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Vector Control of Permanent Magnet Synchronous Machine Drive Based on Matrix Converter

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ABSTRACT
A matrix converter (MC) based vector control of high speed permanent magnet synchronous motor (PMSM) drive with current hysteresis control is designed. Signals of current hysteresis controller and selection of input voltages are analyzed in detail. How to decide on or off of power switch of matrix converter under current hysteresis control is also deduced in this thesis. Vector control of permanent magnet synchronous motor (PMSM) using current hysteresis control based on matrix converter (MC) is presented. In order to improve utilization of input voltage resources, input voltages are divided into 6 sections within one period. A simple modulation control strategy based hysteresis control is analyzed in details. According to outputs of current controller and section of input voltages, a proper input voltage should be selected to increase or decrease output current of matrix converter by simple modulation strategy. The selection table is analyzed and partially deduced. Finally, simulation system is built up. Results of simulation show that the matrix converter based vector control of high speed PMSM drive has the quality of feasibility and efficiency, which brings out theoretical foundations of experimental prototype.

***Keywords* -** Brushless Dc Motor, Matrix converter, Matrix converter unit, Permanent Magnet, Synchronous Motor, Pulse width modulation, Space vector modulation

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I. INTRODUCTION

In modern days, in controlling of Drives, vector control of induction machines is very popular and the application of same in case of PMSM with advancements in power electronics yields best results. In this main objective is to control the PMSM by vector control using Matrix converter. Here vector control comprises of six voltage sectors and one hysteresis comparator and which is same as in case of simple modulation control. This system gives good dynamic performance and as well as theoretical results.

In the recent days vector control of permanent magnet synchronous motor (PMSM) has been popular due to its simple circuitry. Recent research has indicated that PMSM could become a serious competitor to the induction motor (IM) for high performance servo applications. Mathematical model of a PMSM is developed with the help of Park and Clarke transformations. The concept of vector control is applied to PMSM to obtain linear dynamics similar to that of a DC motor. The linearized model consists of two control loops namely, current loop and speed loop. The objective of the control scheme is to achieve very fast response [1],[2].

Because of its advantages such as simplicity, dynamic performance and overload capability, permanent magnet synchronous motor is widely used in industry, CNC machine tools and aviation. As a kind of decoupling control method, vector control of AC motors has similar performance as DC motors, which is trend of AC motors. Matrix converter has nearly sine wave input current, adjustable input power factor, without large capacitor for DC filter and energy storage. Matrix converter is potentially popular in AC drives.

II. PERMANENT MAGNET SYNCHRONOUS MOTOR

The Permanent magnet synchronous motors (PMSM) are very popular in a wide range of applications. Compared to a DC motor, the PMSM misses a commutator; therefore it is more reliable than a DC motor. The PMSM also has advantages when compared to an AC induction motor. Now a days, permanent magnet synchronous motor is designed not only to be more powerful but also with lower mass and lower moment of inertia. The PMSM generates the rotor magnetic flux with permanent magnets, achieving higher efficiency. Therefore, the PMSM is used in applications which gives high reliability and efficiency.[3]

The operating principle of PMSM is based on the two things which are rotating magnetic field and magnetic locking. Whenever three phase supply is given to the stator of a PMSM, a 3-phase RMF will be developed on the other hand rotor is with permanent magnets. The magnetic locking of rotor poles and Stator RMF causes rotor to rotate at synchronous speed.

Permanent magnet synchronous motor has the characteristics of simple structure, small size, light weight, low loss, high efficiency, and in comparison to the DC motor, it has no commutator and brushes and other shortcomings. And in comparison to asynchronous motors, it does not require reactive excitation current, thus it has high efficiency, high power factor, large moment of inertia, stator current and stator resistance losses decreased, and the rotor parameters can be measured, the control performance is good; and in comparison with the general synchronous motor, it eliminates the excitation device, simplifying the structure and improving efficiency.[4]

IV. MATRIX CONVERTER

The matrix converter is an array of controlled semiconductor switches that connects directly the three-phase source to the three-phase load. This converter has several attractive features that have been investigated in the last two decades. In the last few years, an increase in research work has been observed, bringing this topology closer to the industrial application. This paper presents the state-of-the-art view in the development of this converter, starting with a brief historical review [7]. An important part of the thesis is dedicated to a discussion of the most important modulation and control strategies developed recently. Special attention is given to present modern methods developed to solve the commutation problem. Some new arrays of power bidirectional switches integrated in a single module are also presented. Finally, this thesis includes some practical issues related to the practical application of this technology, like overvoltage protection, use of filters, and ride-through capability.[6]

III. BLOCK DIAGRAM OVERVIEW

The vector control of high speed PMSM based on matrix converter consists of following blocks shown in fig 1 and each block will be explained briefly in this chapter and without which we cannot realize the blocks in the MatLab/Simulink and The following are the main control blocks involved current controller, voltage sectors and switching table.

Framework of three phases-three phases matrix converter based vector control of permanent magnet synchronous motor with current control[8] abc is three input voltage resources of matrix converter, and ABC is three output phases of matrix converter. i_A*, i_B*, i_C* are references of permanent magnet synchronous motor stator currents, i_A, i_B, i_C are real stator currents. Real stator currents are compared respectively with their references. With simultaneous input voltage section and selecting right input voltage, power switches of matrix converter are set on or off by switch table. Then, error between real stator current and its reference is constrained.

V. SWITCH MODES OF MATRIX CONVERTER

Three phases matrix converter is a 3×3 switch matrix, mainly composed of 9 bidirectional power switches. Switch function of power switch S_{ij} is defined in equation 1..

$$S_{ij} = \begin{cases} 1 \\ 0 \end{cases} \quad (i = a, b, c,\ j = A, B, C) \qquad (1)$$

Where ‘0’ for off and ‘1’ for on.
Three AC input phases of matrix converter must not be shorted. When three output phases are connected with inductive load, they must not be opened. So, the constraint of switch function is just as follows,

$$S_{aj} + S_{bj} + S_{cj} = 1\ (j = A, B, C) \qquad (2)$$

By switch function and its constraint of 9 bidirectional power switches, we can get 27 switch modes of the 9 power switches. During vector control of permanent magnet synchronous motor

with modified current control, states of the 9 power switches are selected from the 27 switch modes.[9]
The load and source voltages are referenced to the supply neutral, "0" in Fig. 1, and can be expressed as vectors defined by,

$$v_o = \begin{matrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{matrix} \quad v_i = \begin{matrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{matrix} \tag{3}$$

The relationship between load and input voltages can be expressed as,

$$\begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix} \tag{4}$$

Where $S_{Aa}(t), S_{Ba}(t) \ldots\ldots S_{Cc}(t)$ are switching functions of Aa, Ba and Cc lines.

$$V_o = T.v_i \tag{5}$$

In the same form, the following relationships are valid for the input and output currents were written in the Equation 3.6.

$$i_i = \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} \quad i_0 = \begin{bmatrix} i_A(t) \\ i_B(t) \\ i_C(t) \end{bmatrix} \tag{6}$$

$$I_i = T^T.i_o \tag{7}$$

'T' is the instantaneous transfer matrix and T^T is the transpose of 'T'.
Equations 7 and 5 give the instantaneous relationships between input and output quantities. To derive modulation rules, it is also necessary to consider the switching pattern that is employed.

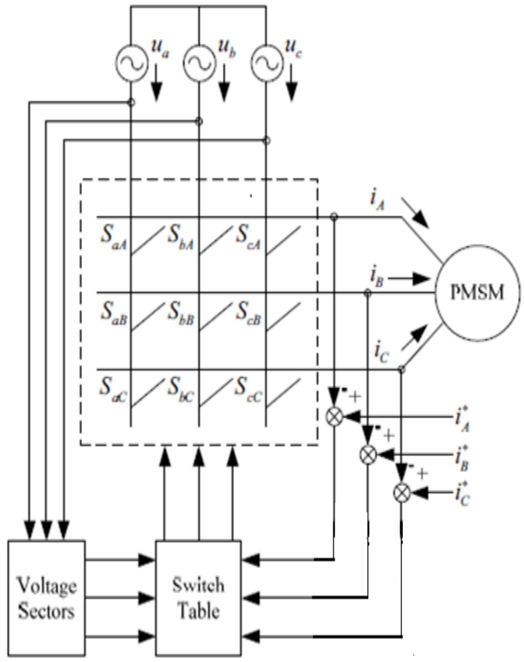

Fig. 1 Block diagram of proposed system

The Proposed MatLab model of a matrix converter based vector control of high speed PMSM is as shown in Fig 1. It consists of PMSM fed by Matrix converter and which is fed by three phase voltage source.The switches triggering will be done primarily by selecting 3 switches corresponding to one phase three groups were formed from 9 switches. This subsystem generates signals which are required for the operation of matrix converter and how the generation happened here is described below.The inputs to the total subsystem are three phase real stator currents (I_{abc}), rotor speed which can be taken from PMSM to form a closed loop and reference speed which is taken as 1000rad/sec[10][11].

By taking those three phase real stator currents as input, Depending on certain conditions the subsystem generates pulses and triggers the matrix converter switches. The transformations and calculations will be discussed at corresponding blocks.[12]

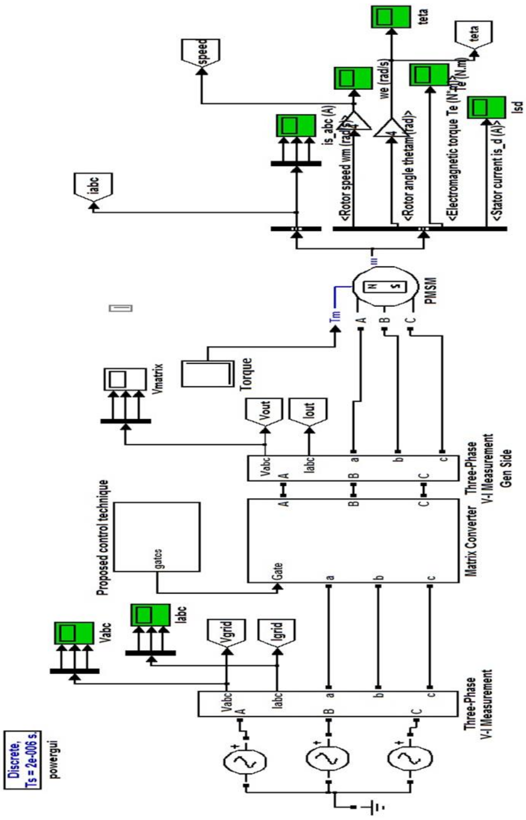

Fig.2 MatLab model of Vector control of PMSM based on Matrix converter

VI. RESULTS

PERFORMANCE OF VECTOR CONTROL BASED ON SIMPLE MODULATION STRATEGY

The performance of vector control of PMSM based on matrix converter will be obtained from the observation of output waveforms of PMSM fed by the Matrix converter. The following are the waveforms which include Speed, Electromagnetic torque, Stator current-axis Stator current, rotor angle etc.

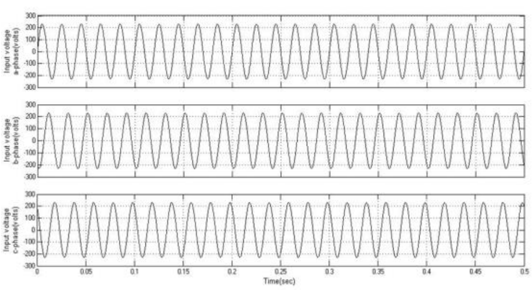

Fig. 3 Input voltage waveform to the Matrix converter

OUTPUT WAVEFORMS OF MATRIX CONVERTER FOR NO-LOAD (TL=0 NM):

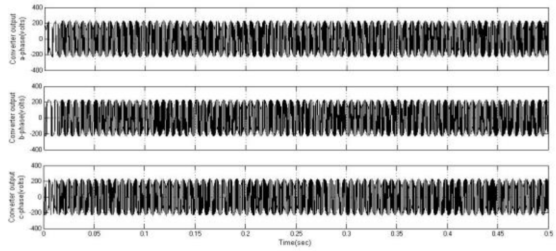

Fig. 4 Output Voltage waveforms of Matrix converter (3-Phase) for T_L=0 Nm

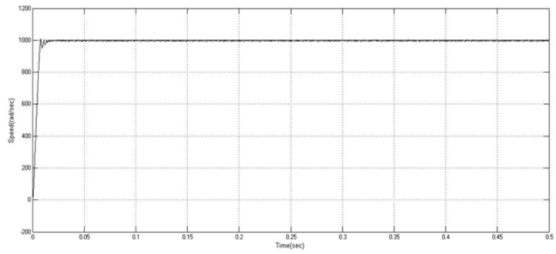

Fig. 5 Speed response of PMSM for T_L=0 Nm

The output voltage of a matrix converter shown in the fig. 4 describes how the switching of six switches of nine at a time to connect 3-phase input to 3-phase output. The output voltage of the matrix converter is similar compared to Inverter fed PMSM and it somewhat resembles full bridge Inverter output since here we are using matrix converter as a inverter at each instant with different switches.

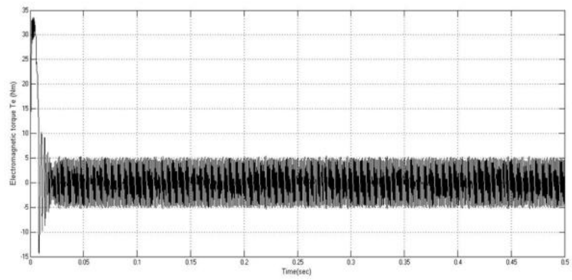

Fig. 6 Electromagnetic torque response of PMSM for T_L=0 Nm

The Electromagnetic torque response of PMSM shown in the Fig. 6 shows that Even Though the torque subjected to peaks at starting it reaches steady state value in few milliseconds. The response of electromagnetic torque shows that there is an impulse form at starting and gradually reaches to steady state torque in 0.02 seconds

PERFORMANCE DURING REVERSING

The performance can be assessed by Speed, Electromagnetic torque, Stator current and d-axis stator current and also the input current. Here the performance can be observed by two ways.

1) For T_L=0 Nm: Reference speed of machine is taken 1000rpm at t=0sec and subjected to reversing speed of -1000rpm at t=0.2secs and again motor is forwarded to 1000rpm at t=0.4secs.
2) For T_L=6 Nm: Reference speed of machine is taken 1000rpm at t=0sec and subjected to reversing speed of -1000rpm at t=0.2secs and again motor is forwarded to 1000rpm at t=0.4secs.

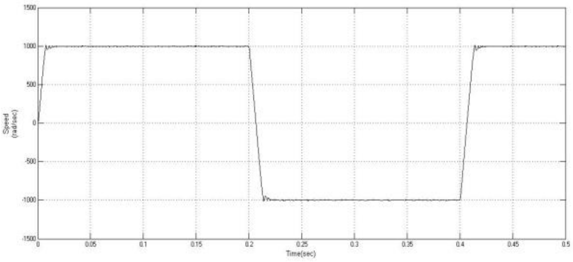

Fig. 7 Speed response of PMSM for T_L=0 Nm

The speed response of PMSM shown in the fig 7 shows that the Speed of PMSM reached to 1000rpm within less time and maintained same up to 0.2sec and transition takes place immediately after 0.2secs and reaches the negative speed in few milliseconds by close observation it is appearing that the machine takes more time for reversal rather than initial steady state speed.

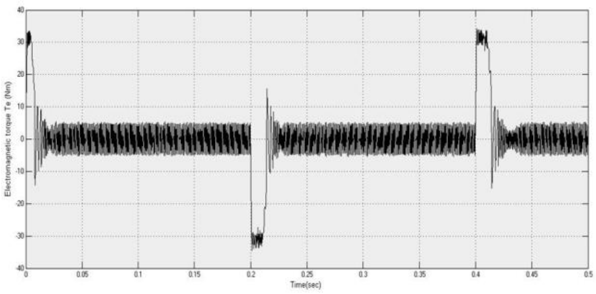

Fig. 8 Electromagnetic torque response of PMSM for T_L=0 Nm

The electromagnetic torque response of PMSM shown in the fig. 8 shows that Similar to the speed transition the electromagnetic torque also follow analogous path and it is high during starting. The torque of the machine reaches to negative peak implies negative torque since reversal taken place initially just after reversal.

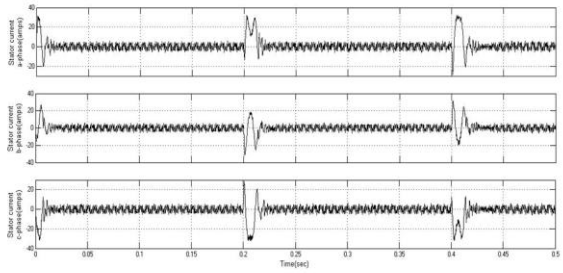

Fig. 9 Stator current of PMSM (3-phase) for T_L=0 Nm

The stator current of PMSM shown in the fig 9 shows that the 3-phase stator currents are of PMSM experiences high magnitude during starting and maintains the steady wave form gradually and there is peak overshoot at t=0.2sec and current reduced gradually since motor crosses zero speed during reversal. The current again reaches to high value and maintains the steady value after reversal process.

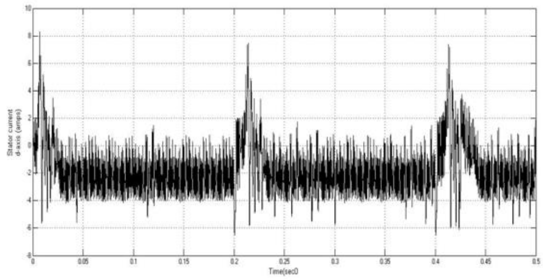

Fig. 10 Stator d-axis current waveform of PMSM for T_L=0 Nm

The stator d-axis current of PMSM is shown in the fig. 10 shows that it consists of spikes at starting and also during reversing and there is no much importance given to this discussion.

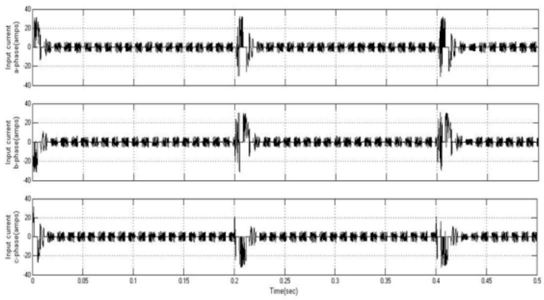

Fig. 11 Input current waveform of PMSM for T_L=0 Nm

The input current to the Matrix converter shown in the fig. 11 shows that it consists of harmonics implies induces harmonics or draws harmonic current from source.

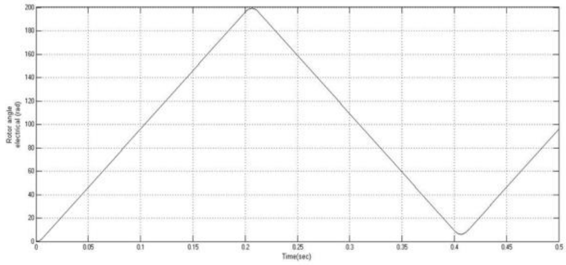

Fig. 12 Rotor angle waveform of PMSM for T_L=0 Nm

The rotor angle of PMSM shown in the fig. 12 shows that the rotor angle of PMSM Reaches to 200 electrical radians and it is then changed to 0 electrical radians which implies opposite direction.

The above all waveforms give the performance of PMSM during reversal applied with No-load and certain observations were written. Though there is a problem of harmonics from source side it is advisable to use because of its simple circuitry and fast dynamic response.

VII. CONCLUSION

A current control based vector control with simple modulation strategy MC-PMSM is presented and designed. In order to improve utilization of input voltage resources, input voltages are divided into 6 sections within one period. A current controller composed of single current hysteresis control is proposed and analyzed in details. According to outputs of current controller and section of input voltages, a proper input voltage is selected for increasing or decreasing output current of matrix converter or stator current of PMSM. The selection table is partially deduced. Simulating results show that Matrix converter based vector control of high speed PMSM drive with current controller the quality of feasibility and efficiency, which brings out theoretical foundations of experimentation. It also shows that the power factor of the system maintained unity when machine is under loading condition which implies the feasibility of power factor improvement.

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