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Speed Control of Five-Phase Induction Machine using Direct Torque Control

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Abstract

Induction motor is the most applied motor in the industrial applications .The Direct Torque Control (DTC) technique has a feature of precise and quick torque response. In DTC, the generation of inverter switching state is made to restrict the stator flux and electromagnetic torque errors within the respective flux and torque hysteresis bands. This paper presents a novel method to improves the performance of a five-phase induction machine (IM) driven by a five leg inverter. The proposed approach describes the use of classic direct torque control (DTC) technique for induction motor control. In induction motor drive the frequently occurring stator flux demagnetization is investigated when the IM runs at lower speeds, and a solution is provided to overcome this phenomenon. It can be observed that the proposed technique can significantly improve the rate of change of stator flux, the torque response, and the speed response compared with traditional method.

Key words

Five Leg Inverter, Five Phase Induction Motor, DTC, Feedback Control

I. Introduction

Three-phase induction machine in industry is mostly used for speed control. For speed control ac drives are used which require a power electronic converter for their supply (mostly an inverter with a dc link), therefore number of machine phases is effectively unlimited. Multi-phase ac drive applications have increases enormously, since multiphase machines tender many advantages over their three-phase counterparts [1-5]. The Space Vector Pulse Width Modulation (SVPWM) method is an advanced, computation-intensive PWM method and best among all the PWM techniques. Because of its superior performance characteristics, it has been finding well- known application in recent years. The Pulse Width Modulation methods discussed so far have only considered implementation on half bridges operated independently, giving suitable Pulse Width Modulation methods performance. [6-10] with a machine load, the load neutral is normally isolated, which causes interface among the phases. This interface was not considered before in the Pulse Width Modulation discussion.

Multiphase Motor drives are mostly proposed for high power application such as traction and hybrid vehicles aircraft and etc. The advantage of multiphase machines, with respect to conventional three-phase machines are reduced torque pulsations, reduced dc-link harmonics, higher torque density, greater fault tolerant, improvement of the drive noise characteristic, reduction in the required rating per inverter leg and achieving a high power motor drive with a less dangerous dc-link voltage and high reliability [10-17]. Among multi-phase schemes, five-phase and six-phase schemes are more common.

This paper deals with a five phase induction motor (FPIM) speed control. Induction motor (IM) has a low cost and is suitable for many manufacturing applications. In this paper a high performance FPIM drive is proposed. Induction motor drives controlled by direct torque control (DTC) have been still now employed in high performance industrial application [18-21], has achieved a quick torque response, and has been applied in various industrial applications.

II. Five Leg Inverter

The five-phase voltage source inverter (VSI) contains a switching network of 10 power switches arranged to form 5 legs, each leg supplies one motor phase, Fig 1 shows the voltage source five phase inverter. Only one of the power switches of the same leg can operate in the "on" state to avoid the short circuit of the dc-link, where (Sa, Sb, Sc, Sd, Se) are switching functions of the inverter legs with value "1" indicates that the upper switches in the corresponding switching arms are "on", while the "0" indicates the "on" state of the lower switches. So, 32 possible states can be obtained. In this case, the voltages applied to the five phase induction motor are determined only by the inverter switching modes and regarded as discrete values. The machine phase voltage can be computed using the switching function associated to one inverter leg [17].

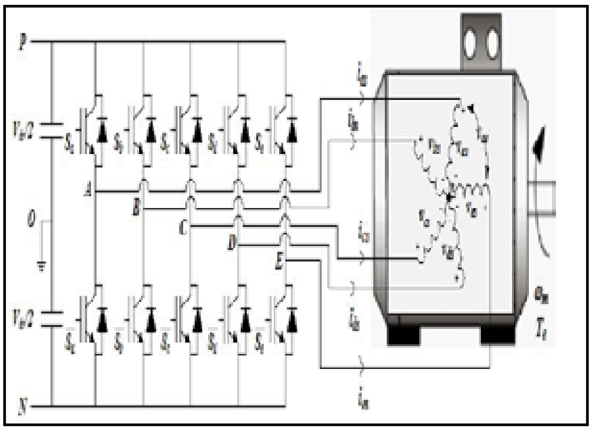

Fig. 1 : Five legs inverted fed five phase induction motor

The proposed mainly consist of a five phase induction motor drive consists of dc power supply, filter, five leg inverter, DTC controller. The Dc supply fed inverter block converts the DC supply into the AC to supply power to five phase induction motor. The motor speed is sensed and the sensed actual speed and the motor reference speed are compared. The speed error and change in speed error is given as the input to the DTC controller and the output of the FLC is the Electromagnetic torque (Te*) and the quadrature-axis stator current reference is calculated from electromagnetic torque (Te*) equation. The flux component of current for the desired rotor flux is (ψ) determined, the variation of magnetizing inductance (Lm) will cause some drift in the flux. The slip frequency is generated from i □ in feed forward manner, signal is added with speed signal to generate frequency signal. The unit vector the the signal cos and sin are generated by integration, command current and in the vector control are compared with the respective and currents

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generated by transformation of phase current equation with help of unit vector. The respective error generate the voltage command signal through P-I compensators and these voltage commands are then converted into and voltages, these voltages are given to the input of SVPWM. The outputs of the Space vector pulse width modulation are the signals that drive the inverter. Among various modulation techniques for inverter, SVPWM technique is an attractive technique which directly uses the control variable given by the control system and identifies each switching vector as a point in complex space.

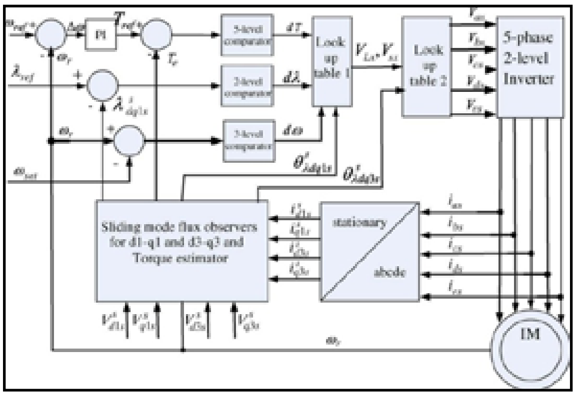

Fig. 2 : Proposed system controller for five leg inverter fed induction motor drive.

III. Voltage-Vector Selection

For the classic DTC, the estimated electromagnetic torque and stator-flux linkage are compared with the reference torque and stator flux. Their errors can be controlled within a predefined torque and flux band using a comparator-based hysteresis controller. The required rate of change of the electromagnetic torque and stator-flux linkage can be determined according to the output state of the two controllers. These can be used to select appropriate voltage vectors so as to manipulate the magnitude and phase angle of stator-flux linkage. Based on these, the electromagnetic torque and stator-flux linkage can be controlled.

Fig 2 shows the DTC control system block diagram. The five phase currents of the IM are transformed from the *abcde* reference frame into the stationary reference frame. The $d1$–$q1$ and $d3$–$q3$ stator-flux linkage are estimated by sliding-mode flux observers

The torque is related to the load angle which can be changed by altering the voltage-vector magnitude. There are two virtual voltage vectors that force the same polarity of rate of change of stator flux and torque but with a difference in the magnitude of the change. The short virtual voltage vector VSx produces a lower rate of change of electromagnetic torque compared with the long vector VLx. The short virtual vector can reduce the torque ripple. Therefore, a five-level comparator controller is developed so as to utilize VSx and VLx vectors according to the speed and torque requirements.

Table 1:

$d\lambda$	dT	Sector 1	2	3	4	5	6	7	8	9	10
1	+2	V_{L2}	V_{L3}	V_{L4}	V_{L5}	V_{L6}	V_{L7}	V_{L8}	V_{L9}	V_{L10}	V_{L1}
	+1	V_{S2}	V_{S3}	V_{S4}	V_{S5}	V_{S6}	V_{S7}	V_{S8}	V_{S9}	V_{S10}	V_{S1}
	0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
	-1	V_{S10}	V_{S1}	V_{S2}	V_{S3}	V_{S4}	V_{S3}	V_{S6}	V_{S7}	V_{S8}	V_{S9}
	-2	V_{L10}	V_{L1}	V_{L2}	V_{L3}	V_{L4}	V_{L5}	V_{L6}	V_{L7}	V_{L8}	V_{L9}
0	+2	V_{L5}	V_{L6}	V_{L7}	V_{L8}	V_{L9}	V_{L10}	V_{L1}	V_{L2}	V_{L3}	V_{L4}
	+1	V_{S5}	V_{S6}	V_{S7}	V_{S8}	V_{S9}	V_{S10}	V_{S1}	V_{S2}	V_{S3}	V_{S4}
	0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
	-1	V_{S9}	V_{S10}	V_{S1}	V_{S2}	V_{S3}	V_{S4}	V_{S5}	V_{S6}	V_{S7}	V_{S8}
	-2	V_{L9}	V_{L10}	V_{L1}	V_{L2}	V_{L3}	V_{L4}	V_{L5}	V_{L6}	V_{L7}	V_{L8}

(A)VIRTUAL VOLTAGE-VECTOR SET LOOKUP TABLE ($-\omega$set $<\omega$act $\leq\omega$set)

Table 2 :

$d\lambda$	dT	Sector 1	2	3	4	5	6	7	8	9	10
1	+2	V_{L2}	V_{L3}	V_{L4}	V_{L5}	V_{L6}	V_{L7}	V_{L8}	V_{L9}	V_{L10}	V_{L1}
	+1	V_{S2}	V_{S3}	V_{S4}	V_{S5}	V_{S6}	V_{S7}	V_{S8}	V_{S9}	V_{S10}	V_{S1}
	0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
	-1	V_{S10}	V_{S1}	V_{S2}	V_{S3}	V_{S4}	V_{S5}	V_{S6}	V_{S7}	V_{S8}	V_{S9}
	-2	V_{L10}	V_{L1}	V_{L2}	V_{L3}	V_{L4}	V_{L5}	V_{L6}	V_{L7}	V_{L8}	V_{L9}
0	+2	V_{L5}	V_{L6}	V_{L7}	V_{L8}	V_{L9}	V_{L10}	V_{L1}	V_{L2}	V_{L3}	V_{L4}
	+1	V_{S5}	V_{S6}	V_{S7}	V_{S8}	V_{S9}	V_{S10}	V_{S1}	V_{S2}	V_{S3}	V_{S4}
	0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
	-1	V_{S9}	V_{S10}	V_{S1}	V_{S2}	V_{S3}	V_{S4}	V_{S5}	V_{S6}	V_{S7}	V_{S8}
	-2	V_{L9}	V_{L10}	V_{L1}	V_{L2}	V_{L3}	V_{L4}	V_{L5}	V_{L6}	V_{L7}	V_{L8}

(B)VIRTUAL VOLTAGE-VECTOR SET LOOKUP TABLE (0 $<\omega$act $\leq\omega$set)

The 32 inverter states are distributed in the $d1$–$q1$ and $d3$–$q3$ vector space using vector-space decomposition. There are four magnitudes of space vectors: long, medium, short, and null. The voltage magnitudes are 0.6472, 0.4, and 0.2472 Vdc, respectively.

For the five-phase system, it is required to null the $d3$–$q3$ vector-space voltage in order to produce sinusoidal phase volt- ages. it can be observed that the voltage vectors in the $d1$–$q1$ vector space can have the same direction (for example, $V1$, $V11$, $V21$), but in the $d3$–$q3$ vector space, the direction of the medium vector ($V11$) is opposite to the long and short voltage vectors ($V1$, $V21$). This feature can be used to decrease and cancel the $d3$–$q3$ stator flux if the location of the stator flux is known [13]. For example, if the stator flux is located in sector {1} of the $d1$–$q1$ vector space, all the vectors in sector {3} can be used to increase the $d1$–$q1$ stator flux as the radial components of these vectors are in the positive direction of stator flux. Under this condition, when the $d3$–$q3$ stator flux satisfies $7\pi/10$ $\theta\lambda$dq3 $17\pi/10$, if $V13$ is employed, the $d3$–$q3$ stator flux increases; if $V3$ or $V23$ are employed, the $d3$–$q3$ stator flux decreases. The opposite effects occur if $-3\pi/10$ $\theta\lambda$dq3 $7\pi/10$ is satisfied. Thus, the $d3$–$q3$ voltage vector (hence, the flux) can be controlled (hence eliminate using this voltage-vector cancellation feature. According to the aforementioned cancellation method, it can be derived that there are two groups of canceling voltage vectors in each sector.

The medium and long vector (for example, inverter states $V1$ 11001 and V11 10000) can be selected alternatively so as to eliminate the $d3–q3$ voltage vector, where the maximum resultant voltage-vector magnitude is $0.553V$dc in the $d1–q1$ vector space. The ratio of the dwell times of the long vector and medium vector is 1.618. The short and medium vectors (for example, inverter states $V21$ 01001 and $V11$ 10000) can be utilized to eliminate the $d3–q3$ voltage vector, where in this case, the maximum resultant vector magnitude is restricted to $0.342V$dc in the fundamental vector space. The ratio of the dwell times of the medium vector and the short vector is 1.618. A two-level five-phase SVM technique has been pro- posed previously to eliminate the $d3–q3$ component [14], [15] as has an SVM-DTC technique with $d3–q3$ elimination [16]. There are five voltage vectors selected during each switching period, and the aim is to control the $d3–q3$ voltage second product to be zero over the switching period. The maximum vector length formulated is $0.526V$dc in $d3–q3$ vector plane. The stator flux and torque variables are not directly controlled if SVM-DTC is employed. However, classic DTC is a variable structure control strategy. This method provides direct control of the stator flux and electromagnetic torque through optimum selection of the inverter states in each sampling period. Because flux and torque are motor variables that are directly controlled, there is no need for a pulse width modulator, as used in vector-controlled drives or SVM-DTC drives. During each switching period, an individual voltage vector is selected, and the maximum resultant voltage-vector magnitude of $0.553V$dc is developed in the $d1–q1$ vector space for the five-phase drive system. This increases the voltage vector by 5% using classic DTC. This can improve the torque and flux response significantly.

Therefore, a new virtual vector space is defined that can eliminate the $d3–q3$ component, as shown in Fig. 3. VLx represents the resultant vector using medium and long voltage vectors for cancellation, and VSx represents the resultant vector using medium and short voltage vectors. There are two virtual vectors with different magnitudes available to control the torque and flux while maintaining zero $d3–q3$ voltage. This can be used to fine-tune the rate of change of electromagnetic torque and the regulation of stator flux.

IV. Results and observations:

The proposed model is simulated using MATLAB /SIMULINK software. The control system block set and simpowersystem block sets are used to develop the proposed mode. The motor is simulated using developed d-q model in the stationary reference frame. The machine is fed by a five leg PWM voltage source inverter and a closed loop Direct Torque Controller. The torque is limited to twice the rated value (16.67 Nm).

Five phase induction motor rating -Table III

Power	7.5 hp
Voltage	400 Volt
Poles	4
Frequency	50 Hz
Stator Resistance	0.22 Ω
Rotor Resistance	0.16
Mutual inductance	151.5 mH
Mechanical motion inertia	0.04 Kg-m^2

The five phase induction motor rating are shown in the Table III, mathematical modeling of five phase motor is performed in the simulink environment later it is fed to five phase inverter, the corresponding model of the proposed system is shown in the figure fig(2), which shows the individual subsystems for three phase inverter and proposed controller and a five phase induction motor.

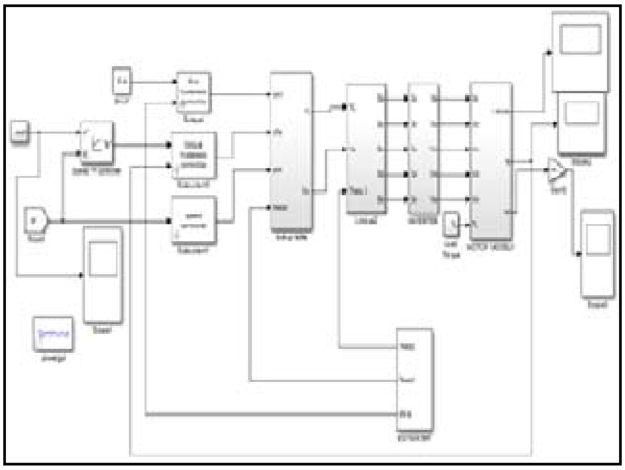

Fig. (3) : Matlab/simulink model of proposed system

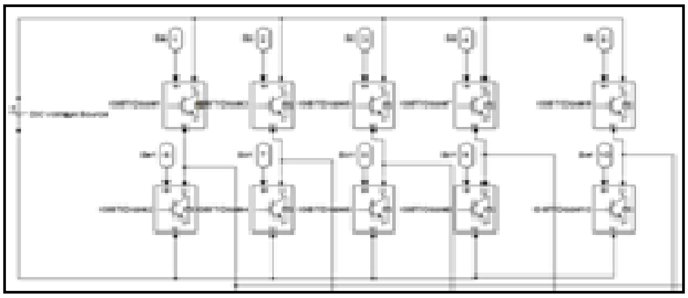

Fig. (4) : Matlab/simulink model of five phase inverter

The FPIM when fed with a proposed direct torque controller produce a response of drive current as show in the fig(5), the initial instabilities in the current are belongs to the install startup of motor. The motor current found stable after a 0.1 sec, the simulation is executed up to 0.5 sec.

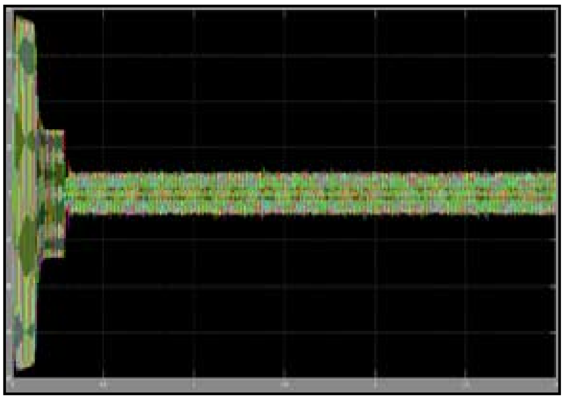

Fig. (5) : Five phase induction motor current

The electromagnetic torque response of the five phase induction motor when fed with proposed controller is shown in the Fig(5), as observed an initial drastic rise in the motor torque later it become stable at 10(N/M).

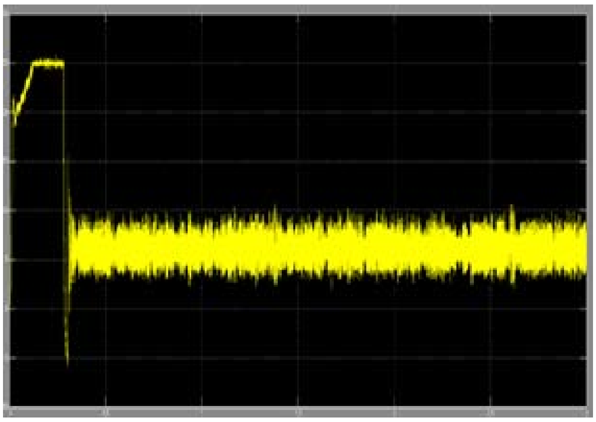

Fig. (6) : Electromagnetic Torque (N/M) of induction motor.

The speed characteristic of a FPIM is 2000 rpm, the effect of Direct Torque Controller is observed efficient on induction motor control, the machine speed rice linearly and it becomes stable after 0.05 sec.

Fig. (7) : Speed response of induction motor

The proposed system performance when it is applied with direct torque controller is observed effective in tremens of its various parameters such as machine current, speed and electromagnetic torque.
The smooth speed operation of five phase induction motor when applied with the various dynamic loads is ineffective for considerable time span of operation.

V. Conclusion

A novel method is described to improves the performance of a five-phase induction machine (IM) driven by a five leg inverter. The use of classic direct torque control (DTC) technique for induction motor control is simulated in Matlab/simulink. In DTC, the switching pulse is generated according to the lookup table provided in closed loop pwm generation which is further made to the stator flux and electromagnetic torque errors. The Dynamic response of the five phase induction motor drive control found enhanced in matlab/simulation results. The proposed methodology can be applied to high power multiphase drive control systems.

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