A Comparative Analysis of fuzzy logic and PID controller in industrial application of flywheel

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DECLARATION

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ABSTRACT

In this thesis work, I have considered the case study of flywheel. The conventional control scheme i.e PID controller is always effective in the actual applications in any of the industrial control system. Unwanted variations in the desired results are sometimes seen due to unknown causes. These unknown causes need to be considered so that actual results which a system is supposed to produce. In this thesis work the fluctuation in motor generator set due to variations in the applied voltage, induced current or speed variation are actually badly affecting the working of motor generator set so the fly wheel is used to help the system to perform better. In some other cases where load is increased or decreased or if load is fluctuating a stable performance of system is required. These variations are due to uncertain causes which are knowingly or unknowingly affecting the system performance are considered in fuzzy logic controller. The convention PID controllers are unable to formulate control scheme for them. The intelligent control like FLC is considering these uncertain causes within their domain. Hence the flywheel which is safe guarding and controlling the motor generator set effectively .The control scheme using FLC formulated in this thesis's work shows considerably efficient work performance of this industrial control mechanism.

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List of symbol

P	Proportional
D	Derivative
I	Integrative
PI	Proportional Integrative Controller
PD	Proportional Derivative Controller
PID	Proportional Derivative Controller
K_p	Proportional Gain
K_d	Derivative Gain
K_i	Integrative Gain
FLC	Fuzzy Logic Controller
P_m	Mechanical Power of Machine
I_a	Armature current
R_a	Resistance of Armature winding
V_f	Applied Voltage
E_b	Back emf
T_a	Armature torque
N	Speed
I	Moment of Inertia
ω	Angular Velocity
E_k	Kinetic Energy
m	Mass
r	Radius
F	Force
T_i	Integrative Time

Chapter: 1

Literature Review

1.1literature Review

Yasuhiko Dote et.al. studied that in industry fuzzy logic has been mostly used for control and measurement describe controls in the past, at present and in the future The successful history of fuzzy systems developed and applied to industry in Japan is as follows .because Rule-based inference is simple and powerful Fuzzy control is efficient technology at low cost for automation in industry Fuzzy control could solve easily nonlinear control problems with language introducing human knowledge into controllers Fuzzy technology was able to solve problems which had not been solved there are many problem in fuzzy system are now recognized as rigorous mathematical analysis of fuzzy systems has not been well established. The problems which can be solved only by fuzzy technology have not been investigated. Design methods of fuzzy systems have not been developed well."Ad hoc" methods have been used in most cases. This paper suggests the combination of neuro and fuzzy computing as soft computing used for industrial applications. Computing as soft computing used for industrial applications. Soft computing differs from conventional (hard) computing in that, unlike hard computing, it is the human mind. The guiding principle of soft computing is: underlying soft computing in its current incarnation have linked to many earlier innuences .[1]

Jong-Hwan Kim et. al. this paper describes the in industrial applications proportional integral derivative (PID) controllers are widely use. They exhibit poor performance when apply to systems containing unknown nonlinearities, such as dead zones, saturation, and hysteresis. the performance of our scheme via experiments performed on a dc servomotor position control tested under varying load conditions. They propose a fuzzy logic-based precompensation approach for PID controllers. in this results show that the fuzzy precompensated PID controllers have superior performance compared to conventional PID controllers. In his experimental test bed, the variations in loading conditions correspond to variations in the level of nonlinearities in the plant. In past, the proposed scheme is robust to variations in load. his scheme is easily implement in practice simply by add a fuzzy precompensator to an existing PID controller .the advantage of our present approach is that an existing PID control system can be easily modified into our control structure simply by adding the fuzzy precompensator. The propose control scheme has very good performance compared to a conventional PID controller. His experimental results on a DC-motor position control test bed demonstrate the robustness of our scheme to variations in loading conditions.[3]

Pin-Yan Tsai' et al In this paper, they applied the auto-tuning PID-Like fuzzy controller to some studied on adaptive control system. high order to enhance the flexibility and control capability of the controller they developed, three parameters, including system error (e(k)), error change (e(k)) and the change of error change (e(k)), arc used as the reference inputs of the fuzzy mechanism. For demonstrating the superiority of the controller they designed, two types of control systems, i.e., periodic control and model reference control, are studied and simulated. For a comparison, the traditional fuzzy controller with two inputs system error and change in error was also performed. an auto-tuning PID-Like fuzzy controller based on three influencing factors, including e(k), e(k) and E(k) is design and presented. Its applications in adaptive control systems, such as periodic control and model reference control, are studied and simulate. From the simulation results, the controller they develop can generate more appropriate farce to control the system and make the system output more effectively track the reference model output. In addition, no complex and mass computations are needed in the tuning mechanism. It cleared improve and shorten. the reaction time of the controller needed. It also show that the controller they develops highly promote the potential of fuzzy controller in real application.[4]

111 **Du Tai-hang** et al. they use of the electric motor control system and the principle of rolling plastic deformation in this paper they describe the stable state mathematical model of cold rolling process is establish. The dynamic process of cold rolling is simulate by using the MATLAB/ Simulink. Cold rolling control system exist time-delay, time-varying, large inertia, nonlinear and other problems. Setting parameters of traditional PID controller is difficult. This paper put forward methods which combine structure of a fuzzy control and PID control. By MATLAB simulating, results show that static and dynamic

performance of fuzzy adaptive PID controller is better than the traditional PID controller. Sing the MATLAB simulation, results shows that the fuzzy adaptive PID controller achieve good results in the controlling tension between cold-rolling tracks .Compare with the traditional PID controller, fuzzy PID system is of good response curve with a small overshot, high stable precision and short settling time. The tension constant of cold-rolling is significant to ensure that the smooth of continues rolling and improve the thickness accuracy, so fuzzy adaptive PID controller is of very important application value in the cold-rolling systems [5].

Zhang Ming-guang,et at. in this paper through introducing 1/1 pade series to approximate the time delay unit and use the two steps of design approach, the internal model control system can be change into conventional PID unity feedback control systems. Then use fuzzy inference to tune the PID parameters online, the fuzzy self-tuning PID internal model controller is realize. This controller combines the advantage of fuzzy controller, internal model control and PID control. Fuzzy controller use to overcome the uncertainty of mathematical model of the real plant. Internal model control use to resolve the large time-delay of the coke oven temperature control system. Simulation experiments have been done to coke oven temperature control system. Simulation results shows that system adopted fuzzy self-tuning PID internal model control have smaller steady error, smaller overshoot, shorter adjusting time, faster rising time and comparatively strong robustness. From simulation results, they could conclude that comparing with internal model control, they saw, fuzzy self tuning PID internal model control has the many advantages: System has faster rise time, small overshoot and nearly eliminates oscillation. That the system has more better dynamic performance. System has very good steady quality with shorter adjusting time and smallest steady error. When the plant’s parameters change, system adopt fuzzy self-tuning PID internal model control has strong robustness which can regulate system into steady state fast.[6]
Sanju Saini et at**.** This paper present a comparison of performance of controllers such as PID, PI controller, Self tuned fuzzy controller, G.A fuzzy PID & self tune ANFIS, for dc motor speed control. Simulation results have demonstrate that the use of self tune ANFIS results in a good dynamic behaviour of the dc motor, a perfect speed tracking with no

overshoot, give better performance and high robustness than those obtained by use of the conventional controllers. Intelligent techniques such as fuzzy logic controllers & their hybrid (ANFIS) are use for dc motor speed control. From simulations result, it is concluded that the use of ANFIS reduce design efforts. Also, it results in minimum undershoot t& overshoot & increases the speed of response. Its response is even good under variable reference speed which is shown from the results of second set of simulation.[7]

B. sharmila et al. in This paper focuses on the possibility of neuro-fuzzy controller for network control systems. The neuro-fuzzy controller have been developed for controlling the speed of the network dc motor by exploiting the combine features of neural networks and fuzzy logic concept. The major challenges in network control systems are the network induce delays and data packet losses in the closed loop. These challenge degrade the performance and weaken the systems. Furthermore the performance of the network DC motor using neuro-fuzzy controller is compared with the Ziegler - Nichols tuned proportional integral- derivative and fuzzy logic controllers. Base on the simulation results using MATLAB/SIMULINK package, it is found that the neuro-fuzzy controller can be a practical choice for a network control system due to its robustness beside parameter uncertainty. This paper has focused on the application of neuro-fuzzy controller for NCSs. The usefulness of the proposed controller was confirmed on the networked environment for motor control. In order to build the NCS for motor control, the network-induced delays and packet losses are analyzed to clarify the source of the network challenge. Comparative performance evaluations of the neuro-fuzzy controller for the network motor control are done with the conventional PID and fuzzy logic controller. Simulation results show the usefulness of the proposed neuro-fuzzy controller approach for the control of dc motor in all network variation and deteriorations. The studies on using intelligent controls improve and strengthen the network control systems concepts in the future.[8]

Atul Kumar Dewangan, et al. in this paper tuning the parameters of a PID controller is most important in PID control. Ziegler and Nichols planned the well-known Ziegler-Nichols method to tune the coefficients of PID controllers. This tuning method is very easy, but cannot assurance to be always helpful. For this reason, these papers investigate the design of self tuning for a PID controller. The controller includes two parts: conventional PID controller and fuzzy logic control (FLC) part, which has self tuning capability in set point tracking performance. The proportional (KP), integral (KI) and derivate (KD) gains in a system can be self-tuned on-line with the output of the system in control. The conventional PI controller (speed controller) in the chopper-fed DC Motor Drive is replaced by the self tuning PID controller, to compose them more common and to get minimum steady-state error, also to improve the other dynamic performance (overshoot). Computer simulation is conduct to display its performance and results show that the future design is success over the conventional PID controller. Two inputs- three outputs self tuning of a PID controller was designed and use for implementing a chopper fed-DC motor drive. The controllers combine the fuzzy technique with the PID technique to make the fuzzy self-tuning of a PID controller. The fuzzy part can be adjusting the three parameters of PID controller on-line according to the change of error and change in error. It concluded that the fuzzy self tuning controller as compared with the conventional PID controllers, it provide improvement show in both transient and the steady states response, fuzzy self tuning has no overshoot and have a smaller steady state error compared to the conventional PID controller. It can be mention here that this controller is able to mass at the stable region with inflexible performance on tracking the reference signal without wanted to exceed the received safety limitation range of the dc motor performance as armature current (Ia) and armature voltage (Va) that show in result that the maximum overshoot of the stream pulses that represents armature voltage a V did not beat 279Volt. The simulation results show that fuzzy self-tuning of a PID controller has fairly similar characteristics to its conventional equal and provides good performance.[9]

Essam Natsheh et al. In this paper proportional-integral-derivative (PID) controller and fuzzy logic controllers are compared for use in direct current (DC) motors positioning system. A simulation studied of the PID position controller for the armature-control with fixed armature current and fixed field controlled with fixed field current DC motors is performed. Fuzzy rules and the inference mechanism of the fuzzy logic controller (FLC) are evaluated by using conventional rule-lookup table that program the control knowledge in a rules form. The presentation review of the studied position controllers is based on transient response and error integral criteria. The results obtained from the FLC are not only better in the rise time, percent overshoot, and speed fluctuations but also much better in the controller output signal construction, which is much remarkable in terms of the hardware completion. The design and implementation of armature-controlled and field-controlled DC motor system using both conventional PID and PID-like FLC have been presented. Comparison of experimental results of the conventional PID controller and PID-like FLC shows that the PID-like FLC is able to perform better than the conventional PID controller. Results signify that even without knowing the details of the control plants, they were able to construct a well performed fuzzy logic controller based on the knowledge about the position controller.[10]

K. Anil Naik et al. In this paper PID controller with Internal Model Control (IMC) tuning method for the dc motor was presented for robust operation. The IMC has a single tuning parameter to regulate the performance and robustness of the controller. The proposed tuning method is very efficient in controlling the overshoot, dynamics and the stability of the speed-control system of the dc motor. The result of the IMC tuning method have been compared in the center of controller with particular frequency (PF) based tuning and Ziegler-Nichols (Z-N) closed loop tuning. A notable progress in stability of the system has been observed with IMC tuning justifying its applicability. Simulated results given in the paper show the possibility and flexibility of the IMC tuning method in the dc motor. A new robust IMC tuning based PID controller is future for dc motor control system. The proposed tuning technique has been found to increase the stability of the dc motor system. Dissimilar cases have been considered and compared to defend the suitability of the IMC tuning PID controller. From the result table it is found that the gain margins IMC tuning controller was 23.7dB higher compared with SF tuning controller and 8.9dB higher when compared with Z-N tuning controller, equally, settling time and rise time has improved with IMC tuning controller.[11]

Justin Ammerlaan et al. In this paper fuzzy logic is a normal basis for solving and molding s problems involving inexact knowledge and continuous systems. Fortunately, fuzzy logic systems are always static and subjective. In this paper they addressed the question of whether systems based on fuzzy logic can effectively adjust themselves to dynamic situations. They studied design and implement an adaptive fuzzy logic agent for playing robo cup soccer tournament and then conduct a numerical analysis of the presentation of the agent. They also extend the agent to incorporate adaptation in the cooperative situations that arise in this field, and estimate its performance under such conditions. Consequences from their analysis finally prove that their adaptive fuzzy logic agent can adjust quickly and successfully to the changing dynamic situations with which it is presented. From visual observation of the linear trends on the plots in Figures 8 and 9 it can readily be seen that the distance between the centre attacker and the defensive player is increasing in the adaptation plot, and remaining approximately linear in the no adjustment plot. Observation of a development is sufficient verification for this test. Due to the uncertainty apparent in this variable, at-test would not be able to give a sufficient degree of confidence. This visible rising trend, however, provide sufficient evidence to refuse the null hypothesis. The result obtained from this test indicates that the system kindly adapts to the opposing agent's actions. While the difference between the no adaptation case and the adaptation case is not excessively big, this indicates that the original set piece rule base dentition for this variable was sensibly high-quality, only requiring moderate amounts of modification before attaining an best definition.[12]

Manish Kumar et al. in this paper design of an proficient fuzzy logic controller involve the optimization of parameters of fuzzy sets and proper selection of rule base. There are several techniques reported in recent literature that used neural network construction and inherent algorithms to learn and optimize a fuzzy logic controller. This paper develops methodologies to learn and optimize fuzzy logic controller parameters based on neural network and genetic algorithm. The strategy have been developed applied to control an reversed pendulum and results has been compared for three dissimilar fuzzy logic controllers developed with the help of iterative learned from operator experience, genetic algorithm and neural network. The results explained that Genetic- Fuzzy and Neuro-Fuzzy approaches were able to study rule base and identify membership function parameters exactly. This paper presents a variety of methods to automatically learn the fuzzy logic controller parameters (e.g. membership function and rule base). The methods presented were based on genetic algorithm and neural network. A study has been carried out to compared the performance of controllers developed via three different methods. The controller developed has been used to control an inverted pendulum. The results illustrate that genetic-fuzzy and neuro-fuzzy controllers perform good. Genetic-Fuzzy controller was able to minimize the show index (PI) and there was no overshoot. The neuro-fuzzy approach bring the system to the final position in least amount of time, although it had a little larger PI. The advantage of the neuro-fuzzy controller could be seen in its fast junction as compared to the genetic-fuzzy approach. Both approaches were able to learn the rule base quite correctly. Whereas the plant used for illustrating the relative performance of the three controllers is a simple one, the approach is same applicable to more complex systems.[13]

E Venkata Narayana et al. In this paper evaluated the performance of conventional PID (Proportional, Integral and Derivative) controller with respect to the planned fuzzy based intelligent controller in the process of controlling the position of a spacecraft-satellite system. In general this approach is has non linearity in performance. Hence, offers major restraint in using the conventional PID controller. Also PID controller offer a major constriction in the selection of controller gain. In order to attain economics in terms of cost for a non linear space craft-satellite attitude system, it was desired to save on-board thruster fuel. Because the cost incurred toward fuel plays a major role in the overall economy. This required minimum time for control and response. This can be achieved by design a control schemes, which controls successfully in minimum time. Recent research should go on result the possible methods to achieve all the above said problems. With this aspect, this paper proposes such an successful controller design by introducing fuzzy logic based clever concepts in the designing of a spacecraft-satellite attitude control system. Lastly, this paper drafts the performance study of conventional PID controller versus proposed Fuzzy based controller designs. The entire system is modeled using MATLAB/SIMULINK and the simulation results illustrate that the proposed controller has good quality robustness, rapidity and good dynamic performance. In this paper fuzzy logic based intelligent controller design was introduced for controlling non linear spacecraft-satellite attitude control system. From the results, Even though, the PID controller produce the response with lower rise time and delay time compared with fuzzy logic controller, but it offer very high settling time due to the oscillatory behaviour in transient period. It has cruel oscillations with a very high peak overshoot which causes the damage in the system performance. The proposed fuzzy logic controller can effectively remove these dangerous oscillations and provides smooth operation in transient period. It is giving a steady state error, which is a significantly low value. Hence, it was concluded that the conventional PID controller could not be used for the control of non-linear processes like satellite position. So, the proposed fuzzy logic based controller design can be a preferable option for this.[14]

Chapter: 2

Controller: Unconventional and PID controller

2.1 Conventional control

Conventional control term is widely used in an engineers everyday life in many forms. We can control a situation, such as a fireman bringing the fire under control with the so many process control variables i.e valve of water tap etc. The term control observably implies the restoration of a desirable state which has been disturbed by external or internal influences.

Control processes exist in the most various areas. In life, for instance, control processes serve to protect plants and and industries in economics, demand and supply control the price and delivery time of a product. In any of these cases, disturbances may occur that would change the initially established state. It is the function of the control system to recognize the disturbed state and correct it by the appropriate means. In technology the term control is not only useful to the control process.

2.2 What is controller?

Controller is a device, in which closed loop control process i.e one variable (controlled variable) namely the variable to be controlled is continuously monitoring and comparing other variables, the reference variable and influenced in such a manner as to bring about adjustment to the reference variable. The sequence of action resulting in this way takes place in a closed loop. There are different types of controllers as elaborated below.

2.3 Types of controller

2.3.1 Conventional controller

2.3.2 Fuzzy controller

2.3.1Conventional controller

As conventional controllers such as P, PI, PD, PID, all their different types and realizations, and other controller types. It is a characteristic of all conventional controllers that one has to know a mathematical model of the process in order to design a controller. This type of control has a lot of sense since It is simple and based on 3 basic performance types: proportional (P), integrative (I) and derivative (D). Instead of using a small number of complex controllers, a larger number of simple PID controller used to control simpler processes in an industrial gathering in order to automate the certain more complex process.. In spite their simplicity they can be used to solve even a very complex control problems, especially when combined with different functional blocks, filters (compensators or correction blocks), selectors etc It can be expected that it will be a backbone of many complex control systems

2.4 There are different types of controller in an industry. Some of them are listed below

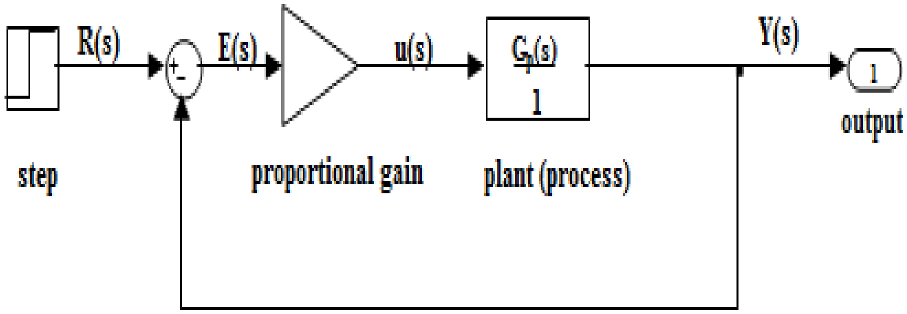
2.4.1 Proportional control
2.4.2 Integral control
2.4.3 Derivative control
2.4.4 Proportional-integral controller (PI controller)
2.4.5 Proportional-derivative controller (PD controller)
2.4.6 Proportional-integral-derivative Controller (PID controller)

2.4.1 Proportional control

The output value is the error, e, multiplied by a constant. This means that the output will always be proportional to the error i.e if the error is large, the corrective output value is large.[18]

$$u(t) = K_p e(t) + b$$

where u(t) is the controller output, e(t) is the error, K_p is proportional gain, b is the controller bias. Proportional control action responds to only the present error. For a small value of proportional gain, a large error yields a small corrective control action. Conversely, a large proportional gain will result in a small error and hence a large control signal. The controller bias is necessary in order to ensure that a minimum control action is always present in the control loop.[17]



2.1**:** Proportional controller block diagram

Any energy transfer requires a finite amount of time, P control action without any lag does not occur in practice. When the time lag between manipulated and controlled variable is so small, however, that it does not have any effect on the system, this behavior is called proportional control action of a system or a P controlled system.[15]

Proportional band

The gain of a proportional controller is generally described in terms of its proportional band (*PB*). It is the proportion of full controller range by which the measured value must change in order to cause the correcting device to change by 100%. [17]

It is defined as, $PB = \frac{1}{K_c}$

2.4.2 Integral control

The output value of the integral term is proportional the cumulative history of the error found by integrating the error over a given time. The aim of the integral term is to eliminate the proportional term steady state error. Its primary effect on a process control system is to permanently attempt to gradually eliminate the error. The action of the integral controller is based on the principle that the control action should exist as long as the error is different from zero, and it has the tendency to gradually reduce the error to zero. The integrator control signal u(t) is proportional to the duration of the error and is given by:[17]

$$u(t) = K_i \left(\int_0^t e(t)dt \right)$$

Where $k_i = k_c/Ti$

Ti= Reset time

1/Ti = Reset rate

Integration of the error with respect to time will produce an output that increases for a positive error, and decreases for a negative error. In other words, the integral term effectively keeps a ‘running total’ of the error. When the error is constant and positive, as shown in the figure, the integral output will give a constantly increasing output [17]. Integral control can be seen as always look at the total past history of the error by continuously integrating the area under the error curve and falling any offset. There will be the better the error signal and the larger the correcting action from the integral controller.

In a real system of course, the error should not remain constant (as the corrective actions of the controller will reduce it), so when the error is eventually zero, the integral output will stay at a constant value.[18].The best situation is achieved under the integral constant is as small as possible without causing oscillation and without being too responsible for the load or thermal mass often integral will be set to zero until proportional band is close to ideal.

Undesirable effects of integral control

While integral control is very helpful for removing steady-state errors it is also responsible for sometimes introducing unwanted effects into the control loop in the form of increase settling time, reduced stability and integral finish.

Reduced stability**:** The existence of the integral action may lead to increased oscillations within the control loop. These oscillations usually have a tendency to shift the system towards the border of instability. In many cases these oscillations will result in the loop becoming unstable

Increased settling time: An increase of the closed-loop system settling time is generally cause by the increased oscillations as a result of the present integral action.

2.4.3 Derivative controller

Derivative is the third and final element of PID control. Derivative responds to the rate of change of the process (or error). Derivative is normally applied to the process only. It has also been used as a part of a temperature transmitter to overcome lag in transmitter measurement.[18]

Some manufacturers use the term rate or pre-act instead of derivative. Derivative, rate and pre-act are the same thing. The controller output is calculated by the rate of change of the error with time.[19]

$$u(t) = K_d \left(\frac{de(t)}{dt} \right)$$

Derivative control action tends to increase the dynamic response of the controlled variable by falling the process settling time, the time it takes the process to attain the steady state. But if the process measure is noisy that is if I contains random fluctuations, high frequency, then the derivative of the measured variable will change broadly and derivative action will amplify noise unless the measurement is filtered. The derivative action is rarely used for flow control loops because the flow control responds fast and the flow measurement is noisy.

2.4.4 PI controller

Its speed of response of PI controller is less than P controller but more than I controller. It eliminates the steady state error

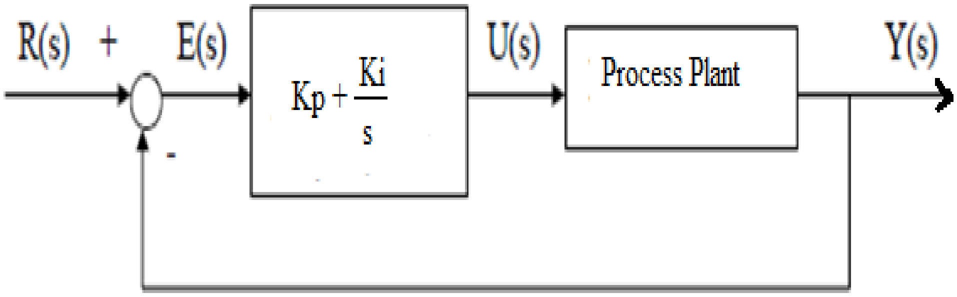


Fig 2.2:PI controller block diagram

PI controller forms control signal in the following way:

$$u(t) = K\left[e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau\right],$$

Where

T_i integral time constant of PI controller

This is graphically shown in fig 2.3 assuming K = 1 and Ti = 1.

Constant Ki = K/T is called "reset mode". Integral control is also sometimes called [19] Reset control.

The name comes from the term "manual reset" which marks a manual change of operating point or of "bias" u0 in order to eliminate error. PI controller performs this function automatically. If control signal of P controller in proportional area is compared with PI controller output signal it can be seen that constant signal u0 is replaced with signal proportional with the area under error curve:[19]

$$u_o = \frac{K}{T_i}\int_o^t e(\tau)d\tau .$$

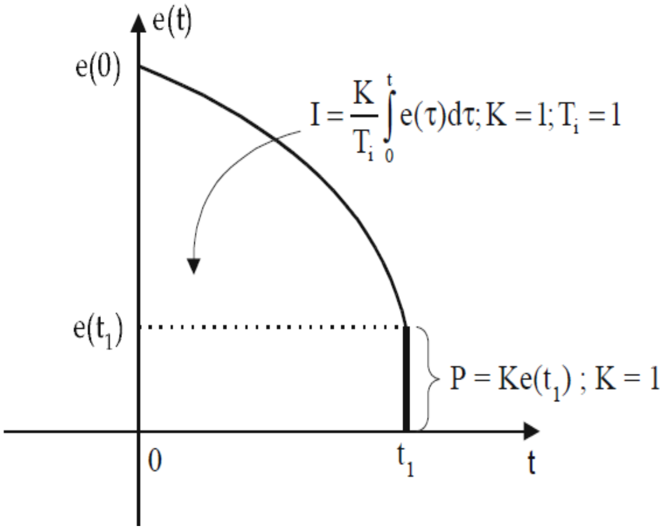


Fig. 2.3: PI controller signal generation

The fact that u0 is replaced with an integral allows PI controller to remove steady state error. On the other hand, P controller cannot reduce steady state error since it does not have any algorithm that would allow for the controller to increase control signal u(t) in order to increase controlled variable y(t) if in some moment t1 error e(t1) = const. > 0. Proportional control law stays constant in this case and it will not try to change a controlled variable in such manner that control error is diminish.[19]

The effect of adding integral action is to eliminate steady-state error. When error exists, it is integrated with all the preceding errors, thereby increasing or decreasing the output of the PI controller depending upon whether the error is positive or negative. Thus, as the error accumulate in the integral term, the output changes so as to remove the error. A P controller will have a constant output when a steady-state error exists, thereby perpetuate the error. A PI controller used the error to prevent steady-state error. As an example to illustrate how PI control work

2.4.5 PD controller

The phase lead of PD controller is small than D controller and decreases the speed of response of D controller. The best PD control algorithm is physically unrealizable because it can’t be implemented accurately using either analog or digital components. It is only used in batch process control. It is stable, gives less offset than P alone, more fast response, decrease lag, reduces the settling time and peak overshoot.

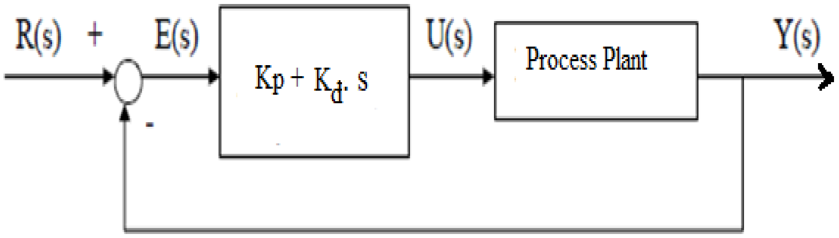


Figure 2.4: PD controller block diagram

In this circumstance, the controller outputs in time domain is given by

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt}$$

2.4.6 PID controller

The initials P.I.D. stand for proportional, integral, and derivative. These are mathematical functions which when given an input value will each produce a characteristic output value; the proportional function is a multiplier, the integral function gives the cumulative value of the input, and the derivative determines rate of change in input. In a PID-based control system, these functions are combined to control the value of a process variable, such as temperature, speed, etc. The input to each function is the difference between the variable's set value and the variable's real measured value. This difference is referred to as the error. The P, I and D functions are apply to the error, and the output value from each function is mutual and used to control the performance of a device, such as a heater, motor, etc, to get the process variable to the desired setting, and keep it there

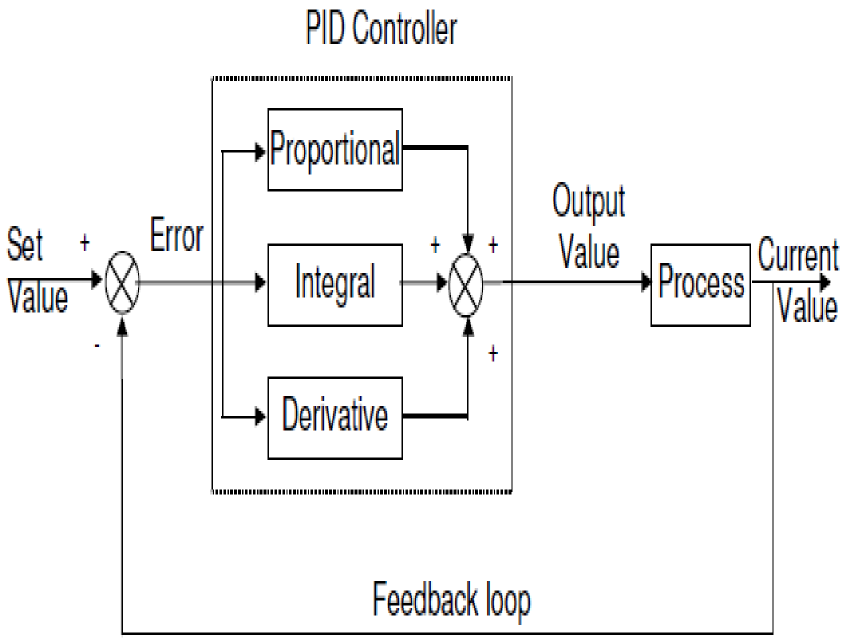


Fig 2.5: General block diagram of PID controller

The effect of the P, I and D terms is determined by some sort of gain or scalar, which is settable by the user. Optimum performance (fast, but stable response to change in input) is achieved by finding the right balance of gain for each term, a method referred to as tuning.[18]

The PID controller is the most common form of feedback. It was an necessary element of early authority and it became the standard tool when process control emerged in the 1940s. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control. PID controllers are today found in all areas where control is used. The controllers come in many different forms. There are stand alone systems in boxes for one or a few loops, which are manufactured by the hundred thousand yearly. PID control is an main element of a distributed control system. The controllers are also implanted in many special purpose control systems. PID control is often joint with logic, sequential functions, selectors, and simple function blocks to build the complex automation systems used for energy production, transportation, and developed. Many complicated control strategies, such as model predictive control, are also controlled hierarchically. PID control is used at the lowest level; the multivariable controller gives the set points to the controllers at the lower level. The PID controller can thus be said to be the “bread and butter’s’ of control engineering. It is an important component in every control engineer’s tool box.[21]

PID controllers have survived much change in technology, from mechanics and pneumatics to microprocessors via electronic tubes, transistors, integrated circuits. The microprocessor has had a theatrical influence on the PID controller. Basically all PID controllers made today are based on microprocessors. This has given opportunity to provide additional features like automatic tuning, gain scheduling, and continuous adaptation.

PID controllers are simple and easy to apply and they are extensively used in industry to solve different control problem. The standard PID controller structure is as shown in figure 2.6 and transfer function is described by fallowing equation in the continuous s-domain (Laplace operator).

$$\boldsymbol{G_{PID}(s) = P + I + D = \frac{U(s)}{E(s)} = K_P + \frac{K_i}{s} + K_d\, s}$$

Or

$$\boldsymbol{G_{PID}(s) = K_P + \frac{K_P}{T_i\, s} + K_P T_d\, s}$$

Where $E(s)$ is control error and $U(s)$ is control signal in s-domain, respectively; K_d=$K_P T_d$ is the derivative gain. T_i is the integration time coefficient K_P is the proportional gain, $K_i = \frac{K_P}{T_i}$ is integration gain, and T_d is referred to as the derivation time coefficient. In this context, the controller outputs in time domain is given by:

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt} + K_i \int_0^t e(t)dt$$

Where e(t) and u(t) are the control output and error signals in time domain, respectively. The action of the proportional gain, K_P reduces the rise time of the system response and steady state error but it never eliminates error. On the other hand the integral gain, K_i reduces the steady sate error and derivate gain, K_d improves stability of system and reduces the overshoot of system as well as improving transient response [22].

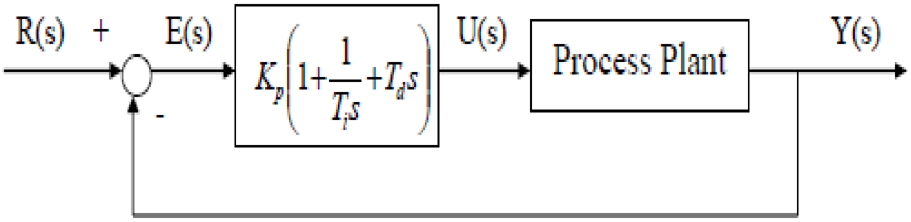


Figure 2.6: PID controller block diagram

2.5 The characteristics of P, I, and D controllers

A proportional controller (Kp) will have the effect of reducing the rise time and will decrease, but never remove, the steady-state error. An integral control (Ki) will have the result of eliminating the steady-state error, but it may create the transient response worse. A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers Kp, Kd, and Ki on a closed-loop system are summarize in the table shown below.

CL RESPONSE	**RISE TIME**	**OVERSHOOT**	**SETTLING TIME**	**S-S ERROR**
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change

Table 2.7: Controller response

Note that this correlation may not be exactly accurate, because Kp, Ki, and Kd are dependent of each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for Ki, Kp and Kd.[20]

Overshoot: this is the magnitude by which the controlled variable 'swings' past the setpoint. 5/10% overshoot is normally acceptable for most loops.

Rise time**:** the time it takes for the process output to achieve the new desired value. One-third the dominant process time constant would be typical.

Decay ratio**:** this is the ratio of the maximum amplitude of successive oscillations.

Settling time**:** the time it takes for the process output to die to between, say +/- 5% of set point.[18]

2.6 Limitations of PID control

While PID controllers are related to many control problems, and frequently perform satisfactorily without any improvements or even tuning, they can perform poorly in some applications, and do not in general give optimal control. The fundamental complexity with PID control is that it is a feedback system, with constant parameters, and no direct knowledge of the process and thus overall performance is reactive and a compromise – while PID control is the best controller with no model of the process [25], PID controllers, when used single, can provide poor performance when the PID loop gains must be decrease so that the control system does not overshoot, oscillate or hunt about the control set point value.

The PID controller can then be use primarily to respond to whatever difference or error remnants between the setpoint (SP) and the real value of the process variable (PV). Since the feed-forward output is not affected by the process feedback, it can never cause the control system to oscillate, thus improving the system response and stability

Another problem occur with PID controllers is that they are linear. Thus, performance of PID controllers in non-linear systems (such as HVAC systems) is variable. A problem with the Derivative term is that small amounts of measurement or process noise can reason large amounts of change in the output. It is frequently supportive to filter the measurements with a low-pass filter in order to remove higher-frequency noise components. but, low-pass filtering and derivative control can cancel each other out, so decreasing noise by instrumentation means is a much better choice. on the other hand, the differential band can be turned off in many systems with little loss of control.

2.7 Tuning

All common methods for control design can be useful to PID control. A number of special methods that are tailor made for PID control have also been developed, these methods are often called tuning methods. Irrespective of the method used it is essential to always consider the key elements of control, sensor noise, and process uncertainly load disturbances, and reference signals. The most well known tuning methods are those developed by Ziegler and Nichols. They have had a major power on the practice of PID control for more than half a century. The methods are based on characterization of process dynamics by a few parameters and simple equations for the controller parameters.[21]

2.8 Tuning of PID controller

Tuning of PID controller means select the numerical value for the PID coefficient. Many industrial process companies have in-house manuals that give rule for the tuning of PID controllers for particular process plant units. Thus for simple processes it is usually possible to give rules and empirical formulae for the PID controller tuning process. Some of these manuals base their events on the pro forma routines of the famous Ziegler–

Nichols methods and their numerous extensions of the associated rules (Ziegler and Nichols, 1942). Ziegler–Nichols method uses an on-line process experiment follow by the use of rules to calculate the mathematical values of the PID coefficients [24, 25].

Types of controller tuning methods contain the trial and error method, and process reaction curve methods. The most general classical controller tuning methods are the Ziegler-Nichols and Cohen-Coon methods. These methods are often used when the numerical model of the system is not available. The Ziegler-Nichols method can be used for both closed and open loop systems, while Cohen-Coon is typically used for open loop systems. A closed-loop control system is a system which uses feedback control. In an open-loop system, the output is not compared to the input [28].

2.9 Ziegler-Nichols Rules for tuning PID Controller

Types of controller	K_p	T_i	T_d
P	0.5	∞	0
PI	0.45Kcr	0.833Tcr	0
PID	0.6Kcr	0.5Tcr	0.125Tcr

Table.2.8 Ziegler-Nichols ultimate sensitivity test

The equation below shows the PID controller

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(t')\,dt' + T_d\left(\frac{de(t)}{dt}\right) \right] + b$$

Where

u is the control signal.

e is the difference between the current value and the set point.

.

Kc is the gain for a proportional controller.

T*i* is the parameter that scales the integral controller.

T_d is the parameter that scales the derivative controller.

t is the time taken for error measurement.

b is the set point value of the signal, also known as bias or offset.

u is the control signal.

e is the difference between the current value and the set point.

K_c is the gain for a proportional controller.

T_i is the parameter that scales the integral controller.

T_d is the parameter that scales the derivative controller

.

t is the time taken for error measurement.

b is the set point value of the signal, also known as bias or offset.

It has been observed that step responses of many processes to which PID controllers are useful have monotonically increasing characteristics and so most conventional methods for PID controllers have been developed perfectly assuming this property. However, there exist some processes that exhibit oscillatory responses to step inputs.

Two tuning methods were developed by Ziegler and Nichols in 1942 and have been generally utilized either in the original form or in adapted forms. One of them, referred to as Ziegler–Nichols‟ decisive sensitivity method, is to determine the parameters as given in Table 2.8 using the data Kcr and Tcr are obtained from the ultimate sensitivity test. Other, referred to as Ziegler–Nichols‟ step response method, is to suppose the model FOPDT and to determine the parameters of the PID controller which are determined from the step response test.

2.10 Transient response of PID controller

Following figures shows the transient response of PID controllers [27]. The below figure 2.10 shows the unit step response of second order system by keeping the values of K_i and K_d constantand varying the values of $K_{p.}$

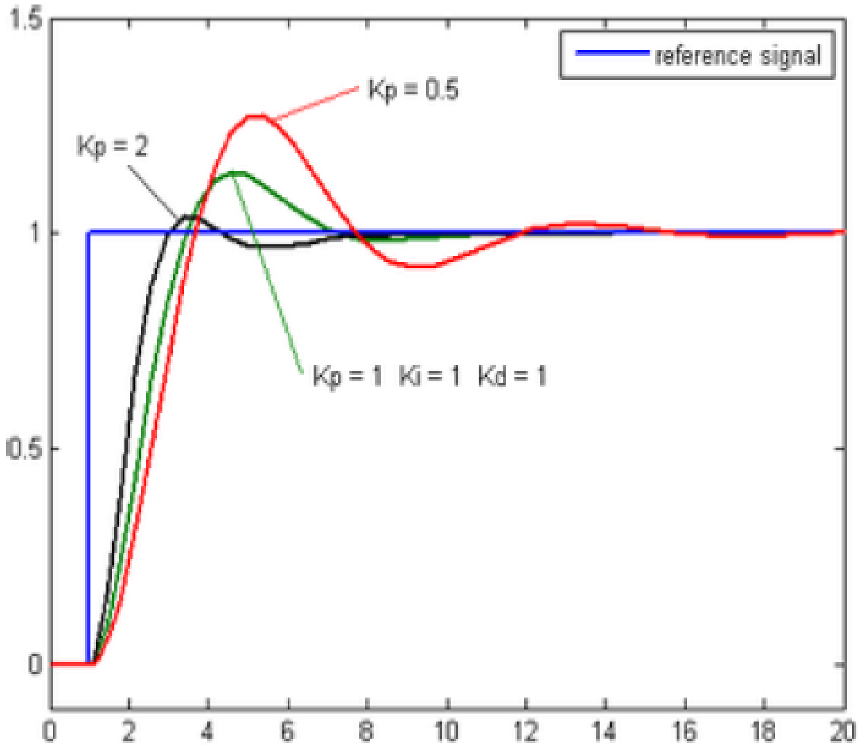


Figure 2.9: Plot of PV vs. time, for the values of Kp (K_d and K_p held constant)

figure 2.10 shows the unit step response of second order system by keeping the values of Kp and K_i constant and varying the value of Kd

- IAE (Integral of absolute error): One more fitness function is the integral of the absolute error as follow:

$$IAE = \int_0^\infty |e(t)|\,dt$$

This criterion penalized large errors less heavily and small errors more heavily compared to ISE.

- ISE (Integral of square error): A appropriate fitness function (Performance index) is the integral of square error.

$$ISE = \int_0^\infty e^2(t)\,dt$$

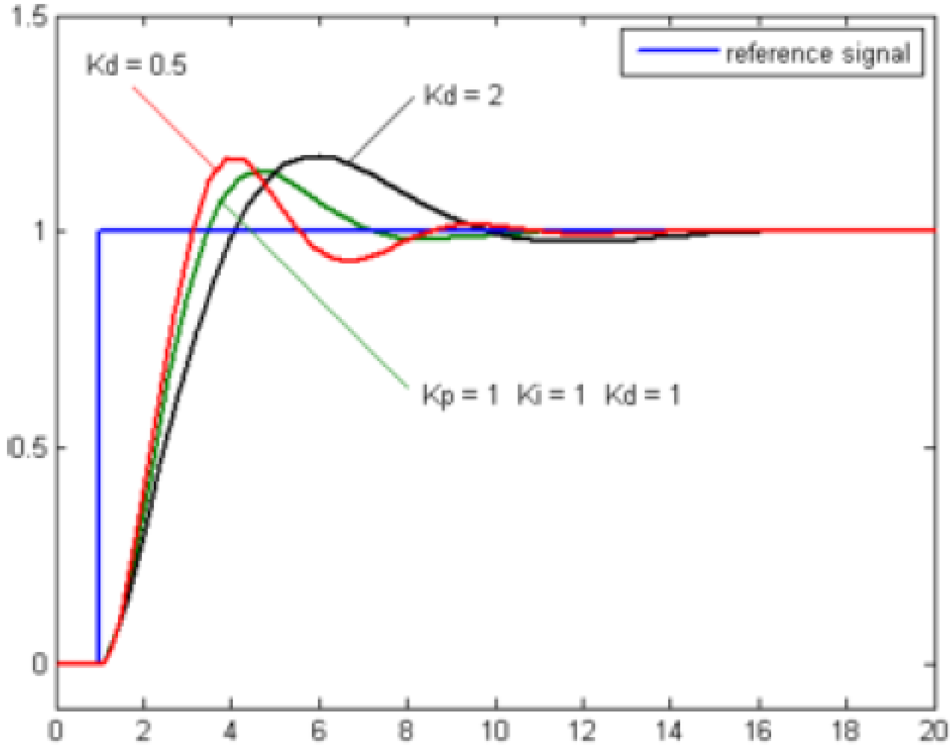


Figure 2.11: Plot of PV vs time, for three values of K_d (Kp & Ki are constant)

2.11 Performance indices

The optimal control cannot be defined accurately in general. A solution, which is best for one particular application for specified set of conditions, may not be best for another problem. In that case minimizing the value of such performance index, optimal constants can be obtain as required for profitable and practical problem.

which is use by most of the control engineers. Such performance indices help us in assessing the quality of a control system. One of that index is cost function

2.3.2 Fuzzy logic

Lotfi Zadeh introduced the concept of Fuzzy Logic (FL).It was discovered and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership.

FL is a problem-solving control system methodology that lends itself to implementation

In systems ranging from simple, embedded micro-controllers to large, small, networked, multichannel lPC or workstation-based control and data acquisition systems. It can be implemented in software, hardware or a combination of both. FL provides a easy way to arrive at a definite conclusion based upon fuzzy, noisy, ambiguous, imprecise, or missing input information. FL's approach to control problems mimics how a person would create decisions, only much faster. Fuzzy logic imitate the logic of human thought, which is much less rigid than the calculations computers usually perform [30].

On a mathematical level, fuzzy logic abandon the severe bivalent logic of TRUE and FALSE, ONE and ZERO, ON and OFF. Fuzzy logic allows for half-truths. get for an example the scientific classification of a whale. Despite the fact that it looks like a fish, it swims like a fish, it smells like a fish, and every third grader in the country is skeptical when told that it is not a fish, the whale is 100% mammal, 0%fish. If a fuzzy logician were classifying the whale, he would allow the what to belong to both the mammal set and the fish set, to certain degrees [31].

Fuzzy logic provides a platform for easily encoding human knowledge into the control of a system on an engineering level. It has been used in an rising number of applications, especially in Japan. The Sendai railway in Japan is controlled by fuzzy logic controllers. Applications have been developed in tracking problems, interpolation, tuning, classification, voice recognition, handwriting, and image stabilization in video cameras, washing machines, air conditioners, vacuum cleaners, hot plates, electric fans and Lexus automatic transmissions.

An inverted pendulum experiment was demonstrated in 1987 that "produced balancing responses nearly 100 times shorter than those of conventional PID controller" [32].

PID controllers and variations there of work fine in many control systems. But when the system to be controlled contains uncertainty or is highly complex, nonlinear or poorly understood fuzzy control may work better. Fuzzy logic is a technique of characterizing knowledge in terms of fuzzy sets and a rule base. A fuzzy system has one or more inputs that are fuzzified, a rule base that is evaluate according to the inputs, and one or more outputs that are defuzzified into "crisp" values. Bring fuzzy logic to control problems is a way to use a human expert's knowledge about an analog process in a digital computer. Fuzzy logic is not always the best way to solve a control problem, but it offers several advantages.

Advantage of fuzzy logic

There are many advantage of fuzzy logic some them are given below:

Fuzzy rules often take the place of a math model. Therefore, fuzzy logic is useful if a mathematical model of a process does not exist, is too difficult to encode, is too complex to be evaluated in real-time, or requires too much memory.

Fuzzy logic applies to all points in the state space. Fuzzy logic is helpful in situations where the control variables are continuous.

Other advantage of fuzzy, in situations that may make fuzzy control advantageous are when there are high ambient noise levels, it is important to use inexpensive sensors, or it is important to use low precision microcontrollers. They are easy to prototype and apply and simpler to verify and describe. They can be maintained and extended with better accuracy in less time.

Disadvantage of fuzzy logic

One problem is that the control of some systems cannot be easily specified in terms of an IF/THEN rule base.

Chapter: 3

Case study of dc motor and flywheel

3.1Introduction to dc motor

Electric machines are the simplified means of converting energy. They are the electromechanical energy conversion devices. Motors take electrical energy and produce mechanical energy. Electromechanical energy conversion occurs when there is a change in magnetic flux linking a coil, associated with mechanical motion.

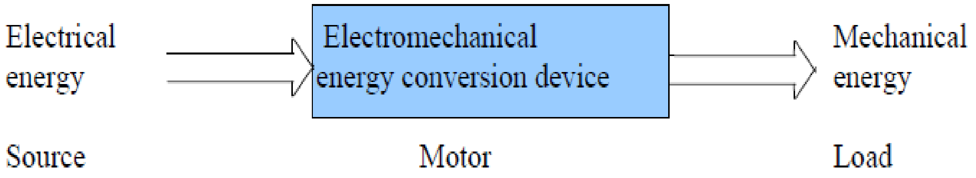


Fig: 3.1 Energy conversion process

The input is electrical energy from the supply source and the output is mechanical energy to the load. Dc motor is available in various sizes. Some examples of large motor applications include elevators, hoists, electric trains and heavy metal rolling mills. Examples of small motor applications in automobiles, robots, hand power tools and food blenders. It has many applications in medicine, micro-machines are electric machines with parts the size of red blood cells.[33]

3.2 Basic principle of dc motor

The basic principle of dc motor is that when electrical energy is supplied to a conductor lying perpendicular to a magnetic field, the interaction of current flowing in the conductor and the magnetic field will produce mechanical force. This simplified process is elaborated with the help of following figure .

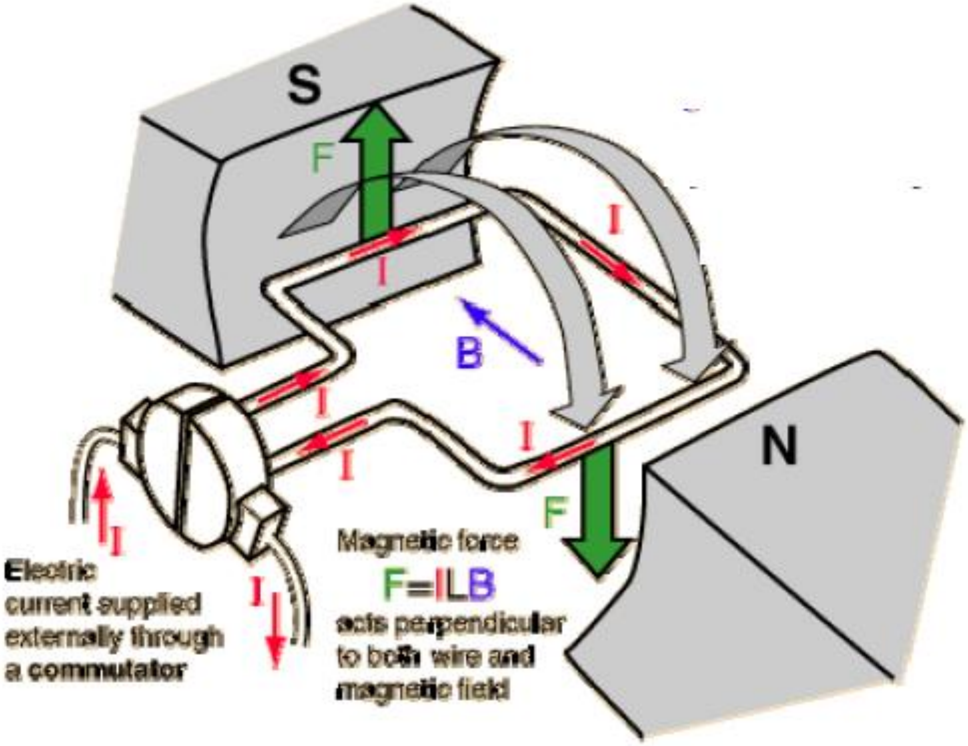


Fig: 3.2 torque production in dc motor

Consider a coil is placed in a magnetic field of flux density **B** (figure 3.2). Current I flow through it, when the two ends of the coil are connected across a DC voltage source. With the interaction of magnetic field and electric current A force is exerted on the coil as a result .The force on the two sides of the coil is such that the coil starts to move in the direction of force.[33]

In an actual dc motor, several such coils are wound on the rotor, all of which practice force, resulting in rotation. Torque is being produced, the conductors are moving in a magnetic field. At the same time at different positions, the flux linked with it changes, which causes an emf to be induced. The greater the current in the wire, or the greater the magnetic field, the faster the wire moves because of the greater force created. This voltage is in opposition to the voltage that causes current flow through the conductor and is referred to as a counter-voltage or back emf.

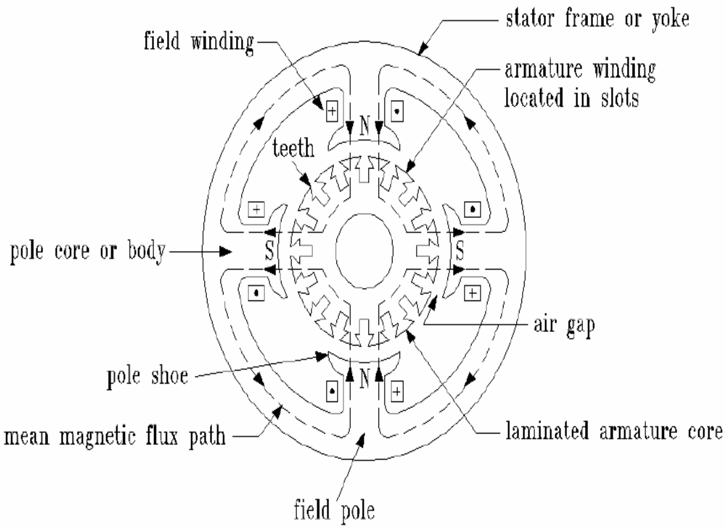


Fig: 3.3 Schematic diagram of dc motor

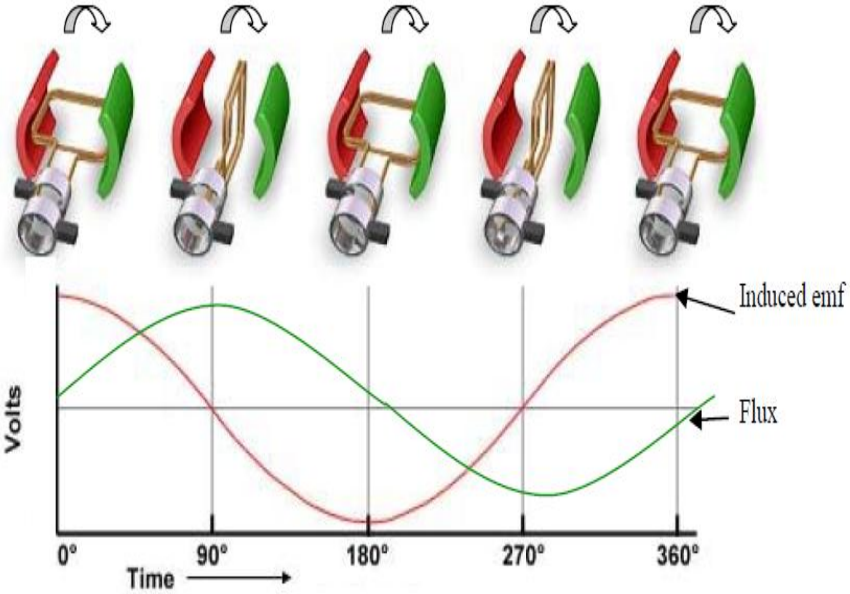


Fig: 3.4 Induced voltage in armature winding of dc motor

The current due to this counter-voltage tends to oppose the very cause for its production according to Lenz’s law. The value of current flowing through the armature is dependent upon the difference between the applied voltage and this counter-voltage.

Eventually, the rotor slows just enough so that the force created by the magnetic field

$F = Bil$ equals the load force applied on the shaft. Then the system moves at constant velocity.

3.3 Torque developed

The equation for torque developed in a dc motor can be derived as follows.

Since $\boldsymbol{B}=\frac{\emptyset}{\boldsymbol{A}}$ where A is the area of the coil,

The force on one coil of wire $\boldsymbol{F} = i\,\boldsymbol{l} \times \boldsymbol{B}$ Newton

Where $\boldsymbol{l}$ and $\boldsymbol{B}$ are vector quantities

Therefore the torque for a multi turn coil with an armature current of *Ia*

$$T=K\emptyset I_a \tag{3.1}$$

Where ∅ is flux/pole in weber

K is a constant depending on coil geometry

I_a is the current flowing in armature winding

The mechanical power generated is the product of the machine torque and the mechanical speed of rotation [34]

$$P_m=\omega_m T$$

$$=\omega_m K\emptyset I_a \tag{3.2}$$

3.4 Armature torque of dc motor

Torque is the turning moment of a force about an axis. It is measured by the product of radius (r) and force (F) at right angle to which the force acts.

$$T=F*r$$

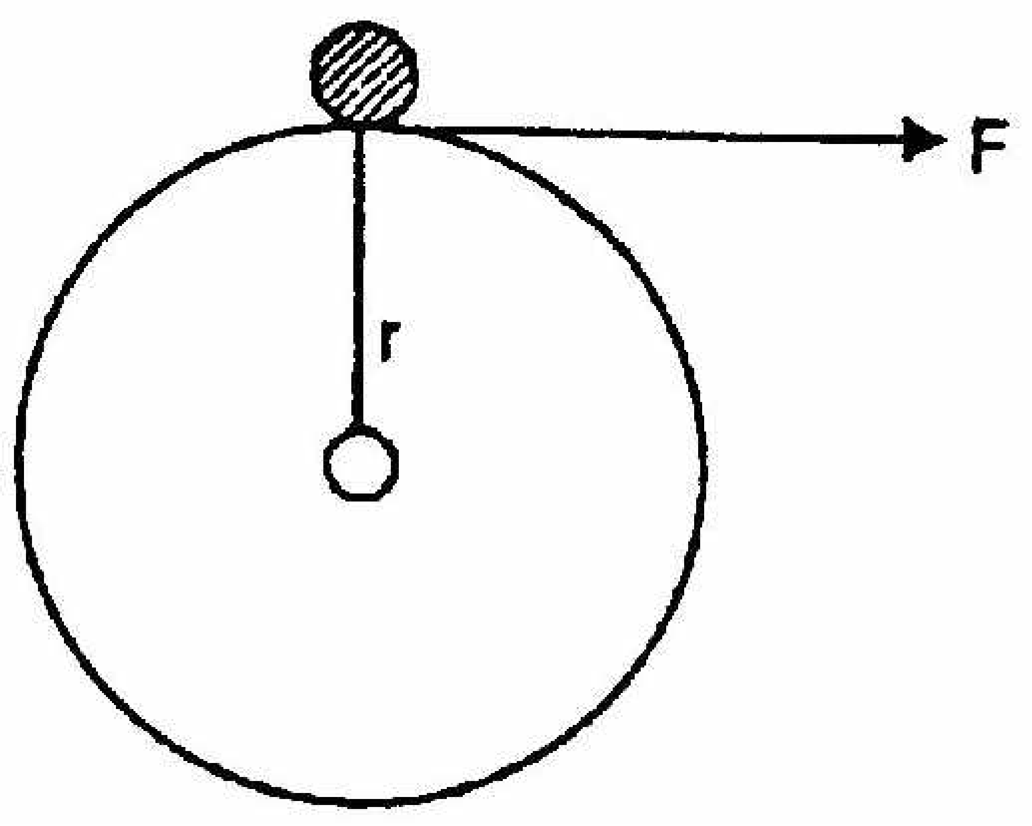


Fig 3.5: Armature torque

each conductor exerts a torque, tending to rotate the armature. The sum of the torques due to all armature conductors is known as gross or armature torque (Ta). In a d.c. motor, each conductor is acted upon by a circumferential force F at a distance r, the radius of the armature Fig. 3.5.

Let in a d.c. motor

P = Number of poles

Ø = Flux per pole in Wb

Z = Total number of armature conductors

l = Effective length of each conductor in m

B = Average flux density in Wb/m2

A = Number of parallel paths

r = Average radius of armature in m

i = Current in each conductor = Ia/A

Force on each conductor, F = B i l newtons

Torque due to one conductor = F ´ r newton- metre

Total armature torque, Ta = Z F r newton-metre

= Z B i l r

B = f/a, i = Ia/A, where a is the x-sectional area of flux path per pole at radius r. Clearly, a = 2pr l /P.

$$T_a = Z \times \frac{\emptyset}{2} \times I_a / A \times l \times r \qquad (3.3)$$

$$Z = \frac{\emptyset}{2\pi r l / p} \times I_a / A \times r \times l \qquad (3.4)$$

$$= \frac{Z \emptyset I a}{2\pi A} \text{ N-m}$$

$$T_a = 0.159 Z \theta I_a \left(\frac{P}{A} \right) \text{N-M} \qquad (3.5)$$

Since Z, P and A are fixed for a given machine,

$$T_a \propto \emptyset I_a$$

Hence torque in a d.c. motor is directly proportional to flux per pole and armature current.

For a series motor, flux f is directly proportional to armature current Ia provided magnetic saturation does not take place.

$$T_a \propto I^2_a$$

For a shunt motor, flux f is practically constant.

$$T_a \propto I_a$$

3.5 Speed of dc motor

$$E_b = V - I_a R_a$$

$$\text{But } E_b = \frac{P \emptyset Z N}{60 A}$$

$$\frac{P \emptyset Z N}{60 A} = V - I_a R_a$$

$$N = \left(V - \frac{I a R a}{\emptyset} \right) \frac{60 A}{P Z} \qquad (3.6)$$

$$N = K \left(\frac{V - I a R a}{\emptyset} \right) \qquad \text{where k is} \left(\frac{60 A}{P Z} \right)$$

$$\text{But } V - I_aR_a = E_a$$

$$N = K\frac{Eb}{\emptyset}$$

$$N \propto \frac{Eb}{\emptyset}$$

Therefore, in a d.c. motor, speed is inversely proportional to flux per pole $\emptyset$ and directly proportional to back e.m.f. E_b

3.6 Speed regulation:

$$\%\text{ Speed regulation} = \frac{N.L\ speed - F.L\ speed}{F.L\ speed} \times 100 \qquad (3.7)$$

$$= \frac{\boldsymbol{N0 - N}}{\boldsymbol{N}} \times \mathbf{100}$$

Where N = Full - load speed
No = No load .speed

3.7 Losses in dc motor

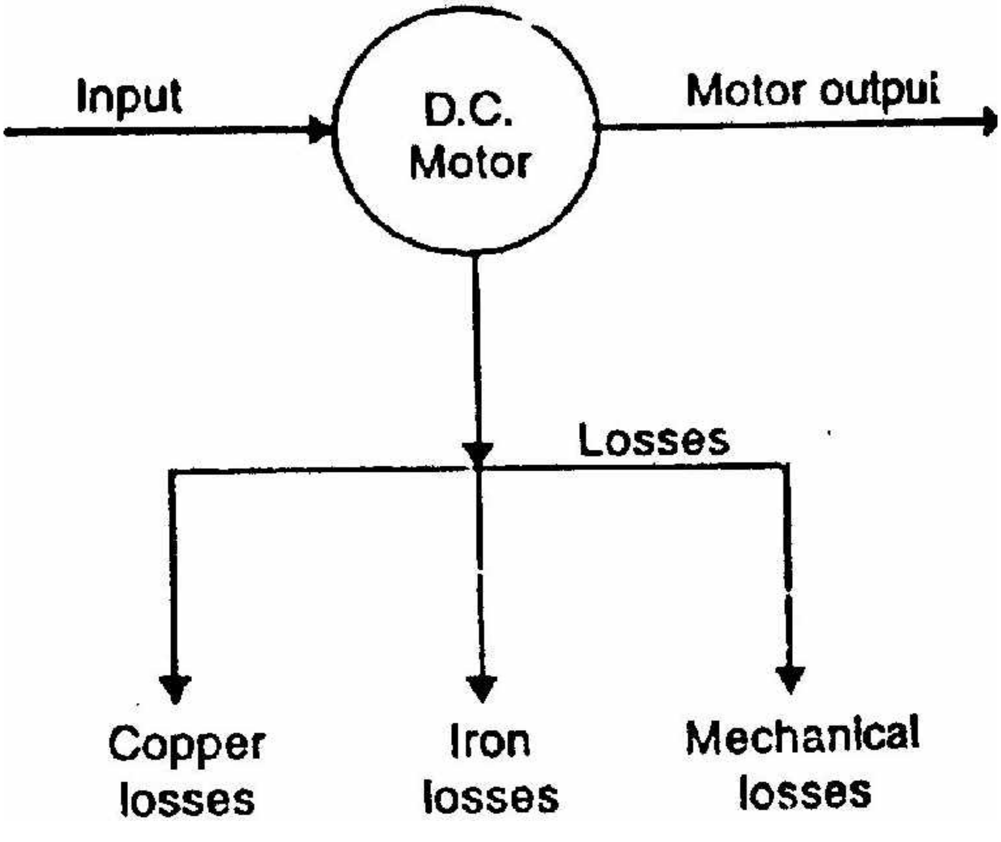


Fig 3.6 losses in dc motor

(i) copper losses (n) Iron losses or magnetic losses

(ii) Mechanical losses

3.7.1 Copper losses

When the electrical current I ampere flow in the resistance of R ohm heat energy is lost at the rate of I^2R jules/sec and power losses I^2R watts. Motor have many field and armature circuit so there are many losses in circuit all resistance losses are include in copper losses. Apart from field Cu loss, armature Cu loss and brush contact loss, Cu losses also occur in interpoles and compensating windings. Since these windings carry armature current (Ia). Armature loss: $I^2_aR_a$ this loss is 30% to 40 of total full load loss

3.7.2 Mechanical losses

The mechanical losses (i.e. friction and windage) vary as the cube of the speed of rotation of the d.c. machine (generator or motor). Since d.c. machines are generally operated at constant speed, mechanical losses are considered to be constant.

3.8 DC Motor Equivalent circuit

The schematic diagram for a dc motor is shown 3.3. A dc motor has two separate circuits: Armature circuit and field circuit. The input is electrical power and the output is mechanical power. In this equivalent circuit, the field winding is supplied from a separate dc voltage source of voltage V_f. R_f represent the resistance.L_f represent the inductance of the field winding. The current If produced in the winding establishes the magnetic field necessary for motor operation. In the armature (rotor) circuit, Vt is the voltage applied across the motor terminals, Ra is the resistance of the armature winding, E_{bs} is the total voltage induced in the armature and

Ia is the current flowing in the armature circuit.

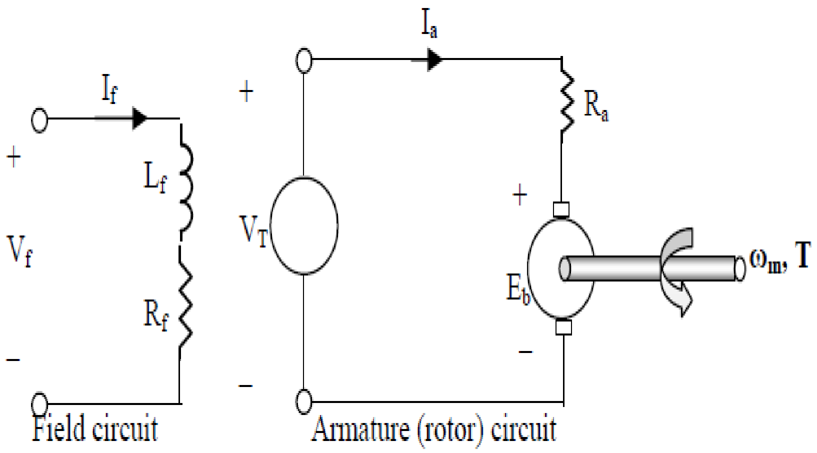


Fig:3.7 dc motor equivalent diagram

3.8.1 Voltage Equation

Applying KVL in the armature circuit of fig 3.7

$$V_T = E_b + I_a R_a \tag{3.8}$$

Where V_T is applied voltage to armature terminal of motor

R_a is resistance of armature winding

Applying KVL in the field circuit of Figure 3.3

$$V_f = R_f I_f \tag{3.9}$$

Where V_f is applied voltage to field winding

R_f is resistance of field winding

I_f is current through the field winding

3.8.2 Power transfer equation

We have obtain the following relationship for torque developed in the motor from equation no 1

$$T_{dev} = K\emptyset I_a \tag{3.10}$$

The developed power is the power converted to mechanical form, and is given by from equation no 2

$$P_{dev} = \omega_m T_{dev} \tag{3.11}$$

$E_b I_a$(electrical power) $= \omega_m T_{dev}$ (mechanical

Where N is speed in revolution per minute

ω is related to angular speed(in radian per second)

$$\omega=\frac{2\pi N}{60}$$

$\emptyset \propto I_f$ Flux in field winding is directly proportional to field current

If the induced voltage at the first operating speed N_1 and field winding current I_{f1} s given by

$$E_{b1}=K(K_f I_{f1})\,\frac{2\pi N1}{60} \tag{3.12}$$

And field winding current theI_{f2} induced voltage at the first operating speed N2, is given by:

.

$$E_{b2}=K\,(K_f I_{f2})(\frac{2\pi N2}{60}) \tag{3.13}$$

Thus induced voltage at these operating point

$$\frac{E_{b1}}{E_{b2}}=\frac{I_{f1}N_1}{I_{f2}N_2}$$

This equation is useful to determine the speed of dc motor

3.8.3 Condition for Maximum Power

Mechanical power developed by motor is $P_m=E_b\,I_a$ (3.14)

$$P_m=VI_a-I_a^2R_a \tag{3.15}$$

R_a and V are fixed, power developed by the motor depends upon armature current. For maximum power, dPm/dIa should be zero.

$$\frac{dPm}{dIa}=V-2I_aR_a=0 \tag{3.16}$$

$$I_a\,Ra=\frac{V}{2}$$

$$V=E_b+I_aR_a$$

$$E_b+\frac{V}{2} \qquad \left[\,I_aR_a=\frac{V}{2}\right]$$

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

Mechanical power developed by the motor is maximum when the back emf is half of applied voltage

3.9 Types of D.C. Motors

Like generators, there are three types of d.c. motors characterized by the connections of field winding in relation to the armature viz.:

3.9.1 Compound-wound motor

There are two types of compound motor connections which has two field windings one connected in parallel with the armature and the other in series with it. it is called short-shunt connection When the shunt field winding is directly connected across the armature terminals Fig. 3.8., it is called long-shunt connection when the shunt winding is so connected that it shunts the series combination of armature and series field Fig. 3.9,.

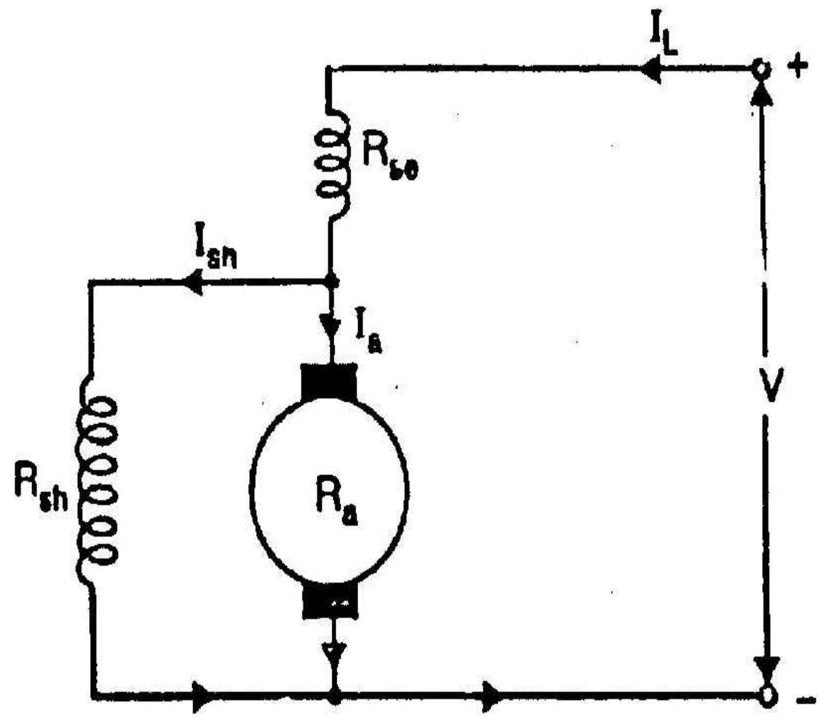


Fig 3.8 compound-wound motor (shirt shunt connection)

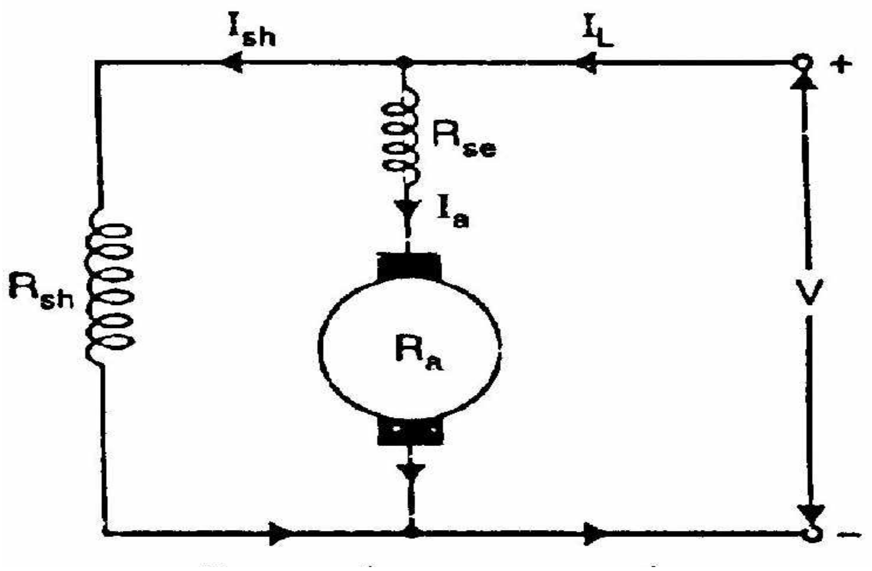


Fig 3.9 compound-wound motor (long shunt connection)

3.9.2 Shunt-wound motor

In this motor the current through the shunt field winding is not the same as the armature current in which the field winding is connected in parallel with the armature Fig. 3.10. Shunt field windings have large number of turns of wire having high resistance are designed to produce the necessary m.m.f. Therefore, shunt field current is relatively small compared with the armature current.

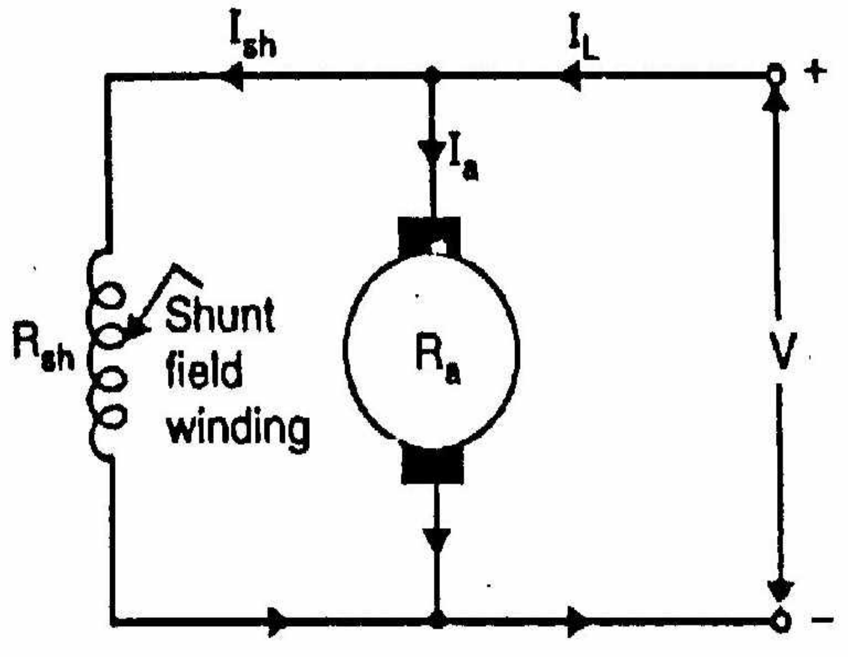


Fig 3.10 shunt wound motor

Shunt field in compound machines is the basic dominant factor in the production of the magnetic field in the machine because the compound motor are always designed so that the flux produced by shunt field winding is significantly larger than the flux produced by the series field winding.

3.9.3 Series-wound motor

In Series-wound motor field winding is connected in series with the armature Fig. 3.11. Therefore, series field winding carries the armature current. Therefore, a series field winding has a relatively small number of turns of thick wire and, therefore, will possess a low resistance.

Since the current passing through a series field winding is the same as the armature current, series field windings must be designed with much less turns than shunt field windings for the same m.m.f.

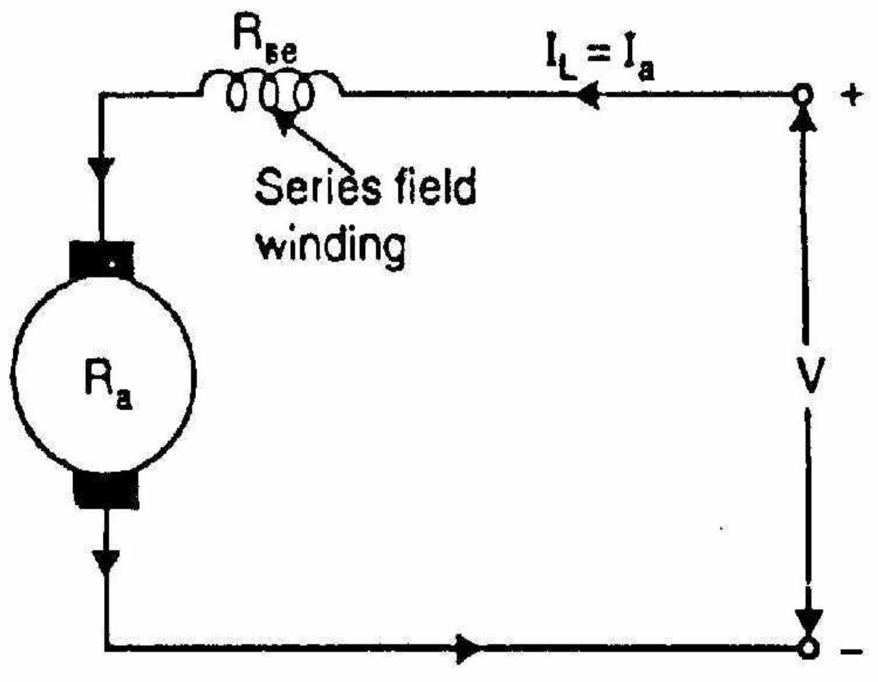


Fig: 3.11Series wound motor

3.10 dc motor Characteristics

There are three principal types of d.c. motors compound motors, series motors and shunt motors. The compound type has two separate field windings wound on the core of each pole. Both shunt and series types have only one field winding wound on the core of each pole of the motor. The performance of a d.c. motor can be judged from its characteristic curves known as motor characteristics, three important characteristic of dc motor are following.

Speed and torque characteristic (N/Ta)

It is the curve between speed N and armature torque Ta of a d.c. motor. It is also known as mechanical characteristic.

Torque and Armature current characteristic (Ta/Ia)

It is the curve between armature torque Ta and armature current Ia of a d.c motor. It is also known as electrical characteristic of the motor.

Speed and armature current characteristic (N/I_a)

It is the curve between speed N and armature current Ia of a d.c. motor. It is very important characteristic as it is often the deciding factor in the selection of the motor for a particular application.

3.10.1 Compound Motors

A compound motor has both series field and shunt field. The shunt field is always stronger than the series field. Compound motors are of two types:

(A) Differential-compound motors in which series field opposes the shunt field

(B) Cumulative-compound motors in which series field aids the shunt field

Differential compound motors are rarely used due to their poor torque characteristics at heavy loads.

(A)Characteristics of Cumulative Compound Motors

Fig.3.12 shows the connections of a cumulative-compound motor. Each pole carries a series as well as shunt field winding; the series field aiding the shunt field.

Ta/Ia Characteristic: The series field increases but shunt field strength remains constant when the load increases. Therefore, total flux is increased and hence the armature torque ($Ta \propto \emptyset Ia$). It may be noted that the shunt motor for a given armature current due to series field torque is less that of a cumulative-compound motor Fig. 3.13.

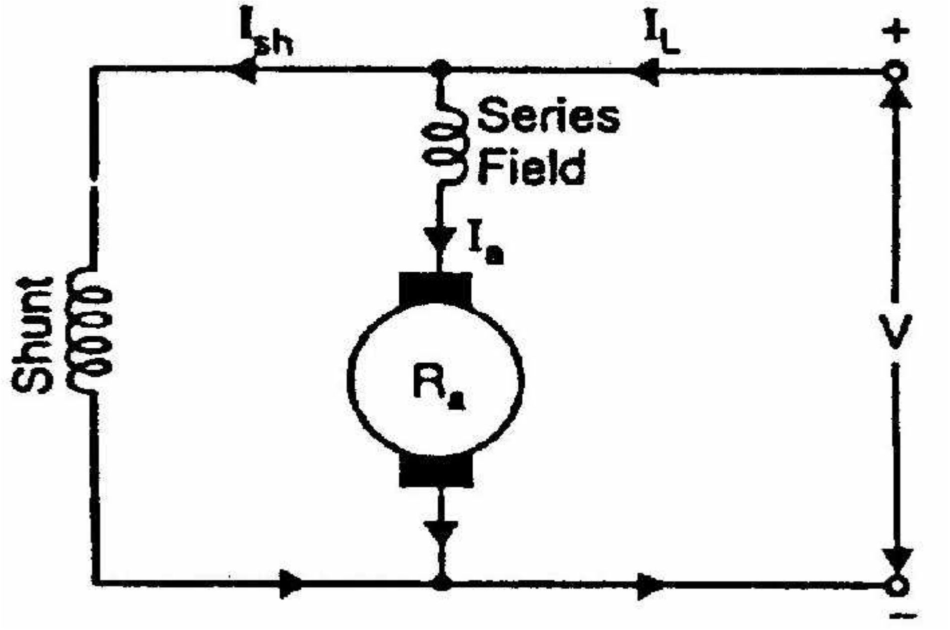
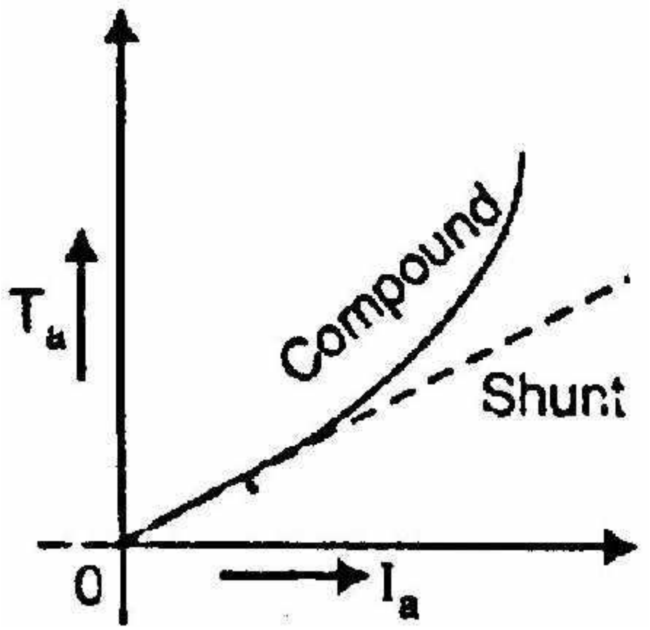


Fig 3.12 Connection diagram of cumulative-compound motor



Fig;3.13 Graph between armature current I_a and armature torque T_a

N/Ta Characteristic: Fig. 3.14 shows N/Ta characteristic of a cumulative compound motor. For a given armature current, the torque of a cumulative compound motor is less than that of a series motor but more than that of a shunt motor.

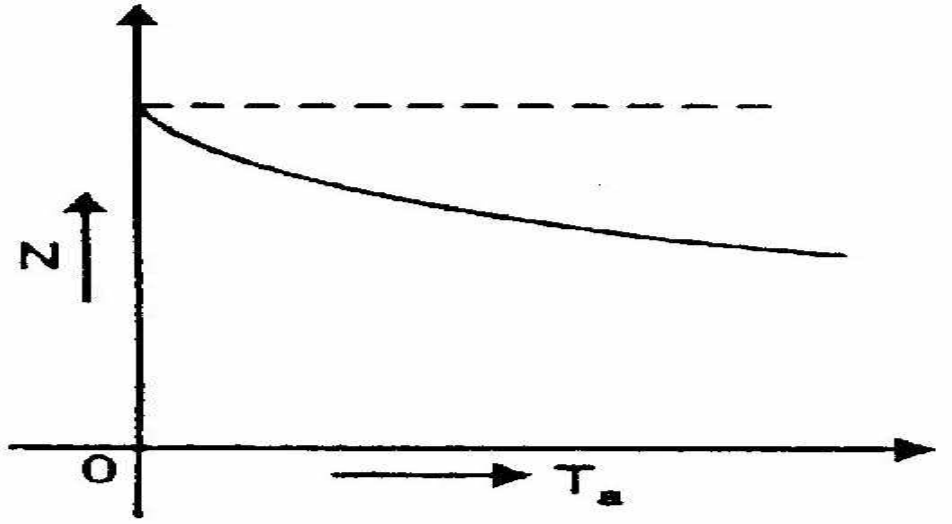


Fig: 3.14 Graph between speed (N) and armature torque T_a

N/Ia Characteristic: The speed regulation of a cumulative compound motor is poor than that of a shunt motor. As explained above, as the lead increases, the flux per pole also increases. as a result, the speed $(N \propto \frac{1}{\emptyset})$ of the motor tails as the load increases Fig. 3.12. It may be noted that as the load is increase, than the increased amount of flux causes the speed to decrease more than does the speed of a shunt motor.

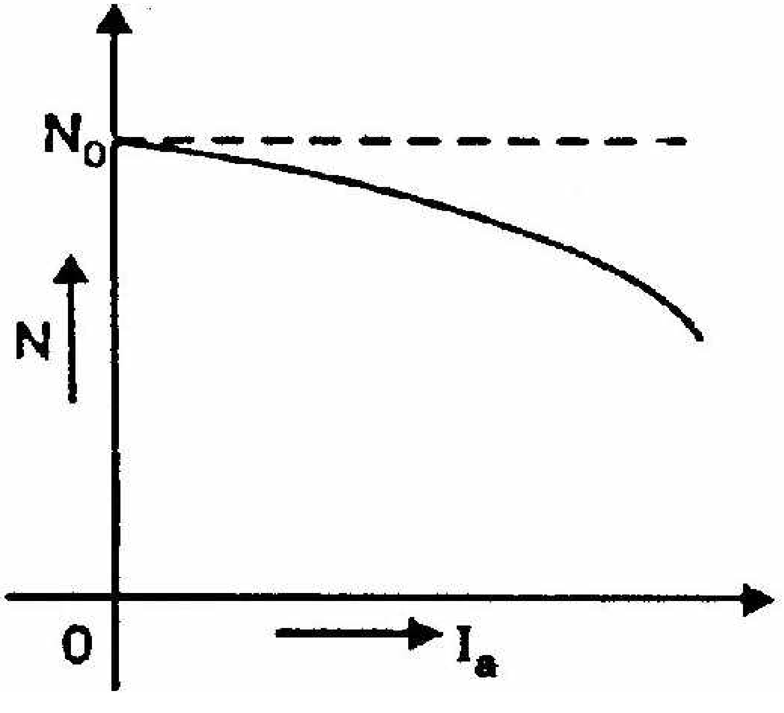


Fig: 3.15 Graph between speed and armature current

3.10.2 Characteristics of Series Motors

In series motor current passing through the field winding is the same as that in the armature. Fig.3.16 shows the connections of a series motor. The armature current is increases If the mechanical load on the motor increases,. Hence, the flux in a series motor increases with the increase in armature current and vice-versa.

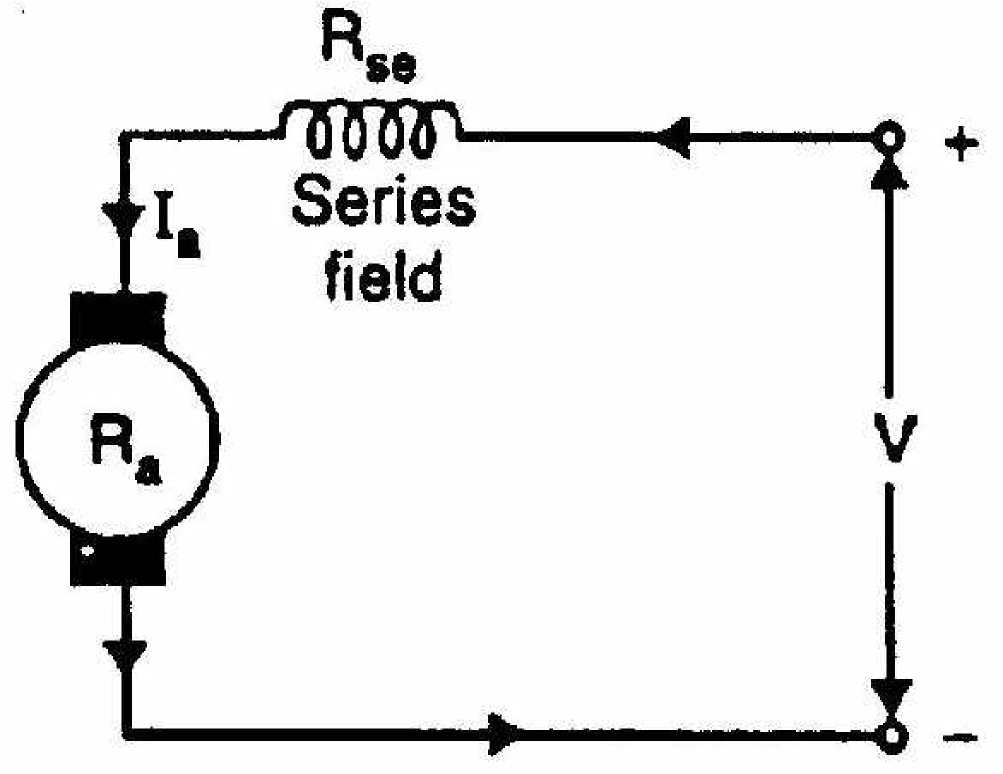


Fig 3.16 Connection of series motor

Ta/Ia Characteristic. We know that:

$$T_a \propto \emptyset Ia$$

After magnetic saturation, $\emptyset$ is constant so that $T_a \propto Ia$

Upto magnetic saturation, $\emptyset \propto I_a$ so that $T_a \propto I^2_a$

The armature torque is directly proportional to the square of armature current up to magnetic saturation. If Ia is doubled, Ta is almost quadrupled.

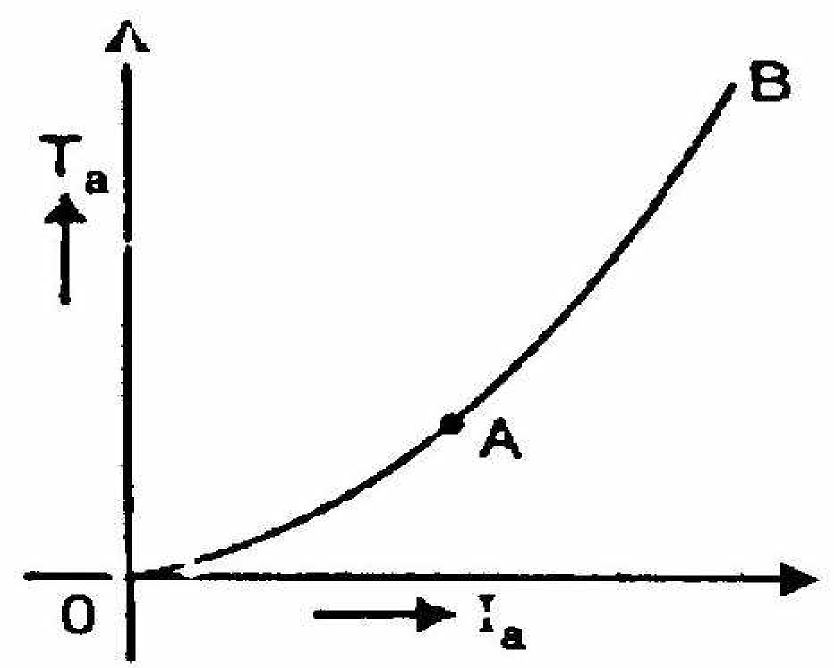


Fig: 3.17 Graph between armature torque and armature current

Therefore, Ta/Ia curve upto magnetic saturation is a parabola portion OA of the curve in Fig. 3.17. However, after magnetic saturation, torque is directly proportional to the armature current.

Portion AB of the curve , Ta/Ia curve after magnetic saturation is a straight line. up to magnetic saturation It may be seen that in the initial portion of the curve , Ta $\propto I^2_a$. This means that compared to a shunt motor starting torque of a d.c. series motor will be very high.

Where $T_a \propto Ia$

N/Ia Characteristic. The speed N of a series motor is given by;

$$N \propto \frac{Eb}{\emptyset} \quad \text{where } E_b = V - I_a (R_a + R_{se}) \qquad (3.17)$$

When the armature current increases, the back e.m.f. E_b decreases due to Ia(Ra + Rse) drop However, Ia(Ra + Rse) drop is quite small under normal conditions and may be ignored.

$$N \propto \frac{1}{\emptyset}$$

$$\propto \frac{1}{Ia} \text{ Up to magnetic saturation}$$

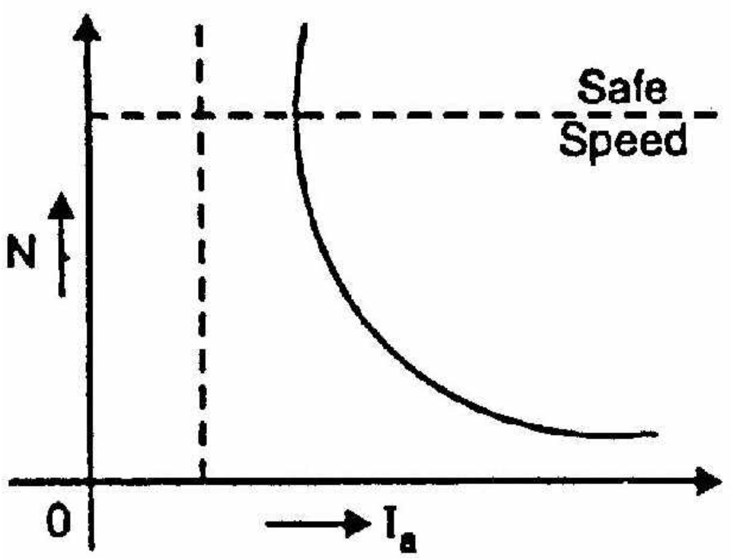


Fig: 3.18 graph between speed and armature current

The N/Ia curve follows the hyperbolic path as shown in Fig. 3.18, up to magnetic saturation. After saturation, the flux becomes constant and so does the speed.

N/Ta Characteristic: The N/Ta characteristic of a series motor is shown in Fig. (3.19). It is clear that series motor develops high speed at low torque and vice-versa. It is because an raise in torque requires an raise in armature current and the field current also increase. The effect is that flux is strengthened and hence the speed drops ($N \propto \frac{1}{\emptyset}$). [36]

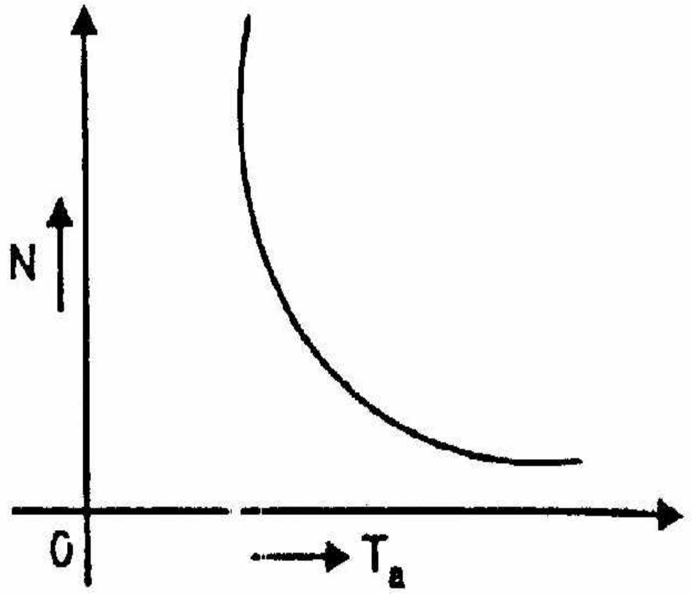


Fig: 3.19 graph between speed and armature current

3.10.3 Characteristics of Shunt Motors

Fig.3.20 shows the connections of a d.c. shunt motor. the field winding is directly connected to the supply voltage V which is constant the field current I_{sh} is also constant. Hence, the flux in a shunt motor is approximately constant.

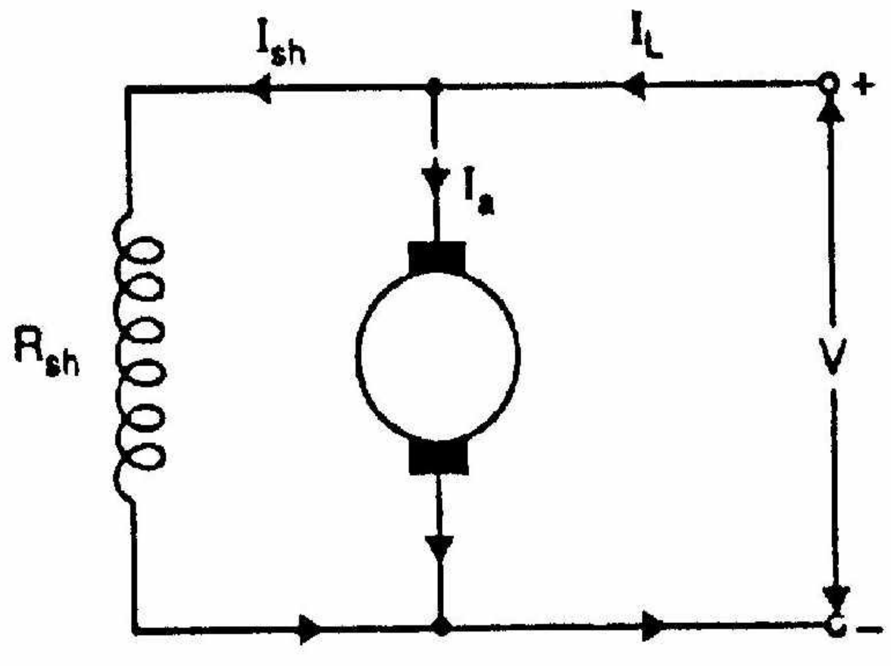


Fig: 3.20 Connection diagram of shunt motor

Ta/Ia Characteristic: We know that in a d.c. motor

$$T \propto \emptyset I_a$$

Since the motor is operating from a constant supply voltage (neglecting armature reaction).flux ∅ is constant.

$$T_a \propto Ia$$

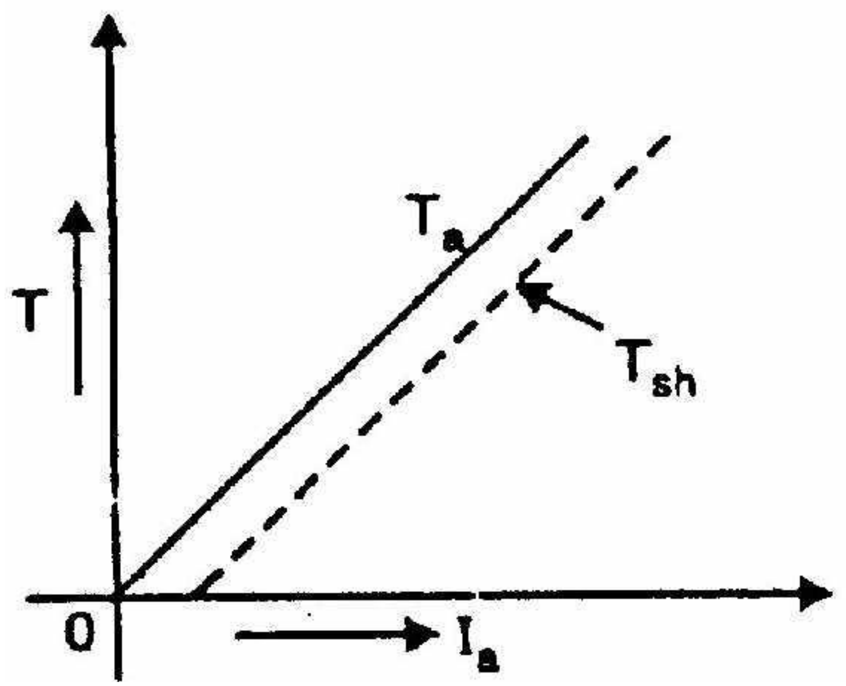


Fig: 3.21 Graph between torque and armature current

Hence Ta and Ia characteristic is a straight line passing through the origin as shown in Fig. 3.21. The armature torque (T_a) is more than shaft torque (T_{sh}) and is shown by a dotted line. It is clear from the curve that a shunt motor cannot be started on heavy load because very large current is required to start shunt motor on heavy load.

N/Ia Characteristic: The speed N of a. d.c. motor is given by;[36]

$$N \propto \frac{Eb}{\emptyset}$$

Under normal conditions the flux ∅ and back e.m.f. E_b in a shunt motor are almost constant. Therefore, as the armature current varies dotted line AB in Fig. 3.21 speed of a shunt motor will remain constant. severely speaking, when load is increased

$$E_b \ (= V- IaRa) \qquad (3.18)$$

∅ reduce due to the armature resistance drop and armature reaction respectively. Still E_b decrease slightly more than ∅ so that the speed of the motor decreases slightly with load

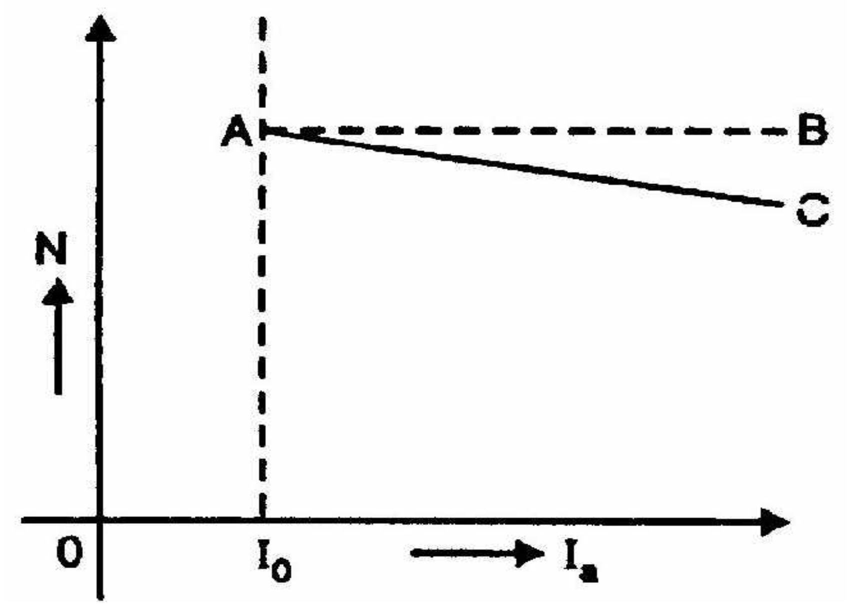


Fig: 3.22 Graph between speed and armature current

N/Ta Characteristic: It may be seen that speed falls fairly as the load torque increases. The curve is obtained by plotting the values of N and Ta for various armature currents Fig. 3.20.

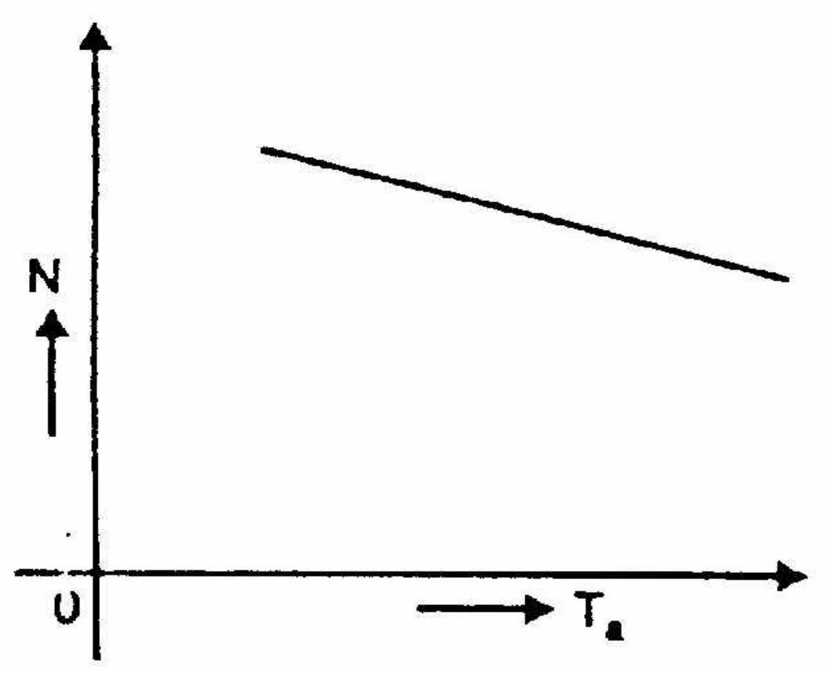


Fig: 3.23 Speed and armature torque

3.11 Applications of d.c. Motors

There are many application of dc motor some are following

3.11.1 Series motors

It is a variable speed motor speed is high at low torque and vice-versa. The motor has a high starting torque. However, at light or no-load, the motor tends to attain dangerously high speed.

It is, therefore, used in elevators and electric traction where large starting torque is required

Where the load is subjected to heavy fluctuations and the speed is automatically required to increase at low torques and vice-versa

Industrial use: sewing machines, hair drier, electric traction, cranes, elevators, air compressors, vacuum cleaners etc.[36]

3.11.2 Shunt motors

The characteristics of a shunt motor expose that it is an approximately constant speed motor. It is, therefore, used where the speed is required to remain almost constant from no-load to full-load. Where the load has 10 be driven at a number of speeds and any one of which is required to remain nearly constant

Industrial use: drills, Lathes, shapers, boring mills, spinning and weaving machines etc.

3.11.3 Compound motors

Differential-compound motors have poor torque characteristics so rarely used. However, cumulative-compound motors are used where suddenly applied heavy loads and fairly constant speed is required with irregular loads.

Industrial use: Shears, presses, reciprocating machines etc.

3.12 There are some advantage and disadvantage of dc motor

Advantages of dc motor

– Deliver high starting torque
– Ease of control
– Near-linear performance

Disadvantages of dc motor

– Large and expensive (compared to induction motor)

– Not suitable in explosive or very cleans [35]

– High maintenance

– Not suitable for high-speed operation due to commutator and brushes environment

3.14 Introduction to flywheel

Several hundred years ago pure mechanical flywheels where used only to keep machines running smoothly from cycle to cycle, thereby provide possible the industrial revolution. During that time several designs and shapes where implemented, but it took until the early 20th century before flywheel rotor shapes and rotational stress were thoroughly analyzed.

After 1970s flywheel energy storage was proposed as a primary purpose for electric vehicles and stationary power backup. At the same time fiber combined rotors where built, and in the 1980s magnetic bearings started to come out. Thus the potential for using flywheels as electric energy storage has long been established by extensive research.[28]

Latest improvement in material, power electronics and magnetic bearings make flywheels a competitive choice for a number of energy storage applications. The uses of compound materials enable high rotational velocity with power bulk greater than that of chemical batteries. Magnetic bearings propose very low friction enabling low internal losses in long-term storage. High speed is popular since the energy stored is proportional only linearly proportional to the mass but the square of the speed. [28].

3.15 What is flywheel ?

A flywheel is an inertial energy-storage device with a significant moment of inertia used as a storage device for rotational energy.[30]It absorb mechanical energy and serves as a reservoir, storing energy during the period when the supply of energy is more than the requirement and releases it during the period when the requirement of energy is more than the supply. [29]

flywheel energy storage systems are considered to be an attractive to electrochemical batteries due to higher life term, higher stored energy density, higher life term, ecologically clean nature and deterministic state of charge

Fig: 3.21 basic component of flywheel energy store system.

As shown in Fig3.21, a typical system consists of a motor/generator, a flywheel, and controlled electronics for connection to a larger electric power system.

Its temporal profile, frequency, or other attributes so the input power may differ from the output power in,. It is changed by the input electronics into a form appropriate for efficiently driving a variable-speed motor. The motor spin the flywheel, which supplies energy mechanically, it delivers energy to a load, slowing down. That reduce in mechanical energy is converted into electrical form by the generator. A confront facing the motor and the generator exclusive is delivery rate power required and also to minimize losses and to size the system for the amount of storage energy. The output electronics change the variable-frequency output from the generator into the electric power necessary by the load. Since the output and input are typically separated in a timely way, many approaches come together the motor and generator into a single machine, and place the output and input electronics into a single unit, to decrease weight and cost.

3.16 Theoretical analysis:

A flywheel stores energy in a rotating mass. Depending on speed of the rotating mass, inertia and a given quantity of kinetic energy is stored as rotational energy. The flywheel is positioned inside a vacuum containment to remove friction-loss from the air and balanced by bearings for a stabile operation.

The kinetic energy stored in a flywheel is proportional to the square of its rotational speed and mass according to [28]

$$E_{k=}\frac{1}{2}I\omega^2 \qquad (3.19)$$

where, I is moment of inertia

ω is the angular velocity of the flywheel.

E_k is kinetic energy stored in the flywheel

The moment of inertia for any object is a function of its mass and shape

For a thin-walled cylinder is. $I=mr^2$ (3.20)

For a thick-walled cylinder is $I=\frac{1}{2}m(r^2{}_1+r^2{}_1)$ (3.21)

The moment of inertia for a solid-cylinder is $I_z=\frac{1}{2}mr^2$ (3.22) where m denotes mass

r denotes a radius

When calculating with SI units, the standards would be for radius, meters
for angular velocity, radians per second
for mass, kilograms ,resulting answer would be in Joules

3.17 Application of flywheel

3.17.1 Transportation:

In the 1950s flywheel-powered buses, known as gyrobuses, were used in Yverdon, Switzerland, Advanced flywheels, such as the 133 kW·h pack of the University of Texas at Austin, can take a train from a standing start up to cruising speed.[30]

It is hoped that flywheel systems can replace conventional chemical batteries for mobile applications, such as for electric vehicles.

3.17.2 Uninterruptible power supply

Flywheel power storage systems in current production have storage capacities comparable to batteries and faster discharge rates. They are mainly used to provide load leveling for large battery systems, such as an uninterruptible power supply for data centers.[30]

3.17.3 Motor sports

The FIA has re-allowed the use of kinetic energy recovery system as part of its Formula 1 2009 Sporting Regulations. Using a always variable transmission, energy is recovered from the drive train during braking and stored in a flywheel. This stored energy is then used in acceleration by altering the ratio of the CVT. In motor sports applications this energy is used to reduce carbon dioxide emissions to improve acceleration. Same technology can be applied to road cars to increase fuel efficiency.

3.18.4 Space application

Flywheel energy storage systems are extensively used in space, military field, power quality and hybrid vehicles. Aircraft, space station, satellites are the main application field in space. In these fields, flywheel systems function as attitude control and energy storage.

Chapter: 4

Implementation: control using FLC

4.1 Flywheel control system

A flywheel is an energy-storage device. It absorbs mechanical energy and serves as a reservoir, storing energy during the period when the supply of energy is more than the requirement and releases it during the period when the requirement of energy is more than the supply.

The typical conventional closed loop control of flywheel is the first step to analysis the performance. The overshoot, rise time and setting time considered as measure parameter. Then for further improvement PID based control scheme is implemented and same overshoot, rise time and setting time are considered of measure parameter. The improvement in the value are considered. It always come we incorporated the ISE and IAE disturbance and model developed is shown here. Finally we applied fuzzy logic controller to control the effectiveness of flywheel performance. The considered improvement in overshoot, setting time and rise time

Control scheme implemented to control the effective working of fly wheel is show in this chapter. The above figure4.1shows the basic scheme for control of fly wheel represented by its equivalent transfer function as shown in the block digram.The friction losses which are contributing for better design is also considered as per its transfer function.The controller here is PID controller which is providing us overshoot 1.198V.rise time 1.08sec and setting time 55 sec.

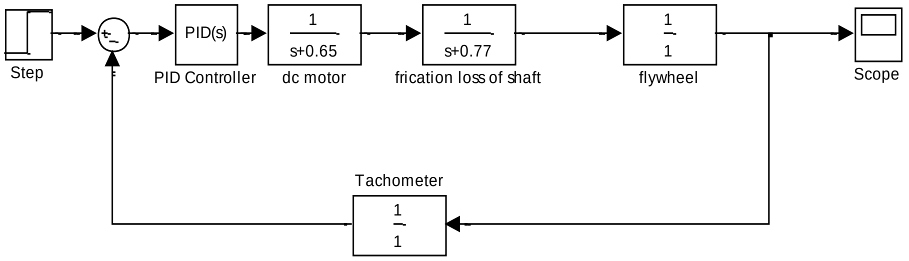


Fig: 4.1 basic scheme of control of flywheel

4.2 PID control scheme with IAE and ISE criterior

PID i.e proportional, integral, derivative based controller are more effective in controlling the system parameter as compared to openloop system.The overshoot ,setting time and rise time all the parameter which are essentially considered while applying the control scheme for control of any parameter.Here in case of flywheel speed control is help in considering all the affcting parameter with in the system or out side the system as per the Proportional,Intergral,Derivative relation existing between input and output

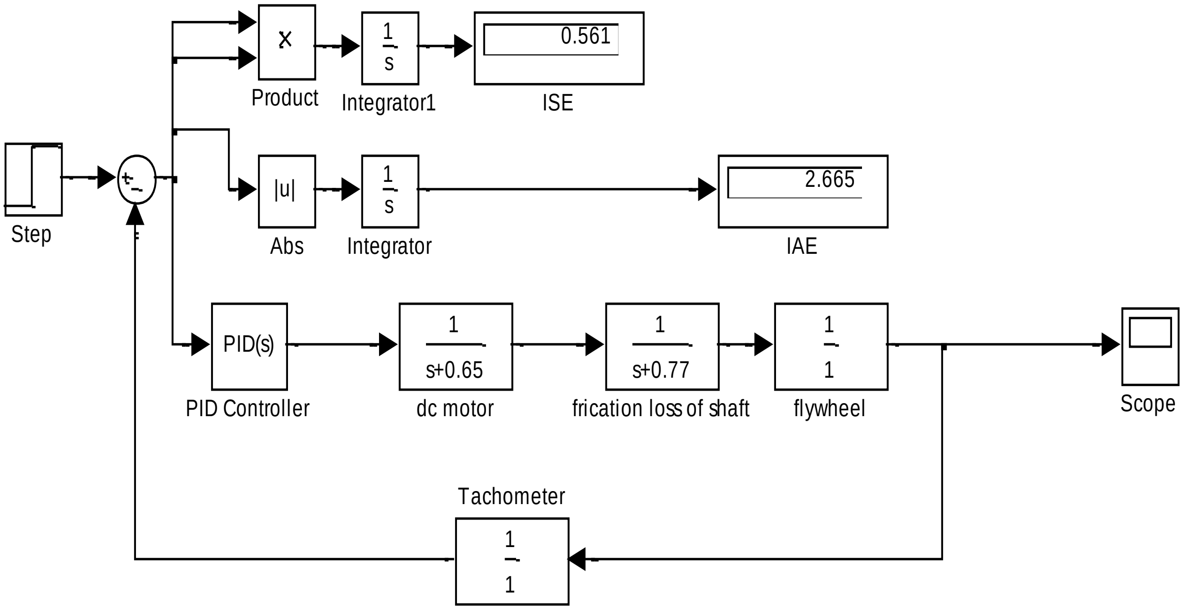


Fig: 4.2 PID control scheme with ISE and IAE

Fig 4.2 show PID control scheme with control criterior applied for controlling error by the Integral square error (ISE) and Integral absolute error (IAE) is 0.581 and 2.685 respectively.

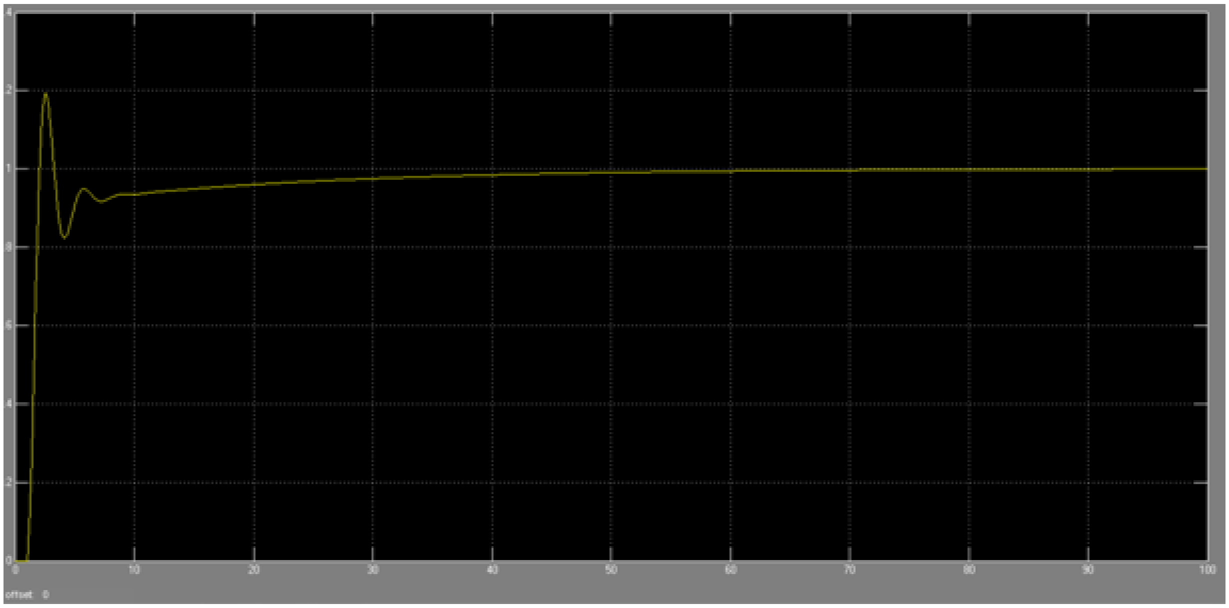


Fig: 4.3 Graph of V vs Time showing over shoot time, setting time and rise time

There is overshoot sec.of 2volts and rise time is 12 sec and the settling time is 55 sec The graph in figure 4.3 shows the overshoot time ,rise time and settling time with PID controller applied.

4.3 FLC control scheme

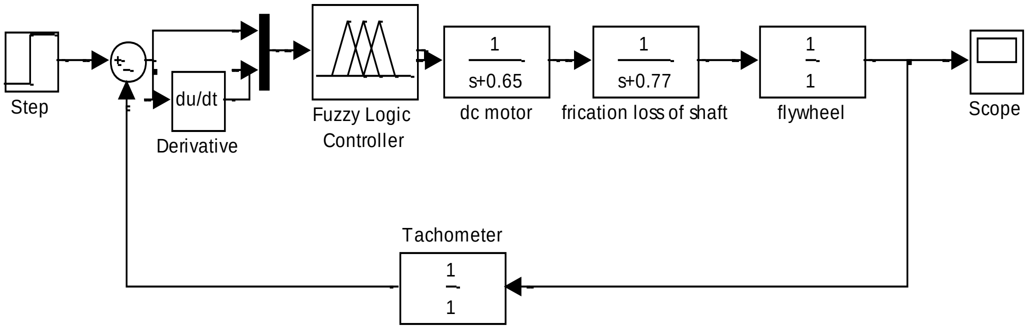


Fig: 4.4 control scheme using FLC

Figure 4.4 shows the control scheme using intelligent controller i.e. fuzzy logic controller whose input is error and change in error du/dt.Considerable improvement in performance of system is observed. The rules made to take control action are shown in table 4.1

Error Change In error	**VL**	**L**	**M**	**H**	**VH**
VL	L	M	H	VH	VH
L	M	M	H	VH	VH
M	H	H	H	VH	VH
H	VH	VH	VH	VH	VH
VH	VH	VH	VH	VH	VH

Table: 4.1 Rules look up table

In the table 4.1 show the rule made to take control action.

The following figure 4.5 shows the graphical results showing no overshoot ,rise time is 1 sec and settling time is 10 sec. The above results are due to the application of FLC control scheme.

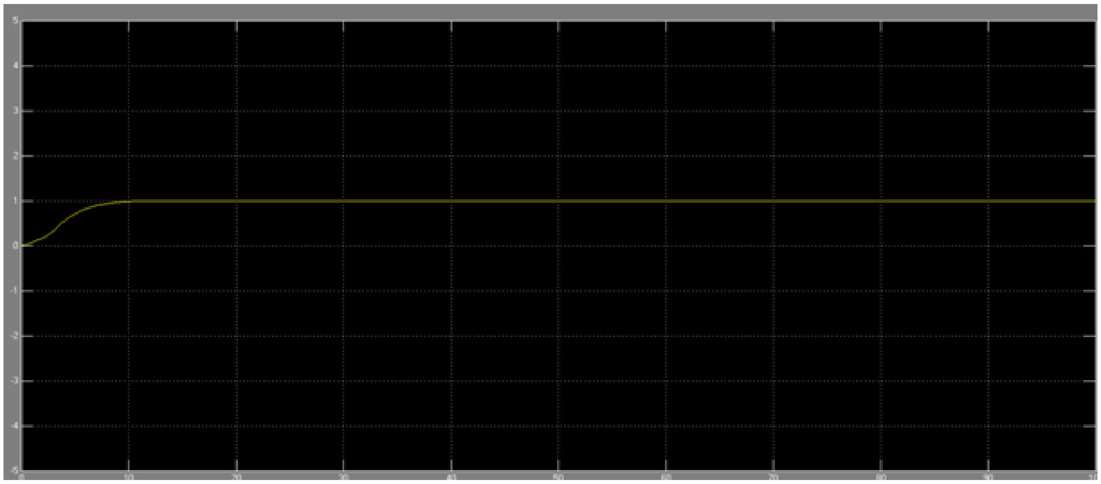


Fig: 4.5 Graphical result of voltage vs time using FLC controller

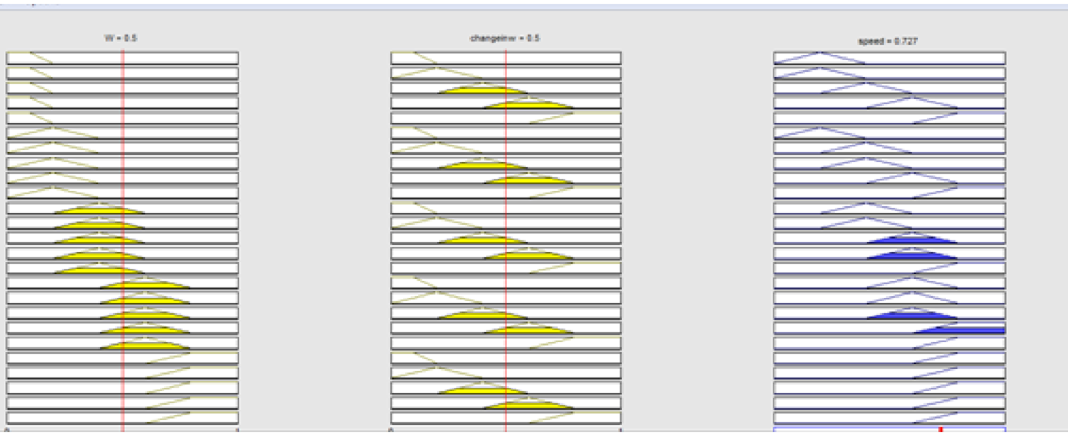


Fig: 4.6(a) Graphical view of rule of FLC controller

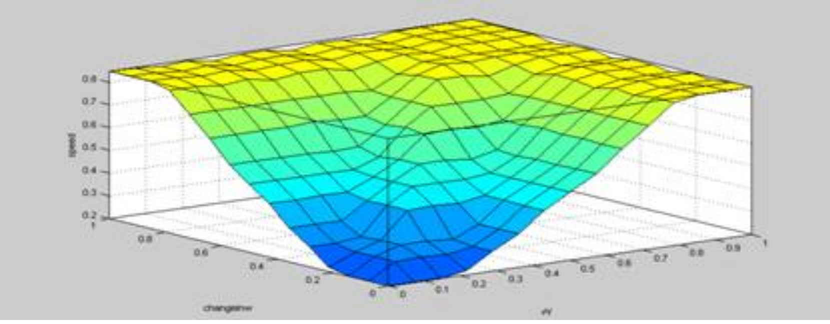


Fig: 4.6(b) Surface view of resultant FLC controller

The above graphs in figure 4.6(a) and 4.6(b) rules and the surface view of resultant FLC control scheme which shows control action on error and change in error.

4.4 FLC control scheme with IAE and ISE

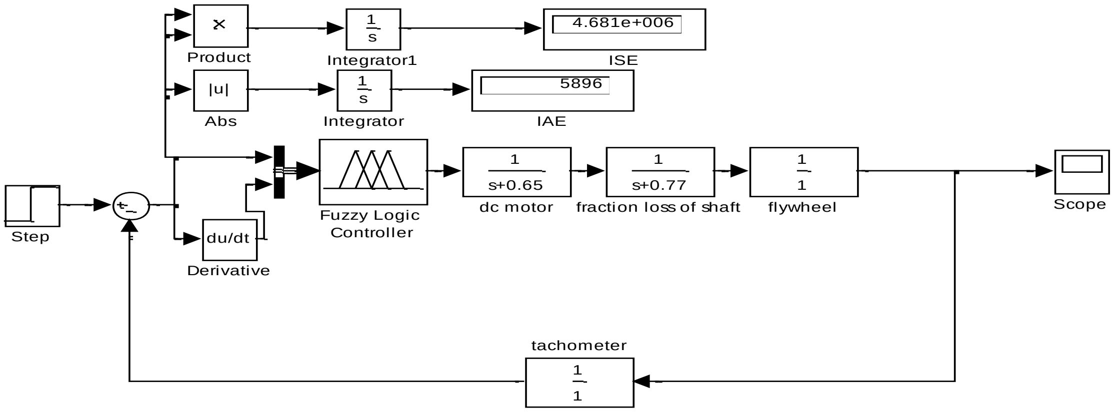


Fig: 4.7 FLC control scheme with ISE and IAE

Fig 4.7 show FLC control scheme with control criterior applied for controlling error by the Integral square error (ISE) and Integral absolute error (IAE) is 4.58 and 58.96 respectively.

Controller name	Overshoot	Setting time	Rise time	ISE	IAE
PID Controller	1.198V	55 sec	1.8sec	0.561	2.665
Fuzzy logic controller	1V	18sec	0.2	0.468	0.5896

Table: 4.2 comparison of different parameter of PID and fuzzy controller

Chapter: 5

Future scope

.Comparative performance evaluations of the neuro-fuzzy controller for the fly wheel motor control can be done. Simulation results show the usefulness of the proposed PID controller and FLC controllers but still there is a scope of improvement in the work performance which can be achieved through the techniques of neuro-fuzzy controller. The ant colony system i.e ACS approach for the control of fly wheel can be tested for improved results. In all network variation and deteriorations the studies shows that on using intelligent control schemes improve and strengthen the network control systems performances.

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