Energy Optimization of Field Oriented Poly-Phase Induction Motor Drive

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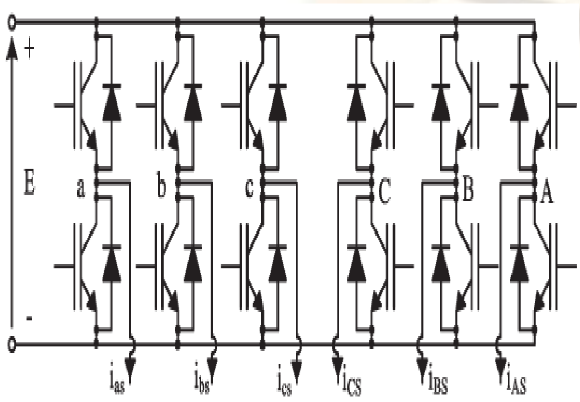
Abstract—The use of six-phase induction motor for industrial drives presents several advantages over the conventional three-phase drive such as improved reliability, magnetic flux harmonic reduction, torque pulsations minimization, and reduction on the power ratings for the static converter. For these reasons, six-phase induction motors are beginning to be a widely acceptable alternative in high power applications. A typical construction of such drives includes an induction machine with a dual three-phase connection, where two three-phase groups are spatially shifted 30 electrical degrees, a six-leg inverter, and a control circuit. By controlling the machine's phase currents, harmonic elimination and torque-ripple reduction techniques could be implemented.

***Index Terms*—*Six phase induction machine,* Field-oriented control (FOC), space vector pulse width modulation (SVPWM).**

I. INTRODUCTION

THREE-PHASE induction machines are today a standard for industrial electrical drives. Cost, reliability, robustness, and maintenance-free operation are among the reasons these machines are replacing dc drive systems. The development of power electronics and signal processing systems has eliminated one of the greatest disadvantages of such ac systems, that is, the issue of control. With modern techniques of field-oriented vector control, the task of variable-speed control of induction machines is no longer a disadvantage. The need to increase



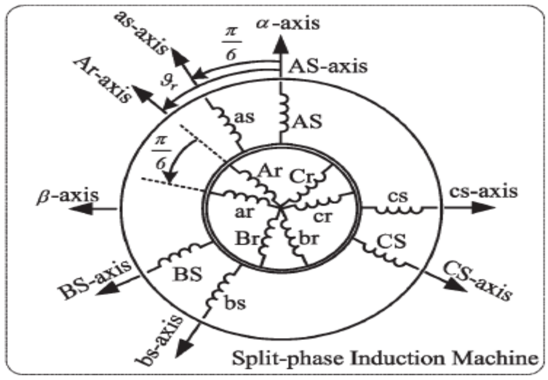


Fig.1.Six-phase voltage-source-inverter-fed split-phase machine.

system performance, particularly when facing limits on the power ratings of power supplies and semiconductors, motivates the use of phase number other than three, and encourages new pulse width modulation (PWM) techniques, In a multiphase system, here assumed to be a system that comprises more than the conventional three phases, the machine output power can be divided into two or more solid-state inverters that could each be kept within prescribed power limits[1]. Also, having additional phases to control means additional degrees of freedom available for further improvements in the drive system. A particular case of split-phase or dual-stator machine, the six-phase machine can be built by splitting a three-phase winding into two groups. Usually these three-phase groups are displaced by 30 electrical degrees from each other. This arrangement composes an asymmetrical six-phase machine since the angular distance between adjacent phases is not all the same . The analysis of an induction machine for multiple phases and arbitrary displacement between them is presented in [3] where the six-phase induction machine is used as an example and an equivalent circuit has been derived. The model for a six-phase machine was developed in [4]. Reliability is one of the advantages in using six-phase systems. In the case of failure of one of the phases, either in the machine or in the power converter, the system can still operate at a lower power rating since each three-phase group can be made independent from each other. In the case of losing one phase, the six-phase machine can continue to be operated as a five-phase machine as described in [5]. Among the different multiphase drive solutions, one of the most interesting and widely discussed in the literature is the dual three-phase induction machine having two sets of windings spatially shifted by 30 electrical degrees with isolated neutral as shown in Fig. 1.[6] In authors demonstrated, by analog simulation of a six-step voltage-fed dual-three phase induction drive, that 30 electrical degrees displacement between the two stator winding sets eliminates the sixth harmonic pulsating torque component and also significantly reduces the rotor losses by reducing the rotor current harmonic components.

SIX PHASE INVERTER:-

The inverter input dc voltage is regarded further on as being constant. Each switch is assumed to conduct for 180.Phase delay between firing of two switches in any subsequent two phases is equal to 360/6 =60. One complete cycle of operation of the inverter can be divided into six distinct intervals indicated in the time domain waveforms of leg voltages. at any instant in time there are six switches that are 'on' and six switches that are 'off'. In this mode of operation there are three conducting switches from the upper six and three from the lower six, or vice versa. This mode of operation leads to, as shown shortly, a square wave phase-to-neutral output voltage waveform, the reason being the spatial displacement between the six-phases of 60°.

II PROPOSED SCHEME:-

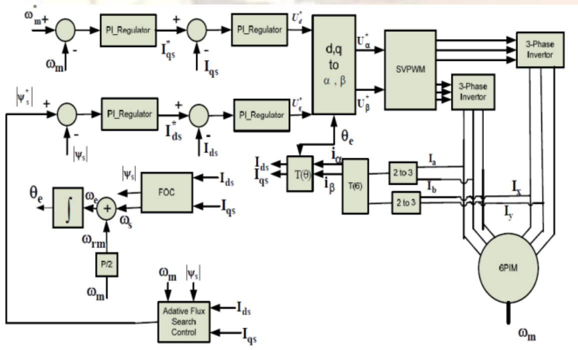


Fig2:-Diagram of adaptive flux search control of FOC of six phase induction motor.

FIELD ORIENTED CONTROL SCHEME

The Field Orientated Control (FOC) consists of controlling the stator currents represented by a vector. The six phase induction motor model is controlling by field oriented control as shown in fig2.[7] This control is based on projections which transform a three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system. These projections lead to a structure similar to that of a DC machine control. Field orientated controlled machines need two constants as input references: the torque component (aligned with the q co-ordinate) and the flux component (aligned with d co-ordinate). As Field Orientated Control is simply based on projections the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation (steady state and transient).The basic scheme for FOC as shown in fig.3[8]

THE BASIC SCHEME FOR FOC

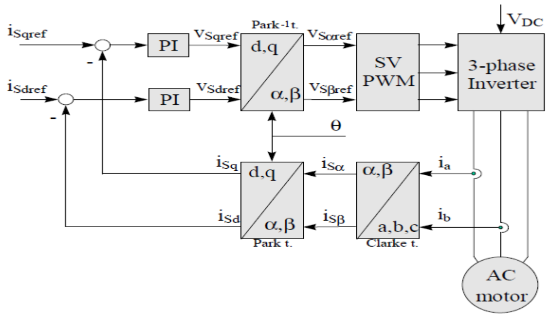


Fig3.schematic of FOC

II. MACHINE MODEL

The Six-phase induction machine considered in this paper consists of a stator with two separate windings shifted by 30 electrical degrees and a double neutral point, having similar pole numbers and parameters. The popular method in six phase induction machine modeling is VSD (Vector Space Decomposition) [9], [10]. In VSD method, the machine modeling is achieved in three two-dimensional orthogonal subspaces [11]. Fundamental harmonic of the machine and the harmonics of the order 12n±1 (n=1, 2, 3 …) are mapped to the (d-q) subspace. Harmonics of the order 6n±1 (n=1, 3, 5 …) are mapped to (z1-z2) subspace and produces losses and then they must be reduced to improve efficiency. This (d-q) model can be described by the following set of differential equations:

$$v_{d,qs} = R_s i_{d,qs} + \frac{d\psi_{d,qs}}{dt} \pm j\omega_e \psi_{d,qs} \qquad (1)$$

$$0 = R_r i_{d,qr} + \frac{d\psi_{d,qr}}{dt} \mp j(\omega_e - \omega_r)\psi_{d,qs}$$

$$\psi_{d,qs} = L_s i_{d,qs} + M i_{d,qr} \qquad (2)$$
$$\psi_{d,qr} = L_r i_{d,qr} + M i_{d,qs}$$

Where;

$$\omega_r = \frac{P}{2}\omega_m , L_s = L_{ls} + M , L_r = L_{lr} + M , \qquad (3)$$
$$M = 3L_{ms}$$

$$v_{z1,z2} = R_s i_{z1,z2} + L_{ls}\frac{di_{z1,z2}}{dt} \qquad (4)$$

The control algorithm and supplying voltage must minimize the current harmonics generated in the (z1-z2) subspace.Electromechanical energy conversion is as the following:

$$T_e = \frac{3P}{2}\frac{M}{L_r}(\psi_{dr} i_{qs} - \psi_{qr} i_{ds}) \quad (5)$$

$$T_e - T_l = \frac{J}{P}\frac{d\omega_r}{dt} + \frac{F}{P}\omega_r \quad (6)$$

While F is the coefficient of friction, J is the motor inertia constant, and P is the number of pole pairs. To achieve the field oriented control with the rotor flux orientation, the phase of reference system such that the rotor flux is entirely in the q-axis, resulting in

$$\psi_{qr} = 0 \quad (7)$$

Thus

$$T_e = \frac{3P}{2}\frac{M}{L_r}(\psi_{dr} i_{qs}) \quad (8)$$

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} = \frac{R_r M}{L_r} i_{ds} \quad (9)$$

$$\omega_s = \frac{R_r M}{L_r}\frac{i_{qs}}{\psi_{dr}} \quad (10)$$

MOTOR LOSSES DETERMINATION AND ADAPTIVE FLUX SEARCH CONTROL

. The main electrical losses in motor are consist of core and copper losses. This kind of loss can be improved by suitable optimization algorithm. The core losses consist of hysteresis and eddy current losses. This loss is proportional to square magnitude of flux as:

$$|\Psi_s| = \sqrt{\Psi_{sd}^2 + \Psi_{sq}^2} \quad (11)$$

$$P_{core} \alpha |\Psi_s|^2 \Rightarrow P_{core} = k|\Psi_s|^2 \quad (12)$$

Stator and rotor copper losses are given by:

$$P_{cu} = P_{cus} + P_{cur} = \frac{1}{2}R_s(I_{sd}^2 + I_{sd}^2) + \frac{1}{2}R_r(I_{rd}^2 + I_{rd}^2)$$

(13)

Copper loss in (d-q) subspace are determined by the corresponding resistances and currents

$$P_z = \frac{1}{2}R_s(I_{sz1}^2 + I_{sz2}^2) + \frac{1}{2}R_s(I_{rz1}^2 + I_{rz2}^2) \quad (14)$$

As see from (11), core loss is dependent on motor flux. If motor has a load or speed under its nominal point and flux reference is in nominal point, system efficiency is low. For increasing 6PIM efficiency, motor flux is reduced until the input power reduced and output power is not changed. In this study, the motor output power is kept constant because its output torque and speed is constant. Output power is expressed as:

$$P_{out} = T_e * w_{rm} \quad (15)$$

After calculating the input power the efficiency is as:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + Losses} \quad (16)$$

The main advantage of search control is that it does not depend on motor or converter parameters as other efficiency control strategies do, and it leads to the true optimal efficiency. An obvious disadvantage is its slow speed. The Search control techniques iteratively adjusted the machine flux reference. The loss power is relative to machine flux thus for a given load and speed, the stator flux is varied to optimal point with fixed load and speed.

III. SIMULATION AND EXPERIMENTAL RESULTS

In order to validate the efficiency of the proposed method,
a simulation model as fig4. is implemented using Matlab. Simulation results of efficiency optimization of FOC 6PIM. In these simulations, motor speed reference is 1500rpm. Experimental results are shown in fig..5. The test-bed is composed of a six-phase induction motor. Two three-phase inverters are designed and used to drive of the motor.This results are temparory and future work are under process.
Simulation and experimental results have almost similar responses.

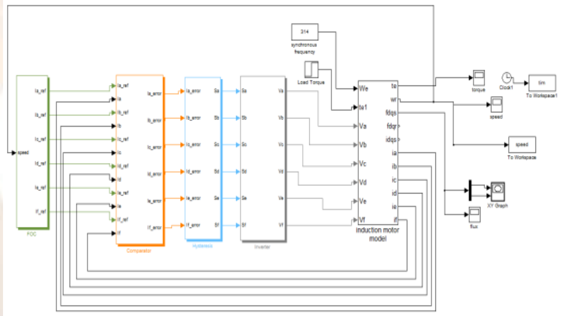
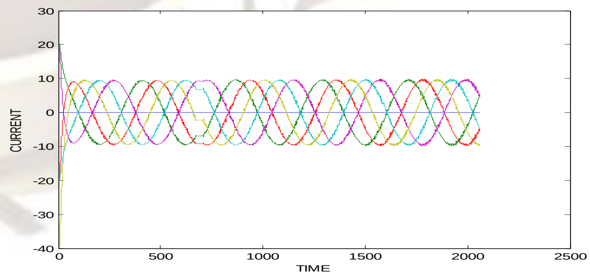


Fig.4: Simulation model of Six Phase induction motor with FOC controller.



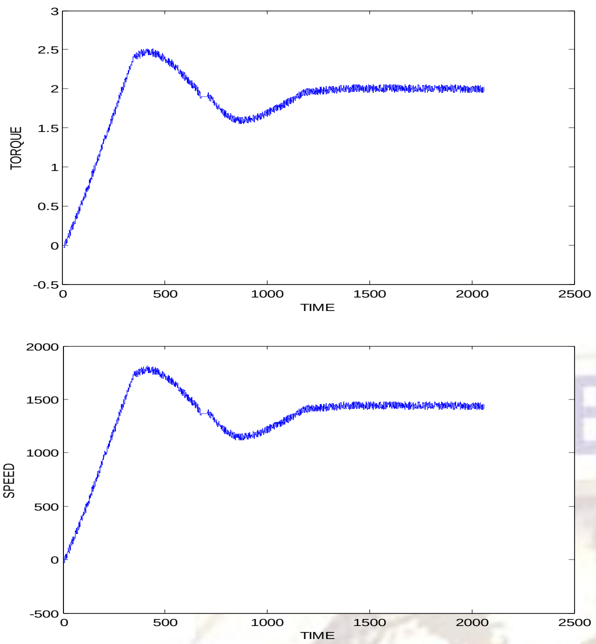


Fig.5 Output waveforms of current, torque and speed.

IV. CONCLUSION

A simple and effective space vector motor control for six-phase voltage source- inverter-fed six-phase split-phase induction motors has been presented in this paper. Multiphase systems are broadly used in industry to achieve higher power levels based in limited-range power converters. Additional torque production can be obtained in these systems This method is based on the adaptive variation of flux in FOC of 6PIM to loss minimization.. It getting better performance and increase the efficiency of motor. Harmonic elimination and torque ripple reduction technique could be implemented.

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