters is done taking into accounts the following assumptions and conventions.

1) The current entering node a is considered to be positive.

2) The switches S1 and S2 are unidirectional, i.e. they conduct current in one direction.

3) The current through S1 is denoted as i1 and the current through S2 is i2. The switching sequence is so design is shown in Figure 2.3 below. Here, switch S1 is on for the time duration $0 \leq t \leq T1$ and the switch S2 is on for the time duration $T1 \leq t \leq T2$. When switch S1 is turned on, the instantaneous voltage across the load is ν out = Vin/ 2.

When the switch S2 is only turned on, the voltage across the load is ν out = Vin/ 2.

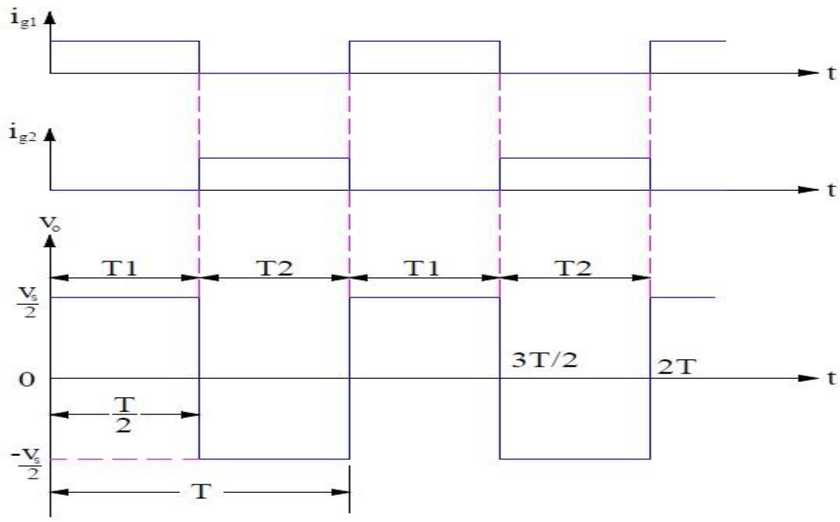


Fig 2.3 Single phase Half Bridge DC-AC inverter output waveforms

2.3 SINGLE PHASE FULL BRIDGE INVERTER

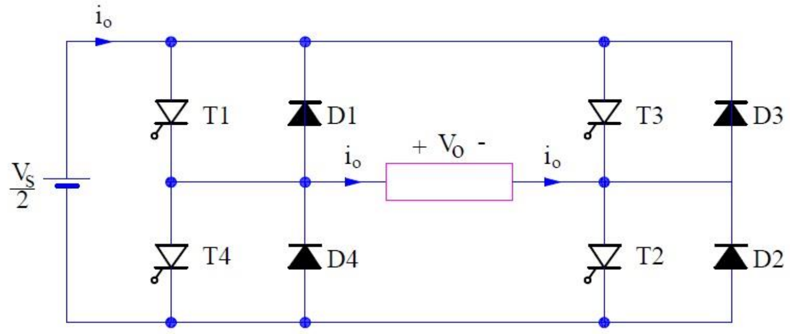


Fig 2.4 Single phase Full Bridge DC-AC inverter

A single-phase bridge DC-AC inverter is shown in Figure 2.4 above. The analysis of the single-phase DC-AC inverters is done taking into account following assumptions and conventions.

1. The current entering node a in figure 2.4 is considered to be positive.
2. The switches S1, S2, S3 and S4 are unidirectional, i.e. they conduct current in one direction.

2.4 OPERATIONS

I. When the switches S1 and S2 are turned on simultaneously for a duration $0 \leq t \leq T1$, the input voltage Vin appears across the load and the current flows from point a to b. Q1 – Q2 ON, Q3 – Q4 OFF ==> v o = Vs

II. If the switches S3 and S4 turned on duration $T1 \leq t \leq T2$, the voltage across the load the load is reversed and the current through the load flows from point b to a. Q1 – Q2 OFF, Q3 – Q4 ON ==> v o = -Vs

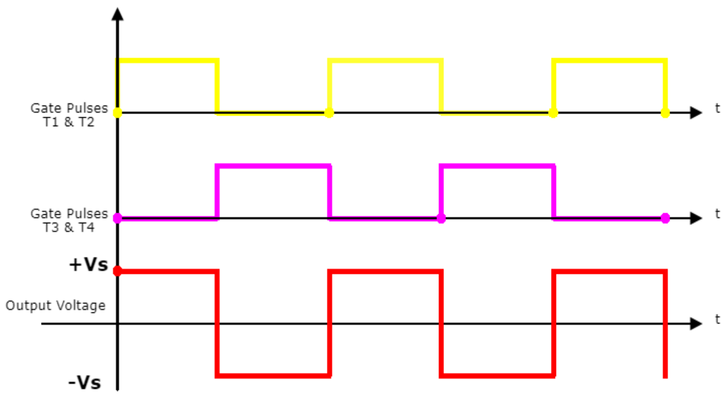


Fig 2.5 Single phase full Bridge DC-AC inverter output waveforms

2.5 3-PHASE INVERTERS

Three phase inverters are normally used for high power applications. The advantages of a three-phase inverter are:

- The frequency of the output voltage waveform depends on the switching rate of the switches and hence can be varied over a wide range.
- The direction of rotation of the motor can be reversed by changing the output phase sequence of the inverter.
- The ac output voltage can be controlled by varying the dc link voltage. The general configuration of a three phase DC-AC inverter is shown in Figure 2.6 Two types of control signals can be applied to the switches:
- 180° conduction
- 120° conduction

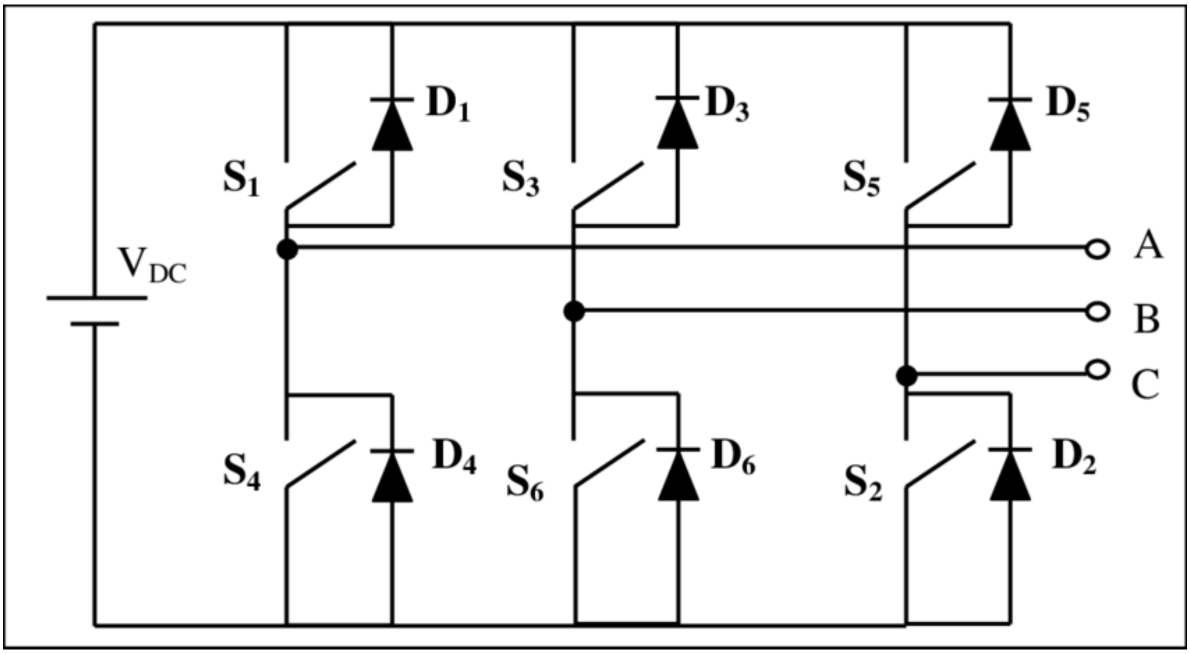


Fig 2.6 Circuit diagram of three phase bridge inverter

2.6 180-DEGREE CONDUCTION WITH STAR CONNECTED RESISTIVE LOAD

The configuration of the three-phase inverter with star connected resistive load is shown in Figure 2.6. The following convention is followed:

- A current leaving a node point a, b or c and entering the neutral point n is assumed to be positive.
- All the three resistances are equal, Ra = Rb = Rc = R

In this mode of operation each switch conducts for 180°. Hence, at any instant of time three switches remain on. When S1 is on, the terminal A gets connected to the positive terminal of input DC source. Similarly, when S4 is on, terminal A gets connected to the negative terminal of input DC source. There are six possible modes of operation in a cycle and each mode is of 60° duration and the explanation of each mode is as follows:

$$v_{an} = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_{in}}{3n\pi}\left[1+\sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin(n\omega t)$$

$$v_{bn} = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_{in}}{3n\pi}\left[1+\sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin\left(n\omega t-\frac{2n\pi}{3}\right)$$

$$v_{cn} = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_{in}}{3n\pi}\left[1+\sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin\left(n\omega t-\frac{4n\pi}{3}\right)$$

$$v_{ab} = v_{an} - v_{bn} = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_{in}}{n\pi}\sin\frac{n\pi}{2}\sin\frac{n\pi}{3}\sin\left(n\omega t+\frac{n\pi}{6}\right)$$

$$v_{bc} = v_{bn} - v_{cn} = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_{in}}{n\pi}\sin\frac{n\pi}{2}\sin\frac{n\pi}{3}\sin\left(n\omega t-\frac{n\pi}{2}\right)$$

$$v_{ca} = v_{cn} - v_{an} = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_{in}}{n\pi}\sin\frac{n\pi}{2}\sin\frac{n\pi}{3}\sin\left(n\omega t-\frac{7n\pi}{6}\right)$$

Fig 2.7 Modes of Operations

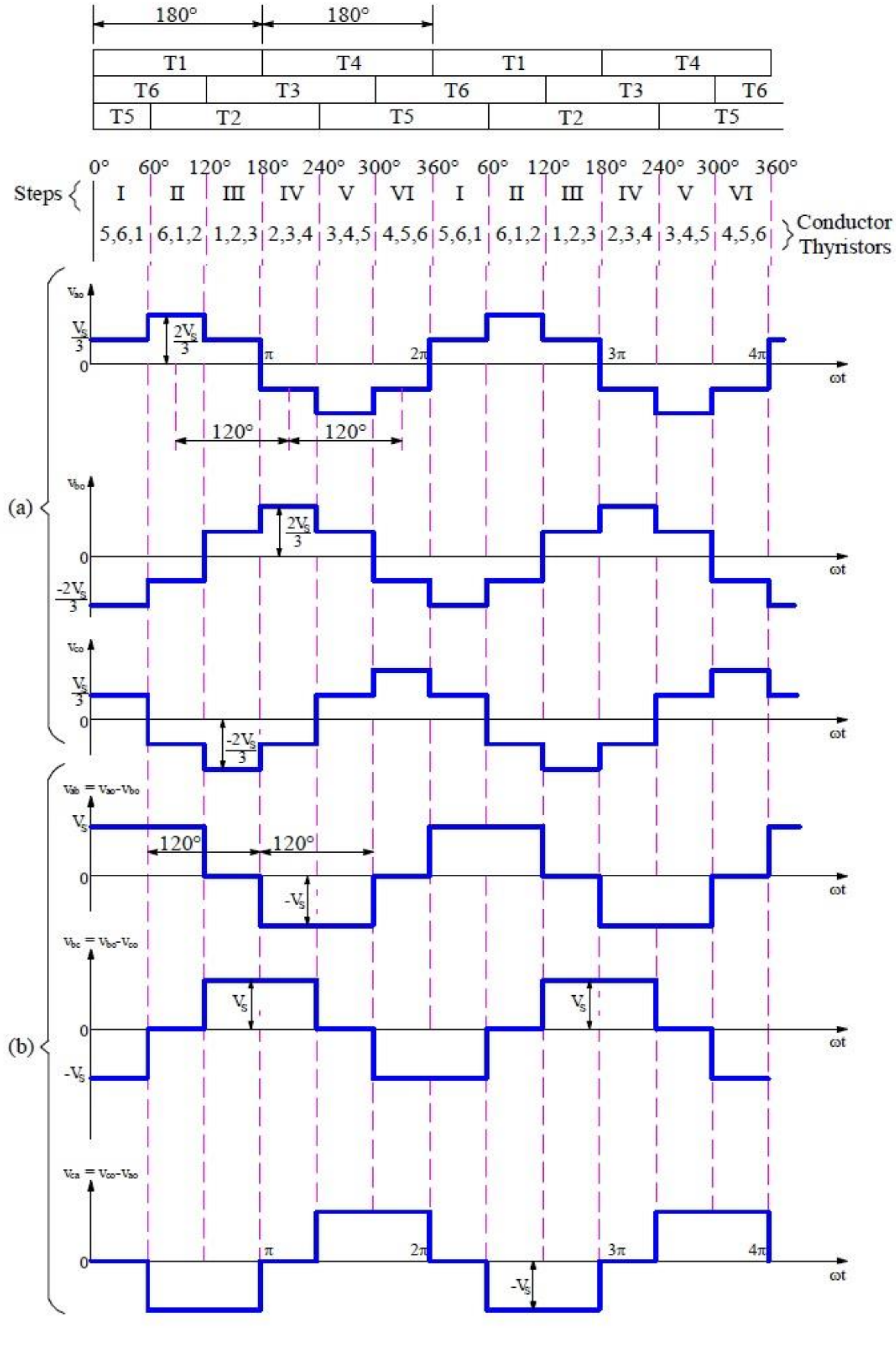


Fig 2.8 Line and phase voltages of three phase bridge inverter

2.7 THREE PHASE DC-AC CONVERTERS WITH 120° CONDUCTION MODE

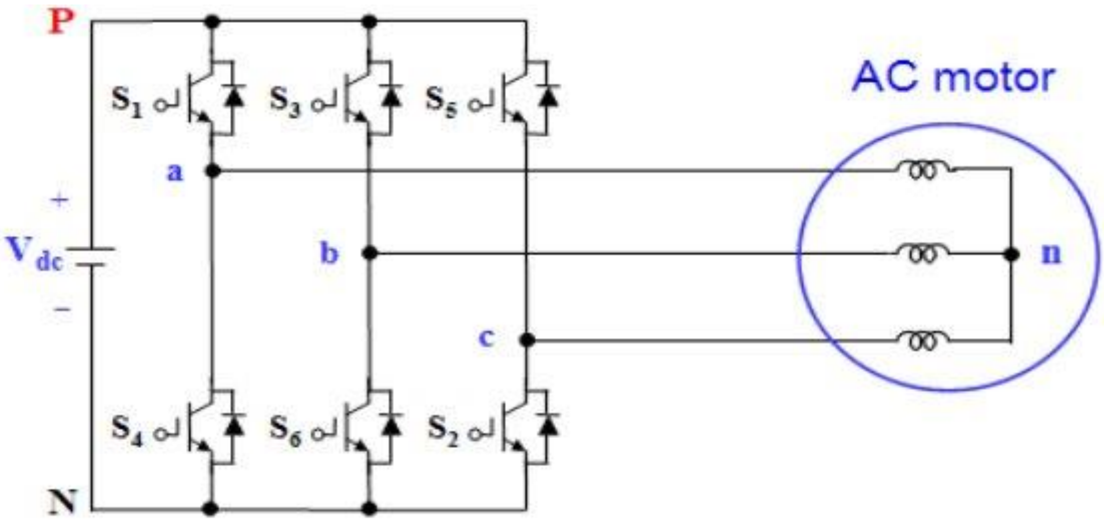


Fig 2.9 Circuit diagram of three phase bridge inverter

In this mode of conduction, each electronic device is in a conduction state for 120°. It is most suitable for a delta connection in a load because it results in a six-step type of waveform across any of its phases. Therefore, at any instant only two devices are conducting because each device conducts at only 120°. The terminal A on the load is connected to the positive end while the terminal B is connected to the negative end of the source. The terminal C on the load is in a condition called floating state. Furthermore, the phase voltages are equal to the load voltages as shown below.

Phase voltages = Line voltages

Vab = V

Vbc = −V/2

Vca = −V/2

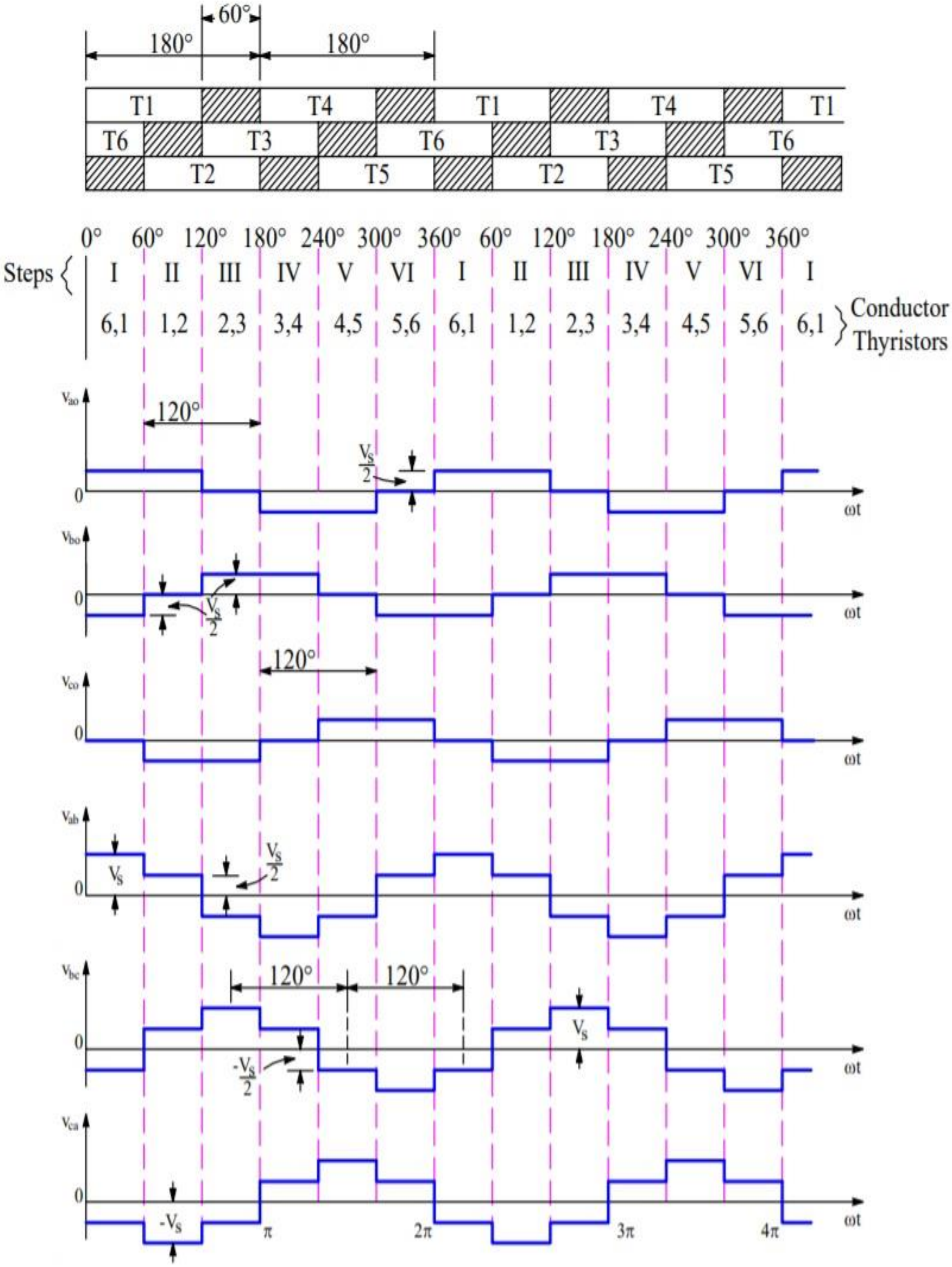


Fig 2.10 Line and phase voltages of three phase bridge inverter

PULSE WIDTH MODULATION TECHNIQUES

2.8.1 INTRODUCTION

PWM is a technique that is used to reduce the overall harmonic distortion (THD) in a load current. It uses a pulse wave in rectangular/square form that results in a variable average waveform value f(t), after its pulse width has been modulated. The time period for modulation is given by T. Therefore, waveform average value is given by

$$\boldsymbol{y = \frac{1}{T}\int_0^T f(t)dt}$$

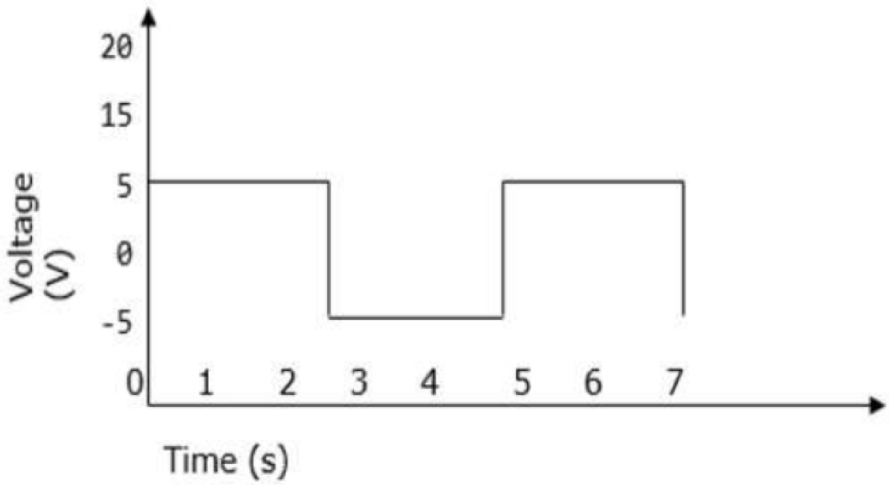


Fig 2.11 Square waveform used for PWM technique

2.8.2 SINUSOIDAL PULSE WIDTH MODULATION

In a simple source voltage inverter, the switches can be turned ON and OFF as needed. During each cycle, the switch is turned on or off once. This results in a square waveform. However, if the switch is turned on for a number of times, a harmonic profile that is improved waveform is obtained.

The sinusoidal PWM waveform is obtained by comparing the desired modulated waveform with a triangular waveform of high frequency. Regardless of whether the voltage of the signal is smaller or larger than that of the carrier waveform, the resulting output voltage of the DC bus is either negative or positive.

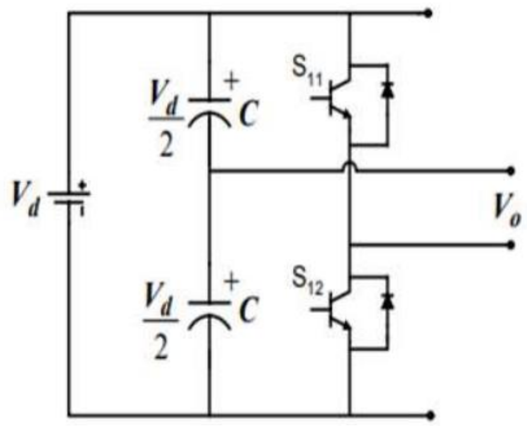


Fig 2.12 Schematic diagram of Half bridge PWM inverter

The sinusoidal PWM (SPWM) method also known as the triangulation, sub harmonic, or sub oscillation method, is very popular in industrial applications. The SPWM is explained with reference to figure 2.12, which is the half-bridge circuit topology for a single-phase inverter.

For realizing SPWM, a high-frequency triangular carrier wave is compared with a sinusoidal reference of the desired frequency. The intersection of and waves determines the switching instants and commutation of the modulated pulse. The PWM scheme is illustrated in Figure 2.12, in which Vc the peak value of triangular carrier wave and Vr is that of the reference, or modulating signal. The figure shows the triangle and modulation signal with some arbitrary frequency and magnitude. In the inverter of Figure 2.12 the switches and are controlled based on the comparison of control signal and the triangular wave which are mixed in a comparator. When sinusoidal wave has magnitude higher than the triangular wave the comparator output is high, otherwise it is low.

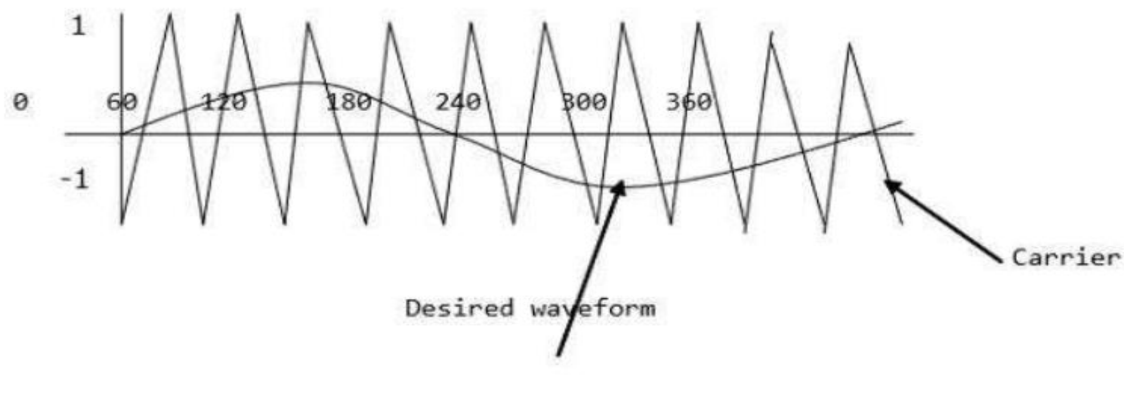


Fig 2.13 Sinusoidal PWM waveform

The sinusoidal amplitude is given as Am and that of the carrier triangle is give as Ac . For sinusoidal PWM, the modulating index m is given by Am/Ac .

2.8.3 Multiple PWM

The multiple PWM has numerous outputs that are not the same in value but the time period over which they are produced is constant for all outputs. Inverters with PWM are able to operate at high voltage output.

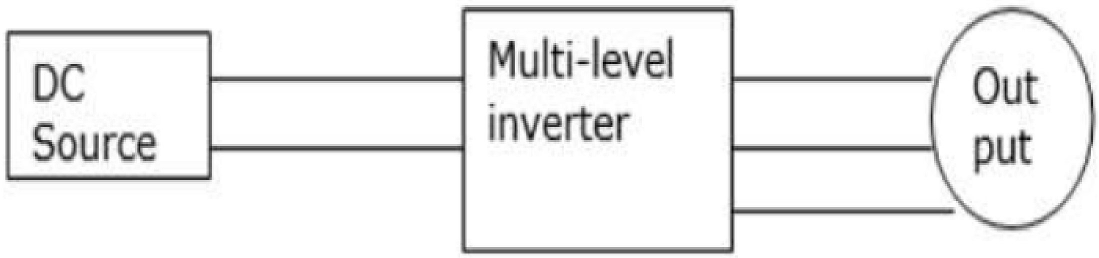


Fig 2.14 Block diagram of multiple PWM technique

The waveform below is a sinusoidal wave produced by a multiple PWM.

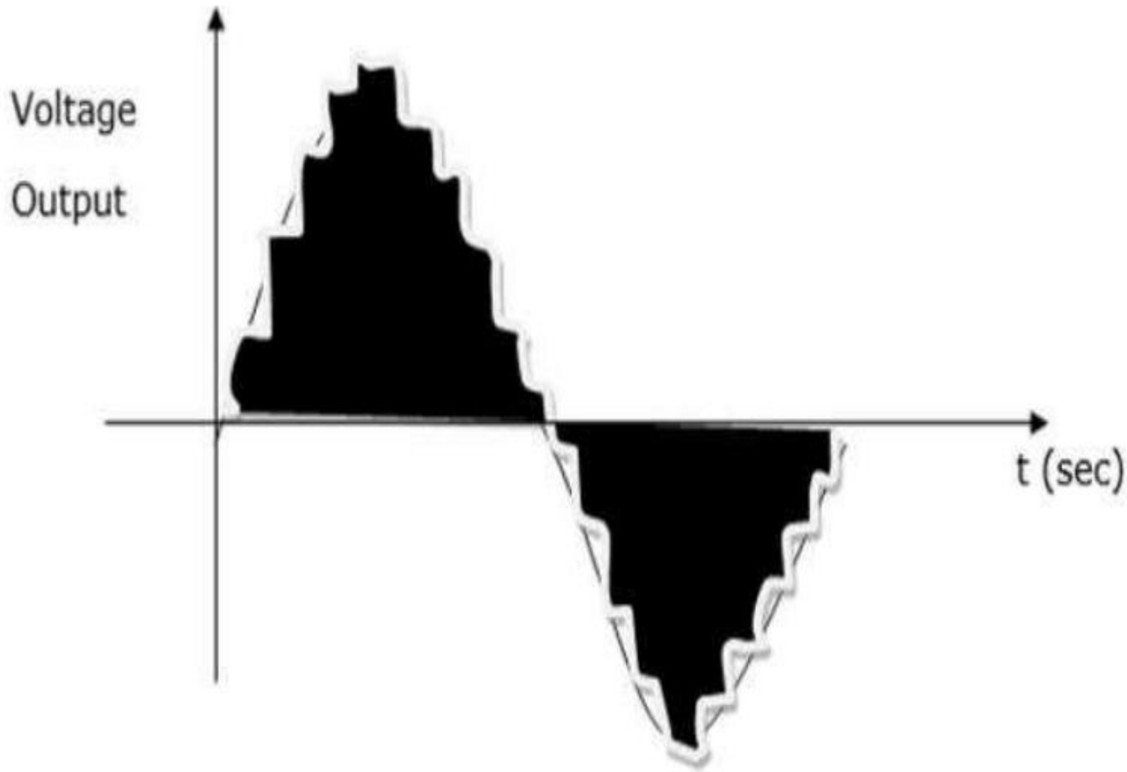


Fig 2.15 Waveform of multiple PWM technique

2.8.4 VOLTAGE AND HARMONIC CONTROL

A periodic waveform that has frequency, which is a multiple integral of the fundamental power with frequency of 60Hz is known as a harmonic. Total harmonic distortion (THD) on the other hand refers to the total contribution of all the harmonic current frequencies.

Harmonics are characterized by the pulse that represents the number of rectifiers used in a given circuit. It is calculated as follows

$h = (n \times P) + 1$ or -1

Where n − is an integer 1, 2, 3, 4…. n

P − Number of rectifiers

Harmonics have an impact on the voltage and current output and can be reduced using isolation transformers, line reactors, redesign of power systems and harmonic filters.

CHAPTER - 3

ELECTRIC MOTORS

3.1 INTRODUCTION

The fossil fuels proved out to be the base of energy source in the early 1970s. EVs are preferred over conventional IC engine driven vehicles because of the benefits of EVs such as efficiency and eco-friendly design. Despite being easily controllable, the commutator and brushes present in the DC machines may demand frequent maintenance. The reluctance motors show fluctuations in torque produced, which is not advisable in such applications. The power density of asynchronous motors is lesser than that of permanent magnet brushless motors, thereby, limiting the use of these machines for high power density applications. The advancements in the PMSM are accelerated with the developments in the field of power electronics and the permanent magnet materials. Higher efficiency, lower volume and higher torque/weight ratio are some of the major advantages of these motors which magnifies the use of these motors.

Electric motors convert electrical energy into mechanical energy. Two types of electric motors are used in electric vehicles to provide power to the wheels: the direct current (DC) motor and the alternating current (AC) motor.

DC electric motors have three main components:

- A set of coils (field) that creates the magnetic forces which provide torque
- A rotor or armature mounted on bearings that turns inside the field
- Commutating device that reverses the magnetic forces and makes the armature turn, thereby providing horsepower.

As in the DC motor, an AC motor also has a set of coils (field) and a rotor or armature, however, since there is a continuous current reversal, a commutating device is not needed. Both types of electric motors are used in electric vehicles and have advantages and disadvantages, as shown here. While the AC motor is less expensive and lighter weight, the DC motor has a simpler controller, making the DC motor/controller combination less expensive. The main disadvantage of the AC motor is the cost of the electronics package needed to convert (invert) the battery‘s direct current to alternating current for the motor. Past generations of electric vehicles used the DC motor/controller system because they operate off the battery current without complex electronics. The DC motor/controller system is still used today on some electric vehicles to keep the cost down. However, with the advent of better and less expensive electronics, a large number of today's electric vehicles are using AC motor/controller systems because of their improved motor efficiency and lighter weight.

These AC motors resemble motors commonly used in home appliances and machine tools, and are relatively inexpensive and robust. These motors are very reliable, and since they have only one moving part, the shaft, they should last the life of the vehicle with little or no maintenance.

Electric Motor Comparison	
AC Motor	**DC Motor**
Single – speed transmission	Multi-speed transmission
Light weight	Heavier for same power
Less expensive	More expensive
95% efficiency at full load	85-95$ efficiency at full load
More expensive controller	Simple controller
Motor/Controller/Inverter more expensive	Motor/controller less expensive

Table 3.1 – Electric Motor Comparison

3.2 TYPES OF MOTORS USED IN ELECTRIC VEHICLES

- DC Series Motors
- Brushless DC Motors
- Permanent Magnet Synchronous Motors (PMSM)
- Three Phase AC Induction Motors
- Switched Reluctance Motors (SRM)

3.3 DC SERIES MOTORS

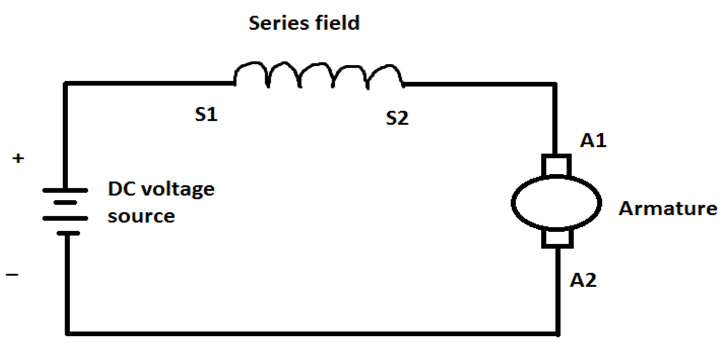


Fig 3.1 Schematic Diagram of DC Series Motor

DC Series Motors are powerful and efficient, making them a popular choice for electric vehicle propulsion. These motors can vary in size depending on the specific needs of the application, but they all operate by passing direct current (DC) electricity through coils to generate a magnetic field and create rotational motion. DC series motors have many advantages when it comes to electricity consumption; their efficiency increases as speed drops, allowing less energy consumption at lower speeds which is ideal for electric vehicles.

Additionally, they provide excellent speed control due to their simple design; this allows for precise torque output adjustment that the user can easily modify based on their needs. The cooling system of a DC series motor is also an important factor to consider in an electric vehicle context. Since these motors produce high amounts of heat during operation, proper ventilation must be provided to ensure that temperatures remain within safe operating levels. Additionally, fans or other cooling systems may need to be installed around the motor itself in order to maintain its performance over time.

This ensures that power delivery remains consistent even after extended periods of use without any decrease in efficiency or torque output.

3.4 BRUSHLESS DC MOTORS

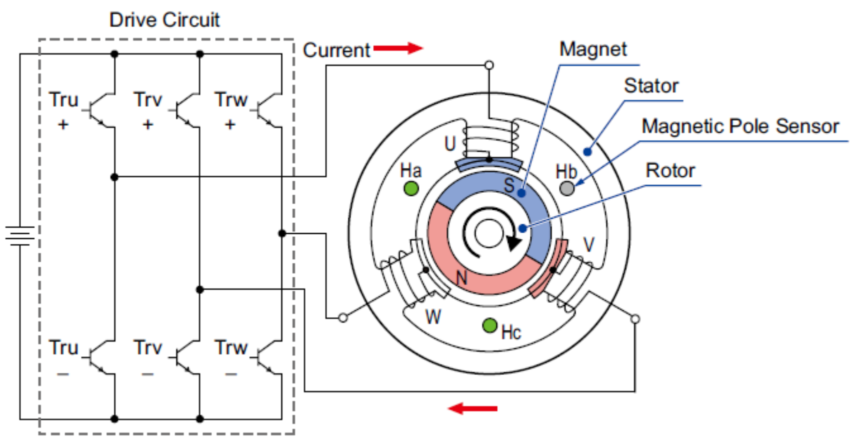


Fig 3.2 Circuit Diagram of Brushless DC Motor

As their name implies, these motors are brushless versions of the more traditional DC motor.

This type of motor is more suitable than its predecessor due to the automation benefits it provides. The lack of brushes allows for a simpler and smaller design which improves heat management and increases operational efficiency. Due to their efficient design, Brushless DC Motors provide a number of advantages over other types of motors in terms of cost considerations as well. They require fewer parts such as bearings since they don’t need any mechanical commutation; this helps reduce overall costs associated with manufacturing and maintenance.

Additionally, because the power circuit can be much simpler, they typically have lower energy losses resulting in higher energy savings compared to other motor designs. Finally, there’s no denying that Brushless DC Motors offer superior performance when compared to other motor types available today. With improved reliability and longer life expectancy due to reduced friction and wear from their brushless feature, combined with increased torque density capabilities thanks to an optimal winding configuration, you can be sure that your electric vehicle will run smoothly at all times. Moreover, these motors also provide quieter operation making them ideal for applications where noise levels must remain low.

3.5 PERMANENT MAGNET SYNCHRONOUS MOTORS (PMSM)

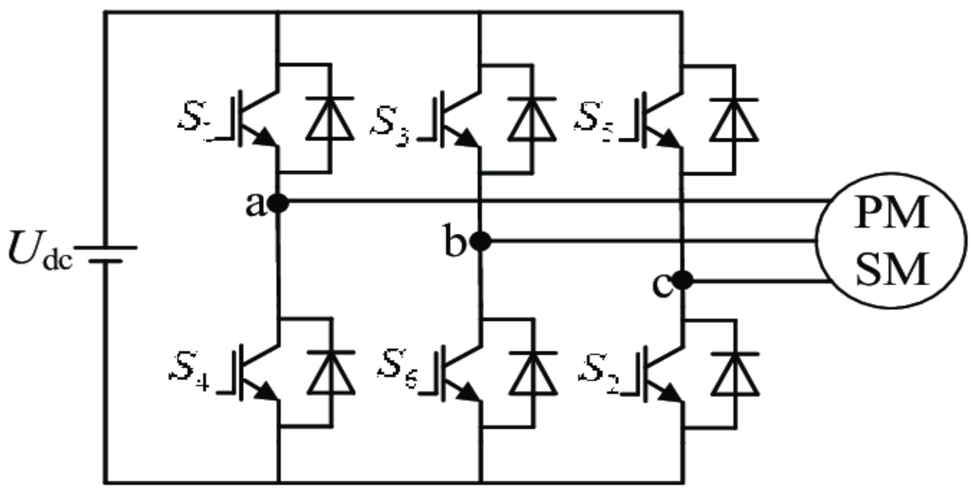


Fig 3.3 Circuit Diagram of permanent magnet synchronous motors (PMSM)

PMSMs have efficiency benefits over conventional induction motors due to their high power density obtained from magnetic flux between the stator and rotor. This means they require less current than comparable induction motors in order to achieve the same output of torque or speed. The rotor design also has advantages when it comes to torque control, as permanent magnet synchronous motors can easily be adjusted with variable frequency drives.

Another advantage of this type of motor is its flexibility in terms of configurations. A brushless DC motor consists of two main parts: a stator and a rotor. However, a PMSM can be configured into different types depending on how many poles are used in each part; single-phase or three-phase versions being the most common ones found in electric vehicles today. Additionally, there are several winding options available which allow users to customize their system according to specific requirements without compromising on performance or reliability.

3.6 THREE PHASE AC INDUCTION MOTORS

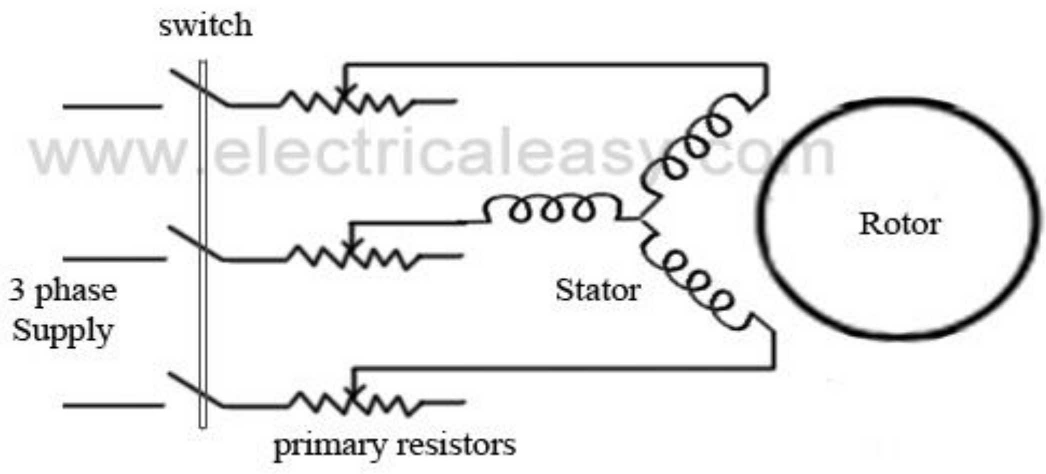


Fig 3.4 Circuit Diagram of Three Phase Ac Induction Motors

These motors feature higher torque control compared to other types of electric vehicle motors, making them ideal for applications requiring precise power output.

They also have excellent power efficiency, so they can be used in situations where energy conservation is important. In addition, these motors have a lower risk of overheating due to their cooling system design. The downside with the three phase AC induction motor is that it has limited speed variations capabilities; therefore, this type of motor may not be suitable for all applications. Additionally, there are certain regulatory compliance issues associated with using this type of motor as well which must be taken into consideration before investing in one.

Finally, these motors tend to be somewhat more expensive than other types available on the market today. Overall, though, the advantages of choosing a three phase AC induction motor make it an attractive option when selecting components for your electric vehicle. Its high level of torque control makes it great for precision jobs while its efficient use of energy saves money in the long run.

3.7 SWITCHED RELUCTANCE MOTORS (SRM)

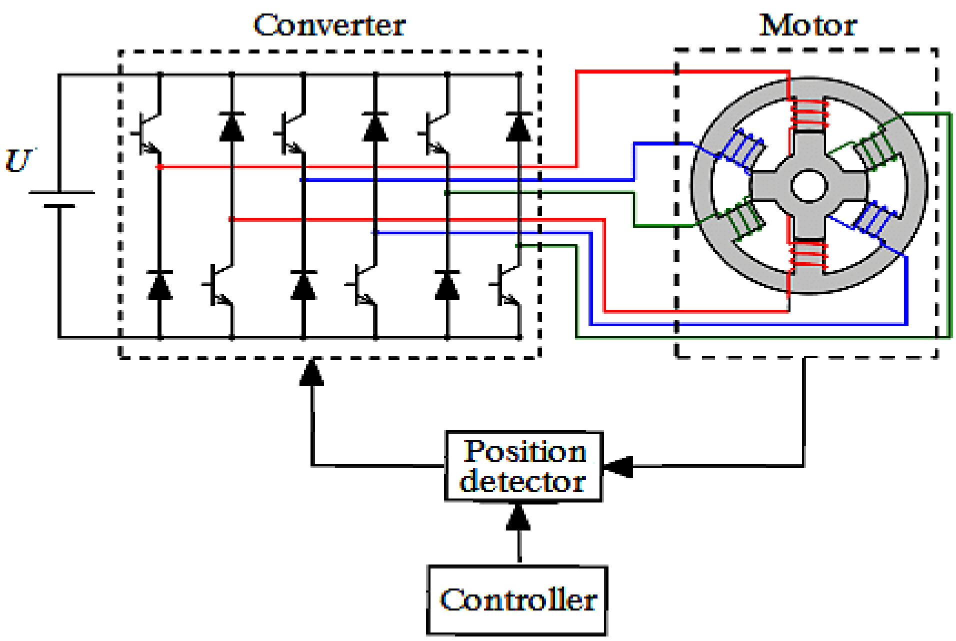


Fig 3.5 Circuit Diagram of Switched Reluctance Motors (SRM)

You may want to consider a Switched Reluctance Motor (SRM) for its powerful torque control and cost-effectiveness, especially in situations where precise power output is needed.

SRMs are constructed with an arrangement of electromagnets that produce magnetic fields when they're energized, which creates the mechanical force required to drive the rotor. The advantage of this design lies in its ability to vary the reluctance variation as it rotates, allowing for more accurate torque control and making operation easier compared to other types of motors. Additionally, SRMs are known for their excellent efficiency and low heat dissipation, further increasing their cost-efficiency.

Overall, SRMs offer an effective solution for electric vehicles who need precisely controlled torque or speed ratings at a lower cost point than most alternatives available today. Their simple yet robust design ensures easy operation while also providing superior performance qualities such as reduced levels of noise pollution and improved reliability over time.

With all things considered though, it's important for you to weigh your unique needs against potential drawbacks before deciding if an SRM should be used in your application.

CHAPTER – 4

HALL SENSORS

4.1 INTRODUCTION

A Hall Effect Sensor is a widely used sensor that provides rotor position feedback to a motor controller. Let’s understand the significance of this sensor in an automotive motor control system.

A BLDC motor control system is a complicated circuit where several components work in tandem to make the motor move in a desired manner. Efficiency, Durability and Performance are the attributes that concern the engineers the most while designing such a system.

While the magnets and coils take care of the electrical aspect, a microcontroller acts as the brain that drives the motor. But even the sharpest brain needs sensory inputs. The two sensory inputs that assume much importance here are Speed and Position. Let’s understand them in the context of motor commutation. This example will drive home the importance of a hall-effect sensor in an automotive motor controller application. The importance of Hall effect sensors in automotive motor control solutions can be observed in electric power steering (EPS) systems. In an EPS system, a small electric motor assists the driver in turning the steering wheel, making it easier to manoeuvre the vehicle at low speeds.

To ensure precise control of the electric motor, Hall effect sensors are used to detect the position of the steering wheel and the motor’s rotor. These sensors provide feedback to the motor controller, which adjusts the amount of power supplied to the motor based on the driver’s input and the position of the steering wheel. Without Hall effect sensors, the motor controller would not be able to accurately determine the position of the steering wheel or the rotor, which could lead to unstable or erratic.

4.2 MOTOR COMMUTATION

Commutation in a BLDC motor is a 6-step process. A 3-phase H-Bridge is used to create 6 flow vectors each causing a rotation of 60 Degrees (corresponding to the next position) of the motor, thus making a full rotation of 360 degrees. In order to move the motor, the motor controller sends current through the stator’s coil. This produces magnetic field which in turn develops the torque on the rotor (a permanent magnet). As a result, the rotor starts to move.

Now, if the rotor reaches near the magnetic field that is moving it, the rotor will tend to stop because of the changed polarity. At this instance, the magnetic field will begin to attract the rotor and stop the movement. To avoid it, the motor control system switches the current supplied to the stator and a new magnetic field is created and the rotor continues its movement. The process of commutation thus, is all about switching the current at the right instance.

The concept of speed and position comes into the picture as this 'right instance' needs to be sensed when it arrives. A sensor is required to give the feedback to the motor control system indicating when the rotor has reached the desired position. If the commutation is done faster or slower than the speed of the rotor, the magnets go out of sync with the magnetic field of the stator. This causes the rotor to vibrate and stop instead of rotating.

Post one commutation, the position of the rotor has to be determined with respect to the stator so that the next commutation can be initiated. And hence, the position detection is also a crucial parameter. There are many types of sensors used in the electric motor industry like Encoders, Switches and Potentiometer. However, the most widely used and deployed sensor is the Hall Effect Sensor.

4.3 WORKING OF HALL SENSOR IN BLDC MOTOR

Typically, a BLDC motor will have three Hall Effect Sensors fitted on the rotor or the stator. These Hall sensors are placed 120 degrees apart from each other, giving 0 to 360-degree angle position. When these hall sensors come in contact with the magnetic field of the rotor, it generates respective digital pulse in terms of 1 and 0, as shown in the diagram below.

In six steps, these hall sensors are able to give the motor position (Angle). In the diagram, the rectangular waveforms showcase the positive and the negative pulse generated at the corresponding angle by all three Hall Effect Sensors – A, B and C.

A corresponding graph also shows how one commutation is completed in 6 steps as the angle reached 360 degrees.

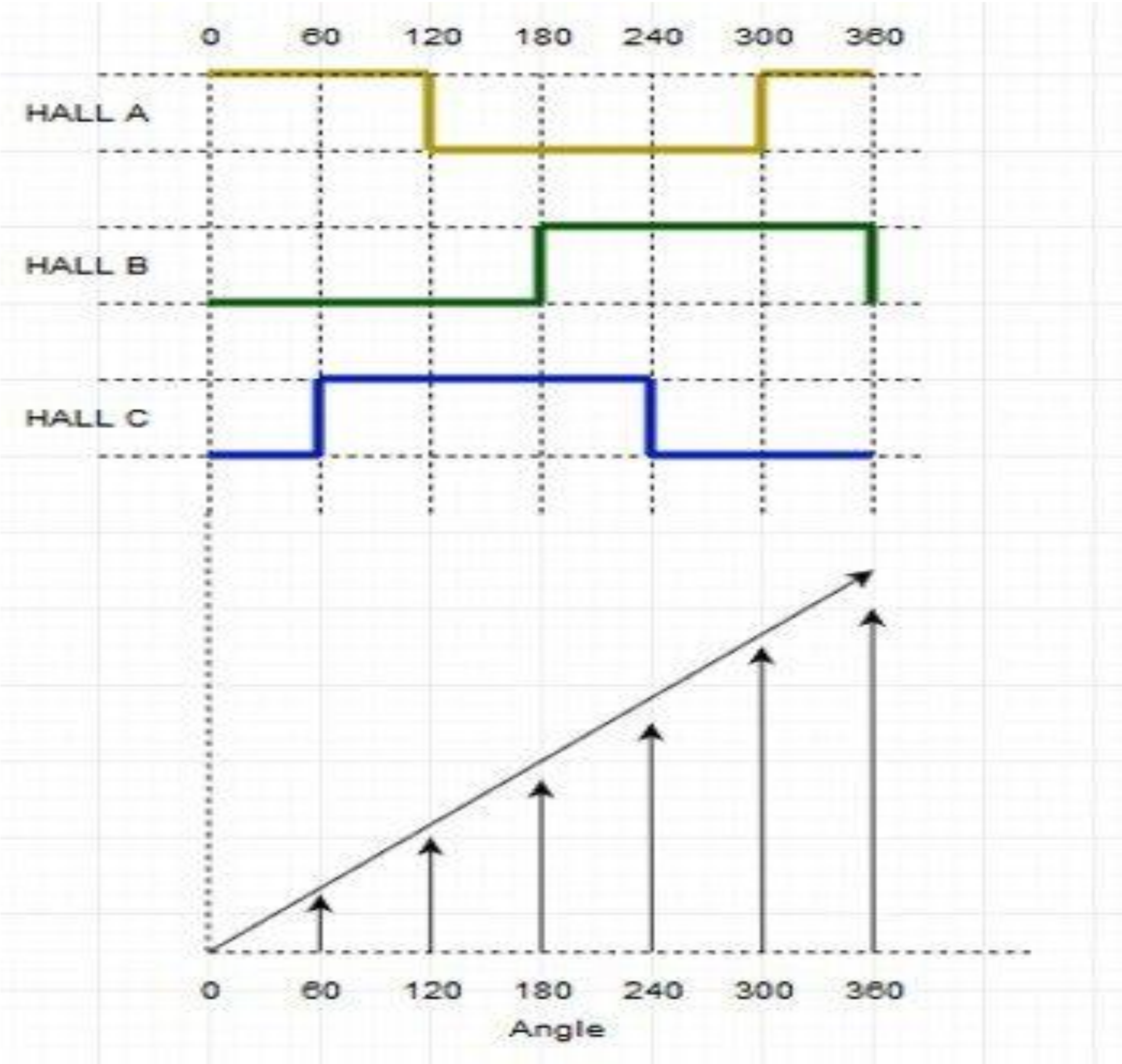


Fig 4.1 Hall Sensor Signals

When the rotor magnet crosses one of the sensors, it produces a low or high signal depending on whether it is the North pole or the South pole of the rotor that has passed. As the rotor crosses all three sensors, these sensors switch between low and high, thus giving out the position of the rotor every 60 degrees.

The diagram below shows a typical BLDC Motor Controller. Three lines going from the motor to the controller depict the signal sent by the three Hall Effect Sensors.

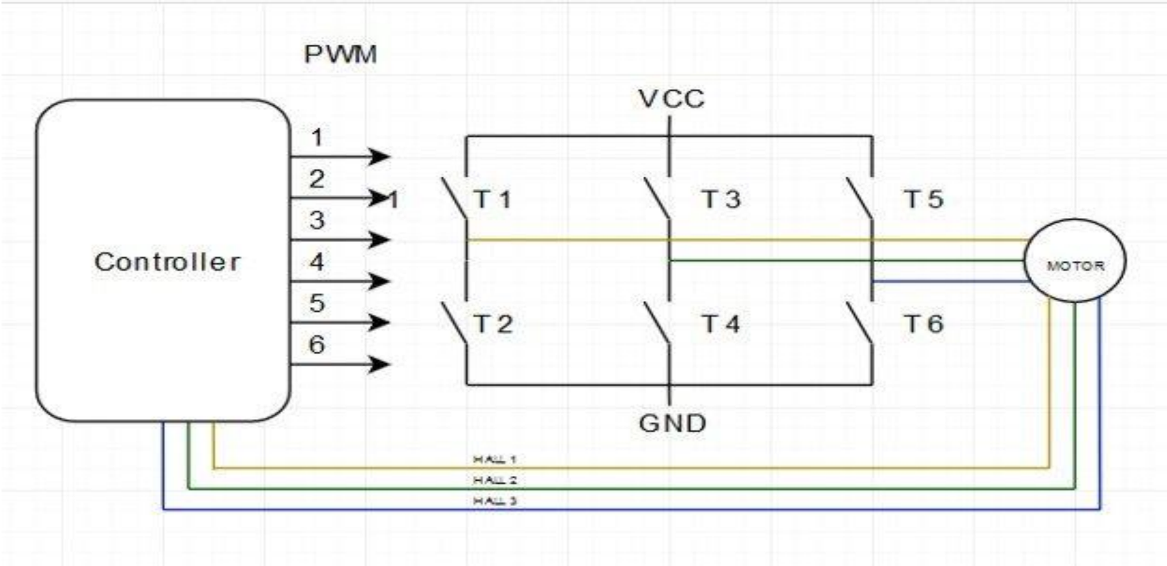


Fig 4.2 Hall-sensor-controlled BLDC motor drive system

The Hall-effect Sensor is able to distinguish between the positive and negative charge moving in opposite direction. The magnetic field detected by the hall-effect sensor is converted to the suitable analog or digital signal that can be read by the electronic system, usually a motor control system.

Shown below In the truth table derived from the readings of the three Hall Effect Sensors. As you can see, the transistor state of the H-Bridge depends on the signal detected by the sensor. The downward arrow shows the clockwise movement (CW) and the upward arrow shows counter clockwise movement (CCW).

HALL A	HALL B	HALL C	Transistor State	
1	0	0	T3	T2
1	0	1	T3	T6
0	0	1	T1	T6
0	1	1	T1	T4
0	1	0	T5	T4
1	1	0	T5	T2

Table 4.1 Truth Table of Hall Sensors

Now that we have the truth table and the graph, the angle (position) and the speed of the rotor can be easily calculated.

- **Angle Calculation:** It is calculated based on the Hall Effect Sensor signal as shown in **fig** According to the Hall sensor pulse, 0 – 360-degree angle is calculated.
- **Speed Calculation:** Speed calculation is done by calculating periods of the Hall Effect Sensor signal. With the help of period, frequency and speed are calculated as per the following formula. Frequency = 1 / Period.

Only one hall sensor is enough for calculating the speed.

4.4 IMPROVEMENT IN PERFORMANCE

The use of Hall effect sensors in electric vehicles allows for precise monitoring and control of the motor's speed and position, which in turn enables the vehicle to deliver efficient and reliable performance. For example, the sensor allows the vehicle to accurately control the motor's torque output, which is essential for maintaining the vehicle's stability and traction control.

The Hall effect sensor also has some role to play in regenerative braking, which is a key feature of electric vehicles. It allows them to recover energy during braking and store it in the battery for later use. This not only improves the vehicle's overall energy efficiency, but also extends the vehicle's range which is USP of any EV model.

In addition, the Hall effect sensor also plays a role in the safety of electric vehicles. By monitoring the position of the wheels and other components, the sensor can detect any potential issues or malfunctions in the system. The diver can be alerted in time and corrective action can be taken to prevent accidents or damage to the vehicle.

CHAPTER – 5

CLASSIFICATION OF CONTROLLERS

5.1 INTRODUCTION

In recent years, the control system has assumed an increasingly important role in the development and advancement of modern civilization and technology. Practically every aspect of our day-to-day activities is affected by some type of control systems. Automatic control systems are found in abundance in all sectors of industry, such as quality control of manufactured products, automatic assembly line, machine- tool control, space technology and weapon systems, computer control, transportation systems, power systems, robotics and many others. It is essential in such industrial operations as controlling pressure, temperature, humidity, and flow in the process industries.

Recent application of modern control theory includes such non-engineering systems as biological, biomedical, control of inventory, economic and socio-economic systems. The basic ingredients of a control system can be described by:

- Objectives of control.
- Control system components.
- Results or output.

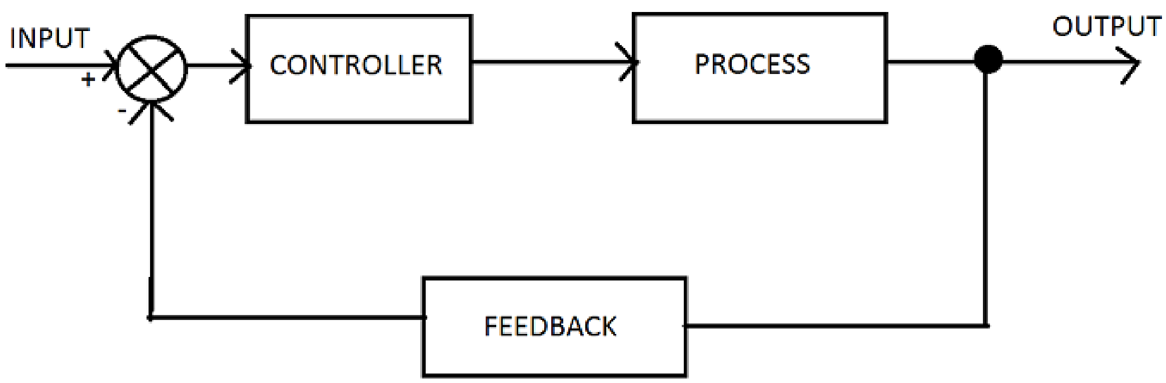


Fig 5.1 Block Diagram of Control System

An automatic controller is used to compare the actual value of plant result with reference command, determine the difference, and produce a control signal that will reduce this difference to a negligible value. The manner in which the automatic controller produces such a control signal is called the control action.

An industrial control system comprises an automatic controller, an actuator, a plant & a sensor (measuring element). The controller detects the actuating error command, which is usually at a very low power level, and amplifies it to a very high level. The output of the automatic controller is fed to an actuator such as a hydraulic motor, an electric motor or a pneumatic motor or valve (or any other sources of energy). The actuator is a power device that produces input to the plant according to the control signal so that the output signal will point to the reference input signal.

The sensor or the measuring element is a device that converts the output variable into another optimum variable, such as a displacement, pressure or voltage, that can be used to compare the output to the reference input command. This element is in a feedback path of the closed loop system. The set point controller must be converted to reference input with the same unit as the feedback signal from the sensor element.

5.2 CLASSIFICATION OF INDUSTRIAL CONTROLLERS

Industrial controllers may be classified according to their control action as:

- Two-position or on-off controllers
- Proportional controllers
- Integral controllers
- Proportional-plus- integral controllers
- Proportional-plus- derivative controllers
- Proportional-plus-integral-plus-derivative controllers

Type of controller to use must be decided depending upon the nature of the plant and the operating condition including such considerations as safety, cost, availability, reliability, accuracy, weight and size. Two-position or on-off controllers:

In a two-position control system, the actuating part has only two fixed positions, which are, in many simple cases, simply on and off. Due to its simplicity and inexpensiveness, it is being very widely used in both industrial and domestic control systems. Let the output signal from the controller be u(t) and the actuating error signal be e(t). Then mathematically,

$$u(t)= Ul, fore(t)>0$$

Where, zero or Ul and U2 are constants and the minimum value of U2 is usually either UI

5.3 PROPORTIONAL CONTROL

A proportional control system is a type of linear feedback control system. Proportional control is how most drivers control the speed of a car. If the car is at target speed and the speed increases slightly, the power is reduced slightly, or in proportion to the error (the actual versus target speed), so that the car reduces speed gradually and reaches the target point with very little, if any, "overshoot", so the result is much smoother control than on off control.

In the proportional control algorithm, the controller output is proportional to the error signal, which is the difference between the set point and the process variable. In other words, the output of a proportional controller is the multiplication product of the error signal and the proportional gain.

This can be mathematically expressed as Pout=Kp e(t)

Were,

Pout: Output of the proportional controller

Kp: Proportional gain

e(t): Instantaneous process error at time 't'. e(t) = SP-

PVSP: Set point

PV: Process variable

With increase in Kp:

- Response speed of the system increases.
- Overshoot of the closed-loop system increases.
- Steady-state error decreases.

But with high Kp value, the closed-loop system becomes unstable.

5.4 INTEGRAL CONTROL:

In a proportional control of a plant whose transfer function doesn't possess an integrator 1/s, there is a steady-state error, or offset, in the response to a step input. Such an offset can be eliminated if an integral controller is included in the system.

In the integral control of a plant, the control signal, the output signal from the controller, at any instant is the area under the actuating error signal curve up to that instant. But while removing the steady-state error, it may lead to oscillatory response of slowly decreasing amplitude or even increasing amplitude, both of which is usually undesirable.

5.5 PROPORTIONAL-PLUS-INTEGRAL CONTROLLERS

In control engineering, A PI Controller (proportional-integral controller) is a feedback controller which drives the plant to be controlled by a weighted sum of the error (difference between the output and desired set-point) and the integral of that value. It is a special case of the PID controller in which the derivative (D) part of the error is not used.

The PI controller is mathematically denoted as

$$G_c = K_p + \frac{Ki}{s} \text{ or}$$

$$G_c = K_p \left(1 + \frac{1}{sTi} \right)$$

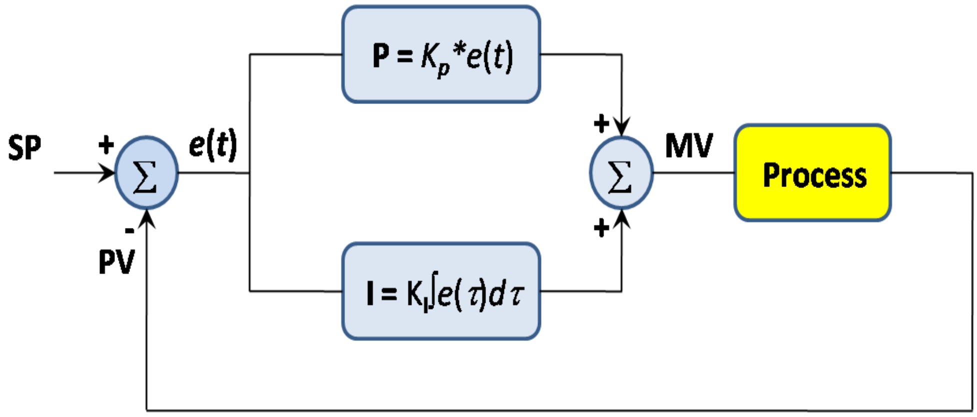


Fig 5.2 PI Controller

Integral control action added to the proportional controller converts the original system into high order. Hence the control system may become unstable for a large value of Kp since roots of the characteristic eqn. may have a positive real part. In this control, proportional control action tends to stabilize the system, while the integral control action tends to eliminate or reduce steady-state error in response to various inputs. As the value of Ti is increased,

- Overshoot tends to be smaller
- Speed of the response tends to be slower.

5.6 PROPORTIONAL-PLUS-DERIVATIVE CONTROLLERS

Proportional-Derivative or PD control combines proportional control and derivative control in parallel. Derivative action acts on the derivative or rate of change of the control error. This provides a fast response, as opposed to the integral action, but cannot accommodate constant errors (i.e., the derivative of a constant, nonzero error is0). Derivatives have a phase of +90 degrees leading to an anticipatory or predictive response. However, derivative control will produce large control signals in response to high frequency control errors such as setpoint changes (step command) and measurement noise. requires a

In order to use derivative, control the transfer functions must be proper. This often pole to be added to the controller.

$G_{pd}(s)=K_p+ K_d s$ or

$=K_p(1+T_d s)$

With the increase of Td

- Overshoot tends to be smaller
- Slower rise time but similar settling time.

5.7 PROPORTIONAL-PLUS-INTEGRAL-PLUS-DERIVATIVE CONTROLLERS

The PID controller was first placed on the market in 1939 and has remained the most widely used controller in process control until today. An investigation performed in 1989in Japan indicated that more than 90% of the controllers used in process industries are PID controllers and advanced versions of the PID controller. PI controllers are fairly common, since derivative action is sensitive to measurement noise "PID control" is the method of feedback control that uses the PID controller as the main tool. The basic structure of conventional feedback control systems is shown in Figure below, using a block diagram representation. In this figure, the process is the object to be controlled. The purpose of control is to make the process variable y follow the set-point value r. To achieve this purpose, the manipulated variable # is changed at the command of the controller. As an example of processes, consider a heating tank in which some liquid is heated to a desired temperature by burning fuel gas. The process variable y is the temperature of the liquid, and the manipulated variable u is the flow of the fuel gas. The "disturbance" is any factor, other than the manipulated variable, that influences the process variable. Figure below assumes that only one disturbance is added to the manipulated variable. In some applications, however, a major disturbance enters the process in a different way, or plural disturbances need to be considered. The error e is defined by er-y. The compensator C(s) is the computational rule that determines the manipulated variable u based on its input data, which is the error e in the case of Figure. The last thing to notice about the Figure is that the process variable y is assumed to be measured by the detector, which is not shown explicitly here, with sufficient accuracy instantaneously that the input to the controller can be regarded as being exactly equal to y.

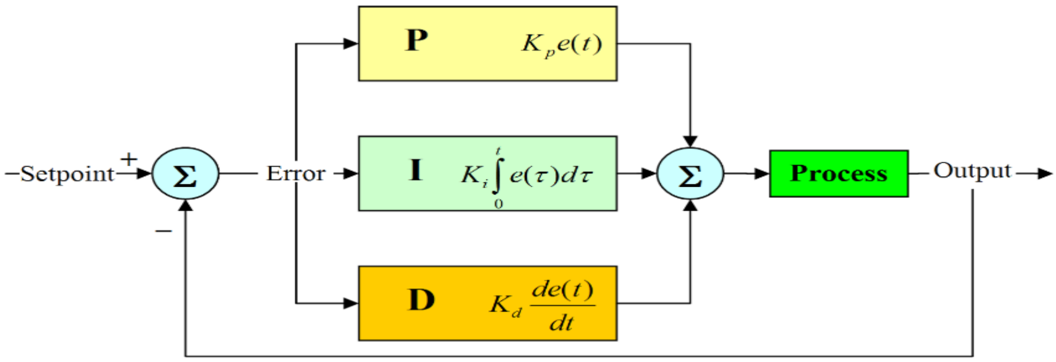


Fig 5.3 PID Controller

Most modern PID controllers in industry are implemented in programmable logic controllers (PLCs) or as a panel-mounted digital controller. Software implementations have the advantages that they are relatively cheap and are flexible with respect to the implementation of the PID algorithm.

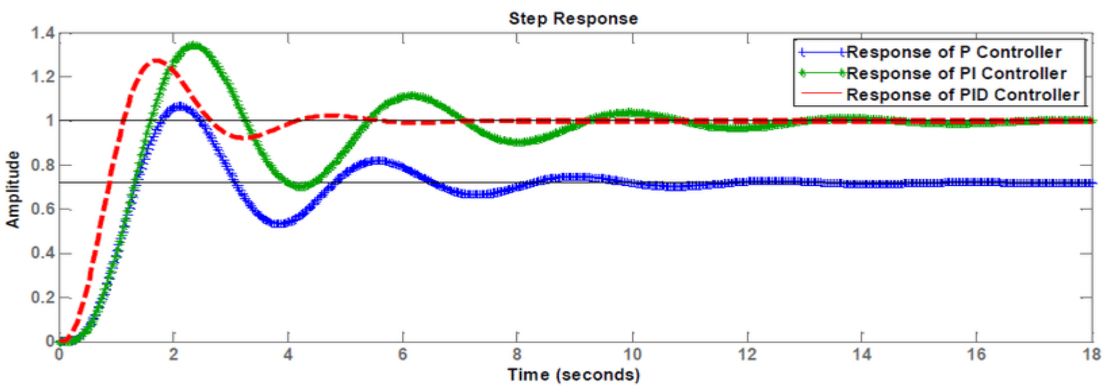


Fig 5.4 Closed Loop Step Response

A PID controller (Proportional, Integral and Differential) is used to control devices, such as Drives to maintain control of a varying system. This is in most cases done through the Examination of signals from sensors placed in the system, called feedback signals. When the feedback signal is received, it is compared with the desired value, or set point. Based on this comparison a calculation is made of what the necessary response is, in order to make the feedback signal match the set point. This calculation is performed by a P, a PI or a PID controller. The main difference between a P, a PI and a PID controller is the accuracy at which it is possible to control the feedback according to the set point. This introduction will cover the reach of propositional (P), the integral (I), and the derivative (D) controls, and how it is used to obtain a desired response. In this control we will be the feedback system. The system to be controlled provides the excitation for the plant. Designed to control the overall system behaviour.

5.8 PID CONTROLLERS

PID controllers are a family of controllers. PID controllers are sold in large quantities and are often the solution of choice when a controller is needed to close the loop. The reason PID controllers are so popular is that using PID gives the designer a larger number of options and those options mean that there are more possibilities for changing the dynamics of the system in a way that helps the designer. If the designer works it right, s/he can get the advantages of several effects. In particular, starting with a proportional controller, and adding integral and derivative terms to the control the designer can take advantage of the following effects.

- The proportional, integral and derivative outputs are added together.
- The PID controller can be thought of as having a transfer function.
- The PID controller transfer function can be obtained by adding the three terms.

$$PID(s) = Kp + Ki/s + s\,Kd$$

- The transfer function can be combined into a pole-zero form.

$$PID(s) = [s\,Kp + Ki + s^2Kd]/s$$

Since there is a quadratic in the numerator, there are two zeroes in this transfer function as well as the obvious pole at the origin, s = 0. Now, here's a good way to think about the effect of using a PID controller.

The PID controller transfer function really adds a pole at the origin, and two zeroes that can be anywhere in the s-plane that the designer wants, depending upon the designer's choice of the three gains.

$$PID(s) = [s\ Kp + Ki + s^2Kd]/s$$

5.9 PID CONTROLLER STRUCTURE

In this tutorial we assume the controller is used in a closed loop unity feedback system. The variable denotes the tracking error which is sent to the PID controller. The controller single u forms the controller to plant equal to the Proportional gain (KP) times the magnitude error gain Integral gain (KI) times the integral of the time pulse the Derivative gain (KD) times the derivative of the error.

5.10 PID PARAMETERS

We are most insured in four major characteristics of the closed loop step response • Rise time: the time it takes for the plant output y to rise beyond 90%of the desired Level for the first time.

- Overshoot: how much the peak level is higher than the steady state, normalized against the steady state.
- Settling time: the time it takes for the system to converge to its steady state.
- Steady state error: the difference between the steady state output and the desired output.

5.11 FUZZY LOGIC CONTROLLER

Fuzzy logic control (FLC) is the most active research area in the application of fuzzy set theory, fuzzy reasoning, and fuzzy logic. The application of FLC extends from industrial process control to biomedical instrumentation and securities. Compared to conventional control techniques, FLC has been best utilized in complex ill-defined problems, which can be controlled by an efficient human operator without knowledge of their underlying dynamics.

A control system is an arrangement of physical components designed to alter another physical system so that this system exhibits certain desired characteristics. There exist two types of control systems: open-loop and closed-loop control systems. In open-loop control systems, the input control action is independent of the physical system output. On the other hand, in a closed-loop control system, the input control action depends on the physical system output. Closed-Hoop control systems are also known as feedback control systems. The first step toward controlling any physical variable is to measure it. A sensor measures the controlled signal, A plant is a physical system under control. In a closed-loop control system, forcing signals of the system inputs are determined by the output responses of the system. The basic control problem is given as follows:

The output of the physical system under control is adjusted by the help of an error signal. The difference between the actual response (calculated) of the płant and the desired response gives the error signal. For obtaining satisfactory responses and characteristics for the closed-loop control system, an additional system, called as compensator or controller, can be added to the loop. The basic block diagram of the closed-loop control system is shown in Figure 1. The fuzzy control rules are basically IE-THEN rules.

5.12 ARCHITECTURE AND OPERATIONS OF FLC SYSTEM

The basic architecture of a fuzzy logic controller is shown in Figure 2. The principal components of an FLC system is a fuzzifier, a fuzzy rule base, a fuzzy knowledge base, an inference engine, and a defuzzifier. It also includes parameters for normalization. When the output from the defuzzifier is not a control action for a plant, then the system is a fuzzy logic decision system. The fuzzifier present converts crisp quantities into fuzzy quantities. The fuzzy rule base stores knowledge about the operation of the process of domain expertise. The fuzzy knowledge base stores the knowledge about all the input-output fuzzy relationships. It includes the membership functions defining the input variables to the fuzzy rule base and the out variables to the plant under control. The inference engine is the kernel of an FLC system, and it possesses the capability to simulate human decisions by performing approximate reasoning to achieve the desired control strategy. The defuzzifier converts the fuzzy quantities into crisp quantities from an inferred fuzzy control action by the inference engine.

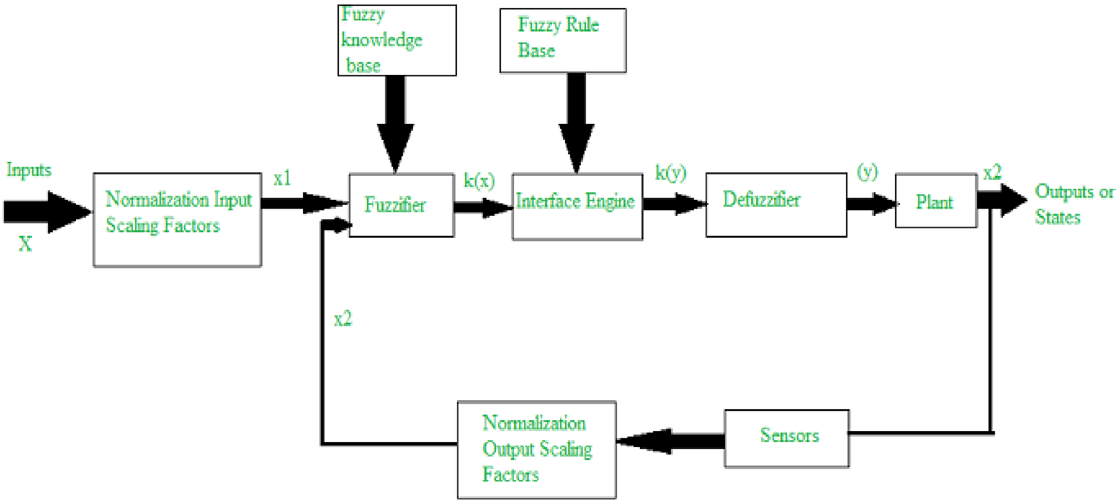


Fig 5.5 Basic Architecture of FLC System

In designing a fuzzy logic controller, the process of forming fuzzy rules plays a vital role. There are four structures of the fuzzy production rule system (Weiss and Donnel, 1979) which are as follows:

i. A set of rules that represents the policies and heuristic strategies of the expert decision-maker.
ii. A set of input data that are assessed immediately prior to the actual decision.
iii. A method for evaluating any proposed action in terms of its conformity to the expressed rules when there is available data.
iv. A method for generating promising actions and determining when to stop searching for better ones.

The various steps involved in designing a fuzzy logic controller are as follows:

Step 1: Locate the input, output, and state variables of the plane under consideration.

Step 2: Split the complete universe of discourse spanned by each variable into a number of fuzzy subsets, assigning each with a linguistic label. The subsets include all the elements in the universe.

Step 3: Obtain the membership function for each fuzzy subset.

Step 4: Assign the fuzzy relationships between the inputs or states of fuzzy subsets on one side and the output of fuzzy subsets on the other side, thereby forming the rule base.

Step 5: Choose appropriate scaling factors for the input and output variables for normalizing the variables between [0, 1] and [-1, 1] interval.

Step 6: Carry out the fuzzification process.

Step 7: Identify the output contributed from each rule using fuzzy approximate reasoning.

Step 8: Combine the fuzzy outputs obtained from each rule.

Step 9: Finally, apply defuzzification to form a crisp output.

The above steps are performed and executed for a simple FLC system. The following design elements are adopted for designing a general FLC system:

1. Fuzzification strategies and the interpretation of a fuzzifier.

2. Fuzzy knowledge base: Normalization of the parameters involved; partitioning of input and output spaces; selection of membership functions of a primary fuzzy set.

3. Fuzzy rule base: Selection of input and output variables; the source from which fuzzy control rules are to be derived; types of fuzzy control rules; completeness of fuzzy control rules.

4. Decision· making logic: The proper definition of fuzzy implication; interpretation of connective “and”; interpretation of connective “or”; inference engine.

5. Defuzzification materials and the interpretation of a defuzzifier.

CHAPTER – 6

ADAPTIVE PID CONTROLLER

6.1 INTRODUCTION

An adaptive PID controller is a variation of the PID controller that can automatically adjust its parameters in response to changes in the system being controlled. The controller's parameters are online tuned when the motor is running using a Recursive Least Squares (RLS) method. The adaptive PID controller adopts an online parameter adjustment method according to the state of the system, which gives it better system adaptability.

6.2 PID CONTROLLER

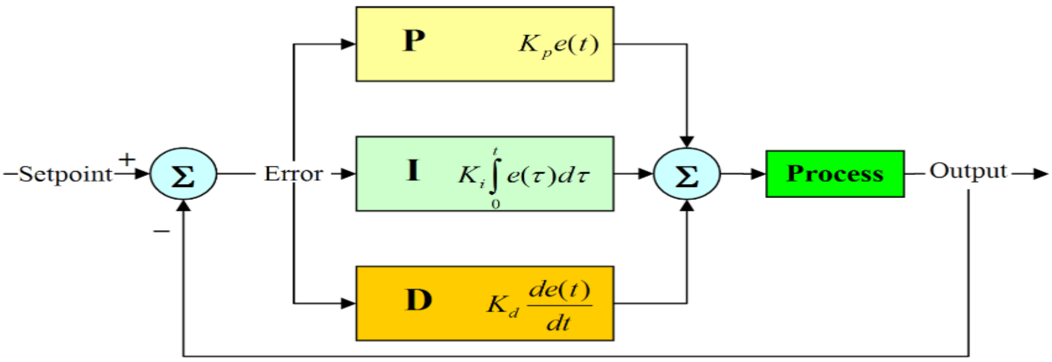


Fig 6.1 PID Controller

A PID (Proportional – Integral – Derivative) controller is an instrument used by control engineers to regulate temperature, flow, pressure, speed, and other process variables in industrial control systems. PID controllers use a control loop feedback mechanism to control process variables and are the most accurate and stable controller.

PID control is a well-established way of driving a system towards a target position or control parameters. It's practically ubiquitous as a means of controlling temperature and finds application in a myriad of chemical and scientific processes as well as automation. PID control keeps the actual output from a process as close to the target or setpoint output as possible.

	Rise Time	Overshoot	Settling time	Steady state error	oscillation
Kp	Decrease	Increase	NT	Decrease	increase
KI	Decrease	Increase	Increase	Eliminate	increase
KD	NT	Decrease	Decrease	NT	de/increase

Table 6.1 - Characteristics of PID Parameters in various Responses

6.3 PID - TUNING METHODS

- ZN (Ziegler Nicholes) reaction curve method
- ZN step response method
- ZN Frequency response method
- ZN self-oscillation method
- Matlab/Simulink

6.4 ADAPTIVE PID CONTROLLER – GAIN CONTOLLING STRUCTURE

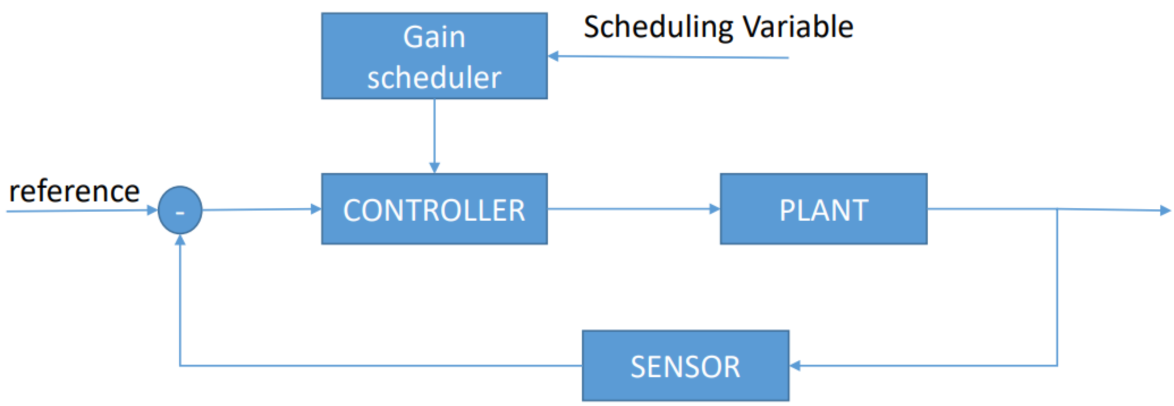


Fig 6.2 APID Controller with Gain Scheduling

Basic PID Controller Structure: Start with a standard PID controller structure. The PID controller calculates an output (control signal) based on the error between the desired setpoint and the actual process variable.

The basic PID control equation is: $PID(s) = Kp + Ki/s + s\, Kd$

are the proportional, integral, and derivative gains, respectively.

Gain-Scheduling: Incorporate gain-scheduling into the PID controller. This involves adjusting the PID gains based on the current operating conditions or parameters of the system. The parameters that may influence the gains can include process variables like temperature, pressure, velocity, etc., or any other relevant parameters.

Parameter Adaptation Algorithm: Implement an algorithm to adaptively adjust the PID gains based on the current operating conditions. This could be done using techniques like:

Online Parameter Estimation: Estimate the optimal PID gains continuously based on real-time data from the system. Techniques like recursive least squares (RLS) or Kalman filters can be employed for this purpose.

Model-Based Adaptation: Use a mathematical model of the system to predict the optimal gains for different operating conditions. Adjust the gains based on the deviation between the predicted and actual system behaviour.

Gain Scheduling Mechanism: Define rules or algorithms that determine how the PID gains should be adjusted as the operating conditions change. This could involve using lookup tables, interpolation techniques, or mathematical models to map the system parameters to appropriate PID gains.

Feedback Mechanism: Include a feedback mechanism to evaluate the performance of the controller and adjust the gains accordingly. This could involve analysing the response of the system to control inputs and tuning the gains to optimize performance metrics such as rise time, settling time, overshoot, etc.

Implementation Considerations: Consider the computational complexity and real-time constraints when implementing the adaptive PID controller. Ensure that the adaptation algorithm can run efficiently and provide timely updates to the PID gains without causing instability or excessive control oscillations.

Overall, the adaptive PID controller with gain-scheduling capabilities provides a flexible and robust control solution that can adapt to changes in the system dynamics and operating conditions, leading to improved performance and stability across a wide range of operating scenarios.

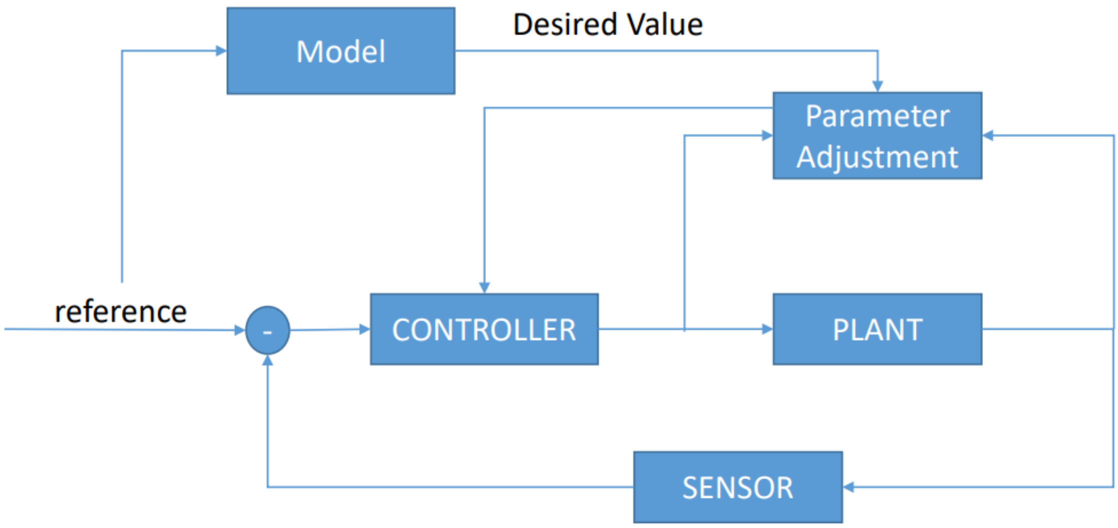


Fig 6.3 Block Diagram of APID Controller

6.5 COMPARSION OF CONVENTIONAL & ADAPTIVE PID CONTROLLERS

Conventional PID Control	Adaptive PID Control
Analytical approach	Learning based approach
Good for linear systems	Suitable for non-linear systems
Sensitve to the change of plant system	Doesn't need to know the detail of the plant system
Fast calculation just in time	Slow in learning phase

Table 6.2 - Comparison of PID vs APID

CHAPTER – 7

MATLAB

7.1 INTRODUCTION

If you are new to MATLAB, you should start by reading Manipulating Matrices. The most important things to learn are how to enter matrices, how to use the (colon) operator, and how to invoke functions. After you master the basics, you should read the rest of the sections below and run the demos.

At the heart of MATLAB is a new language you must learn before you can fully exploit its power. You can learn the basics of MATLAB quickly, and mastery comes shortly after. You will be rewarded with high productivity, high-creativity computing power that will change the way you work.

7.2 TYPICAL USES INCLUDE

i. Math and computation
ii. Algorithm development
iii. Modelling, simulation, and prototyping
iv. Data analysis, exploration, and visualization
v. Scientific and engineering graphics
vi. Application development, including graphical user interface building

7.3 MATLAB SYSTEM

The MATLAB system consists of five main parts:

7.3.1 DEVELOPMENT ENVIRONMENT

This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, and browsers for viewing help, the workspace, files, and the search path.

7.3.2 THE MATLAB MATHEMATICAL FUNCTION LIBRARY

This is a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

7.3.3 THE MATLAB LANGUAGE

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create complete large and complex application programs.

7.3.4 HANDLE GRAPHICS

This is the MATLAB graphics system. It includes high-level commands for two-dimensional and three-dimensional data visualization, image processing. animation, and presentation graphics. It also includes low-level commands that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

7.3.5 THE MATLAB APPLICATION PROGRAM INTERFACE (API)

This is a library that allows you to write C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

7.4 DEVELOPMENT ENVIRONMENT

This chapter provides a brief introduction to starting and quitting MATLAB, and the tools and functions that help you to work with MATLAB variables and files. For more information about the topics covered here, see the corresponding topics under Development Environment in the MATLAB documentation, which is available online as well as in print.

CHAPTER – 8

SIMULATION & RESULTS

8.1 SIMULATION OF SPEED CONTROL OF ELECTRIC VEHICLES USING ADAPTIVE PID CONTROLLER

The Speed control of electric vehicles analysis is simulated in the MATLAB environment when applied to the various speed references using Adaptive PID Controller.

8.2 APID CONTROLLER

An adaptive PID controller is a variation of the PID controller that can automatically adjust its parameters in response to changes in the system being controlled. The controller's parameters are online tuned when the motor is running using a Recursive Least Squares (RLS) method. The adaptive PID controller adopts an online parameter adjustment method according to the state of the system, which gives it better system adaptability.

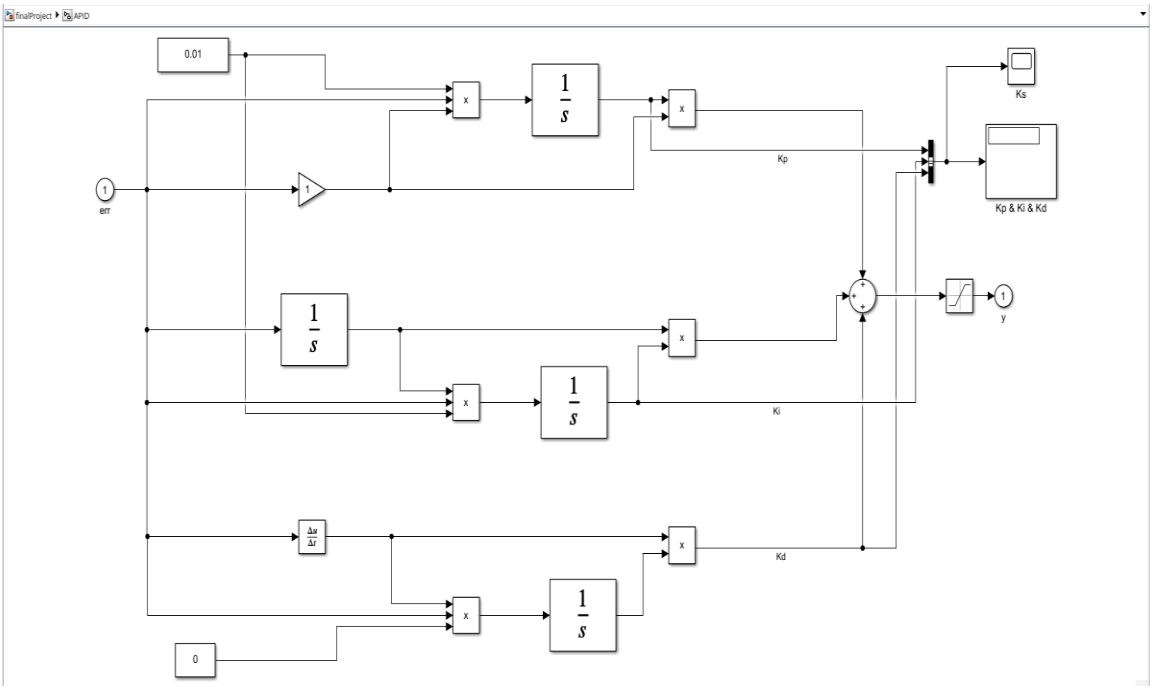


Fig 8.1 APID Block

8.3 BLDC MOTOR

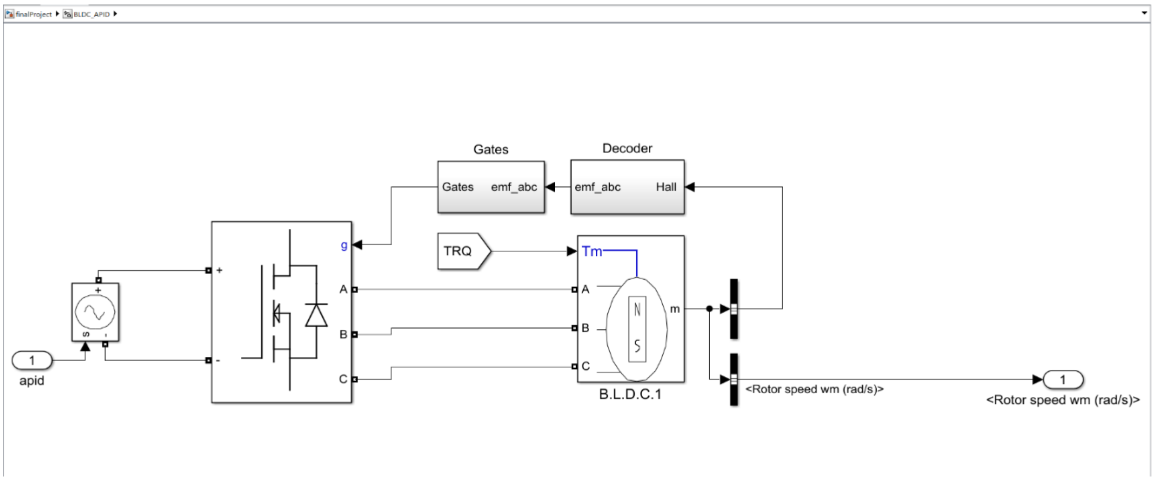


Fig 8.2 BLDC Motor Block

This type of motor is more suitable than its predecessor due to the automation benefits it provides. The lack of brushes allows for a simpler and smaller design which improves heat management and increases operational efficiency. Due to their efficient design, Brushless DC Motors provide a number of advantages over other types of motors in terms of cost considerations as well. They require fewer parts such as bearings since they don't need any mechanical commutation; this helps reduce overall costs associated with manufacturing and maintenance.

8.4 FILTER

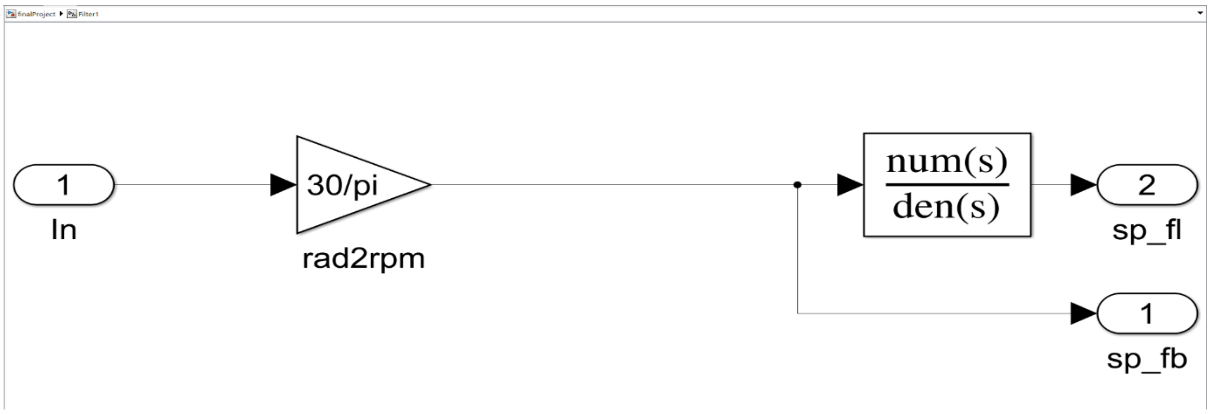


Fig 8.3 Filter Block

Fig. 8.3 shows the conversion of radians per second to rotation per minute. A nifty formula works to convert angular velocity from radians per second (rad/s) to revolutions per minute (RPM): RPM = (rad/s) * (60/2π).

A conversion factor in this equation (60/2π) is the transition between seconds and minutes, as well as deftly handling the conversion between radians and revolutions. Basically, the frequency in RPM can be obtained by multiplying the angular frequency in radians per second by 2π and then dividing by 60.

8.5 HALL SENSORS

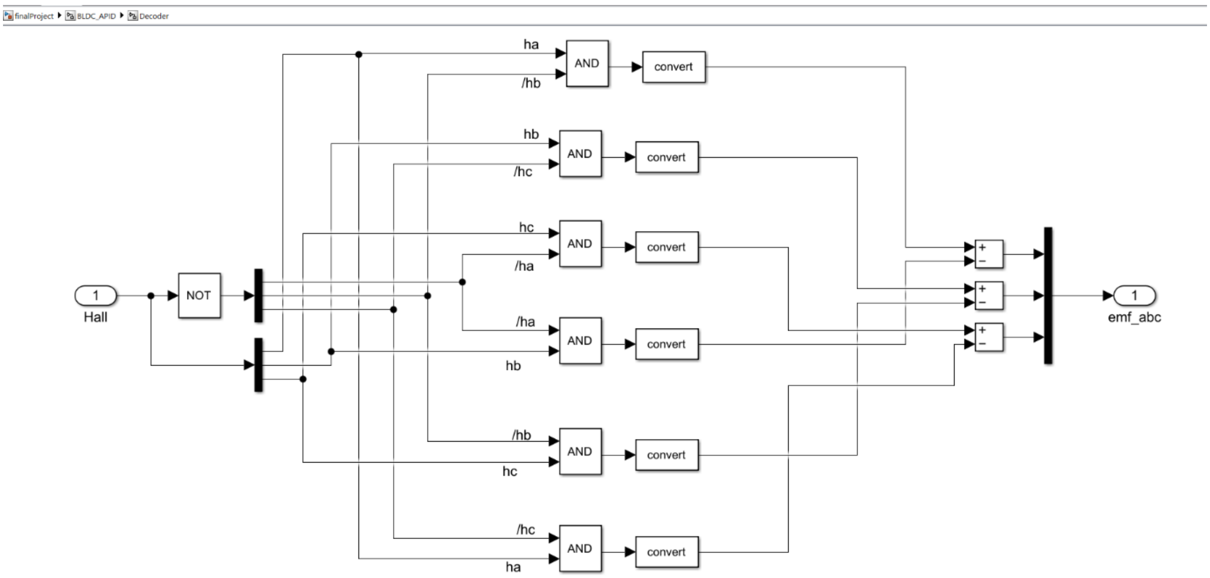


Fig 8.4 Hall Sensors Block

To ensure precise control of the electric motor, Hall effect sensors are used to detect the position of the steering wheel and the motor's rotor. These sensors provide feedback to the motor controller, which adjusts the amount of power supplied to the motor based on the driver's input and the position of the steering wheel. Without Hall effect sensors, the motor controller would not be able to accurately determine the position of the steering wheel or the rotor, which could lead to unstable or erratic.

8.6 RESULTS

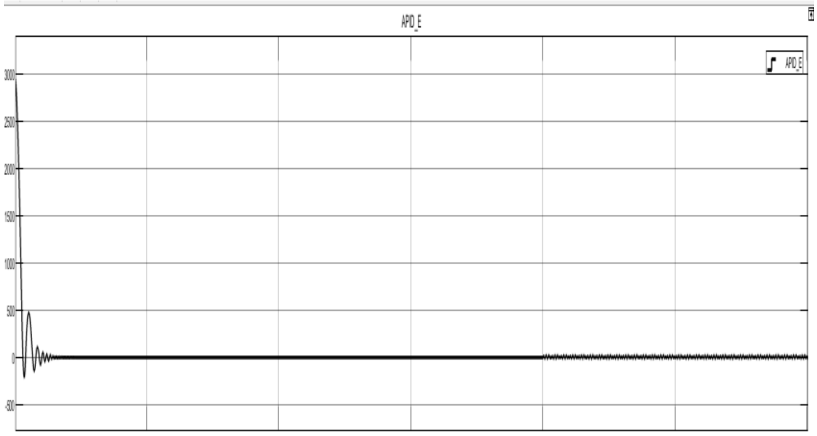


Fig 8.5 APID_E

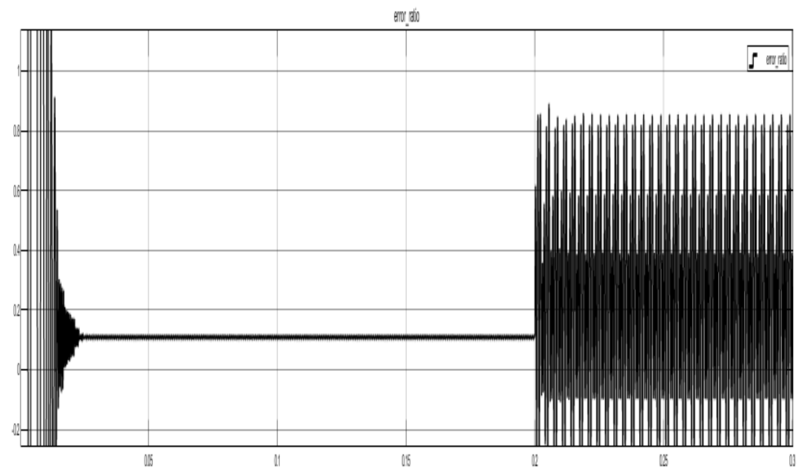


Fig – 8.6 Error Ratio

Figure 8.6 shows PID Controller Performance on the benchmark platform and same requirements. Figure 8.5 shows the simulated waveform of the controller. Where, in no load condition, the controller gave overshoot and never touch the required signal, that might be possible, the researcher always checked the performance with load. From the performance, it can say that, the controller can be used for higher load and fast response where precision performance is not mandatory.

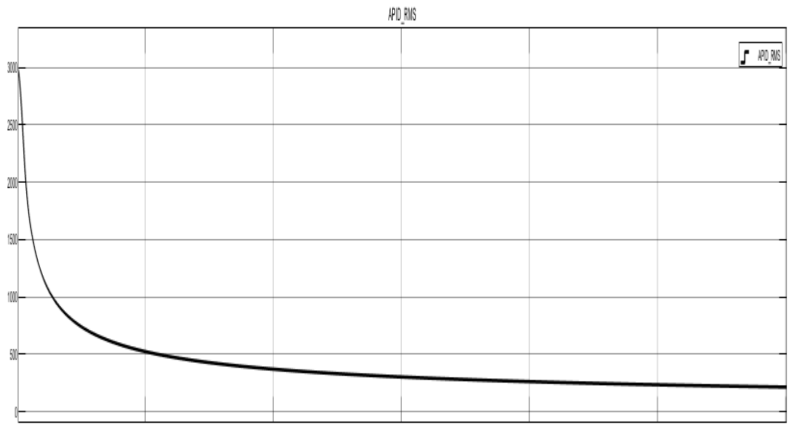


Fig – 8.7 APID_RMS

Figure 8.7 filter is used, when used in a BLDC motor control system, can help reduce these oscillations. It does this by smoothing out the current waveform, thereby reducing the electrical noise. This results in a more stable and accurate motor operation.

This means the motor can react more quickly to changes in load or speed requirements, which is particularly beneficial in applications where rapid motor response is critical. can enhance the motor’s performance by reducing oscillations and errors, and improving response time. This leads to a more efficient and reliable motor operation.

By using the filter for the BLDC motor it reduces the oscillations and error in the output and it results the faster response. by reducing the error in the output, the motor’s response time can be improved.

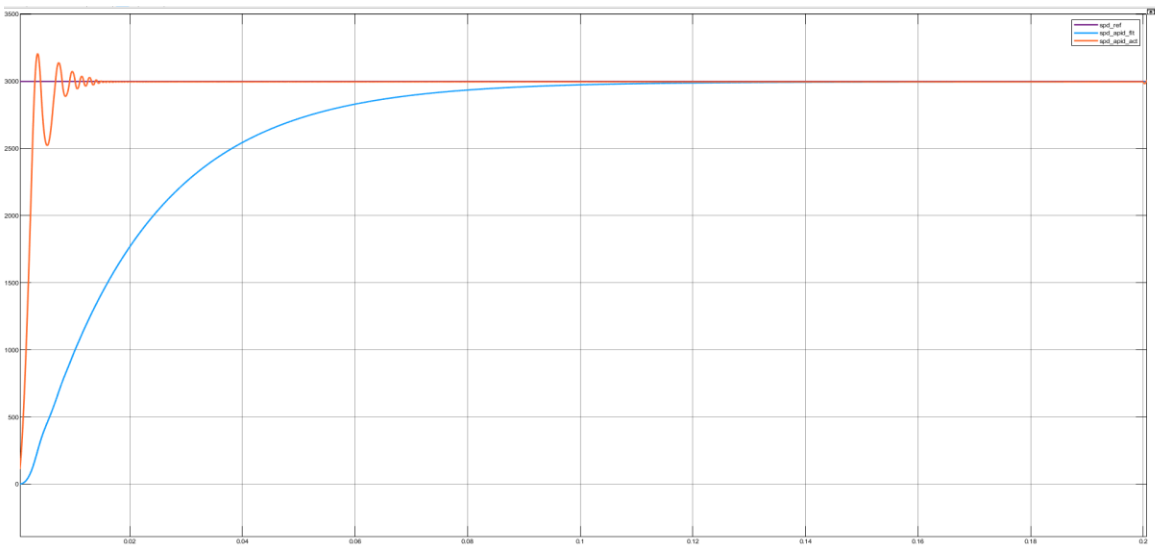


Fig 8.8 The output of the Adaptive PID controller

Measurements	Value
Rising time (No load/ with load)	36.386 ms / 51.542 ms
Max / Min high	1003 rpm / 998.939 rpm (-2.061)
With load maximum high	999.3 rpm
Overshoot	0.452%
With load overshoot	0.499%
With load undershoot	1.963%

TABLE 8.1 - SIMULATED MEASUREMENTS FOR 1000RPM

Figure 8.8 shows the adaptive PID controller output. This output with torque load Te 10 N-m and its supply voltage is 48 DC volt. The output of the controller had an overshoot of 0.497% and undershoot is 1.963% (48V/unit), settling time 0.35 seconds (0.1seconds/unit) and had no steady-state error. The performance indicates that the adaptive PID controller has very good controllability than the existing other controller but needs little improvement. So, the results of the proposed adaptive PID controller simulation model for the BLDC motor speed control. Here the simulation results are shown in figure and the particulars are shown in table 8.1.

CHAPTER – 9

CONCLUSION & FUTURE SCOPE

9.1 CONCLUSION

In the pursuit of improving electric vehicle (EV) performance and efficiency, the implementation of advanced control strategies plays a pivotal role. Among these strategies, the Adaptive Proportional-Integral-Derivative (PID) controller stands out as a promising approach for achieving precise speed control while accommodating varying operational conditions and system dynamics inherent in EVs. Through the integration of adaptive techniques into the conventional PID framework, this project aims to elevate the speed control capabilities of electric vehicles, ensuring optimal performance across diverse driving scenarios.

In conclusion, the project on speed control of electric vehicles using an adaptive PID controller represents a significant advancement in the field of electric vehicle control systems. By harnessing the synergies between adaptive control techniques and the PID framework, this project offers a comprehensive solution for addressing the challenges of speed control in electric vehicles while unlocking new opportunities for performance optimization, energy efficiency, and sustainability. As electric vehicles continue to gain traction as a viable alternative to conventional vehicles, the adoption of adaptive PID controllers holds immense promise for shaping the future of transportation towards a cleaner, smarter, and more sustainable paradigm.

9.2 FUTURE SCOPE

This Project Future scope may include,

- Incorporating machine learning algorithms, such as reinforcement learning or neural networks, into the adaptive PID controller can further enhance its adaptability and performance.
- Extending the adaptive PID controller to handle multiple control objectives simultaneously, such as maximizing energy efficiency, minimizing response time, and ensuring passenger comfort, would be an intriguing avenue for future research.
- Adapting the adaptive PID controller for use in autonomous vehicles presents unique challenges and opportunities. Future research could focus on developing adaptive control strategies tailored specifically for autonomous driving applications, addressing issues such as path following, obstacle avoidance, and decision-making under uncertainty.

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