DIRECT TORQUE AND FIELD ORIENTED CONTROL OF PMSM USING SVPWM TECHNIQUE

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ABSTRACT

In recent years, variable speed drives using synchronous motors operating from static frequency converter have become very versatile and a real competitor to both DC and IM drives, especially in high power, low speed range. Unlike the IM, the synchronous motor can be operated at variable power factor (leading, lagging or unity) as desired. So, there is an increasing use of synchronous motors as adjustable speed drives. Different types of control schemes have been suggested for variable speed AC drives fed from static power sources. Static power sources are now available with DC link inverters of voltage source (VSI) or current source (CSI) type and cyclo converters. The use of pulse width modulation (PWM) technique in case of VSI drives allows efficient and smooth operation, free from torque pulsations and cogging, lower volume and weight and provides a higher frequency range compared to CSI drives. Even for voltage source inverter, the commutation circuit is not needed, if the self-extinguishing switching devices are used. This project initially discusses the problems associated with different motors and why we are adapting the permanent magnet synchronous motor (PMSM). It presents the PMSM mathematical model based on the rotor reference frame. Later, it discusses about the control strategies which are used for controlling the PMSM. They are scalar control and vector control considering the consistency of selecting the optimal control of PMSM we go for Field Oriented Control and Direct Torque Control which are of vector type. In this work, we found the PWM technique which is suitable for generating pulse to the Voltage Source Inverter such that maximum voltage is utilized. The total work mainly concentrates on optimum control of PMSM with maximum voltage utilization with less switching losses. Key words: Permanent magnet synchronous motor, Mathematical modeling, Field

Keywords: Oriented Control, Direct Torque Control, Pulse Width Modulation, Voltage Source Inverter.

I INTRODUCTION

Electrical ac machines have been playing an important role in industry progress during the last few decades. All kinds of electrical ac drives have been developed and applied, which serve to drive manufacturing facilities such as conveyor belts, robot arms, cranes, steel process lines, paper mills, waste water treatment and so on. With the advances in power semiconductor devices, converter topologies, microprocessors, application specific ICs (ASIC) and computer-aided design techniques since 1980s, ac drives are currently making tremendous impact in the area of variable speed motor control systems. Nowadays, as in every area of the technology, a development process has been proceeded in industrial driving systems. The improvement of the switching speeds of the switching equipment has enabled control techniques which have high switching frequency and feasibility of high efficiency driving systems.

Among the ac drives, permanent magnet synchronous machine (PMSM) drives have been increasingly applied in a wide variety of industrial applications. The reason comes from the advantages of PMSM: high power density and efficiency, high torque to inertia ratio, and high reliability. Recently, the continuous cost reduction of magnetic materials with high energy density (e.g., samarium cobalt and neodymium-boron iron) makes the ac drives based on PMSM more attractive and competitive. In the high performance applications, the PMSM drives are ready to meet sophisticated requirements such as fast dynamic response, high power factor and wide operating speed range.

Control methods for electric motors can be divided into two main categories depending upon what quantities they control. The control algorithm, Scalar Control controls only magnitude. In scalar control the relationship between voltage/current and frequency are kept constant through the motors speed range. In scalar control we have poor dynamic performance of the drive system. In vector control with control of both magnitude and the angle of the flux it is possible to achieve higher dynamic performance of the drive system than scalar control can offer. Vector control techniques have made possible the application of PMSM for high performance applications where traditionally only dc drives were applied. The vector control scheme enables the control of the PMSM in the same way as a separately excited DC motor operated with a current-regulated armature supply where then the torque is proportional to the product of armature current and the excitation flux. Similarly, torque control of the PMSM is achieved by controlling the torque current component and flux current component independently.

It is now recognized that the two high-performance control strategies for PMSM are field-oriented control (FOC) and direct torque control (DTC).

II CONTROL STRATEGIES FOR PMSM

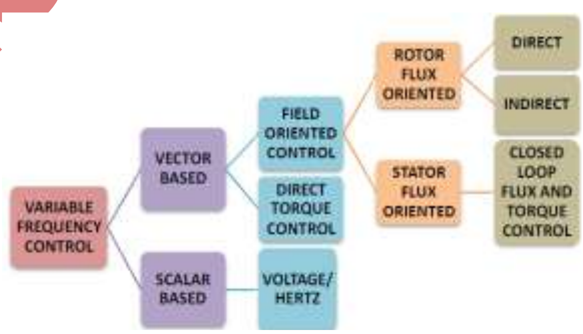

Fig 1: Overview of available control strategies

With control of both magnitude and the angle of the flux it is possible to achieve higher dynamic performance of the drive system than scalar control can offer. Two different types of strategies exist for vector control, Field Oriented Control and Direct Torque Control.

III DIRECT TORQUE CONTROL (DTC)

The torque of the permanent magnet synchronous motor is controlled by inspecting the armature current since electromagnetic torque is proportional to the armature current. For high dynamic performance, the current control is applied on rotor flux (dq) reference system that is rotated at synchronous speed. In this system, if the change of the back electromotor force (emf) and the inductance are sinusoidal, armature circuit inductance and magnet magnetic flux are constant. The main principle of DTC is to select the appropriate voltage vectors according to the stator magnetic flux, difference between the reference and real torque. The current control circuit that is constituted with the pulse width modulation (PWM) comparator circuit is not used in DTC. Therefore, if the DTC method is compared to PWM current control, it yields advantages such as; less parameter dependence and fast torque response as shown in fig 2 [4].

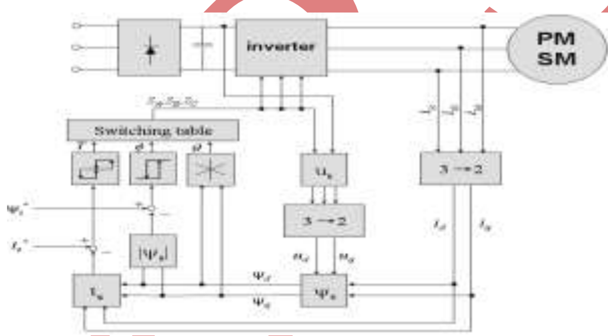

Fig 2: Scheme of SVPWM based on DTC for PMSM

The typical DTC includes two hysteresis controllers, one for torque error correction and one for flux linkage error correction. The hysteresis flux controller makes the stator flux rotate in a circular fashion along the reference trajectory. The hysteresis torque controller tries to keep the motor torque within a pre-defined hysteresis band. The control algorithm determines a control signal whose amplitude depends on the difference between desired and actual value. This control signal can assume any value in a given interval. The three signals used in the control action of a DTC system are torque error, flux linkage error and the angle of the resultant flux linkage vector.

IV FIELD ORIENTED CONTROL (FOC)

The field oriented control method is used in most of the AC motor drives to obtain high torque bandwidth and control performance. The principle of field oriented control of electrical drives is based on the control of both the magnitude and the phase of each phase current and voltage waveforms. In the field oriented control (FOC), phase currents and voltages are represented by vectors. In this control technique, some projections which transform a three-phase speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system are used to provide great simplification in expression of control equations. These transformations lead to a structure similar to that of a DC machine control In Field Oriented Control the goal is to control the direct and quadrature axis current id and iq to achieve the requested torque.

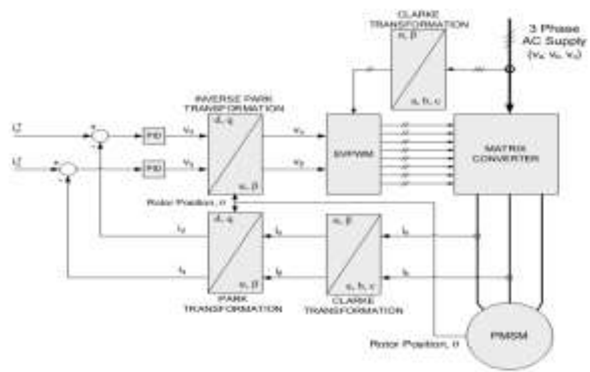

Fig 3: Scheme of SVPWM based on FOC for PMSM

Field oriented controlled machines need two input references. These are the torque component (aligned with the q-axis) and the flux component (aligned with d-axis). The aim of FOC is to perform real time control of torque and flux components separately. As stated above, to perform field oriented control, the control equations are projected from a three-phase non-rotating frame into a two co-ordinate rotating frame by using mathematical transformations. The mathematical transformations have been named as Clarke and Park transformations which simplify the expression of control equations and removes time dependencies. The good torque response, accurate speed control and full torque capability at zero speed are the advantages. The block diagram shown in figure 3 illustrates a permanent magnet synchronous motor control scheme based on field orientation principle.

V SPACE VECTOR PULSE WIDTH MODULATION:

Another method for increasing the output voltage about that of the SPWM technique is the space vector PWM (SVPWM) technique. In the SVPWM technique, the duty cycles are computed rather than derived through comparison as in SPWM. The SVPWM technique can increase the fundamental component by up to 27.39% that of SPWM. The fundamental voltage can be increased up to a square wave mode where a modulation index of unity is reached. SVPWM is accomplished by rotating a reference vector around the state diagram, which is composed of six basic non-zero vectors forming a hexagon. A circle can be inscribed inside the state map and corresponds to sinusoidal operation. The area inside the inscribed circle is called the linear modulation region or under-modulation region.

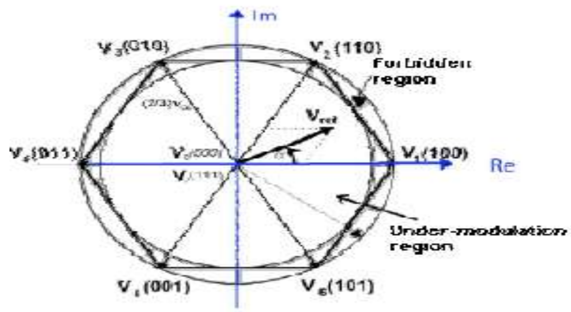

Fig 4: Under-modulation and Over-modulation Regions in Space Vector Representation

As seen in Figure 4, the area between the inside circle and outside circle of the hexagon is called the nonlinear modulation region or over-modulation region. The concepts in the operation of linear and nonlinear modulation regions depend on the modulation index, which indirectly reflects on the inverter utilization capability.

VI SIMULATION AND RESULTS ANALYSIS

Here the MATLAB/Simulink model of the permanent magnet synchronous motor is developed according to the dq model. In the simulation, the stator magnetic flux amplitude value is assumed to be the same as the value of the permanent magnet flux.

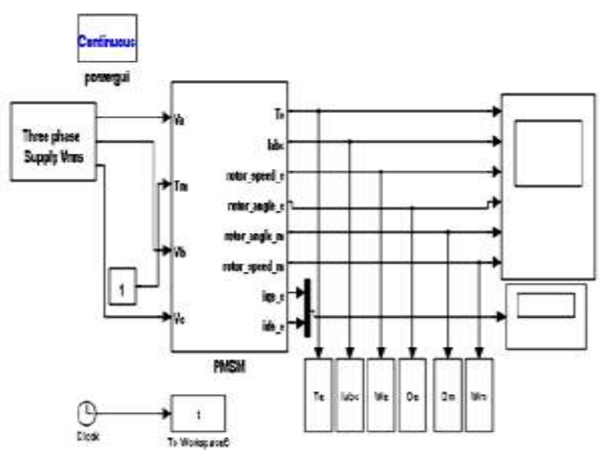

Fig 5: Simulation model of PMSM

CASE 1: SIMULATION MODELS OF FIELD ORIENTED CONTROL FOR PMSM BASED ON SPWM TECHNIQUE:

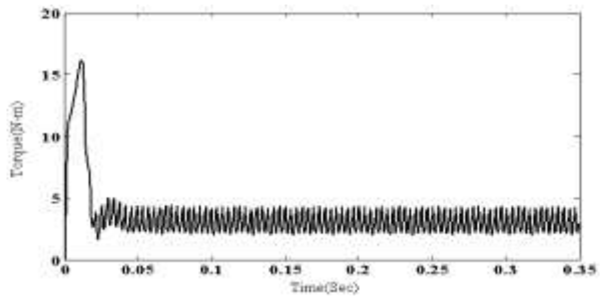

Fig 6: Torque characteristics for SPWM based FOC of PMSM

The torque characteristics for SPWM based FOC of PMSM has more number of oscillations and in speed characteristics it take more time to attain steady state position which can be seen in the figure 6 and 7 respectively.

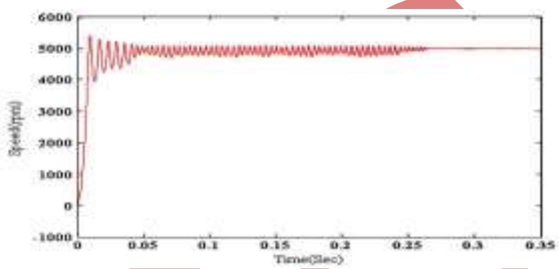

Fig 7: Speed characteristics for SPWM based FOC of PMSM

CASE 2: SIMULATION MODELS OF FIELD ORIENTED CONTROL FOR PMSM BASED ON THIPWM TECHNIQUE:

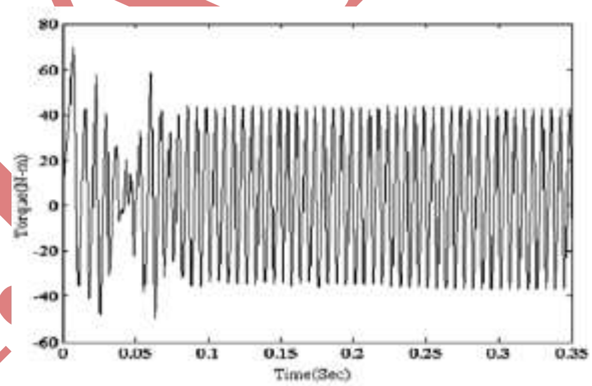

Fig 8: Torque characteristics for THIPWM based FOC of PMSM

The torque characteristics for Third Harmonic Injection PWM based FOC of PMSM has more number of oscillations compared to Sine PWM and in speed characteristics it has never attained a steady state position, as shown in the figure 8 and 9 respectively.

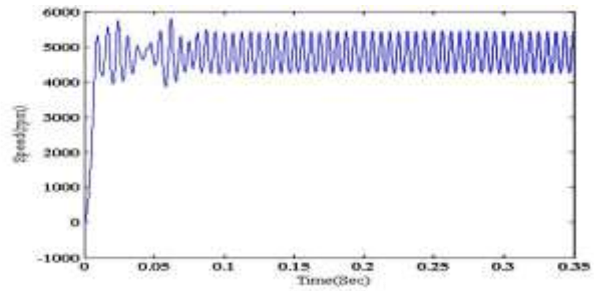

Fig 9: Speed characteristics for THIPWM based FOC of PMSM

CASE 3: SIMULATION MODELS OF FIELD ORIENTED CONTROL FOR PMSM BASED ON SVPWM TECHNIQUE:

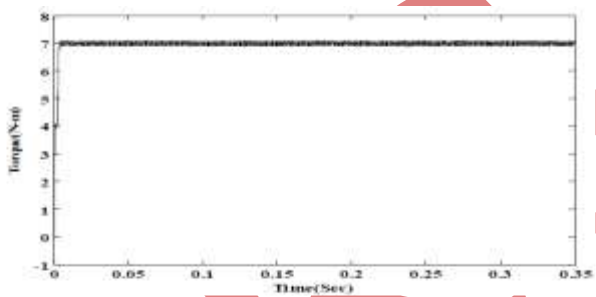

Fig 10: Torque characteristics for SVPWM based FOC of PMSM

The torque characteristics for Space Vector PWM based FOC of PMSM has less number of oscillations compared to Sine PWM and in speed characteristics it has attained a steady state position with in no time, as shown in the figure 10 and 11 respectively.

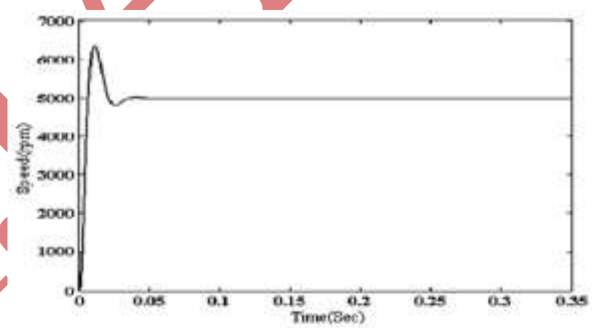

Fig 11: Speed characteristics for SVPWM based FOC of PMSM

CASE 4: SIMULATION MODEL OF DIRECT TORQUE CONTROL FOR PMSM BASED ON SPACE VECTOR PWM TECHNIQUE:

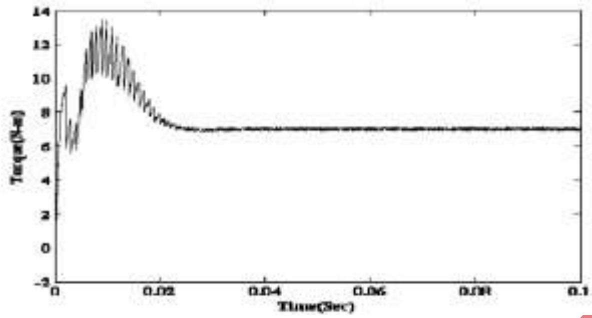

Fig 12: Torque characteristics for SVPWM based DTC of PMSM

The torque characteristics for Space Vector PWM based DTC of PMSM initially have more number of oscillations and later followed the same as Space Vector based FOC of PMSM and the in speed characteristics it has attained a steady state position in less time but not better than that of Space Vector based FOC of PMSM which can be seen in the figure 12 and 13 respectively.

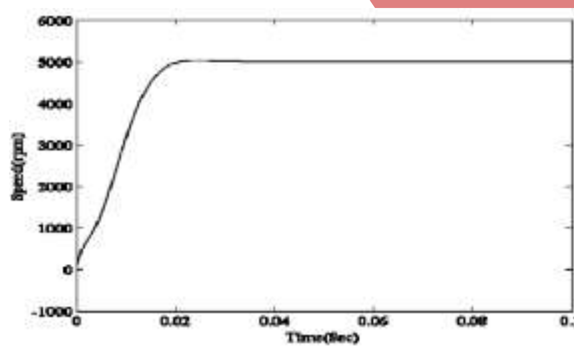

Fig 13: Speed characteristics for SVPWM based DTC of PMSM

Comparison of Total Harmonic Distortion of various PWM techniques for FOC of PMSM

CONTROL TECH	SPWM	SVPWM	THIPWM	SVPWM+ FOC	SVPWM+ DTC
THD	28.97	12.47	4.59	12.47	23.24

VII CONCLUSION

Two control strategies are proposed for PMSM drive, field oriented control (FOC) using SVPWM, SPWM and Third Harmonic Injection PWM and direct torque control (DTC) using SVPWM. The field oriented control (FOC) method estimates the stator current at the next sample using the motor equations. Also, on the basis of the field-oriented control, the reference currents of PMSM are calculated in terms of minimum torque ripples and fixed speed operation. Thereupon, the difference between estimated and calculated reference currents are applied to choose a proper switching vector based on SVPWM, and so as with the SPWM. But while considering the Third Harmonic Injection PWM it is highly non-linear, so it increases the non-linearity of the system, so it cannot be used in controlling the PMSM. While in direct torque control (DTC) method the flux and torque are calculated and compared with the reference values using hysteresis comparators. Thereupon, the difference between estimated and calculated reference torque values are applied to choose a proper switching vector using flux table based on SVPWM, which is used to feed the inverter pulses so as to control the PMSM.

Several numerical simulations using MATLAB/SIMULINK have been carried out in steady-state and transient-state. According to the results, the proposed techniques are able to reduce torque ripple, minimize speed error, and lessen time to reach transient-state at abrupt mechanical load changes. In addition, we could have some other advantages like, constant switching frequency, fast transient response, and tunable output torque and speed with lower error. But considering the consistency of selecting the control technique for PMSM, on comparing both the techniques FOC shows better performance in both torque and speed dynamics.

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