Performance Comparison of P and PI Controller for Speed Control of Three Phase Brushless DC Motor

[1]Htet Htet Lwin and [2]Nang Mwe Seng,
[1]Assistant Lecturer, [2]Lecturer,
[1,2]Department of Mechatronic Engineering, Pyay Technological University, Pyay, Myanmar

***Abstract*—** In this paper, propose PI controller techniques for speed control of three-phase brushless DC motor. The mathematical model of the brushless DC motor is improved and it is used to analyze the performance of the controllers. This system compares analysis of proportional (P) and proportional-plus-integral (PI) controller for three-phase brushless DC motor. The control system parameters such as rise time, peak time, steady-state error, settling time, peak overshoot, are used to compare the speed response of PI controller and P controller. The simulation of the proposed scheme was done in SIMULINK environment. The PI controller has reduced overshoot, less steady-state error and less settling time. Results show that the PI controller has better performance than P controller.

Keywords* –Brushless DC motor, Proportional controller, Proportional-Integral controller, Speed control*

I. INTRODUCTION

Brushless DC motor provides many applications such as, automotive, aerospace, household appliances, office automation and different industries. The advantages include its noiseless operation, long operation life, high efficiency, wide speed range, high dynamic response, low temperature and can withstand vibrations and shock, which get better stability of the system [1] [2]. BLDC motor is a type of permanent magnet synchronous motors that are powered by a DC electric source. The current commutation is done by a six-step inverter. The commutations are resolved by rotor position which can be detected by position sensor or sensor less mechanisms [3] [4]. Instead of conventional brushed DC motor, brushless DC motors were more used through the solid state power semiconductors. There are two types of in synchronous motors; a sinusoidal back EMF and trapezoidal back EMF but for brushless DC motors a rectangular is similar to trapezoidal back EMF. Both have stator generated magnetic fields by rotating a rotor these magnetic fields created torque in a magnetic rotor [5]. In this motor current and torque, voltage and rpm are related linearly. Normally from the Hall Effect sensor, the signal for commutation is generated [6].

In this method, the speed is controlled in a closed loop by measuring the actual speed of the motor. The error between the set speed and actual speed is calculated. A Proportional plus Integral (PI) controller is used to amplify the speed error and dynamically adjust the PWM duty cycle [7]. To achieve desired level of performance, the motor requires suitable speed controllers. In permanent magnet motors, speed can be control by using proportional integral (PI) controller. The PI controllers are widely used in industrial control systems because they are easily implemented and they have simple control structure. These controllers are difficult to use as there are some control complexity such as nonlinearity, load disturbances and parametric variations [8].

The PI controller is applied in various fields in engineering owing to its simplicity, robustness, reliability and easy tuning parameters. PI Controller is used to get desire response in different process industries. It is a block in control system which takes error signal as input and gives an output which affects the dynamics of the system. This output is an actual signal which reduces the difference between the desire signal and actual signal [9].

In this paper, the performance of speed control of BLDC motor is verified through simulation analysis on MATLAB Simulink platform. The response of the PI controller is free from these dangerous oscillations in transient period. Hence the PI controller is better than the conventional controller.

II. MATHEMATICAL MODEL OF BLDC MOTOR

A. *Transfer Function Model*

The transfer function is one most important concepts of control theory which is based mathematical models and widely used in automotive control fields. Some control design and analysis methods, such as the root-locus method and the frequency response method, are also developed based on the system transfer function.

Therefore, transfer function of BLDC motor is:

$$G(s) = \frac{\omega_m}{V_s} = \frac{K_t}{s^2 JL + (RJ + K_f L)s + K_f R + K_e K_t} \qquad (1)$$

$$G(s) = \frac{\omega_m(s)}{V_s(s)} = \frac{\frac{1}{K_e}}{\tau_m \cdot \tau_e \cdot s^2 + \tau_m \cdot s + 1} \qquad (2)$$

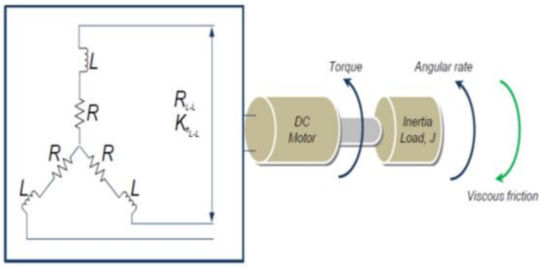

Figure 1: Brushless DC motor schematic diagram

where $\tau_m = \sum \frac{RJ}{K_e K_t}$ is the mechanical time constant and $\tau_e = \sum \frac{L}{R}$ is the electrical time constant.

where:

- V_s : DC source voltage
- i : Armature current
- T_e : Electrical torque
- K_f : Friction constant
- J : Rotor inertia
- T_L : Mechanical load

R : Armature resistance
L : Armature inductance
K_e : Back-emf constant
K_t : Torque constant
ω_m : Angular velocity

B. Open-Loop response of BLDC Motor

The models transfer function verified by comparing the simulation results of these models with Matlab model. The results of the presented models show the open-loop step response of brushless DC motor.

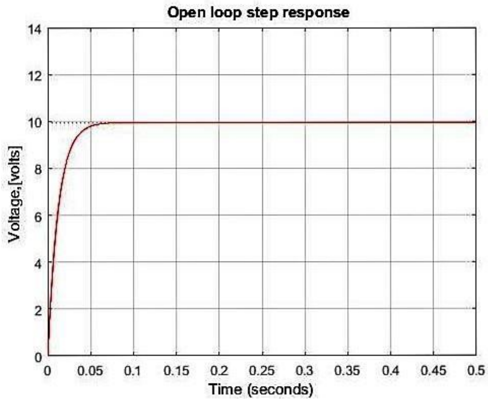

Figure 2: Open-loop step response of BLDC motor

III. Speed Control of BLDC Motor

There are two control loops that used in speed control of brushless DC motor. The inner loop is used to synchronize gate pulse of the inverter and the electromotive force. The outer loop used to change the DC bus voltage to control the speed [10]. The speed control is achieved by using the model block diagram shown in Fig.3 which consists of PI, PMBLDC, VSI, hall sensor, decoder. The two types of controller will be discussed as follows:

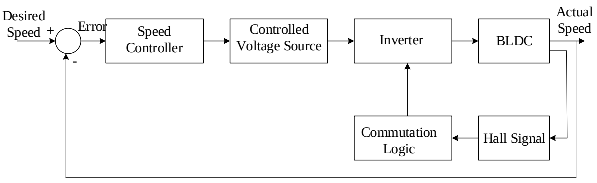

Figure 3: Block diagram of speed control of BLDC motor

A. Proportional Controller

A proportional or P-Only controller is the simplest algorithm in the PID family. In this control strategy, the control framework acts in a way that the control exertion relative to the error. The main task of the P controller is to decrease the steady-state error of the system. As the proportional gain factor K increase, the steady-state error of the system decreases. Despite of the reduction, P control can never eliminate the steady-state error of the system. In the Laplace domain, this can be written as:

$$C(s) = K_p \cdot E(s) \tag{12}$$

where K_p is the proportional gain.

B. Proportional Integral Controller

Proportional Integral controller is mainly used to eliminate steady-state error resulting from P controller. Fig. 4 shows the Proportional-Integral (PI) controller block diagram.

The transfer function of the most basic form of PI controller is,

$$C(s) = K_p + \frac{K_i}{s} \tag{13}$$

where, K_p is the proportional gain and K_i is the integral gain.

The higher the proportional factor the more unstable the system. The smaller it is the more difficult to reach the set point in a given time. The proportional factor or gain of the PI controller is tuned to maintain the speed at a desired level. The advantage of both P-controller and I-controller are combined in PI-controller. The proportional action increases the loop gain and cause to decreases the variations of system parameters. The integral action eliminates or reduces the steady-state error.

The actual speed of BLDC motor is obtained using the speed / position encoder and is compared with the set value and the error is processed by the PI speed controller.

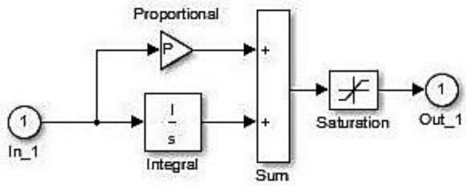

Figure 4: Block diagram of PI control system

IV. Simulation Results

Simulink model of a BLDC motor with the P and PI controller is designed in a Matlab Simulink tool. The Simulink model consists of a three phase supply via inverter and a BLDC motor. The model is coupled with a PI controller for the speed control of the motor.

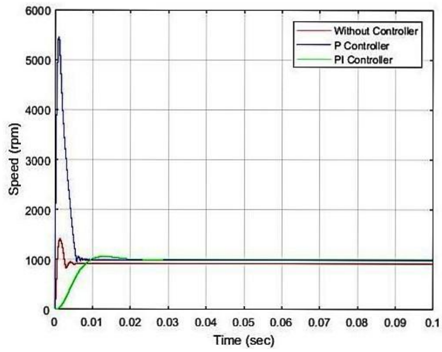

Figure 5: Speed response of BLDC motor for desired speed of 1000 rpm

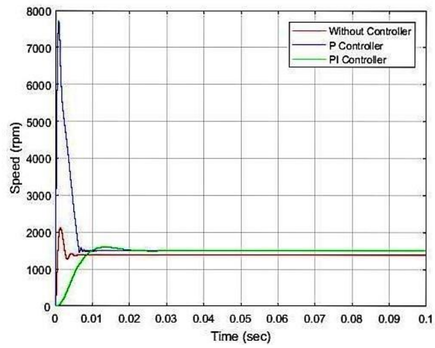

Figure 6: Speed response of BLDC motor for desired speed of 1500 rpm

Fig. 5 shows the performances of the system without controller and using P and PI controller at desired speed of a 1000 rpm in loaded condition. The result shows that the system without controller has a very high overshoot and a steady-state error than the system with controller. By using P controller, there is having overshoot and steady-state error but error is less than without controller. For PI controller, both of overshoot and steady-state error is the least compared to the other two. Fig. 6 is for the performances at the desired speed of 1500 rpm. When the speed is increased, overshoot becomes larger. Settling time is reduced by higher speed.

Performance comparison of P and PI controllers at different speeds under loaded conditions is shown in Table 1.

From performance comparison, PI controller has better control performance than P controller for all three desired speeds. P controller has less settling time but there is steady-state error and more overshoot in the response. In order to reduce the overshoot and steady-state error, a PI controller is used. But, PI cannot provide less the settling time.

Table 1: Perfromance Comparison

Speed (rpm)	P Controller		PI Controller	
	Maximum Overshoot (%)	Settling Time (ms)	Maximum Overshoot (%)	Settling Time (ms)
1000	44.40	9.82	0.67	18.58
1500	61.76	9.14	0.74	17.39

CONCLUSION

The performance of a three phase BLDC drive system using P and PI speed controllers are evaluated. The simulation of the brushless DC motor has been done using the software package MATLAB/SIMULINK. Simulation results showed that PI controller reduces overshoot and eliminate the steady-state error. This controller is more efficient at closed loop response for speed control of three-phase BLDC motor.

References

[1] C.-L. Xia, Permanent Magnet Brushless DC Motor Drives and Controls.Singapore: John Wiley & Sons Singapore Pte.Ltd., 2012.

[2] M. Thesis, "BLDC Motor Modelling and Control – A Matlab ® /Simulink ® Implementation –," 2005.

[3] Hao, He, et al. "Influences of machine structure on high speed PMBLDC motor '' Electrical Machines and Systems (ICEMS) 17th International Conference on. IEEE, 2014.

[4] A. Purna Chandra Rao, Y. P. Obulesh and Ch. Sai Babu "Mathematical Modeling of BLDC Motor with Closed Loop Speed Control Using PID Controller under Various Loading Condition" ISSN : 1819-6608 Volume-7, Issue-10, Oct.-2012.

[5] MS. JULI SINGH. "Analysis the Speed Control of BLDC Motor Drive Using Sensors" International Journal of Engineering Research and Applications, ISSN: 2248-9622 Volume-2, Issue-3, pp. 2868-2884, May-Jun 2012.

[6] Richa Papdeja 1, P.Sankala 2 "Modelling and Simulation of Three Phase Brushless DC Motor With Using Model Reference Adaptive Controller" International. J. Journal of Inventions in Computer Science and Engineering, Volume 1 Issue 3 2014.

[7] Arshiya Parveen, 2J . E Muralidhar "Analysis of Speed Control of Brushless Dc Motor" IJCTA Vol.8, No.1, Ja, Pp.59-70, Jan-June 2015.

[8] Mekha M.L, Manju G "Speed Control of BLDC Motors Using MRAC" International Journal of Engineering Technology (IRJET)

P- ISSN: 2395-0072, Volume: 03 ISSUE:06, June 2016.

[9] J. Zhang, N. Wang and S. Wang, "A developed method of tuning PID controllers with fuzzy rules for integrating process," Proceedings of the American Control Conference, Boston,pp. 1109-1114, 2004.

[10] Hayder Salim Hameed, Baquba, Diyala, Iraq, "Brushless DC Motor Controller Design Using Matlab Application" IEEE International Scientific Conference of Engineering Sciences (ISCES), 2018.