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A Review on Control of a Brushless DC Motor Drive

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Abstract— This paper represents the modeling parameters of the Permanent Magnet Brushless DC (PMBLDC) motor drive using Mat-lab / Simulink Software. The modelling of Permanent Magnet Brushless DC (PMBLDC) motor drive is useful in various phenomenon's such as aerospace modelling and more other applications. In this Paper, the modelling of PMBLDC motor drive is done by using various components such as current, Speed controllers and sensors are installed to sense the various factors such as speed, current, and the output obtained from the inverter. The basic purpose of designing of such drive is to gives the certain ideas about designing of the motor drive using Mat-lab / Simulink and how it helps in various applications such as electric Traction, automotive industries and more other places.

Keywords— *PMBLDC, modelling, DC motor P-I Controller & I-P Controller PID Controller Self-tuning fuzzy PID controller. Genetic Algorithm.*

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I. INTRODUCTION

A brushless DC (BLDC) motor is becoming more popular in sectors such as automotive (particularly electric vehicles (EV)) [8], HVAC, white goods and industrial because it does away with the mechanical commutator used in traditional motors, replacing it with an electronic device such as IGBT and MOSFET that improves the reliability and durability of the motor. Another advantage of a BLDC motor is that it can be made or available in smaller as well as lighter in size than a brush type with the same power output, making the former suitable for applications where small space is needed. The downside is that BLDC motors do need electronic management to run. For example, a microcontroller – using input from hall sensors indicating the position of the rotor for that purpose – it is needed to energize the stator coils at the correct moment. Precise timing allows for accurate speed and torque control, as well as ensuring the motor runs at peak efficiency. This article explains the fundamentals of BLDC motor operation and describes typical control circuit for the operation of a three-phase unit [1] - [2]. The article also considers some of the integrated modules – that the designer can select to ease the circuit design – which are specifically designed for BLDC motor control.

The Permanent magnet brushless motors are categorized into two kinds depending upon the back EMF waveform, Brushless AC (PMBLAC) and Permanent Magnet Brushless DC (PMBLDC) motors. PMBLDC motors have trapezoidal back EMF and quasi-rectangular current waveform. PMBLDC motors are quickly becoming famous in industries like HVAC industry [44 - [48]], military equipment, medical Appliances, electric traction, automotive, aircrafts, disk drive, industrial drives and instrumentation because of their high efficiency, silent operation, high power factor, reliability, compact, low maintenance and high power density The brushes of a conventional motor transmit power to the rotor windings which, when energized, turn in a fixed magnetic field [53] - [54] - [68] - [71] - [72] . Friction between the stationary brushes and a rotating metal contact on the spinning rotor causes wear. In addition, power can be lost due to poor brush to metal contact and arcing [79] - [80] - [82] - [83] - [85] - [86] - [87]. Because a BLDC motor dispenses with the brushes – instead employing an "electronic commutator" the motor's reliability and efficiency is improved by eliminating this source of wear and power loss.

In addition, BLDC motors boast a number of other advantages over brush DC motors and induction motors, including better speed versus torque characteristics; faster dynamic response; noiseless operation; and higher speed ranges [121]. Moreover, the ratio of torque delivered relative to the motor's size is higher, making it a good choice for applications such as washing machines and EVs, where high power is needed but compactness and lightness are critical factors While some of the new achievements of modern control theory, including pole placement and optimal control linear regulator based on precise feedback linearization, model reference adaptive control, are used to the control technology of motor to effectively improve the performance of brushless DC motor [3] - [4] - [5] - [6]. But modern control theory is still dependent on the precise mathematical model of the motor, the motor performance parameters changes are impacted vulnerability by various uncertainties. A BLDC motor is known as a "synchronous" type because the magnetic field generated by the stator and the rotor revolve at the same frequency. One benefit of this arrangement is that BLDC motors do not experience the "slip" typical of induction motors.

II. CONSTRUCTION AND OPERATING PRINCIPLE

Unlike any other rotating electrical machine BLDC motor have also the similar construction and operating principle. It has two main elements the first one is rotor and the second one is stator. The other important parts are stator winding and permanent magnet which is mounted on the stator and rotor respectively. Permanent magnets are also called as rotor magnet. [43] - [45].

Rotor- The brushless DC motor have two basic design constraints for rotor, The first one is inner rotor design and the second one is outer rotor design. In case of inner rotor design the rotor magnets are surrounded by the stator winding and are fixed into the housing of the motor. One of most advantageous point for the inner rotor construction is its ability to dissipate heat which is generated inside the stator winding. Due to the proper heat dissipation property this type of motor able to produce more torque. For this reason, the majority of BLDC motor are of inner rotor design type. [101] - [102]. The other one is outer rotor design in this type of construction the stator winding are placed in the core of the motor and the rotor magnet surrounds the stator winding. The rotor magnet works as an insulator between the stator winding and the yoke of the machine hence heat generated inside the stator winding is not dissipated homogeneously throughout the motor. Due to the location of stator winding the outer rotor design of BLDC motor operates on low voltage and current. Means its rated voltage and rated current are lower as compared to the similar rating of inner rotor design BLDC motor. The primary advantage of this type of rotor is its relatively low cogging torque.

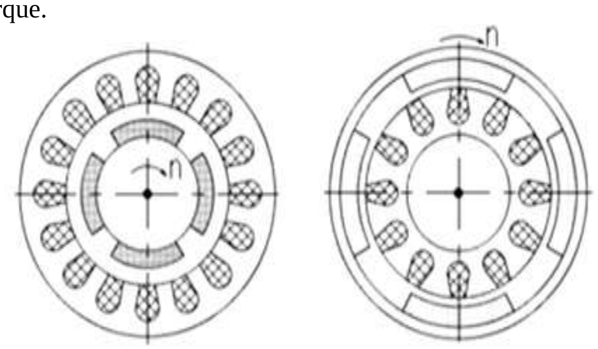

Fig.1 Inner rotor and outer rotor design

The stator of a permanent magnet brushless DC motor comprises of stacked steel laminations with windings kept in the slots that are cut along the inner periphery. Most of the permanent magnet brushless DC motors have three stator windings linked in star. Each of these windings is assembled along with various coils interconnected to derive a winding. One or more than one coils are kept in the slots and they are interconnected to form a winding. Each of these windings is distributed over the stator peripheral area to form an even numbers of poles. The stator winding wound either in clock wise or in counter clock wise direction to along with each arm of the stator to produce magnetic poles. The primary difference between AC and DC motor is the applied power to the armature. From this point of view, a BLDC motor actually is an AC motor. [106] - [145]. The BLDC motor converts electrical energy into mechanical energy using electromagnetic principles. The energy conversion method is fundamentally the same in all electric motor. Motor operation is based on the attraction or repulsion between magnetic poles. In three phase motor the process start when current flows through one of the three stator winding generates a magnetic pole that attracts the closest permanent magnet of the opposite pole. The rotor will move if the current shift to an adjacent winding. Sequentially charging of each winding will cause the rotor to follow the rotating field.

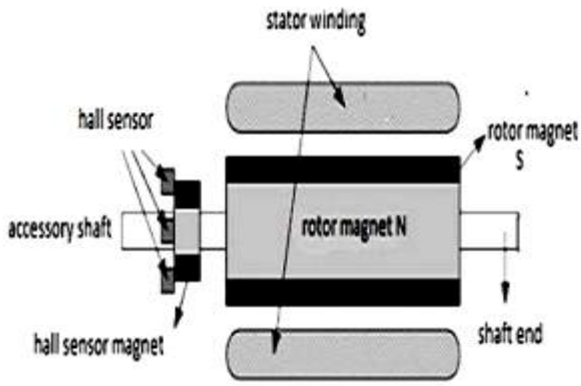

Fig. 2 Rotor and Hall sensors of PMBLDC motor

III. ADVANTAGES OF BLDC MOTOR OVER OTHER MOTORS

In this section we are going to made the comparison of different parameters of brushless DC motor with induction motor as well as brushed DC motor. Due to the advantages mentioned below the brushless DC motor are most widely accepted motor for industrial as well as commercial application over the other type of motor having the similar rating. On the basis of highlighted advantages, the brushless DC motor having the capability to replace the other type of motor and owing to its wide range of application.

Table I
Comparison of BLDC Motor with Brushed DC and Induction Motor

Advatages	**Brushless DC motor**	**Brushed DC motor**	**Induction motor**
Mechanical Structure	Field Winding on stator and permanent magnets on rotor.	Field Winding on the rotor and stator are made of permanent magnets or electromagnet	Both the rotor and stator have windings but the AC lines are connected to the stator
Maintenance	No maintenance	Periodic maintenance because of brushes	Low maintenance
Speed-Torque characteristic	Flat – operation at all speeds with rated load	Moderate – Loss in torque at higher speeds because of losses in brushes	Non-linear
Efficiency	High	Moderate	High efficiency
Commutation method	Using solid state switches	Mechanical contacts between brushes and commutator	Special starting circuit is required

Speed Range	High - no losses in brushes	Moderate – losses in brushes	Low determined by the AC line frequency; increases in load further reduces speed
Detecting method of rotors position	Hall sensors, optical encoders, etc.	Automatically detected by brushes and commutator	NA
Direction reversal	Reversing the switching sequence	Reversing the terminal voltage	By changing the two phases of the motor input
Electrical noise	Low	High – as brushes used	Low
System cost	High-because Of external Controller requirement	Low	Low

IV. MATHEMATICAL MODELLING OF PMBLDC MOTOR

In this review paper mathematical modelling of BLDC motor in star connection is proposed [107] - [129] - [133], with the few assumptions such that equivalent winding resistance of all the three phases is R and similarly the inductance of all the three phases is L, where L is equals to $L_S - M$. Where L and M are self-inductance and mutual-inductance of the windings respectively [154]. The following equation which describes the equivalent circuit.

$$v_a = Ri_a + L\frac{di_a}{dt} + e_a \quad (1)$$

$$v_b = Ri_b + L\frac{di_a}{dt} + e_b \quad (2)$$

$$v_c = Ri_c + L\frac{di_a}{dt} + e_c \quad (3)$$

Thus

$$v_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + e_a - e_b \quad (4)$$

$$v_{bc} = R(i_b - i_c) + L\frac{d}{dt}(i_b - i_c) + e_b - e_c \quad (5)$$

$$v_{ca} = R(i_c - i_a) + L\frac{d}{dt}(i_c - i_b) + e_c - e_a \quad (6)$$

Where

R: Armature resistance; L_S: Armature inductance; M: Mutual inductance which describes the flux linkage between two windings? $e_{a,b,c}$: The Back-EMF; $i_{a,b,c}$: The armature currents flowing through windings; $v_{a,b,c}$: The phase voltages; v_{bc}, v_{ab} and v_{ca}: The phase-to-phase voltages

The relationship between phase currents is given by-

$$i_a + i_b + i_c = 0 \quad (7)$$

two equations are sufficient to describe the system behavior because one voltage is combination of the other two voltages [57]. By using equation (7) we can formulate equation (4) and (5) as From the Newton's second law of motion, the relation between electromagnetic torque T_e and speed of motor ω_m can be written as following:

$$T_e - T_i = J\frac{d\omega_m}{dt} + B\omega_m \quad (8)$$

$$\omega_m = \frac{d\theta_m}{dt} \quad (9)$$

Where

T_i: Load torque in N-m; J: Moment of inertia in kg/m^2;

B: Damping constant

The Back-EMF and electromagnetic torque can be expressed as

$$e_a = \frac{k_e}{2}\omega_m F(\theta_e) \quad (10)$$

$$e_b = \frac{k_e}{2}\omega_m F\left(\theta_e - \frac{2\pi}{3}\right) \quad (11)$$

$$e_b = \frac{k_e}{2}\omega_m F\left(\theta_e - \frac{4\pi}{3}\right) \quad (12)$$

$$T_a = \frac{k_t}{2} i_a F(\theta_e) \quad (13)$$

$$T_b = \frac{k_t}{2} i_b F\left(\theta_e - \frac{2\pi}{3}\right) \quad (14)$$

$$T_c = \frac{k_t}{2} i_c F\left(\theta_e - \frac{4\pi}{3}\right) \quad (15)$$

Where k_e is Back-EMF constant k_t is electromagnetic torque constant. The electrical angle $\theta_e = \frac{P}{2}\theta_m$ The function $F(\theta)$ is a function of rotor position, which gives the trapezoidal waveform of back-EMF? One period of function can be given as,

$$F(\theta_e) = \begin{cases} 1, 0 \le \theta_e \le \frac{2\pi}{3} \\ 1 - \frac{6}{\pi}\left(\theta_e - \frac{2\pi}{3}\right), \frac{2\pi}{3} \le \theta_e \le \pi \\ -1, \pi \le \theta_e \le \frac{5\pi}{3} \\ 1 + \frac{6}{\pi}\left(\theta_e - \frac{2\pi}{3}\right), \frac{5\pi}{3} \le \theta_e \le 2\pi \end{cases} \quad (16)$$

Due to the symmetry design of motor, the Back-EMF signal of each phase is 120 degrees' phase shifted with respect to each other as shown in figure 3. Shows the Back EMF and current in each phase.

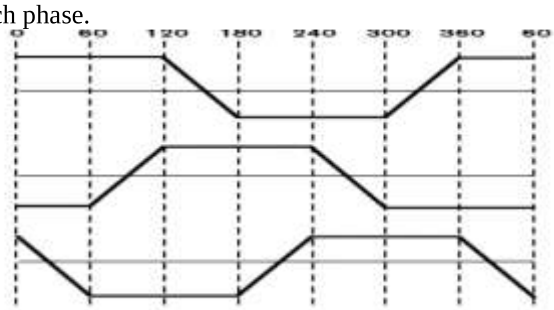

Fig. 3 Desire Waveforms of Three Phase BLDC Motor

V.CONVERTER TOPOLOGY USED FOR BLDC MOTOR DRIVE

Electronic commutation is used to control BLDC motors; it makes the drive costlier when comparing with other electric motors. Conventionally for a three phase BLDC motor six switches are used to drive the motor [16] - [17], as shown in Fig.3 Nowadays many studies are focusing on how to reduce the cost of BLDC motor drive [49]- [50] - [51] - [89] - [90] - [91]. Four switch topology is a way to reduce the cost of three phase BLDC drive; where it reduces the number of switch by two [6], as shown in Fig.4. The main drawback of the four switch topology is speed limitation of BLDC motor. A conventional four switch BLDC drive can operate only up to half of the rated speed. By combining two input dc-dc boost converter with four switch BLDC drive topology, a low cost three phase BLDC drive can be formed for hybrid electric vehicle [100] - [103]. Two input dc-dc boost converter is used to supply the voltage to four switch converter. By regulating the output voltage of two input dc BLDC motor; the motor can run up to rated speed.

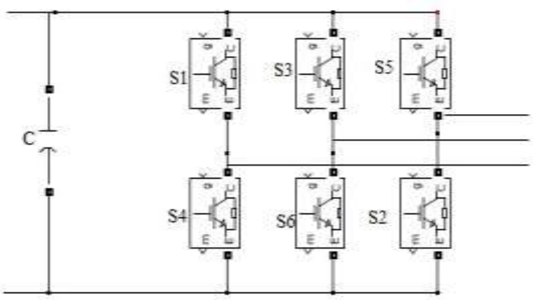

Fig.4 Conventional six-switch converter topology

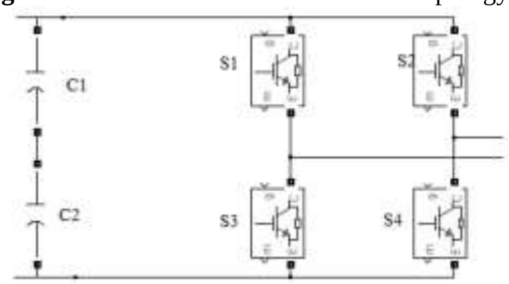

Fig.5 Four-switch converter topology

In four switch topology, four switches are used instead of six and one phase is directly connected to the common point of dc-dc capacitor [60]. The topology is shown in fig. 4.the desired back-emf and current profile are shown in fig. 3. In the case of the BLDC motor drive, for every mode one phase current will be zero.

VI. BLDC MOTOR WITH COLSED LOOP MODEL

The Brushless DC motor drive system consists of permanent magnet synchronous motor fed by a three-phase voltage source inverter [52] - [55] - [56] - [92]. Fig. 6 shows the overall closed loop system configuration of three phase BLDC motor drive as we know that the open loop system is more stable than close loop system hence for making the close loop BLDC drive more stable as per the desired application the different type of controller along with the converter topology are used. The inner loop of the drive consists hall effect sensor which is used to provide the information about the rotor position of the BLDC drive based on that information the Gate signal generator generates the commutating signals for three phase VSI. The triggering pulse is nothing but the back EMF of the motor which is coming from the particular position of the rotor. Gate signal generator includes the back EMF generator and gate logic decoder and the combined effect of these two signal along with the reference signal generates the triggering pulses.

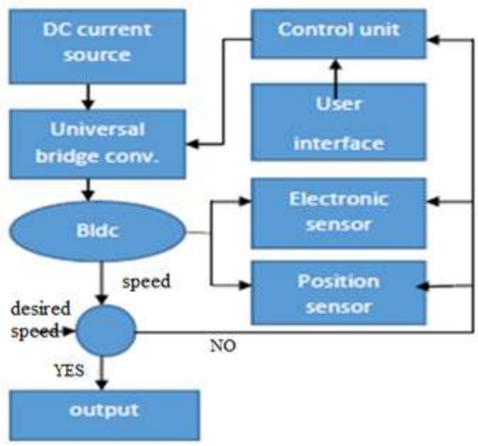

Fig. 6 Block diagram of closed loop model PMBLDC drive.

VII. CONTROL SCHEME FOR BLDC MOTOR DRIVE

Brushless DC motor known as permanent magnet synchronous motor or may be described as electronically commuted motor which do not have brushes, which means their rotor and stator runs at same frequency that are powered with direct current (DC) inverter/switching power supply, which is build up by using a universal bridge [78].

The configuration of BLDC motor controller consists of power converter in which three phase VSI work as a brushes of BLDC motor and to operate the VSI power are fed to VSI with different type of converters like Bidirectional converter,

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CUCK converters, SEPIC converters etc. these converters handles the power and power factor requirement of the drive. Along with the converters the drive system consists of the PMSM, hall sensor and different type of control algorithms. [99] - [109] - [114]. Three phase VSI transforms power mains to the PMSM which in turn converts electrical energy into mechanical energy. BLDC motor has rotor position sensors controlled by the command signals, the different command signal used in BLDC drive are torque, voltage, speed, current and so on. The type of BLDC drive is determined by the structure of control algorithms based on that algorithms two main type of drive are becoming more popular which is nothing but voltage source and current source based drive [115] - [118] - [155]. Permanent magnet synchronous machine with either sinusoidal or trapezoidal back-EMF waveforms is used by both voltage source and current source based drive [43].

a) P-I Controller & I-P Controller.

as a proportional as well as an integral term in the forward path, the block diagram with a P-I controller for a dc motor drive is shown in Fig. 7 The integral controller has the property of making the steady-state error zero for a step change, although a P-I controller makes the steady-state error zero [38], it may take a considerable amount of time to accomplish this. Fig. 6 shows I-P controller along with a dc motor drive, where the proportional term is moved [138]. The analysis in S- domain is discussed in this section to study the transient and the steady-state behavior for both controllers.

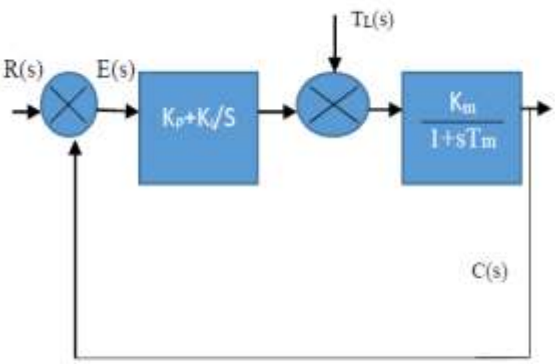

Fig.7 Block diagram with P-I controller.

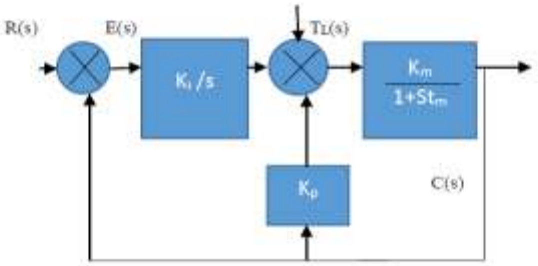

Fig. 8 Block diagram with I-P controller

The closed loop transfer function of P-I controller between the output C(S) and the input R(S) is given by,

$$\frac{C(s)}{R(s)} = \frac{K_m\left(sK_P + K_i\right)}{T_m s^2 + \left(1 + K_m K_p\right)s + K_m K_i} \qquad (17)$$

Where K_i and K_p ,are the integral and the proportional gains of P-I or I-P controller, T_m , is the mechanical time constant of motor, and K_m , is the motor gain constant. The transfer function between the output C(S) and the load torque disturbance $T_L(s)$ is given by

$$\frac{C(s)}{T_L(s)} = \frac{s\left(1 + sT_m\right)}{T_m K_p s^2 + \left(K_m + T_m K_i + K_p\right)s + K_i} \qquad (18)$$

The closed loop transfer function of I-P controller between the output $C(s)$ and the input $R(s)$ is given by,

$$\frac{C(s)}{R(s)} = \frac{K_i K_m}{T_m s^2 + \left(1 + K_m K_p\right)s + K_m K_i} \qquad (19)$$

From the above equation it is seen that the, P-I and I-P controllers have the same characteristic equations, and it can be seen that the zero introduced by the P-I controller is absent in the case of the IP controller. Therefore, the overshoot in the speed, for a step change in the input reference $R(s)$ is expected to be smaller for the I-P control.

b) PID Controller.

Fast development of science and technology requires a system which has higher response speed higher control accuracy and higher stability and PID controller is one of the latest control strategy in which traditional PID controller is used to control all the model of linear processes. But most industrial processes are non-linear in nature and some process is difficult or cannot established mathematical model at the same time so the general PID control cannot achieve precise control of such processes [113].

Classic PID control technique is used for its simplicity and robustness. The principle of PID control is to establish a control with proportion, integration and differential, then choosing proper linear combination in order to control the process [149] – [152]. For obtaining satisfactory result change in parameter $\left(k_{p,} k_{i,} k_d\right)$ is required as shown in following equation.

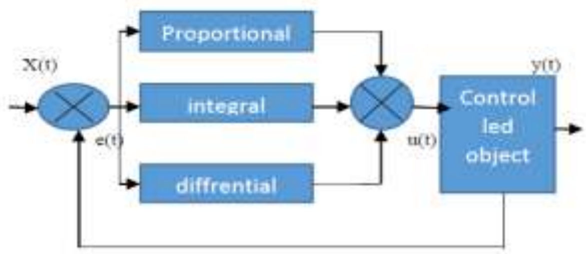

Fig.9 Schematic of a PID controller

$$e(t) = x(t) - y(t) \qquad (20)$$

The control law for PID controller is:

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{de(t)}{dt} \qquad (21)$$

Where k_p is proportion gain coefficient, k_i is integration time coefficient, k_d is differential time coefficient.

- Proportion part-: proportional link in PID controller is used to reflect the deviated signal. If deviation is present, then it can reduce the deviation of the signal from the original one.
- Integral part-: the integral part is used to minimizes or to eliminates the steady state error and also improves the steady state stability of the system.
- Differential part-: can reflect the change trend of deviation signal (change rate), and before the value of the deviation signal become too large, the system introduced in an effective early correction signal, speed up the action of the system, reduce the adjusting time.

The problem in the PID controller is to choose the three parameters to be suitable for the controlled plant. There are many methods to define the parameters of PID controller such as try and error, Ziegler-Nichols methods and three different cost function genetic algorithm techniques.

c) Fuzzy control

The operation of BLDC drive controlled in two ways, The first one is torque and the second one is speed. The fuzzy logic controllers are used to control both these parameter simultaneously. It contains two loops the first loop contains current control and the second loop contains or adjust the speed of the BLDC drive. [1]- [8]. Fuzzy logic linguistic are expressed in the form of If and Then rules. These rules define the range of values known as fuzzy membership function. The below figure 10, Shows the different type fuzzy membership functions.

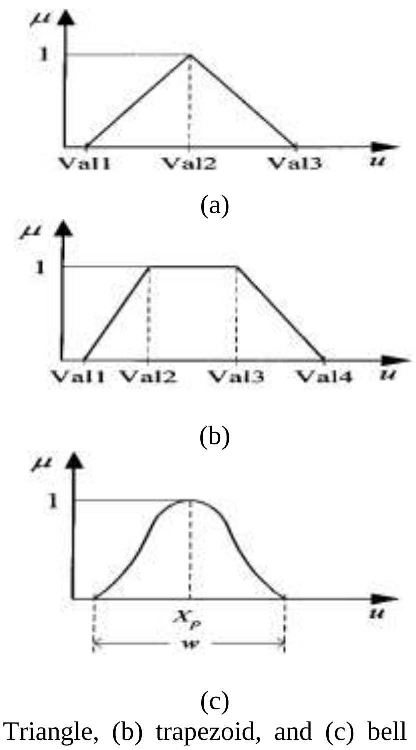

Fig.10 (a) Triangle, (b) trapezoid, and (c) bell membership functions

The most important things in fuzzy logic control system designs are the process design of membership functions for inputs and outputs and design of fuzzy if-then rule knowledge base. A membership function is a graphical representation of the magnitude of participation of each input. There can be different memberships functions associated with each input and output response.

Fuzzy logic expresses operational laws in linguistic terms instead of mathematical equations [2]- [3] - [4] - [5] - [6]. Many systems are too complex to model accurately, even with complex methods become infeasible in these system. However, fuzzy logic's linguistic term provides a feasible method for defining the operational characteristics of such system. Fuzzy logic controllers can be considered as a special class of symbolic controllers [7] - [8].

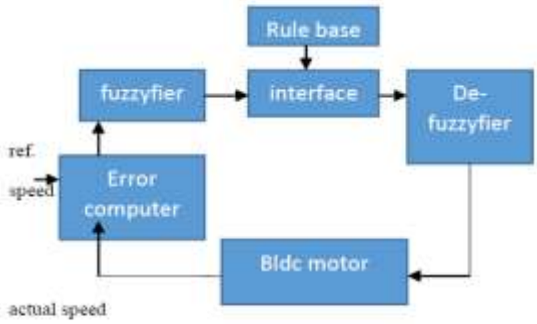

Fig. 11 General Fuzzy logic controller

The configuration of the fuzzy logic controller block diagram is shown in Fig.11. The three features of symbolic controllers become fuzzification, fuzzy inference, and defuzzification. The quality of control which can be achieved using fuzzy controller is determined by the number of membership function. With increase in the number of membership function, the quality of control improves. Therefore, a compromise has to be considered between the quality of control and computational time to choose the number of linguistic variables. For the speed control of BLDC motor study.

Seven linguistic variables for each of the input and output variables are used to describe them. Fig. illustrates the membership function of fuzzy logic controller that used the "fuzzyfication" of two input values and "defuzzyfication" output of the controller.

If p1 is NB and p2 is NB Then out is PB,
If p1 is NB and p2 is NM Then out is PB,
If p1 is NB and p2 is NS, then out is PM,
If p1 is NB and p2 is Z Then out is PM,
Here p1 and p2 are two inputs.

P_1 \ P_2	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	Z
NM	PB	PM	PM	PS	PS	Z	NS
NS	PM	PM	PS	PS	Z	NS	NS
Z	PM	PS	PS	Z	NS	NS	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NS	NM	NM	NB
PB	Z	NS	NS	NM	NM	NB	NB

Table.2 Rule base of fuzzy logic controller

d) Self-tuning fuzzy PID controller.

Although Ziegler and Nichols proposed an efficient technique to tune the coefficients of a PID Controller and improve the performance by optimizing the PID parameters using different optimization techniques but cannot guarantee to be always effective, So self-tuning of PID controller is required [36] - [37 - [39] - [40] - [41] - [42] - [46], and this fuzzy-PID controller fulfill the need. The controller includes two parts: conventional PID controller and fuzzy logic control (FLC) part, which has self-tuning. Now the control action of the PID controller after self-tuning can be describing as: Fuzzy self-tuning PID controller with error e and error change rate ec as input, PID parameter k_p, k_i, k_d as output e and ec can satisfy the self-tuning of the PID parameters. Using the fuzzy control rules to modify the PID parameters online, where we constitute a fuzzy self-tuning PID controller [136] - [137] - [139]. Where e is error and ec is error change rate, so k_e and k_{ec} quantitative factors, k_u is the scaling factor from all aspects of stability, response speed, overshoot, and steady-state error of the system and other considerations, PID controller three parameters $\left(k_p, k_i, k_d\right)$ role as follows [141]:

- The proportional coefficient *Kp* is to accelerate the response speed of the system and improve the regulation accuracy of the system. However, the more easily *Kp* larger system overshoot, or even make the system unstable. *Kp* Value is too small. It will reduce the regulation accuracy, so that slow down the response, thereby extending the regulation time, static and dynamic characteristics of the system deteriorates.
- Differential coefficient K_d is to improve the dynamic characteristics of the system, mainly inhibit change deviation in any direction in response to the process, in advance of the forecast error. But K_d too large, it will advance the process of brake response, thereby extending the regulation time, reduce anti-jamming performance of the system.

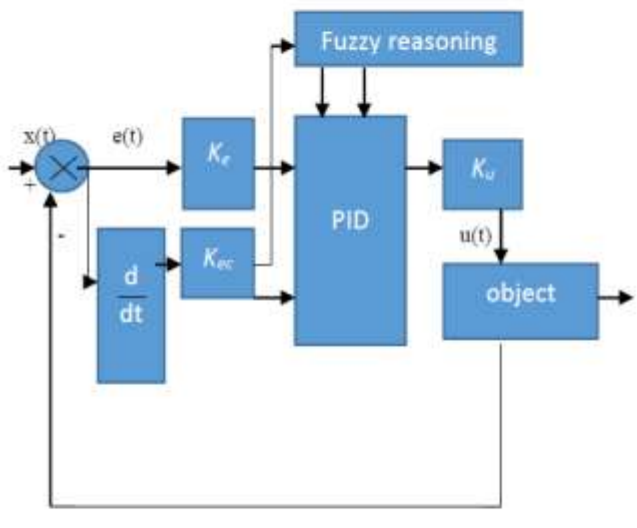

Fig. 12 Block diagram of Fuzzy self-tuning PID control system.

e) Genetic Algorithm

Genetic algorithms are a type of optimization algorithm, meaning they are used to find the optimal solution(s) to a given computational problem that maximizes or minimizes a particular function. Genetic algorithms represent one branch of the field of study called evolutionary computation [54], in that they imitate the biological processes of reproduction and natural selection to solve for the 'fittest' solutions [58]. Like in evolution, many of a genetic algorithm's processes are random, however this optimization technique allows one to set the level of randomization and the level of control [98]. These algorithms are far more powerful and efficient than random search and exhaustive search algorithms [114], yet require no extra information about the given problem. This feature allows them to find solutions to problems that other optimization methods cannot handle due to a lack of continuity, derivatives, linearity, or other features.

i. Encoding

Individual binary string consists of three coefficient gain parameter of PID controller *Kp, Ki* and *Kd* is used to ensure that the variables are independent. Unsigned binary coding is applied for encoding [22].

ii. Initialization

The first population is generated at random within the boundaries. The boundaries for PID controller constant have been chosen such that not too many PID controller constants leading system to be unstable

iii. Objective Function

An essential step for GA is choosing objective function, which is used to evaluate the fitness of each chromosome. For the design of a GA-PID controller we use integral of the squared error (ISE).

iv. Fitness Function

The fitness function is the function that the algorithm is trying to optimize [65]. The word "fitness" is taken from evolutionary theory. It is used here because the fitness function tests and quantifies how 'fit' each potential solution is. The fitness function is one of the most pivotal parts of the algorithm, so it is discussed in more detail at the end of this section. The term chromosome refers to a numerical value or values that represent a candidate solution to the problem that the genetic algorithm is trying to solve [23], [24].

The fitness value concluded as Fitness value=1/performance index (6) In order to overcome the large energy of controller, we add square term of controller output u(t). Thus fitness function is defined as follows:

$$J = \int_0^\infty (\omega_1 Ie(t) + \omega_2 u^2(t) d(t) + \omega_3 t_r \qquad (22)$$

v. Selection

In our problem design, standard roulette wheel selection has been applied to select individual from the current pool of population. The offspring are produced based on the selection value. The selection value depends on the fitness value of individual, bigger the fitness value more offspring the individual produce [25].

f) Neural Network Controller.

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A four-layer neural network as shown in figure (13), [28], Nodes in the input layer represent input linguistic variables. Nodes in the membership layer act as the membership functions. Moreover, all the nodes in the rule layer form a fuzzy rule base. In the proposed FNN, the units in the input (the i layer), membership (the j layer), rule (the k layer) and output layers (the o layer) are two, six, nine and one, respectively.

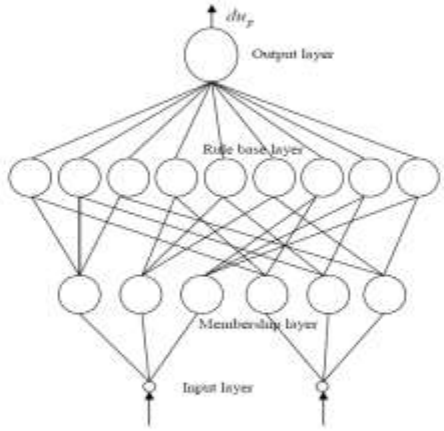

Fig. 13 Neural Network Layers

g) *BLDC Motor Speed controller with ANN Based PID Controller*

The overview of different type of speed controller for BLDC motor drive including Artificial Neural network based proportional, Integral & Derivative (PID) controller is given in this section. We know that the conventional feedback controller finds a wide range of application in industrial as well as commercial application. PID controller is one of the earliest controller that were used in controlling the speed of BLDC motor and it proves it effectiveness in different applications. To apply the PID controller it is not necessary to find out the exact mathematical model of the plant or system hence it is very effective to use PID controller for the system whose mathematical models are difficult.. In spite the number of advantages there are some disadvantages related to PID controller. These controller works on the optimal setting of the plant. If any of the parameter of the plant getting changed the output of the controller are disturbed because it is a fixed gain feed-back controller. Therefore, the controller needs to be returned to obtain the new optimal setting. For the system which is operated under variable time delay, large non-linearity and noise, the PID controller does not give optimal result for that system. For these type of highly complex and nonlinear system only PID controller are not enough to give the sustainable or desired result because of their limitations. For that purpose, many research work have been started on artificial neural network (ANN) based PID controller also called as Neuro-PID intelligent controller. ANN controller are involved with any conventional controller like PI, IP, Fuzzy etc. to obtain the desired result in process or control industries. The most widely applied neuro control scheme is the direct in verse model neuro-control approach. In this approach neural network is trained to learn the inverse of the plant either offline or online. Once trained, it can then be configured to control the plant.

i. *PID controller Based on Neuro Action*

ANN adaptive mechanism is basically used to measure the disturbance from the output and tunes the various parameter of the PID controller according to it. With the help of tuning the parameter it can minimizes the disturbance and improves the performance of the controller. Feed forward adaptive control offers the advantage of fast action without involving any inner closed loops however suffers from the disadvantage of effect of unmeasured disturbances and amount of disturbances. PID gains are tuned by using neural networks.

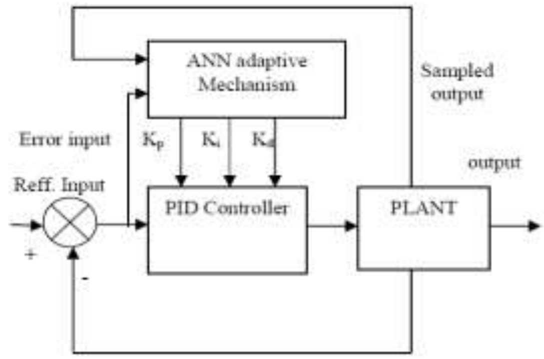

Fig. 14 ANN based PID controller

In order to get fast convergence and attain the better solution for a local minimum problem back propagation method is used to tune the PID gains. Neural network can be trained to perform as a controller by learning an inverse model of the plant or as an emulator by indenting the forward modal. Among many neural networks learning methods the back propagation algorithm is the most widely used in a wide variety of applications.

ii. *PID Control Algorithm Based on ANN*

The specific implementation of PID control algorithm based on BP neural network as shown in fig. in control problems there has been development on neuro-control for robots control problems. Although various intelligent control methods may be applied to this problems, PID control is a major approach since it is robust to noise and stable for parameter change [163] - [164] - [165]. Using the back-propagation method, various kinds of neuro-controllers could be trained in such a way that the desired plant output is attained as much as possible.

The PID speed controller is adopted with the ANN algorithm in the process industries because the process control system includes different type of non-linearity and Gaussian noise during their operation. The control system with the self-tuning PID controller is shown in the fig. above. The output of the neural network and the values of different PID parameters are selected in a suitable way according to the specific problem. Neuro controllers are classified in three ways. The first one is series type second one is parallel type and the third one is self-tuning type. The series type neuro controller shows the inverse dynamics of the plant for what it is used and it plays an important role as a part of the neural network. Parallel type of neuro controller are used to adjust the control input using by a conventional controller. Apart from that the self-tuning neuro controller are tune the various control parameter including series, parallel and conventional controller.

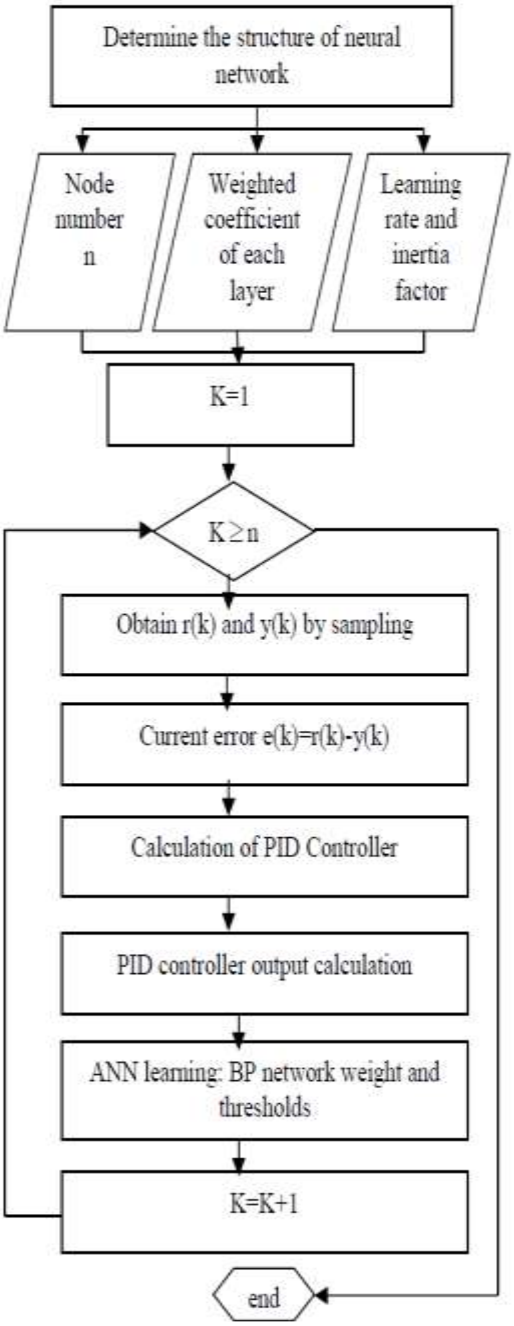

Fig.15 PID control algorithm based on Artificial-Neural Network

VIII. Analysis Of Different Speed Controllers

The performance analysis of same rating of BLDC motor with different type of speed controllers on no load are specified in the below table. On the basis of different parameter like rise time, settling time, peak overshoot, steady state error, torque ripple, speed ripple etc. With the help of these parameters we can conclude the relative stability or performance of BLDC motor the parameters which is mentioned here are varies due to different type of loading like step loading continuous loading periodic loading etc.

These parameters are also rating dependent means if the rating of motor and reference speed are changed these parameters are changed.

Table 3. Performance Comparision of Different Speed Controllers

CONTROLLER	SPECIFICATIONS		
	SETTLING TIME	OVER SHOOT	RISE TIME
PI	Increase	Increase	Decrease
PID	Decrease	Decrease as compared to PI	Increase as compared to PI
FUZZY	Decrease as compared to PID	Decrease as compared to PID	Increase as compared to PID
FUZZY + PID	Decrease as compared to FUZZY	Decrease as compared to FUZZY	Increase as compared to FUZZY

IX. Conclusion

It was concluded in this paper that the different types of converter are used for the supply of BLDC motor drive as per application like bidirectional converter for vehicle application, power factor correction CUCK or SEPIC converter. These converters are known as conventional converter which is used with constant DC link voltage of the VSI. The speed of the motor is controlled by controlling the duty ratio of high frequency pulse width modulation (PWM) single. Different type of speed controllers is also used for controlling the drive speed at desired value. Like PI, IP, PID, FUZZY, etc. These controllers are used according to the application needed. It was shown that PI controller maintain the steady state accuracy. Means the application where we need minimum error the PI controller is used. The IP controller has integrated both fuzzy and PI controller. During the large speed error, the fuzzy controller is selected by switch and PI controller are selected when high steady state accuracy is needed.

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