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A Review of position and speed estimation techniques of MLI based PMSM

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Abstract - *This paper deals with the comparison of different position and speed estimation techniques which are used in multilevel inverter fed Permanent Magnet Synchronous Motor (PMSM). There are four techniques which are reviewed here that is Hall effect pulse based estimator, Reduced flux observer, Open loop flux estimator and Flux algebraic estimator. These methods are simulated for completion of this review analysis where the estimation of rotor position and speed, electrical measurement and Hall Effect pulses are used in sensorless vector control of PMSM to achieve the same performance as observed at sensor based control of PMSM. This review also describes various complexity and cost of the methods, estimation of performance, parameters uncertainty and measurement error.*

Key Words: Vector Control, flux estimation, sensorless, comparative analysis, PMSM, reduced observer, Multi-level Inverter (MLI).

1. INTRODUCTION

The sensor less speed control of PMSM is widely since last 20 year but the PMSM is fed with MLI which has dc voltage input. Cascaded H-bridge inverter is also a multi-level inverter usually defoliate the performance of PMSM due to unbalance voltage. This unbalance voltage is controlled by variable duty cycle based predictive control model. The duty cycle generated by this predictive model are revised according to the dc link voltage sensed across the cells [1].

The well-known method is sensing by the encoder or resolvers which are required always to align the stator current in permanent magnet synchronous motor as a part of vector control strategy. To avoid such electro-mechanical devices, sensor less approach is adopted which is achieved by measurement of stator voltage, current or hall effect pulses to expedite the sensor less strategy of mechanical parameters [2].

Bucciarelli et al. [3] has developed the efficient model of PMSM as state of art of efficiency mapping technique validating direct quadrature model. All the operating points have been covered within 2% of error difference only validating direct-quadrature model experimentally.

Yousfi et al. [4] mentioned the comparison of different technique for sensor less approach in MLI based PMSM where flux linkage technique with real time power processing devices used in open loop flux estimation is relatively compared with reduced flux observation.

The authors [5-7] have mentioned the concept of hysteresis for achieving the control switching which helps to obtain linear characteristic of dc motor in MLI based PMSM. The sensed current is compared with reference current under hysteresis band. For five level inverter, there are four no. of hysteresis band. The error is adjusted towards zero in this approach. The torque-ripple characteristic of PMSM also matters when used with 2- level, 3-level and 5-level inverter. For smooth conduction, model predictive control strategy is adopted which neither involve cascaded PI controller in the system nor any weighing factor.

Many other symmetrical and asymmetrical multi-level inverters to drive PMSM with reduced switch concept to generate 9, 13 and 17 level voltage output. The performance analysis is done with modulation technique with constant torque operation. The reduced switch model of MLI reduces the installation cost, area and size of the system. This also helps in low stress level at overall circuit reduces the heat dissipation in the system which in turn increases the reliability of the system.

The above discussion is about the control of MLI based PMSM in terms of sensing techniques, topologies and algorithm used in controllers. But in each MLI based PMSM, rotor position and speed sensing with sensorless approach must be incorporated to achieve the smooth performance of MLI based PMSM.

Therefore, in this article various position and speed estimation algorithms have been reviewed for

- Hall effect pulse based algorithm
- Reduced flux algorithm
- Open loop flux algorithm
- Algebraic estimation of flux

2. PMSM MODEL

This section is about the information related to PMSM model used in simulation because of the investigations of methods has to manipulate the basic equations of PMSM. The mathematical model of PMSM are in stationery frame i.e. (α, β) and rotating frame (d, q) which are given in equation forms as follows

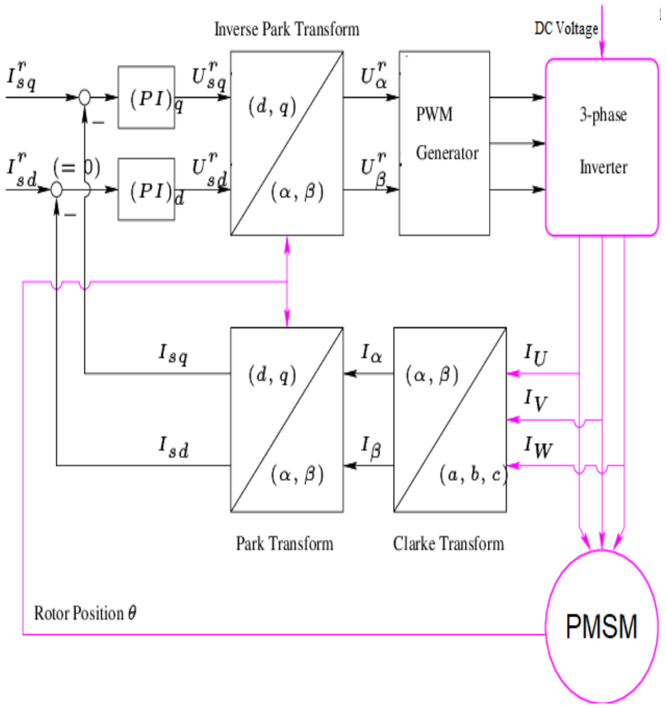
$$V_\alpha = Ri_\alpha + \frac{d\phi_\alpha}{dt} \qquad V_\beta = Ri_\beta + \frac{d\phi_\beta}{dt} \tag{1}$$

$$\phi_\alpha = L_\alpha i_\alpha + \phi_m \cos\theta \qquad \phi_\beta = L_\beta i_\beta + \phi_m \sin\theta \tag{2}$$

$$V_d = Ri_d + \frac{d\phi_d}{dt} - \omega\phi_q \qquad V_q = Ri_q + \frac{d\phi_q}{dt} + \omega\phi_d \tag{3}$$

$$\phi_d = L_d i_d + \phi_m \qquad \phi_q = L_q i_q \tag{4}$$

Φm is maximum flux linkage by permanent magnet of PMSM. Lα and Lβ are the inductance in α, β frame, Ld and Lq are the inductances in d, q frame. Since PMSM is a non-salient synchronous machine, therefore, these inductances are same in magnitude. R is the winding resistance and θ is the actual rotor angle



3. Discussion On Position and Speed Estimation Technique

The mechanical sensor works to provide the feedback to the system. The rotor angle is extracted from the sensed speed. Rotor angle plays an important role to control the synchronous motor. For this purpose, speed feedback is sensed accurately to track the velocity reference in speed control loop in the control strategy. Therefore, replacement of mechanical sensor for developing the sensorless approach which is also part of system algorithm, following methods are to be studied

3.1 Hall effect pulse based algorithm

Hall effect pulse based system works on the phenomena of hall effect. These sensor doesn't make any contact with rotor but provide the signal to the controller. Based on these signals, the rotor angle level is decided during implementation of algorithm. The sensed signal from hall effect sensor are digitally processed. These sensors detect when it enters in every new sector of 60 degree of rotor. The angular position is obtained by

$$\theta(t) = \int_{t1}^{t2} \omega(t)\,dt + \theta_k \tag{5}$$

ω(t) is the instantenous angular velocity t2 is the instant when magnetic axis enters sector k (k = 1, 2, 3, 4, 5, 6). θ_k is the initial angle of sector k.

The zero order position [9-10] are used by apply Taylor's series which ensures the speed inside each sector to be of constant value. The rotor speed with the help of zero order algorithm as

$$\omega(t) = \omega_{0k} = \frac{\pi/3}{\Delta t_{k-1}} \tag{6}$$

Δt_{k-1} is the time for rotor magnetic axis when it crosses the previous section k-1.

3.2 Reduced Flux Algorithm

In this algorithm, the difference of state variables and estimated variables are observed to find the required rotor position and speed. It expedites different peculiarities in algorithm complexity and sensitivity. It affects the flux linkage model of the PMSM in a two stationery frame as given below in the equation

$$\dot{x} = Ax + Bu \qquad y = Cx \tag{7}$$

Where

$$A = \begin{pmatrix} -\gamma & 0 & \gamma & 0 \\ 0 & -\gamma & 0 & \gamma \\ 0 & 0 & 0 & -w_e \\ 0 & 0 & w_e & 0 \end{pmatrix}$$

$$B = \begin{pmatrix} I & 0 \\ 0 & I \\ 0 & 0 \\ 0 & 0 \end{pmatrix} \tag{8}$$

$$C = \begin{pmatrix} 1/L & 0 & -1/L & 0 \\ 0 & 1/L & 0 & -1/L \end{pmatrix}$$

Where $\gamma = R/L$

The input vector is

$$u = \begin{pmatrix} V_\alpha \\ V_\beta \end{pmatrix} \tag{9}$$

The full state vectors are

$$u = \begin{pmatrix} \phi_\alpha \\ \phi_\beta \\ \phi_{m\alpha} \\ \phi_{m\beta} \end{pmatrix} \tag{10}$$

Where $\phi_{m\alpha} = \phi_m \cos\theta_e$ and $\phi_{m\beta} = \phi_m \sin\theta_e$

And the output vectors are measured current i.e.

$$y = \begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} \tag{11}$$

In this state space model we and θ_e is the electrical rotor speed and position of the rotor of PMSM respectively.

3.3 Open Loop Flux Algorithm

Position sensing of rotor via open loop flux linkage have been reported in many articles. But it became reality when digital computers come into the picture to apply algorithm for sensing rotor position based on flux linkage. PI controller is also incorporated with this algorithm to get accurate sensing position. The flux linkages is estimated in αβ- frame by measuring phase voltage and current

$$\phi_{\alpha\beta} = \int (V_{\alpha\beta} - Ri_{\alpha\beta})dt \tag{12}$$

The estimation of motor current $\hat{i}_{\alpha\beta}$ is obtained as

$$\begin{aligned} \hat{i}_\alpha &= \frac{1}{L}[\hat{\phi}_\alpha - \phi_m \cos\hat{\theta}] \\ \hat{i}_\beta &= \frac{1}{L}[\hat{\phi}_\beta - \phi_m \sin\hat{\theta}] \end{aligned} \tag{13}$$

The estimation of difference between actual current and estimated currents in αβ-frame and dq-frame are as follows

$$\begin{aligned} \Delta i_{\alpha\beta} &= i_{\alpha\beta} - \hat{i}_{\alpha\beta} \\ \Delta i_a &= -\Delta i_\alpha \sin\hat{\theta} + \Delta i_\beta \cos\hat{\theta} \end{aligned} \tag{14}$$

The PI controller is used for cancellation of error obtained by eq. 14 with the help of accelerating or decelerating the dq-frame. The output of this PI-controller is the estimated actual speed of the rotor.

3.4 Flux Algebric Estimation Algorithm

Fig. 2 shows the flux algebraic algorithm. In previous discussion, the flux linkage estimation is only to determine the actual rotor position which is also considered as true rotor position because this flux linkage is always synchronized with rotor position. The measurement imperfection in this process is corrected with the help of filters but the error observed in phase angle and magnitude of flux estimation.

This offset is generated due to motor operation in the frequency range below the cut off frequency of filter. The integration of eq. (12) by pure integrator provides the variables in drifts and saturations. In this integration process, there must be an initial condition due to which rotor has to put at know position which is not a feasible idea. The authors [8] has mentioned the methodology for avoiding such initial condition and requirement of pure integrator.

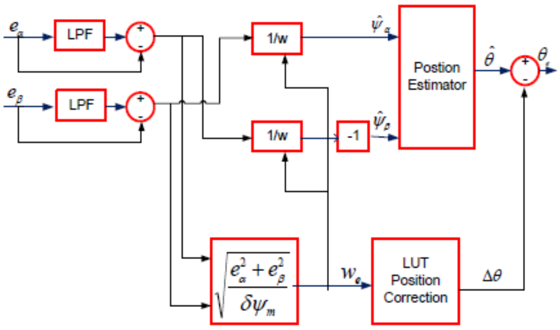


Fig. 2 Flux algebraic algorithm

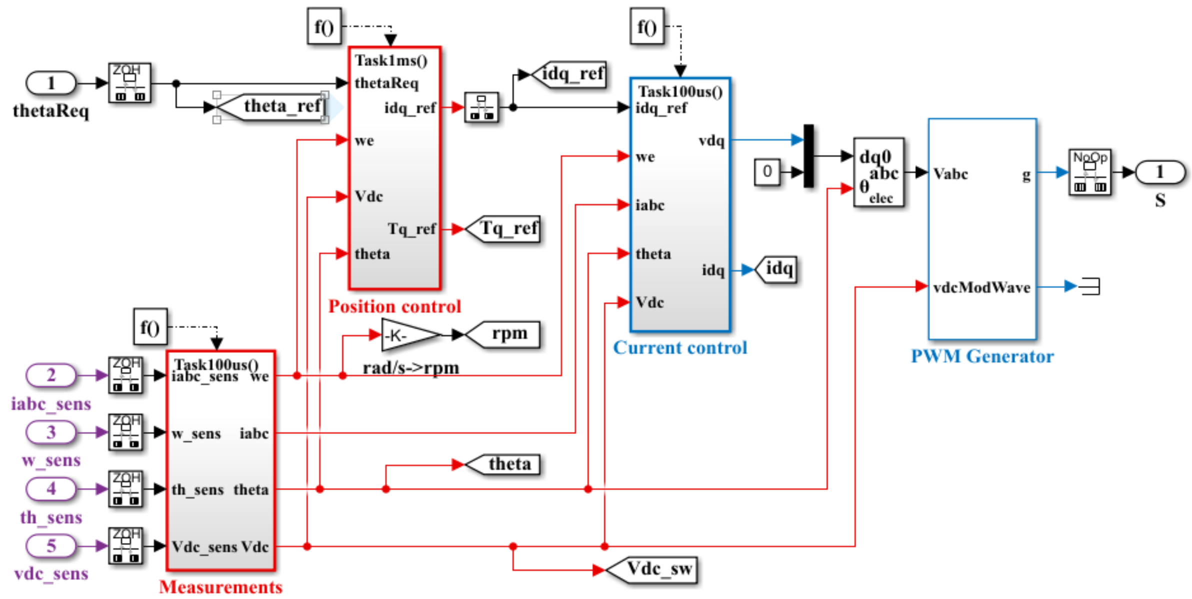


Fig.3 Simulation control strategy for Hall effect based sensor input to the position control algorithm

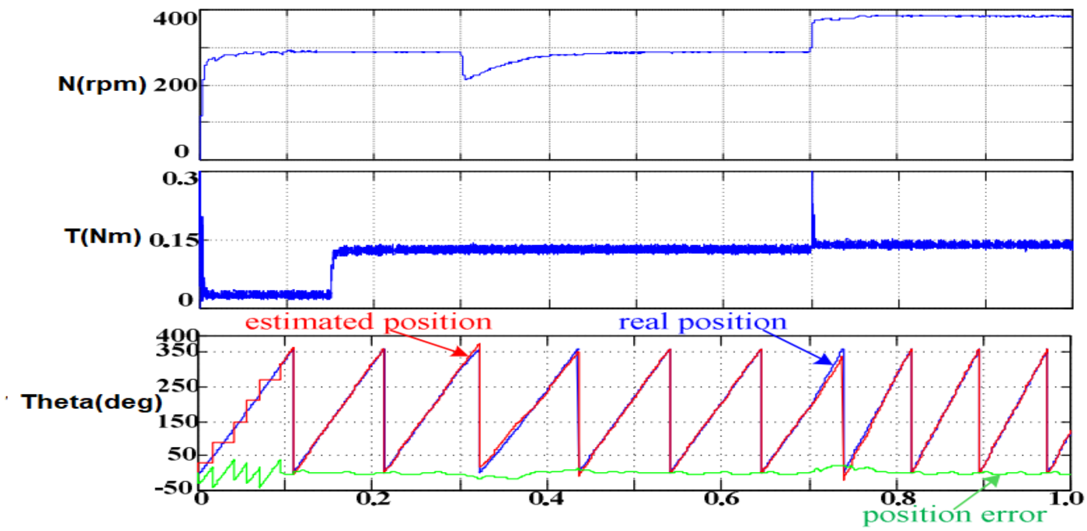


Fig. 4 Simulation Result Based on Hall effect Sensor Input To The Position Control

4. SIMULATION RESULT ANALYSIS

The simulation analysis has been performed for understanding the differences between actual speed and reference speed, actual position and reference position in the case of hall effect based rotor position sensing, the basic control block is mentioned in fig. 3. The transition from 200rpm to 400rpm of speed has been captured which shown in Fig. 4. This transition took place within 100μs between 0.7s to 0.8s.

The positional error in second figure of fig. 4 is found less than 20 always as indicated in figure. This error is traced with the help of real postion and estimated position. In the same way, the open loop flux estimator provides the margin of 7-degree and reduced flux observer method provides margin of 1-degree. The transition time of speed each cases are varying with respect to sensor-less flux estimation strategy adopted in each case.

5. CONCLUSION

The above article is related to comparative study of position and speed sensing of PMSM . These methods provide better speed regulation and proper position sensing. For this purpose, one method of hall sensing simulated to understand in better way. The system may be analyzed with other algorithm also. But these four methods provide better performance form implementation point of view. With each methods, the rotor position error is within 5 to 10% of error as discussed above. So from practical aspects, these methods can be tested with hardware set ups also.

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