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Real Time Implementation of Sensorless PMSM Drive Using MRAS Speed Estimation Technique

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Abstract:
In the advance motor drives, permanent magnet plays an important role. I the previous technology speed control of the permanent magnet synchronous motor is achieved with the help of sensors like encoders, resolvers. This sensors act as feedback system in the speed control drives. Due to the use of sensors, system is having some limitations like environmental condition, weight, available space, cost, etc. Therefore it's not preferable to use such sensors to get better performance. In that case, sensor less speed estimation techniques are used to achieve the speed control of permanent magnet synchronous motor. Speed estimation of PMSM by using modern reference adaptive control strategy is discussed in this paper. Simulation of the speed control of PMSM is studied in the software in loop environment by using Opal RT.

Keywords: MRAS, PMSM

I. INTRODUCTION

For the production of air gap magnetic flux permanent magnet synchronous motor uses permanent magnet instead of using electromagnet. Because of the number of advantages of permanent magnet it's getting popularity in many industries. Permanent magnet material used in the earlier PMSM is of very low energy and can be easily demagnetize. Industrial application of the PMSM is increased drastically because of the development of high energy magnetic materials like Aluminium Nickel and Cobalt alloys (ALNICO), Strontium Ferrite, Samarium Cobalt (SmCo) and Neodymium Iron-Boron (NdFeB). PMSM motor is having stator winding supplied with three phase AC supply which produces rotating magnetic field while constant magnetic field is produced by the high power density permanent magnet equipped on the rotor. Torque is produced due to interaction of those two magnetic fields [1]. Accurate knowledge of rotor position and speed of motor is important to achieve high performance of speed control drive [2] [3] which can be done with the help of sensors like resolvers and encoders. This sensors are mounted on the shaft of the motor. It requires additional electronic circuit which leads to additional space requirement. Position sensors used in speed control are very sensitive to the change in environmental conditions. Therefore they can't use in the industries like chemical industry. Use of sensorless drives in the speed control of PMSM is one of the approach to eliminate the use of mechanical sensors. In this approach, by using motor parameters speed and position of the PMSM is estimated instead of measuring it. With the elimination of mechanical sensors higher performance of the speed control of PMSM can be achieved [2] [3] [4]. Modelling and simulation is usually used in designing drives compared to building actual system prototypes because of the cost reduction.[8] It is difficult to implement actual prototype to identify early defects in the system which may be time and cost consuming. In actual industrial practice it's common to test the simulate system in the real time environment before actual hardware implementation. In this paper implementation of the real time simulation of sensorless PMSM drive on RT-LAB Electrical simulator is described. For this purpose OP-4510 is used.

II. MODELLING OF PMSM

Mathematical modelling of PMSM is required while performing the simulation of sensorless speed control of PMSM. The dq axis mathematical model of the PMSM is used for the analysis of steady state as well as transient state performance of PMSM. The equations of the PMSM are presented in dq reference frame are composed of voltage equation, stator flux linkage equation, electromagnetism torque equation, the mechanical movement equation. Certain assumptions are made while modelling are as follows:

1. EMF is induced is sinusoidal
2. Saturation is neglected
3. Field current dynamics is neglected
4. Hysteresis and eddy current losses are neglected

With the consideration of above assumptions voltage equations of PMSM can be represented in matrix form as given below.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} R_s + pL_q & \omega_r L_d \\ -\omega_r L_q & R_s + pL_d \end{bmatrix} \begin{bmatrix} i_q \\ i_d \end{bmatrix} + \begin{bmatrix} \omega_r \lambda_f \\ p\lambda_f \end{bmatrix} \tag{1}$$

Current equations of the motor given by following

$$\frac{di_d}{dt} = \frac{1}{L_q} V_d - \frac{R_s}{L_d} i_d + \frac{L_q}{L_{de}} \omega_r i_q \tag{2}$$

$$\frac{di_q}{dt} = \frac{1}{L_q} V_q - \frac{R_s}{L_q} iq + \frac{L_d}{L_q} \omega_r i_d - \frac{\lambda_f}{L_q} \omega_r \tag{3}$$

Torque equation of the motor is given by

$$T_e = \left(\frac{3}{2}\right) \left(\frac{P}{2}\right) (\lambda_d i_q - \lambda_q i_d) \tag{4}$$

This is the dynamic model of PMSM used in vector control.

III. SPACE VECTOOR PULSE WIDTH MODULATION TECHNIQUE

The PWM is technique used the proposed system is SVPWM which produces the voltage vector using various switching modes of the inverter. Based on the principle of operation generation of SVPEM waveform includes the sector judgment model, calculation model of operation, time of fundamental vectors, calculation model of switching time and generation model of SVPWM waveforms. Fig.1 gives the overall model of SVPWM used to generate gate pulses. It is the combination of all the above subsystems and forms single SVPWM subsystem.
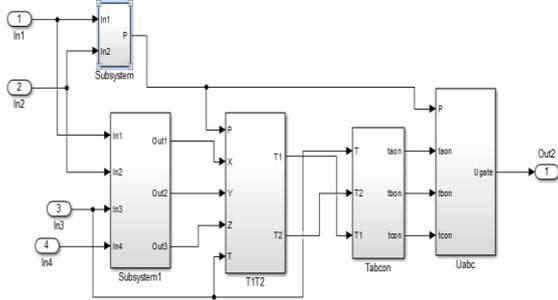
Figure.1. Overall model of SVPWM

IV. ESTIMATION TECHNIQUE

Fig. 2 shows the block diagram of MRAS technique. MRAS is the most effective method for the speed and position estimation in case of sensorless AC drives. MRAS is having two independent models. One is the reference frame which is independent of the variable to be estimated and another is adjustable model which depends on variable to be estimated. Stator current equations are consider as adjustable model while the PMSM is consider as reference model. Output of these models is given to the adaptation mechanism which gives the estimated variable as output.
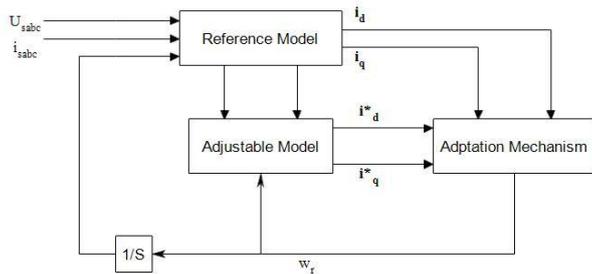

Figure.2. MRAS Block Diagram

$$p\begin{bmatrix} i^*_{ds} \\ i^*_{qs} \end{bmatrix} = \begin{bmatrix} -\dfrac{R_s}{L_s} & \omega_r \\ -\omega_r & \dfrac{R_s}{L_s} \end{bmatrix}\begin{bmatrix} i^*_{ds} \\ i^*_{qs} \end{bmatrix} + \dfrac{1}{L_s}\begin{bmatrix} V^*_d \\ V^*_q \end{bmatrix} \qquad (5)$$

By using this equation adjustable model of MRAS is designed. Fig. 3 shows the Simulink model of adjustable mechanism.
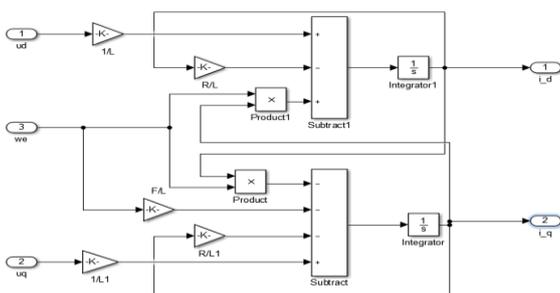

Figure.3. Model of Adjustable Mechanism

Outputs obtain from the PMSM as reference model and adjustable model are used by adaptive mechanism for the speed estimation. Rotor speed is integrated to obtain rotor position. Fig.4 shows the Simulink model of adaptation mechanism.
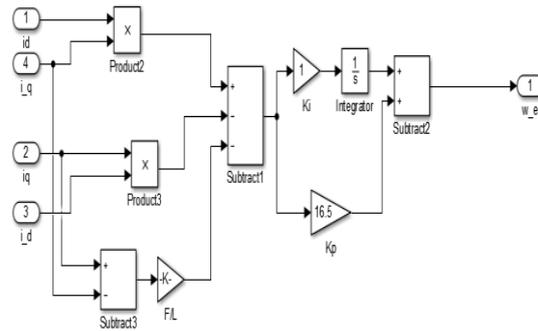

Figure.4. Model of Adaptation Mechanism

V. MODELLING OF PMSMREAL TIME SIMULATION

Opal-RT is leading testing equipment use for the hardware-in-loop and software-in-loop testing for various electromechanical, electrical and power electronics system. Opal-RT is used for validating results of system simulation which is to be tested in real time. MRAS based state estimation technique for the sensorless control of PMSM has been implemented in software-in-loop environment with its mathematical modelling using OP-4510. By using real time simulation cost and time for the testing is reduced. Fig.5 shows the OP-4510.

Figure.5. OP-4510

Fig.6 shows the complete Simulink diagram for the sensorless control of PMSM using MRAS which consist of two subsystems. Those are master subsystem and console subsystem. Master subsystem in simulation consist of all the computational details while console subsystem consist of scope and displays. For the communication of master and console subsystem OpComm block is used. Fig.7 shows the console subsystem of the simulation.
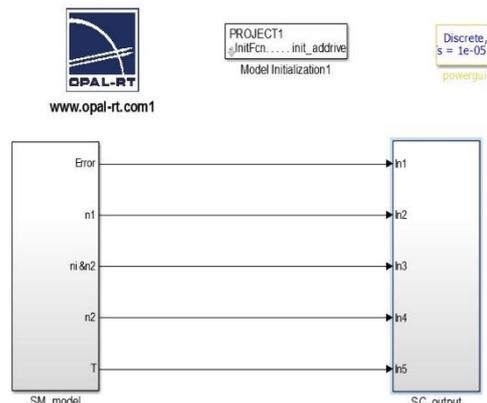

Figure.6. Complete Simulink Diagram of Real Time Simulation of Sensorless PMSM Drive
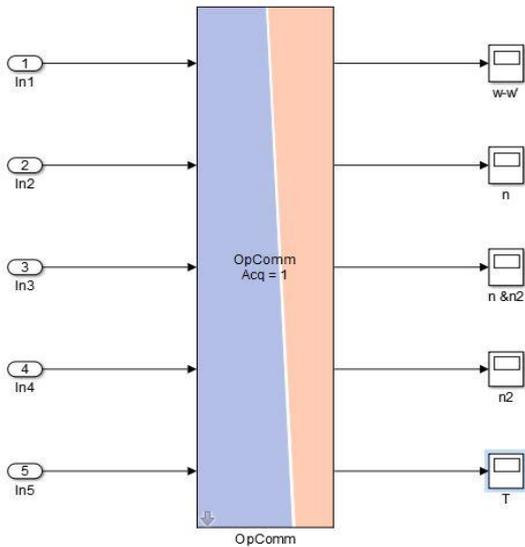
Figure.7. Console Subsystem

VI. MODELLING OF PMSMRESULTS AND DISCUSSION

The test cases derived together are supposed to demonstrate the overall performance of the estimation method and represent real position scenarios that could occur in a real time application. Different test cases and there results by using Opal-RT are given below.

a. Case 1:

In this case, reference speed of the PMSM is kept constant and the torque value is increase by using step function at some instant. Reference speed is set constant at 1000rpm and Torque value of the PMSM is initially zero and it increased to 5 Nm at the instant of 0.2 sec. Results for this case are shown below: Fig.8 shows the applied torque to the motor. Initially the torque value is zero. Step is applied at the instant of 2 sec and is equal to 5 Nm. Variation of the torque value with respect to the average value can be seen in the graph.
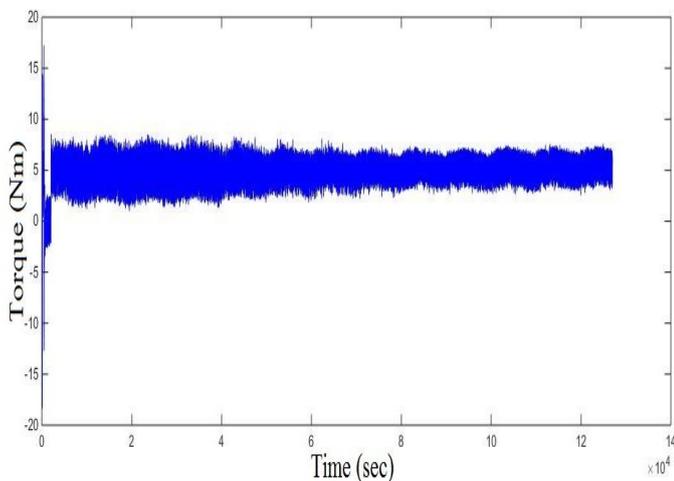

Figure.8. Electromagnetic torque (Nm)

Fig.9 shows the graph of actual speed of PMSM. From the graph it is seen that the approximate actual speed of the PMSM is equal to 1000 rpm which is nothing but the set reference speed of the motor. Minimum and maximum speed of PMSM from the graph is 988rpm and 1006 rpm. Therefore percentage variation of the actual speed of the motor is 1.8% with respect to reference speed.
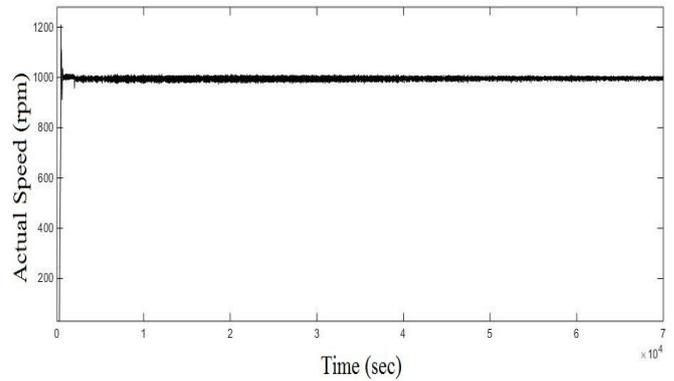

Figure.9. Actual Speed of PMSM (rpm)

Fig.10 shows the estimated speed of the PMSM using sensorless MRAS technique. From the graph it can be seen that the estimated speed of the PMSM by using motor parameters follows the reference speed of the motor. Minimum and maximum value of the estimated speed from the graph is equal to 995 rpm and 1005 rpm. Therefore percentage variation of the estimated speed with respect to reference speed is 1%.
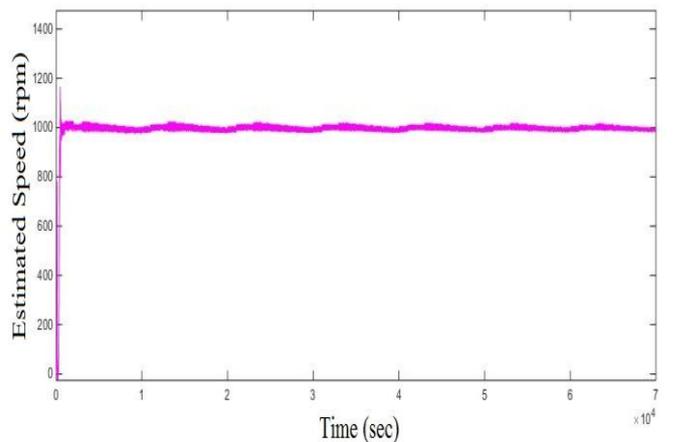

Figure.10. Estimated Speed of PMSM (rpm)

Fig.11 shows the error generated between the reference speed and estimated speed of PMSM which approximately zero. This error signal is used for the estimation of the speed of PMSM. Variation of the speed is about 20 rpm in the graph.
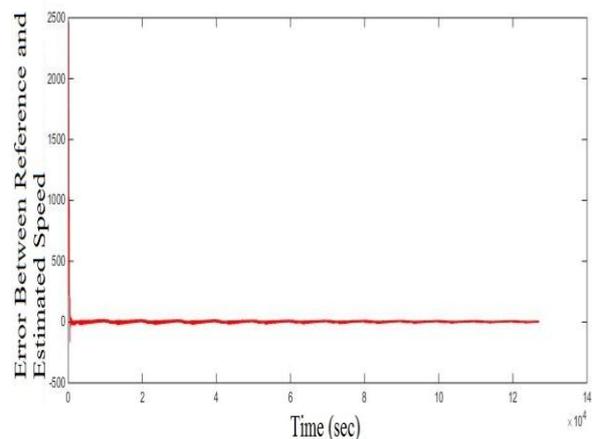

Figure.11. Error between Reference and Estimated speed of PMSM (rpm)

b. Case II

In 2nd case, reference speed of PMSM is kept constant equal to 1000 rpm while the torque value of PMSM is changed at

different instants. Torque value of PMSM is changed to 0-3-7-5 Nm at 0-2-4-7 sec. respectively. Behavior of the speed can be seen according to changes in the torque value.
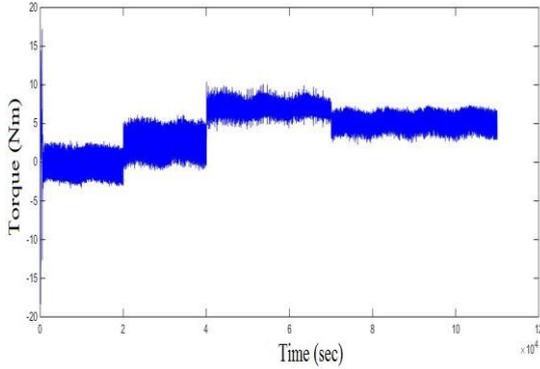

Figure. 12. Changes in Electromagnetic Torque (Nm)

Changes in the torque value can be seen in fig.12. From the graph it can be seen that torque value changes according to the changes in the applied torque value. Initially at time 0 sec it is zero and at instant 2 sec it changes to 3 Nm. Variation in the torque value reduces with increase in the torque value.
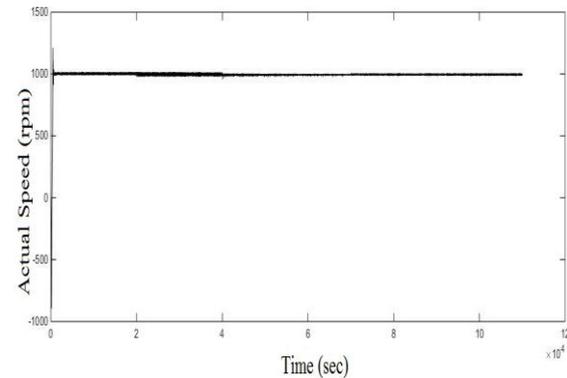

Figure.13. Actual Speed of PMSM with Change in Electromagnetic Torque

As the reference speed of PMSM is set to 1000 rpm, it can be seen from the fig.13 that actual speed follows reference speed when there is change in the electromagnetic torque value of PMSM. When the torque value is equal to 3 Nm minimum speed of motor is equal to 984 rpm and maximum speed is 1115 rpm. Therefore percentage variation is 3%. When torque value of motor is changed to 7 Nm minimum value of the actual speed of PMSM is 988 rpm while maximum value is 1002 rpm. Therefore percentage variation is 1.4%. As torque value increases variation in the torque and actual speed of motor reduces. Fig.14 shows the graph of estimated speed of PMSM by using speed estimation technique. Estimated speed of PMSM follows the set reference speed.
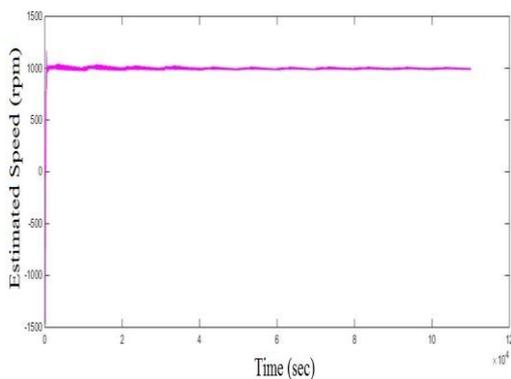

Figure.14. Estimated speed of PMSM with change in Torque

Fig.15 shows the error generated between reference speed which is nothing but the applied speed and estimated speed of PMSM. Maximum error generated is $\pm$ 16 rpm.
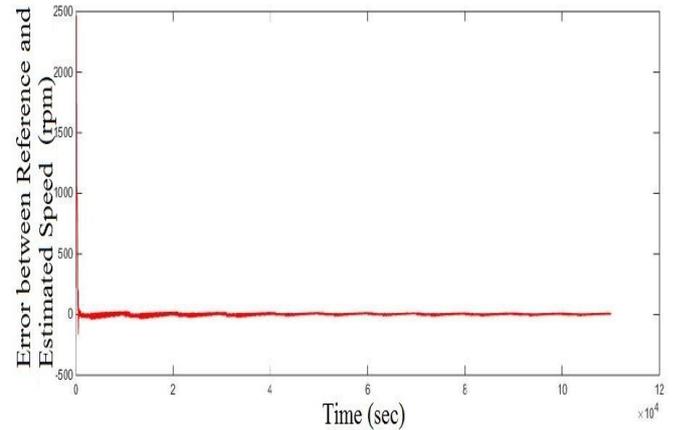

Figure.15. Error between Reference and Estimated Speed with Change in Electromagnetic Torque

c. Case III:

Electromagnetic torque of the PMSM is set equal to 5 Nm in this case while the reference speed of PMSM changed at different time instants. Initially value of the torque is equal to 0 Nm and after 0.2 sec it changed to 5 Nm. Reference speed of PMSM is equal to 1000-1200-1300-1000 rpm at 0-1-3-5 sec.
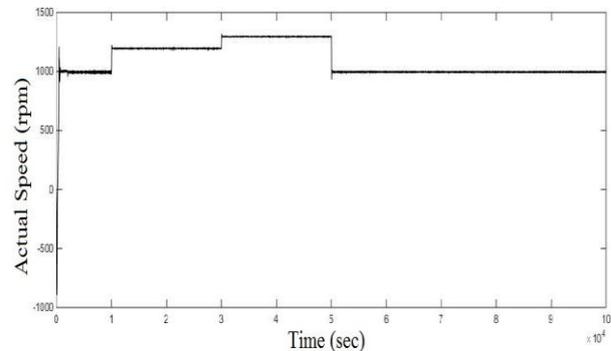

Figure.16. Actual Speed of PMSM with Change in Reference Speed

Reference speed of the PMSM is changed at different instant. Fig.16 shows the change in actual speed of PMSM. Minimum actual speed of PMSM is 1283 rpm and maximum speed is 1303 rpm. Percentage variation in actual speed is 1.5% when reference speed of the PMSM is 1300 rpm. Fig.17 shows the estimated speed of PMSM. Froom the graph it can be seen that the estimated speed of PMSM follows set reference speed. Variation in the speed is minimum when the speed is high.
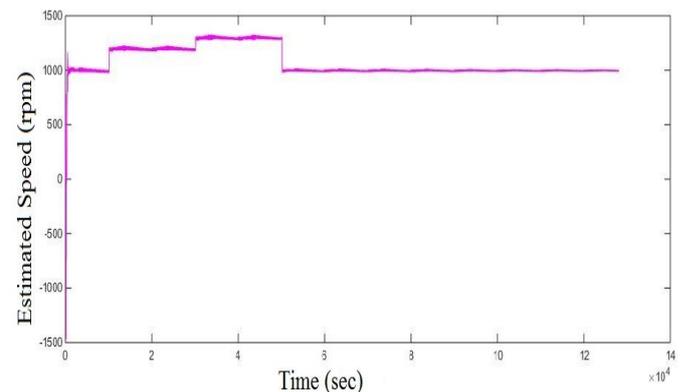

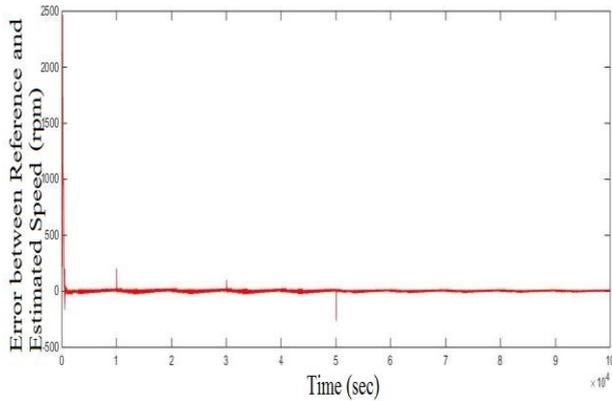**Figure.17. Estimated Speed of PMSM with Change in Reference Speed**

Figure.18. Error between Reference Speed and Estimated Speed of PMSM with Change in Reference Speed

Fig.18 shows the error generated between reference speed which is already set and the estimated speed of the PMSM with the help of estimation technique. Error signal generated is in the range of ± 9 rpm.
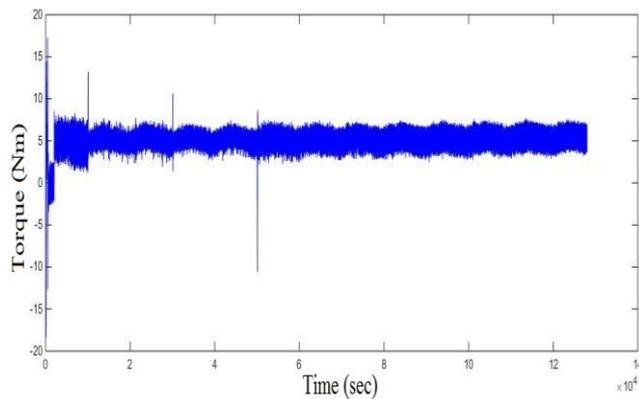

Figure.19. Electromagnetic Torque with Change in Reference Speed

Fig.19 shows the graph of the electromagnetic torque with the changes in reference speed of the PMSM. Variation in the value of electromagnetic torque is about ± 2 Nm. Variation in the torque value is less when the reference speed of the motor is set to 1300 rpm and variation is high when reference speed is set to 1000 rpm.

d. Case IV:

In case IV, reference speed and electromagnetic torque of the PMSM are changed. Values of the torque and reference speed of PMSM are changed at different time instants. Reference speed of PMSM is set to 1000-1200-1300-1000 rpm at 0-1-3-5 sec while in the same simulation electromagnetic torque of the PMSM is set to 0-3-7-5 Nm at 0-2-4-7 sec.
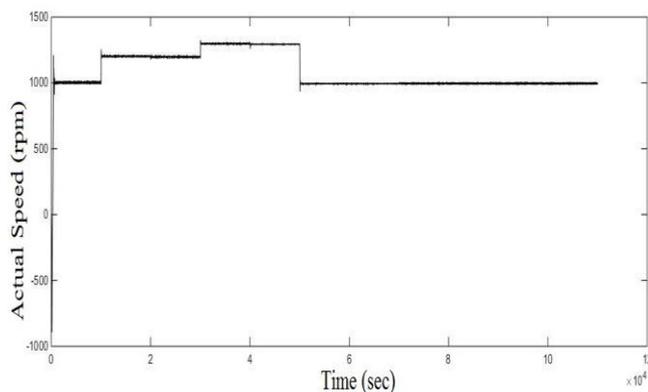

Figure.20. Actual Speed of PMSM with Change in Reference Speed and Electromagnetic Torque

Fig.20 shows the actual speed of the motor which is nearly equal to the reference speed of the motor. Change in the value of the electromagnetic torque is not going to affect the changes in the actual speed of PMSM.
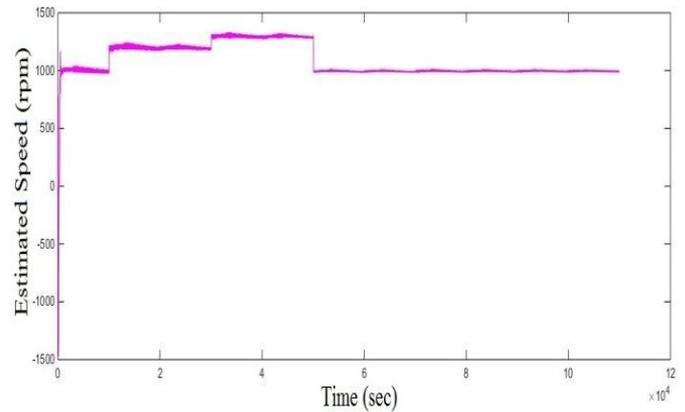

Figure.21. Estimated Speed of PMSM with Change in Reference Speed and Electromagnetic Torque

Fig.21 is the graph of estimated speed of the PMSM which is calculated with the help of speed estimation tecchnique. From the graph t can be seen that the estimated speed of the PMSM follows the set reference speed. Fig.22 shows the error signal generated between reference speed and estimated speed of the PMSM.
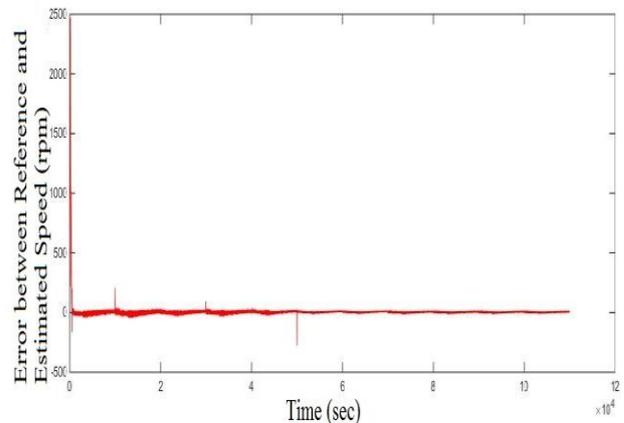

Figure.22. Error between Reference Speed and Estimated Speed with Change in Reference Speed and Electromagnetic Torque

Changes in the set value of electromagnetic torque can be seen in the fig.23. Electromagnetic torque of the motor changes according to the changes provided. Variation in the torque value is less when it is having higher value. Variation is about ± 2 Nm.
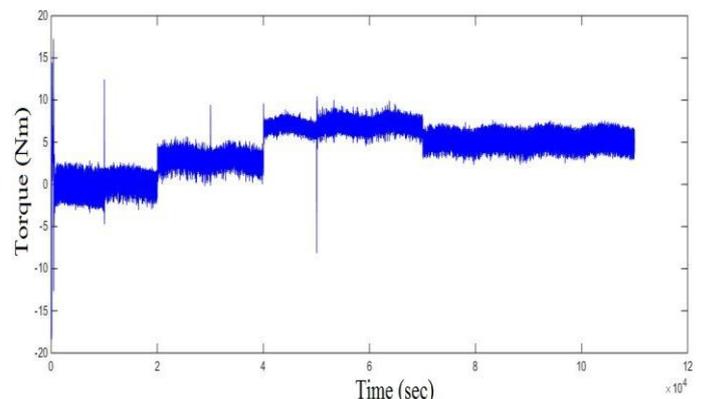

Figure.23. Electromagnetic Torque of PMSM with Change in Reference Speed and Electromagnetic Torque

VII. CONCLUSION

A detailed Simulink model for a PMSM drive system with SVPWM based on model reference adaptive system has being developed and is implemented on the Opal-RT for real time simulation. Mathematical model can be easily incorporated in the simulation and the presence of numerous toll boxes and support guides simplifies the simulation. Real time simulation of the sensorless PMSM drive using MRAS speed estimation technique is done with the help of OP-4510. In this real time simulation, PMSM model is directly use as the reference model while current equations of the PMSM are used as adjustable model. Adaption mechanism is use to get the rotor speed depending on the outputs of reference model and adjustable model. From the simulation results it observe that the transient performance of the drive is good. Estimated speed of the PMSM follows set reference speed. When there is change in the electromagnetic torque of PMSM, it will not affect the actual speed of the motor.

VIII. REFERENCES

[1].Enrique L. Carrillo Arroyo, "Modelling and Simulation of Permanent Magnet Synchronous Motor Drive ystem," University of Puerto Rico Mayaguez Campus, Puerto Rico, 2006.

[2].Pragasen Pillay and Krishnan.R, "Modeling, Simulation and Analysis of Permanent-Magnet Motor Drives, Part I: The Permanent-Magnet Synchronous Motor Drive," IEEE Trans. Ind. Appl., vol. 25, no. 2, pp. 265-273, Apr. 1989.

[3].Ambarisha Mishra, Vasundhara Mahajan, Pramod Agarwal and S.P.Srivastava, "MRAS Based Estimation of Speed in Sensorless PMSM Drive," In IEEE Conf. on Power India, pp. 1-5, 2012.

[4].P.Mahesh, Narri Yadaiah, "Real time implementation of state estimation technique for a sensorless PMSM drive," In 39th National System Conf. (NSC), pp. 1-6, 2015.

[5].Gomaa F. Abdelnaby, "Sensorless Field Oriented Control of Permanent Magnet Synchronous Motor," International Journal of Current Engineering and Technology, vol. 5, pp. 172-178, 2016.

[6].Christy Varghese, "Control of Permanent Magnet Synchronous Motor using MRAS," International Journal of Latest Trends in Engineering and Technology (IJLTET), vol. 3, pp. 71-77, 2014.

[7].P.Mahesh, Narri Yadaiah, "Real time implementation of state estimation technique for a sensorless PMSM drive," In 39th National System Conf. (NSC), pp. 1-6, 2015.

[8].Zheng-Guang Wang, Jian-Xun Jin, You-Guang Guo, and Jian-Guo Zhu, "SVPWM Techniques and Applications in HTS PMSM Machines Control," Journal of Electronic Science and Technology of China, vol. 6, pp. 191-197, 2008.

[9].J. Ting-ting Liu, TAN Yu, WU Gang, WANG Shu-mao, "Simulation of PMSM Vector Control System Based on Matlab/Simulink," International Conf. on Measuring Technology and Mechatronics Automation, vol. 2, pp. 343-346, 2009.