Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 4, Issue 4, April -2017

Speed estimation of Permanent Magnet Synchronous Motor

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Abstract- *This paper presents the speed estimation of permanent magnet synchronous motor (PMSM) without sensor. Efforts are kept to eliminate mechanical sensor for speed estimation. Use of speed sensor increases the cost and also the maintenance of PMSM. The technique used for estimation of speed is Model Reference Adaptive System (MRAS). The speed estimation is done for constant speed drive. The estimated speed is independent on stator resistance (R_s) and is only dependent on q-axis stator inductance (L_q) of motor. The reference and adjustable model equations used are simple and less computation is required. Vector control strategy is used for speed control of PMSM. Online estimation of rotor speed is possible by implementing the scheme presented in this paper.*

Keywords--*Model Reference Adaptive System, Permanent Magnet Synchronous Motor, Speed Estimation, Vector Control***,** *Field Oriented Control*.

I. INTRODUCTION

Permanent Magnet Synchronous Motor (PMSM) has wide applications. It is used in fibre spinning mills, Rolling mills, Cement mills; Ship propulsion, Electric vehicles, Servo and robotics drive [3]. It is also used in railways as a direct drive for traction motor, household applications such as refrigerators, washing machines etc.
PMSM offers advantages like high efficiency, high power density, fast dynamic response, high torque to inertia ratio [4], wide speed range, reliability &robustness and compactness [4].
Use of sensor decreases the robustness of drive and also its mounting is also a problem to some extent. A sensorless drive is presented which eliminates the use of sensor for sensing speed of PMSM and speed can be estimated from terminals voltages and currents of motor.
Many methods are available for parameter estimation in literature [2,4,8,10,11,12]. Some of the methods are Extended Kalman Filter (EKF), Least Square (LS), Luenberger Observer (LO), Artificial Intelligence (AI), Genetic Algorithm (GA), Partial Swarm Optimization (PSO), and Model Reference Adaptive System (MRAS).
This paper deals with speed estimation of PMSM by MRAS technique based on reactive power. Here instantaneous reactive power equation is used as reference model and steady state reactive power equation is used as an adjustable model. Paper also includes mathematical modelling equations of PMSM and from the estimated rotor position; vector control of drive is achieved. The simulation of presented scheme is done is MATLAB / SIMULINK for constant speed and satisfactory results are obtained.

II. PRESENTED SCHEME

2.1. Mathematical Modelling of PMSM

For mathematical modelling of PMSM assumptions made are: Back EMF is sinusoidal, Saturation of core is neglected and core losses are negligible.
The d-axis & q-axis stator voltages in rotor reference frame [8] are given as follows:

$$V_{ds} = R_s i_{ds} + L_d\,(di_{ds} / dt) - \omega_s L_q i_{qs} \quad \text{---------} \quad (1)$$

$$V_{qs} = R_s i_{qs} + L_q\,(di_{qs} / dt) + \omega_s L_d i_{ds} + \omega_s \lambda_{af} \quad \text{---------} \quad (2)$$

$$\omega_s = (P/2)\omega_r$$

Here R_s is the stator resistance, L_d& L_q are the d-axis and q-axis stator inductances, and λ_{af} is the mutual flux linkages between stator and rotor. P is the number of poles, ω_r is the mechnanical speed and ω_s is the electrical speed.
The equation for electromechanical torque [8] can be written as:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left[\lambda_{af} i_{qs} + (L_d - L_q) i_{ds} i_{qs}\right] \quad \text{---------} \quad (3)$$

$$T_e - T_l = J\left(\frac{d\omega_r}{dt}\right) + B\omega_r \quad \text{---------} \quad (4)$$

Where T_l is load torque, J is inertia of rotor and load connected in kg-m^2, B is damping coeffiecient in N-m-s /rad.

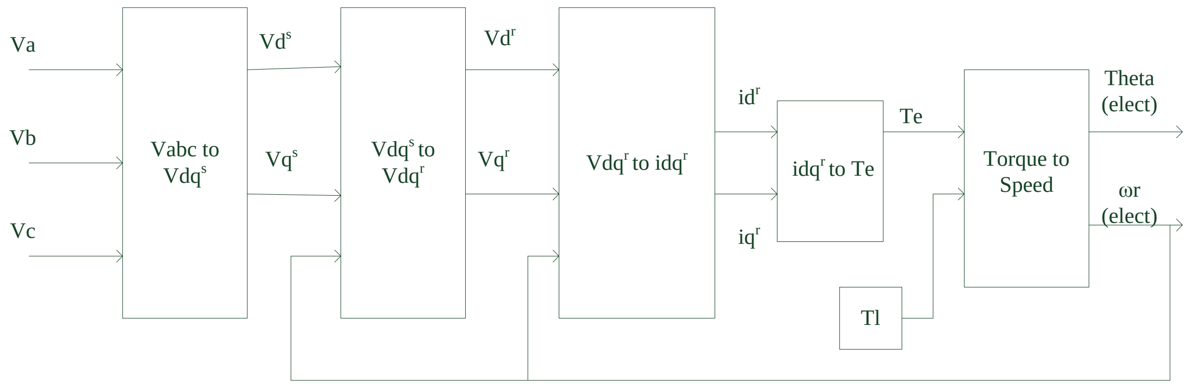

Figure 1.Block diagram for simulation of PMSM

2.2. Speed Estimation based on MRAS

2.2.1. Basic Structure of MRAC

The estimated quantity i.e. speed is derived by MRAS scheme. A block diagram showing basic structure of reactive power based MRAS for speed estimation of PMSM[12]is shown inFigure 2. The reference model will be independent of speed while the adjusable model will be speed dependent. The output calculated from reference model is instantaneous reactive power (Q_{ref}) and that calculated from adjustable model is steady state reactive power (Q_{est}).

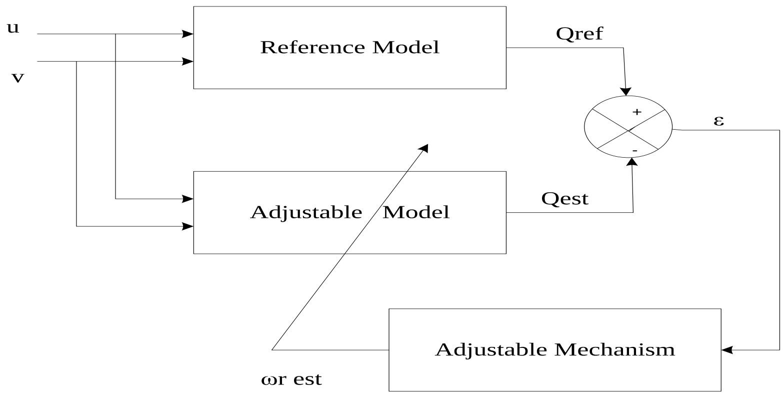

Figure 2. Basic Structure of MRAC [12]

These quantities are compared to generate an error signal and are given to adaptation mechanism which is generally a PI controller. The output of PI controller is the estimated quantity. The estimated speed (ω_r) is used to tune the adjustable model until both the reactive powers becomes equal.

2.2.2. Mathematical Equations of Reactive Power

Instantaneous reactive power (Q) [1, 5, 6, 8, 9, 12] can be expressed mathematically as under:

$Q_1 = V_{qs}i_{ds} - V_{ds}i_{qs}$ ------- (5)

Substituting equations 1 & 2 in equation 5 we get following equation for reactive power

$Q_2 = \omega_s (L_d i_{ds}^2 + L_q i_{qs}^2) + (L_q i_{ds} p i_{qs} - L_d i_{qs} p i_{ds}) + \omega_s i_{ds} \lambda_{af}$ ------ (6)

For steady state considering the derivative terms as zero we get

$Q_3 = \omega_s (L_d i_{ds}^2 + L_q i_{qs}^2) + \omega_s i_{ds} \lambda_{af}$ -------- (7)

For vector control of PMSM considering $i_{ds} = 0$ in above equation we get following equation for reactive power under steady state.

$Q_4 = \omega_s L_q i_{qs}^2$ -------- (8)

From above equations of reactive powers Q_1 is selected as reference model and Q_4 is considered as adjustable model. In equation 8, Q_4 is dependent on only one parameter i.e. L_q.

Advantages of selecting Q_1& Q_4 as reactive powers are that the reactive power is independent on stator resistance (R_s), reduced computational complexity and is free from integrator related problems, as estimation of back EMF is not required.

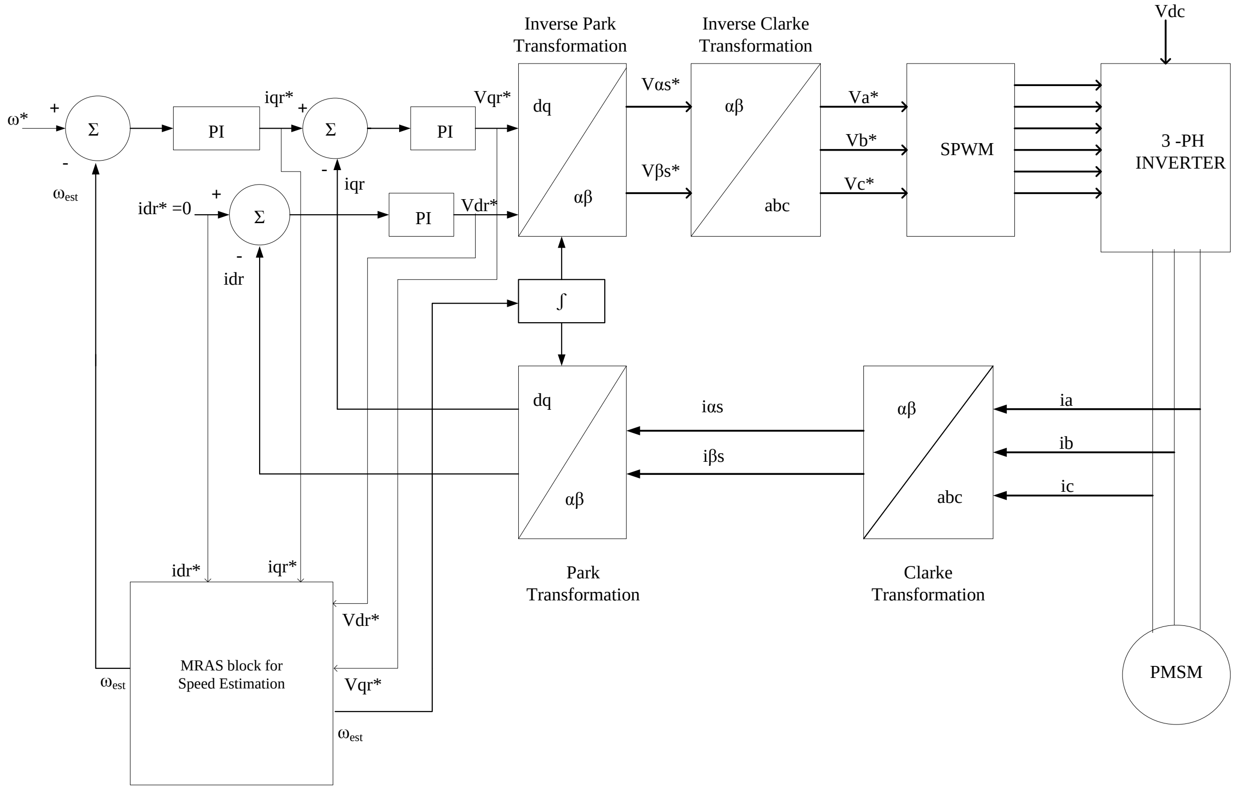

Figure 3. Block diagram of Vector control of PMSM drive with Speed Estimation

III. SIMULATION RESULTS

The presented speed estimation scheme is simulated in MATLAB / SIMULINK under constant speed operation. The simulation results of d-axis & q-axis currents and estimated rotor speed are shown here in the support of the work studied.
The d-axis & q-axis stator currents in rotor reference frame are shown below in Figure 4 & in Figure 5 respectively.
The reference speed is kept constant at 183 rad /sec and from Figure 6 it can be judged that the estimated speed is nearly same as the reference speed.

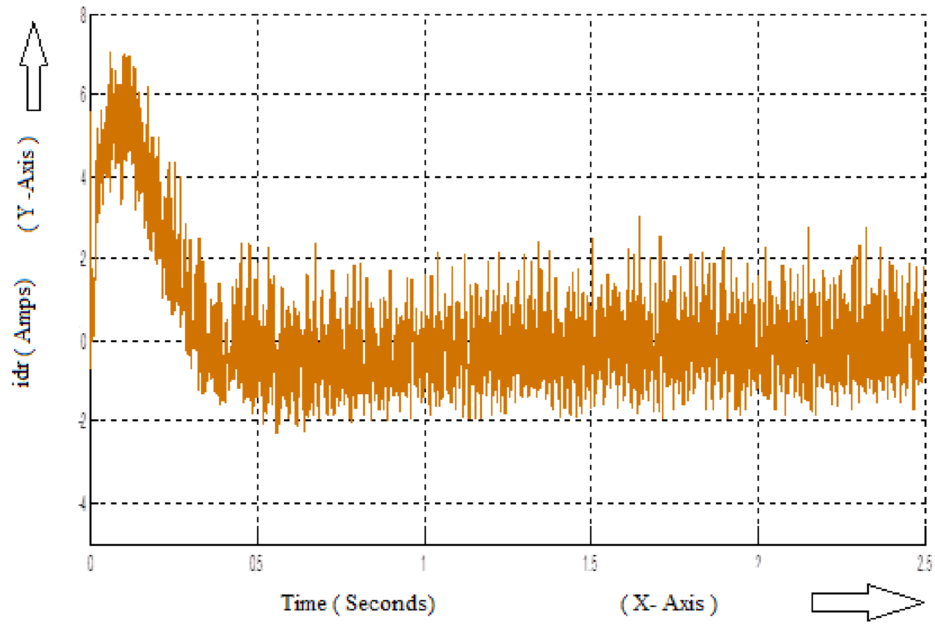

Figure 4. id^r vs Time

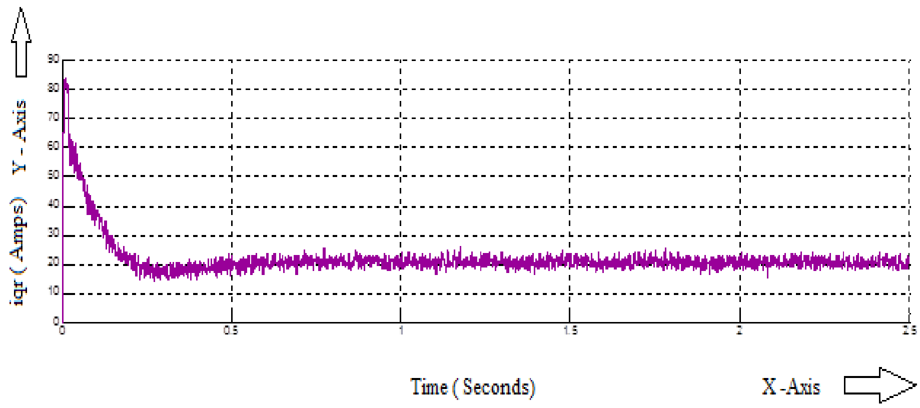

Figure 5. iq^r vs Time

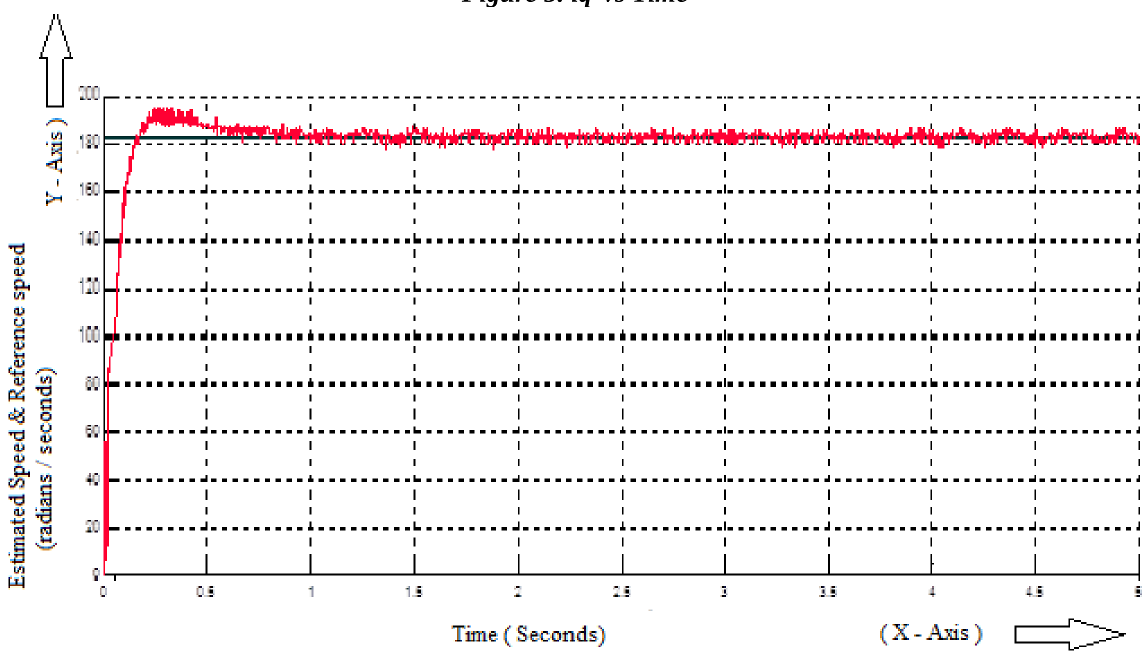

Figure 6. Reference Speed & Estimated rotor speed (ω_{est}) vs Time

Table 1 Motor Parameters used in simulation [7]

Rated Power	= 5 H.P.
No of Poles	= 6.
Rated Speed	= 183 rad/sec.
Stator Resistance	= 0.242Ω.
d-axis inductance	= 5.06 mH.
q-axis inductance	= 6.42 mH.
Rotor Flux Linkages	= 0.24 wb.

IV. CONCLUSION

The simulation results show that the presented scheme works well for speed estimation without using any speed sensor. The method is simple as it is having less computational complexity and also is less sensitive to noise.

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