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# Modeling Of Induction Motor and Fault Analysis

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**Abstract:** *Motor current signature analysis is the reference method for the diagnosis of induction machines faults in vector control technique, the special reference frames, electromagnetic torque of the smooth air gap machine is similar to the expression for the torque of the separately excited DC machine. Variable speed drives applications are common in the aerospace, appliance, railway, and automotive industries and also electric generators for wind turbines. In this paper, a simple and effective technique is presented that allows the diagnosis of machines faults for induction machines drives in vector control technique. In case of induction machines the control is usually preformed in the reference frame (d-q) attached to the rotor flux space vector. Simulation and experimental results are shown to validate the scheme.*

**Keywords:** Induction motor, vector control, Simulink, Matlab, fault analysis, parameter.

## I. INTRODUCTION

Introduction motors are widely used in industrial applications for their intrinsic ruggedness and reduced cost. Recently, the use of adjustable speed drives has spread in many applications. Most of the industrials motors are used today are in fact induction motors. Induction motors have been used in the past mainly in applications requiring a constant speed because conventional methods of their speed control have either been expensive or highly inefficient.

This type of control scheme uses more mathematical calculations and algorithms, which involves heavy computing and needed efficient and costly controllers. Here we introduce a novel theory to improve the performance of the motor running it at optimum voltage and frequency for optimum motor efficiency at different points. This is an offline method and not for online and real time control. In some applications, where continuous operation is a key item, such as railway applications. And a wind generator, The need for a preventive fault diagnosis is an extremely important point. In this paper, fault detection and the prognosis of rotor faults are critical for industrial applications, although rotor Faults share only about 20% of the overall induction machine faults [1]. In fact, the breakage of a bar leads to high current in adjacent bars, thus leading to potential further breakage and stator faults as well.

## II. PERFORMANCE OF INDUCTION MOTOR

Energy supplied to the induction motor is distributed in the two parts, the first is in the form of mechanical output and second one is in the form of losses. For the high performance of the motor the motor losses should be small, so the output of motor goes high. An efficient motor not only saves the energy, hence money, but will also generate Less internal heat, and run cooler and more quietly [2]. It is also likely to last longer and more reliable than a less efficient motor.

The better performance of the motor is related to the maximum efficiency of the motor. There are different methods to improve the performance of the induction motor. Variable speed drive (VSD) is most applicable technology for the improvement of motor performance. VSD is used to regulate the speed of a motor to suit with the load demand. A VSD offers the reduce power, wider speed, torque and power ranges, and shorter response time. Induction motor efficiency is dependent on many motor parameters; however it is a function of the operating speed and applied voltage, frequency.

## III. CONTROL OF INDUCTION MACHINEDRIVES

Nowadays, common solutions for high-power applications are based on drives that include a voltage source inverter (VSI) feeding an induction motor or a permanent magnet synchronous motor. However, old-fashioned solutions based on a current source inverter or on thyristors are still employed, whereas old schemes based on dc series motors or direct dc motors are no longer used.

Different control schemes are adopted and tailored to the specific application. Typically, variable structure controls are used for high-performance traction drive systems that change according to the operating conditions, particularly according to the speed and flux levels. The basic structure is a direct rotor flux field-oriented vector control, whose scheme is shown in Fig. 1. The vector control algorithm consists of two current loops for flux



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and torque regulation. Moreover, an external rotor flux loop is used to set the flux level by means Of the direct stator reference current. A similar control structure is used in high-power applications, where transient operations often occur.

Direct and inverse Clark transformations are represented by blocks  $D$  and  $D^{-1}$ , respectively. Standard PI regulators with anti windup systems are used for the control loops in a  $(d-q)$  reference frame that is synchronous with the rotor flux. The rotor flux is estimated through a stator-model-based observer obtained by integrating the stator voltage equation and taking into account the leakage flux [3] as

$$\overline{\phi_r} = \frac{L_m}{L_r} \left[ \int (\overline{v_s} - R_s \overline{i_s}) dt - \sigma L_s \overline{i_s} \right] \quad (1)$$

Where  $L_m$  is the magnetizing inductance,  $L_r$  is the rotor inductance and  $L_s$  is the stator inductance.  $\overline{v_s}$  And  $\overline{i_s}$  are the space vectors of the stator voltage and current, respectively;  $\sigma = 1 - L_m^2/L_s L_r$  this corresponds to the voltage-current observer block in Fig. 1. In the actual implementation of (1), a low-pass filter is used instead of a pure integrator. This choice reduces drifts due to errors and offsets in the acquired signals. However, the uses of low-pass filter results in a wrong computation of the rotor flux space vector in terms of magnitude and angle. An estimate of the stator pulsation is used to compensate for these errors, i.e.,

$$\tilde{\omega}_s = \frac{R_r L_m}{L_r} \frac{i_q^*}{\phi_r^*} + p \omega_r \quad (2)$$

Where  $\omega_r$  is the measured mechanical speed,  $p$  is the pole pairs number,  $i_q^*$  is the reference value for the torque current,  $\phi_r^*$  is the reference value for the rotor flux, and  $R_r$  is the rotor resistance. Relationship (2) is represented in Fig. 1 by the stator frequency estimation block and is used for three main purposes. It is used as the feed-forward compensation in the phase-locked loop (PLL) block used for the tracking of the flux angle. As stated previously, it is used to compensate for errors in the magnitude and the angle of the rotor flux caused by the low pass filter used for the integration. Eventually, it is used in the decoupling terms that are blocked together with the magnitude of the rotor flux estimated by (1) and the measured currents in the synchronous reference frame to compute the dynamic back electromotive- force compensation terms

$$\tilde{v}_d = -\tilde{\omega}_s \sigma L_s i_q \quad (3)$$

$$\tilde{v}_q = \tilde{\omega}_s \left( \sigma L_s i_d + \frac{L_m}{L_r} |\overline{\phi_r}| \right) \quad (4)$$

The magnitude of the estimated flux  $\phi_r$  is eventually used as a feedback signal for the outer loop. The output of the PLL block, which is the tracked and Corrected rotor flux angle  $\tilde{\theta}_s$ , is used for the reference frame matrix transformations  $p(\tilde{\theta}_s)$  and  $p^{-1}(\tilde{\theta}_s)$ . The value of the reference quadrature stator current is obtained from the reference torque and the reference flux signal through the following equation:

$$i_q^* = K_T \frac{T^*}{\phi_r^*} \quad (5)$$

Where  $K_T = (2L_r / 3pL_m)$ . On the other hand, the reference flux is obtained by relying on the nominal values for the torque and the rotor flux, i.e.,

$$\phi_r^* = \sqrt{\frac{T^*}{T_{nom}}} \phi_{rnom} \quad (6)$$

This choice keeps the slip frequency quite constant, providing better robustness of the control system against speed errors and reducing the losses at low torque. This is suited to traction applications, where high-torque dynamics are not requested, and it does not prevent reaching the maximum torque at low speed when needed. In this paper, reference is made to an induction motor drive fed by a pulse width modulation (PWM) VSI insulated-gate bipolar transistor inverter. Typically, in traction drive systems, the switching frequency is very low, making the detection of the faults through the signal injection strategy impossible. Moreover, industries are particularly interested in diagnostic techniques that do not require additional sensors. This paper proposes a simple processing technique that exploits already available control signals for the rotor fault diagnosis.

#### IV. VECTOR CONTROL

Vector control is the most popular control technique of AC induction motors. In special reference frames, the expression for the electromagnetic torque of the smooth-air-gap machine is similar to the expression for the torque of the separately excited DC machine. In the case of induction machines, the control is usually performed in the reference frame (d-q) attached to the rotor flux space vector. That's why the implementation of vector control requires information on the modulus and the space angle (position) of the rotor flux space vector. The stator currents of the induction machine are separated into flux- and torque-producing components by utilizing transformation to the d-q coordinate system, whose direct axis ( $d$ ) is aligned with the rotor flux space vector. That means that the  $q$ -axis component of the rotor flux space vector is always zero.

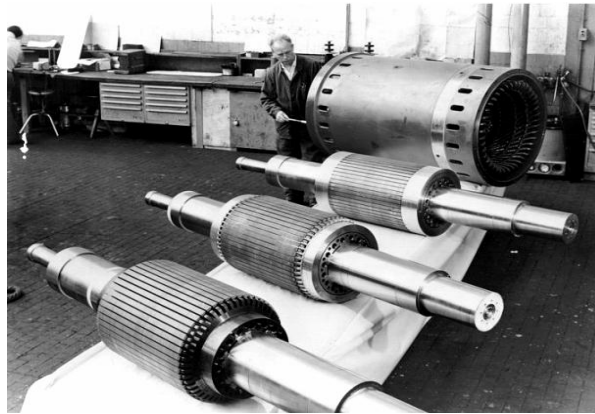


Fig. 1 2500 kW, 3 kV, 24,000 rpm induction motor

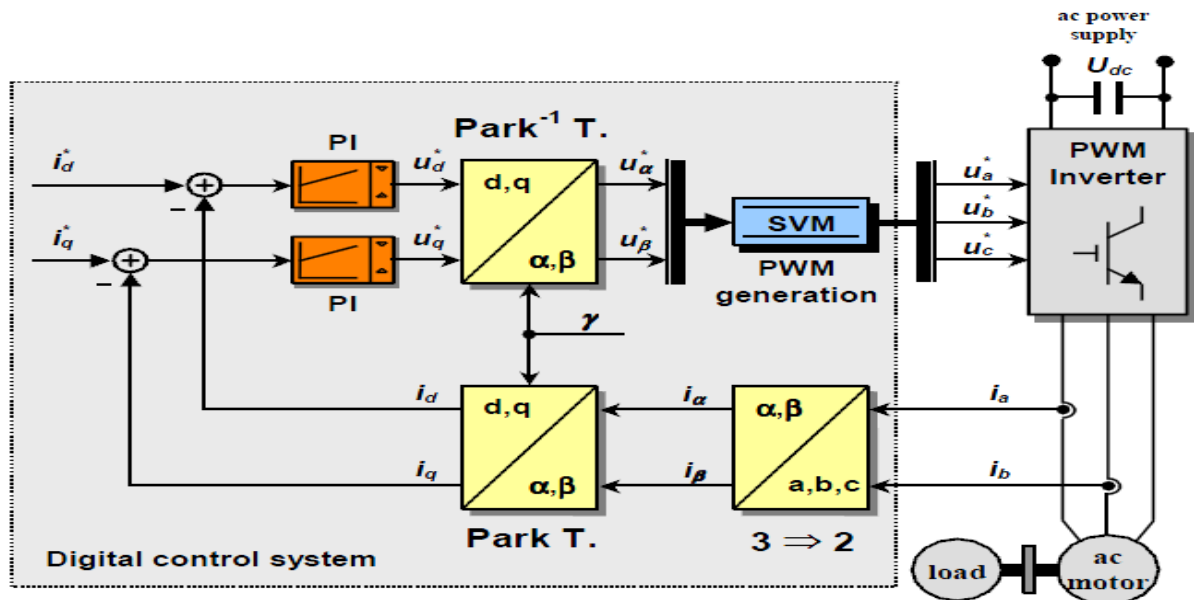


Fig.2 Complete block diagram of vector control method

To perform vector control, follow these steps:

- Measure the motor quantities (phase voltages and currents)
- Transform them to the 2-phase system ( $\alpha, \beta$ ) Using a Clarke transformation
- Calculate the rotor flux space vector magnitude and position angle
- Transform stator currents to the d-q coordinate system using a Park transformation



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- The stator current torque- ( $i_{sq}$ ) and flux- ( $i_{sd}$ ) Producing components are separately controlled
- The output stator voltage space vector is calculated using the decoupling block
- An inverse Park transformation transforms the Stator voltage space vector back from the d-q Coordinate System to the 2-phase system fixed with the stator
- Using the space vector modulation, the output 3-Phase voltage is generated

The components  $i_{s\alpha}$  and  $i_{s\beta}$ , calculated with a Clarke transformation, are attached to the stator reference frame  $\alpha, \beta$  in vector control; all quantities must be expressed in the same reference frame. The stator reference frame is not suitable for the control process. The space vector  $i_s$  is rotating at a rate equal to the angular frequency of the phase currents. The components  $i_{s\alpha}$  and  $i_{s\beta}$  depend on time and speed. These components can be transformed from the stator reference frame to the d-q reference frame rotating at the same speed as the angular frequency of the phase currents. The  $i_{sd}$  and  $i_{sq}$  components do not then depend on time and speed. The component  $i_{sd}$  is called the direct axis Component (the flux-producing component) and  $i_{sq}$  is called the quadrature axis component (the torque-producing component). They are time invariant; flux and torque control with them is easy.

Knowledge of the rotor flux space vector magnitude and position is key information for AC induction motor vector control. With the rotor magnetic flux space vector, the rotational coordinate system (d-q) can be established. There are several methods for obtaining the rotor magnetic flux space vector. The flux model Implemented here utilizes monitored rotor speed and stator voltages and currents. It is calculated in the stationary reference frame ( $\alpha, \beta$ ) attached to the stator. The error in the calculated value of the rotor flux, influenced by the changes in temperature, is negligible for this rotor flux model. For purposes of the rotor flux-oriented vector control, the direct-axis stator current  $i_{sd}$  (the rotor flux-producing component) and the quadrature axis stator current  $i_{sq}$  (the torque producing component) must be controlled independently. However, the equations of the stator voltage components are coupled. The direct axis component  $v_{sd}$  also depends on  $i_{sd}$  and the quadrature axis component  $v_{sq}$  also depends on  $i_{sq}$ . The stator voltage components  $v_{sd}$  and  $v_{sq}$  cannot be considered as decoupled control variables for the rotor flux and electromagnetic torque. The stator currents  $i_{sd}$  and  $i_{sq}$  can only be independently controlled (decoupled control) if the stator voltage equations are decoupled and controlling the terminal voltages of the induction motor indirectly controls the stator current components  $i_{sd}$  and  $i_{sq}$ .

## V. FAULTS DETECTION TECHNIQUES

Modern measurement techniques in combination with advanced computerized data processing and acquisition show new ways in the field of induction machines monitoring by the use of spectral analysis of operational process parameters (e.g. temperature, pressure, steam flow, etc.). Time domain analysis using characteristic values to determine changes by trend setting, spectrum analysis to determine trends of frequencies, amplitude and phase relations, as well as cepstrum analysis to detect periodical Components of spectra are used as evaluation tools. In many situations, vibration monitoring methods were utilized for incipient fault detection. However, stator current monitoring was found to provide the same indication without requiring access to the motor. In what follows, some of the main stator current signature based technique is presented.

- The Classical Fast Fourier Transform (FFT)
- Wavelet Analysis
- Current park's vector approach
- Power spectral density analysis

## VI. DEVELOPMENT OF SIMULINK MODEL

The block model of the induction motor system with the controller was developed using the power system, power electronics, control system, signal processing toolboxes & from the basic functions available in the Simulink library in Matlab / Simulink. The entire system modeled in Simulink is a closed loop feedback control system consisting of the plants, controllers, samplers, comparators, feedback systems, the mux, de-mux, summers, adders, gain blocks, multipliers, clocks, sub-systems, integrators, state-space models, subsystems, the output sinks (scopes), the input Source etc.

Voltage equations

$$V_a = |V| \sin(\omega t + \theta) \dots\dots\dots 1$$

$$V_b = |V| \sin(\omega t - 2\pi/3 + \theta) \dots\dots\dots 2$$

$$V_c = |V| \sin(\omega t - 4\pi/3 + \theta) \dots\dots\dots 3$$

$$V_{ds} = \sqrt{2}/3(V_a - \frac{1}{2}V_b - \frac{1}{2}V_c) \dots\dots\dots 4$$

$$V_{qs} = \sqrt{2}/3(\frac{\sqrt{3}}{2}V_b - \frac{\sqrt{3}}{2}V_c) \dots\dots\dots 5$$

Current equations

$$I_a = \sqrt{\frac{3}{2}} * I_d \dots\dots\dots 6$$

$$I_b = \sqrt{\frac{3}{2}} * [(-\frac{1}{2})I_d - (\frac{\sqrt{3}}{2})I_q] \dots\dots\dots 7$$

$$I_c = \sqrt{\frac{3}{2}} * [(-\frac{1}{2})I_d + (\frac{\sqrt{3}}{2})I_q] \dots\dots\dots 8$$

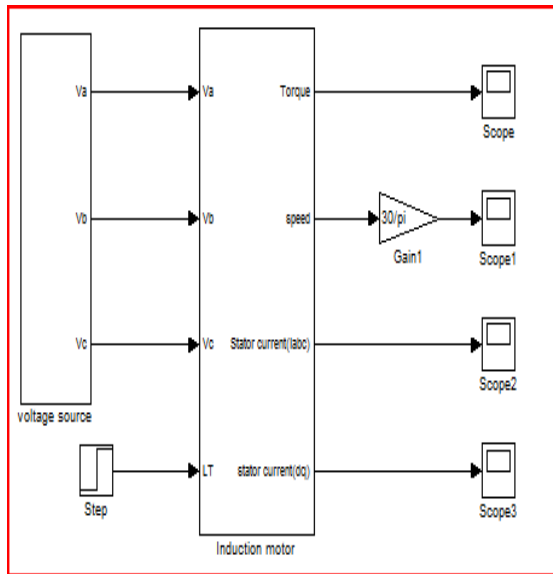


Fig. 3. Induction motor with supply

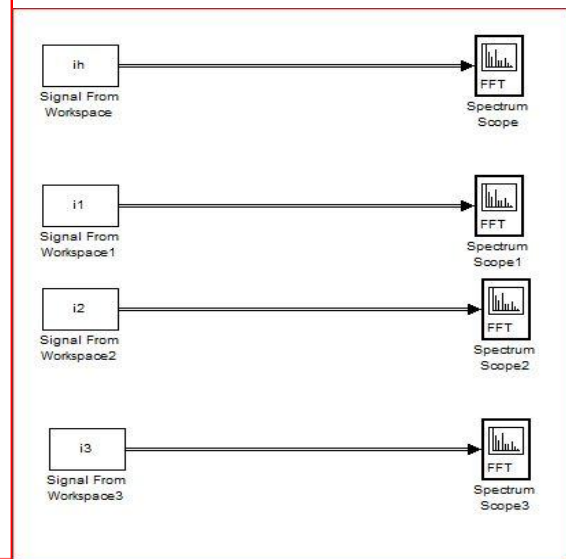


Fig.4.Spectral power density

## VII. SIMULATION AND RESULTS

Extensive research activities were carried out to model rotor asymmetries to accurately predict the behavior of the machine under faulty conditions. Here, the procedure was validated with a machine model, whose parameters are taken from the machine used for the experiments. Specifically, a 7.5-kW three-phase two-pole pair's induction machine was used to verify the agreement between simulations. The rotor fault is one broken bar that was modeled increasing the resistance of one squirrel cage rotor bar.



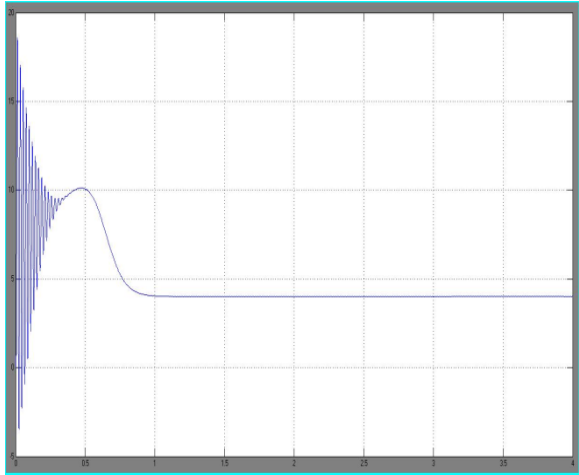


Fig.5. Healthy motor torque

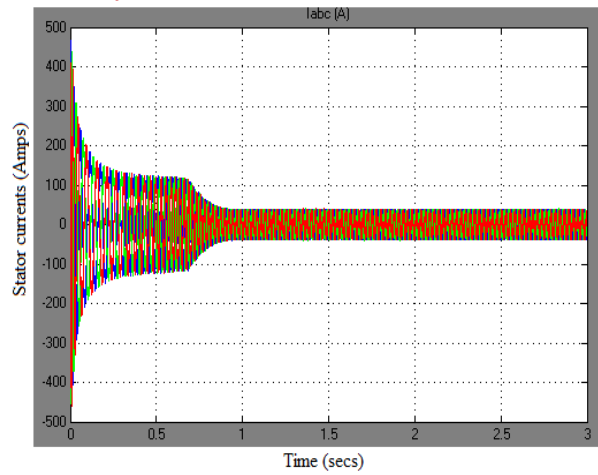


Fig. 6. Three phase stator currents vs time

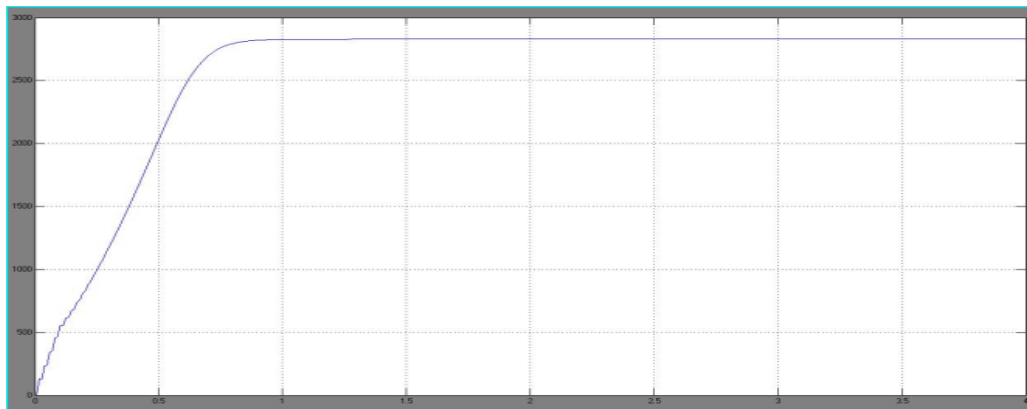


Fig. 7. Speed for healthy motor

## WAVELET OUTPUTS

### HEALTHY MOTOR CURRENT SIGNAL ( $i_a$ )

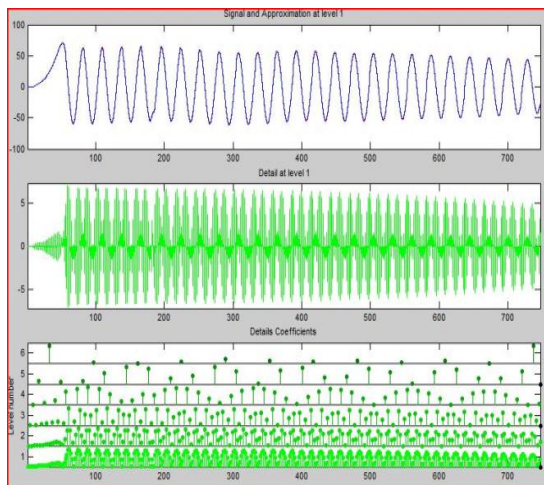


Fig.8. Approximation signal for healthy induction motor

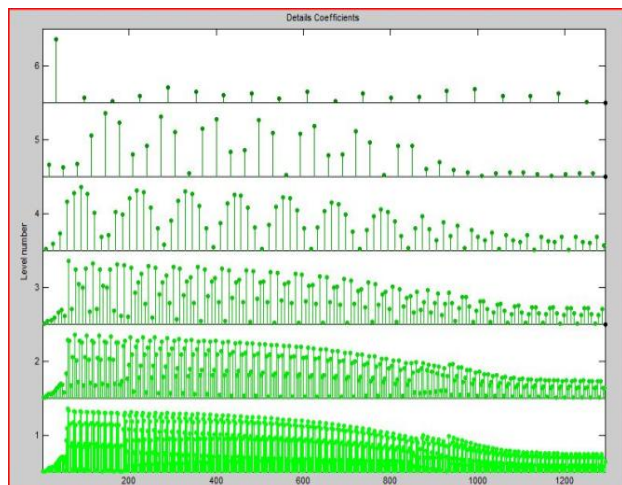
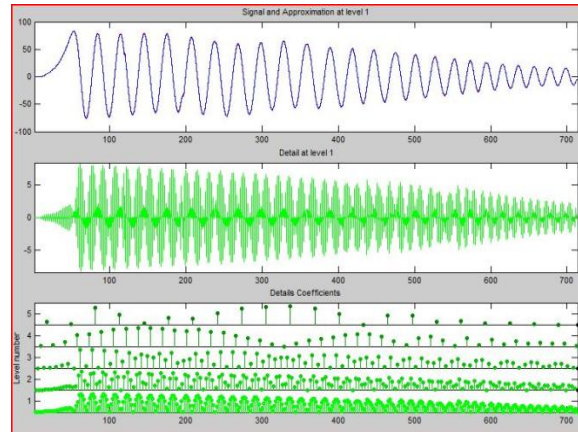
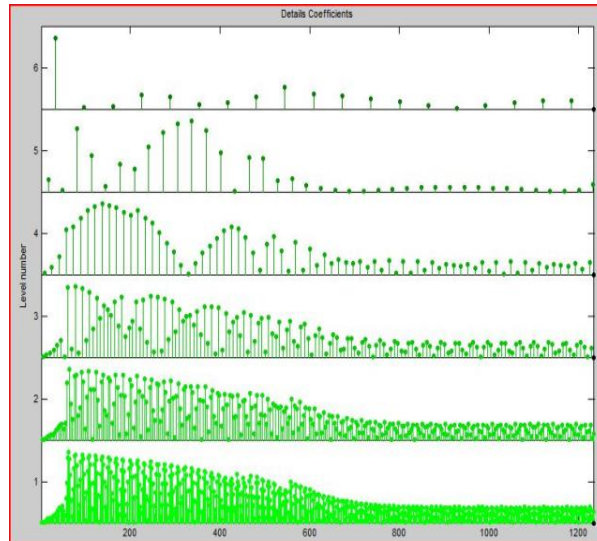


Fig.9. Details coefficients for healthy induction motor

**ONE BAR BROKEN CURRENT SIGNAL ( $i_a$ )**

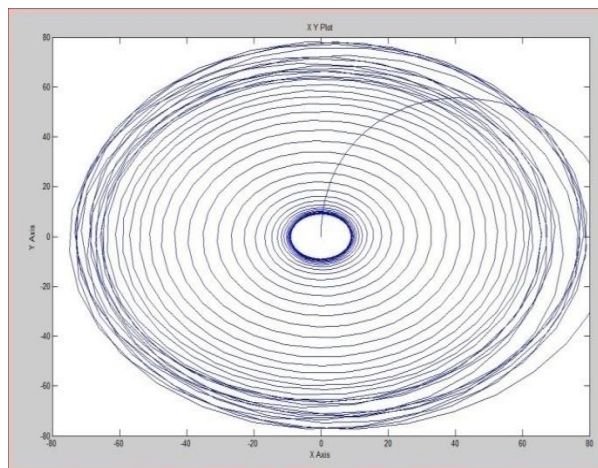


**Fig.10.Approximation signal for one broken bars induction motor**



**Fig.11.Details coefficients for one broken bars induction motor**

**PARK'S CURRENT VECTOR APPROACH**



**Fig.12.park's current vector approach for healthy broken induction motor**

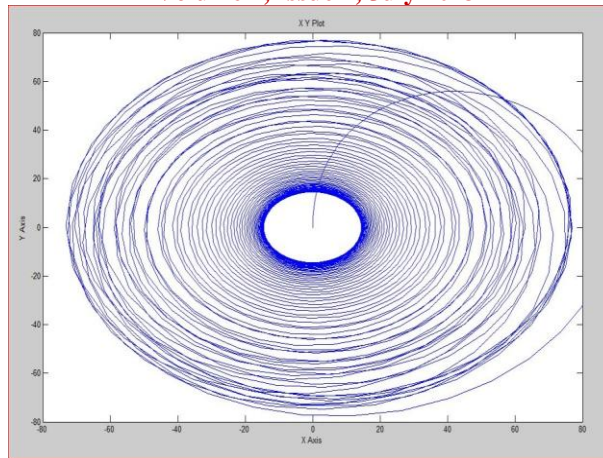


Fig.13.park's current vector approach for one bar induction motor

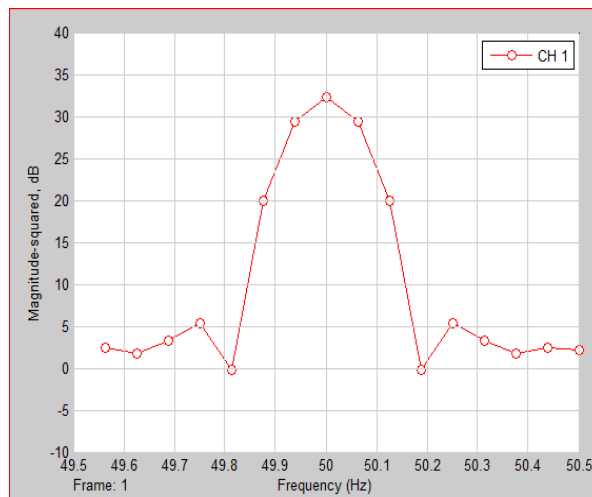


Fig.14.Spectral power density for healthy induction motor

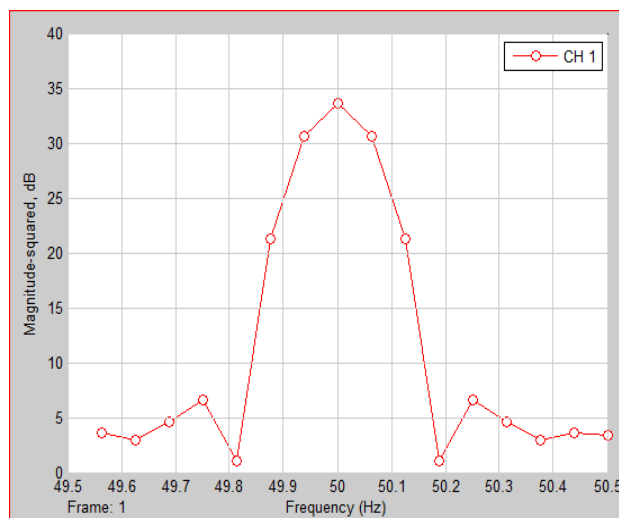
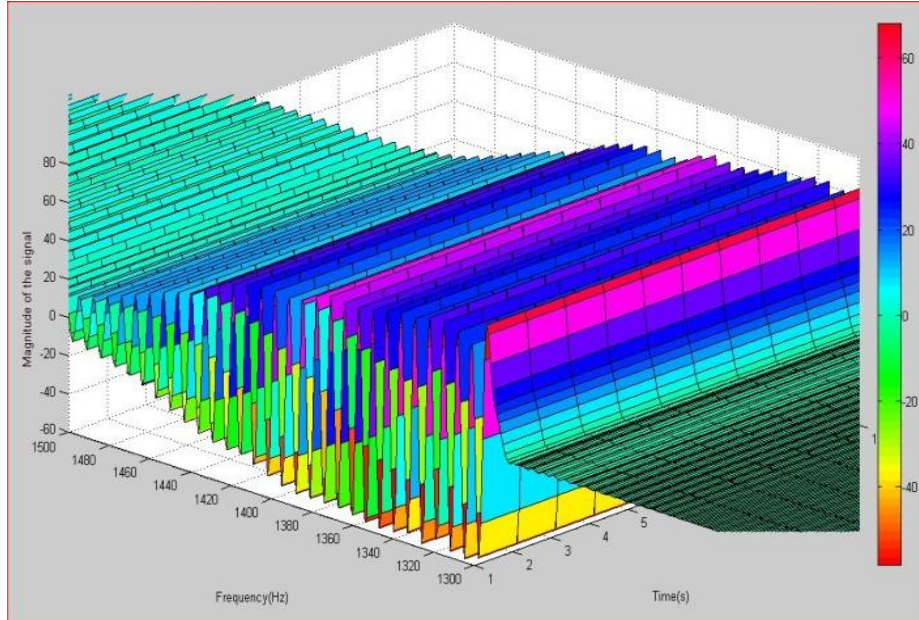
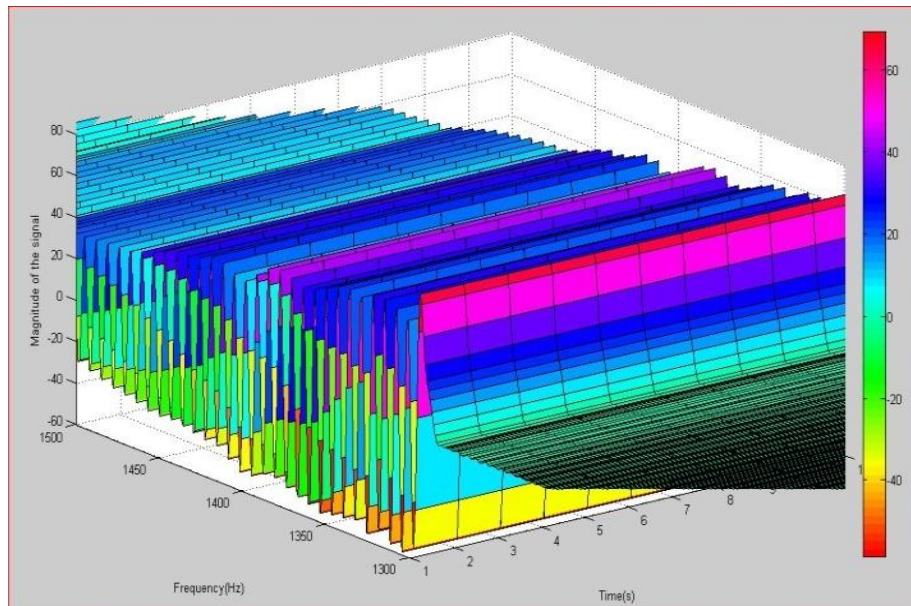


Fig.15.Spectral power density for one bar broken induction motor





**Fig.16.STFT coefficients for healthy motor induction motor**



**Fig.17.STFT coefficients for one bar broken induction motor**

## VIII. CONCLUSION

We have seen the simulation circuit and simulation results of induction machine. This method has been tailored to control rotor flux field oriented control drives in transient conditions. During transient condition, torque, speed varies, preventing the use of vector control technique for an effective diagnosis of rotor faults. The obtained analytical frequencies in the stator spectrum can be related to the experimental ones of normal operation and under rotor bar faults. Stator current of healthy and fault motors are analyzed by using wavelet daudechies 6-level decomposition technique, park's current vector approach, spectral power density and short time Fourier transformations. This analysis shows the difference between healthy, single and double broken rotor bar and three bar broken rotor of induction motor.



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#### APPENDIX

The induction motor is 10hp having following parameters

No. of poles	= 4
Rated power	= 7.5kw
Rated stator voltage	= 380 V
Nominal Stator current	= 15.3 A
Rated frequency	= 50 Hz
Rated speed	= 1440 rpm
Stator resistance	= 0.54 ohm
Rotor resistance	= 0.58 ohm
Stator inductance	= 88.4mH
Rotor inductance	= 83.3mH
Magnetizing inductance	= 81.7mH

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