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Comparative Performance Study for Closed Loop Operation of an Adjustable Speed Permanent Magnet Synchronous Motor Drive with Different Controllers

Chiranjit Sain[1], Atanu Banerjee[2], Pabitra Kumar Biswas[3]
[1,2] Electrical Engineering Department, NIT Meghalaya, 793003, India
[3] Electrical & Electronics Engineering Department, NIT Mizoram, 796012, India

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ABSTRACT

In this paper an extensive comparative study is carried out between PI and PID controlled closed loop model of an adjustable speed Permanent Magnet Synchronous Motor (PMSM) drive. The incorporation of Sinusoidal Pulse Width Modulation (SPWM) strategy establishes near sinusoidal armature phase currents and comparatively less torque ripples without sacrificing torque/weight ratio. In this closed loop model of PMSM drive, the information about reference speed is provided to a speed controller, to ensure that actual drive speed tracks the reference speed with ideally zero steady state speed error. The entire model of PMSM closed loop drive is divided into two loops, inner loop current and outer loop speed. By taking the different combinations of two classical controllers (PI & PID) related with two loop control structure, different approximations are carried out. Hence a typical comparative study is introduced to familiar with the different performance indices of the system corresponding to time domain and frequency domain specifications. Therefore overall performance of closed loop PMSM drive is tested and effectiveness of controllers will be determined for different combinations.

Corresponding Author:

Chiranjit Sain
Department of Electrical Engineering,
National Institute of Technology Meghalaya,
Bijni Complex, Laitumkhrah, Shillong- 793003, India.
Email: chiranjitsain@nitm.ac.in

1. INTRODUCTION

The Permanent Magnet Synchronous Motor (PMSM) is a rotating electrical machine where the stator is a classic three phase stator like that of an induction motor and the rotor has surface mounted permanent magnets. In this regard, The Permanent Magnet Synchronous Motor is equivalent to an induction motor where the air gap magnetic field is produced by a permanent magnet [1]. Thus with the development of permanent materials and control technology the PMSM is mostly used due to high torque/inertia ratio, high power density, high efficiency, reliability and easy for maintenance in different industrial applications. The schematic block diagram of closed loop model of adjustable speed PMSM drive is represented in Figure 1. This model basically involves development of model of PMSM i.e. for machines having sinusoidal air gap flux distribution. The PMSM, therefore, has a sinusoidal induced emf and requires sinusoidal currents to produce constant torque. The rotor position information is very crucial for field oriented control. For widespread industrial applications, such as high performance motor drives, accurate motor speed control is required in which regardless of sudden load changes and parameter variations [2-3]. Hence, the control system must be designed very carefully as it required to ensure the optimum speed operation under the environmental variations, load variations and structural perturbations. In this paper, the model of a complete closed loop adjustable speed Permanent Magnet Synchronous Motor drive is developed using different combination of classical controllers where a three phase two-level voltage source inverter (VSI) feeds the PMSM armature and the VSI is switched according to a sinusoidal pulse width modulation (SPWM) strategy. Some pulse width modulation (PWM) technique can be employed of the self synchronous VSI feeding the PMSM, so that lower order harmonics can be removed from the harmonic spectrum of the armature currents of the PMSM resulting in lower toque ripple. Different combinations of classical controllers such as PI and PID are incorporated in two loop control structure for the determination of various performance indices of a closed loop adjustable speed PMSM drive accordingly [4-5].

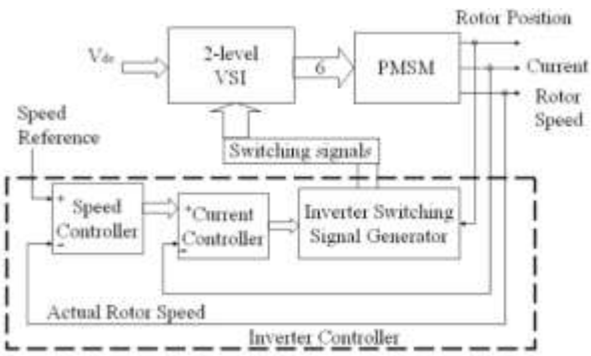

Figure 1. Schematic Block Diagram of Closed Loop Model of Adjustable Speed PMSM Drive

2. SYSTEM DESCRIPTION

The complete set-up of the developed model has been represented in Figure 2, The system comprising of four (05) necessary components like SPWM based Voltage Source Inverter (VSI), PMSM motor, speed and position sensor, controller (Speed and current) and the mechanical block. Here an absolute position encoder is mounted on the rotor, which is assumed capable of providing the rotor position information at each instant of time. The inverter is assumed powered from the DC side by a constant DC voltage source, V_{dc} which is not varied. The controller realization starts with the adjustable speed reference, at which the drive is intended to run, irrespective of the load torque variation within a feasible range [6-7]. The information of this reference speed is provided to a speed controller, which is a PI controller in this model in order to track the reference speed [8]. The speed controller output forms the torque or current reference, which is fed to next controller which is the current controller. The current controller output is fed to the block responsible for the generation of the switching signals of the six power electronic devices of the VSI. The speed control arrangement consists of two loop control system with an outer speed loop and inner current loop. The current controller in this case is also a PI controller. It starts with an adjustable speed reference, with which the actual machine speed, obtained by integrating the rotor position information provided by the absolute position encoder is compared [9].

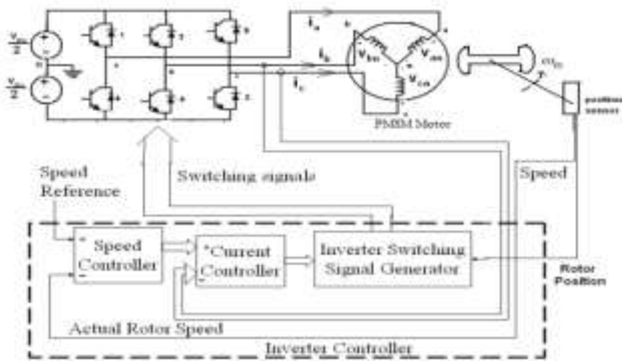

Figure 2. The Scheme of the Closed Loop Adjustable-Speed PMSM Drive with the Sinusoidal Pulse Width Modulated Inverter

The Permanent Magnet Synchronous Machine is analyzed on the basis of "D-Q axes rotor reference frame theory" and the control on the machine is exercised by controlling the q-axis component of the armature current.

3. DESIGN AND MATHEMATICAL ANALYSIS OF CLOSED LOOP ADJUSTABLE SPEED PMSM DRIVE

The design of the speed controller is important from the point of view of imparting desired transient and steady state characteristics to the speed-controlled PMSM drive system. Selection of gain and time constants of such a controller by using the symmetric-optimum principle is straight forward if the d axis stator current is assumed to be zero [10]. As the closed loop system yields a two loop control structure i.e. outer loop is a speed controller loop and inner loop is a current controller loop.

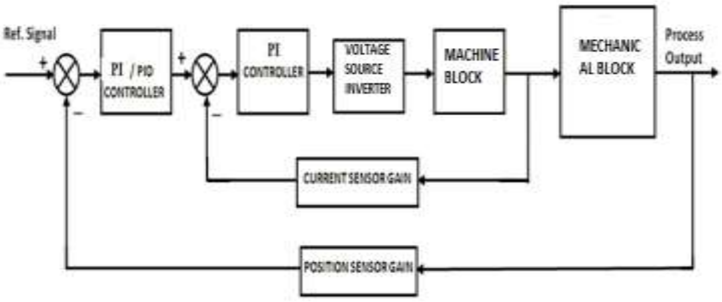

Figure 3. Systematic Block Diagram Representation of a Closed Loop Adjustable Speed PMSM Drive

The reset time and gain of the outer speed PI controller should be critically found out to ensure that the dynamic response of the drive is satisfactory, zero steady state speed error is ensured and the system remains stable. For the closed loop model, block diagram of complete drive system is represented in Figure 3. The transfer functions of all the blocks are determined; afterwards the gain and time constants are calculated in order to design the proposed closed loop model of an adjustable speed PMSM drive [11]. The speed PI controller output is treated as the q axis current reference i_{qs}, which is responsible for generation of electromagnetic torque, for v_{ds}=0, as the approximate analysis of the PMSM suggests. This current reference is compared with actual 'q'-component of armature current (i_{qs}) and the current error is fed to the proportional integral controller with unity gain. The inner current loop is provided for controlled yet fast dynamic of current with least sudden overshoot [12]. The Permanent magnet synchronous motor can be modelled by the following set of equations

$$v_{qs} = (R_s + L_q p) i_{qs} + \omega_r L_d i_{ds} + \omega_r \lambda_{af} \quad (1)$$

$$v_{ds} = (R_s + L_d p) i_{ds} - \omega_r L_q i_{qs} \quad (2)$$

The Electromagnetic torque is given by

$$T_e = \frac{P}{2} J p \omega_r + \frac{P}{2} B_1 \omega_r + T_l \quad (3)$$

$$T_{em} = \frac{3}{2}\frac{P}{2}(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad (4)$$

Where $\lambda_{qs} = L_q i_{qs}$ and $\lambda_{ds} = L_d i_{ds} + \lambda_{af}$ (5)

The motor q axis voltage equation with d-axis current being zero becomes

$$v_{qs} = (R_s + L_q p) i_{qs} + \omega_r \lambda_{af} \quad (6)$$

And the electromechanical equation is

$$P(T_e - T_l)/2 = Jp\omega_r + B_l\omega_r \quad (7)$$

Where the electromagnetic torque is given by

$$T_e = \frac{3}{2} . \frac{p}{2} . \lambda_{af} i_{qs} \quad (8)$$

If the load is assumed to be frictional, then

$$T_l = B_l\, \omega_m \quad (9)$$

This upon substitution gives the electromechanical equation as

$$(Jp + B_t)\omega_r = \{3/2 \left(\frac{p}{2}\right)^2 \lambda_{af}\} i_{qs} = K_t i_{qs} \quad (10)$$

Where $B_{t=} \frac{P}{2} B_l + B_l$ (11)

$$K_t = \frac{3}{2} \left(\frac{p}{2}\right)^2 \lambda_{af} \quad (12)$$

The inverter is modelled as gain with a time lag by

$$G_r(s) = \frac{K_{in}}{(1 + ST_{in})} \quad (13)$$

Where $K_{in} = 0.65\, V_{dc}/V_{cm}$ (14)

$$T_{in} = 1/2f_c \quad (15)$$

Where V_{dc} is the dc-link voltage to the inverter, V_{cm} is the maximum control voltage and f_c is the switching (carrier) frequency of the inverter.

The induced emf loop crosses the q-axis current loop and it could be simplified by moving the pick–off point for the induced emf loop from speed to current output point. This gives the current-loop transfer function from Figure 4.

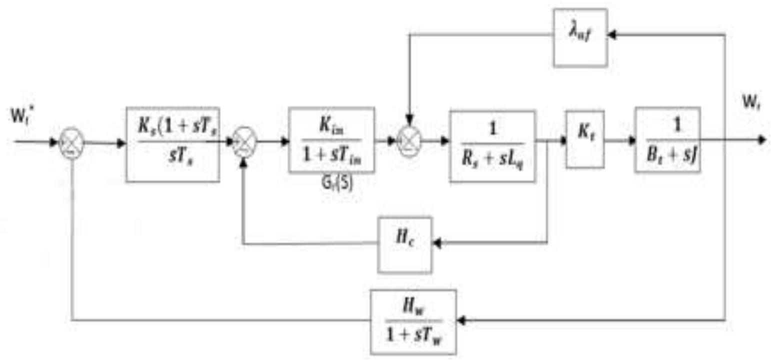

Figure 4. Block Diagram of the Speed-Controlled PMSM drive

$$G_i(s) = \frac{K_{in}K_a(1+sT_m)}{H_c K_{in} K_a (1+sT_m) + (1+sT_{in})\{K_b K_a + (1+sT_a)(1+sT_m)\}} \quad (16)$$

Where

$$K_a=\frac{1}{R_s}, T_a=\frac{L_q}{R_s}, K_m=\frac{1}{B_t}, T_m=\frac{J}{B_t}, K_b=K_t K_m \lambda_{af} \quad (17)$$

The following approximations are valid near the vicinity of crossover frequency

$$1+sT_r \cong 1 \quad (18)$$

$$1+sT_m \cong sT_m \quad (19)$$

$$(1+sT_a)(1+sT_{in}) \cong 1+s(T_a+T_{in}) \cong 1+sT_{ar} \quad (20)$$

Where $T_{ar}=T_a+T_{in}$ (21)

With this the current loop transfer function is approximated as

$$G_i(s) \cong \frac{(K_{in}K_aT_m)s}{K_bK_a+(T_m+H_cK_{in}K_aT_m)s+(T_{ar}T_m)s^2} \quad (22)$$

$$G_i(s) \cong \left(\frac{T_mK_{in}}{K_b}\right)\frac{s}{(1+sT_1)(1+sT_2)} \quad (23)$$

Where $T_1+T_2=\frac{T_m}{K_aK_b}+T_{in}+\frac{K_{in}T_m}{K_b}$ (24)

and

$$T_1T_2=\frac{T_mT_{ar}}{K_aK_b} \quad (25)$$

Machine (armature) block can be represented as

$$G_a(s)=\frac{K_a}{1+ST_a} \quad (26)$$

Torque constant

$$K_t=\frac{3}{2}\left(\frac{P}{2}\right)^2.\lambda_{af} \quad (27)$$

Mechanical gain

$$K_m=\frac{1}{B_t} \quad (28)$$

$$G_b(S)=\frac{K_tK_m\lambda_{af}}{(1+ST_m)} \quad (29)$$

Where mechanical time constant

$$T_m=\frac{J}{B_t} \quad (30)$$

Motor (mechanical)

$$G_m(S) = \frac{K_m K_t}{(1+ST_m)} \quad (31)$$

Simplified current loop transfer function becomes

$$G_{is}(S) = \frac{K_i}{(1+ST_i)} \quad (32)$$

The proportional and integral gains of PI controller are derived as

$$K_{ps} = K_s = \frac{4}{9K_g T_{wi}} \quad (33)$$

$$K_{is} = \frac{Ks}{T_s} \quad (34)$$

Therefore the transfer function of PI controller is derived as

$$G_s(S) = \frac{K_s}{T_s} . \frac{(1+ST_s)}{S} \quad (35)$$

$$G_w(S) = \frac{H_w}{1+ST_w} \quad (36)$$

The speed loop with the simplified current loop is shown in Figure 5. Near the vicinity of cross over frequency, the following approximations are valid

$$(1 + sT_m) \cong sT_m \quad (37)$$

$$(1+sT_i)(1+sT_\omega) \cong 1+sT_{\omega i} \quad (38)$$

$$(1+sT_\omega) \cong 1 \quad (39)$$

The speed loop with the simplified current loop is shown in Figure 5. Near the vicinity of cross over frequency, the following approximations are valid

$$G_S(s) = \frac{K_P s + K_i}{s} X \frac{K_s}{(1+sT_i)} X \frac{K_i K_m}{(1+sT_m)} \quad (40)$$

The speed loop transfer function with the approximate is given by

$$G_s(s) \cong \frac{K_i K_m K_t H_w K_s (1+sT_s)}{T_m T_s s^2 (1+sT_{wi})} \quad (25)$$

from which the closed loop speed transfer function is obtained as

$$\frac{W_r}{W_r^*} = \frac{K_g \frac{K_s}{T_s}(1+sT_s)}{T_s s^3 + s^2 + K_g \frac{K_s}{T_s}(1+sT_s)} \quad (41)$$

Where

$$K_g = \frac{K_i K_m K_t}{T_m} \quad (42)$$

Simplified speed control loop, Exact speed control loop using PID controller as shown in Figure 6 and Figure 7.

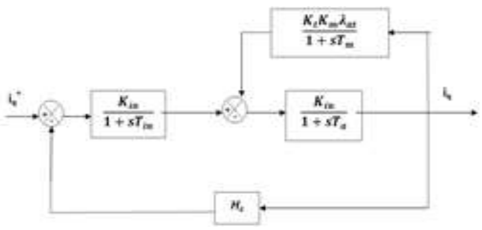

Figure 5. Current Control Loop

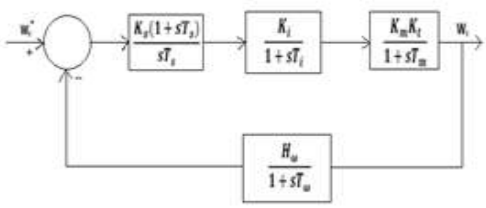

Figure 6. Simplified Speed Control Loop

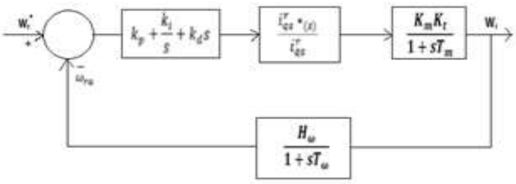

Figure 7. Exact Speed Control Loop Using PID Controller

4. PERFORMANCE OF CLOSED LOOP PMSM DRIVE USING PI CONTROLLER

PI control is a name commonly given to two-term control; P stands for Proportional term and I for Integral term. P-I controller is mainly used to eliminate the steady state error resulting from P controller. The characteristics of PI control actions are (i) steady state accuracy improves (ii) rise time increases (iii) bandwidth decreases (iv) overshoot reduces. Increasing the proportional gain speeds up the transient response (reference tracking response and disturbance rejection response) and decreases the output offset from the desired constant reference value. Increasing gain may lead to instability [13-14]. Actually by increasing gain increases the size of the control signal, this may lead to saturation or limiting problems with the system actuators. The presence of integral action in a controller usually leads to a wider range of closed loop transient responses sometimes unstable ones. It generally slows down the response. The addition of integral action eliminates constant offset signals in steady state for both reference tracking and disturbance rejection responses. In this proposed closed loop model of PMSM drive, PI controller is chosen as a speed as well as a current controller in different combinations so as to reach the desired performance of the system [15-16]. The transfer-function of the PI controller is given as $G_{PI}(s) = (K_p + \frac{K_I}{s})$ ... (43) where K_p and K_I are the proportional and integral gains respectively. SIMULINK block diagram of a closed loop PMSM drive using P current controller and PI speed controller as shoen in Figure 8. SIMULINK block diagram of a closed loop PMSM drive using current, speed both PI controller, and P current controller and PID speed controller as shown in Figure 9 and Figure 10.

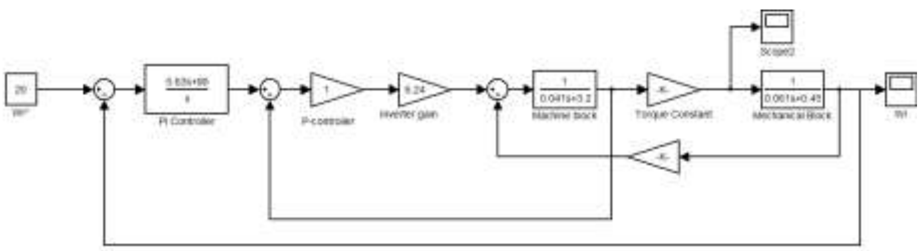

Figure 8. SIMULINK Block Diagram of a Closed Loop PMSM Drive Using P Current Controller and PI Speed Controller

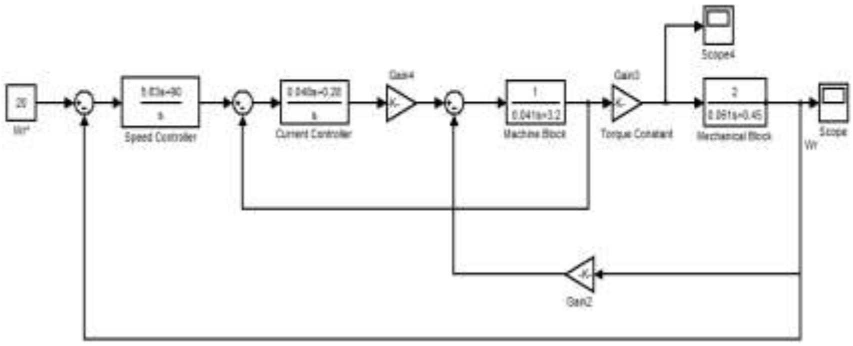

Figure 9. SIMULINK Block Diagram of a Closed Loop PMSM Drive Using Current and Speed Both PI Controller

5. PERFORMANCE OF CLOSED LOOP PMSM DRIVE USING PID CONTROLLER

PID control is a name commonly given to three-term control; P stands for Proportional term, I for Integral term, and D for Derivative term of the controller. PID controllers are probably the most widely used industrial controllers. Basically PID controller is a combination of PI and PD controllers. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system [17-18]. It is a lag-lead compensator. One of the main advantages of the P-I-D controller is that it can be used with higher order processes including more than single energy storage. Thus the PID control may be used when the system requires improvements in both transient and steady state performances. The characteristics of PID control actions are (i) no oscillations (ii) improves the transient response (iii) improves the steady state performance. An advantage of using a derivative control action is that it responds to the rate of change of the actuating error and can produce a significant correction before the magnitude of the actuating error becomes too large. Derivative control action thus anticipates the actuating error, initiates an early corrective action, and tends to increase the stability of the system. Therefore derivative control action is always used in combination with proportional or proportional plus integral control action. In this proposed model, both the current and speed loop are designed with PID controller for getting improved response [19-20]. The transfer-function of the PID controller is given as $G_{PID}(s)=(K_p + sK_D + \frac{K_I}{s})$,........ (44) Where K_p, K_D and K_I are the proportional, derivative and integral gains respectively. Here the selection of three gains is such that the two zeros are to be placed at the negative real axis. So essentially the transfer-function becomes $G_{PID}(s)=\frac{K(s+z_{c1})(s+z_{c2})}{s}$ .....(45); where proportional gain, $K_p = K(z_{c1}+z_{c2})$ .... (29), derivative gain, $K_D = K$ .... (46) and integral gain $K_I = K * z_{c1} * z_{c2}$ ....(47)

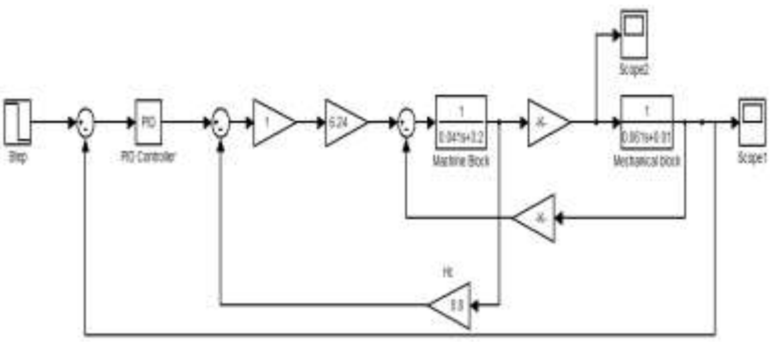

Figure 10. SIMULINK Block Diagram of a Closed Loop PMSM Drive Using P Current Controller and PID Speed Controller

6. DISCUSSION AND COMPARATIVE PRERFORMANCE EVALUATION BETWEEN PI AND PID CONTROLLED PMSM DRIVE

The entire model of PMSM closed loop drive is divided into two loops, inner loop current and outer loop speed as shown in Figures 11-28. In the first case current control loop is determined using mathematical block diagram representation, using PI controller. By getting the simplified and exact current loop transfer functions of current controller, it is added to the speed control loop i.e. outer loop using PI controller. Simplified current loop transfer function is coupled with simplified speed loop and exact current control loop is coupled with exact speed control loop**.** Hence a typical performance study is introduced to familiar with the different performance indices of the closed loop system corresponding to time domain and frequency domain specifications. The time domain specifications of overall closed loop system like peak time, rise time, settling time, steady state value etc are determined analytically which in turn helps to familiar with the performance of PI controlled PMSM drive accordingly [21-22]. The frequency domain specifications of the system like gain margin, phase margin, gain and phase cross over frequencies are also determined by bode- diagram representation respectively. The stability analysis of overall speed and current loop representation of closed loop adjustable speed PMSM drive can be determined by root locus plot representation. Therefore different performance indices can be taken for the determination of dynamic as well as steady state response of closed loop PMSM drive As the overall structure comprising of two loops and two kinds of classical controllers such as PI and PID are taken, therefore different combinations of controllers are taken into consideration for the performance study of closed loop model [23].

The performance of a control system is much dependent on its time domain specifications. The time response of a control system is usually divided into two parts: the transient response and steady-state response. The transient response of a practical control system often exhibits damped oscillations before reaching steady state. Here in this section for the determination of time domain performance characteristics four combinations of different classical controllers (PI & PID) are taken into consideration. By observing the different specifications of time domain analysis like rise time, settling time, peak overshoot, percentage error etc. a comparative study may be carried out. As per the convention rise time is the time required for the response to rise from 10%-90% of the final value in cases of over damped or critically-damped systems, or 0-100% of the final value in case of under damped systems [24]. Here in this analysis rise time is much lesser (i.e. 0.221 sec) in the 4^{th} case i.e. if the combination of current and speed both loop can be configured by using a PID controller. Therefore the presence of derivative control in both loops improves system response. The time required for the response to damp out all the transients is commonly called the settling time. The settling time is related to the largest time constant of the system. Since the settling time is inversely proportional to the undamped natural frequency of the system, value of damping ratio is usually determined from the requirement of permissible maximum overshoot. It is observed that among the four cases the system is settled faster in the 4^{th} case i.e. current loop PID and speed loop PID. However performances of all the systems are determined by this specification. Peak overshoot is the peak value of the response curve measured from unity. If the final steady-state value of the response differs from unity, then it is common to use percentage overshoot. The amount of maximum overshoot directly indicates the relative stability of the system [25]. It is observed that the addition of derivative control action in both the loops, percentage overshoot is decreased and hence improves system performance. Steady state error is the difference between actual output and desired output as time tends to infinity. The speed response is found to be slightly under damped, caused by the speed controller setting. The electromagnetic torque response is found to be almost ripple-free, mainly because of the SPWM inverter and the machine inductances. The speed response shows a slight overshoot as desired, because while designing the speed loop, the damping ratio has been assumed 0.707. The developed torque is initially high in order to bring the speed near to its set quickly. The steady state error in speed is obtained to be zero and the speed settles within a time duration which is acceptable. Better speed and torque response can be achieved by designing a PID speed controller as compared to a PI controller [26-27].

By the term frequency response, we mean the steady-state response of a system to a sinusoidal input. In frequency-response methods, we vary the frequency of the input signal over a certain range and study the resulting response. Bode diagram is one of the effective method for determination of frequency response characteristics of a closed loop system. The phase margin is that amount of additional phase lag at the crossover frequency required to bring the system to the verge of instability. The crossover frequency is the frequency at which the magnitude of open loop transfer function is unity [28-29]. On the other hand gain margin is the reciprocal of the magnitude at the frequency at which the phase angle is -180°. Thus a positive gain margin means that system is stable, and a negative gain means that the system is unstable. Here in the entire cases gain margin, phase margin, cross over frequencies are determined and it is observed that the gain margin is positive in all the cases and phase margin is increased with the addition of derivative control action in both the cases.

The root locus method yields a clear indication of the effects of parameter adjustment. By using the method, the designer can predict the effects on the location of the closed loop poles by varying the gain value or adding open-loop poles and/or open-loop zeros. By observing the root locus plots approximate stability can be obtained very quickly which in turn helps to familiar with the stability performance of the system accordingly [30].

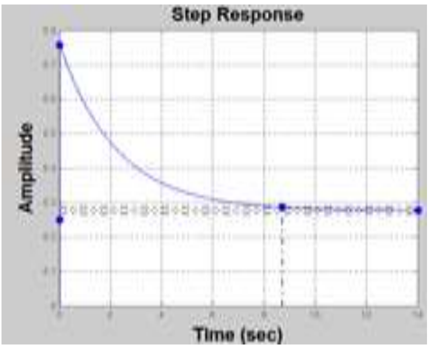

Figure 11. Step Response Representation of Exact Current Loop

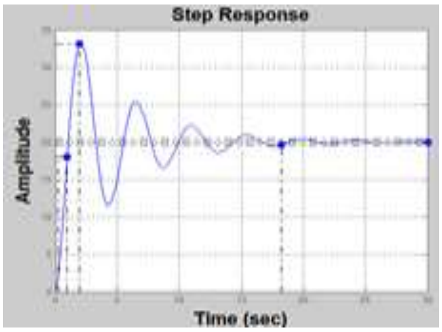

Figure 12. Step Response Representation of Simplified Speed Control Loop with PI Controller

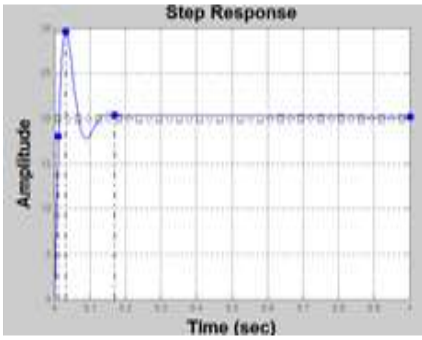

Figure 13. Step Response Representation of Simplified Speed Control Loop with PID Controller

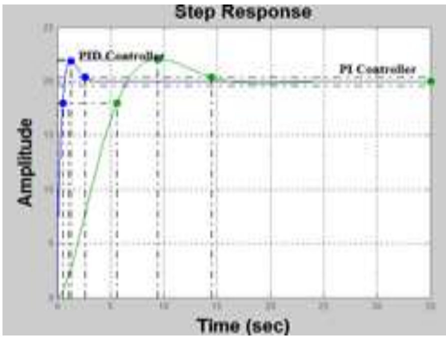

Figure 14. Comparative Step Response Characteristics of Overall Speed and Current Loop Using PID and PI Controller

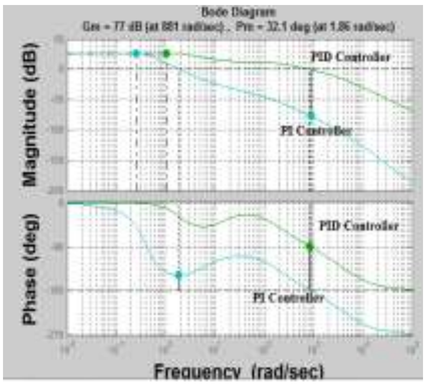

Figure 15. Comparative Bode Diagram Representation of Overall Speed and Current Loop Using PID And PI Controller

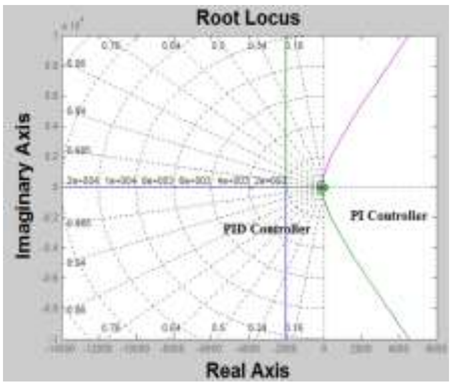

Figure 16. Comparative Root Locus Plot Representation of Overall Speed and Current Loop Using PID and PI Controller

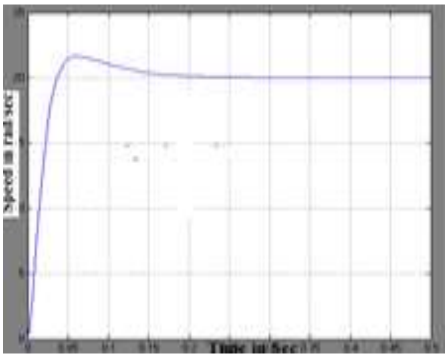

Figure 17. Actual Speed vs. Time Waveform using P Current Controller and PI Speed Controller of the Closed Loop Adjustable Speed PMSM Drive When a Step Change in Reference Speed of 20 rad/sec is introduced

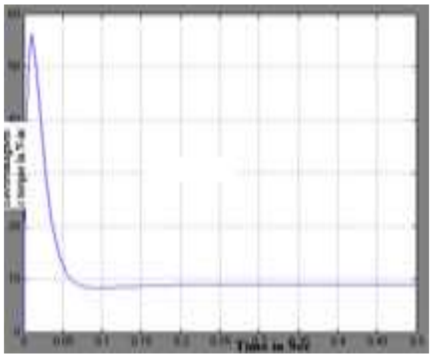

Figure 18. Electromagnetic Torque vs. Time Waveform of the Closed Loop Adjustable Speed PMSM Drive using P Current Controller and PI Speed Controller

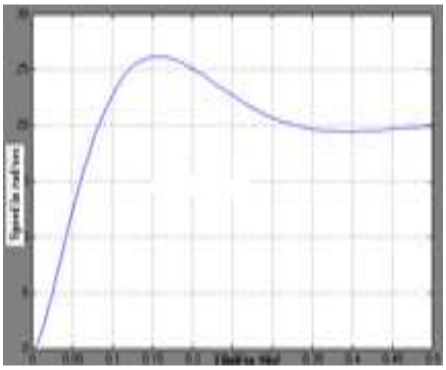

Figure 19. Actual Speed vs. Time Waveform using Current and Speed Both PI Controller of the Closed Loop Adjustable Speed PMSM Drive When a Step Change in Reference Speed of 20 Rad/Sec Is Introduced

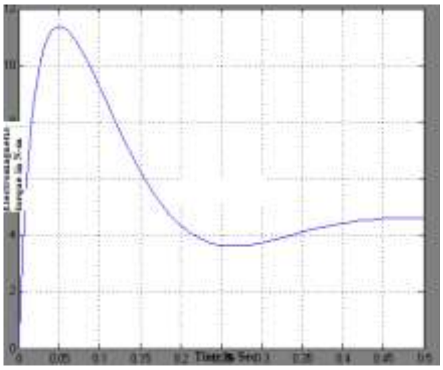

Figure 20. Electromagnetic Torque vs. Time Waveform of the Closed Loop Adjustable Speed PMSM Drive Using Current and Speed Both PI Controller

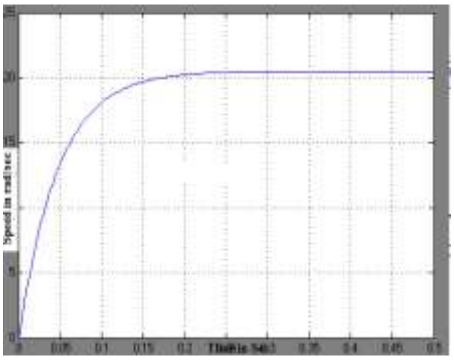

Figure 21. Actual Speed vs. Time Waveform Using P Current Controller and PID Speed Controller of the Closed Loop Adjustable Speed PMSM Drive When a Step Change in Reference Speed Of 20 Rad/Sec Is Introduced

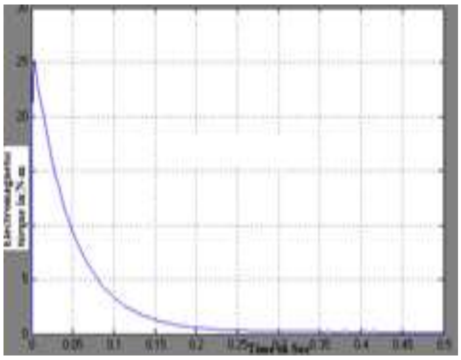

Figure 22. Electromagnetic Torque vs. Time Waveform of the Closed Loop Adjustable Speed PMSM Drive Using P Current Controller and PID Speed Controller

6.1 Different Case Studies

Case 1: Current loop PID, Speed loop PI

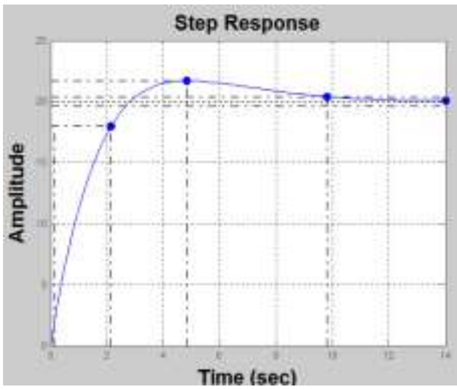

Figure 23. Step Response Characteristics of Overall Speed and Current Loop Using PI and PID Controller

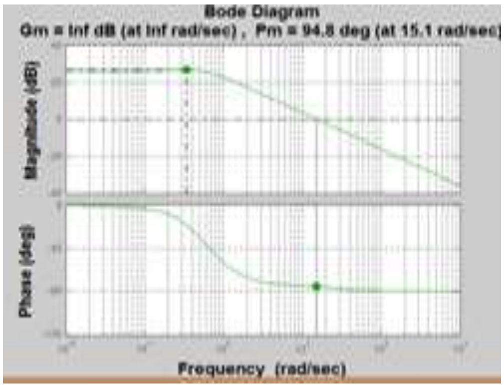

Figure 24. Bode Diagram Representation of Overall Speed and Current Loop Using PI and PID Controller

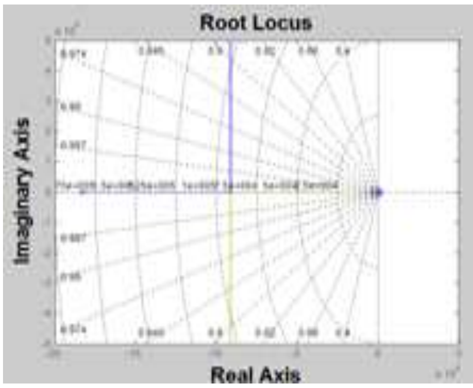

Figure 25. Root Locus Plot Representation of Overall Speed and Current Loop Using PI and PID Controller

Case 2: Current loop PID, Speed loop PID

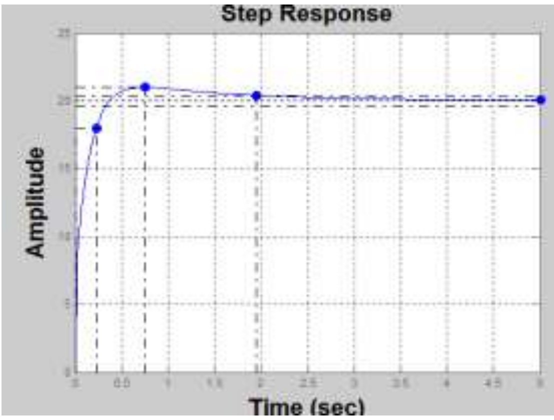

Figure 26. Step Response Characteristics of Overall Speed and Current Loop Both Using PID Controller

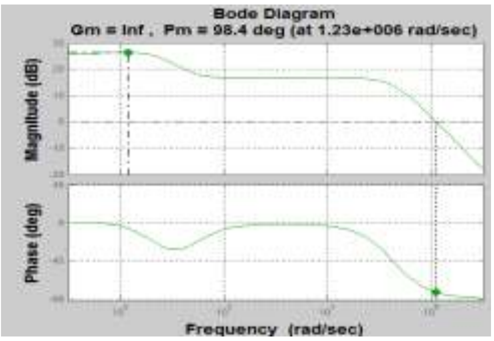

Figure 27. Bode Diagram Representation of Overall Speed and Current Loop Both Using PID Controller

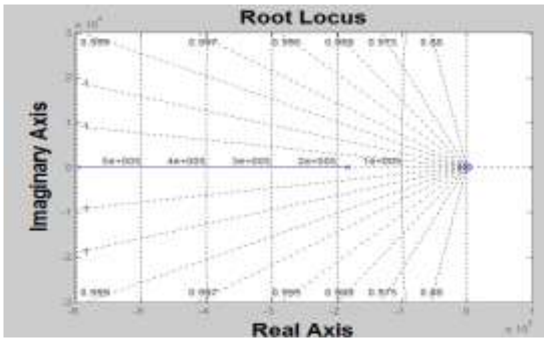

Figure 28. Root Locus Plot Representation of Overall Speed and Current Loop Both Using PID Controller

Table 1. Performance of Time Domain Analysis

Speed controller Transfer Function	Current controller Transfer Function	Rise Time (sec)	Settling Time (sec)	Peak overshoot (%)	% of error
$\left(5.63+\frac{90}{S}\right)$	$\left(0.048+\frac{0.28}{S}\right)$	4.54	14.5	10.2	0
$\left(9.8251+\frac{6.78}{S}+3.67S\right)$	$\left(0.048+\frac{0.28}{S}\right)$	0.505 sec	2.59 sec	9.32	0
$\left(0.84+\frac{0.28}{S}\right)$	$\left(5.0407+\frac{6.783}{S}+0.367S\right)$	2.01 sec	9.8 sec	8.57	0
$\left(9.825+\frac{6.78}{S}+3.67S\right)$	$\left(5.0407+\frac{6.783}{S}+0.367S\right)$	0.221 sec	1.95 sec	4.96	0

7. CONCLUSIONS

This paper significantly describes the comparative performance analysis of closed loop model of an adjustable speed PMSM drive using classical PI and PID controller. The different performance indices related to time domain specifications of the system like settling time, rise time, peak overshoot, steady state error and frequency domain specifications like gain margin, phase margin, cross over frequencies etc. are determined analytically. Overall Performance of the closed loop model of the PMSM drive is tested and monitored. Hence the system behaviour is sensitive for parameter variations in order to tuning the controller gains. Therefore this model can predict dynamic as well as steady state behaviour of the system respectively. Hence a more stable performance with reduced overshoot, faster response, better accuracy can be gained by designing a PID controlled adjustable speed PMSM drive. By comparing all the performance indices, the drawbacks of a classical PI controller as current and speed can be overcome by incorporating a classical PID controller for widespread applications. By taking the two loops control structure consisting of outer loop speed and inner loop current, the overall structure can be implemented using different classical controllers and soft computing controllers in future. Finally one hardware/experimental setup will be developed for the validation of the results obtained from analytical studies. Thus the choice of controller may be an effective tool for closed loop control of a PMSM drive in specific environment for performance optimization.

APPENDIX

The parameters of the Permanent Magnet Synchronous Machine (PMSM), on which the studies are made in this paper, are: Number of pole P=4, armature resistance R_s= 3.2 ohm, combined moment of inertia J= 0.061 kg-m^2, damping co-efficient F_n=0.45 Nm-s/radian, d-axis inductance L_d=0.053H, q-axis inductance Lq=0.041H, torque constant K_t=0.927N.m/A, mechanical gain K_m=100 rad/s/Nm, electrical gain K_a=0.3125, motor mechanical time constant T_m=6.1s, dc link voltage V_{dc}=96V, switching frequency f_c=2Khz, maximum control voltage V_{cm}=10V.

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BIOGRAPHIES OF AUTHORS

Chiranjit Sain received B.Tech in Electrical Engineering from Asansol Engineering College, Asansol, India and also received M.Tech from National Institute of Technical Teachers Training and Research, (NITTTR) Kolkata, India in the specialization of Mechatronics Engineering under Electrical Engineering department. Presently he is working as an Assistant Professor in the Electrical Engineering Department at Siliguri Institute of Technology, Siliguri India since 2010 and also pursuing Ph.D in the Electrical Engineering Department from National Institute of Technology, Meghalaya, India. His present research of interests includes Electrical Machine-Drives Systems, Power Electronics Converters, Soft-computing analysis etc.

Atanu Banerjee was born in Asansol, West Bengal, India. He received his B.E. degree in Power Electronics Engg. from the Nagpur University in the year of 2001 and M.E in Electrical Engg. Department with specialization in Power Electronics & Drives in 2008 from Bengal Engineering & Science University, Shibpur (Now IIEST, Shibpur). He has completed his Ph.D in Electrical Engg from the Indian School of Mines, Dhanbad, India in 2013. He worked in industries for almost three years & has academic experience of more than 12 years. Presently he is in National Institute of Technology, Meghalaya as an assistant professor and Head of the Department in the Electrical Engg. Department. His research interests include induction heating and high frequency switching in power electronic converters, adjustable speed drives. He has published few books & several journal/conference research papers. Also Dr. Banerjee has filed two patents to the Govt. of India. Currently he is guiding few research scholars for M-Tech & Ph.D.

Pabitra Kumar Biswas was born in West Bengal, India in 1980. He completed his B.Tech from Asansol Engg. College, WBUT, India. He received his ME. Degree from Bengal Engineering and Science University, West Bengal, India and PhD. Degree in Electrical Engineering from National Institute of Technology, Durgapur, India. He is presently working as an Assistant Professor and Head of the Department in Electrical Engineering at National Institute of Technology, Mizoram, India. He has published a numbers of research papers in National/International Conference Records/Journals. From 16.07.2007 to 05.02.2015, he served as an Assistant Professor in Electrical Engineering in Asansol Engineeng College, Asansol, India. His research interests include Electromagnetic Levitation System, Active Magnetic Bearing and Power electronics.