Performance Enhancement of CSI Fed PMSM during Low Speed Operation with Stator Resistance Compensation

Jayanthi K[1] Panneer Selvam N[2]
[1]P.G. Scholar [2]Associate Professor
[1,2]V.S.B Engineering College, Karur

Abstract— This paper proposed the direct torque control method for current source inverter fed PMSM to achieve high performance at low speed operation. During low speed operation estimation of stator flux and torque for direct torque control is very difficult due to the variation in stator resistance. This parameter variation from the set value affects the system at low speed of the PMSM. Many controlling techniques were introduced to compensate the stator resistance variation. A novel Fuzzy Logic Control method is used to compensate the stator resistance variation and the simulation results and hardware results are prove that the performance of the CSI fed PMSM has been improved.

Key words: CSI, PMSM, DTC, Stator resistance

I. Introduction

High-power medium-voltage drives are widely implemented in industry to control the speed and torque of high-power synchronous motors for quality improvement and reduction of system energy loss[1]. The VSI fed drives are mostly used in low and medium power applications. In medium-voltage high-power electric drive applications, the current-source inverter (CSI) fed drives are used increasingly due to following advantages:[2-4]

- Inherent four quadrant operation
- Motor friendly waveforms
- Reduced harmonics
- Reliable short circuit protection

In many applications of today's automatically machines high performance drive is essential. The field of power electronics has attached more attention on ac motor control. Due to the developments in power electronics and microelectronics enables the PMSM to be a competitor to Induction motors[5].

The advantages of PMSM are as:

- More simplicity
- Low maintenance
- Low dependency on motor parameter
- Good dynamic torque response
- Simple design
- High rate torque/inertia

The direct torque control offers more advantages in terms of simple control scheme, good dynamic response of torque and this scheme does not need the rotor parameters to realize the torque as well as flux control compared to other schemes[6-9].

DTC is not sensitive to parameter variation. Through a look up table, the space vector of the inverter is chosen .Thus the torque and stator flux of the PMSM is directly controlled [10].

During low speed operation of PMSM, changes in temperature or frequency reduces the performance of DTC due to stator resistance variation [11]. This in turn produces an error in the calculated stator flux magnitude and torque. So it is necessary to compensate the stator resistance variation.

In this paper proposed to overcome the problem of flux and the torque estimation at low speed, by a novel method of fuzzy logic topology. In this method the difference between the reference and actual stator resistance is estimated and it is fed to the fuzzy logic control system. By the simulation studies the performance of the CSI fed PMSM at low speed operation is examined.

II. PMSM Modelling

The PMSM stator is similar to that of wound rotor synchronous motor. The back emf produced by the permanent magnet and by an excited coils are same. So the mathematical model is similar for both PMSM and wound rotor synchronous motor. The assumptions made for modeling the PMSM are as:

1) The magnetic saturation effects are negligible.
2) Magnetic hysteresis is negligible.
3) Sinusoidal back emf.

The rotor reference frame, stator dq equations of PMSM are as:

$$e_{ds}=R_s i_{ds}+p\psi_{ds}-\omega_r\psi_{qs}$$
$$e_{qs}= R_s i_{qs}+p\psi_{qs}-\omega_r\psi_{ds} \qquad (1)$$

where $\psi_{qs}= L_{qs}i_{qs}$ and $\psi_{ds}= L_{ds}i_{ds}+\psi_{af}$

ψ_{af} is the magnet mutual flux linkage.

The electromagnetic torque can be given as:

$$T= 3p[\psi_{af}i_{qs}+(L_{ds}-L_{qs})i_{ds}i_{qs}]/2 \qquad (2)$$

When the flux is constant ids=0, then

$$T=3\ \psi_{af}i_{qs}/2 = Ki_{qs} \qquad (3)$$

K is the motor constant of torque. In the state space form,

$$Pi_{ds}=(e_{ds}-R_s i_{ds}+\omega_r L_{qs}i_{qs})/L_{ds}$$
$$Pi_{qs}=(e_{qs}-R_s i_{qs}+\omega_r L_{ds}i_{ds}-\omega_r\psi_{af})/L_{qs}$$
$$P\omega_r=(T-B\omega_r-T_l)/J$$
$$p\theta_r=\omega_r \qquad (4)$$

e_{ds} and e_{qs} are obtained by e_a,e_b,e_c as defined below through the parks transformation,

$$\begin{bmatrix} e_{qs} \\ e_{ds} \\ e_{os} \end{bmatrix} = 2/3 \begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \qquad (5)$$

ΔT_e	*S_1*	*S_2*	*S_3*	*S_4*	*S_5*	*S_6*
1	*I_3*	*I_4*	*I_5*	*I_6*	*I_1*	*I_2*
0	*0*	*0*	*0*	*0*	*0*	*0*
-1	*I_6*	*I_1*	*I_2*	*I_3*	*I_4*	*I_4*

Table 1: Direct Torque Control-Switching table

The input power to the PMSM is,

$$P=e_a i_a+e_b i_b+e_c i_c \text{(interms of abc variables)}$$
$$P=3/2(e_{ds}i_{ds}+ e_{qs}i_{qs}) \text{(interms of dq variables)} \qquad (6)$$

The park transformation defined above is not power invariant, so the factor 3/2 exists.

III. ASSESSMENT OF FLUX AND TORQUE IN DTC

The stator flux is derived using the stator voltage and current equations. The flux equation is as follows:

$$\psi_s = \int (e_{ds} - R_s i_{ds})dt \qquad (7)$$

The voltage term can be neglected during very high speed and average speed conditions. At this condition the stator flux expression can be written as:

$$\frac{d\psi s}{dt} = e_{ds} \qquad (8)$$

When the stator voltage vector is zero, the stator flux is also zero.It can be given as:

$$\frac{d\psi s}{dt} = 0 \qquad (9)$$

The knowledge of amplitude and angular position of flux controller is important for DTC. Depending on the flux position, DTC is chosen between appropriate set of vectors corresponding to amplitude of the stator flux amplitude.

The hysterisis control of stator flux and torque plays an major role in direct torque control of PMSM. This directly selects the one of the six non zero voltage vector and two zero voltage vectors of the inverter. This is shown in the fig.

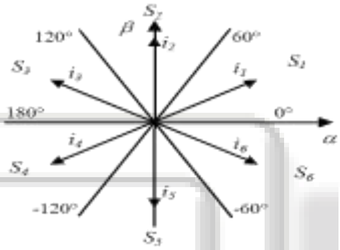


Fig. 1: DTC and six sectors

The switching table of the direct torque control scheme is as shown in the table:

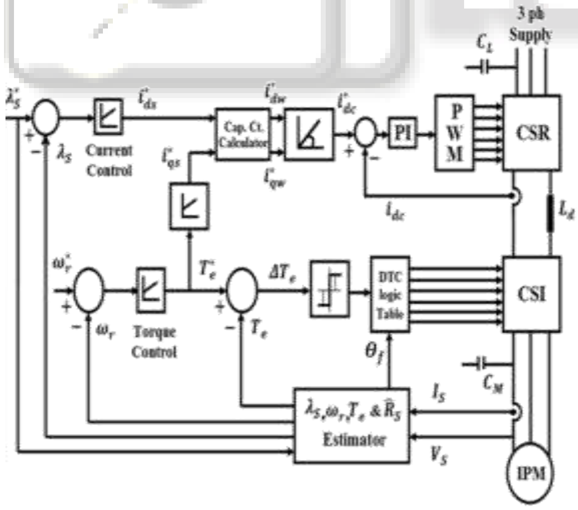


Fig. 2: Control strategyof CSI fed PMSM with DTC

IV. STATOR RESISTANCE ESTIMATION AND COMPENSATION

The ac and dc motors are designed to run at different speeds.Some of them will run as a variable speed motors and others will be as a constant speed motor.In this Permanent Magnet Synchronous motor is a constant speed motor.It will always run at its synchronous speed.Nowadays in major applications, PMSMs replacing the Induction motors due to its advantages.

In this paper the performance of the PMSM is improved by maintaining the constant torque for various speed condition.Especially at low speed the torque is maintained as constant.The speed and torque equations can be expressed as:

$$N_s = 120f/P \qquad (10)$$

where Ns is the synchronous speed of the PMSM, f is the frequency and P is the number of stator poles.

The torque can be expressed as follows:

$$T = 3p[\psi_{af} i_{qs} + (L_{ds} - L_{qs}) i_{ds} i_{qs}]/2 \qquad (11)$$

For changing load condition also the speed of the PMSM is maintained as constant but the torque of the PMSM will not be in stable condition.It gets oscillate.By compensating the stator resistance the torque also maintained as constant irrespective of its speed.Actually this stator resistance variation is due to the temperature variation.Because when the torque gets changes i.e.load changes the temperature gets changes due to the stator voltage variation.At the changing temperature condition if the stator resistance value is measured means it will deviate from its actual value.At this condition the ohms law gets violated.Ohms law will be expressed as:

$$V = IR \qquad (12)$$

Because of the changing stator resistance the estiamtion of flux is complex, which leads to motor to run in the unstable region.To make the motor to run at stable condition, compensation of flux is essential.Here by compensating the stator resistance, the flux compensation is achieved.The flux equations can expressed as:

$$\psi_s = \int (e_{ds} - R_s i_{ds})dt \qquad (13)$$

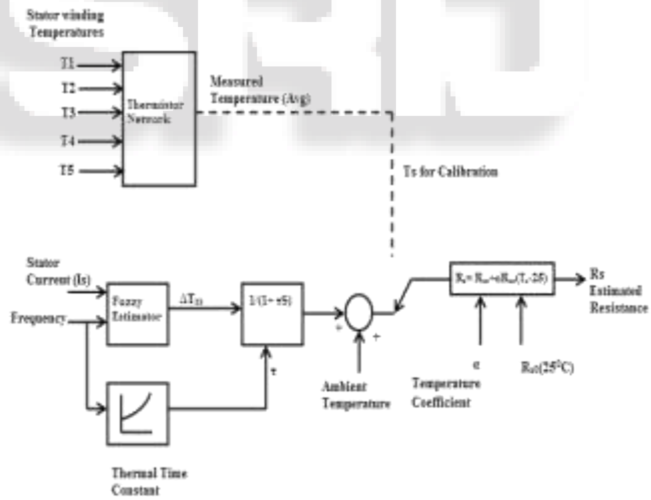


Fig. 3: Stator resistance estimator

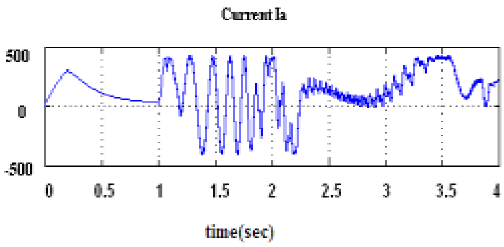
The above figure describes the PI stator resistance estimator.The principle is when the stator resistance gets changes, the stator current and stator flux also gets changes.The change in stator resistance will directly relates the error between the refernce and measured value of stator flux.The change in stator resistance can be expressed as:

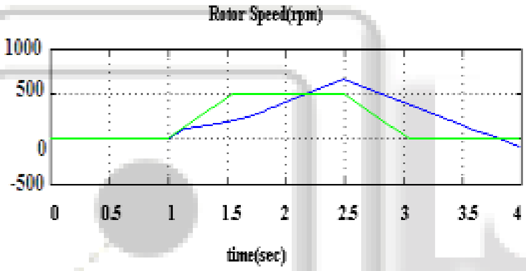
$$\Delta R_s = (K_p + K_I/s)\, \Delta\psi_s \qquad (14)$$

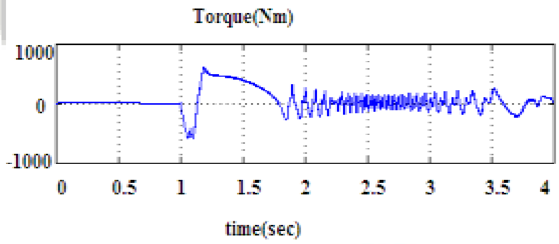
The proportional and integral gains of thePI estimator is denoted as K_p and K_i.In order to attenuate the high frequency components in the estiamted flux, the flux error is passed through a low pass filter.The time constant of this filter should be as low as possible.The output is now given to the PI estimator which gives the change in resistance value due to change in temperature.This process will continued untill there will be a smooth variation in the stator resistance value.The controller directly uses this updated Rs value.

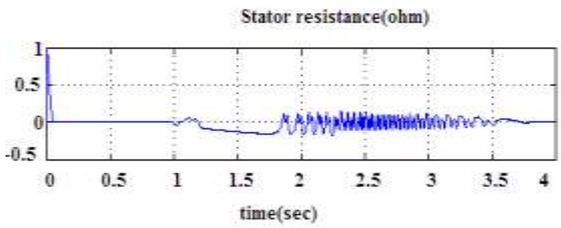
V. RESULTS AND DISCUSSION

The performance of the CSI fed PMSM drive is analysed using MATLAB/SIMULINK model.When the torque suddenly gets change, the speed of the PMSM also gets changes.However the speed has to be maintained as constant in PMSM.The simulation results shows that without compensating the Rs the speed gets changes when torque changes.This is overcomed by compensating the Rs.In our proposed method the speed is maintained as constant for changing torque even at low speed operation also.This can be achieved by compensating the stator resistance.The uncompensated and compensated results are shown below for analysis poin of view:

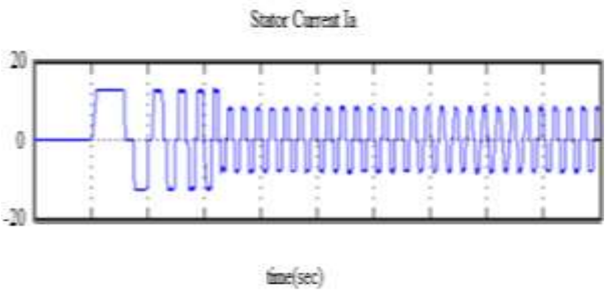


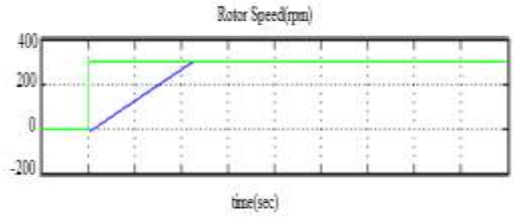


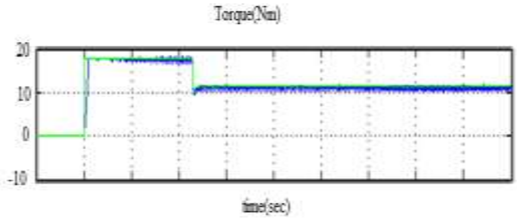


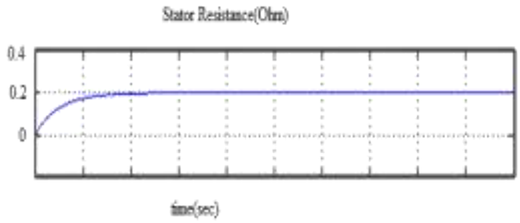


The results after compensation are as shown below:









VI. HARDWARE DIAGRAM AND RESULTS

The hardware set up of CSI fed PMSM is as follows:

Fig. 4: hardware set up of CSI fed PMSM

The results obtained from the hardware setup is as follows:

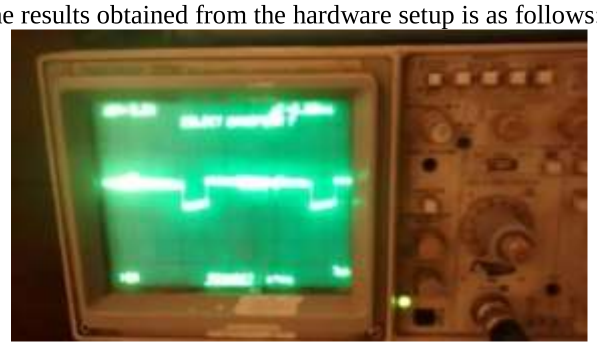


Fig. 5: Pulse Waveform

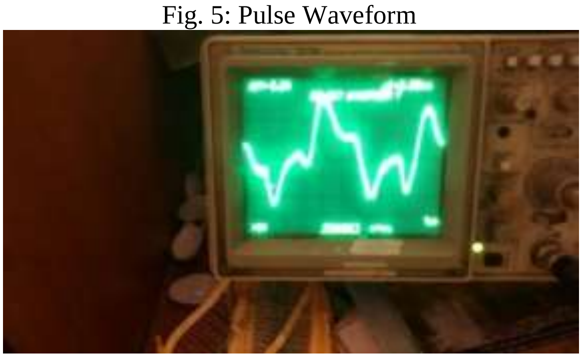


Fig. 6: StatorVoltage Waveform

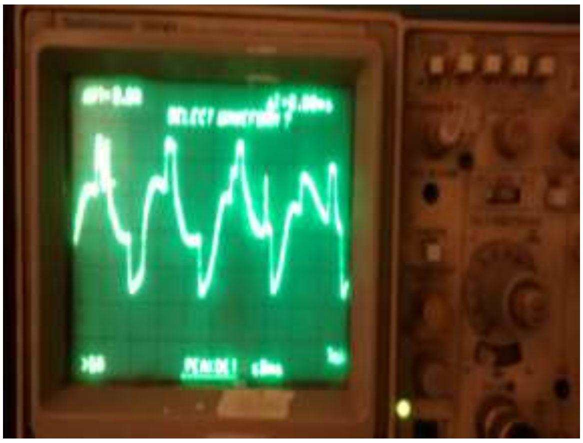


Fig. 7: Stator Current Waveform

VII. Conclusion

The low speed operation os CSI fed PMSM with stator resistance compensation has been proposed in this paper.The stator resistance is estiamted using the flux which is calculated by using the d and q axis currents.The estimated Rs is then compared with refernce value and error is calculated.Based on the error, the corrosponding signal is used as gating signals for both rectifier and inverter circuits which in turn directly controls the current.It will reduces the error between the measured Rs and reference Rs values under low speed operation.The estimation of stator resistance is more accurate by the resistance estimator present in the DTC.So such a drive is well suited for low speed applications.It is demonstrated using the simulink results and it was implemented.

A. *Hardware Specifications*

Number of pole pairs	4
Base Speed	300rpm
Stator Resistance	0.2 Ω
Torque	18Nm
Magnetic Flux	0.4Wb

Table 2: Hardware Specifications

References

[1] Marcin morawiec, “The adaptive backstepping control of permanent magnet synchronous motor supplied by current source inverter”,IEEE transactions on industrial informatics vol. 9, no. 2, May 2013.

[2] N.PanneerSelvam, V.Rajasekaran, “High performance sensorless DTC-CSI fed IM drives for low speed operation with minimum ripple torque”.

[3] H.-J. Lee, S. Jung, and S.-K. Sul, “A current controller design for current source inverter-fed PMSM drive system,” in Proc. 8th Int. Conf. Power Electron., 2011, pp. 1364–1370.

[4] M. J. Melfi, S. D. Rogers, S. Evon, and B. Martin, “Permanent-magnet motor f or energy saving in industrial application,” IEEE Trans. Ind. Appl., vol. 44, no. 5, pp. 1360–1366, Sep./Oct. 2008.

[5] G. R. Slemon and A. V. Gumaste, “Steady state analysis of PMSM drive with current source inverter,” IEEE Trans. Ind. Appl., vol. IA-19, no. 2, pp. 190–197, 1983.

[6] Luukko, J., Pyrhönen, J., “Selection of the Flux Linkage Reference in a Direct Torque Controlled Permanent Magnet synchronous Motor Drive”, IEEE, in Proc. AMC ’98-COIMBRA, pp. 198-203,1998.

[7] L. Zhong, M. F. Rahman, , W. Y. Hu and K. W Lim “Analysis of Direct Torque Control in Permanent Magnet Synchronous motor Drives”, IEEE Tran. on Power Electronics vol. 12. No. 3 May 1997.

[8] R. J. Kerkman, B. J. Seibal, T. M Rowan and D. Schlegel, “A new flux and stator resistance identifier for AC drive systems,” Conf Record, IEEE-IAS, Orlando, Florida, pp. 310-318, Oct. 1995.

[9] S. M. Malik, E. Elbuluk and Donald S. Zinger, “PI and fuzzy estimators for Tuning the stator resistance in direct Torque Control of Induction Machines”, IEEE Tran. on Power Electronics, Vol 13. No.2, March, 1998.

[10] PETER VAS, “Sensorless vector and direct torque control”, OXFORD University press-1998.

[11] B.K.BOSE, “Modern Power Electronics and AC Drives”, Prentice-Hall, Inc-2002

