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Speed Control & Ripple Reduction of PMSM Using PI Controller for Electric Vehicle Application

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ABSTRACT: Permanent magnet synchronous machines are used for many applications like aerospace, electric vehicles, industries, household appliances etc., as they are highly efficient. But the major problem which affects the working of PMSMs is the voltage, speed, torque ripples. In order to reduce these ripples several control techniques are currently available. Voltage feedback flux weakening control is the popular technique as it is robust and simple. It will not change in accordance with machine parameters. For fast speed dynamics and less ripples fuzzy logic speed controller is used in this work. The results are demonstrated in MATLAB/Simulink
.

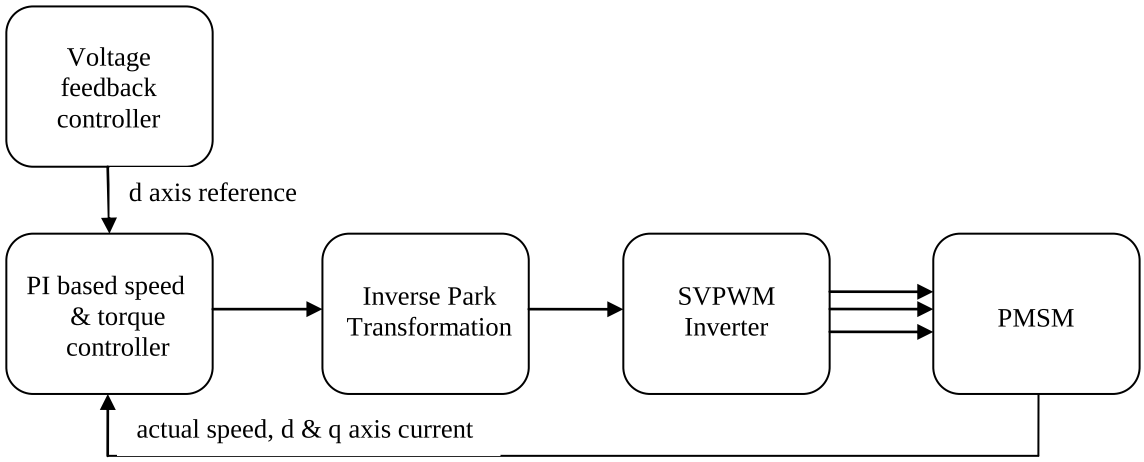
KEYWORDS: : Speed control, Ripple reduction, PMSM, Electric vehicle, PI controller.

I.INTRODUCTION

Permanent magnet synchronous machine are widely used in electric vehicles due to its robustness, high torque current ratio, high power weight ratio, efficiency etc. But the speed range of PMSM is restricted to lesser region due to the voltage and current of the inverter. For generating proper currents there are several control techniques have been developed. Out of which voltage feedback control is most used as they are robust against any parameter variation than feed forward methods which will depend upon machine parameters. But due to the current and voltage variations the voltage loop shows non linearity, which will make the tuning more difficult in the flux weakening regions.

The linearizing of voltage loop alone cannot assure good dynamics and less ripples. Due to the less voltage control in the flux weakening region, more ripples will be generated there. Thus the improving of speed dynamics might be difficult in the flux weakening region. The feedback voltage ripples can be reduced by providing small pi gains. Hence a PI controller is used in this paper.

II.SYSTEM MODEL AND ASSUMPTIONS



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For the generation of proper current signals in flux weakening operation there are many control techniques have been developed. There are many feed forward methods available for the controlling but the problem with these feed forward methods is that they may change in accordance with the machine model. But the control strategy named voltage feedback flux weakening control is powerful as they do not change with the motor parameter variations. Hence they are most standard control structure used now a days. The voltage feedback portion in this control strategy exhibits some non linearity that makes tuning more difficult. The less voltage control in flux weakening region causes more voltage ripples. These feedback voltage ripples causes more oscillations in constant power regions. These voltage ripples might be caused by current and speed ripples which are generated by torque ripples due to the ideal installation. This paper shows that the voltage ripples are more generated by means of current ripples in flux weakening regions which will affect the improvement of speed of the motor.
The voltage ripples may be cut down by introducing smaller p and i gains to the system. But this will affect the speed. To solve this problem a nonlinear PI controller can be used. There are several other factors like load torque ripple, non ideal installations of motor parts can cause disturbance to control system. The disturbances causes voltage ripples and reduce the system performance. Though there are many non ideal factors that cause ripples, the ripples in the measurable speed is only taken in to consideration. The ripples can be directly added into the system through voltage feedback terms and indirectly by adding voltage ripples through q- axis current ripples by speed PI controller.

The mathematical model is derived based on the following assumptions:

- stator will be balanced with sinusoidal distributed magneto motive force(mmf)
- It is assumed to have balanced windings and balanced inputs
- inductances verses rotor position will be sinusoidal in nature
- any saturation and parameter changes are neglected

III. PROPORTIONAL INTEGRAL (PI) CONTROLLER

The output of a Proportional integral controller combines the outputs of a proportional and integral controller

$$u(t)=K_P e(t)+K_I \int e(t)\, dt \quad (1)$$

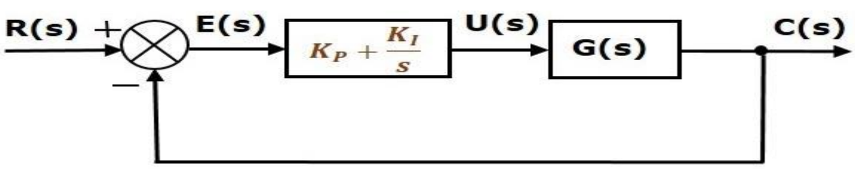
Apply Laplace transform on both sides -

$$U(s)=\left(K_P+\frac{K_I}{s}\right)E(s)$$

$$\frac{U(s)}{E(s)}=K_P+\frac{K_I}{s} \quad (2)$$

Hence, the transfer function of proportional integral controller is $K_P+\frac{K_I}{s}$.

The following figure depicts the block diagram of a unity negative feedback closed loop control system with a proportional integral controller.



Basic closed loop of PI controller

The proportional integral controller is used to reduce steady state error while maintaining the stability of the control system. Other benefits of the proportional integral controller includes

- Good transient response.
- Provides simplicity and directness.
- Helps in the controller gain stabilization.
- Eliminates the offset error.
- Improves stability, Gain Margin & Phase Margin.

The discrete incremental form of a speed PI controller can be expressed as

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$$i^{*}_{q,MTPA}(k) = i^{*}_{q,MTPA}(k-1) + Di^{*}_{q,MTPA}(k) \quad (3)$$

where $Di^{*}_{q,MTPA}(k)$ is the incremental component of current command in each control cycle, i.e.

$$Di^{*}_{q,MTPA}(k) = k_{ps}[e_n(k) - e_n(k-1)] + e_n(k)k_{is}T_s \quad (4)$$

where

Ts is the control period of the speed loop
k denotes the step of the speed control cycle
$Di^{*}_{q,MTPA}(k)$ is the incremental component of current command in each control cycle
e_n is the speed tracking error, i.e. $(n^{*}-n)$

IV. PERMANENT MAGNET SYNCHRONOUS MOTORS

The permanent magnet synchronous motors (PMSM) has become extremely popular and upcoming motors in electric vehicle industry. It is an Ac synchronous machine with field excitation provided by permanent magnet. The factors that makes PMSM a popular one in EV industry is its advantages like high efficiency, high torque to weight ratio, less noisy, sparkless operation, more compact and lighter than AC induction machine, smooth low and high speed operations, etc. It has a permanent magnet rotor and windings on stator as in an brushless DC motor. But stator with windings is designed in such a way to provide sinusoidal flux density in air gap as in similarly in an induction motor. There are several control strategies available for high performance PMSM like vector control, direct torque control(DTC), maximum torque per ampere(MTPA) for utilizing maximum efficiency at various operating regions and conditions. In this paper a vector control along with maximum torque per ampere is incorporated. Manufacturing of high performance PMSM is a complex and costly process for a single piece prototype.

Construction of PMSM

Construction of PMSM is similar to that of a synchronous motor. The difference while comparing PMSM with a synchronous motor is that PMSM have permanent magnet as rotor which is not seen in synchronous motor. The stator windings will be excited by electric power while rotor gets excited by permanent magnet. Depending on how magnets are attached to the rotor, PMSM is classified into two types,

a. Surface Mounted PMSMs
b. Buried or interior PMSMs

The working principle of a permanent magnet synchronous motor is similar to that of a synchronous motor. It mainly depends on the rotating magnetic field that produces emf at synchronous speed. When a three phase supply is given, the stator windings get energized and a rotating magnetic field is created in between the air gaps. The torque will be produced when the rotor field poles hold the rotating magnetic field at synchronous speed and rotor rotates continuously. The air gap between the stator and rotor is crucial to PMSM's operation. The windage losses will be minimised if the air gap is high. A variable frequency power supply has to be provided as the PMSM are not self starting ones.

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Basic model of the system

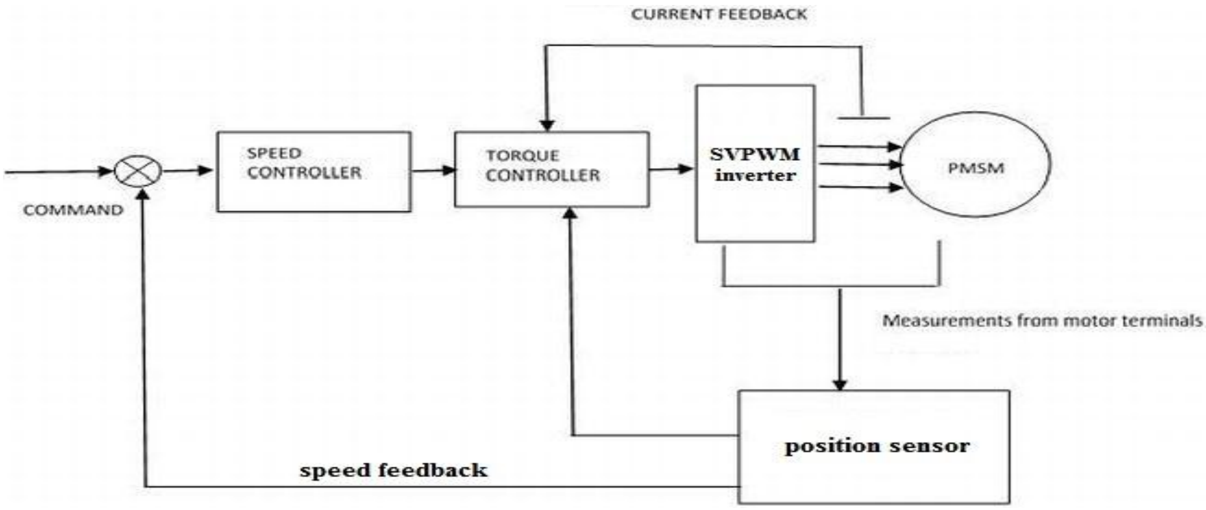

Fig 5.3 Basic model of PMSM

The main components of the system shown above are

- Permanent magnet synchronous motor
- SVPWM fed inverter
- Speed controller
- Torque controller
- Position sensors

The two phase windings will 3 T_1 /2 turns per phase for mmf equality, assuming that each of the three phase windings has T_1 turns per phase and equal current magnitudes. By resolving the mmfs of the three phases along the d and q axes, the d and q axis mmfs can be determined. On both sides of the equations, the common term, i.e, the number of turns in the winding is cancelled, leaving the current equal. The q-axis here is assumed to be lagging behind the a-axis by θ_r. The relationship between dqo and abc currents is given by different types of transformation matrices.

Voltage equation in rotor frame is given by

$$v_d = R_s i_d + L\frac{di_d}{dt} - \omega_e L_s i_q \quad (5)$$

$$v_q = R_s i_q + L_s\frac{di_q}{dt} - \omega_e (L_s i_d + \varphi_m) \quad (6)$$

The mechanical torque is,

$$T_e = \frac{3}{2}P(\varphi_m i_q + (L_d - L_q) i_d i_q) \quad (7)$$

The speed is,

$$\omega_r = \int \frac{T_e - T_L - B\omega_r}{J} \quad (8)$$

$$\theta = \int \omega_r$$

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V. RESULT AND DISCUSSION

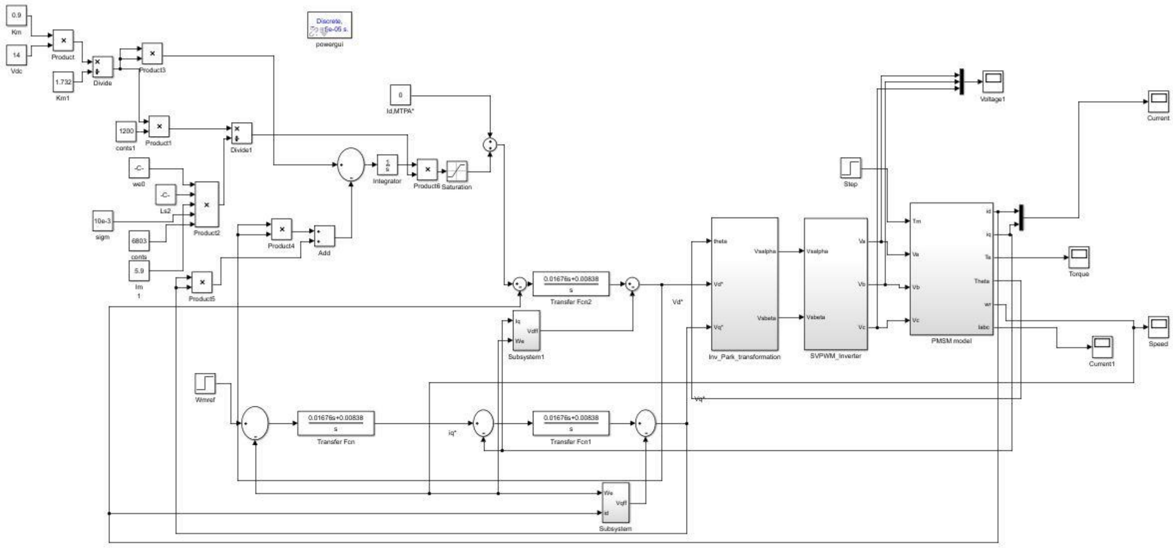

Fig 1 Main simulation of speed control of PMSM with a PI controller

The fig 1 shows the main simulation diagram in matlab of a speed control of PMSM with a pi controller. The main blocks that includes in this simulation is inverse park transformations block, SVPWM inverter voltage feedback controlled, speed and torque controller, and a PMSM motor.

The fig 2 shows the expansion of SVPWM inverter block. It consists of six switches which generates the three phase voltages to the PMSM. The six switches will be triggered using six pulses at its gate terminals. These pulses are generated using SVPWM. The pulses thus generated is shown in fig 3. The work have done in both loaded and noloaded conditions.

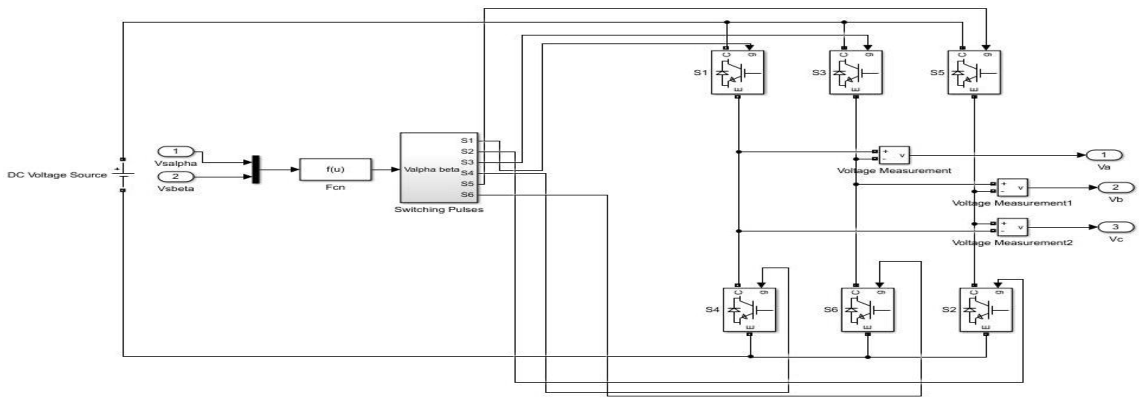

Fig 2 SVPWM inverter

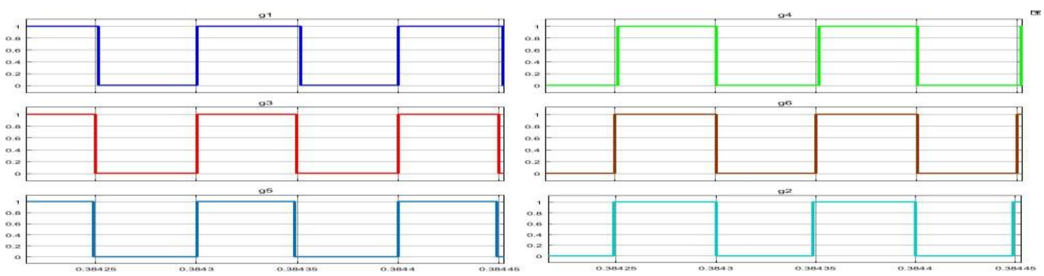

Fig 3 Pulse to switches

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Fig 4 shows the voltage waveform with a magnitude of 220v. The fig 5 and fig shows the speed and torque waveforms in noloaded condition

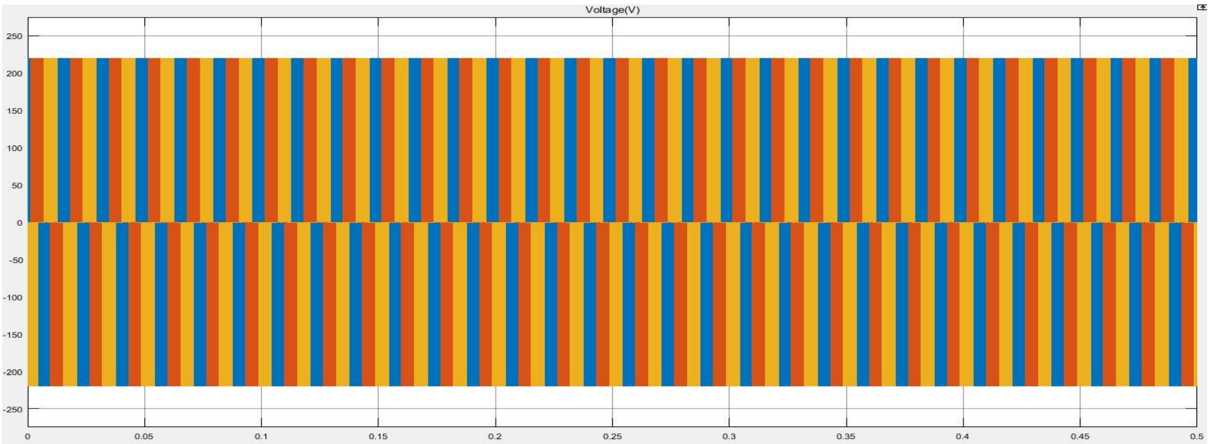
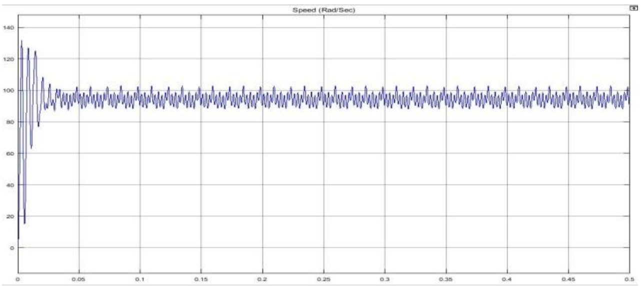


Fig 4 voltage waveform



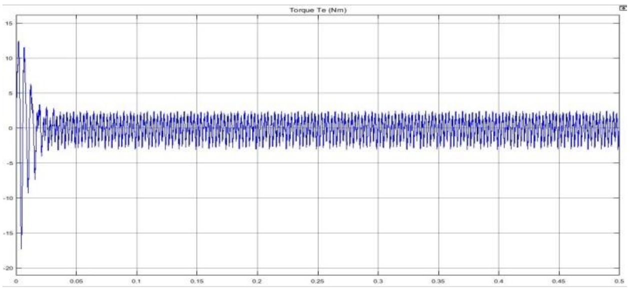
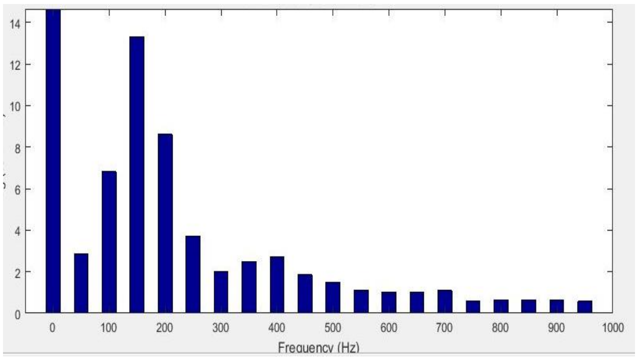


Fig 5 Simulation of speed waveform

Fig 6 simulation of torque waveform

The FFt analysis of speed current and torque waveforms of PMSM connected pi controller is shown in fig 6 and fig 7 respectively. It has been found that on FFT analysis, the THD of speed is 18.86%, current is 18.17% and that of torque is 20.76%



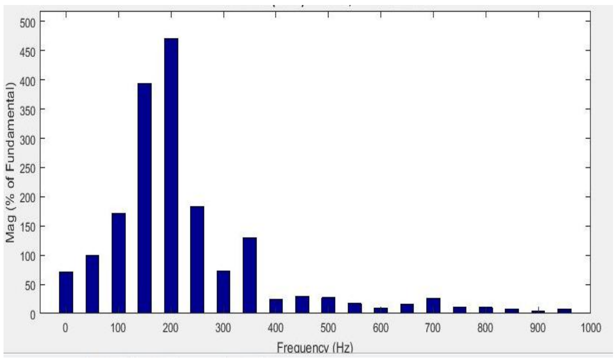


Fig 6 FFT analysis on speed waveform
THD=18.86%

Fig 7 FFT analysis on torque waveform
THD= 20.76%

The following figures shows the simulation results obtained when a load of 5Nm is applied on 0.1s. Fig 8 shows the d and q axis currents. Fig 9 and fig 10 shows the speed and torque waveforms obtained in the loaded condition.

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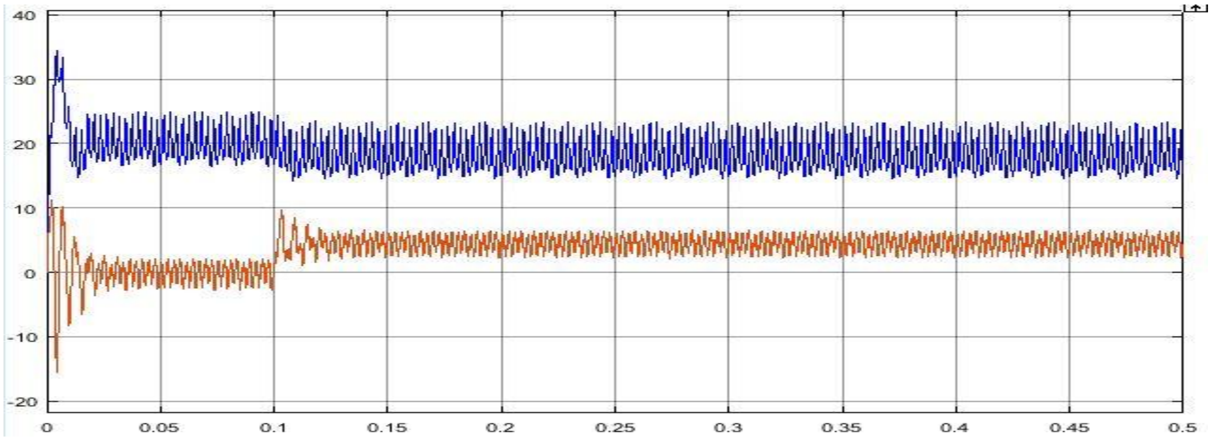
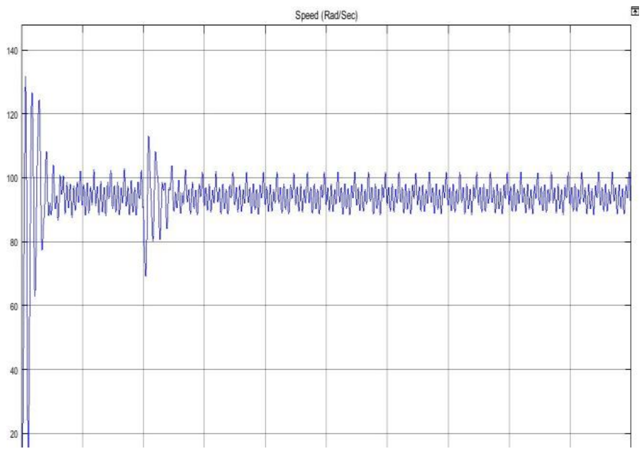


Fig 8 Simulation of d an q axis currents when a load torque of 5Nm is applied at 0.1s



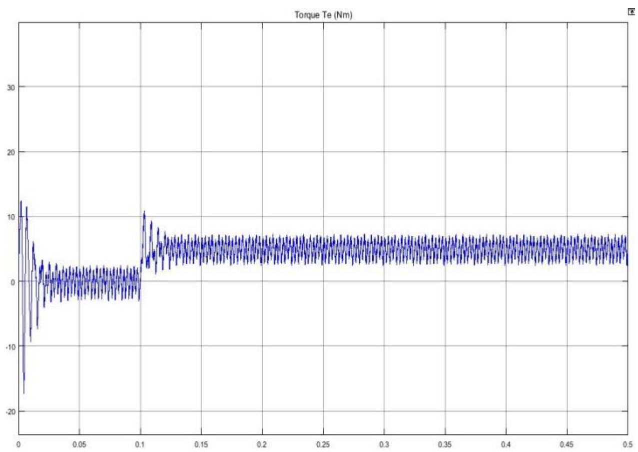
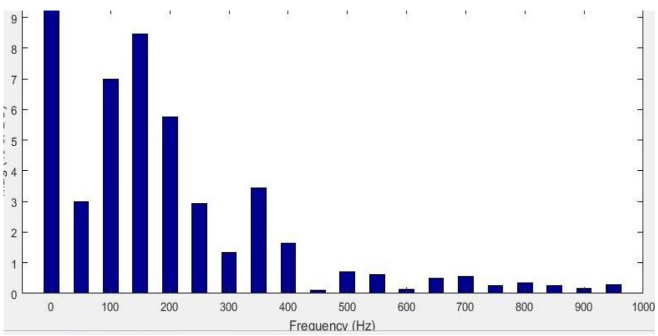


Fig 9 Simulation of speed waveform

Fig 10 Simulation of torque waveform

The figure 11 shows the fft analysis of speed waveform obtained when the pi controller controlled PMSM is run on a load of 5NM for 0.5s. In this analysis it has been found that the THD on speed wave form is 13.80%,current is 16.64% and torque is 13.90%.



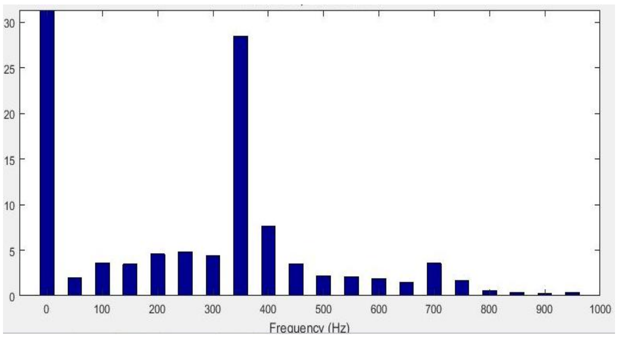


Fig 11 FFT analysis on speed waveform
THD= 13.80%

Fig 12 FFT analysis of torque on loaded condition
THD=13.90%

Table 1 and 2 shows the performance analysis and fft analysis on PMSM which is controlled by a PI controller

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		PI controlled PMSM	
		No Load	Load
Voltage		220v	220v
Current	d	16.75A	15.92A
	q	0.177A	4.73A
Speed		96.97rad/s	91.57rad/s
Torque		0.19Nm	4.7Nm

Table 1 Performance analysis

	PI Controlled PMSM	
	No load	Load
Current	18.17%	16.64%
Speed	18.86%	13.80%
Torque	20.76%	13.90%

Table 2 FFT Analysis comparison

VI.CONCLUSION

The simulation of speed control of permanent magnet synchronous motor by voltage feedback control technique is done and the results are analysed. The PI controller is used and the system performances while using it is observed and analysed. From the results, it can prove that the performance of the system while incorporated with PI controller is more efficient and effective. Bases on the FFT analysis, it can be seen that by using PI controller ripples can be reduced. But the PI controller depends on the tuning of the parameters hence the performance depends on tuning. The hardware implementation and assessment of the proposed system can be done in the future

REFERENCES

[1] C. Wang and Z. Q. Zhu, "Fuzzy Logic Speed Control of Permanent Magnet Synchronous Machine and Feedback Voltage Ripple Reduction in Flux-Weakening Operation Region," in IEEE Transactions on Industry Applications, vol. 56, no. 2, pp. 1505-1517, March-April 2020.

[2] C. Wang, Z. Q. Zhu, and H. Zhan, "Adaptive voltage feedback controllers on the non-salient permanent magnet synchronous machine," Int. Conf. on Electr. Mach. ICEM, pp. 1374-1380, 2018.

[3] C. Wang, Z. Q. Zhu, "Fuzzy logic speed controller with adaptive voltage feedback controller of permanent magnet synchronous machine," Int. Conf. on Electr. Mach. ICEM, pp. 1374-1380, 2018.

[4] C. Xia, B. Ji, and Y. Yan, "Smooth speed control for low-speed high-torque permanent-magnet synchronous motor using proportional–integral–resonant controller," IEEE Trans. Ind. Electron., vol. 62, no. 4, pp. 2123-2134, 2015

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 8, August 2021 ||

| DOI:10.15662/IJAREEIE.2021.1008007 |

[5] S. Bolognani, S. Calligaro, and R. Petrella, “Adaptive flux-weakening controller for interior permanent magnet synchronous motor drives,” IEEE J. Emerg. Sel. Topics Power Electron. vol. 2, no. 2, pp. 236–248, Jun. 2014.

[6] L. Harnefors, S. E. Saarakkala and M. Hinkkanen, "Speed Control of Electrical Drives Using Classical Control Methods," *in IEEE Transactions on Industry Applications*, vol. 49, no. 2, pp. 889-898, March-April 2013

[7] M. Tursini, E.Chiricozzi, and R. Petrella, “Feedforward flux-weakening control of surface-mounted permanent-magnet synchronous motors accounting for resistive voltage drop,” IEEE Trans. Ind. Electron., vol. 57, no. 1, pp. 440–448, Jan. 2010.

[8] X. Guo, X. Wen, F. Zhao, X. Song and X. zhuang, "PI parameter design of the flux weakening control for PMSM based on small signal and transfer function," *2009 International Conference on Electrical Machines and Systems*, 2009

[9] J. X. Shen, Z. Q. Zhu, D. Howe, and J. M. Buckley, “Fuzzy logic speed control and current-harmonic reduction in permanent-magnet brushless AC drives,” IEE Proc. Electr. Power Appl., pp. 437–446, 2005.

[10] J. L. Silva Neto and H. Le-Huy, "An improved fuzzy learning algorithm for motion control applications [PM synchronous motors]," *IECON '98. Proceedings of the 24th Annual Conference of the IEEE Industrial Electronics Society)*, vol.1, pp. 1-5 1998.