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OVERLOAD PROTECTION USING ARTIFICAL INTELLIGENCE FOR DC MOTORS

1Mr.D.S.Veeranna, 2BASAM SAJAN, 3KASARVENI PRANEETH, 4NUKALA MAITHRI, 5RAPOLU SUPRAJA

1scholar, 2Assistant Professor

1scholar,

2DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING J.B.INSTITUTE OF ENGINEERING AND TECHNOLOGY (UGC AUTONOMOUS)

ABSTRACT

This paper describes the design and implementation of overload protection for DC motor speed control application based on Artificial Intelligence (AI). A replica of DC motor hardware was modeled for simulation. Two neural network models were designed under no load and rated torque conditions to predict the output voltage to be applied for the given DC motor to achieve desired setpoint speed. From the output of a Proportional Integral (PI) controller the Neural network model will predict the voltage to be applied and a comparator will determine whether the voltage that has to be applied for the current load exceeds than that for the rated torque of the DC motor. The outcome from the comparison is the safety for the equipment by not exceeding rated current value and thereby reduce the thermal degradation of motor windings. A PI controller with delimiter can limit the output of the PI controller and thereby protect the motor windings from higher voltages, still, the windings get degraded when the motor run under overload conditions with lower setpoint speed for longer period. Simulation and real-time experiments along with the results are presented to demonstrate the reliability of the proposed control method over the traditional PI controller in DC motor speed control applications.

CHAPTER-1

1.1 INTRODUCTION

DC motors are used in various control applications including valve actuators, drives for centrifugal pumps, belt driven applications and disk drives because of the features such as high torque, adaptability to various types of control methods and better speed control performance over a wide range resulting in a high level of flexibility for solving complex drive problems. Even though there are several factors that contribute to damage to motor windings such as mechanical damage and high temperature, the prime factor which all the various factors lead to, is the thermal degradation of insulation. The lifespan of insulation is reduced to half for each 10°C increase in winding temperature .The research on the application of Artificial Intelligence (AI) in the field of control system engineering has enjoyed much attention over the past few decades and the credits for this goes to the advancement in computing capability and deep learning algorithms. The power of AI in areas such as auto-tuning of Proportional-IntegralDerivative (PID) controller parameters , wind energy drainage system monitoring and control provides a strong evidence for the rapid growth and promising future for intelligent control. In this paper, the feasibility of using a combination of AI and PI controller for DC motor speed control and overload monitoring is studied and the controller performance is compared with the classical PI controller in real time

1.2 BACK GROUND

The two essential facts that dictate the speed control for a DC motor are as follows. When the speed of the rotor is regulated, the armature current is determined by the load torque while the rotor speed is determined by load torque under armature current regulation. The relationship between load torque and rotor speed is inversely proportional and the rotor speed reaches zero at stall torque. The rotor speed reaches its maximum value and consumes less current at no load torque condition. On the other hand, at rated torque value, the speed of the rotor decreases and more current flows through the armature coil. The increase in load or moment of inertia will cause the high motor currents followed by thermal degradation of the motor windings from I 2R (I-Current, R-Resistance) heating. The change in load will vary depending on applications. For example, in motor operated valves, if the valve is not operated for a certain period the valve torque increases due to the deposit of particles in between the valve seating area which in turn increases the moment of inertia of the rotor. Various devices and circuits are used along with the motor control circuitry to monitor fault conditions. Such devices include ground fault relays, transient voltage protectors, harmonic filters and thermal overload relays. The thermal overload relays function as overload protector for electric motors and are widely used in the industry . The question arises with these techniques is that what happens to the motor winding when the hardware fails. To vanquish the above problems, we have introduced the overload protection technique at software level using the AI. A PID controller is a closed loop control mechanism consisting three basic coefficients which are varied to achieve optimal response for a control system and is commonly used in process industries. The purpose of this research is to study how to eliminate the overvoltage signal from the controller without affecting the controller performance under high load condition for a DC motor speed control application. Another serious issue for using a conventional PID controller is that the change in nominal inertia affects the motion control system stability . Even though various tuning methods are existing for the PID controllers, the proper tuning of controllers is still a serious issue for many control applications. A comparison study on the performance of Artificial Neural Networks (ANN) and fuzzy logic control techniques over conventional control techniques for DC motor speed control was conducted by Mo-yuven Chow and Alberico Menozzi. The study states the classical PI controller is more constrained and less flexible compared to that of a fuzzy logic controller.

1.3.LITERATURE REVIEW IN "ZHIGUANG HUA, DONGDONG ZHAO, MANFENG DOU, LIMING YAN, HAITAO ZHANG, "MODELING AND CONTROL OF BRUSHLESS DC MOTOR FOR COMPRESSOR DRIVING", IN *IEEE ENERGY CONVERSION CONGRESS AND EXPOSITION (ECCE)*, 2017, P. 5553-5556." With the advantages of small size, light weight and more compact construction, brushless DC motor (BLDCM) has been widely applied to the field of industry. Centrifugal compressor converts the kinetic energy of the air into pressure, and it can be used to provide air to the full cell. The drive and control strategy of BLDCM not only affect the characteristics of centrifugal compressor, but also has an impact on the performance of full cell, especially in the range of high speed. Models of high speed BLDCM and centrifugal compressor with 1 kW rated power and 250,000 rpm rated speed are built in this paper. Drive and control method of three-phase six-state for the BLDCM is introduced in detail, and it is used to drive the centrifugal compressor. The characteristics of speed, torque, voltage and current are present and the relationship between air pressure and air mass flow is researched. In recent years high speed brushless DC motor (BLDCM) drives are gradually replacing induction motors drives in many areas, especially with the development of rare-earth permanent magnet materials such as SmCo, NdFeB. The BLDCM, with the electrical circuit to replace the mechanical brush and the commutator, has the advantages of good regulation performance, high power density, etc The motor is used as drive motor to reduce the weight and volume of centrifugal compressor, which can be used to provide air to the full cell. Control method of three-phase six-state for the BLDCM can reduce noise and shakes in commutation process, and insure the motor speed regulated smoothly. Square-wave current flows in only two phases at any time and the back electromotive force (EMF) is trapezoidal wave. The good regulation performance of the motor has an active influence on the output air mass flow and air pressure of the compressor, and the air flow and pressure affect dynamic performance of fuel cells directly. The efficient of full cell can be improved when air in the cathode is adequately combusted. Therefore, the high speed BLDCM and centrifugal compressor have a good application prospects for the fuel cells. The BLDCM for a 50 kw, 7,000 rpm centrifugal compressor is designed and the result is validated by finite element method . An Ultrahighspeed, low power electrical drive system is developed and some BLDC drives have been used in automotive fuel pumps Centrifugal compressor supplies the air continuously and it has a good **application** prospects in the fuel cell system. Centrifugal compressor is an inevitable trend to optimize the volume and weight of the fuel cell system. A classical dynamic model of centrifugal compressor is proposed by Greitzer. Dynamic equations of air flow and pressure are built in the model, and the drive torque is regarded as a control variable . The model which takes speed into account is built by Gravdahl. In the model, speed is regarded as a control variable to research the effect of compressor speed on air flow and pressure. Because of the coupling relationship between air flow, air pressure and speed, the air pressure changes with the air flow dramatically. The nonlinear coupling relationship increases the control difficulty of the compressor and affects the safety of fuel cells directly. Some scholars has present some methods to decrease the coupling. Dynamic disturbance decoupling control (DDC) solves the coupling problem between air flow and pressure, and the effect of air pressure from air flow is reduced

IN "HARSHA KUKDE, A. S. LILHARE, " SOLAR POWERED BRUSHLESS DC MOTOR DRIVE FOR WATER PUMPING SYSTEM", IN INTERNATIONAL CONFERENCE ON POWER AND EMBEDDED DRIVE CONTROL (ICPEDC) 2017, P. 405-409." this paper describes solar PV system worn for pumping system in order to gain the maximum benefits from solar source along with also gives soft starting of BLDC motor. The model is inured study manifold parameter alternative effects upon the PV array in conjunction with operating temperature along with solar irradiation level. This paper accommodates an analysis regarding the photovoltaic system's interpretation in real time in addition to the factor disturbing it such Temperature along with Irradiation. BLDC Motor speed is regulated all the way through inverter. The VSI is regulated via fundamental frequency switching, escaping the losses owing to high-frequency switching, in regulate to augment the efficiency of the proposed system. Solar energy is remarkably exclusive form of renewable energy sources which has procurement increasing attention in modernistic year. The power generation from solar source is always clean; free from pollution furthermore a bend in nature due to that solar source is mostly used any place, where it gives maximum benefits from source. In recent year, the price of solar PV panel is going downwards which increase attention to use solar PV application in modernistic year. Renewable energy sources based application used in industries and hometown application. Among all other application based solar PV system, water pumping is most effective, crucial and cost effective application for power generation by Solar PV array. For water pumping system generally induction motor, dc motor are used in rural as well as grid connected area for induction motor. For pumping load, simple, low cost and efficient motor is generally used. Basically for pumping section, induction motor is generally preferred it is easily available in market furthermore gives good performances for any load condition but when induction motor is preferred for solar PV based application, it suffers from overheating phenomenon of motor , if voltage of motor is going to low, due to that it require a complicated control. Under low voltage condition, efficient, reliable and cost effective motor has to be used. So, The BLDC motor is used for such application. The brushless DC motor is ideal choice for application that requires high reliability, high efficiency and power to volume ratio. Generally, a BLDC motor is well thought-out to be a high concert motor that is proficient of providing enormous amounts of torque more than a vast speed range. For Solar PV based application, BLDC motor is undoubtedly compete with any other motor for pumping application as it gives superior performance of motor along with soft starting. BLDC motor is advancement of most of the DC motor and they have almost same torque and speed usual curve uniqueness .The key variation between two is the use of brushes. BLDC motor for pumping system technique along with solar PV source, both combination increases its utilization and reliability. Maximum benefits from solar PV, is obtained by using maximum power point tracking (MPPT) algorithm. For MPPT tracking, generally P &O, incremental conductance algorithm is used. Among that incremental conductance gives best performance under rapidly changing atmospheric condition, however it shows poor performance at low irradiance level using the DC– DC converters. This paper elaborate idea for proper use of Solar PV based application and soft starting of BLDC motor. For maximum benefits from solar PV array, boost converter is Used and switch of boost converter is operated through incremental conductance MPPT algorithm. The following proposed system gives benefits of solar PV based application driven by BLDC motor for water pump as shown in fig.1.There are various ways to control speed of BLDC motor like hysteresis control and other control scheme are used. But following configuration is simple, low cost, noise free and having least component of the system; make configuration is suitable for water pumping system

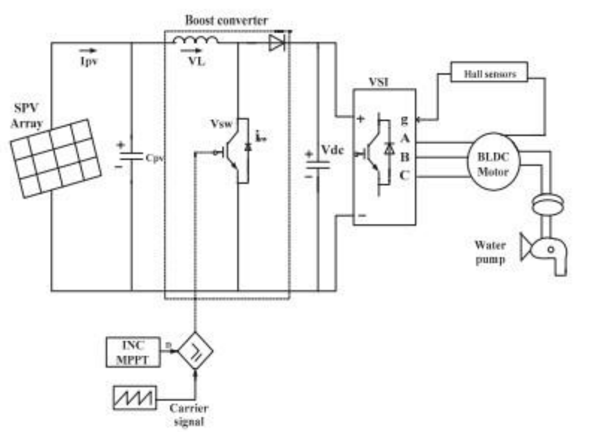


Fig: Configuration of the SPV array fed BLDC motor driven water pumping system.

IN " JIRAPUN PONGFAI, WUDHICHAI ASSAWINCHAICHOTE, "OPTIMAL PID PARAMETRIC AUTO-ADJUSTMENT FOR BLDC MOTOR CONTROL SYSTEMS

BASED ON ARTIFICIAL INTELLIGENCE", IN INTERNATIONAL ELECTRICAL ENGINEERING CONGRESS (IEECON) 2017, P. 1-4." — This paper considers the comparison performance and effectiveness of the PID controller auto-tuning for brushless DC motor (BLDC motor) by applying artificial intelligence (AI) algorithm and the classical method of PID parameters tuning. Neural network algorithm (NN) and genetic algorithm (GA) are among the well-known artificial intelligences algorithm existing todays while the classical method is Ziglor-Nichol method (ZN). To compare the performances of the controller, the convergence rate and the transient response analysis is examined by considering a criterial evaluated performance of the overshoot, the steady state error and the rise time. From the BLDC motor simulation results, it is found that the NN has given the better transient response than the GA and the ZN when evaluated in the convergence rate and the transient response analysis.

IN "F. ARAMA, B. MAZARI, A. DAHBI, K. ROUMMANI, M. HAMOUDA, "ARTIFICIAL INTELLIGENCE CONTROL APPLIED IN WIND ENERGY CONVERSION SYSTEM", IN *INTERNATIONAL RENEWABLE AND SUSTAINABLE ENERGY CONFERENCE (IRSEC)* 2014, P. 831-835. The objective of this paper is to study the dynamic response of the wind energy conversion system (WECS) based on the Doubly Fed Induction Generator (DFIG). The DFIG rotor is connected to the grid via a converter. The active and reactive power control is realized by the DFIG rotor variables control, using the field oriented control (FOC). The vector control of DFIG is applied by the use of tow regulators PI and the neural network regulator (NN). The generator mathematical model is implemented in Matlab/ Simulink software to simulate a DFIG of 1.5 MW in order to show the efficiency of the performances and robustness of the studied control systems. The simulation obtained results shows that the robustness and response time of the neural network regulator is better than those obtained by the PI classical regulator Wind power is one of the renewable energies which has a use growth in the world due to clean and non-polluting nature of this technology. Several machines were used in WECS, but the range of wind speed was limited in classical machines, the advanced technology created DFIG which solves this problem and makes these systems more powerful. Several control methods of the DFIG are appeared, among them, the vector control . The principle of this control is to make DFIG similar to separate excitation DC machine. Zerzouri et al. have tried to improve the performance of a DFIG wind energy conversion system, they have proposed the vector control with the PI controller to decouple the active and reactive power of the stator. They have used a single PI in each control loop, but this control has oscillations, exceedances, and the decoupling is not fully maintained. Poitiers et al. have used the RST polynomial controller, they have found that the RST control is more robust than the PI control compared to the rotor resistance variation, but the oscillations remain apparent. Hamane et al. have investigated the decoupling control of active and reactive DFIG powers by the Sliding Mode (SM) regulator which shows superiority over PI during robustness testing, but this method had a slow response time. Viswanadha et al.have commanded the DFIG by two methods; the DPC command and the power transfer matrix model, they have concluded that the power transfer matrix method has a better result than the DPC command. Giannakis et al. have presented a study of the decoupled control of P-Q without mechanical sensor for DFIG-based WECS with intelligent controllers. They are focused on the implementation of fuzzy logic controllers combined with conventional PI for the adjustment of active and reactive power. In these last years, a big interest is given to the use of neural network in identification and control of the nonlinear systems ; this is mainly due to their capacities of training and generalization. Mishra et al have developed an indirect vector control by implementing intelligent controllers (Fuzzy and Neural network) to control the speed of an induction motor (IM), they have concluded that the controller based on the neural network has a more robust than the PI and fuzzy logic controllers. This paper presents a comparison between the WECS performance using PI and NN controllers.

The PI regulator is simple and easy in implementation and gives acceptable performances, but it hasn't robustness in case of parameter variations.The neural network controller is proved to be an interesting method for the design of controllers and applied in many fields because of its excellent properties, such as insensitivity to external disturbances and parameter variations, It can present also fast dynamic responses if the switching devices support a high frequency

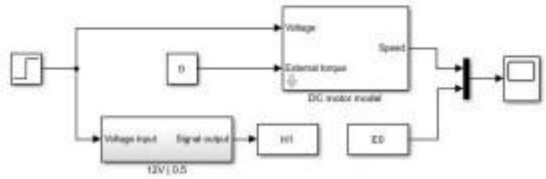
IN " WEN ZONGZHOU, LI GUOCHAO, "UNDERGROUND DRAINAGE SYSTEM BASED ON ARTIFICIAL INTELLIGENCE CONTROL", IN *IEEE 3RD INTERNATIONAL CONFERENCE ON COMMUNICATION SOFTWARE AND NETWORKS* 2011, P. 700-703." By analyzing common artificial intelligence technologies, the paper introduced design of software and structure of a drainage system of coal mine underground based on artificial intelligence control. By detecting water level in sump and other parameters, the system controls pumps to work by turns and standby pump to start at duly time, so as to schedule dumps run reasonably, and it has function of fault alarming, which decreases labor intensity of workers greatly and improves utilization rate of devices. The system also has good expansibility and is fit for different fields Coal mine water in the mine water into the production process Roadway or face, or exposed and mined the area tunnel collapse Spread due to the water. Water is mainly precipitation, surface water, broken Layer of water, aquifer water, and mined areas of water. Mine water reaches a certain Cubic number, if not promptly discharged from coal mines will seriously affect the health Production safety [I]. Therefore, the mine drainage system can work safely and reliably Directly related to the coal mine for personal and property safety. In this paper, AI (Artificial Intelligence, AI)The basic control system theory, is introduced based on artificial intelligence Able to control the underground drainage system. The system can stop intelligent open Pumps, automatic rotation, fault alarm and other functions, for the realization of underground drainage. Unattended system laid the foundation

1.4.PROJECT OVERVIEW

The two essential facts that dictate the speed control for a DC motor are as follows. When the speed of the rotor is regulated, the armature current is determined by the load torque while the rotor speed is determined by load torque under armature current regulation. The relationship between load torque and rotor speed is inversely proportional and the rotor speed reaches zero at stall torque. The rotor speed reaches its maximum value and consumes less current at no load torque condition. On the other hand, at rated torque value, the speed of the rotor decreases and more current flows through the armature coil. The increase in load or moment of inertia will cause the high motor currents followed by thermal degradation of the motor windings from I 2R (I-Current, R-Resistance) heating. The change in load will vary depending on applications. For example, in motor operated valves, if the valve is not operated for a certain period the valve torque increases due to the deposit of particles in between the valve seating area which in turn increases the moment of inertia of the rotor. Various devices and circuits are used along with the motor control circuitry to monitor fault conditions. Such devices include ground fault relays, transient voltage protectors, harmonic filters and thermal overload relays. The thermal overload relays function as overload protector for electric motors and are widely used in the industry . The question arises with these techniques is that what happens to the motor winding when the hardware fails. To vanquish the above problems, we have introduced the overload protection technique at software level using the AI. A PID controller is a closed loop control mechanism consisting three basic coefficients which are varied to achieve optimal response for a control system and is commonly used in process industries. The purpose of this research is to study how to eliminate the overvoltage signal from the controller without affecting the controller performance under high load condition for a DC motor speed control application. Another serious issue for using a conventional PID controller is that the change in nominal inertia affects the motion control system stability . Even though various tuning methods are existing for the PID controllers, the proper tuning of controllers is still a serious issue for many control applications. A comparison study on the performance of Artificial Neural Networks (ANN) and fuzzy logic control techniques over conventional control techniques for DC motor speed control was conducted by Mo-yuven Chow and Alberico Menozzi. The study states the classical PI controller is more constrained and less flexible compared to that of a fuzzy logic controller. The emerging techniques in controller design improve the performance and stability of the control system compared to that of the conventional controller designs.

1.5. METHODOLOGY

Quantitative approach has been exercised in this thesis as research methodology. The quantitative methodology applied to this thesis has been organized as follows: Initially, this research performs the analysis of potential hazards and fault conditions for motor and motor protection methods. Also, a detailed study on the application of AI for sequential prediction and control systems were done. The above investigation shapes the problems and limitations with the existing techniques and formulates the problem definition. Modelling the hardware and designing the solution for the identified problems followed by implementation of the design in real-time is the next stage in this methodology. The DC motor model was modeled using realtime hardware-in-the-loop control platform for a DC motor hardware in Matlab/Simulink. The model was verified by simulating the same for no load and full load speed at rated voltage and comparing with the motor data sheet. The derivative term of the PID controller for a DC motor speed control application will be zero due to the first order transfer function of a DC motor . As a result, the PID controller turns to a PI controller. The conventional PI controller under variable load conditions was experimented to study the response from a speed control system for a DC motor. The responses for the mathematical model of DC motor were within the tolerance limit and the same model was used to generate the training data and testing data for designing neural network models for the proposed solution. Even though the speed of the motor measured in real time was within the tolerance limit, the slight noise in the measurement can be eliminated by the mathematical model due to its stable output. The prediction of the supply voltage to obtain corresponding speed was done by the neural network model designed using the neural network toolbox in Matlab/Simulink. The proposed solution was tested in real-time followed by comparing with the classical control methods comprises the evaluation of test results



DC MOTOR MODELLING

The DC motor is a power actuator device that delivers energy to a load by converting direct current electric energy into rotational mechanical energy. The dynamic equations for a DC motor are as follows:

$$d\omega/dt = 1/J\,(K_m - B.\omega - m) \qquad (1)$$
$$di/dt = 1/L\,(V - R.i - K_e\omega) \qquad (2)$$

Where, J is the moment of inertia of the rotor, Km is motor torque constant, i is the armature current, B is motor viscous friction constant, m is the external disturbance/load torque, L is electric inductance, R is electric resistance, and Ke is electromotive force constant . The values for above parameters for the given DC motor were calculated and shown in Table I from the motor response to various real-time experiments.

DC MOTOR PARAMETERS

Parameters	Symbol	Value	Units
Motor torque constant	K_m	8.91×10^{-2}	N.m/A
Armature coil resistance	R	5.0	Ω
Moment of inertia of the rotor	J	9.52×10^{-5}	$Kg.m^2$
Viscous friction constant of the motor	B	1.28×10^{-4}	N.m/rad/s
Inductance of the armature coil	L	0.167	H

Above Figure shows the Simulink model designed for studying the behavior analysis between the DC motor hardware and the mathematical model. The 12V|0.5 block perform the scaling of the signal for the input to the control module. The H0 block applies the signal to the motor driver unit while, E0 block collects the feedback signals from the encoder and calculates the speed of the DC motor. Figure shows step input response of the system and the mathematical model under full load and noload conditions. To test the accuracy of the model, the load torque was varied in mathematical model as well as in real time followed by comparing the measured speed from both, with the actual no-load speed (789 rpm) and rated speed (639 rpm) for the given DC motor. The speed tolerance for given DC motor is +/-15 rpm .

PROPOSED METHOD

The entire idea behind the method revolves around utilizing the controlling capability of a conventional PI controller along with the prediction capability of Artificial Intelligence. The setpoint speed is fed into the PI controller which calculates the corrected value of speed and delivered to the neural network model which predicts the voltage to the DC motor. The voltages from two different neural network models (one trained under the noload condition and other trained under full load condition) are then compared to monitor the variation in voltage from the load variations and delivered to the DC motor. The block diagram representation of the proposed solution is shown in figure 5. The motor will be tripped at software level if an overload condition is detected while, the motor will run smoothly under normal load conditions. The maximum load condition was determined from the rated torque for the given DC motor i.e., 0.03 N-m.

A. DATA PRE-PROCESSING

The data consists of features which are the descriptive attributes and labels which are the outputs/predictions from the neural network. In this research, the setpoint i.e., the speed of the rotor at different voltages are the features and corresponding voltages are the labels. The rotor speed and corresponding voltage are collected by simulating the model using the plant identification tool from the neural network tool box in Matlab/Simulink. The sample data collected were loaded into the neural fitting tool in Matlab, in matrix column format followed by dividing the data sets into 70 percent for training, 15 percent for validation and 15 percent for testing. The validation data helps to stop training when the generalization is not further improving, by measuring the network generalization while the testing data helps to provide an independent measure of network performance. From the experiments conducted, it was observed that the prediction accuracy was less for 10,000 data samples. As a result, a total of 100,000 samples were collected, shuffled and divided into two sets in which one set consists 0f 70,000 data for training and the other set consisting of 30,000 data for testing and validation.

Implementation

The PI controller regulates the input speed to neural network model based on the set point speed and the measured feedback. The controller gain values were identified using the PID tuner tool from control system toolbox in MATLAB. From the PI controller output one of the neural network model (trained under no-load condition) will predict the voltage input that has to be applied to DC motor. On the other hand, the other neural network model (trained under rated torque condition) will predict the voltage for monitoring the overload condition from the setpoint speed. A comparator along with a switch will route the safe voltage to the control system hardware. The final comparison was done to ensure that the armature current not exceeding the rated current of the motor and thereby ensure the equipment safety.

CHAPTER-2

CONTROLLERS

2.1 P-I CONTROLLER

P-I controller is mainly used to eliminate the steady state error resulting from P controller. However, in terms of the speed of the response and overall stability of the system, it has a negative impact. This controller is mostly used in areas where speed of the system is not an issue. Since P-I controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations. If applied, any amount of I guarantees set point overshoot.

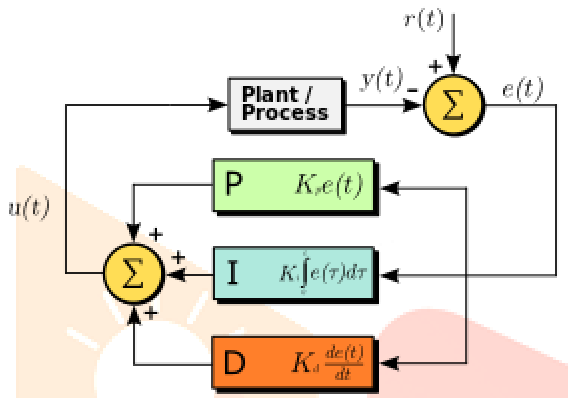


Fig.2.1: PID controller

A proportional–integral–derivative controller (PID controller) is a control loop feedback mechanism(controller) commonly used in industrial control systems. A PID controller continuously calculates an error valueas the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error over time by adjustment of a control variable, such as the position of a control valve, adamper, or the power supplied to a heating element, to a new value determined by a weighted sum.

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

where

K_p: Proportional gain, a tuning parameter

K_i: Integral gain, a tuning parameter

K_d: Derivative gain, a tuning parameter

e: Error $= SP - PV$

t: Time or instantaneous time (the present)

τ: Variable of integration; takes on values from time 0 to the present t.

Equivalently, the transfer function in the Laplace Domain of the PID controller is

$$L(s) = K_p + K_i/s + K_d s$$

where

s: complex number frequency

PROPORTIONAL TERM:

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain constant.

The proportional term is given by:

$$P_{\text{out}} = K_p e(t)$$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (see the section on loop tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

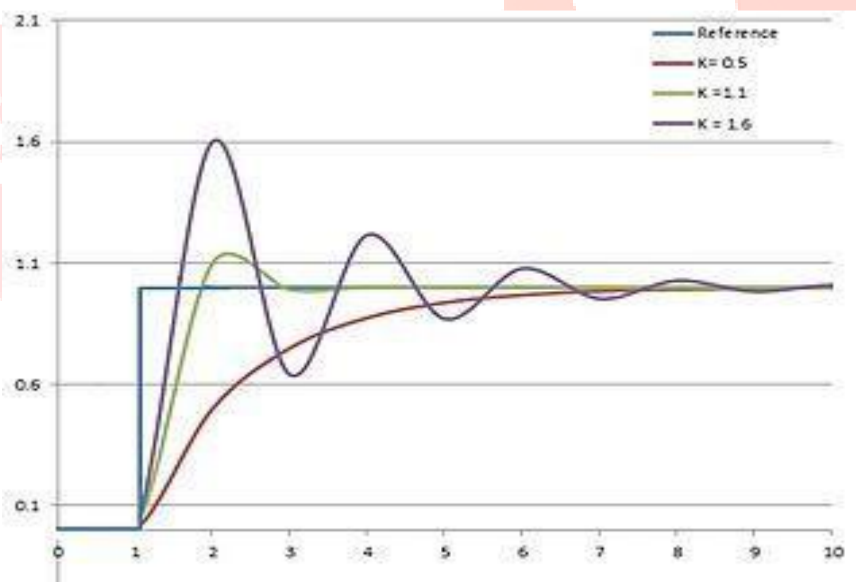


Fig.: Plot of PV vs time, for three values of K_p (K_i and $K_d$held constant)

INTEGRAL TERM:

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain (K_i) and added to the controller output.

The integral term is given by:

$$I_{\text{out}} = K_i \int_0^t e(\tau)\, d\tau$$

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the setpoint value (see the section on loop tuning).

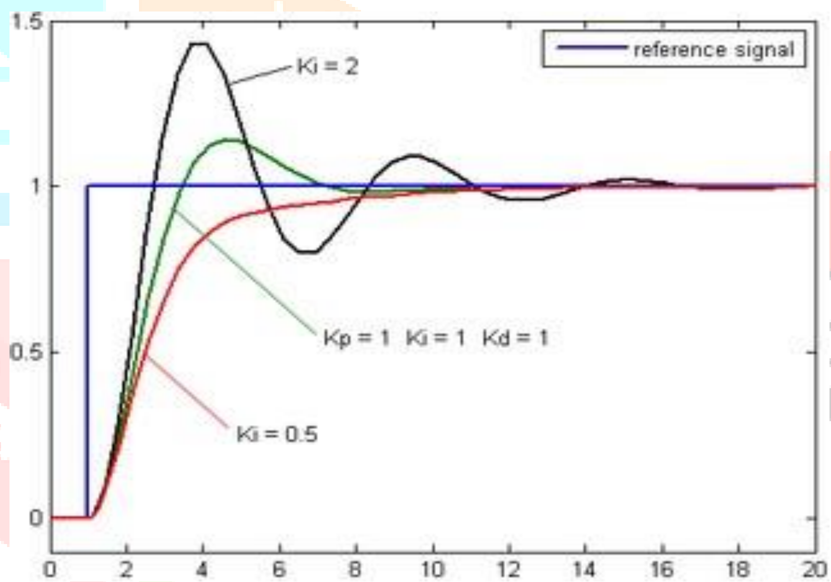


Fig.: Plot of PV vs time, for three values of K_i (K_p and $K_d$held constant)

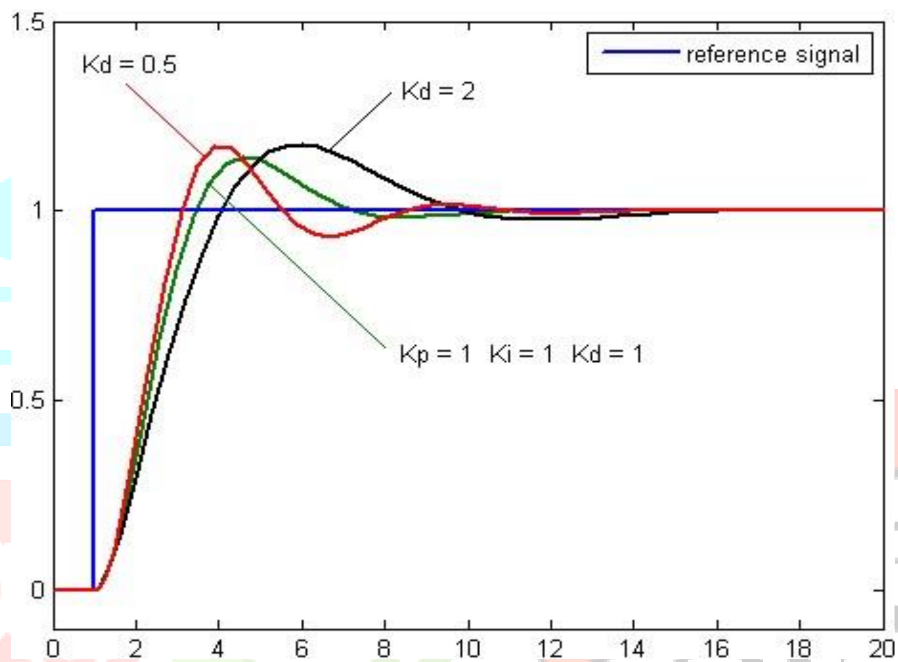
DERIVATIVE TERM

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d.

The derivative term is given by:

$$D_{\text{out}} = K_d \frac{d}{dt} e(t)$$

Derivative action predicts system behavior and thus improves settling time and stability of the system.[12][13]An ideal derivative is not causal, so that implementations of PID controllers include an additional low pass filtering for the derivative term, to limit the high frequency gain and noise.[14] Derivative action is seldom used in practice though - by one estimate in only 25% of deployed controllers[14] - because of its variable impact on system stability in real-world applications.



Plot of PV vs time, for three values of K_d (K_p and $K_i$held constant)

2.2 PID Controller

A PID controller is an instrument used in industrial control applications to regulate temperature, flow, pressure, speed and other process variables. PID (proportional integral derivative) 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 level. It's a practically ubiquitous as a means of controlling temperature and finds application in myriad chemical and scientific processes as well as automation. PID control uses closed-loop control feedback to keep the actual output from a process as close to the target or setpoint output as possible.

What is a PID Temperature Controller?

A PID temperature controller, as its name implies, is an instrument used to control temperature, mainly without extensive operator involvement. A PID controller in a temperature control system will accept a temperature sensor such as a thermocouple or RD as input and compare the actual temperature to the desired control temperature or setpoint. It will then provide an output to a control element.

What is a Digital PID Controller?

A digital PID controller reads the sensor signal, normally from a thermocouple or RTD and connects the measurement to engineering units, such as degree Fahrenheit or Celsius, that are then displayed in a digital format.

History of PID Controller

The first evolution of the PID controller was developed in 1911 by Elmer Sperry. However, it wasn't until 1933 that the Taylor Instrumental Company (TIC) introduced the first pneumatic controller with a fully tunable proportional controller. A few years later, control engineers went eliminate the steady state error found in proportional controllers by resetting the point to some artificial value as long as the error wasn't zero. This resetting ―integrated‖ the error and became known as the proportional-Integral controller. Then, in 1940, TIC developed the first PID pneumatic controller with a derivative action, which reduced overshooting issues. However, it wasn't until 1942, when Ziegler and Nichols tuning rules were introduced that engineers were able to find and set the appropriate parameters of PID controllers. By the mid-1950's, automatic PID controllers were widely adopted for industrial use.

How Does a PID Controller Work?

A proportional integral derivative (PID) controller can be used as a means of controlling temperature, pressure, flow and other process variables. As its name implies, a PID controller combines proportional control with additional integral and derivative adjustments which help the unit automatically compensate for changes in the system.

PID Controller Basics

The purpose of a PID controller is to force feedback to match a setpoint, such as a thermostat that forces the heating and cooling unit to turn on or off based on a set temperature. PID controllers are best used in systems which have a relatively small mass and those which react quickly to changes in the energy added to the process. It is recommended in systems where the load changes often and the controller is expected to compensate automatically due to frequent changes in setpoint, the amount of energy available, or the mass to be controlled.

PID Controller Working Principle

The working principle behind a PID controller is that the proportional, integral and derivative terms must be individually adjusted or "tuned." Based on the difference between these values a correction factor is calculated and applied to the input. For example, if an oven is cooler than required, the heat will be increased. Here are the three steps:

Proportional tuning involves correcting a target proportional to the difference. Thus, the target value is never achieved because as the difference approaches zero, so too does the applied correction.

Integral tuning attempts to remedy this by effectively cumulating the error result from the "P" action to increase the correction factor. For example, if the oven remained below temperature,
―I‖ would act to increase the head delivered. However, rather than stop heating when the target is reached, "I" attempts to drive the cumulative error to zero, resulting in an overshoot.

Derivative tuning attempts to minimize this overshoot by slowing the correction factor applied as the target is approached.

PID Temperature Controller Working Principle

A proportional integral derivative (PID) controller can be used as a means of controlling temperature, pressure, flow and other process variables. As its name implies, a PID controller combines proportional control with additional integral and derivative adjustments which help the unit automatically compensate for changes in the system.

Types of PID Controller

There are three basic types of controllers: on-off, proportional and PID. Depending upon the system to be controlled, the operator will be able to use one type or another to control the process.

On/Off Control

On/Off PID Controller Types An on-off pid controller is the simplest form of temperature control device. The output from the device is either on or off, with no middle state. An on-off controller will switch the output only when the temperature crosses the set point. One special type of on-off control is a limit controller. This controller uses a latching relay, which must be manually reset, and is used to shut down a process when a certain temperature is reached.

Proportional Control

Proportional Control PID Controller Proportional controls are designed to eliminate the cycling associated with on-off control. A proportional controller decreases the average power supplied to the heater as the temperature approaches set point. This has the effect of slowing down the heater so that it will not overshoot the set point but will approach the set point and maintain a stable temperature. This proportioning action can be accomplished by turning the output on and off for short time intervals. This "time proportioning" varies the ratio of "on" time to "off" time to control the temperature.

Standard PID Controller

This standard PID controller combines proportional control with integral and derivative control (PID), which helps the unit automatically compensate for changes in the system. These adjustments, integral and derivative, are expressed in time-based units; they are also referred to by their reciprocals, RESET and RATE, respectively. The proportional, integral and derivative terms must be individually adjusted or "tuned" to a particular system using trial and error. PID controllers provide the most accurate and stable control of the three controller types.

Temperature Control Using PID

A good example of temperature control using PID would be an application where the controller takes an input from a temperature sensor and has an output that is connected to a control element such as a heater or fan. The controller is usually just one part of a temperature control system, and the whole system should be analyzed and considered in selecting the proper controller.

PID Controller Problem Example

Almost every process control application would benefit from PID control. Here are several PID controller problem examples:

- **Heat treatment of metals:** "Ramp & Soak" sequences need precise control to ensure desired metallurgical properties are achieved.

- **Drying/evaporating solvents from painted surfaces:** Over-temperature conditions can damage substrates while low temperatures can result in product damage and poor appearance.

Curing rubber: Precise temperature control ensures complete cure is achieved without adversely affecting material properties.

Baking: Commercial ovens must follow tightly prescribed heating and cooling sequences to ensure the necessary reactions take place.

How to Tune a PID Controller

Many rules have evolved over the years to address the question of how to tune a PID controller. Probably the first, and certainly the best known, are the Zeigler-Nichols (ZN) rules.

Zeigler-Nichols (ZN) Rules

First published in 1942, Zeigler and Nichols described two methods of tuning a PID loop. The first method entails measuring the lag or delay in response and then the time taken to reach the new output value. The second depends on establishing the period of a steady-state oscillation. In both methods these values are then entered into a table to derive values for gain, reset time and rate.

ZN is not without issues. In some applications it produces a response considered too aggressive in terms of overshoot and oscillation. Another drawback is that it can be time-consuming in processes that reacts slowly.

For these reasons some control practitioners prefer other rules such as Tyreus-Luyben or Rivera, Morari and Skogestad.

How to Tune PID Controller Manually

Manual tuning of PID controller is done by setting the reset time to its maximum value and the rate to zero and increasing the gain until the loop oscillates at a constant amplitude. (When the response to an error correction occurs quickly a larger gain can be used. If response is slow a relatively small gain is desirable).

Then set the gain to half of that value and adjust the reset time so it corrects for any offset within an acceptable period. Finally, increase the rate until overshoot is minimized.

How to Automate Tuning of PID Controller

Most PID controllers sold today incorporate auto-tuning functions. Operating details vary between manufacturers, but all follow rules where the controller ―learns‖ how the process responds to a disturbance or change in set point and calculates appropriate PID settings.

Newer and more sophisticated PID controllers, such as OMEGA's Platinum series of temperature and process controllers, incorporate fuzzy logic with their auto-tune capabilities. This provides a way of dealing with imprecision and nonlinearity in complex control situations, such as are often encountered in manufacturing and process industries and helps with tuning optimization.

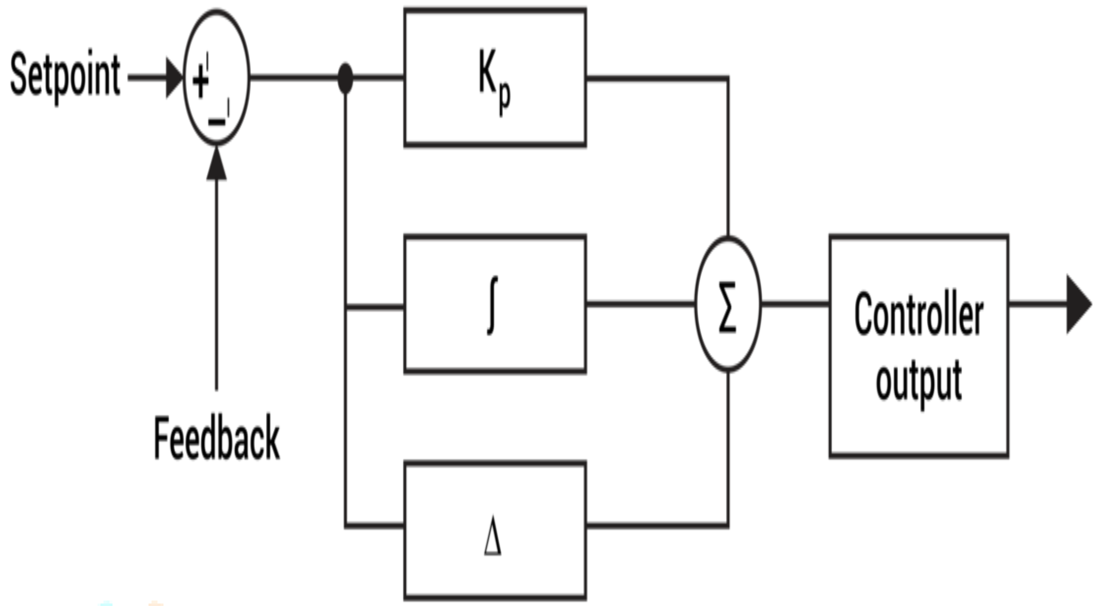
PID Temperature Controller Tuning

In the case of a temperature controller like OMEGA‘s CNi8 series, when "Auto Tune" is selected the controller activates an output. By observing both the delay and rate with which the change is made it calculates optimal P, I and D settings. Manual tuning PID temperature controller allows for fine-tuning if needed. (Note that this controller requires the set point to be at least 10°C above the current process value for auto tuning to be performed).

PID Controller Gain Tuning

PID controller gain tuning can be difficult. The proportional method is the easiest to understand.

In this instance, the output of the proportional factor is the product of gain and measured error ε. Thus, larger proportional gain or error makes for greater output from the proportional factor. Setting the proportional gain too high causes a controller to repeatedly overshoot the setpoint, leading to oscillation. While setting the proportional gain too low make the loop output negligible. One way to offset this steady-state error is using the Zeigler-Nichols method of setting the I and D gains to zero and then increasing P gain until the loop output starts to oscillate.



Modelling and Training of Neural Network Recurrent Neural Networks (RNN) are the traditional neural network architecture that is used for the sequence to sequence prediction [17]. The Levenberg-Marquardt algorithm is used for training the neural network. Even though the algorithm consumes more memory, the processing time is very less and automatically stops when the generalization reaches a point at which there will be no further improvement [18]. The measure of generalization is calculated from the mean square error of validation samples. The network parameters consist of a single input layer, 100 hidden layers with sigmoid transfer function as activation and a single output layer with a linear transfer function as activation.

Finally, the model has been tested for the test datasets.

CHAPTER-3 ARTIFICAL INTELLIGENCE

The Artificial Intelligence tutorial provides an introduction to AI which will help you to understand the concepts behind Artificial Intelligence. In this tutorial, we have also discussed various popular topics such as History of AI, applications of AI, deep learning, machine learning, natural language processing, Reinforcement learning, Q-learning, Intelligent agents, Various search algorithms, etc.

Our AI tutorial is prepared from an elementary level so you can easily understand the complete tutorial from basic concepts to the high-level concepts.

What is Artificial Intelligence?

In today's world, technology is growing very fast, and we are getting in touch with different new technologies day by day.

Here, one of the booming technologies of computer science is Artificial Intelligence which is ready to create a new revolution in the world by making intelligent machines.The Artificial Intelligence is now all around us. It is currently working with a variety of subfields, ranging from general to specific, such as self-driving cars, playing chess, proving theorems, playing music, Painting, etc.

AI is one of the fascinating and universal fields of Computer science which has a great scope in future. AI holds a tendency to cause a machine to work as a human.

Artificial Intelligence is composed of two words **Artificial** and **Intelligence**, where Artificial defines *"man-made,"* and intelligence defines *"thinking power"*, hence AI means *"a man-made thinking power."*

So, we can define AI as:

"It is a branch of computer science by which we can create intelligent machines which can behave like a human, think like humans, and able to make decisions."

Artificial Intelligence exists when a machine can have human based skills such as learning, reasoning, and solving problems

With Artificial Intelligence you do not need to preprogram a machine to do some work, despite that you can create a machine with programmed algorithms which can work with own intelligence, and that is the awesomeness of AI.

It is believed that AI is not a new technology, and some people says that as per Greek myth, there were Mechanical men in early days which can work and behave like humans.

3.1 Why Artificial Intelligence?

Before Learning about Artificial Intelligence, we should know that what is the importance of AI and why should we learn it. Following are some main reasons to learn about AI:

- With the help of AI, you can create such software or devices which can solve real-world problems very easily and with accuracy such as health issues, marketing, traffic issues, etc.
- With the help of AI, you can create your personal virtual Assistant, such as Cortana, Google Assistant, Siri, etc. ○ With the help of AI, you can build such Robots which can work in an environment where survival of humans can be at risk.
- AI opens a path for other new technologies, new devices, and new Opportunities.

3.2 Goals of Artificial Intelligence

Following are the main goals of Artificial Intelligence:

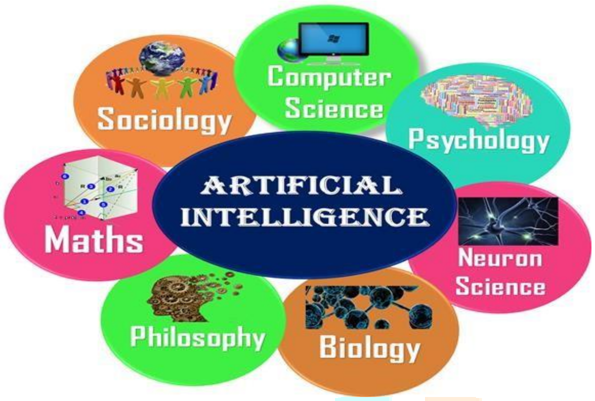
1. Replicate human intelligence
2. Solve Knowledge-intensive tasks
3. An intelligent connection of perception and action
4. Building a machine which can perform tasks that requires human intelligence such as:
   - Proving a theorem ○ Playing chess
   - Plan some surgical operation ○ Driving a car in traffic
5. Creating some system which can exhibit intelligent behavior, learn new things by itself, demonstrate, explain, and can advise to its user.

What Comprises to Artificial Intelligence?

Artificial Intelligence is not just a part of computer science even it's so vast and requires lots of other factors which can contribute to it. To create the AI first we should know that how intelligence is composed, so the Intelligence is an intangible part of our brain which is a combination of **Reasoning, learning, problem-solving perception, language understanding, etc**.

To achieve the above factors for a machine or software Artificial Intelligence requires the following discipline:

- Mathematics
- Biology
- Psychology
- Sociology
- Computer Science
- Neurons Study
- Statistics



3.3 Advantages of Artificial Intelligence

Following are some main advantages of Artificial Intelligence:

- **High Accuracy with less errors:** AI machines or systems are prone to less errors and high accuracy as it takes decisions as per pre-experience or information.
- **High-Speed:** AI systems can be of very high-speed and fast-decision making, because of that AI systems can beat a chess champion in the Chess game.
- **High reliability:** AI machines are highly reliable and can perform the same action multiple times with high accuracy.
- **Useful for risky areas:** AI machines can be helpful in situations such as defusing a bomb, exploring the ocean floor, where to employ a human can be risky.
- **Digital Assistant:** AI can be very useful to provide digital assistant to the users such as AI technology is currently used by various E-commerce websites to show the products as per customer requirement.
- **Useful as a public utility:** AI can be very useful for public utilities such as a self-driving car which can make our journey safer and hassle-free, facial recognition for security purpose, Natural language processing to communicate with the human in humanlanguage, etc.

3.4 Disadvantages of Artificial Intelligence

Every technology has some disadvantages, and thesame goes for Artificial intelligence. Being so advantageous technology still, it has some disadvantages which we need to keep in our mind while creating an AI system. Following are the disadvantages of AI:

- **High Cost:** The hardware and software requirement of AI is very costly as it requires lots of maintenance to meet current world requirements.
- **Can't think out of the box:** Even we are making smarter machines with AI, but still they cannot work out of the box, as the robot will only do that work for which they are trained, or programmed.
- **No feelings and emotions:** AI machines can be an outstanding performer, but still it does not have the feeling so it cannot make any kind of emotional attachment with human, and may sometime be harmful for users if the proper care is not taken.
- **Increase dependency on machines:** With the increment of technology, people are getting more dependent on devices and hence they are losing their mental capabilities.
- **No Original Creativity:** As humans are so creative and can imagine some new ideas but still AI machines cannot beat this power of human intelligence and cannot be creative and imaginative.

3.5 Application of AI

Artificial Intelligence has various applications in today's society. It is becoming essential for today's time because it can solve complex problems with an efficient way in multiple industries, such as Healthcare, entertainment, finance, education, etc. AI is making our daily life more comfortable and fast.

1. AI in Astronomy ○ Artificial Intelligence can be very useful to solve complex universe problems. AI technology can be helpful for understanding the universe such as how it works, origin, etc.
2. AI in Healthcare ○ In the last, five to ten years, AI becoming more advantageous for the healthcare industry and going to have a significant impact on this industry. ○ Healthcare Industries are applying AI to make a better and faster diagnosis than humans. AI can help doctors with diagnoses and can inform when patients are worsening so that medical help can reach to the patient before hospitalization.
3. AI in Gaming ○ AI can be used for gaming purpose. The AI machines can play strategic games like chess, where the machine needs to think of a large number of possible places.
4. AI in Finance ○ AI and finance industries are the best matches for each other. The finance industry is implementing automation, chatbot, adaptive intelligence, algorithm trading, and machine learning into financial processes.
5. AI in Data Security

○ The security of data is crucial for every company and cyber-attacks are growing very rapidly in the digital world. AI can be used to make your data more safe and secure. Some examples such as AEG bot, AI2 Platform,are used to determine software bug and cyber-attacks in a better way.

6. AI in Social Media ○ Social Media sites such as Facebook, Twitter, and Snapchat contain billions of user profiles, which need to be stored and managed in a very efficient way. AI can organize and manage massive amounts of data. AI can analyze lots of data to identify the latest trends, hashtag, and requirement of different users.

7. AI in Travel & Transport

○ AI is becoming highly demanding for travel industries. AI is capable of doing various travel related works such as from making travel arrangement to suggesting the hotels, flights, and best routes to the customers. Travel industries are using AI-powered chatbots which can make human-like interaction with customers for better and fast response.

8. AI in Automotive Industry ○ Some Automotive industries are using AI to provide virtual assistant to their user for better performance. Such as Tesla has introduced TeslaBot, an intelligent virtual assistant.

○ Various Industries are currently working for developing self-driven cars which can make your journey more safe and secure.

9. AI in Robotics: ○ Artificial Intelligence has a remarkable role in Robotics. Usually, general robots are programmed such that they can perform some repetitive task, but with the help of AI, we can create intelligent robots which can perform tasks with their own experiences without pre-programmed. ○ Humanoid Robots are best examples for AI in robotics, recently the intelligent Humanoid robot named as Erica and Sophia has been developed which can talk and behave like humans.

10. AI in Entertainment ○ We are currently using some AI based applications in our daily life with some entertainment services such as Netflix or Amazon. With the help of ML/AI algorithms, these services show the recommendations for programs or shows.

11. AI in Agriculture ○ Agriculture is an area which requires various resources, labor, money, and time for best result. Now a day's agriculture is becoming digital, and AI is emerging in this field. Agriculture is applying AI

as agriculture robotics, solid and crop monitoring, predictive analysis. AI in agriculture can be very helpful for farmers.

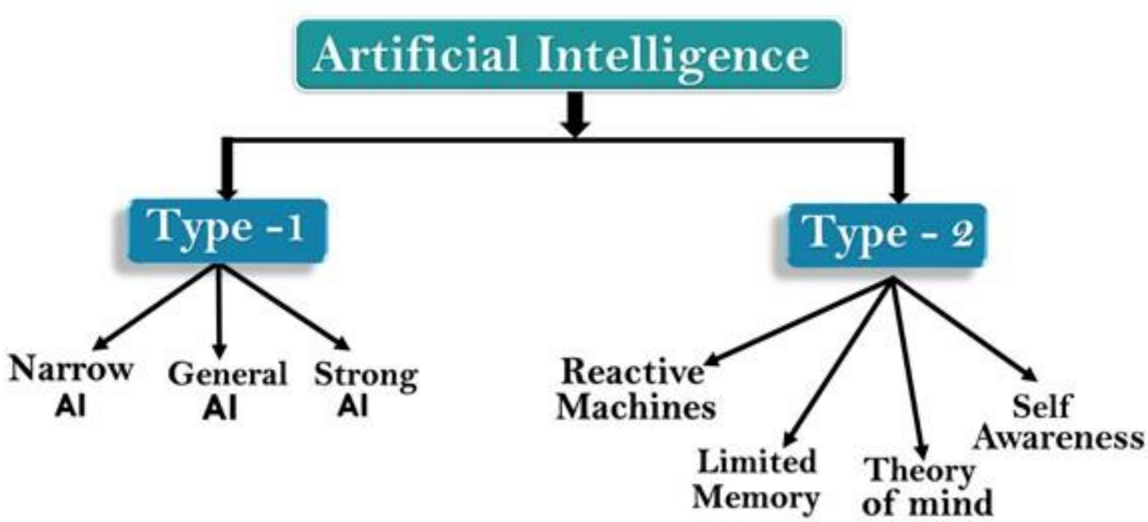
12. AI in E-commerce

○ AI is providing a competitive edge to the e-commerce industry, and it is becoming more demanding in the e-commerce business. AI is helping shoppers to discover associated products with recommended size, color, or even brand.

13. AI in education: ○ AI can automate grading so that the tutor can have more time to teach. AI chatbot can communicate with students as a teaching assistant. ○ AI in the future can be work as a personal virtual tutor for students, which will be accessible easily at any time and any place.

3.6 Types of Artificial Intelligence:

Artificial Intelligence can be divided in various types, there are mainly two types of main categorization which are based on capabilities and based on functionally of AI. Following is flow diagram which explain the types of AI.



AI type-1: Based on Capabilities

1. Weak AI or Narrow AI:

○ Narrow AI is a type of AI which is able to perform a dedicated task with intelligence.The most common and currently available AI is Narrow AI in the world of Artificial Intelligence.

○ Narrow AI cannot perform beyond its field or limitations, as it is only trained for one specific task. Hence it is also termed as weak AI. Narrow AI can fail in unpredictable ways if it goes beyond its limits.

- Apple Siriis a good example of Narrow AI, but it operates with a limited pre-defined range of functions.
- IBM's Watson supercomputer also comes under Narrow AI, as it uses an Expert system approach combined with Machine learning and natural language processing.
- Some Examples of Narrow AI are playing chess, purchasing suggestions on e-commerce site, self-driving cars, speech recognition, and image recognition.

2. General AI: ○ General AI is a type of intelligence which could perform any intellectual task with efficiency like a human.

- The idea behind the general AI to make such a system which could be smarter and think like a human by its own. ○ Currently, there is no such system exist which could come under general AI and can perform any task as perfect as a human.
- The worldwide researchers are now focused on developing machines with General AI.
- As systems with general AI are still under research, and it will take lots of efforts and time to develop such systems.

3. Super AI: ○ Super AI is a level of Intelligence of Systems at which machines could surpass human intelligence, and can perform any task better than human with cognitive properties. It is an outcome of general AI. ○ Some key characteristics of strong AI include capability include the ability to think, to reason,solve the puzzle, make judgments, plan, learn, and communicate by its own.

- Super AI is still a hypothetical concept of Artificial Intelligence. Development of such systems in real is still world changing task.

Artificial Intelligence type-2: Based on functionality

1. Reactive Machines

- Purely reactive machines are the most basic types of Artificial Intelligence. ○ Such AI systems do not store memories or past experiences for future actions. ○ These machines only focus on current scenarios and react on it as per possible best action.
- IBM's Deep Blue system is an example of reactive machines.
- Google's AlphaGo is also an example of reactive machines.

2. Limited Memory ○ Limited memory machines can store past experiences or some data for a short period of time.

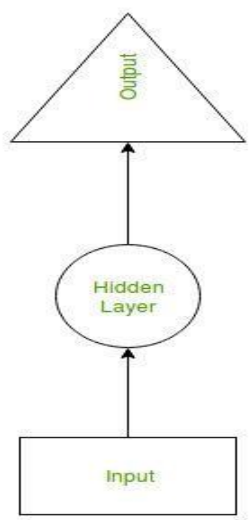
- These machines can use stored data for a limited time period only.
- Self-driving cars are one of the best examples of Limited Memory systems. These cars can store recent speed of nearby cars, the distance of other cars, speed limit, and other information to navigate the road.

4. Self-Awareness

- Self-awareness AI is the future of Artificial Intelligence. These machines will be super intelligent, and will have their own consciousness, sentiments, and self-awareness.
- These machines will be smarter than human mind. o Self-Awareness AI does not exist in reality still and it is a hypothetical concept.

CHAPTER-4 Recurrent Neural Network(RNN)

RNN are a type of Neural Network where the **output from previous step are fed as input to the current step**. In traditional neural networks, all the inputs and outputs are independent of each other, but in cases like when it is required to predict the next word of a sentence, the previous words are required and hence there is a need to remember the previous words. Thus RNN came into existence, which solved this issue with the help of a Hidden Layer. The main and most important feature of RNN is **Hidden state**, which remembers some information about a sequence.



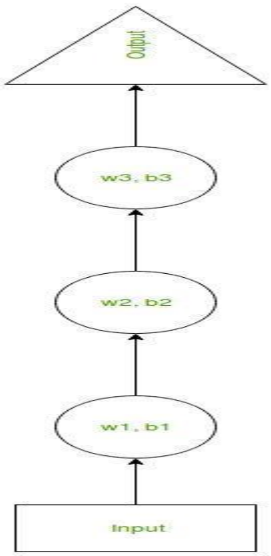
RNN have a **"memory"** which remembers all information about what has been calculated. It uses the same parameters for each input as it performs the same task on all the inputs or hidden layers to produce the output. This reduces the complexity of parameters, unlike other neural networks.

4.1 How RNN works

The working of a RNN can be understood with the help of below example:

Example:

Suppose there is a deeper network with one input layer, three hidden layers and one output layer. Then like other neural networks, each hidden layer will have its own set of weights and biases, let's say, for hidden layer 1 the weights and biases are (w1, b1), (w2, b2) for second hidden layer and (w3, b3) for third hidden layer. This means that each of these layers are independent of each other, i.e. they do not memorize the previous outputs.



Now the RNN will do the following:

- RNN converts the independent activations into dependent activations by providing the same weights and biases to all the layers, thus reducing the complexity of increasing parameters and memorizing each previous outputs by giving each output as input to the next hidden layer.
- Hence these three layers can be joined together such that the weights and bias of all the hidden layers is that.

- **Formula for calculating current state:**

$$h_t = f(h_{t-1}, x_t)$$

where:
h_t -> current state h_{t-1} -> previous state x_t -> input state

- **Formula for applying Activation function(tanh):**

$$h_t = \tanh\left(W_{hh}h_{t-1} + W_{xh}x_t\right)$$

where:

w_{hh} -> weight at recurrent neuron w_{xh} -> weight at input neuron

- **Formula for calculating output:**

$$y_t = W_{hy} h_t$$

Y_t -> output

W_{hy} -> weight at output layer

Training through RNN

1. A single time step of the input is provided to the network.
2. Then calculate its current state using set of current input and the previous state.
3. The current ht becomes ht-1 for the next time step.
4. One can go as many time steps according to the problem and join the information from all the previous states.
5. Once all the time steps are completed the final current state is used to calculate the output.
6. The output is then compared to the actual output i.e the target output and the error is generated.
7. The error is then back-propagated to the network to update the weights and hence the network (RNN) is trained.

4.2 Advantages of Recurrent Neural Network

1. An RNN remembers each and every information through time. It is useful in time series prediction only because of the feature to remember previous inputs as well. This is called Long Short Term Memory.
2. Recurrent neural network are even used with convolutional layers to extend the effective pixel neighborhood.

4.3 Disadvantages of Recurrent Neural Network

1. Gradient vanishing and exploding problems.
2. Training an RNN is a very difficult task.
3. It cannot process very long sequences if using tanh or relu as an activation function.

CHAPTER-5

DC MOTOR

Brushless DC electric motor (BLDC motors, BL motors) also known as electronically commutated motors (ECMs, EC motors), or synchronous DC motors, are synchronous motors powered by DC electricity via an inverter or switching power supply which produces an AC electric current to drive each phase of the motor via a closed loop controller. The controller provides pulses of current to the motor windings that control the speed and torque of the motor.

The construction of a brushless motor system is typically similar to a permanent magnet synchronous motor (PMSM), but can also be a switched reluctance motor, or an induction (asynchronous) motor.

The advantages of a brushless motor over brushed motors are high power to weight ratio, high speed, and electronic control. Brushless motors find applications in such places as computer peripherals (disk drives, printers), hand-held power tools, and vehicles ranging from model aircraft to automobile

5.1 Brushless vs. brushed motors

Brushed DC motors were invented in the 19th century and are common. Brushless DC motors were made possible by the development of solid state electronics in the 1960s.

An electric motor develops torque by alternating the polarity of rotating magnets attached to the rotor, the turning part of the machine, and stationary magnets on the stator which surrounds the rotor. One or both sets of magnets are electromagnets, made of a coil of wire wound around an iron core. DC running through the wire winding creates the magnetic field, providing the power which runs the motor. However, each time the rotor rotates by 180° (a halfturn), the position of the north and south poles on the rotor are reversed.

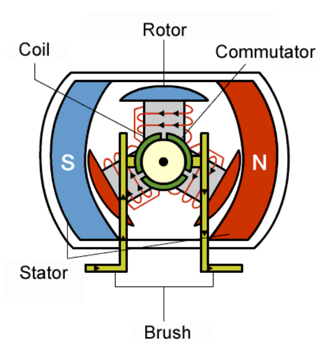


Figure illustrates the general principle of the brushed motor.

If the magnetic field of the poles remained the same, this would cause a reversal of the torque on the rotor each half-turn, and so the average torque would be zero and the rotor would not turn. Therefore, in a DC motor, in order to create torque in one direction, the direction of electric current through the windings must be reversed with every 180° turn of the rotor (or turned off during the time that it is in the wrong direction). This reverses the direction of the magnetic field as the rotor turns, so the torque on the rotor is always in the same direction.

5.2 Commutator

In brushed motors, invented in the 19th century, this is done with a rotary switch on the motor's shaft called a commutator. It consists of a rotating cylinder divided into multiple metal contact segments on the rotor. The segments are connected to wire electromagnet windings on the rotor. Two or more stationary contacts called "brushes", made of a soft conductor like graphite press against the commutator, making sliding electrical contact with successive segments as the rotor turns, providing electric current to the windings. Each time the rotor rotates by 180° the commutator reverses the direction of the electric current applied to a given winding, so the magnetic field creates a torque in one direction.

5.3 Disadvantages of commutator

The commutator has many engineering disadvantages that has led to the decline in use of brushed motors. These disadvantages are:

- The friction of the brushes sliding along the rotating commutator segments causes power losses that can be significant in a low power motor.
- The soft brush material wears down due to friction, creating dust, and eventually the brushes must be replaced. This makes commutated motors unsuitable for low particulate or sealed applications like hard disk motors.
- The resistance of the sliding brush contact causes a voltage drop in the motor circuit called *brush drop* which consumes energy.
- The repeated abrupt switching of the current through the inductance of the windings causes sparks at the commutator contacts. These are a fire hazard in explosive atmospheres, and create electronic noise, which can cause electromagnetic interference in nearby microelectronic circuits.

During the last hundred years high power DC brushed motors, once the mainstay of industry, were replaced by alternating current (AC) synchronous motors. Today brushed motors are only used in low power applications or where only DC is available, but the above drawbacks limit their use even in these applications. Brushless motors were invented to solve these problems

5.4 Brushless solution

The development of semiconductor electronics in the 1970s allowed the commutator and brushes to be eliminated in DC motors. In brushless DC motors, an electronic servo system replaces the mechanical commutator contacts. An electronic sensor detects the angle of the rotor, and controls semiconductor switches such as transistors which switch current through the windings, either reversing the direction of the current, or in some motors turning it off, at the correct time each 180° shaft rotation so the electromagnets create a torque in one direction. The elimination of the sliding contact allows brushless motors to have less friction and longer life; their working life is only limited by the lifetime of their bearings.

Brushed DC motors develop a maximum torque when stationary, linearly decreasing as velocity increases. Some limitations of brushed motors can be overcome by brushless motors; they include higher efficiency and a lower susceptibility to mechanical wear. These benefits come at the cost of potentially less rugged, more complex, and more expensive control electronics.

A typical brushless motor has permanent magnets which rotate around a fixed armature, eliminating problems associated with connecting current to the moving armature. An electronic controller replaces the brush/commutator assembly of the brushed DC motor, which continually switches the phase to the windings to keep the motor turning. The controller performs similar timed power distribution by using a solid-state circuit rather than the brush/commutator system.

Brushless motors offer several advantages over brushed DC motors, including high torque to weight ratio, more torque per watt (increased efficiency), increased reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling. This in turn means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter.

Brushless motor commutation can be implemented in software using a microcontroller or microprocessor computer, or may alternatively be implemented in analogue hardware, or in digital firmware using an FPGA. Commutation with electronics instead of brushes allows for greater flexibility and capabilities not available with brushed DC motors, including speed limiting, "micro stepped" operation for slow and/or fine motion control, and a holding torque when stationary. Controller software can be customized to the specific motor being used in the application, resulting in greater commutation efficiency.

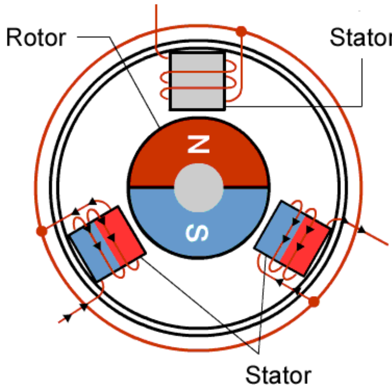


Figure : A BLDC Motor.

The maximum power that can be applied to a brushless motor is limited almost exclusively by heat; too much heat weakens the magnets and will damage the winding's insulation.

When converting electricity into mechanical power, brushless motors are more efficient than brushed motors. This improvement is largely due to the frequency at which the electricity is switched determined by the position sensor feedback. Additional gains are due to the absence of brushes, which reduces mechanical energy loss due to friction. The enhanced efficiency is greatest in the no-load and low-load region of the motor's performance curve. Under high mechanical loads, brushless motors and high-quality brushed motors are comparable in efficiency.

Environments and requirements in which manufacturers use brushless-type DC motors include maintenance free operation, high speeds, and operation where sparking is hazardous (i.e. explosive environments) or could affect electronically sensitive equipment.

The construction of a brushless motor may resemble that of a stepper motor. Unlike a stepper, a brushless motor is usually intended to produce continuous rotation. Stepper motors generally do not include a shaft position sensor for internal feedback of the rotor position. Instead a stepper controller will rely on a sensor to detect the position of the driven device. They are frequently stopped with the rotor in a defined angular position while still producing torque. A well designed brushless motor system can also be held at zero rpm and finite torque.

5.5 What is Brushless DC motor?

A brushless DC motor (known as BLDC) is a permanent magnet synchronous electric motor which is driven by direct current (DC) electricity and it accomplishes electronically controlled commutation system (commutation is the process of producing rotational torque in the motor by changing phase currents through it at appropriate times) instead of a mechanically commutation system. BLDC motors are also referred as trapezoidal permanent magnet motors.

Unlike conventional brushed type DC motor, wherein the brushes make the mechanical contact with commutator on the rotor so as to form an electric path between a DC electric source and rotor armature windings, BLDC motor employs electrical commutation with permanent magnet rotor and a stator with a sequence of coils. In this motor, permanent magnet (or field poles) rotates and current carrying conductors are fixed.

The armature coils are switched electronically by transistors or silicon controlled rectifiers at the correct rotor position in such a way that armature field is in space quadrature with the rotor field poles. Hence the force acting on the rotor causes it to rotate. **Hall sensors** or rotary encoders are most commonly used to sense the position of the rotor and are positioned around the stator. The rotor position feedback from the sensor helps to determine when to switch the armature current.

This electronic commutation arrangement eliminates the commutator arrangement and brushes in a DC motor and hence more reliable and less noisy operation is achieved. Due to the absence of brushes BLDC motors are capable to run at high speeds. The efficiency of BLDC motors is typically 85 to 90 percent, whereas as brushed type DC motors are 75 to 80 percent efficient. There are wide varieties of BLDC motors available ranging from small power range to fractional horsepower, integral horsepower and large power ranges.

The construction of this motor has many similarities of three phase induction motor as well as conventional DC motor. This motor has stator and rotor parts as like all other motors. Stator of a BLDC motor made up of stacked steel laminations to carry the windings. These windings are placed in slots which are axially cut along the inner periphery of the stator. These windings can be arranged in either star or delta. However, most BLDC motors have three phase star connected stator.

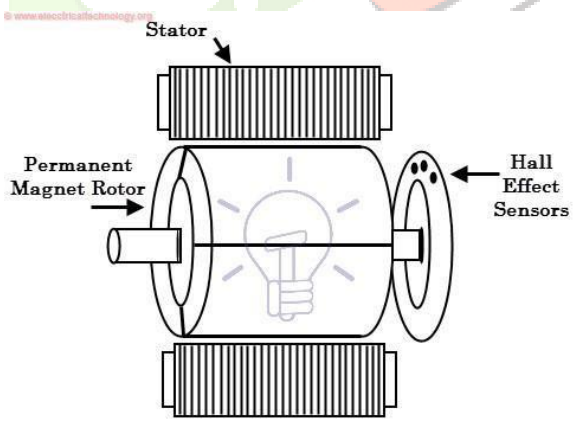


Figure 3 BLDC motor with hall effect sensors

Each winding is constructed with numerous interconnected coils, where one or more coils are placed in each slot. In order to form an even number of poles, each of these windings is distributed over the stator periphery.

The stator must be chosen with the correct rating of the voltage depending on the power supply capability. For robotics, automotive and small actuating applications, 48 V or less voltage BLDC motors are preferred. For industrial applications and automation systems, 100 V or higher rating motors are used.

Rotor

BLDC motor incorporates a permanent magnet in the rotor. The number of poles in the rotor can vary from 2 to 8 pole pairs with alternate south and north poles depending on the application requirement. In order to achieve maximum torque in the motor, the flux density of the material should be high. A proper magnetic material for the rotor is needed to produce required magnetic field density.

Ferrite magnets are inexpensive, however they have a low flux density for a given volume. Rare earth alloy magnets are commonly used for new designs. Some of these alloys are
Samarium Cobalt (SmCo), Neodymium (Nd), and Ferrite and Boron (NdFeB). The rotor can be constructed with different core configurations such as the circular core with permanent magnet on the periphery, circular core with rectangular magnets, etc.

5.6 Hall Sensors

Hall sensor provides the information to synchronize stator armature excitation with rotor position. Since the commutation of BLDC motor is controlled electronically, the stator windings should be energized in sequence in order to rotate the motor. Before energizing a particular stator winding, acknowledgment of rotor position is necessary. So the Hall Effect sensor embedded in stator senses the rotor position.

Most BLDC motors incorporate three Hall sensors which are embedded into the stator. Each sensor generates Low and High signals whenever the rotor poles pass near to it. The exact commutation sequence to the stator winding can be determined based on the combination of these three sensor‘s response.

5.7 Working Principle and Operation of BLDC Motor

BLDC motor works on the principle similar to that of a conventional DC motor, i.e., the Lorentz force law which states that whenever a current carrying conductor placed in a magnetic field it experiences a force. As a consequence of reaction force, the magnet will experience an equal and opposite force. In case BLDC motor, the current carrying conductor is stationary while the permanent magnet moves.

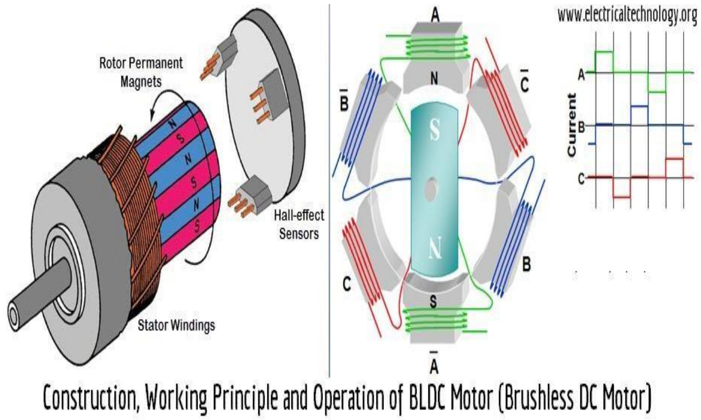


fig4 bldc motor construction

When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.

Consider the figure below in which motor stator is excited based on different switching states. With the switching of windings as High and Low signals, corresponding winding energized as North and South poles. The permanent magnet rotor with North and South poles align with stator poles causing motor to rotate.

Observe that motor produces torque because of the development of attraction forces (when North-South or South-North alignment) and repulsion forces (when North-North or South-South alignment). By this way motor moves in a clockwise direction

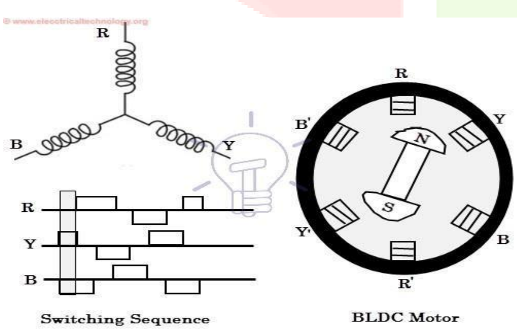


Fig switching sequence of BLDC

Here, one might get a question that how we know which stator coil should be energized and when to do. This is because; the motor continuous rotation depends on the switching sequence around the coils. As discussed above that Hall sensors give shaft position feedback to the electronic controller unit.

Based on this signal from sensor, the controller decides particular coils to energize. Halleffect sensors generate Low and High level signals whenever rotor poles pass near to it. These signals determine the position of the shaft.

5.8 Brushless DC Motor Drive

As described above that the electronic controller circuit energizes appropriate motor winding by turning transistor or other solid state switches to rotate the motor continuously. The figure below shows the simple BLDC motor drive circuit which consists of MOSFET bridge (also called as inverter bridge), electronic controller, hall effect sensor and BLDC motor.

Here, Hall-effect sensors are used for position and speed feedback. The electronic controller can be a microcontroller unit or microprocessor or DSP processor or FPGA unit or any other controller. This controller receives these signals, processes them and sends the control signals to the MOSFET driver circuit

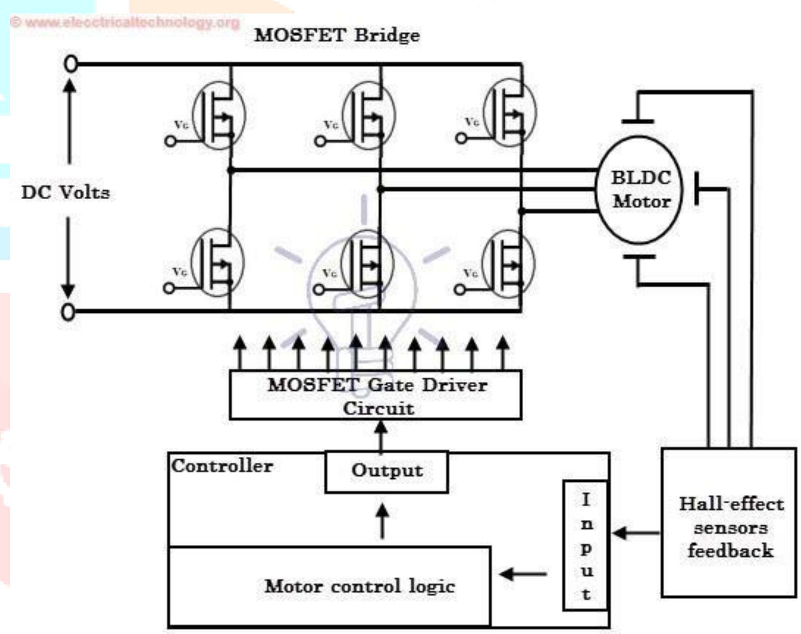


Fig . BLDC motor drive circuit

In addition to the switching for a rated speed of the motor, additional electronic circuitry changes the motor speed based on required application. These speed control units are generally implemented with PID controllers to have precise control. It is also possible to produce fourquadrant operation from the motor whilst maintaining good efficiency throughout the speed variations using modern drives.

5.9 Advantages of BLDC Motor

BLDC motor has several advantages over conventional DC motors and some of these are

- It has no mechanical commutator and associated problems
- High efficiency due to the use of permanent magnet rotor
- High speed of operation even in loaded and unloaded conditions due to the absence of brushes that limits the speed
- Smaller motor geometry and lighter in weight than both brushed type DC and induction AC motors
- Long life as no inspection and maintenance is required for commutator system
- Higher dynamic response due to low inertia and carrying windings in the stator
- Less electromagnetic interference
- Quite operation (or low noise) due to absence of brushes

5.10 Disadvantages of BLDC Motor

- These motors are costly
- Electronic controller required control this motor is expensive
- Not much availability of many integrated electronic control solutions, especially for tiny BLDC motors
- Requires complex drive circuitry
- Need of additional sensors

5.11 Applications of BLDC Motors

Brushless DC motors (BLDC) are used for a wide variety of application requirements such as varying loads, constant loads and positioning applications in the fields of industrial control, automotive, aviation, automation systems, health care equipments, etc. Some specific applications of BLDC motors are

- Computer hard drives and DVD/CD players
- Electric vehicles, hybrid vehicles, and electric bicycles
- Industrial robots, CNC machine tools, and simple belt driven systems
- Washing machines, compressors and dryers
- Fans, pumps and blowers

5.12 COMMUTATION TORQUE RIPPLES IN BLDC MOTORS

In conventional DC motors with brushes, the field winding is on the stator and armature winding is on the rotor. The motor is expensive and requires maintenance due to the brushes and accumulation of brush debris, dust, commutator surface wear, and arcing. The brushless DC (BLDC) motor could overcome this issue by replacing the mechanical switching components (commutator and brushes) using electronic semiconductor switches. The BLDC motor has a permanent magnet rotor and a wound field stator, which is connected to a power electronic switching circuit

BLDC motor drives have high efficiency, low maintenance and long life, low noise, control simplicity, low weight, and compact construction. Due to these features, the BLDC motor has become a very popular and viable product in the market. In fact, the BLDC motor has more advantages compared with other types of AC motors in the market.

Based on the shape of the BEMF (Fig. 1), brushless motors can be trapezoidal or sinusoidal. In the BLDC motor, permanent magnets produce an air gap flux density distribution, which is trapezoidal, resulting in trapezoidal BEMF waveforms.

Torque pulsations in BLDC motors brought about by the deviation from ideal conditions are either related to the design factors of the motor or to the power inverter supply, thereby resulting in non-ideal current waveforms. Undesirable torque pulsation in the BLDC motor drive causes speed oscillations and excitation of resonances in mechanical portions of the drive, leading to acoustic noise and visible vibration patterns in high-precision machines. BLDC motor torque pulsations produce noise and vibration in the system. Therefore, minimization or elimination of noise and vibration is a considerable issue in BLDC drive.

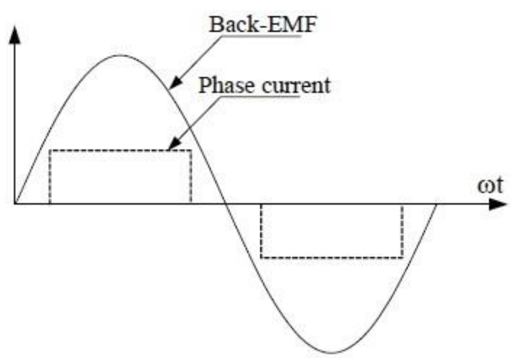


Fig Sinusoidal Induced EMF

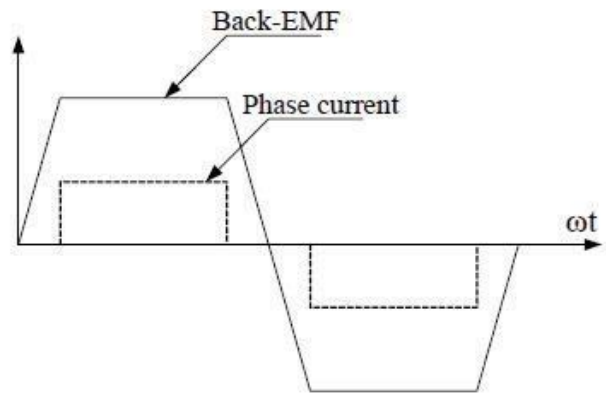


Fig Trapezoidal Induced EMF

Torque pulsations are mainly minimized by two techniques: improved motor designs and improved control schemes. Improved motor design techniques for pulsating torque minimization include skewing, fractional slot winding, short pitch winding, increased number of phases, air gap windings, adjusting stator slot opening and wedges , and rotor magnetic design through magnet pole arc, width, and positions.

For improved motor control schemes, digital control-based techniques, such as adaptive, preprogrammed current, harmonics injection techniques, estimators and observers, speed loop disturbance rejection, high speed current regulators, commutation torque minimizations. The digital control found in many applications in motor drive systems, is used in applications requiring high-speed and precision control. Advanced microprocessors, microcontrollers, and digital signal processors are used to generate and analyze drive system signals as well as detect and protect the system from abnormal over-voltage conditions.

PM BLDC control drive system

The BLDC control drive system is based on the feedback of rotor position, which is obtained at fixed points typically every 60 electrical degrees for six-step commutation of the phase currents. To switch the motor stator coils in the correct sequence and at the correct time, the position of the rotor field magnets must be known. The exact location of the rotor field magnets can be sensed by Hall Effect sensors or by using encoders. The function of the controller is to switch the appropriate currents in the right stator coils at the right time and sequence by taking the information supplied by the sensor and processing it with preprogrammed commands to achieve the desired motor performance.

For a BLDC motor drive with a 120 electrical degree conduction time, the current produces the torque spike every 60 degrees, causing the rotor to pulsate at a frequency six times the fundamental one. As the torque is a product of induced voltage and current, and the voltage does not change spike-wise, these spikes are mainly produced by the rapid transition of the current with a slight delay at the switching instants

Sources of torque ripples in PM BLDC motors

The general sources of torque ripples in BLDC motors fall in three main categories:

a) Motor Nature,

b) Motor Structure, and

c) Motor Control.

Motor nature:

Ripples associated with motor nature refer to the physical properties and parameters of the motor‘s manufactured materials. Better selection of materials lead to better performance.

Motor structure:

This is associated with the motor‘s design parameters, such as shape and dimensions. Careful consideration of these parameters leads to good performance design.

Motor Control:

Many techniques have been introduced to minimize torque ripples. This paper will highlight the minimization of torque ripples in BLDC motors from the motor control side.

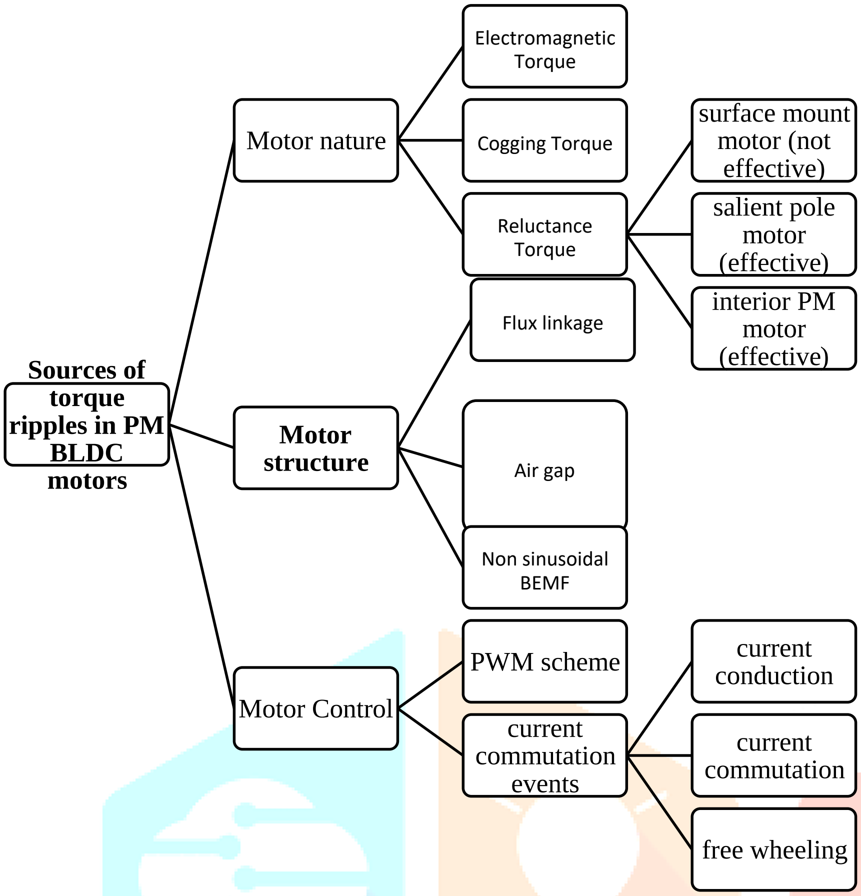


Fig Sources of torque ripples in PM BLDC motors

As stated by Jahns, a pulsating torque (PT) refers to any source of divergence from ideal conditions in either the motor or associated power converter in a PMAC motor drive, which typically gives rise to undesired torque pulsations.

The PT is the sum of the cogging and ripple torque components. Cogging torque ripple comes from the interaction of the teeth and slots with permanent magnet. It is usually reduced through rational motor structuring, such as skewing stator teeth or rotor magnet poles, notching in teeth, shifting magnet poles pair, and setting the optimum ratio of pole arc to pole pitch. No stator excitation is involved in cogging torque production .

Ripple torque components are generated by the interaction of stator current magneto motive forces, which could be the mutual or alignment and the reluctance torque. Mutual torque results from the interaction of the current‘s mmf with rotor magnet flux distribution. The reluctance results from the interaction of the current‘s mmf with the angular variation in the rotor magnetic reluctance. In surface-mounted PMAC machines, no reluctance torque is generated.

The minimization of these torques entails using techniquesto adjust the design of PMAC machines to produce characteristics that are as close as possible to the ideal one. The second approach is the utilization of various controls and drive approaches. This paper focuses on the minimization of torque in a BLDC motor using the control side approach.

Control techniques to minimize the torque ripples in BLDC machines

Various hybrid converter topologies have been proposed with a dc–dc converter to improve torque performance of two-level (2-level) inverter-fed BLDCM .

A buck converter has been employed between the dc supply and conventional 2-level inverter for the speed control of BLDCM, which can significantly reduce the torque ripple at lower speeds. A super-lift Luo-converter has been employed in front of the 2-level inverter to lift the dc-bus voltage to the desired value for the torque ripple suppression at high-speed work conditions .

A novel circuit topology with single-ended primary inductor converter (SEPIC) and a switch selection circuit has been proposed for torque ripple suppression of BLDCM drive with dc-bus voltage control. To reduce the commutation torque ripple, a voltage control strategy has been proposed to equalize the slew rates of incoming and outgoing phase currents.

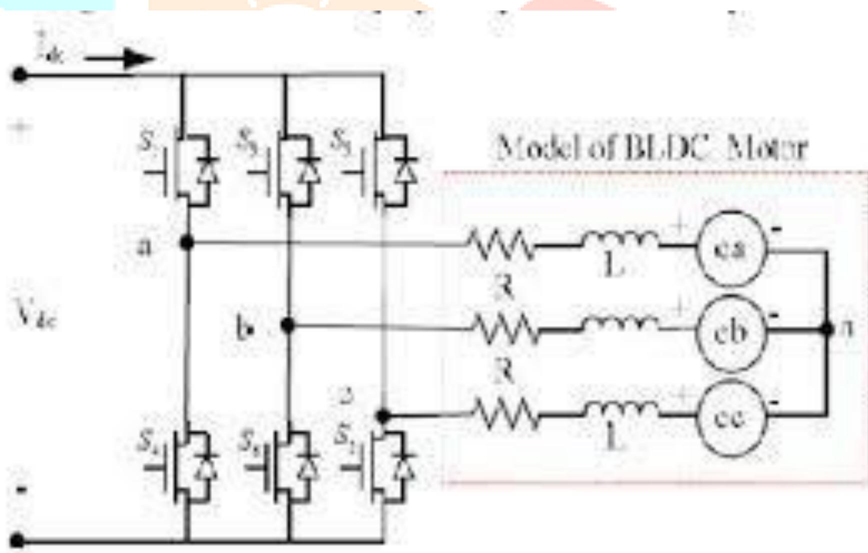


Fig.1 Schematic diagram of two level inverter fed BLDC motor

A novel circuit topology has been proposed for torque ripple suppression of the BLDCM drive system which is built by a three-level diode clamped multilevel inverter (3-level DCMLI) with two SEPICs and a commutation voltage selection circuit. In an average torque control method using one-cycle control has been proposed using dc-bus voltage and current measurements, without using back EMF and accurate rotor position information.

In order to suppress the torque ripple for BLDCM, a current optimization technique has been proposed in both conduction mode and commutation mode using integral variable structure control. A vector approach has been reported for the suppression of torque ripple of BLDCM drive by synthesizing the motor current supply. For low inductance BLDCM, a novel torque ripple reduction techniques have been proposed based on the instantaneous torque control approach. A compensation method has been developed to correct the position error due to misalignments of magnets and Hall-effect sensors which improves the accuracy of instantaneous torque estimation. Also, adaptive asymmetry compensation function has been developed to eliminate a problem related with a voltage unbalance between three phase windings. A hybrid two- and three-phase switching mode has been proposed to improve the torque performance of direct torque controlled BLDCM drive.

A direct adaptive controller has been proposed to improve inverter current regulation during large back EMF operation, which results in significant torque ripple suppression. A novel current control algorithm has been reported for torque ripple suppression of BLDCM drive using Fourier series coefficients. In most industrial low- and medium-power applications, a conventional 2-level inverter is a preferred choice. The multilevel-inverter-driven ac machines are used in many industrial high-power applications due to lower harmonic distortion of the output currents and operate with reduced *dv/dt* stress as compared to the 2-level inverter-driven ac machines. The BLDCM is widely used in more electric aircraft applications in a power range of 100–150 kW and dc-bus voltage is from 270 to 540 *V* dc. The multilevel converters such as flying capacitor (FC) inverter, cascaded H-bridge (CHB) inverter, and neutral-point clamped (NPC) inverter have been widely used in high-power medium-voltage applications.

For FC inverter, the capacitor clamping requires a large number of expensive and bulky capacitors to clamp the voltage. It requires a complex control for voltage tracking of capacitors, difficult to control precharging of capacitors to the same voltage level, and operates with poor efficiency. A five-level CHB inverter has been proposed for harmonics and torque ripple suppression of BLDCM drive with current and speed closed loop control. This converter needs galvanically isolated dc source for each of the H-bridge. In recent years, the MOSFET-based 3level DCMLIs are preferred to drive BLDCM for low and medium power applications, which produce low current total harmonic distortion (THD) in the stator windings, smaller voltage steps, reduced switching loss under high switching frequency, and lower common mode voltage amplitude than the conventional 2-level inverter.

The 3-level DCMLI topology provides a significant reduction in ripple current for lowinductance BLDCM without the need for very high switching frequency than the 2-level inverter. Also, it operates with a lower number of dc sources and power semiconductor devices than FC multilevel inverter and CHB multilevel inverter.

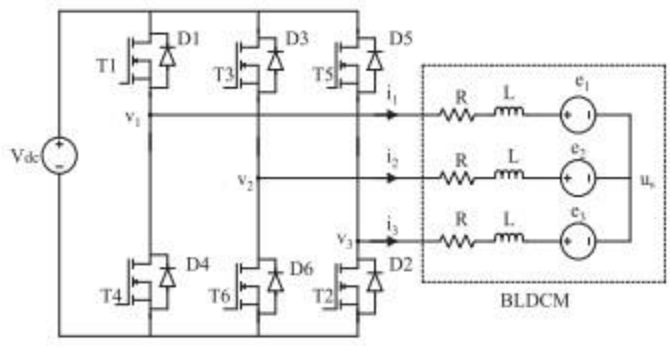


Fig Equivalent model of 2-level inverter-fed BLDCM.

In this paper, a novel converter topology is proposed to reduce the torque ripple of the BLDCM drive system. The proposed converter is composed a modified SEPIC and a MOSFETbased 3-level DCMLI. The modified SEPIC operates with high static gain and less switching voltage stress than classical dc–dc converters. Hence, the modified SEPIC is used in this proposed torque ripple suppression circuit and the duty cycle is adjusted to obtain the desired dcbus voltage based on the spinning speed of the BLDCM. The 3-level DCMLI is used for further reduction of the current ripple and as well as the resultant torque ripple. The MOSFET-based voltage selector circuit is used to apply regulated dc-bus voltage for efficient commutation torque ripple suppression. Simulation and experimental results show that the proposed converter topology with the dc-bus voltage selector circuit significantly reduces the torque ripple during the commutation interval.

CHAPTER-6

SOFTWARE DESCRIPTION

6.1MATLAB

6.1.1 Introduction to Matlab:

Matlab is a high-performance language for technical computing. The name mat lab stands for matrix laboratory. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building.

Matlab is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar no interactive language such as C or FORTRAN.

6.1.2 History of Matlab:

Cleve Barry Moler, the chairman of the computer-science department at the University of New Mexico, he is a mathematician and computer programmer specializing in numerical analysis. Started developing MATLAB in the late 1970s. He designed it to give his students access to LINPACK and EISPACK without their having to learn Fortran. It soon spread to other universities and found a strong audience within the applied mathematics community. Jack Little, an engineer, was exposed to it during a visit Moler made to Stanford University in 1983. Recognizing its commercial potential, he joined with Moler and Steve Bangert. They rewrote MATLAB in C and founded Math Works in 1984 to continue its development. These rewritten libraries were known as JACKPAC. In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation, LAPACK.

6.1.3 Strengths of Matlab:

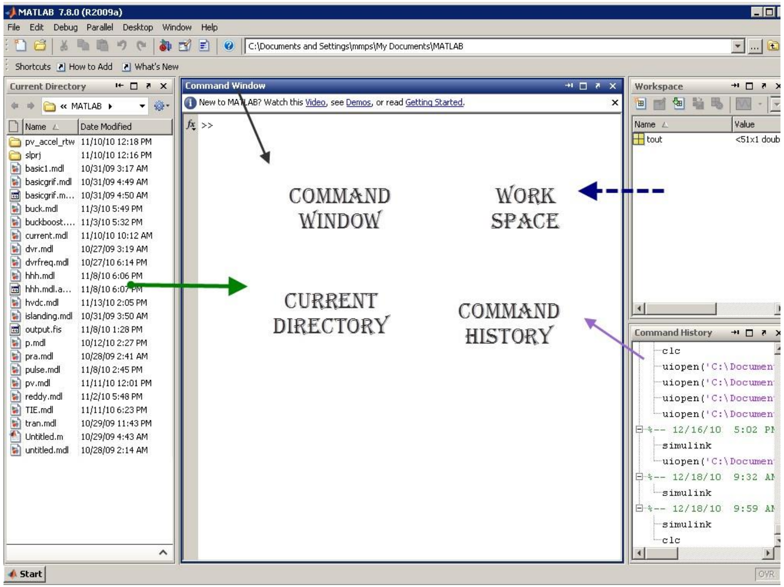
- MATLAB is relatively easy to learn.
- MATLAB code is optimized to be relatively quick when performing matrix operations.
- MATLAB may behave like a calculator or as a programming language.
- MATLAB is interpreted, errors are easier to fix.
- Although primarily procedural, MATLAB does have some object-oriented elements.

6.1.4 Other features:

- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces
- Functions for integrating MATLAB based algorithms with external applications and

6.1.5 Components of Matlab:

- Workspace
- Current Directory
- Command History
- Command Window



Block diagram of Mat lab components

6.1.6 MATLAB and engineering:

MATLAB was first adopted by researchers and practitioners in control engineering, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved in image processing. However, many researchers mostly from Computer Science background feel that MATLAB should be used only for mathematical analysis necessary in image processing and not for implementation of image processing software. Moreover, MATLAB should not be used to simulate computer architectures, systems software and computer networks unless while solving some numeric problem.

Toolboxes in Matlab:

- Simulink
- Fuzzy
- Genetic algorithm
- Neural network
- Wavelet

6.2 SIMULINK

- Introduction:

Simulink is a software add-on to mat lab which is a mathematical tool developed by The Math works,(http://www.mathworks.com) a company based in Natick. Mat lab is powered by extensive numerical analysis capability. Simulink is a tool used to visually program a dynamic system (those governed by Differential equations) and look at results. Any logic circuit, or control system for a dynamic system can be built by using standard building blocks available in Simulink Libraries. Various toolboxes for different techniques, such as Fuzzy Logic, Neural Networks, DSP, Statistics etc. are available with Simulink, which enhance the processing power of the tool. The main advantage is the availability of templates / building blocks, which avoid the necessity of typing code for small mathematical processes.

- Concept of signal and logic flow:

In Simulink, data/information from various blocks are sent to another block by lines connecting the relevant blocks. Signals can be generated and fed into blocks dynamic / static).Data can be fed into functions. Data can then be dumped into sinks, which could be scopes, displays or could be saved to a file. Data can be connected from one block to another, can be branched, multiplexed etc. In simulation, data is processed and transferred only at discrete times, since all computers are discrete systems. Thus, a simulation time step (otherwise called an integration time step) is essential, and the selection of that step is determined by the fastest dynamics in the simulated system.

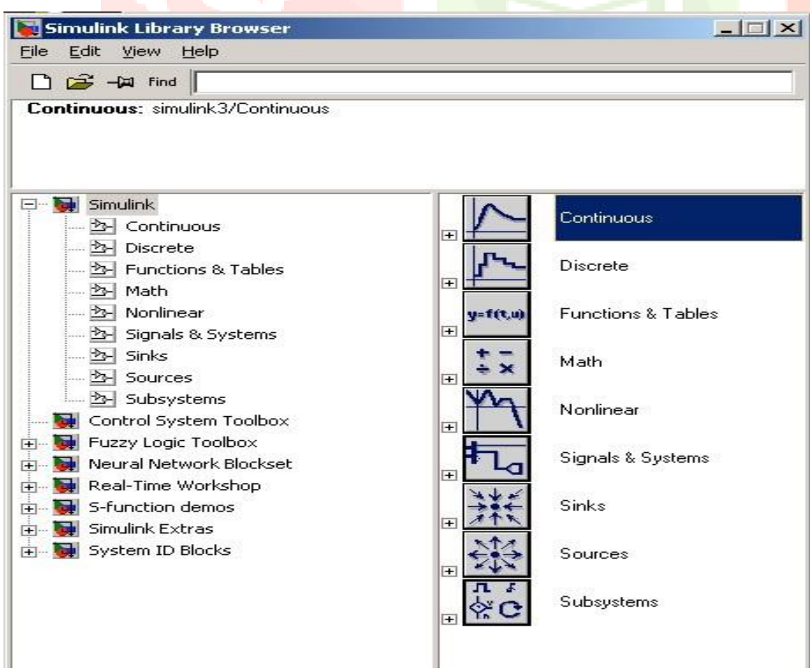


Fig 6.1 Simulink library browser

- Connecting blocks:

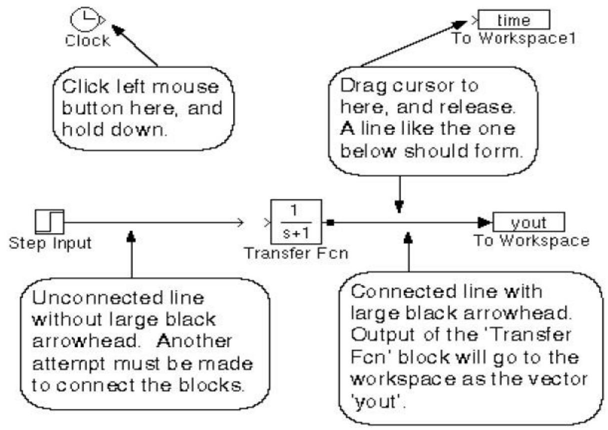


fig 6.2 Connectung blocks

To connect blocks, left-click and drag the mouse from the output of one block to the input of another block.

Sources and sinks:

The sources library contains the sources of data/signals that one would use in a dynamic system simulation. One may want to use a constant input, a sinusoidal wave, a step, a repeating sequence such as a pulse train, a ramp etc. One may want to test disturbance effects, and can use the random signal generator to simulate noise. The clock may be used to create a time index for plotting purposes. The ground could be used to connect to any unused port, to avoid warning messages indicating unconnected ports.

The sinks are blocks where signals are terminated or ultimately used. In most cases, we would want to store the resulting data in a file, or a matrix of variables. The data could be displayed or even stored to a file. The stop block could be used to stop the simulation if the input to that block (the signal being sunk) is non-zero. Figure 3 shows the available blocks in the sources and sinks libraries. Unused signals must be terminated, to prevent warnings about unconnected signals.

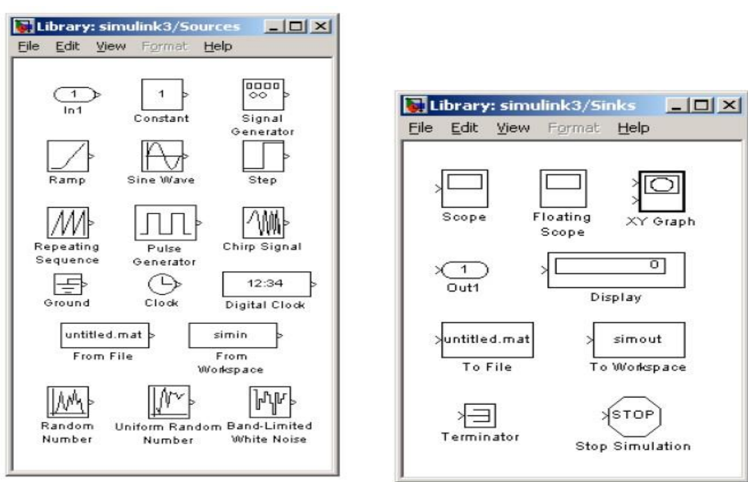


fig 6.3 Sources and sinks

➢ Continuous and discrete systems:

All dynamic systems can be analyzed as continuous or discrete time systems. Simulink allows you to represent these systems using transfer functions, integration blocks, delay blocks etc.

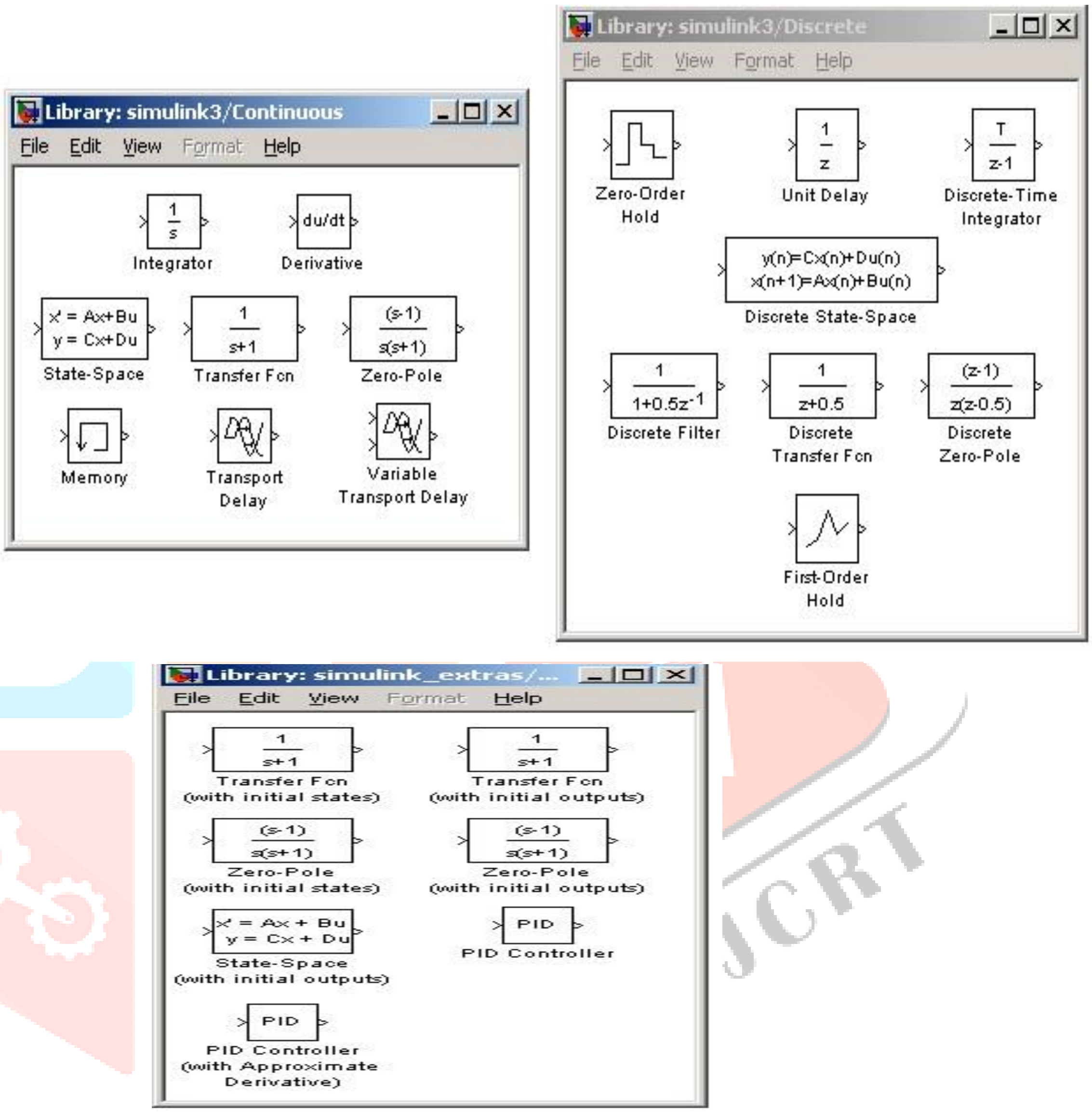


fig 6.4 continous and descrete systems

➢ Non-linear operators:

A main advantage of using tools such as Simulink is the ability to simulate non-linear systems and arrive at results without having to solve analytically. It is very difficult to arrive at an analytical solution for a system having non-linearities such as saturation, signup function, limited slew rates etc. In Simulation, since systems are analyzed using iterations, non-linearities are not a hindrance. One such could be a saturation block, to indicate a physical limitation on a parameter, such as a voltage signal to a motor etc. Manual switches are useful when trying simulations with different cases. Switches are the logical equivalent of if-then statements

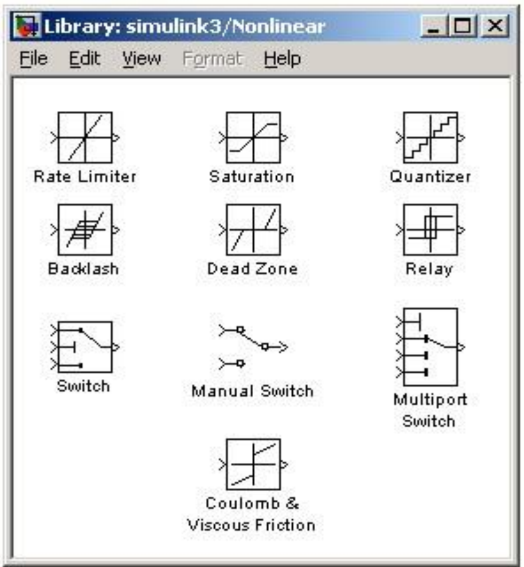


fig 6.5 simulink blocks

➢ Mathematical operations:

Mathematical operators such as products, sum, logical operations such as and, or, etc. can be programmed along with the signal flow. Matrix multiplication becomes easy with the matrix gain block. Trigonometric functions such as sin or tan inverse (at an) are also available.

Relational operators such as _equal to‘, _greater than‘ etc. can also be used in logic circuits.

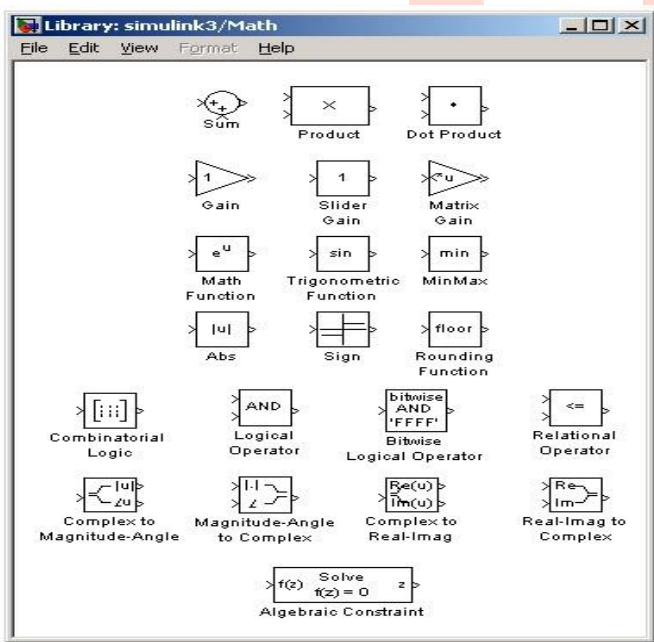


Fig 6.6 Simulink math blocks

➢ Signals & data transfer:

In complicated block diagrams, there may arise the need to transfer data from one portion to another portion of the block. They may be in different subsystems. That signal could be dumped into a GOTO block, which is used to send signals from one subsystem to another.

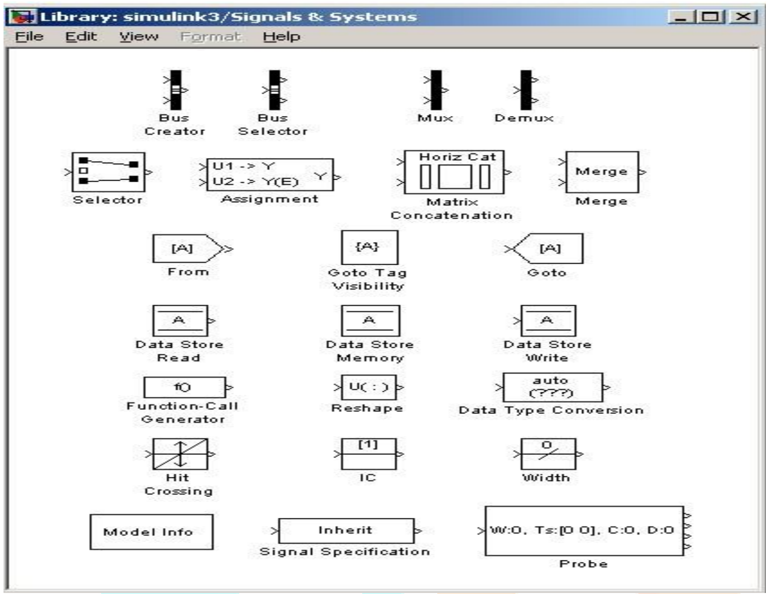


fig signals and systems

Multiplexing helps us remove clutter due to excessive connectors, and makes matrix (column/row) visualization easier.

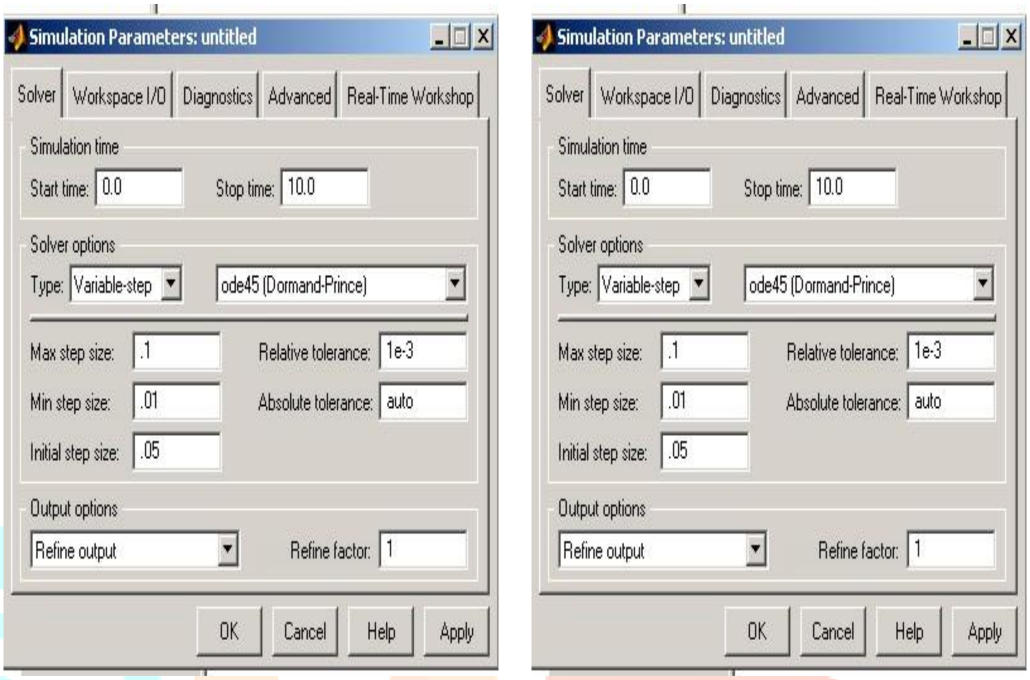
➢ Making subsystems:

Drag a subsystem from the Simulink Library Browser and place it in the parent block where you would like to hide the code. The type of subsystem depends on the purpose of the block. In general one will use the standard subsystem but other subsystems can be chosen. For instance, the subsystem can be a triggered block, which is enabled only when a trigger signal is received.

Open (double click) the subsystem and create input / output PORTS, which transfer signals into and out of the subsystem. The input and output ports are created by dragging them from the Sources and Sinks directories respectively. When ports are created in the subsystem, they automatically create ports on the external (parent) block. This allows for connecting the appropriate signals from the parent block to the subsystem.

➢ Setting simulation parameters:

Running a simulation in the computer always requires a numerical technique to solve a differential equation. The system can be simulated as a continuous system or a discrete system based on the blocks inside. The simulation start and stop time can be specified. In case of variable step size, the smallest and largest step size can be specified. A Fixed step size is recommended and it allows for indexing time to a precise number of points, thus controlling the size of the data vector. Simulation step size must be decided based on the dynamics of the system. A thermal process may warrant a step size of a few seconds, but a DC motor in the system may be quite fast and may require a step size of a few milliseconds.



Simpower system:

- Introduction:

SimPowerSystems software and other products of the Physical Modeling product family work together with Simulink software to model electrical, mechanical, and control systems.

SimPowerSystems software operates in the Simulink environment. Therefore, before starting this user's guide, make yourself familiar with Simulink documentation. Or, if you perform signal processing and communications tasks (as opposed to control system design tasks), see the Signal Processing Block set documentation.

- The Role of Simulation in Design:

Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems. Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques.

Further complicating the analyst's role is the fact that the system is often so nonlinear that the only way to understand it is through simulation.

Land-based power generation from hydroelectric, steam, or other devices is not the only use of power systems. A common attribute of these systems is their use of power electronics and control systems to achieve their performance objectives.

SimPowerSystems software is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. It uses the Simulink environment, allowing you to build a model using simple *click and drag* procedures. Not only can you draw the circuit topology rapidly, but your analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library.

Since Simulink uses the MATLAB computational engine, designers can also use MATLAB toolboxes and Simulink block sets. SimPowerSystems software belongs to the Physical Modeling product family and uses similar block and connection line interface.

- Sim power systems Libraries:

SimPowerSystems libraries contain models of typical power equipment such as transformers, lines, machines, and power electronics. These models are proven ones coming from textbooks, and their validity is based on the experience of the Power Systems Testing and Simulation Laboratory of Hydro-Québec, a large North American utility located in Canada, and also on the experience of École de Technology Supérieure and Université Laval. The capabilities of SimPowerSystems software for modeling a typical electrical system are illustrated in demonstration files. And for users who want to refresh their knowledge of power system theory, there are also self-learning case studies.

The Sim Power Systems main library, power lib, organizes its blocks into libraries according to their behavior. The power lib library window displays the block library icons and names. Double-click a library icon to open the library and access the blocks. The main power lib library window also contains the Powergui block that opens a graphical user interface for the steady-state analysis of electrical circuits.

- Nonlinear Simulink Blocks for Sim power systems Models:

The nonlinear Simulink blocks of the power lib library are stored in a special block library named powerlib models. These masked Simulink models are used by Sim Power Systems software to build the equivalent Simulink model of your circuit. See Improving Simulation Performance for a description of the power lib models library.

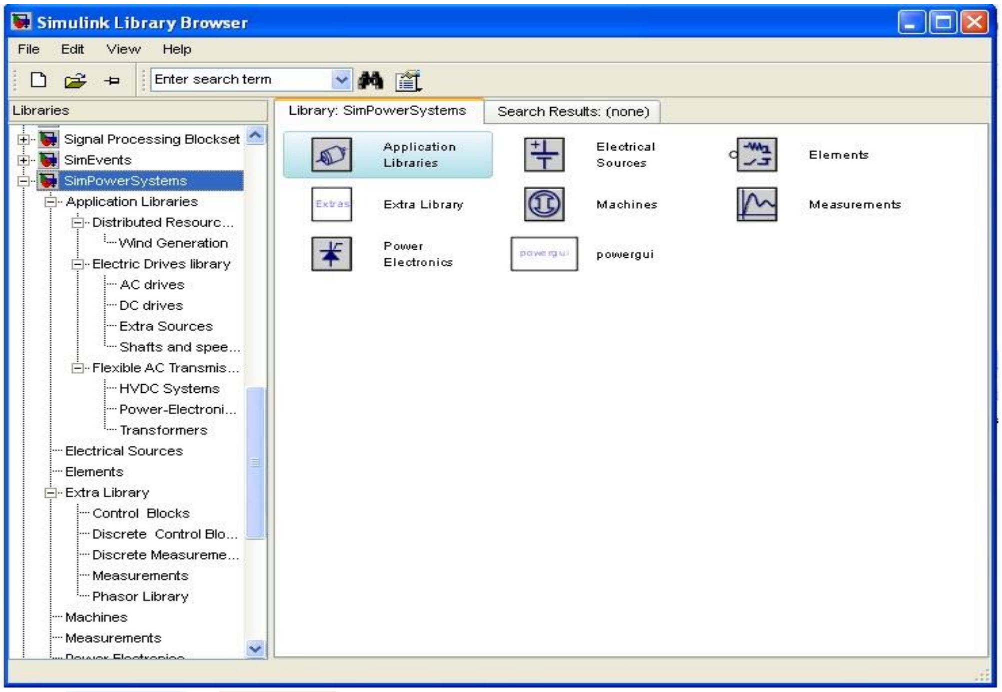


Diagram of simpower system

6.3.Applications of Matlab:

MATLAB is a data-manipulation software package that allows data to be analyzed and visualized using existing functions and user-designed programs. MATLAB is a numerical computing environment and programming language. MATLAB allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. Although it specializes in numerical computing, an optional toolbox interfaces with the Maple symbolic engine, allowing it to be part of a full computer algebra system.

Some of the mat lab applications listed are:

- Orthogonal frequency division multiplexing
- Genetic algorithm data mining
- Speech recognition using VQ method
- Channel Estimation and Detection in DS-CDMA
- Analysis of iterative channel estimation and multi-user detection in multi path DS-CDMA channels
- Time-domain signal detection
- Time-domain signal detection based on second-order statistics for mimo-OFDM systems ➢ Space–time block codes

Basic circuit designing and analyzing of results:

Click on the file and select new model file and a file will be appeared:

Now a block and right click on it, the block will be appearing in the new model file (untitled)

For example consider a sine wave in the source block and in order to obtain or to view the output place the scope block. Join those two blocks. Now a simple circuit is ready, now set the simulation time in the tool bar (default it is set to 10.0), simulate the circuit by clicking on the simulation icon (PLAY BUTTON). Simulation is completed now by double clicking on the
PLAY BUTTON

CHAPTER-7

7.1.CONCLUSION

In this paper we designed and implemented an AI-based protection technique for overload conditions in DC motor speed control applications and examined the performance and reliability of the same with the classical PI controller in real-time. From simulation results and evaluation, it was observed that, the system behavior for overload conditions is better in terms of equipment safety in comparison to its rival PI controller. Even though a delimiter along with a PI controller can limit the output of the PI controller for DC motor protection, from higher voltages, the probability for the occurrence of DC motor winding damage exists when the motor run under overload conditions with lower set point speed for a longer period. The proposed solution proves its feasibility by tripping the motor at the above conditions and thereby, ensure the safety of equipment in a long-term run.

7.2.FUTURE SCOPE

Permanent Magnet Brushless DC (PMBLDC) machines are more popular due its simple structure and low cost. Improvements in permanent magnetic materials and power electronic devices have resulted in reliable, cost effective PMBLDC drives, for many applications. Advances in artificial intelligent applications like neural network, fuzzy logic, Genetic algorithm etc. have made tremendous impact on electric motor drives. The brushless DC motor is a multivariable and non-linear system. In conventional PMBLDC drives speed and position sensing of brushless DC motors require high degree of accuracy. Unfortunately, traditional methods of control require detailed modelling of all the motor parameters to achieve this. TheIntelligent control techniques like, fuzzy logic control/Neural network control etc.It uses heuristic input–output relations to deal with vague and complex situations. This paper presents a literature survey on the intelligent control techniques for PMBLDC motor drives.Various AI techniques for PMBLDC motor drives are described. Attempt is made to provide a guideline and quick reference for the researchers and practicing engineers those are working in the area of

PMBLDC motor drives

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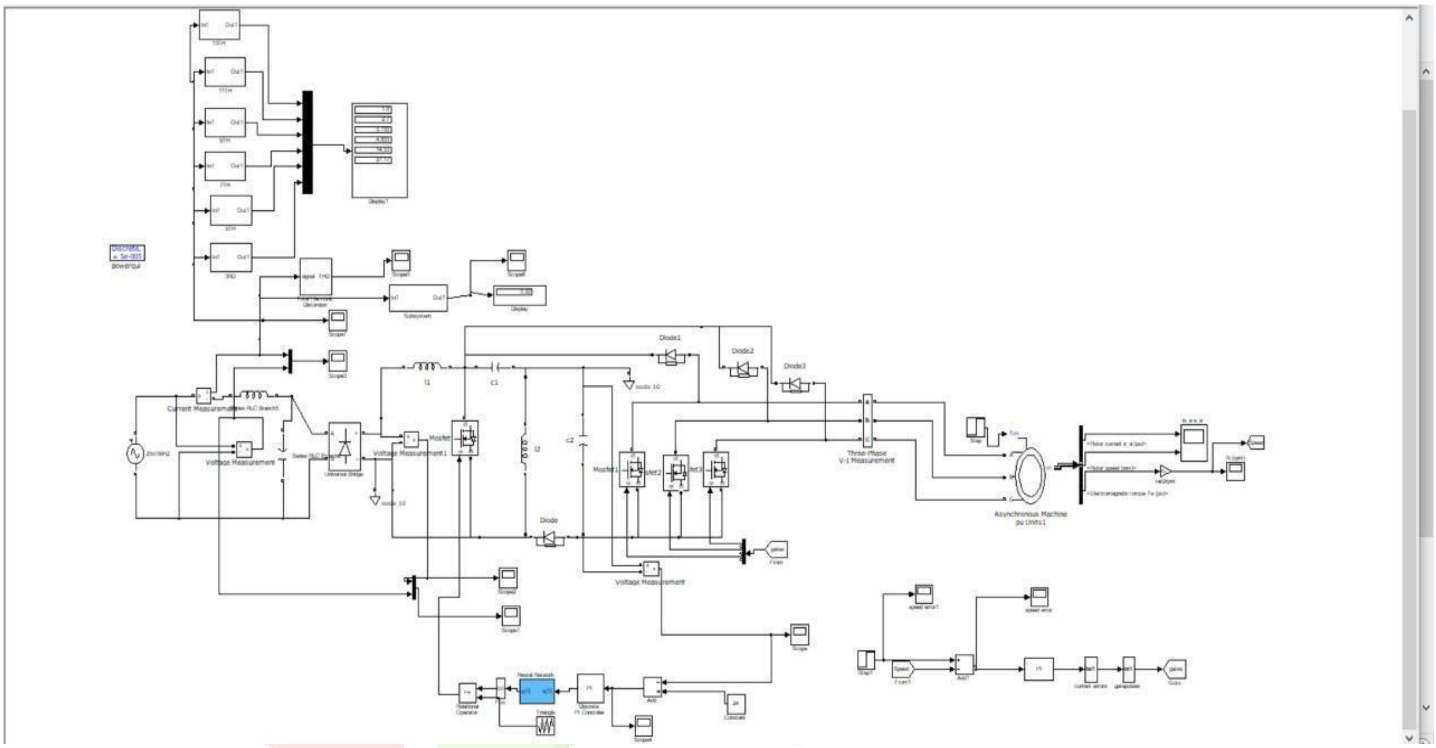
7.3.Applications

The main applications where series motors are best suited are for traction applications. Torque of the series motor is proportional to square of the field current i.e. T α I2. Therefore Starting torque for the series motor is quite high. Because of this property series motors are widely used in electric traction and in crane application.

7.4 Simulation Results



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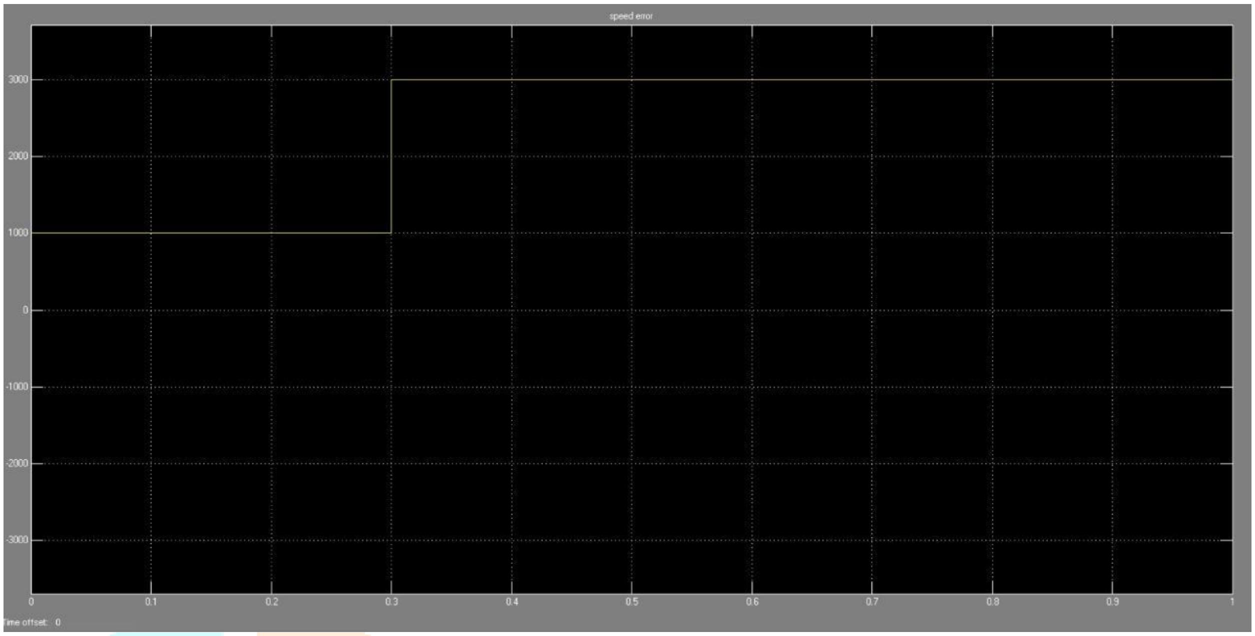
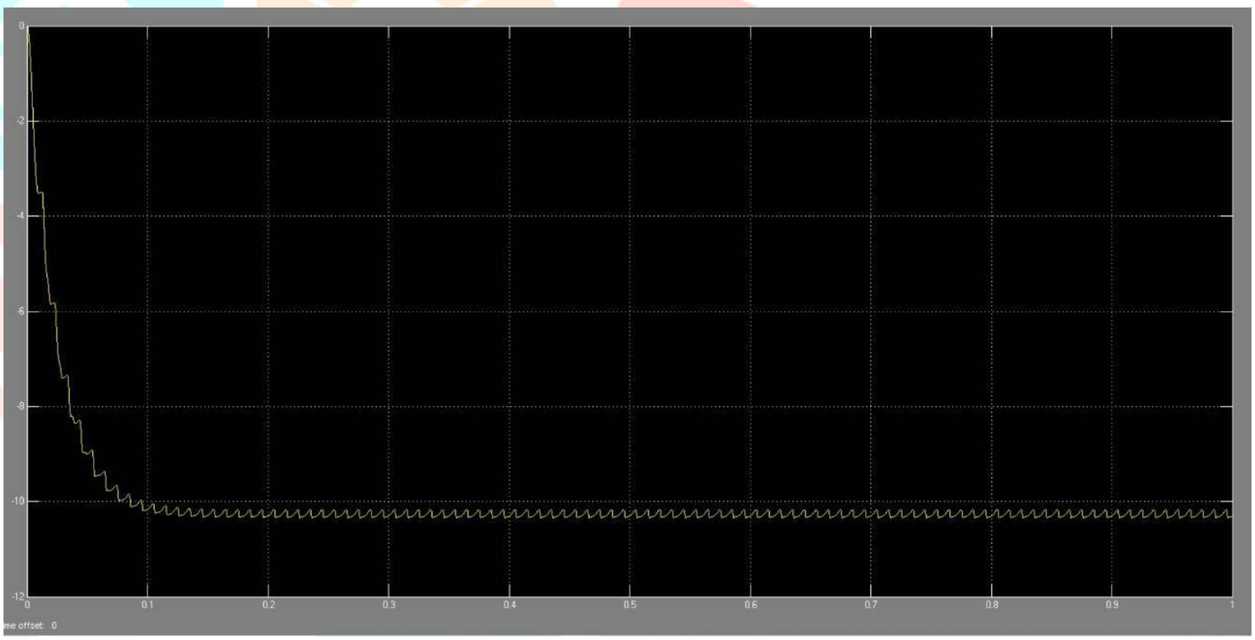
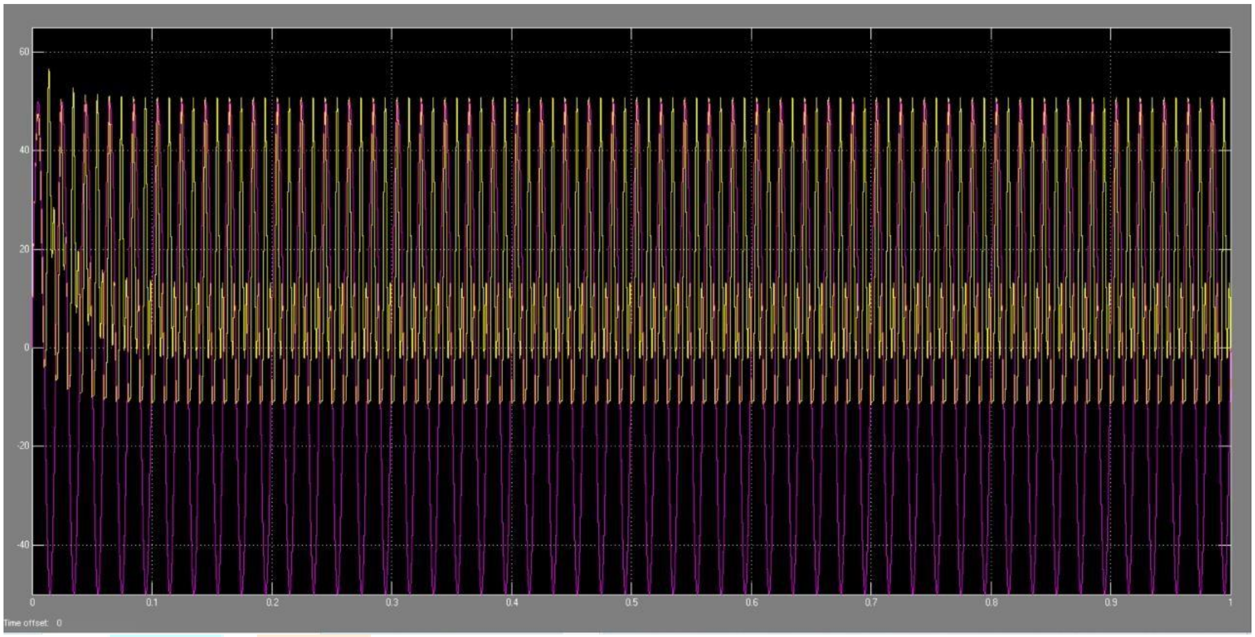


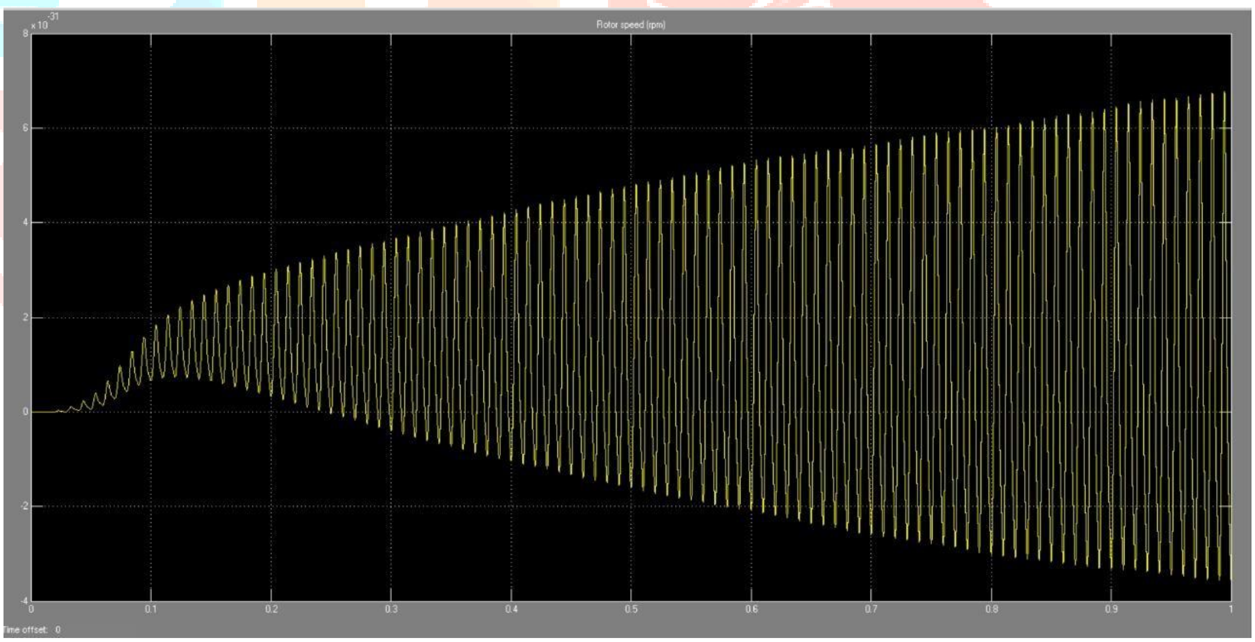
Before Controller response:



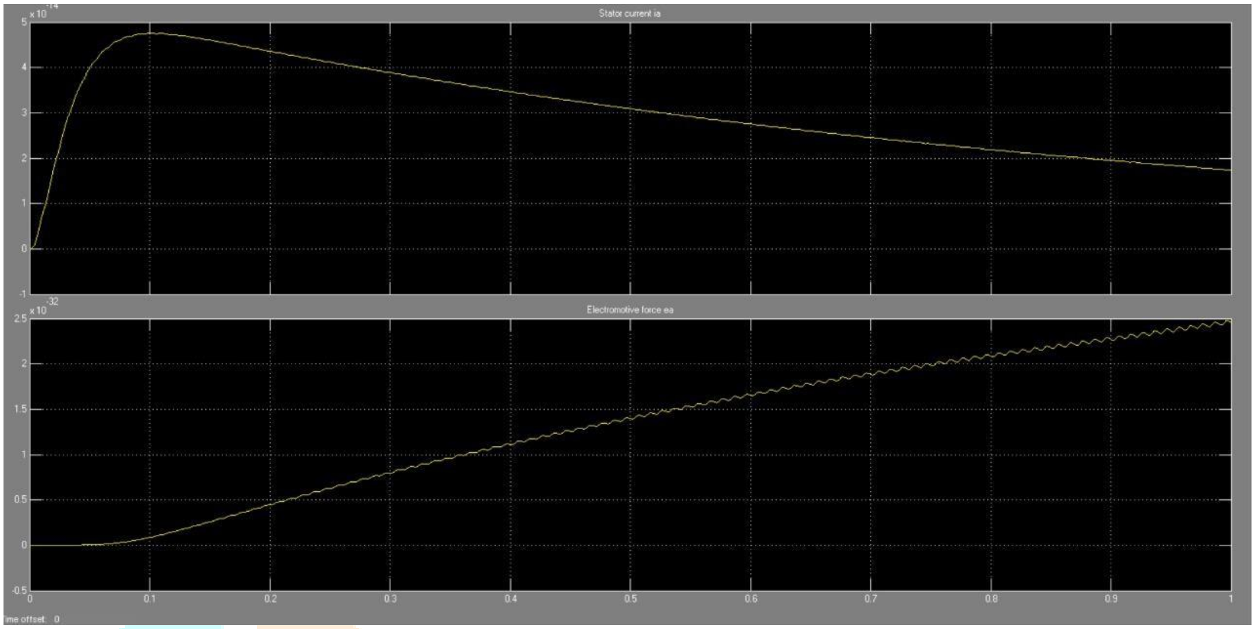
Afterresponse



Rotor Speed



Rotor Current



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