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Bearing Fault Detection of SVPWM Inverter Fed Induction Motor Drives

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Abstract— **It is advantageous to use power electronic inverters fed Induction motor (IM) as it affects the cost and energy efficiency. These induction motors (IM) that are fed by advance inverters are proven in the field of high power drive industrial applications. In this paper, a simulation model representing the correct dynamic response of Space Vector Pulse Width Modulation (SVPWM) inverter fed Induction Motor has been presented and tested by MATLAB/Simulink environment. The transient behaviour of SVPWM fed induction motor has been examined and comparatively analysis is presented for healthy and faulty (bearing fault) condition. The dynamic model of IM is the key component of system to correctly identify and eliminating different faults cause due to changes occurs in parameters during operation and unintended design mistakes. In the proposed simulated system of SPWM and SVPWM inverter fed IM model provides the comparable promising desired results with reduced harmonics, which shows the SVPWM inverter perform better then the SPWM inverter technique. Therefore the detection of bearing fault using signature analysis is successful carried out with SVPWM inverter fed IM drive, So that detection of bearing fault condition is quickly possible.**

Keywords— **Space Vector Pulse Width Modulation (SVPWM), Sine Pulse width Modulation (SPWM), Bearing Fault, signature analysis, Induction Motor (IM)**

I-INTRODUCTION

The majority of the industrial operations are carried out by the electrical motors mainly by induction motor drives. They are popular drive due to their reliable and simple construction. Induction motor is known to be reliable although they are subjected to various kinds of system failures which are inherent to the machine because of its operating conditions. This is the outcome of the various mechanical or electrical forces acting in the IM. There is a different type of machine faults, such as unbalanced parameters as stator and rotor components, winding faults, bearing faults broken rotor bars, load faults etc. as shown in fig.1. Different approaches for fault detection have been used for the particular IM drive faults which can be related to different parameter of IM such as, speed, current, voltage, temperature, efficiency, and vibrations. Therefore, the monitoring of these parameters is necessary in context of safety, economic considerations and reliable operation. [1][10][11]

In 1998, the result of the survey on faults on high voltage induction motors in offshore oil industries, gas terminals, petrochemical industries and refineries show that bearing failures count for total 52 % Failures of IM drive. This result explains the significance of bearing failures for reliable operation in Induction Motor drives. For small and medium size IM drives, There must be a periodically checked scheduled which is carried out by portable equipment that interchanges from machine to machine interference.[2][3]

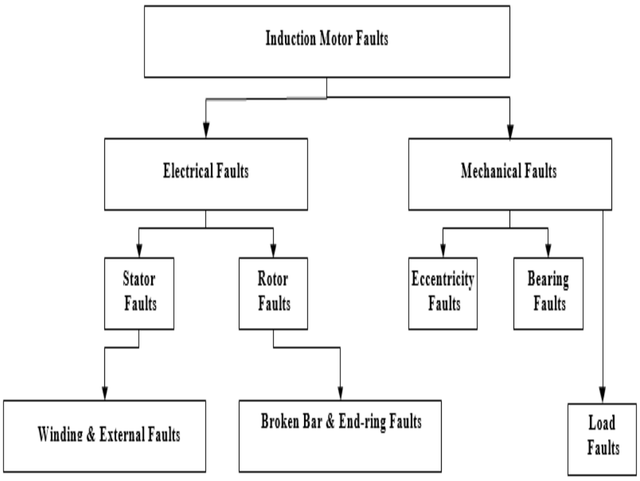

Fig.1 Different Induction Motor Faults

The machine shaft or rotor is always connected to the most common faults of the system. Moreover, according to an IEEE motor reliability study, the percentage failure components of induction motor faults in drive (41%) followed by stator (37%), rotor faults (10%) and other faults (12%) shown in Fig.2. Electric Power Research Institute conducted a survey that concludes that the failure of bearings is responsible for more than 40% burning of AC motors / IM. Thus this paper presents the effects of the bearing faults on IM drive in running condition and deals with its reduction remedy too. There is a comparative analysis on bearing fault detection between SPWM fed IM drive and SVPWM fed IM drives is also presents in this study by signature analysis method.[4][5][12]

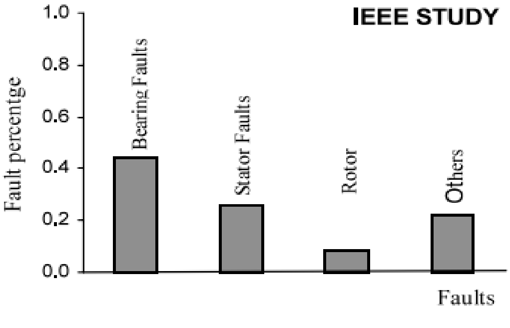

Fig.2 percentage failure components of induction motor

IN the following case first, the outer race crack that is known to be a type of single-point defect, caused by wear from fatigue Fig.3a.

As in second case, outer race is a hole that has been measured likes a fault that shown in Fig.3b. It is an artificial virtual defect

As in third case, a seal deformation is shown in Fig.3c, formed by errors during a cycling fault,

In last case, a bearing corrosion created by environment humidity known as a "generalized roughness" shown in Fig.3d.[6][7]

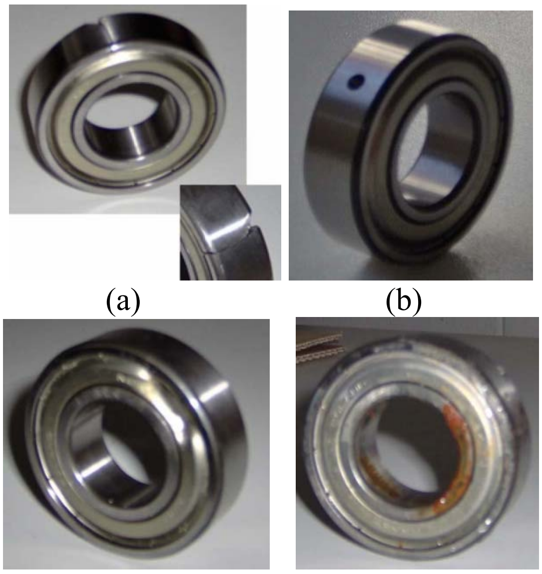
(a) (b)
(c) (d)

Fig.3. (a) Fault 1-Crack in the outer race(b) Fault 2-Hole in the outer race(c) Fault 3-Deformation of the seal(d) Fault 4-Corrosion

II. SPACE VECTOR PULSE WIDTH MODULATION

PWM electric drives are very advantageous for commercially as for uncontrollable rectification of AC supply mains and have a good efficiency, better power factor, relatively low voltage regulation problems. The conventional PWM methods are appropriate for operation of open loop control, so for closed loop controlled IM drive the implementation of a Space vector PWM (SVPWM) technique is adopt. SVPWM method has the switching strategies for the advance inverter that are produced from the acquaintance of stator voltage space phaser. A voltage reference vector is produced to create a field synchronous to the voltage rotating vector under operating in the different states of inverter switching.

By utilising SVPWM gives the reliable operation of the, low current ripple, DC link voltage. Now by Comparing to the Sinusoidal PWM, the SVPWM provides about 15% greater ratio of the utilization of voltage that makes it appropriate for higher power and voltage applications.

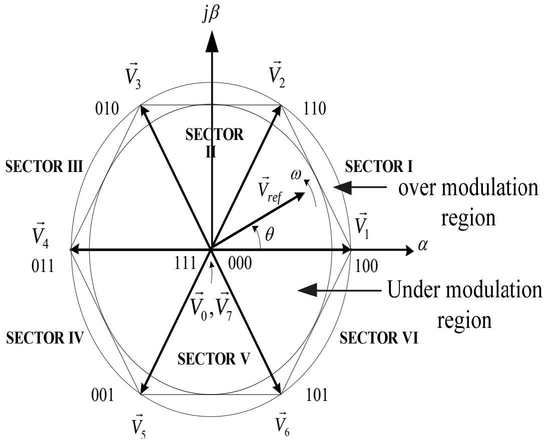

Fig.4 Space voltage vectors in different sectors

The complicated SVPWM scheme requires the identification of a sector by calculation of vector segments, that includes identification of region based on the modulation index and calculation of switching time.[9][13][14]

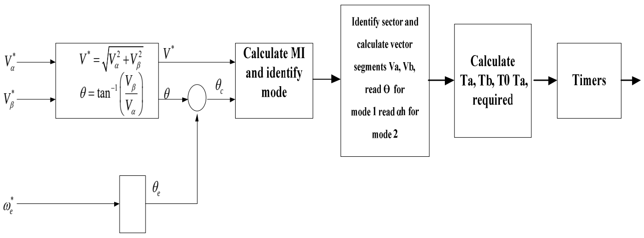

Fig.5 Flow diagram for SVPWM implementation

III. MATHEMATICAL MODELLING OF INDUCTION MOTOR

The importance of modelling the IM is high in terms of its equivalent mathematical characteristics equations, as usually per phase equivalent circuit of IM has been used in model designing. The dynamic model of the IM is achieved by incorporate the quadrature axes and two-phase direct theory of machine and it is advantageous due to its conceptual simplicity obtained with two windings sets (stator and rotor). The dynamic model should full fill the equality between the two machine models (three phase and two phase) and thus this method is appropriate for n-phase IM modelling. Power invariance concept, that means the power must be equal in any phase of IM dynamic model. The essential conversion in currents, voltages and flux linkages is derived as shown in following equations for study the dynamic performance IM model, by using equations (1)-(3).[5][8][11]

$$v_{qs}^s = R_s i_{qs}^s + \frac{d}{dt}\psi_{qs}^s \tag{1}$$

$$v_{ds}^s = R_s i_{ds}^s + \frac{d}{dt}\psi_{ds}^s$$

$$0 = R_r i_{qr}^s + \frac{d}{dt}\psi_{qr}^s - \omega_r \psi_{dr}^s$$

$$0 = R_r i_{dr}^s + \frac{d}{dt}\psi_{dr}^s + \omega_r \psi_{qr}^s$$

Where

ψ^{s}_{qs} = q-axis stator flux linkages

ψ^{s}_{ds} = d-axis stator flux linkages

ψ^{s}_{qr} = q-axis rotor flux linkages

ψ^{s}_{qr} = d-axis rotor flux linkages

R_s , R_r = stator and rotor resistances

ω_r = rotor speed

The developed electromagnetic torque by the interaction of air gap flux and rotor mmf is expressed in general vector form as in eq.2

$$T_e = \frac{3}{2}\frac{P}{2}(\overline{\psi}_m) * (\overline{I}_r) \tag{2}$$

The torque equations can be written in stationary frame with corresponding variables as

$$T_e = \frac{3}{2}\frac{P}{2}(\psi^{s}_{dm} i^{s}_{qr} - \psi^{s}_{qm} i^{s}_{dr}) \tag{3}$$

$$= \frac{3}{2}\frac{P}{2}(\psi^{s}_{dm} i^{s}_{qs} - \psi^{s}_{qm} i^{s}_{ds})$$

$$= \frac{3}{2}\frac{P}{2}(\psi^{s}_{ds} i^{s}_{qs} - \psi^{s}_{qs} i^{s}_{ds})$$

$$= \frac{3}{2}\frac{P}{2} L_m (i^{s}_{dr} i^{s}_{qs} - i^{s}_{qr} i^{s}_{ds})$$

$$= \frac{3}{2}\frac{P}{2}(\psi^{s}_{dr} i^{s}_{qr} - \psi^{s}_{qr} i^{s}_{dr})$$

IV. PROPOSED INDUCTION MOTOR DRIVE FED BY SVPWM INVERTER MODEL

The power semiconductor switches available such as GTOs, MOSFETs and IGBTs etc. are being used now a day for powering the IM drives for attaining the variable speed for different electric machine drives applications. In the most of the industries, electrical drives are fed from PWM inverters are broadly used for variable speed drives applications with cheap pricing. This type of force commutation in inverters provides the efficient and smooth variable frequency and variable voltage.[10][11]

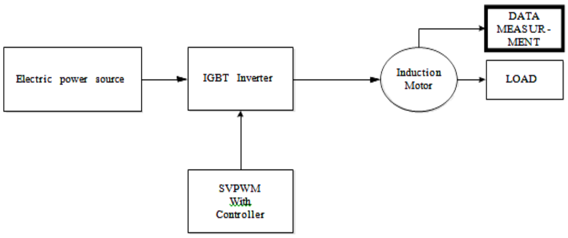

Fig. 6 Block diagram of IM drive System

Many power electronics semiconductor devices have been studied and it has been concluded that the IGBT inverter contributes better and efficient results. In this presented work, a SVPWM and SPWM inverter fed IM drive with IGBT inverter jointly simulation model has been developed in MATLAB/Simulink.

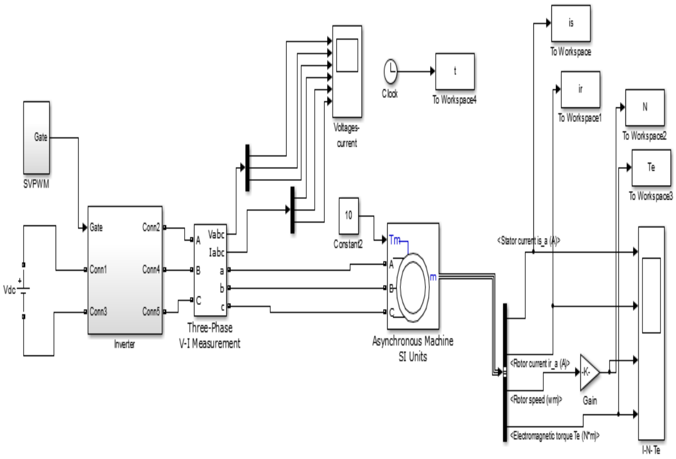

Fig.7 SVPWM Fed Inverter IM drive System

Table: 1
Induction Motor Parameters

Rotor Type	Squirrel Cage	Stator Inductance	0.005839 H
Ref. Frame	Stationary	Rotor Resistance	1.395 ohm
Capacity	4Kw	Rotor Inductance	0.005839 H
Speed	1430 Rpm	No. of Pole	4
Voltage	400V	Mutual inductance	0.1722 H
Frequency	50Hz	Inertia (J)	0.0131 Kg*m^2
Stator Resistance	1.405 ohm	Simulation time	1sec

The proposed machine drive system consists of a 3-phase IM having 4KW power rating, 400V voltage rating, 1430 RPM is fed by SVPWM inverter shown in Fig.7. The base reference wave frequency is 50 Hz and the Space Vector carrier wave's frequency is set to 3050 Hz. That makes the frequency modulation factor (mf) is 61.[1]

V. SIMULATION RESULTS FOR DIFFERENT CONDITIONS OF THE INDUCTION MOTOR *DRIVE*

The signature waveform of stator and rotor current of IM drive fed with both SPWM and SVPWM separately are shown in following Fig.8 and Fig.9 respectively. The peak value of stator current from Fig.8 and peak value of rotor current from Fig.9 is higher in case of SPWM fed drives Therefore it has been concluded from these results that SVPWM fed drives gives better performance than the SPWM fed drives.

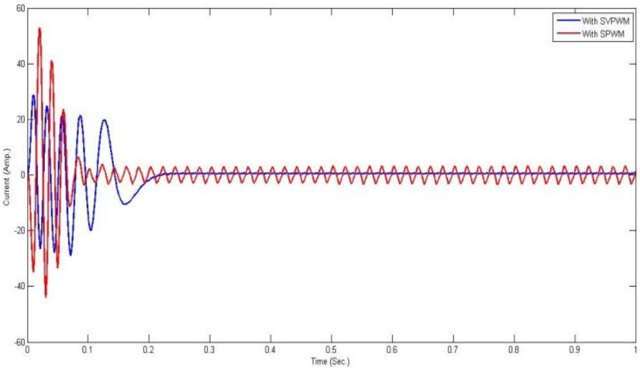

Fig.8 Stator current analysis of SVPWM and SPWM Fed inverter IM drive

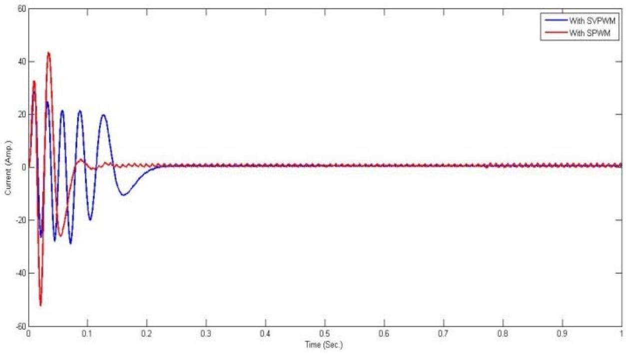

Fig.9 Rotor current analysis of SVPWM and SPWM Fed inverter IM drive

This SVPWM inverter fed IM results has been studied accordingly to peak to peak values of its parameter to identify the bearing fault condition. That means signature analysis is been used for this study. The IM drive results under different condition are shown as in following figures.

(A) Results of healthy condition When Motor at starting condition (S=1,FF=0)

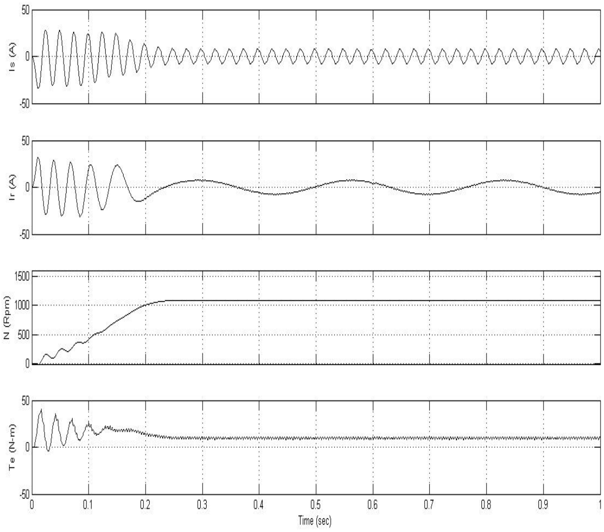

Fig 10 Signature waveform of healthy condition When Motor at starting condition

In this result shown in Fig.10, IM motor drive is fed from SVPWM inverter is in healthy condition and running at the 10 N-m load torque and starting condition that means slip is 1 and Friction Factor (FF)=0. In this results stator current, rotor current, rotor speed and torque signature waveform is used for analysis. All these parameters of the IM are in steady-state condition after 0.25 second.

(B) Results of healthy condition When Motor running under the loading condition(S=0.03,FF=0)

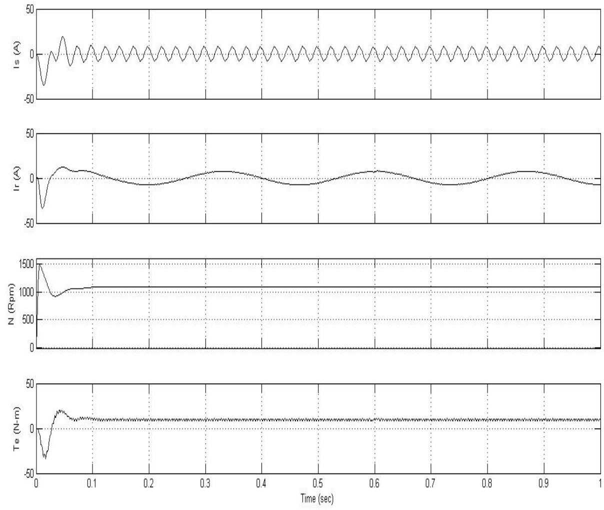

Fig 11 Results of healthy condition When Motor running under the loading condition

In this result shown in Fig.11, IM motor drive is fed from SVPWM inverter is in healthy condition and running at the 10 N-m load torque that means slip is 0.03 and FF=0. All these parameters of the IM are in steady-state condition after 0.20 second. It has been observed that the there is a slight increment of peak value of stator, rotor current and reduction in rotor speed and torque.

(C) Results of healthy condition When Motor running under No-Load condition (S=1,FF=0)

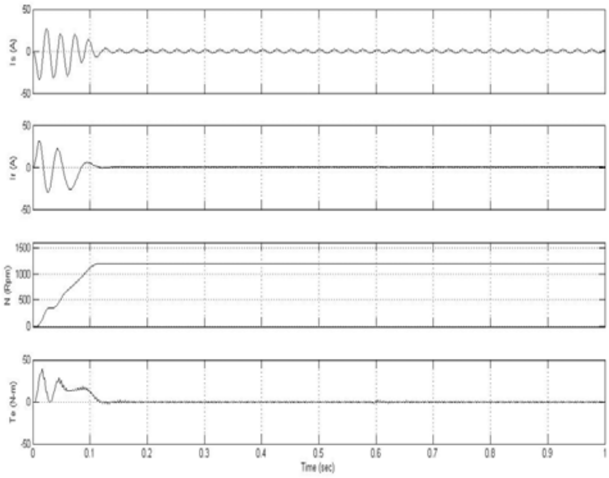

Fig.12 Results of healthy condition When Motor running under No-Load condition

The Fig.12, IM motor drive is fed from SVPWM inverter is in healthy condition and running under no-load condition that means slip is 1 and FF=0. All these parameters of the IM are in steady-state condition after 0.15 second. It has been observed that the there is a slight reduction of peak value of stator and rotor current than to full load condition.

(D) Results of healthy condition When Motor running under No-Load condition (S=0.03,FF=0)

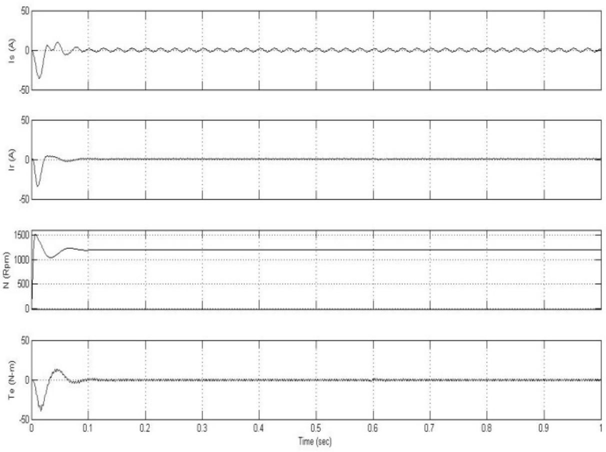

Fig 13 Results of healthy condition When Motor running under No-Load condition

In this result shown in Fig.13, IM motor drive is fed from SVPWM inverter is in healthy condition and running at the No load that means slip is 0.03 and FF=0. All these parameters of the IM are in steady-state condition after 0.10 second. It has been observed that the there is a slight increment of peak value of stator and rotor current compare to the previous condition.

(E) Results of Faulty condition When Motor running under Load condition (S=0.07,FF=0.15)

Fig.14 Results of Faulty condition When Motor running under Load condition (FF=0.15)

In this result shown in Fig.14, IM motor drive is fed from SVPWM inverter is in faulty condition (Bearing Fault Condition) and running at the 10 N-m load torque that means slip is 0.07 and FF=0.15. It has been observed that the there is a large reduction of speed value of IM drive that is now 600 rpm.

(F) Results of Faulty condition When Motor running under Load condition (S=0.07,FF=0.25)

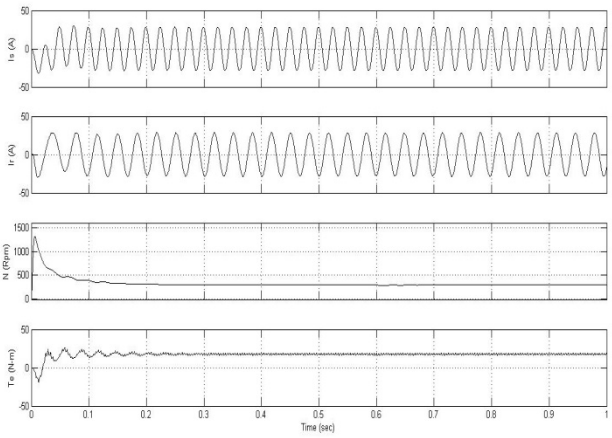

Fig 15 Results of Faulty condition When Motor running under Load condition (FF=0.25)

In this result shown in Fig.15, IM motor drive is fed from SVPWM inverter is in faulty condition (Bearing Fault Condition) and running at the 10 load torque that means slip is 0.07 and FF=0.25. It has been observed that the there is a large reduction of speed value of IM drive that is now 300 rpm.

(G) Results of Faulty condition When Motor running under No-Load condition (S=0.02,FF=0.15)

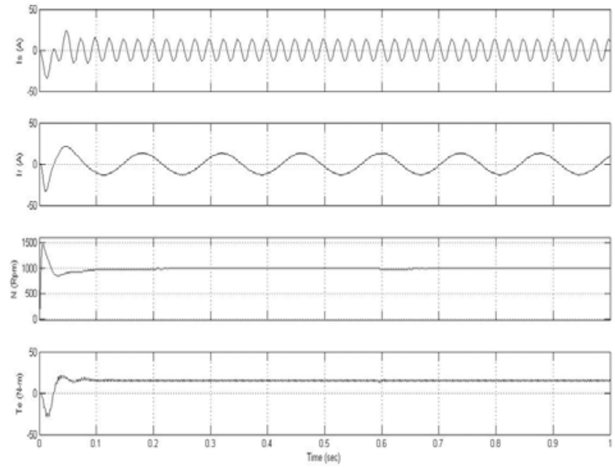

Fig.16 Results of Faulty condition When Motor running under No-Load condition (FF=0.15)

In this result shown in Fig.16, IM motor drive is fed from SVPWM inverter is in faulty condition (Bearing Fault Condition) and running at the No-load torque that means slip is 0.02 and FF=0.15. It has been observed that the there is a large reduction of speed value of IM drive that is now 1000 rpm.

(H) Results of Faulty condition When Motor running under No-Load condition (S=0.02,FF=0.25)

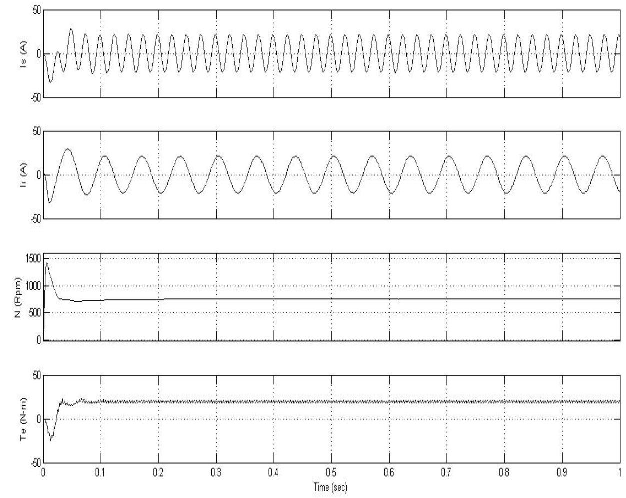

Fig 17 Results of Faulty condition When Motor running under No-Load condition (FF=0.25)

In this result shown in Fig.17, IM motor drive is fed from SVPWM inverter is in faulty condition (Bearing Fault Condition) and running at the No-load torque that means slip is 0.02 and FF=0.25. It has been observed that the there is a large reduction of speed value of IM drive that is now 750 rpm. This is lower than its previous loading faulty condition.

Table 2:
Simulation Results

Load Torque (N-m)	Slip	Friction Factor (N-m-s)	Maximum Peak of Stator Current (A)	Maximum Peak of Rotor Current (A)	Speed (Rpm)	Maximum Peak of Electromagnetic Torque (N-m)
10	1	0	34	31.8	1100	38.3
10	0.03	0	34.8	33.5	1090	31.2
0	1	0	33.5	31.2	1200	36.6
0	0.03	0	35.8	33.8	1200	36
10	0.07	0.15	32.5	31	600	19.6
10	0.07	0.25	31.8	29.5	300	15.6
0	0.02	0.15	34	33.1	1000	26.5
0	0.02	0.25	33	32.2	750	21.7

CONCLUSIONS

SVPWM introduces in this system for minimizing torque and current ripple. This is also cost efficient method of speed control of three phase induction motor. In this work, induction motor (IM) fed by SVPWM inverter model have been developed in the MATLAB/Simulink environment. The system model simulation has efficiently used for the detection of incipient faults (mainly bearing fault) during the time domain of different condition such as no load and full load conditions. This work of analysis has been carried out by creating the bearing fault in different running condition of IM drive. Thus the achieved simulation waveform signature results shows that the normal/healthy condition and the condition when the bearing fault occurs are different and bearing fault can be detect from observing these results. The detection and analysis of the bearing fault by time domain approach is a tedious type procedure and the analysis of time domain can't concludes that at what period of time which frequency exist and its important because key information are hidden in the form of frequency.

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