Closed Loop Speed Control of Permanent Magnet Synchronous Motor Fed by DTC-SVPWM Inverter

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Abstract – This paper presents closed loop speed control by using PID controller and inverter switching in space vector pulse width modulation (SVPWM) technique. The scheme consist of PID controller, Permanent Magnet Synchronous Motor and SVPWM Inverter. The stability of the proposed control system is also proven. Simulation block diagram and Simulation results are presented to verify that how the proposed scheme can achieve speed control at desired speeds. Harmonic content in stator current is negligible.

Keywords – Closed loop speed control , PMSM, Space Vector Pulse Width Modulation (SVPWM).)

I. INTRODUCTION

The PMSMs are gradually taking over the IMs owing to their high efficiency, low maintenance cost, and high power density. However, the PMSM system is not easy to control because it is a nonlinear multivariable system and its performance can be highly affected by parameters variations in the run time. Therefore in this paper speed control of PMSM under disturbances and load varying conditions using PID controller in closed loop is presented. With its three-term functionality covering treatment to both transient and steady-state responses, proportional-integral-derivative (PID) control offers the simplest and most efficient solution to many real-world control problems. Since the invention of PID control in 1910, and the Ziegler–Nichols (Z-N) straight forward tuning methods in 1942, the popularity of PID control has grown tremendously. However, more than 90% of industrial controllers are still implemented based around PID algorithms, [1-3] particularly at lowest levels, as no other controllers match the simplicity, clear functionality, applicability, and ease of use offered by the PID controller. The proposed scheme is not only simple and easy to implement, but also it guarantees an accurate and fast speed tracking [4-5].

II. PMSM MODEL

From the d-q modelling of the motor using the stator voltage equations the equivalent circuit of the motor can be derived as shown in figure 1. Assuming rotor d axis flux from the permanent magnet is represented by a constant current source as described in the following equation $\Psi_f = L_m I_f$ figure below is obtained by the below Equation [1]

$$T_e = \frac{3}{2} P \left[\Psi_d i_q - \Psi_q i_d\right] \quad (1)$$

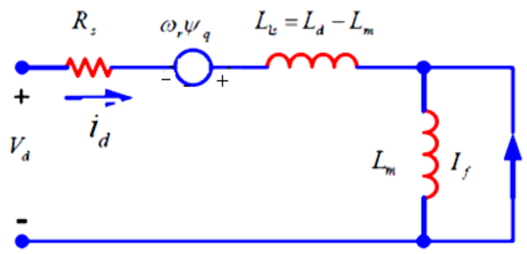

Fig .1(a) Equivalent Circuit of PMSM(d - axis)

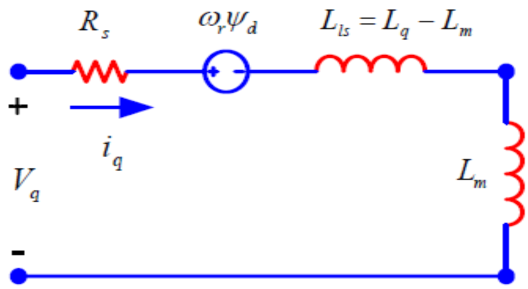

Fig .1(b) Equivalent Circuit of PMSM (q- axis)

Where L_m is the mutual inductance between the stator winding and rotor magnets. Substituting these flux linkages into the stator voltage equations gives the stator equations[6-8].

$$V_q = R_q I_q + \omega_r (L_d I_d + L_m i_f) + \rho\, L_q I_q \quad (2)$$

$$V_d = R_d I_d - \omega_r L_q I_q + \rho\, (L_d I_d + \Psi_f) \quad (3)$$

Where V_d and V_q are d-q axis stator voltages, i_d and i_q are d-q axis stator currents, L_d and L_q are d-q axis inductances. R_s is stator winding resistance per phase, Ψ_d, Ψ_q are stator flux linkage in d-q axis & ω_r is rotor speed in (rad/sec) electrical. Arranging the above equation in matrix form

$$\begin{bmatrix} Vq \\ Vd \end{bmatrix} = \begin{bmatrix} R_q + \rho L_q & \omega_r L_d \\ -\omega_r L_q & R_d + \rho L_d \end{bmatrix} \begin{bmatrix} I_q \\ I_d \end{bmatrix} + \begin{bmatrix} \omega_r L_m I_f \\ \rho \Psi_f \end{bmatrix} \quad (4)$$

$$T_e = T_L + B\omega_r + J\frac{d\omega_m}{dt} \quad (5)$$

Where T_L is load torque, J is moment of inertia, B (viscous friction) is damping coefficient.The developed electromagnetic torque is given by

$$T_e = \frac{3}{2} P \left[\Psi_d i_q - \Psi_q i_d\right] \quad (6)$$

Where P = No. of pole pair = p/2, and p = Total No. of poles Based on theory of dynamics the motion equation of PMSM.ω_m is the motor mechanical speed. Solving for the rotor mechanical speed from the above equation

$$\omega_m = \int \frac{(T_e - T_L - B\omega_r)dt}{\tau} \tag{7}$$

$$\omega_m = \omega_r \, \frac{2}{p} \tag{8}$$

Where ω_r is the rotor electrical speed.

III. PROPOSED CLOSED LOOP SPEED CONTROL

The space vector PWM method is an advanced, computation-intensive PWM method and is possibly the best among all the PWM techniques for variable-frequency drive applications. Because of its superior performance characteristics, it has been finding widespread applications. The PWM methods like sinusoidal PWM, Hysteresis band current control PWM, sinusoidal PWM with instantaneous current control PWM have only considered implementation on half- bridge of three phase bridge inverter. If load neutral is connected to centre tap of DC supply, all three half-bridges operate independently, giving satisfactory PWM performance. With a machine load, the load neutral normally isolated, which causes interaction among the phases. This interaction was not considered in other PWM techniques. The space vector PWM method this interaction of phases and optimizes the harmonic content of three-phase isolated neutral load. For Space vector PWM technique we need to know the concept of rotating space vectors.A three-phase bridge inverter has eight permissible switching states. Table1 gives a summary of switching states and the corresponding phase to neutral voltages of an isolated neutral machine. The fig 2 shows three phase bridge inverter fed PMSM.

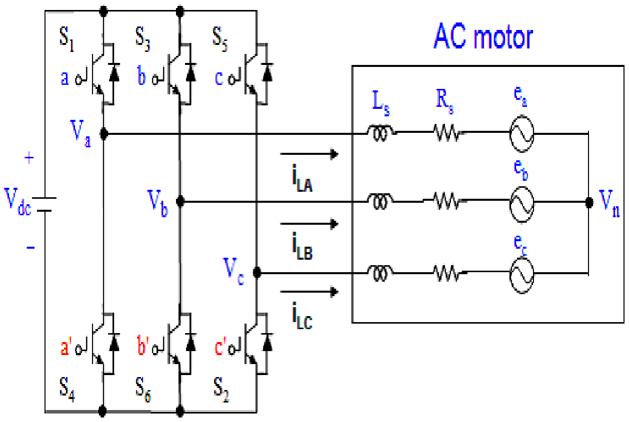

Fig.2 Bridge inverter

Here the power switches of this voltage source inverter are 180° conducting mode, which means only three switching signal S_a, S_b and S_c are needed to uniquely determined the status of six switchers. If the switches in upper leg of certain phase is on, the switching signal for this phase is defined as S = 1, otherwise S=0 represents the switcher in lower leg of this phase is on. In this way there are six effective VSIs and two zero VSI existing in the ordinary operation for a inverter. Assuming that the VSI is located in the a-axis of the a, b, c reference frame with phase a voltage V_a applied alone, then the inverter output VSIs under different switching states can be expressed as

$$V_S = \frac{2}{3} V_{dc}\left(s_a + s_b\, e^{2/3\pi j} + s_c\, e^{-4/3\pi j}\right) \tag{9}$$

$$V_s = \frac{2}{3} V_{dc}(s_a + a s_b + a^2 s_c),\ a = e^{j2/3\pi} \tag{10}$$

Where V_s is the primary voltage vector, S_a, S_b , S_c represent three-phase switching states and 2/3 is a transformation coefficient. According to above equation, the inverter output voltage represent in terms of switching

statue where six effective VSI, $V_1 - V_6$ are apart from each other in space by 60° electric degrees and the two zero VSI , V_0, V_7 are located in the centre of the space-vector plane. The inverter keeps the same state until the

output of the hysteresis controllers changes their outputs at the sampling period. Therefore, the switching frequency is usually is not fixed; it is changes with the rotor speed, load and bandwidth of the flux and torque controllers. The complete simulink model of space vector pulse width modulated inverter is shown in Fig.3.

IV. SIMULATION RESULTS AND DISCUSSIONS

Permanent magnet synchronous motors (PMSM) are widely used in low and medium power applications such as computer peripheral equipments, robotics, adjustable speed drives and electric vehicles.

The model of direct torque controlled permanent magnet synchronous motor (PMSM) drive are developed in MATLAB environment with Simulink & PSB tool boxes to simulate the behavior of drive with PI controller. The MATLAB model of DTC based system is shown in figure 4.Each subsystem of the main simulation model such as Permanent magnet synchronous motors space vector pulse width modulated inverter (SVPWM) inverter, speed controller, torque & flux estimator etc., have its own model in Simulink, according to the set of equations, already discussed in the previous chapters.

In figure 5 shows the speed & torque response of Permanent magnet synchronous motors drive for a set speed of ω_r =500rpm with sudden change in load torque occurs at (t=0.1 sec) from 2 to 5 Nm. (T_L = 2 to 5Nm) the sudden application of load on the motor shaft cause a small dip in the rotor speed, which recovers quickly resulting in zero steady state speed error.

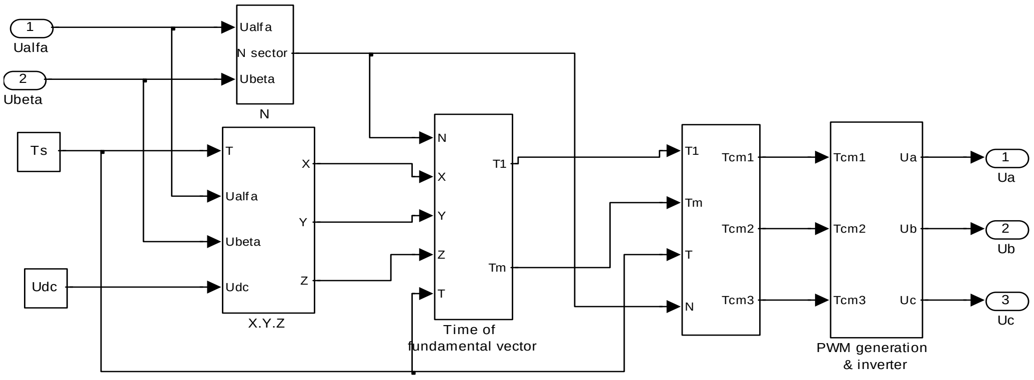

Fig.3 Simulink model of SVPWM inverter

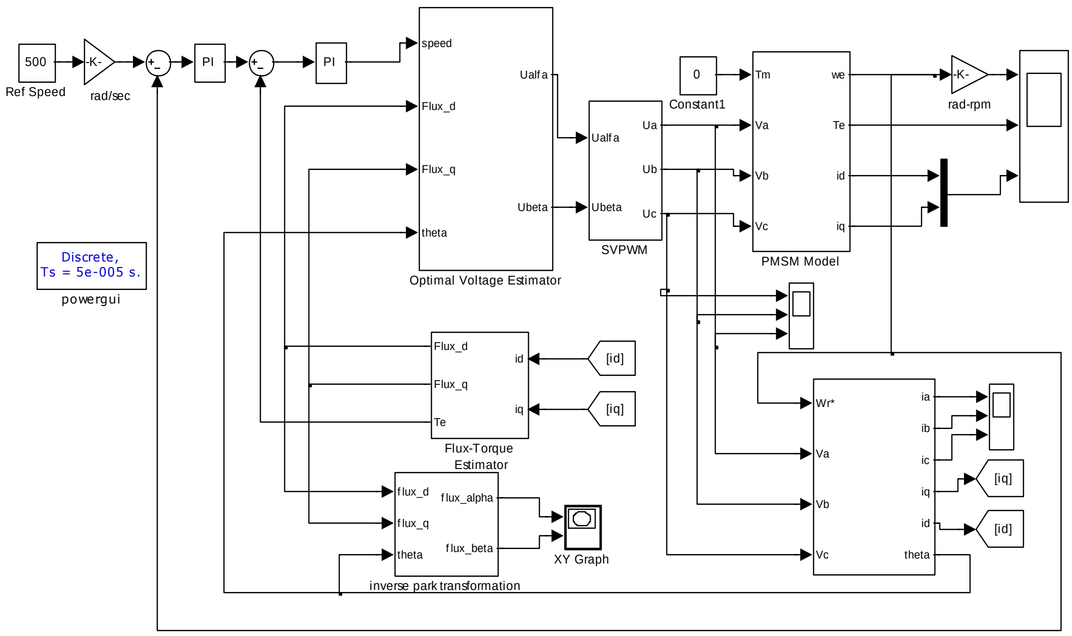

Fig 4 Simulink model of direct torque control scheme of PMSM drive

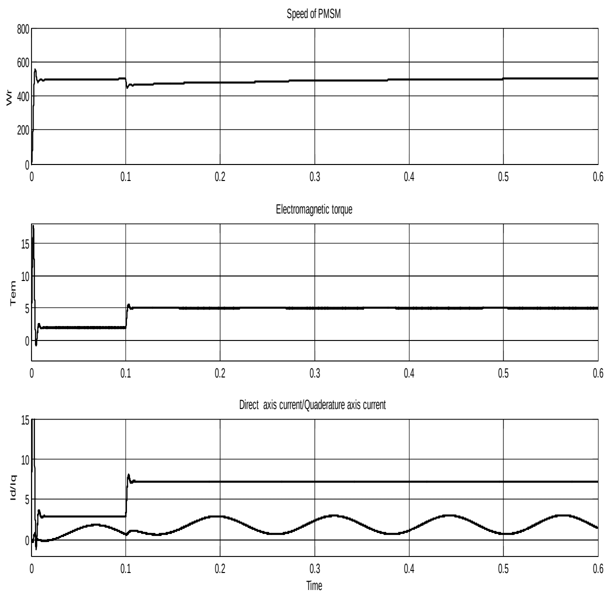

Fig-5 speed pmsm(ω_r in rpm) , electromagnetic torque(In Nm), current I_d, I_q (in ampere)of (for ω_r=500 at t=0.1sec,T_L= 2 to 5Nm)

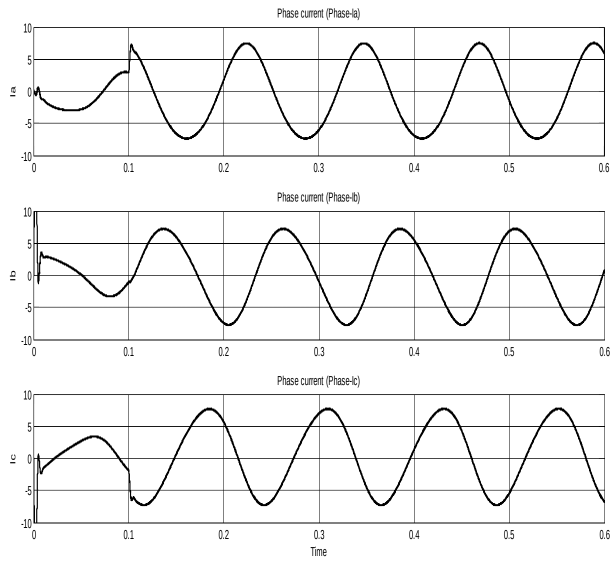

Fig-6 Three phase motor current(in ampere) (for ω_r=500rpm at t=0.1sec,T_L=2 to 5Nm)

The motor current as shown in fig-.6 increases to close up to sinusoidal. An increased load on the shaft of the motor developing increased electromagnetic torque as indicating in fig 6, the PI speed controller activated and recovers the rotor speed back to reference value under such load variation.

The stator phase voltages are maintained constant throughout the change in load torque as shown in fig 7, which is the necessary condition for speed control in all ranges.

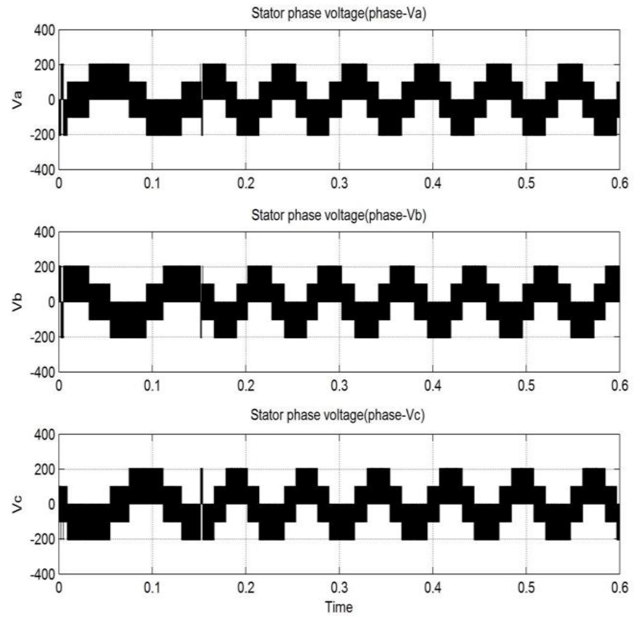

Fig-7 Three phase stator voltage(in volt) (for ω_r=500 at t=0.1sec, T_L=2 to 5Nm)

Fig 8 shows the X-Y axis flux trajectory; there is a change in the circumference as the load changes.

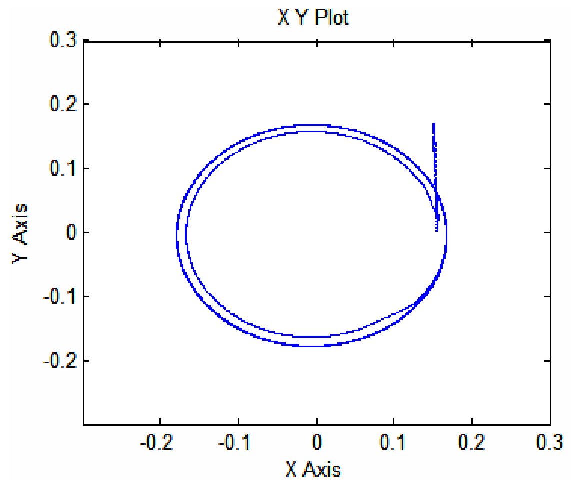

Fig 8 - Flux trajectory between α − axis flux (x axis) and β − axis Flux (y axis)

V. CONCLUSION

DTC is intended for an efficient control of the torque and flux without changing the motor parameters and load. Also the flux and torque can be directly controlled with the space vector modulated inverter voltage vector in DTC.The simulation results are analyzed and show that the torque and speed changing of the PMSM drive is having a small amount of ripple content. The DTC technique is implemented with a SV-PWM inverter. In a SV-PWM inverter, the three levels in the phase voltage permit reduction of the harmonic content in stator voltages and currents and also in torque and flux ripples. The DTC as used for PMSM drive; shows the excellent performance for both steady state as well as dynamic change in speed reference, and also with varying load conditions.

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