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Sensorless Speed Control of Permanent Magnet Synchronous Machine Using Model Reference Adaptive System

***Spurthi A S*[a], *Victor George*[b]**

[a]*Student,Dept of EEE, MSRIT, Bangalore 560054, India*
[b]*Assistant Professor, Dept of EEE, MSRIT, Bangalore 560054, India*

ABSTRACT

The paper presents a steady state Fictitious Quantity (Y) Model Reference Adaptive System (MRAS) to estimate the speed for a vector controlled Permanent Magnet Synchronous Motor (PMSM) drive. The affordability, consistency, compatibility, and environmental considerations are all advantages of the speed sensorless drive. In this paper the rotor reference frame, MRAS models are put up by using the voltages of reference and the currents that are actual. This method requires minimal computing time and uses simple equations that do not include integration or differentiation terms. As a result, any changes in machine parameters will have no effect on the drive's performance. In comparison with MRAS based speed estimation technique, the presented Y-MRAS based speed estimator performs satisfactorily for PMSM drive at varied speeds and load conditions. The proposed speed estimation technique is validated using MATLAB/SIMULINK computer simulation.

Keywords:MRAS, speed estimation vector control, PMSM, speed sensorless

Abbrevation

PMSM – Permanent Magnet Synchronous Machine
MRAS – Model Reference Adapyive System
Y-MRAS – Fictitious Quantity Model Reference Adaptive System

1. INTRODUCTION

The PMSM is more commonly used in applications like as electric vehicles and industrial automation. Because of its efficacy, light in weight, very apt in volume, and having a very high-power density, the PMSM is becoming more sought after. Because of its strong dynamic reaction, the vector-controlled drive is more prominent in industrial applications [2]. In order to have a speed-control in a loop and coordinate transformation, the drives need the rotor speed information. As a result, a speed sensor or speed estimator are necessary. Most often, the rotor shafts are mounted by the speed sensors, that increases inertia and diminishes the system's noise withstand ability. The system will be mechanically robust and inexpensive if the speed estimator is used in the drive. For a sensorless speed PMSM drive, numerous speed estimation algorithms are presented [3]-[4]. Few of those speed estimation techniques are Back-EMF based method [5]-[6], Observer-based method [10]-[11], Artificial intelligence-based methods [12]-[14], Signal Injection based approach [7]-[9] and Model-based approach [15]-[19].

Back EMF-based estimation techniques estimate rotor speed using back EMF (e); this technique works well at greater and average speeds. At lower or zero speed operation, however, becomes negligible and cannot be traced. When this technique is combined with SI technique sensitivity to machine parameters, makes estimating speed extremely difficult. The SI-based technique roughly calculates speed based on machine saliency and it is the one and only technique that executes well at zero speed. Nonetheless, an external hardware is needed for large frequency Signal injection and for drawing out the position. When both e- and SI-based methods are combined the combination exceeds all other techniques, with the benefits of higher and lower-speed operation, respectively; But this scheme is exorbitant.

The methods or the techniques based on Observers (like the Kalman filter, extended Luenburger observer, and sliding mode observer) are more susceptible to machine parameters and have a higher level of complexity. The main benefit of these observers' approach is that the parameters are treated as the state variables that can be estimated along with speed of the shaft. Although, the Kalman filter necessitates beginning conditions, whereas the e- and SI-based methods necessitate filters, reducing their benefits.

The MRAS calculates functional candidates in adjustable and reference models and these models have been expressed differently but, the quantities are equal. The reference model is unaffected by the unknown quantity (in this case, speed), whereas the adjustable model is affected. Errors are generated by the difference between these two variables, and this difference between these two models been sent to the adaption mechanism. Here adjustable model is tuned using the PI output (i.e., speed); this process is repeated until the error is zero. Stability, simplicity, and reduced computational complexity are all advantages of these MRAS-based approaches. They don't require any additional hardware, don't have integrator or differentiator terms, and are least reliant on motor settings. Alternative techniques, like artificial intelligence (fuzzy logic, ANN and other techniques), are newer methods. But they take a lot of memory for the system to be trained and it is complicated to construct.

The proposed technique overcomes the problems of the other speed estimation techniques like Q-MRAS in the situation of zero crossing. In this paper the Y-MRAS speed estimate technique is compared to MRAS speed estimation techniques under various speed and load scenarios. The speed estimation technique appears to function effectively under a variety of machine parameters, speeds, and loads.

The second portion discusses machine modelling. The MRAS speed estimation technique and a proposed speed estimation technique are discussed in Secession III. This approach is implemented by using MATLAB/SIMULINK, and simulation results are shown to demonstrate the performance of estimated algorithm in the fourth secession and conclusion in secession V.

2. MODELLING OF PMSM

The equation states the PMSM stator voltages that are allocated to the rotor reference frame on the d and q axis [3].

$$\begin{pmatrix} v_{\mathrm{ds}} \\ v_{\mathrm{qs}} \end{pmatrix} = \begin{bmatrix} \mathrm{R_s} + \beta \mathrm{L_d} & -\omega_{\mathrm{s}} \mathrm{L_q} \\ \omega_{\mathrm{s}} \mathrm{L_d} & \mathrm{R_s} + \beta \mathrm{L_q} \end{bmatrix} \begin{pmatrix} \mathrm{i_{ds}} \\ \mathrm{i_{qs}} \end{pmatrix} + \begin{pmatrix} 0 \\ \omega_{\mathrm{s}} \lambda_{\mathrm{af}} \end{pmatrix} (1)$$

Where 'λ_{af}' denotes the flux linkage between the stator and rotor mutually, which is caused by the permanent magnet (PM back EMF constant), and 'Lq' is 'q' axis stator inductance and 'Ld' is the 'd'-axis stator inductance,'β' denotes the term ('d/dt ') which is a derivative. 'Rs' is the resistance of the stator, and □$_s$=P□$_r$where these□$_s$and □$_r$ are the rotor speeds in mechanical speed and electrical speed that are in rad/sec, and the 'P' denotes the number of poles in pairs.
The equation (2) states the developedelectromagnetic torque:

$$\mathrm{T}_e = \left(\frac{3}{2}\right) P\left\{i_{qs}\lambda_{af} + \left(L_d - L_q\right) i_{ds} i_{qs}\right\} \qquad (2)$$

Equation (3) states the electromechanical ($\mathrm{T_L}$) governed by PMSM drive's:

$$\mathrm{T}_e - \mathrm{T}_L = J\frac{d\omega_r}{dt} + B\omega_r \qquad (3)$$

Here, PMSM is non-salienthaving back-EMF which is a sinusoidal waveform. Where 'B' is friction coefficient and 'J' is inertia of the motor, '$\mathrm{T_e}$' and '$\mathrm{T_L}$' denotes electric torque and load torque, respectively.

3. TECHNIQUES TO ESTIMATE SPEED

A. Speed Estimation Technique by MRAS

The main advantage of usingMRAS estimation technique is that it has an easy algorithm that is straightforward to build or construct in a digital control system, as well as a faster adaption speed. The PMSM sensorless control has been suggested and implemented using this method. Basically, MRAS has two modelsi.e, the reference model, and the other one is the adjustable model. The deviation signal from these two modelsoutput is sent to the adaptation mechanism here it is a PI controller, and the adaptation mechanism's output is the estimated speed. For PMSM speed estimation, a stator current based MRAS is used. Here the reference model is PMSM itself, while the stator current model's q-axis and d-axis equations are employed as the adjustable model shown in Fig.1.

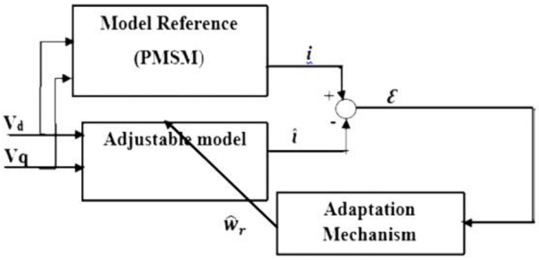

Fig.1: Basic block diagram ofMRAS speed estimation technique

B. The Y-MRAS-Based Speed-Estimation Technique

Y is expressed as the expressions for the reference and adjustable MRAS models[1].

$$Y_1 = v_{qs}^* i_{qs} - v_{ds}^* i_{ds} \quad (4)$$

Substituting (1) in (4):

$$Y_2 = \mathrm{R}_s\left(i_{qs}^2 - i_{ds}^2\right) + \left(L_q i_{qs}\frac{di_{qs}}{dt} - L_d i_{ds}\frac{di_{ds}}{dt}\right) + \omega_s i_{qs} i_{ds}\left(L_d + L_q\right)$$

$$+\omega_s i_{qs}\lambda_{af} \quad (5)$$

In a steady-state situation, Y1 and Y2 are:

$$Y_3 = \mathrm{R}_s\left(i_{qs}^2 - i_{ds}^2\right) + \omega_s i_{qs} i_{ds}\left(L_d + L_q\right) + \omega_s i_{qs}\lambda_{af} \quad (6)$$

The vector control condition ids=0, where Y3 becomes

$$Y_4 = \mathrm{R}_s i_{qs}^2 + \omega_s i_{qs}\lambda_{af} \quad (7)$$

Y2 and Y3 are dependent on all machine parameters in Equation. 4–7, and noise is enhanced due to the existence of these machine parameters. As a result, the adjustable and reference models are Y4 and Y1, respectively, as shown in Figure 2. Y1 is shaft-speed independent, whereas Y4 is shaft-speed dependent.

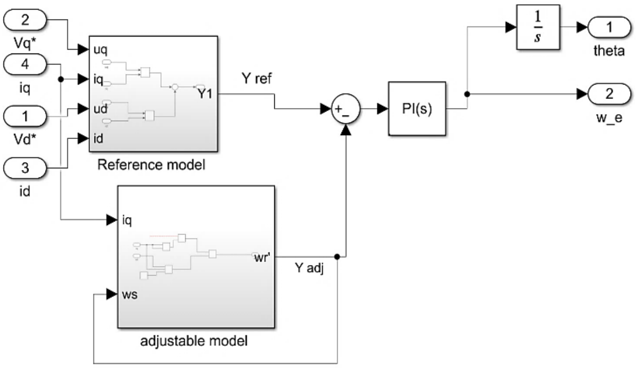

Fig.2: The Y-MRASbased speedestimation technique

The designed PI controller is used to pass the error developed in Eq. 9. The adjustable quantity is tuned using the output (i.e., the estimated rotor speed)from equation 8; this process repeatstill the inaccuracy is zero. The rotor position from the speed is given in equation 10. Figure 2. shows the speed estimation technique of Y-MRAS. Figure 3. shows the block diagram of PMSM with Y-MRAS speed estimation technique.

$$\omega_r^* = k_p * \varepsilon_y + k_i * \int_0^t \varepsilon_y dt + \omega_r^*(0) \quad (8)$$

$$\varepsilon_y = \left(v_{qs}^* i_{qs} - v_{ds}^* i_{ds}\right) - \left(\mathrm{R}_s i_{qs}^2 + \omega_r^* P i_{qs}\lambda_{af}\right) \quad (9)$$

$$\rho_{ms} = \int \omega_s dt = P\rho_{mr} = P\int \omega_r dt \quad (10)$$

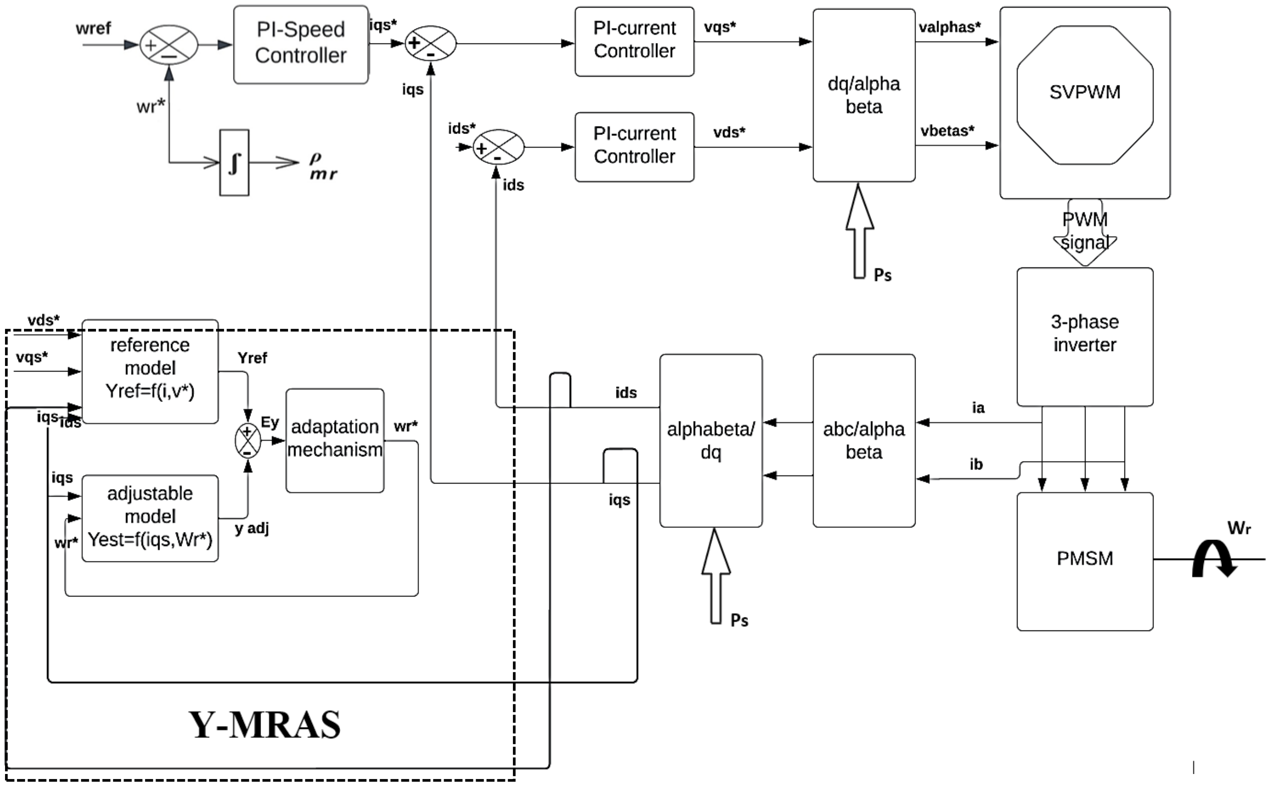

Fig.3 Block diagram of speed sensorless PMSM drive with modified Y-MRAS based speed estimation technique

4. SIMULATION RESULTS

In this section the simulation results of sensorlessspeed control of PMSM using Y-model reference adaptive system is shown and these results are compared with a model reference adaptive system using MATLAB/Simulink.

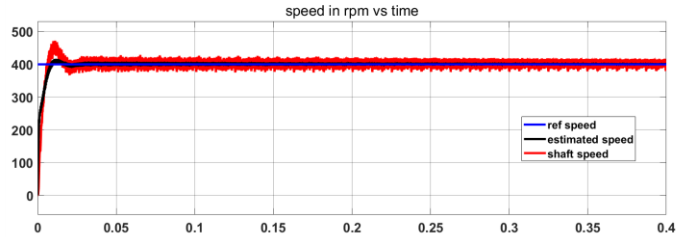

Fig. 4(a)

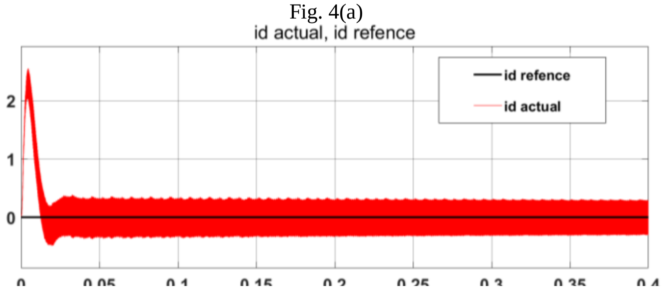

Fig.4(b) ids actual and reference currents.

Here the Y-MRASbased speedestimation technique for a sensorless speed control of PMSM drive shown in (Figure-3) was tested using MATLAB/SIMULINK software at different speed and load condition, and the results are presented accordingly.To, evaluate the balanced three-phase stator currents, the drive used two currents. With the estimated speed, the speed loop was closed, and the position was taken outfrom the speed in a closed loop and was used in the Clarke and Park frame transformation. Table.1 shows the parameters of the machine that were gathered. The recommended approach has a good track record. The currents of the machine are in the d- and q-axes rotor reference frames. Which indicates that the vector control is working properly and displays the torque component current.

The machine is started under no load with a reference speed of 400rpm is in Figure 4; The reference, shaft, and estimated speed are shown in 4(a). In the rotor reference frame, figure 4(b & c) displays the reference and real stator currents. The current ids=0 denotes the vector control drive, while iqs denotes the current of the torque component. Figure 4 (d) show the reference voltages, in d and q-axis and 4 (e) shows the position for PMSM using the MRAS speed estimate technique.

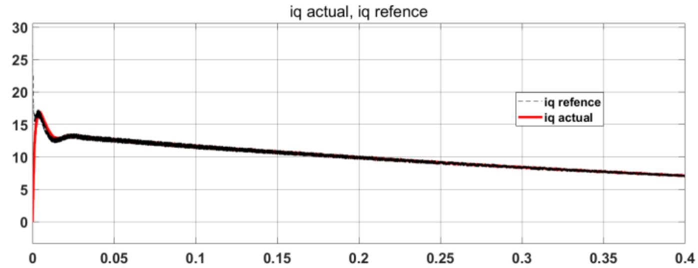

Fig. 4(c) iqs actual and reference currents.

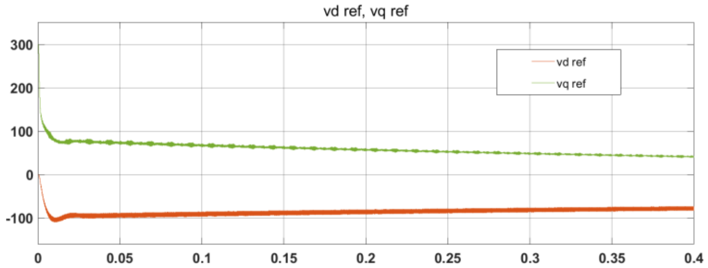

Fig. 4(d) d and q axis reference voltages.

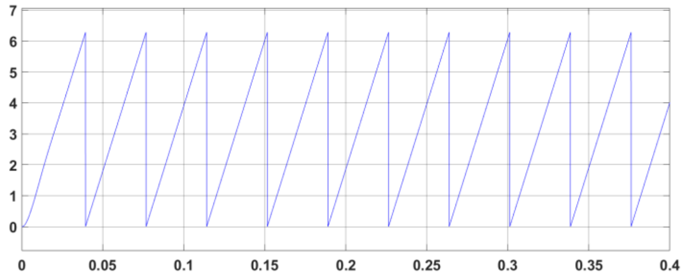

Fig. 4(e)

The machine is started under no load with a reference speed of 400rpm is in Figure 5; The reference, shaft, and estimated speed are shown in 5(a). In the rotor reference frame, figure 5(b & c) displays the reference and real stator currents. The current ids=0 denotes the vector control drive, while iqs denotes the current of the torque component. Figure 5(d) shows the reference voltages, in d and q-axis and 5(e) shows the position for PMSM using the Y-MRAS speed estimate technique.

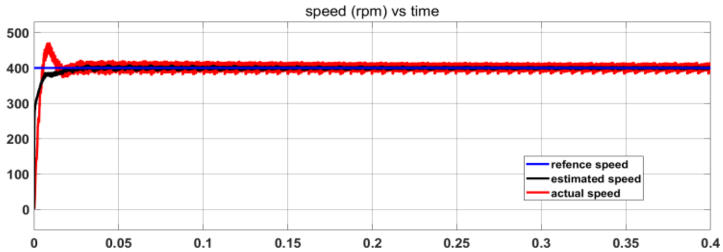

Fig.5(a)

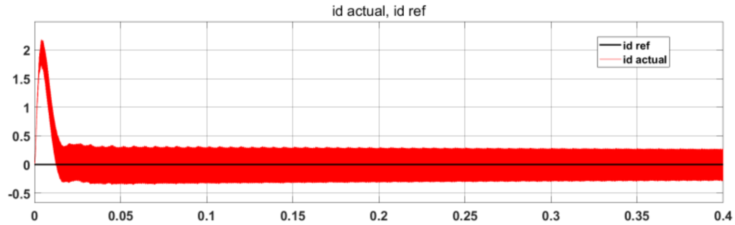

Fig.5(b) ids actual and reference currents

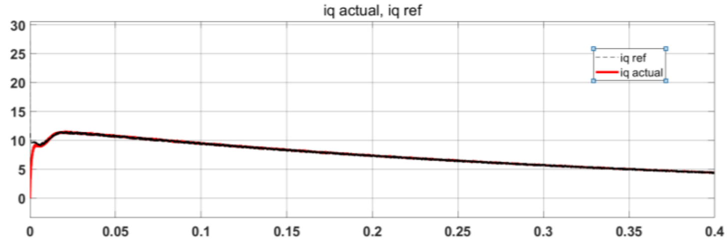

Fig. 5(c) iqs actual and reference currents

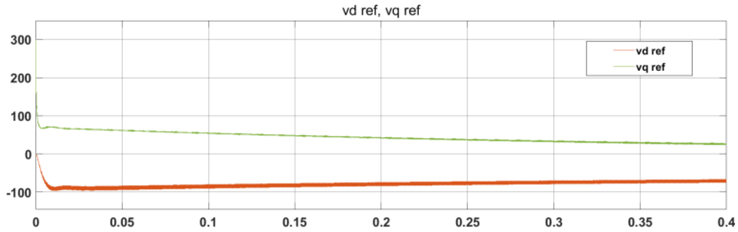

Fig. 5(d) d and q axis reference voltages

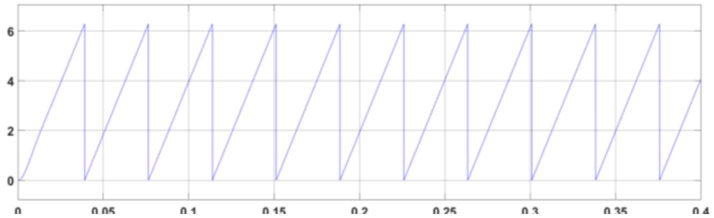

Fig. 5(e)

In Fig. 6, the machine is working at 1Nm load having the reference speed of 600rpm; speed characteristics are shown in Fig. 6(a) where the refence, shaft and estimated speed are shown using MRAS and Fig.6(b) shows the refence, shaft and estimated speed using Y-MRAS speed estimation technique.

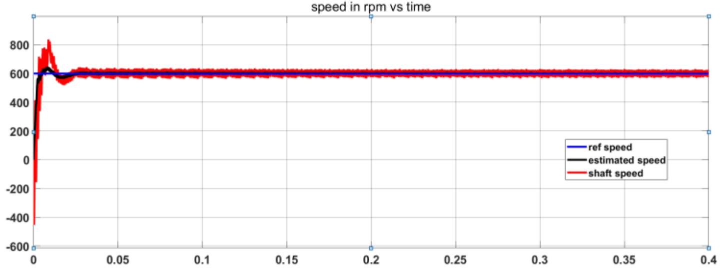

Fig. 6(a)

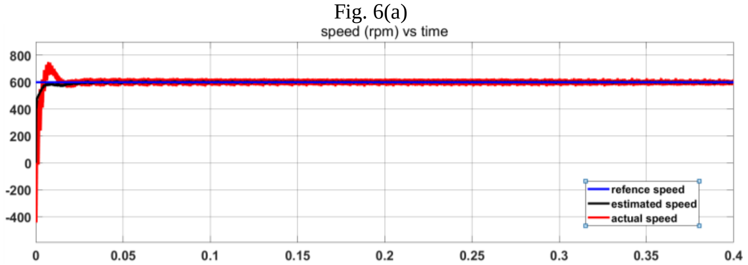

Fig. 6(b)

In Fig. 7, when the machine is working at 1Nm load having the reference speed of 600rpm; it is observed that the ripple content is more using MRAS speed estimation technique shown in Fig. 7(a) compared to Y-MRAS speed estimation technique shown in 7(b).

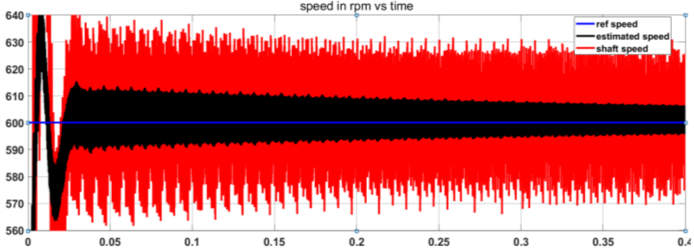

Fig. 7(a)

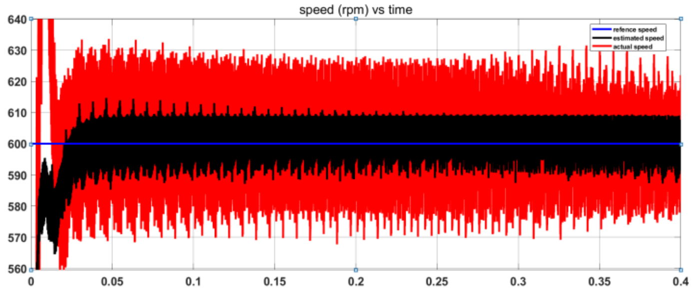

Fig. 7(b)

TABLE I. MACHINE PARAMETERS

Stator phase winding resistance (Rs)	2.875Ω
Pole pair (P)	4
$direct$-$axis$ inductance (Ld)	8.5mH
quadrature $-$ $axis$ inductance (Lq)”	8.5mH
Mutual flux linkage between rotor and stator due to permanent magnet (λaf)	0.175
Machine inertia (J)	4.8µKgm^2

5. CONCLUSION

The paper presented here is a sensorless speed vector control PMSM drive speed estimate technique that is independent of machine parameters. This technique does not require an integrator or a differentiator, which simplifies the system's complexity. The Y-MRAS speed estimation technique has less ripple during steady state than the MRAS speed estimation technique. The results reveal that the improved Y-MRAS speed estimator performs satisfactorily.

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REFERENCES

[1] Sai Shiva Badini, Vimlesh Verma, “MRAS-Based Speed and Parameter Estimation for a VectorControlled PMSM Drive”, RESEARCH ARTICLEElectrica, 2020; 20(1): 28-40

[2] B. K. Bose, "Modern Power Electronics and AC Drives", Prentice Hall PTR, pp. 711, 2002.

[3] R. (Ramu) Krishnan, Permanent magnet synchronous and brushless DC motor drives. CRC Press/Taylor & Francis, 2010.

[4] D. Xu, B. Wang, G. Zhang, G. Wang, and Y. Yu, “A review of sensorless control methods for AC motor drives,” CES Trans. Electr. Mach. Syst., vol. 2, no. 1, pp. 104–115, 2018.

[5] T.-U. Jung, J.-H. Jang, and C.-S. Park, “A Back-EMF Estimation Error Compensation Method for Accurate Rotor Position Estimation of Surface Mounted Permanent Magnet SynchronousMotors,” Energies, vol. 10, no. 8, p. 1160, Aug. 2017.

[6] O. Wallmark, S. Member, and L. Harnefors, “Sensorless Control of Salient PMSM Drives in the Transition Region,” vol. 53, no. 4, pp. 1179–1187, 2006.

[7] E. D. M. Fernandes, A. C. Oliveira, C. B. Jacobina, and A. M. N. Lima, “Comparison of HF signal injection methods for sensorless control of PM synchronous motors,” Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, pp. 1984–1989, 2010.

[8] D. Raca, P. García, D. D. Reigosa, F. Briz, and R. D. Lorenz, “Carrier-signal selection for sensorless control of PM synchronous machines at zero and very low speeds,” in IEEE Transactions on Industry Applications, 2010, vol. 46, no. 1, pp. 167–178.

[9] G. Zhang, G. Wang, and D. Xu, “Saliency-Based Position Sensorless Control Methods for PMSM Drives – a Review,” Chinese J. Electr. Eng., vol. 3, no. 2, 2017.

[10] O. M. Arafa, G. A. Abdel Aziz, M. I. Abu El-Sebah, and A. A. Mansour, “Observer-based sensorless speed control of PMSM: A focus on drive’s startup,” J. Electr. Syst. Inf. Technol., vol. 3, no. 2, pp. 181–209, 2016.

[11] A. Khlaief, O. Saadaoui, M. Boussak, and A. Chaari, “Implementation of stator resistanceadaptation for sensorless speed control of IPMSM drive based on nonlinear position observer,” Proc. - 2016 22nd Int. Conf. Electr. Mach. ICEM 2016, pp. 1071– 1077, 2016.

[12] S. Maiti, V. Verma, C. Chakraborty, and Y. Hori, “An Adaptive Speed Sensorless Induction Motor Drive With Artificial Neural Network for Stability Enhancement,” Ieee Trans. Ind. Informatics, vol. 8, no. 4, pp. 757–766, 2012.

[13] M. Zolfaghari, S. A. Taher, and D. V. Munuz, “Neural networkbasedsensorless direct power control of permanent magnet synchronous motor,” Ain Shams Eng. J., vol. 7, no. 2, pp. 729–740, Jun. 2016.

[14] O. Ouledali, A. Meroufel, P. Wira, and S. Bentouba, “Direct Torque Fuzzy Control of PMSM based on SVM,” Energy Procedia, vol. 74, pp. 1314–1322, 2015.

[15] V. Verma, C. Chakraborty, S. Maiti, and Y. Hori, “Speed sensorlessvector controlled induction motor drive using single current sensor,” IEEE Trans. Energy Convers., vol. 28, no. 4, pp. 938–950, 2013.

[16] A. V. R. Teja, V. Verma, and C. Chakraborty, “A new formulation of reactive-power-based model reference adaptive system for sensorless induction motor drive,” IEEE Trans. Ind. Electron., vol. 62, no. 11, pp. 6797–6808, 2015.

[17] V. Verma and C. Chakraborty, “New series of MRAS for speed estimation of vector controlled induction motor drive,” in IECON 2014 - 40th Annual Conference of the IEEE Industrial Electronics Society, Dallas, TX, 2014, pp. 755–761.

[18] S. Maiti and C. Chakraborty, “An adaptive stator resistance estimation technique for sensorless permanent magnet synchronous motor drive,” Int. J. Autom. Control, vol. 3, no. 2–3, pp. 189–201, 2009.

[19] S. Maiti, C. Chakraborty, and S. Sengupta, “Simulation studies on model reference adaptive controller based speed estimation technique for the vector controlled permanent magnet synchronous motor drive,” Simul. Model. Pract. Theory, vol. 17, no. 4, pp. 585– 596, Apr. 2009.