# Comparative Study of Speed Control of Brushless DC Motor

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This paper presents a comparative study on speed control of brushless DC motor, which has wide applications in electrical vehicles, manufacturing plants, aerospace, etc. Initially, the proportional controller is implemented using the developed mathematical model of BLDC motor. Then, the PID and PII controllers are implemented with speed as its returning path to increase the performance of speed control. The optimum values of PID and PII parameters are evaluated using performance index based constrained optimization. The integral square error is used as a performance index to form the objective function. The objective function is evaluated for different values of parameters using non-linear constrained optimization. The performance is further increased by introducing variable parameters using neural network-based gain scheduling control. The neural network-based control offers better properties such as low overshoot and provides lower susceptibility to parameter variations. To show the effectiveness of the presented approach, extensive simulations are carried out in MATLAB environment.

**Keywords**: PII, PID, Brush less Direct Current Motor, Neural Network, Unconstrained Optimization.

2021. In Prashant Singh Rana, Deepak Bhatia & Himanshu Arora (eds.), *SCRS Proceedings of International Conference of Undergraduate Students*, 19–26. Computing & Intelligent Systems, SCRS, India. https://doi.org/10.52458/978-81-95502-01-1-3

# 1 Introduction

Day-to-day equipment to intricate machines all require use of brushless direct current motors which acts as an electric rotatory actuator as well as an energy converter because it transforms electrical power into magnetic power to mechanical power or movement. Brushless Direct Current motors, also known as BLDCs, provide many advantages over their brushed analogue. BLDCs provide higher efficiency; high torque is to weight ratio, increased torque per watt of power input and requires lower maintenance and this is the reason it has replaced brushed motors in a lot of applications. These kinds of motors work on a homogeneous concept in which the rotational movement is produced through the attraction and the repulsion of enduring magnetic poles of and electro-magnets. However, the method through which these motors are controlled is very different. BLDCs needs intricate controllers to transform Direct Current power to the required number of phase voltages for proper operation, while a brushed motor can be comfortably controlled by a Direct Current Voltage. BLDC can be contemplated as a upside down model of a brushed motor since the permanent magnets now becomes the rotor while the coil turns becomes the stator. A particular major element that differentiates BLDC motor from the other motors is trapezoidal waveform of its back EMF which involves places where the voltage remains unchanged, and this demonstrates that we can control this BLDC motor using DC voltage. BLDC motors does not have commutator. The commutation has to be done by some external means. Therefore, a three-phase inverter is used to supply the BLDC motor. BLDC motors have high torque and high torque ripples as compared to motors that have sinusoidal shaped back-EMF. These motors are also cheaper in cost and are frequently used for general applications. The BLDC drive system consists of BLDC motor, sensor, power electronics converter and a controller.

# 2. Literature Review

BLDC motors have advantages over brushed DC motors and induction motors. They have better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges, rugged construction and so on [1]. Permanent magnet brushless dc motors are more accepted used in high-performance applications. In it, BLDC motor mathematical model is developed and finally closed loop speed control BLDC is carried out with simulation results [2]. The Hall Effect sensors give three 120° overlapping signals, thus providing the six mandatory commutation points. The rising and falling edges of the sensor output are detected, the corresponding flags are generated. It discusses about the trapezoidal control of BLDC motor with the help of a three phase inverter, Shaft position sensors, current sensing, position and speed-sensing [3]. The comparison between the output characteristics of BLDC motor with PI and PID controller is observed and inferred that PID output provides higher efficiency and productivity due to which it will tend to produce high torque in slow-speed span, has higher power quantity, lower maintenance and lesser noise. The paper deals with speed control of closed loop BLDC motor with the use of PID controller and it is compared with PI controlled BLDC motor [4]. This paper is aimed at non-salient sensor less BLDC motor control method, which can drive the motor from standstill to the rated speed. In it, the relationship among pre-positions current, energizing time, and transient speed in startup stage is analyzed [5]. The performance of a three phase BLDC drive system using PI, PID and fuzzy logic speed controllers are evaluated in this paper. It is shown through extensive simulations that the performance of fuzzy logic controller is better than PI and PID controllers [6]. A new switching strategy is presented for MICs fed PMDC motor. With this technique, all switching functions depend on a CSF; the effective duty ratio of the respective switching functions is integer multiples of the CDRDCSF, which is the duty ratio of the CSF [7]. Simulation studies are carried out to study the dynamic performance of the BLOC motor drive fed by a boost converter. A good power factor is achieved for entire voltage ranges with acceptable THD of supply current. The results show the operation of drive with improved power factor at universal AC mains [8].It aims to study the speed control techniques of BLDC motor with conventional PI and PID controllers, and to implement the neural network-based gain scheduled integral controller. The closed loop speed control of BLDC motor drive with PID controller loop is compared with PI controller fed BLDC drive. Simulation results show that current ripple and torque ripple are minimized which enhance the performance of the drive. By comparing the performances of PI and PID controller shows that by applying the load torque to the motor with conventional controller, motor speed will be decreased, and it should regain its speed quickly [9].The dynamic response to the rapid tuning results of the modified PID controller, which can help to control the speed of the motor and maintain constant speed during load changes is examined. On comparing three phase BLDC motor PID controller performance with PI, PID controller provides the best performance compared to the PI and Fuzzy logic and is validated by MATLAB simulation [10]. BLDC motor speed control response using PID controller and ANN controller shows that the settling time for BLDC motor controlled by ANN controller is much lesser than that of PID controller. In PID controller, for tuning the gains trial and error method is used [11].

# 3. Speed Control of DC Motor

## A. BLDC Motor Model

The whole BLDC motor system is controlled using the PID controller, and this controller receives error signal as the deviation between the mentioned speed and the resultant speed. Now we are required to find out the values of different constants of the controller like $K_p$,$K_i$ and $K_d$ for which it will provide us the least error for the controller. For this we are using interior point method to find optimized values of the constants.

The Back EMF magnitude can be written as

$$E = 2NlrBw \quad ......(1)$$

The torque equation is as follows

$$T = \left(\frac{1}{2} i^2 \frac{dL}{d\theta}\right) - \left(\frac{1}{2} B^2 \frac{dR}{d\theta}\right) + \left(\frac{4N}{\pi} Brl\pi i\right) \quad ......(2)$$

Here, N is the number of windings turns per phase, l is the length of the rotor, r is the internal radius of the rotor, $B$ is the rotor magnet flux density, w is the motor's angular velocity, $i$ is the phase current, $L$ is the phase inductance, $\theta$ is the rotor position, R is the phase resistance.

To do so we take error as the main objective of this algorithm. We have taken a clock Block to get the instantaneous value of the error and then this error is passed through the integrator and then sent to the workspace for optimization and this process continues till optimized values are obtained.

## B. PID Control and Neural Network Control

The PID controller algorithm is very easily adjustable, it operates steadily, and it has a simple design, which makes its use very suitable for controlling system. For practical reasons, the common speed control structure is applied in the PID controller.

The output obtained in PI controller in time domain is given by:

$$\text{Output} = K_p e(t) + K_i \int_0^t e(t)dt \qquad \text{......(3)}$$

Here, $K_p$ is the proportional gain, $K_i$ is the integral gain and $e(t)$ is the instantaneous error in the signal.

The output obtained in PID controller in time domain is given by:

$$\text{Output} = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad \text{......(4)}$$

Here, $K_p$ is the proportional gain, $K_i$ is the integral gain, $K_d$ is the proportional gain and $e(t)$ is the instantaneous error in the signal.

Artificial Neural Network control is a technology which process information using its dynamic characteristics to external input. The ANN have been widely used and appreciated, as it has a unique characteristic of high learning and nonlinear mapping of different inputs and providing corresponding outputs for an electric motor drive system. The BLDC motor system is controlled with the PII controller with negative feedback of speed sensors, and this controller receives error signal as the deviation between the mentioned speed and the resultant speed. An unconstrained optimization is utilized to find out the values of different gains of the controller like $K_p$, $K_i$ and $K_d$ for which it will provide us the least error. In this paper, interior point method is employed to find the optimized values. To do so, we take error as the main objective of this algorithm. We have taken a clock Block to get the instantaneous value of the error and then this error is passed through the integrator and then sent to the workspace for optimization and this process continues till optimized values are obtained.

The schematic block diagram is given below in Fig 1.

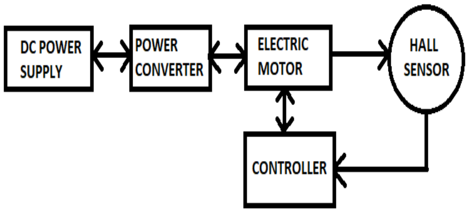


**Fig. 1**: Block diagram of D.C. motor

Transfer function of PID controller is given as:

$$T(s) = K_p + \frac{K_i}{s} + K_d s \quad \text{......(5)}$$

## 4. Simulation Results

The simulations are carried out in MATLAB/ Simulink environment and time interval for the simulation is 0.2 seconds. The performance index for the unconstrained optimization (integral point method) is taken as integral square error (ISE). The Simulink models for PID, PII and Neural network-based gain schedule integral control are shown in Figure 2, Figure 3 and Figure 4 respectively. The comparison of results obtained after implementing the optimized PI, PID and PII control are shown in Fig 5. The optimized parameters are tabulated in table 1.

It is observed that the performance of PI, PID and PII control are almost similar. However, the obtained value of proportional gain in PID control is less than the value obtained in PI and PII control. The speed control is smoother and more effective in Neural network-based control as shown in figure 5. The value of integral gain obtained using neural network is found to be [0,4.4882]. The error signal and control signal in neural network-based gain schedule integral control after optimization is shown in figure 6 and figure 7 respectively.

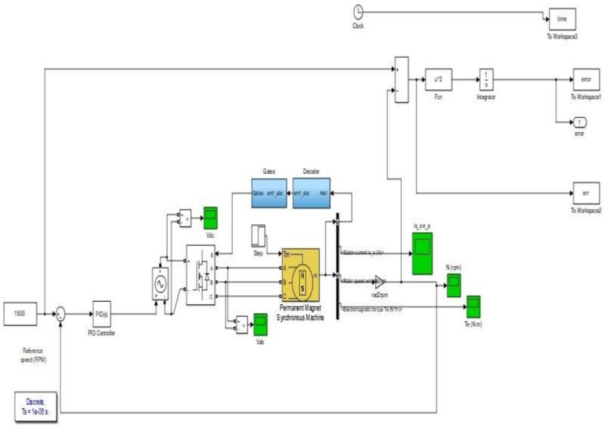


**Fig. 2**: PID Control Simulink Model

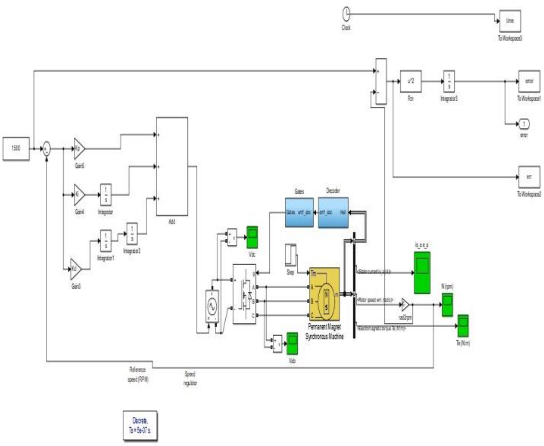


**Fig. 3**: PII Control Simulink Model

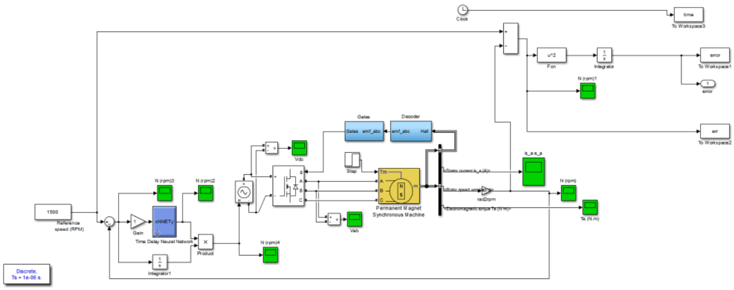

**Fig. 4**: Neural Network Based Gain Schedule Control Simulink Model

**Table 1:** Comparison of parameter values ofPI, PID and PII Control

| Control Parameters | PI | PID | PII |
|---|---|---|---|
| $K_p$ | 0.3402 | 0.1435 | 0.3377 |
| $K_i$ | 37.3708 | 37.4699 | 37.2848 |
| $K_d$ / $K_{ii}$ | - | 0.1955 ($K_d$) | 0.2766 ($K_{ii}$) |

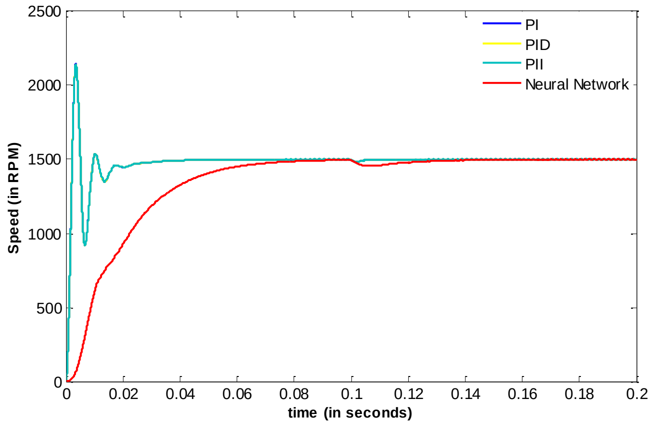


**Fig 5:**Comparison of Response (speed) of PI, PID, PII and Neural Network Based Gain Schedule Integral Control. (Reference speed – 1500 RPM)

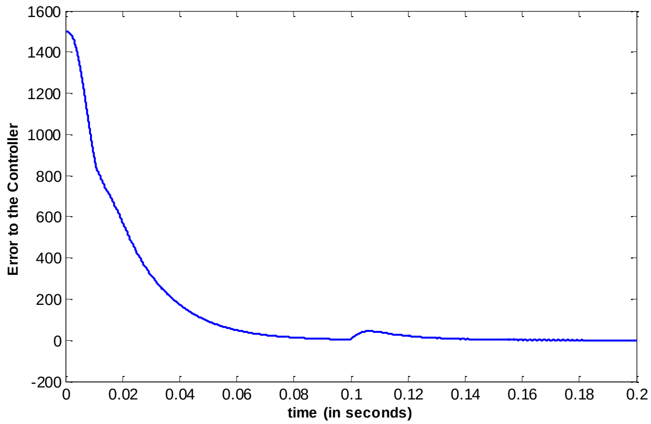


**Fig 6**: Closed-loop error in Neural Network based Gain Schedule Control

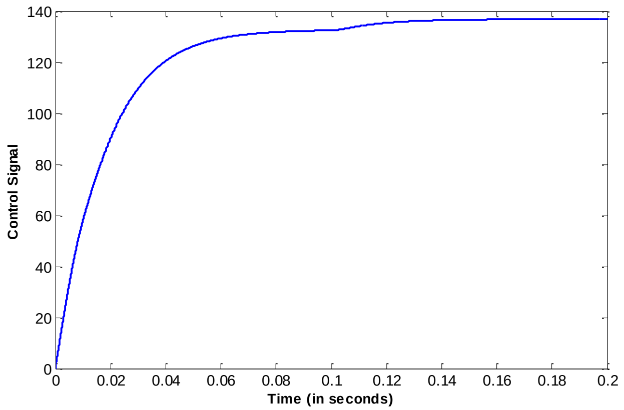


**Fig 7**: Control signal in neural network-based gain schedule control

# 5. Conclusion

This paper presents the comparative performance analysis of PI, PID and PII controllers for the speed control of BLDC motor. It is shown that PID controller provides similar performance as obtained by PI and PII control. However, the proportional gain obtained in PID controller is less than the proportional gain obtained in PI and PII control. The lower value of proportional gain provides a robust control even in the presence of noise. Further, the neural network-based gain schedule integral control was implemented to improve the performance of speed control. It is shown that the presented neural network-based control provides low overshoot and smooth control as compared to the other controllers. The neural network-based control also provides robustness in the presence of noise due to its structure. The simulations obtained from Neural Network based Gain Schedule Control are more effective than the PI, PID and PII control.

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