International Journal of Modern Engineering Research (IJMER)

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1105-1110 ISSN: 2249-6645

Vector controlled PMLSM using simplified Space vector pulse width modulation

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ABSTRACT

This paper aims to develop vector controlled permanent magnet linear synchronous motor (PMLSM) based on simplified space vector pulse width modulation. Mathematical models of PMLSM&SVPWM presented. The present PWM technique does not involve any sector identification and considerably reduces the computation time when compared to conventional space vector PWM technique. To validate the proposed algorithm, simulation studies have been carried out on vector controlled PMLSM drive. A comparison between Scalar control and vector control approach of PMLSM drive will be provided and verified on MATLAB.

Keywords: **offset time, PMLSM, SVPWM, scalar control vector control.**

I. INTRODUCTION

Permanent magnet linear synchronous motor (PMLSM) is a kind of driving equipment for converting electrical energy into linear movement directly without any in-between transferring mechanism [1]. Without the need of any mechanical transformation by using for example gears and screws, the linear drive offers high efficiency, high reliability, high performance motion control and low vibration and noise [2] .PMLSMs are increasingly used as actuators in many automation control fields, including computer controlled machining tools, X-Y driving devices, robots, semiconductor manufacturing equipment, transport propulsion and levitation[3].

The SVPWM was brought forward from 1980's, specifically used for the frequency varying and speed regulation of AC motors. It controls the motor based on the switching of space voltage vectors, by which an approximate circular rotary magnetic field is obtained. Comparing with the sine pulse width modulation (SPWM), the main SVPWM advantage is that it has e.g. a 15% higher utilization ratio of voltage [4].

The conventional SVPWM scheme requires sector identification and look up tables to determine the timings of various switching vectors of the inverter. These makes the implementation of the SVPWM scheme is quite complicated [6-7]. A simplified method, to determine the time duration of the correct offset times duration of the middle inverter vectors in a sampling interval. Considering the voltage generation fashion of the voltage fed inverter that comprised of six power devices in parallel with a freewheeling diode, it can be found that output voltage of the inverter is determined by the different voltages between each inverter arm and the time duration in which the different voltage is maintained.

II. MATHEMATICAL MODEL OF PMLSM

The mathematical model of a permanent magnet linear synchronous motor can be described in the two axis d-q synchronously rotating frame by the following differential equations [5], as

Stator voltage balance equation is given by

$$u_d = R_s \cdot i_d \cdot + L_d \cdot \frac{d i_d}{dt} - \frac{\Pi}{\Gamma} \cdot L_q \cdot v i_q \qquad (1)$$

$$u_q = R i_q + L_q \frac{d i_q}{dt} + (L_d i_d + \Psi_f) \frac{\Pi}{\Gamma} v \qquad (2)$$

The electromagnetic thrust force is given by

$$F_{em} = \frac{3}{2} \frac{\Pi}{\Gamma} (\Psi_f + (L_d - L_q) i_d) i_q \qquad (3)$$

If id=0, electromagnetic thrust force would be expressed as

$$F_{em} = \frac{3}{2} \cdot \frac{\Pi}{\Gamma} \cdot \psi_f \cdot i_q \qquad (4)$$

Therefore the thrust force of PMLSM can be controlled just through the controlling of *i*q which is very like controlling a DC motor.

Considering the mechanical load, the dynamic position movement mechanical balance equation of PMLSM is given by

$$F_{em} = F_d + Bv + M \frac{dv}{dt} \qquad (5)$$

ψ_f , F_d ,B ,M ,v, R, Γ are the flux linkage of permanent magnet, external force, viscous friction coefficient ,mass of moving part, translator velocity ,phase winding resistance, pole pitch. Simulation model of PMLSM is combined with “voltage balance” subsystem and “mechanical balance subsystem”.

III. SIMPLIFIED SVPWM ALGORITHM

The standard topology of a 3-phase VSI is shown in Fig.1, and consists of three phase legs with two switches per leg, arranged so that each phase output can be connected to either the upper or the lower DC bus as desired. In Fig.2, the eight available different switching vectors of the inverter are depicted with the space vector concept. The switching state “1” means the firing for the upper device of one arm and the pole voltage (Vao, Vbo, and Vco) will have half of the DC-link voltage value.

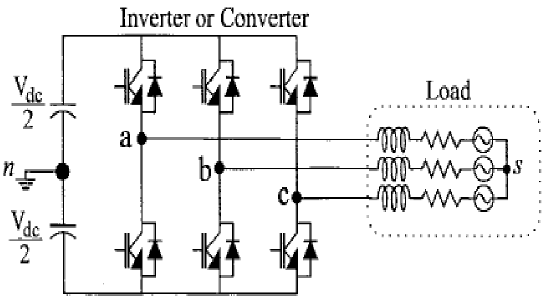


Fig 1: three phase inverter system

Note that the switching states of each arm should be combined with each other to compose the required three-phase output voltage. Because each pole voltage has only two levels according to the related switching state, the time duration in which the different voltages are maintained is definitely related to the voltage modulation task. Therefore, the modulation task can be greatly simplified by considering the relation between the time duration and the output voltage.

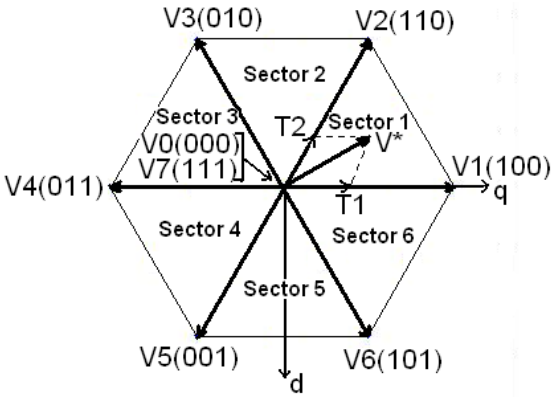


Fig 2: Space vector diagram of the available switching vectors.

The effective voltage that makes an actual power flow between inverter and load. Ts denote the sampling time and Teff denotes the time duration in which the different voltage is maintained. Teff is called the “effective time”. The imaginary time value will be the value is directly related to the phase voltage and one proportional formation can be defined [9] as

$$V_{as}^{*} : V_{dc} = T_{as} : T_{s} \Rightarrow T_{as} = \frac{T_{s}}{V_{dc}} \cdot V_{as}^{*}$$

$$V_{bs}^{*} : V_{dc} = T_{bs} : T_{s} \Rightarrow T_{bs} = \frac{T_{s}}{V_{dc}} \cdot V_{bs}^{*}$$

$$V_{cs}^{*} : V_{dc} = T_{cs} : T_{s} \Rightarrow T_{cs} = \frac{T_{s}}{V_{dc}} \cdot V_{cs}^{*} \qquad (6)$$

Vas*, Vbs*and Vcs* are the A-phase, B -phase, and C-phase reference voltages, respectively. This switching time could be negative in the case where negative phase voltage is commanded. Therefore, this time is called the “imaginary switching time”. Now the effective time can be defined as the time duration between the smallest and largest of three imaginary times given by

$$T_{eff} = T_{max} - T_{min} \qquad (7)$$

Where

$$T_{min} = \min(T_{as}, T_{bs}, T_{cs}), T_{max} = \max(T_{as}, T_{bs}, T_{cs})$$

When the actual gating signals for power devices are generated in the PWM algorithm, there is one degree of freedom by which the effective time can be relocated anywhere within the sampling interval. Therefore, a time-shifting operation will be applied to the imaginary switching times to generate the actual gating times (Tga,Tgb,Tgc) for each inverter arm. This task is accomplished by adding the same value to the imaginary times as [9]:

$$T_{ga} = T_{as} + T_{offset}$$

$$T_{gb} = T_{bs} + T_{offset}$$

$$T_{gc} = T_{cs} + T_{offset} \qquad (8)$$

If the zero-voltage time is symmetrically distributed in one sampling period, the whole modulation task for SVPWM is easily accomplished by the proposed algorithm. To relocate the effective time at the center of the sampling interval, the time shifting value Toffset is

$$T_{offset} = \frac{1}{2} T_{o} - T_{min}$$

Where

$$T_{o} = T_{s} - T_{eff} \qquad (9)$$

IV. SCALAR CONTROL OF PMLSM

Constant volt/hertz control in an open loop is used more often in the squirrel cage induction motor applications. Using this technique for synchronous motors with permanent magnets offers a big advantage of sensor less control. Information about the velocity can be estimated indirectly from the frequency of the supply voltage,[10]. The velocity be calculated as

$$v = 2\Gamma f_s \tag{10}$$

V=electrical linear velocity
Γ =pole pitch in meters
f_s =supply frequency

To maintain the stator flux constant at its nominal value in the base speed range, the voltage-to-frequency ratio is kept constant, hence the name V/f control. If the ratio is different from the nominal one, the motor will become overexcited or under excited.

V. VECTOR CONTROL OF PMLSM

The field oriented vector control (VC) was firstly for induction motors and later for permanent magnet synchronous motor [8]. The basic principle of vector control strategy for the PMLSM is decomposition of a primary part phase current into two orthogonal components. The first component is id current component. the second is iq component. The second iq component is orthogonal to first one. For rotor flux oriented vector control of the PMLSM, the direct axis stator current and the quadrature axis stator current must be controlled independently. Speed loop having Kp=500,Ki=50.Id loop having Kp=2000,Ki=15,Iq loop having Kp=10000,Ki=1000.

If higher velocity required field weakening be applied by controlling id current.

General expression for PI controller can be given as

$$Y = K_P e(t) + K_I \int e(t)dt \tag{11}$$

A derivative part has not been included as large and rapid variations in error without filter may lead to undesirable response of the derivative signal. Three PI control loops are used to control three interactive variables independently. The rotor speed, rotor flux and rotor torque are each controlled by a separate PI controls.

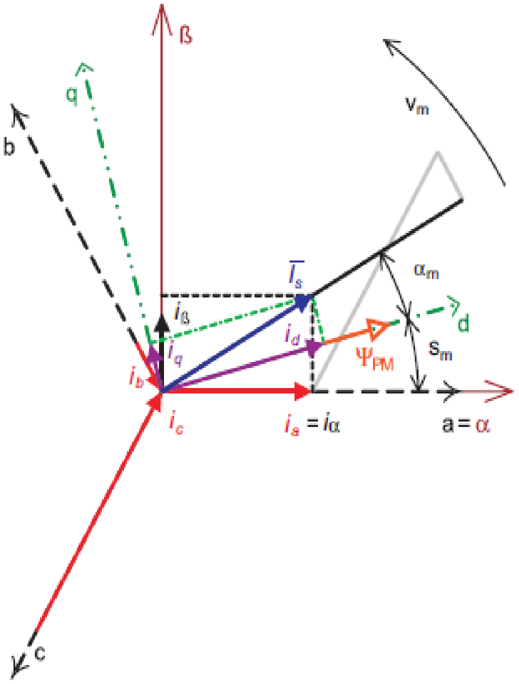


Fig: 3: phase diagram of stator current

From equation (4) thrust force is directly proportional to iq current. From phase diagram equation rewrite as

$$F = \frac{3}{2} \cdot \frac{\Pi}{\Gamma} \cdot \psi_f \cdot i_q = \frac{3}{2} \cdot \frac{\Pi}{\Gamma} \cdot \psi_f \cdot |I_s| . \sin \alpha_m \tag{12}$$

Where α_m is the angle between vectors of primary part Is current and permanent magnet flux ψ_f .during such conditions the flux of permanent magnet flux, ψ_f maintained constant and maximal force is achieved for angle, α_m=90. This condition is satisfied for d-q coordinate system, which has d-axis identical with direction of the permanent magnet flux and a primary part current vector orthogonal to d-axis and id current will be 0. Vector control block diagram shown in figure.4.

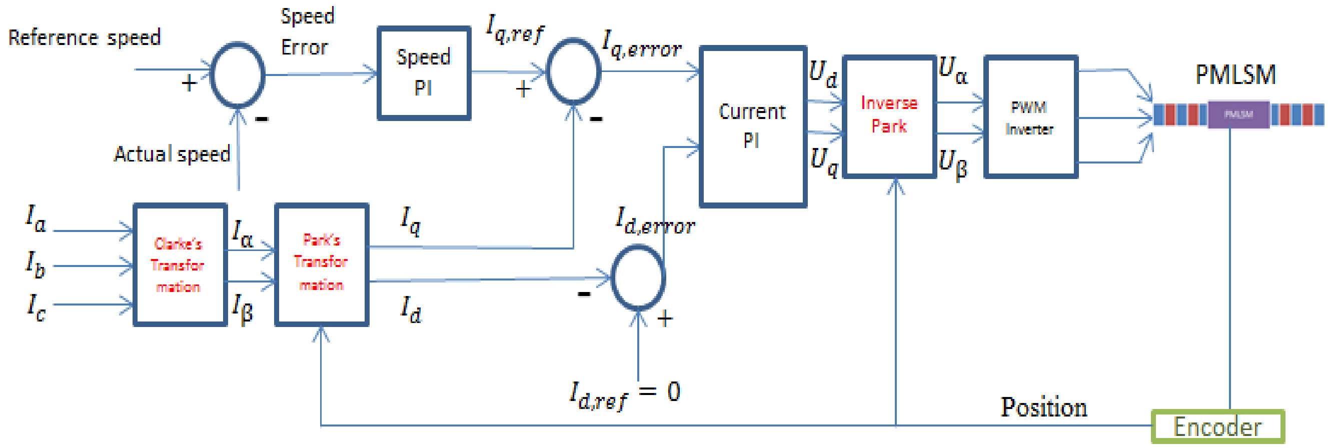


Fig 4: Block diagram of vector control

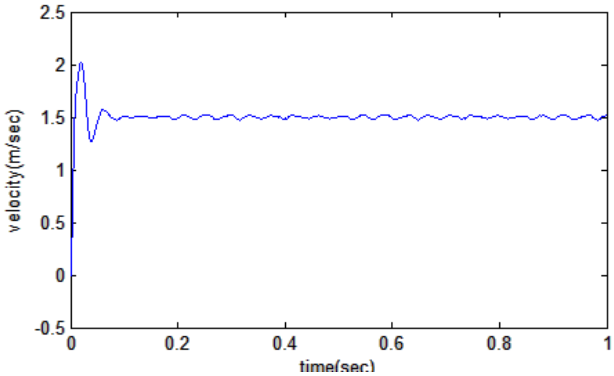
VI. SIMULATION RESULTS AND DISCUSSION

To validate the proposed method, simulation studies have been carried out by using MATLAB/SIMULINK .The motor parameters are shown in table1.

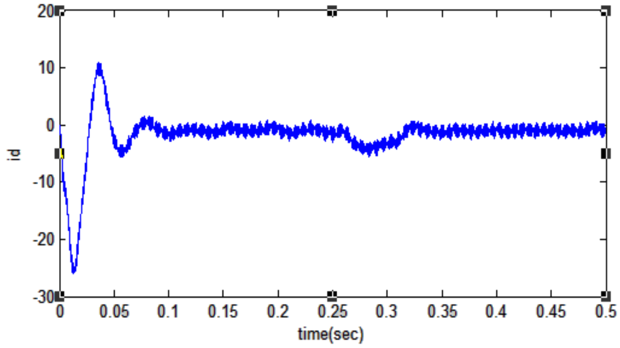
TABLE 1:
Dc bus voltage, Ud=310v,pole pairs, N=2

Stator resistance, Rs	2.04Ω
d-axis inductance ,Ld and q-axis inductance, Lq	7mH
Permanent magnet flux, ψ_f	0.085Wb
Polar pitch, Γ	33mm
Mover mass, m	3kg
Viscous friction coefficient, Bv	0.2 N.M/s

The simulation results of the proposed drive are shown in Fig. 5and Fig.6.The scalar control plots are shown in Fig.5and vector control plots are shown in Fig.6.Id in scalar control variable during a step load is applied but in vector control always zero shown in Fig.6.velocity provide certain overshoot during the starting condition in scalar control shown in Fig.5.in case of vector control negligible overshoot. Thrust force in scalar control provide a large ripples when compare to the vector control. From the Fig.6 velocity feedback used in vector control approach avoid overshoots during starting condition. Dynamic performance of vector control is better than the scalar control of PMLSM drive.



(a)



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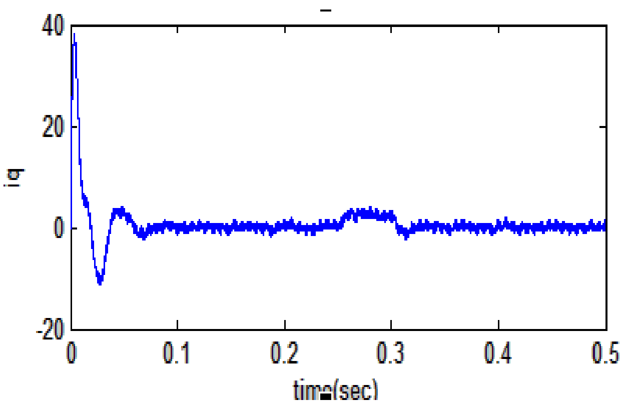
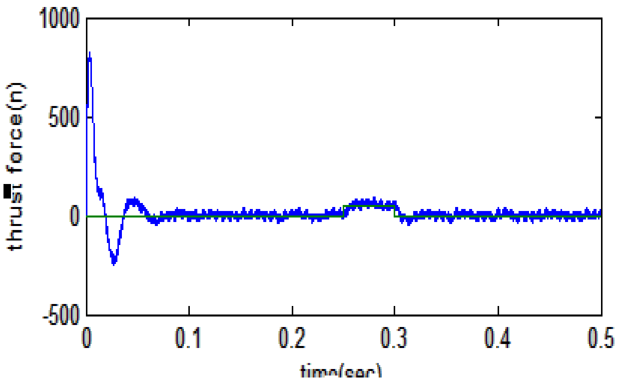
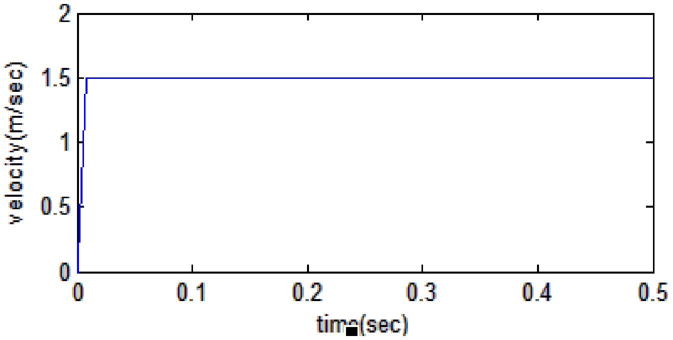


(c)

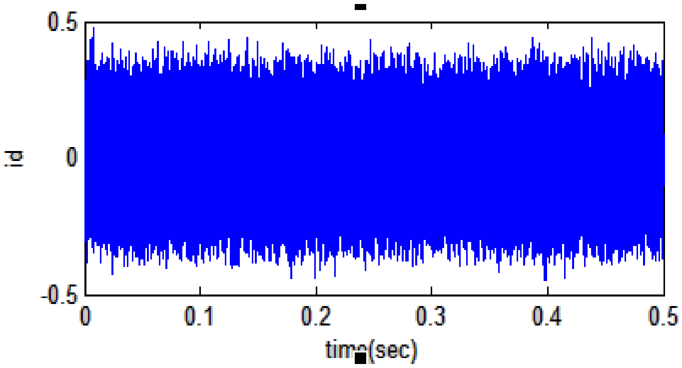


(d)

Fig: 6. Scalar control of PMLSM (a) velocity (b) id (c) iq (d) force when load of 50N applied at 0.25 sec.



(a)



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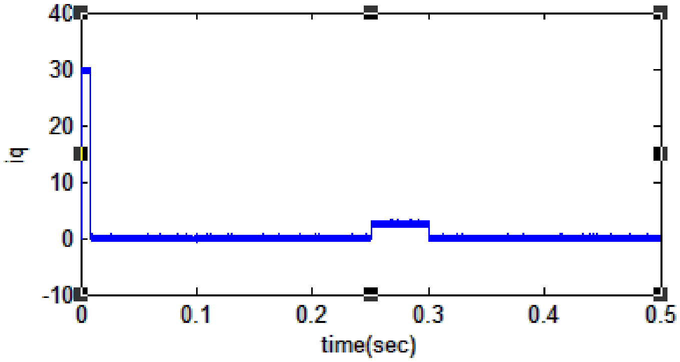

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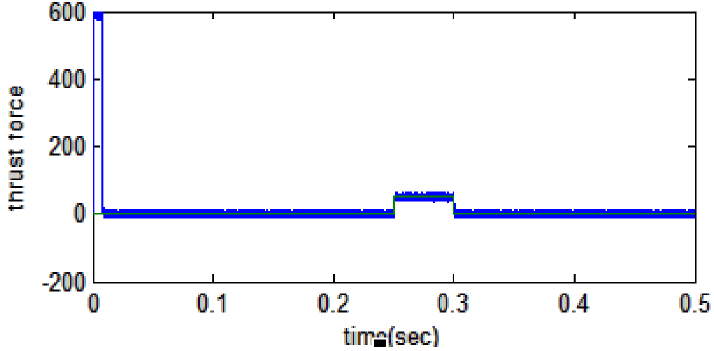

(d)

Fig: 7 vector control of PMLSM (a) velocity (b) id (c) iq (d) force when load of 50N applied at 0.25 sec.

VII. CONCLUSION

The simplified algorithm does not use sector identification and angle information. So it reduces computation time. Vector control with simplified SVPWM gives better performance than the convention current control algorithm.
Vector control as the most common method of PMLSM compare than the scalar control. Vector control provides better dynamic performance than the scalar. Velocity overshoots are reduced in vector control. Magnetizing flux is kept in its nominal value during the whole operation cycle.

Using such control strategy avoids the motor to become under or over excited condition.

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