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A Novel Method for Torque Ripple Minimization of PMSM Using a New Proportional Resonant Controller

Karthika S[1], Saleena Mary George[2]

M. Tech student, Department of Electrical Engineering, RIT Government Engineering College, Kottayam, India[1]

Asst. Professor, Department of Electrical Engineering, RIT Government Engineering College, Kottayam, India[2]

Abstract: The minimization of speed ripple of the permanent magnet synchronous motors (PMSM) in low speed range becomes a major problem while applying the PMSM to refrigerant system. In conventional methods, an iterative learning controller is applied in conjunction with the conventional proportional integral (PI) speed controller to minimize the speed ripple. In this paper a frequency variable resonance controller is applied with the conventional proportional integral speed controller as a PI-RES controller, which provides the reference torque current. The main reference current generated by the PI controller together with the compensation torque current generated by the resonant controller is used to minimize speed ripple. The proposed method is verified through simulation results.

Keywords: Permanent Magnet Synchronous Motor, PI-RES controller, Field Oriented Control

I. INTRODUCTION

The PMSM motors are increasingly being used in a variety of applications. Relative to electricity excitation synchronous machine, due to there is a lack of excitation winding, can cancel brush. PMSM have some merit, such as high power density, high efficiency and high reliance and good dynamic performance [1].Thus, the PMSM is widely used as servo motors in industry. With the variable-speed refrigerant systems performance and energy efficiency is becoming increasingly demanding in recent years, the traditional induction motor used in compressor has gradually been replaced by PMSM. However, there are still some limits for the popularization and application of this variable speed compressor, one of the most serious is the low-speed range of the speed fluctuations and the resulting low-frequency noise and vibration problems.

To overcome the vibration problem of compressor, the compressor operates in high speed range where the rotor and piston inertia relieve the vibration phenomenon. However, this high speed operation decreases the overall system efficiency since it has to be ON/OFF control to reach the demanded temperature. Otherwise, which is of our interest, concentrates on using an additional control effort to compensate these periodic torque pulsations. The predefined load torque compensator is a popular method used to minimize the speed ripple and vibration at low speed [2]. However, in such a method, sufficiently accurate information of the PMSM parameters, in particular the characteristics of torque ripples are required, and a small error or variations in parameters can lead to an even higher torque ripple due to the open-loop feed-forward control [3]. Various methods have been proposed for instantaneous torque estimation [4]. However, since the environment of high temperature and pressure inside the compressor, the sensor less methods are normally has to be used .In [3] iterative learning controller is applied in conjunction with the conventional proportional-integral (PI) speed controller to minimize the speed ripples.

In this paper, a frequency variable resonance controller is applied in conjunction with the conventional proportional-integral (PI) speed controller as a PI-RES speed controller which provides the reference of torque current. Compensation torque current generated by the resonance controller, the proposed controller that together with the main reference current is utilized to minimize speed ripples. PI-RES controllers are also used in the inner control loops to generate the control voltages to obtain pulse-width-modulated signals. The comparison performances between the two control method by using conventional PI controller and PI-RES controller have been evaluated through simulation.

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II. MATHEMATICAL MODEL OF PMSM

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:

1. Saturation is neglected
2. The induced EMF is sinusoidal.
3. Eddy currents and hysteresis losses are negligible.
4. There are no field current dynamics.

Voltage equations are given by

$$V_q = R_s i_q + \omega_r \lambda_d + p\lambda_q \qquad (1)$$

$$V_d = R_s i_d - \omega_r \lambda_q + p\lambda_d \qquad (2)$$

$$\lambda_q = L_q i_q \qquad (3)$$

$$\lambda_d = L_d i_d + \lambda_f \qquad (4)$$

Where V_q is the q-axis voltage, V_d is the d-axis voltage,R_s is the stator resistance, i_d is the d-axis current, i_q is the q-axis current, L_d is the d-axis inductance, L_q is the q-axis inductance, ω_r is the synchronous electric speed . Using the method of field-oriented control of the PMSM, the d-axis current is usually controlled to be zero.

The developed torque motor is being given by

$$T_e = \frac{3}{2} \times \frac{P}{2} \left(\lambda_d i_q - \lambda_q i_d \right) \qquad (5)$$

The mechanical Torque equation is

$$T_e = T_L + B\omega_m + J\left(\frac{d\omega_m}{dt} \right) \qquad (6)$$

Where, ω_m is the mechanical speed, , J is the inertia, T_L is the external load and B is the viscous coefficient.

III. PMSM WITH COMPRESSOR LOAD

At low operating speeds, the speed would oscillate with the same harmonic frequencies as that of ΔT_m.The sources of these speed oscillations are the error torque pulsations . The compressor have position-dependent load torque, the torque varies dramatically for the different position of rotor, and the torque ripple frequency varies for the different rotor speed.

$$\omega_m(s) = \frac{\Delta Tm}{Jm\ S} \qquad (7)$$

$$\Delta T_m = T_e - T_L \qquad (8)$$

Traditionally, the load torque is constant in steady state Condition. Then the outer speed loop can achieve good performance, either in steady-state or dynamic-state by using PI controller. But with the position-dependent load torque, the variety of the ripped term of torque is continual and nearly sinusoidal. Due to the limited bandwidth of the speed loop with PI controller, and standard integrators that can achieve good none-error control only at zero frequency. But it is hard to achieve $\Delta Tm \simeq 0$. ΔTm will ripple with twice rotor frequency, then speed will also ripple with twice rotor frequency. From (7), because of the term of inertia, amplitude of the ripple speed is inverse proportional to the ripple frequency, and then inverse proportional to the rotor speed. Therefore, in the low speed, the speed would severely ripple. It leads to inevitable vibration and the noise in low speed of the compressor, which is the almost operation condition because of the efficiency. Hence it is necessary to suppress the ripple of ΔTm in the low speed of the rotor.

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IV. PROPOSED SCHEME

In order to reduce the rippled term of torque which is continual and sinusoidal with twice the rotor frequency ,it will be good by adding a twice rotor frequency resonant controller together with the PI controller to form a new PI-RES controller. It have good capability to control the harmonics[7].

$$G_{PI-RES}(s) = K_p + \frac{K_i}{s} + \frac{2K_{ri}\,\omega_c s}{s^2+2\omega_c s+\omega^2} \quad (9)$$

Where K_p, K_i andK_{ri},respectively is the proportional ,integral and resonant coefficients. ω_c is the damping coefficient.

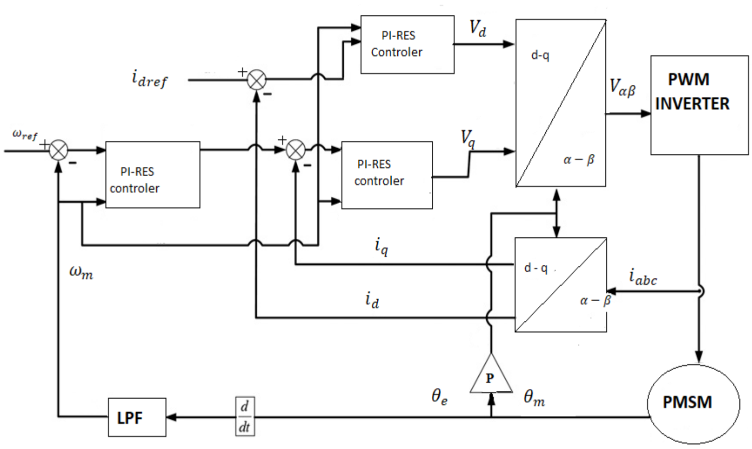
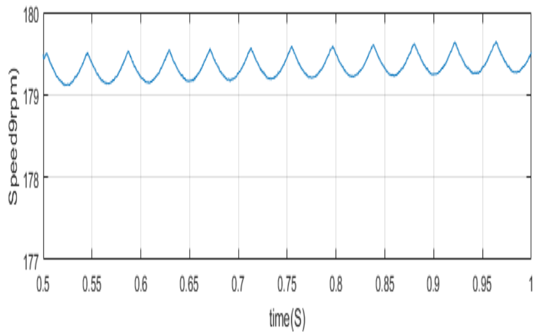


Fig.1.Block diagram of proposed control scheme of PMSM with compressor load

The main reference current generated by the PI term together with the compensation torque current is used to reduce the speed ripples. The compensation torque current generated by the PI-RES controller counteract with the rippled term of compressor load. A low pass filter is used to suppress the high frequency noise in speed signal. The control diagram of the proposed field oriented control is shown in figure 1.It consist of two control loops, an outer speed control loop to adjust the speed and inner current control loop to regulate the current.

V. SIMULATION RESULTS

The proposed control algorithm has been simulated by MATLAB/SIMULINK software .The simulation results were obtained for a 7 kw Permanent magnet synchronous motor. The simulation results show firstly the comparative study of control methods by using PI and PI-RES controller. Figure.2 shows the speed response when the reference speed of the motor set at 180 rpm by using proposed control and conventional PI control. Then the speed ripple is reduced. Figures.3and 4 show the same comparison, for the reference speed 500rpm and 1500 rpm. It is very clear from the figs that the proposed control is able to reduce the speed ripple with compressor load in all the above cases. That is, low speed, medium speed and rated speed.



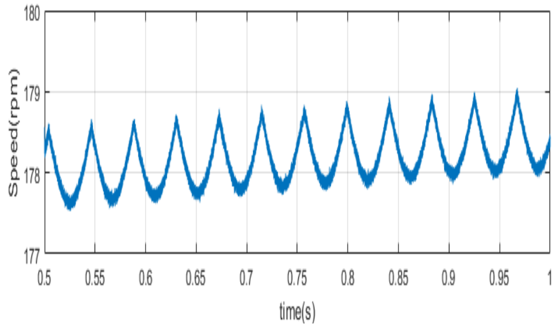


Fig.2 Speed response when the reference speed of the motor is 180rpm (a) By PI –RES controller (b) By PI controller

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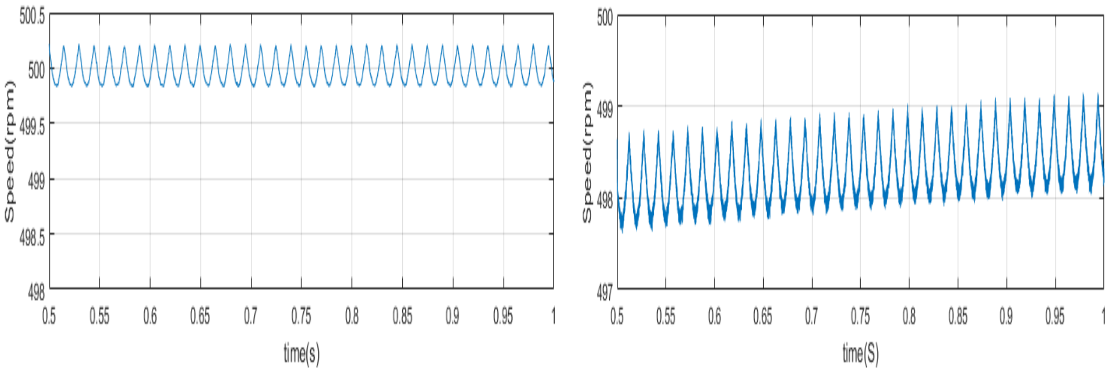

Fig.3Speed response when the reference speed of the motor is 500rpm
(a) By PI –RES controller (b) By PI controller.

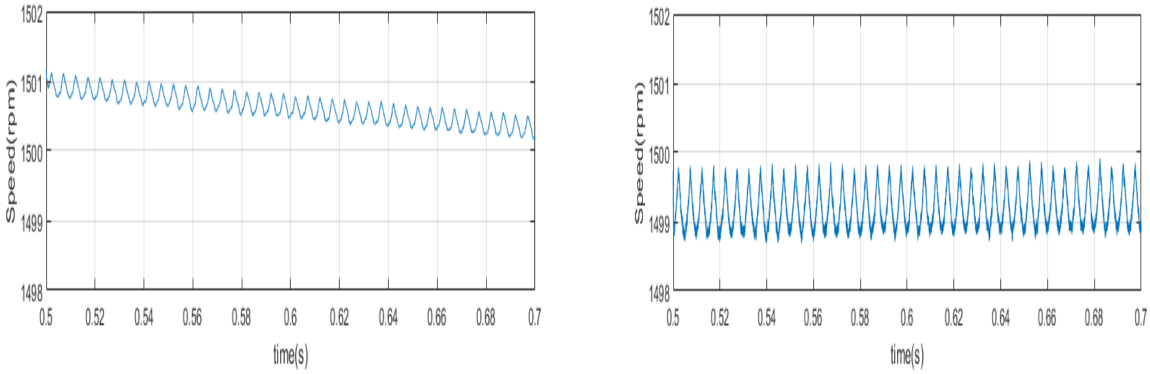

Fig.4 Speed response when the reference speed of the motor is 1500rpm (a) By PI –RES controller (b) By PI controller

Figure.5-8 shows the torque response of the system. At 0.5s position dependent load torque is applied. The torque ripple is reduced in the proposed method as compared with the conventional method. The dynamic response of the PMSM is also compared in figure 7. It is very clear from the speed response and current response that the resonant controller in the speed loop and current loop does not effect the dynamic performance of the system.

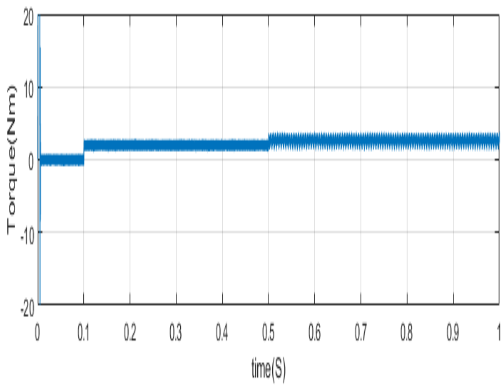

Fig.5Torque response of PI-RES controller

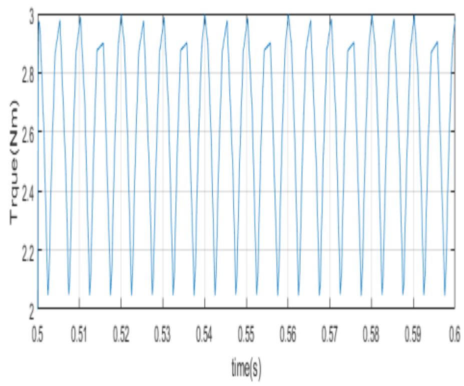

Fig.7 Zoomed portion of torque response(PI-RES) from 0.5s to 0.6s

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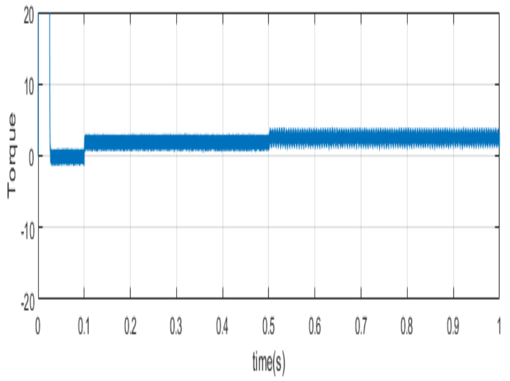

Fig.6Torque response of PI controller

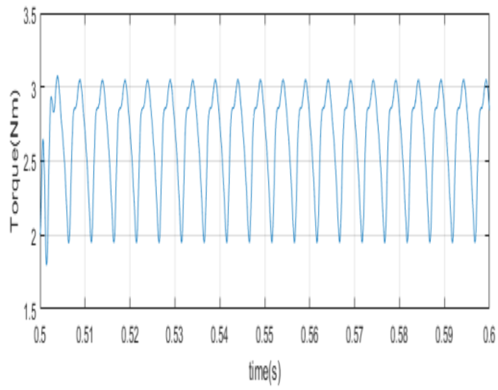

Fig.8 Zoomed portion of torque response (PI) from 0.5s to 0.6s

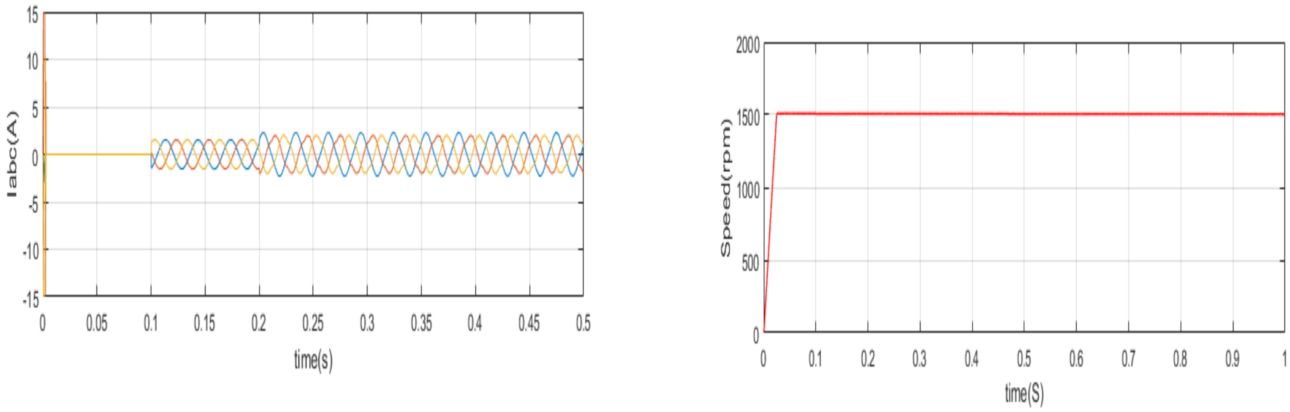

Fig.9 Dynamic response of PMSM using proposed method

VI. CONCLUSION

In this paper a new control strategy for PMSM with compressor load is proposed. A new PI resonant controller is applied in the speed and current control loop to adjust the rippled speed and current when position dependent load is applied. The new control strategy is verified through simulation using MATLAB/SIMULINK. The proposed method is compared with the conventional PI control method.

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