Fault Diagnosis Of Induction Motor Using Vector Control Technique

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Abstract-Motor current signature analysis is the reference method for the diagnosis of induction machine faults in vector control technique. In 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 drive applications are common in the aerospace, electrical appliance, railways, and automotive industries and also in electric generators for wind turbines. In this paper, a simple and effective technique is presented that allows the diagnosis of machine faults for induction machine drives using 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 proposed scheme.

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

I.INTRODUCTION

Induction motors are widely used in industrial applications for their intrinsic ruggedness and reduced cost. Recently, the use of adjustable speed drives has spread to many applications. Most of the inductionmotors 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 involve heavy computing and need 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 requirement, such as railway applications anda wind generator, the need for a preventive fault diagnosis is an extremely important step.In this paper, fault detection and the prognosis of rotor faults are critical for industrial applications, although rotor faults share only about20% of the overall induction machine faults [1]. In fact, the breakage of a bar leads to high current inadjacent bars, thus leading to further breakage and stator faults as well.

II. PERFORMANCE OF AN INDUCTION MOTOR

Energy supplied to the induction motor is distributed in two parts, the first is in the form of mechanical output and second one in the form of losses. For high performance of the motor the motor losses should be small, so the output of motor is high. An efficient motor not only saves 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 performance of a 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 meet with the load demand. A VSD offers 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, applied voltage and 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 thyristor 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 applications. Typically, variable structure controls are used for high-performance traction drive systems that change according to the operating conditions, particularly 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 one for flux and the other for 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

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

where L_m is the magnetizing inductance, L_r is the rotor inductance and L_s is the stator inductance. $\bar{v}_s$ and $\bar{\imath}_s$ is the space vector of the stator voltage and current, respectively; $\sigma = 1 - L_m^2/L_sL_r$ 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.,

$$\widetilde{\omega}_s = \frac{R_rL_m}{L_r}\frac{i_q^*}{\emptyset_r^*} + p\omega_r(2)$$

where ω_r is the measured mechanical speed, p is the pole pairs number, i_q^* is the reference value for the torque current, $\emptyset_r^*$ 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 firstly. It is used as the feed-forward compensation in the phase-locked loop (PLL) block which is for tracking of the flux angle. Secondly 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. finally 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 which are

$$\tilde{v}_d = -\widehat{\omega_s}\sigma L_s i_q(3)$$

and

$$\tilde{v}_q = \widetilde{\omega_s}\left(\sigma L_s i_d + \frac{L_m}{L_r}\left|\overline{\emptyset_r}\right|\right)(4)$$

The magnitude of the estimated flux $\emptyset_r$ 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 transformation $p\ (\tilde{\theta}_s)$ 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:

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

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.,

$$\emptyset_r^* = \sqrt{\frac{T^*}{T_{nom}}}\emptyset_{r_{nom}}(6)$$

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 required, 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) 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 the 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 is 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 the*q*-axis component of the rotor flux space vector is always zero.

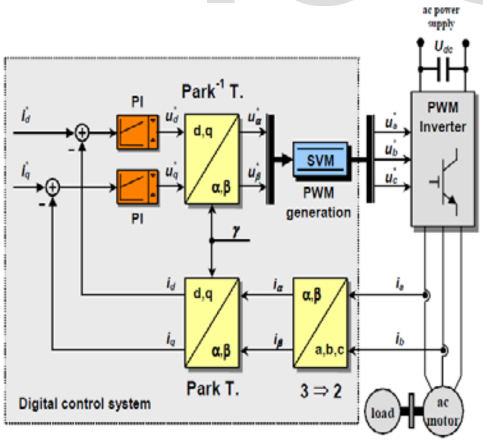

Fig.1 Complete block diagram of vector control method

To perform vector control, follow these stepsare performed:

- Measure the motor parameters (phase voltages and currents)
- Transform them to the 2-phase system (*α*, β) 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
- The control stator current torque- (i_{sq}) and flux- (i_{sd}) producing components are separately controlled
- The calculated output stator voltage space vector is calculated using the decoupling block
- Generatedthe 3-Phase voltageoutputby using the space vector modulation

The components $i_{s\alpha}$ and $i_{s\beta}$, calculated with a Clarke transformation, are attached to the stator reference frame *α*, β in vector control; all quantities must be expressed in the same reference frame. May be the stator reference frame is not suitable for the control process for the following reasons. 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} andi_{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). Since time invariant; flux and torque control are easy.

Knowledge of the rotor flux space vector magnitude and position the 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 modelimplemented here utilizes monitored rotor speed and stator voltages and currents. It is calculated in the stationary reference frame (α, β) 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 the purpose 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} depends on $i_{sd}$and the quadrature axis component v_{sq} 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. Hence the stator currents $i_{sd}$and i_{sq} can only be independently controlled (decoupled control) if the stator voltage equations are decoupled and are controlling the terminal voltages of the induction motor indirectly controls the stator current components i_{sd} andi_{sq}.

V. 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, the output sinks (scopes), the input source etc. The developed Simulink model for the control of various parameters of the SCIM is shown in the Fig.2.

Extensive research was carried out to model rotor asymmetries to accurately predict the behaviour 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 similarities between simulations.

For the rotor fault, one broken bar is considered that was modeled by increasing the resistance of one squirrel cage rotor bar. The machine model was used within a dynamic simulation, including the rotor flux field-oriented vector control structure (Fig. 1).

Simulations were carried out by analyzing an acceleration transient starting with an electrical speed of 125 up to 225 rad/sec, with a ramp in the torque command whose duration is about 3 s. This choice was made to comply with typical torque transient specifications of a railway traction system(Fig3,4)

VI. SIMULATION AND RESULTS

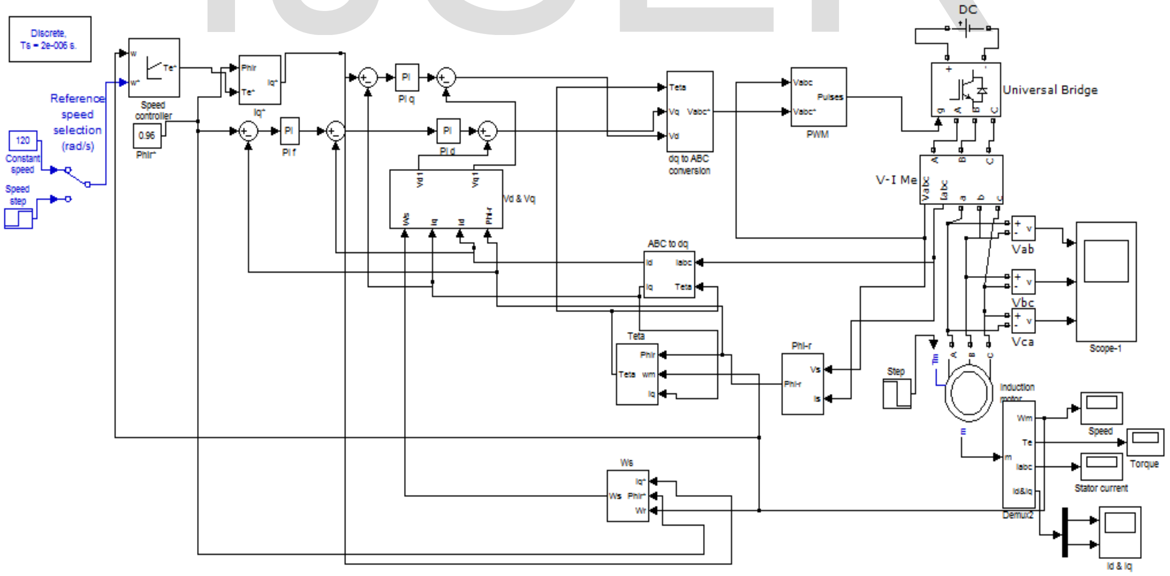

Fig.2: The developed Simulink model of vector control method

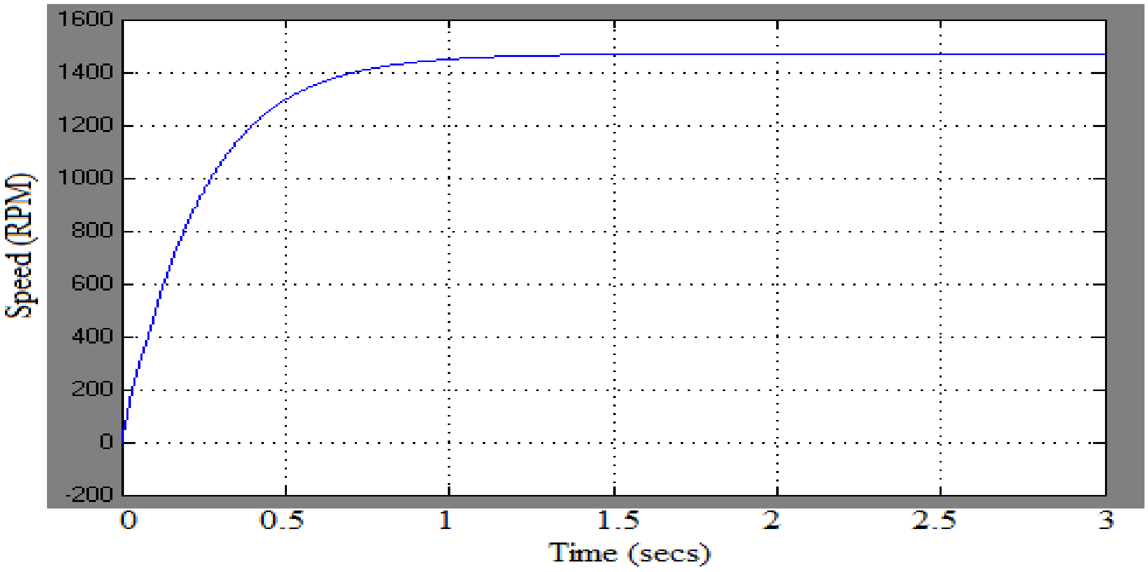

Fig.3: Speed vs time

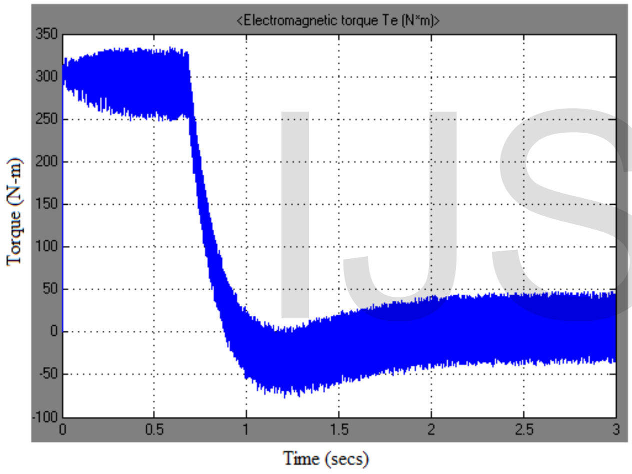

Fig.4: Torque vs time

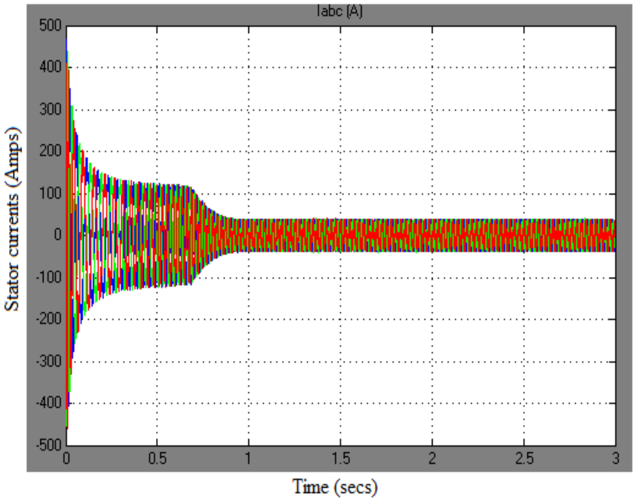

Fig. 5: 3-phase stator currents vs time

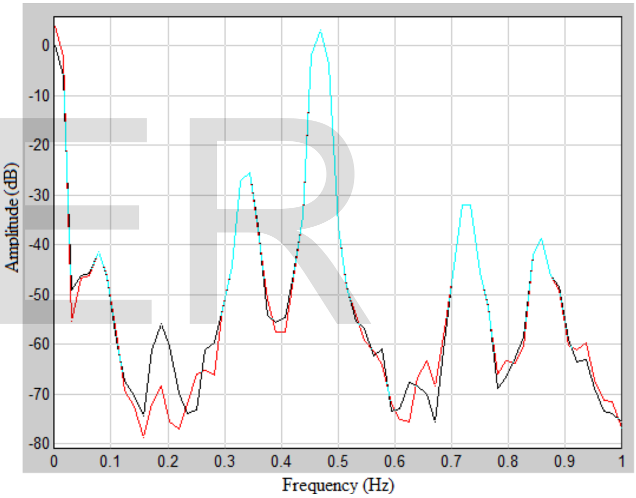

Fig. 6: simulation result for the 7.5-kw machine. Spectrum of the demodulated current with$\omega_d = 0$.

Fig. 5 shows the spectrum of a phase current during the same transient after the demodulation process detailed in Section III for a faulty and a healthy machine, with$\omega_d = 0\, rad/s$. The proposed procedure allows the accurate statement of the amplitude of the sideband components related to the fault. It is noteworthy to mention that this procedure is perfectly suited to a closed-loop system with smaller slip variations.

From the simulation results shown in the Figs. 6 it is observed that the stator current does not Exhibit any overshoot, any undershoot, variations in the response of the flux, torque, terminal voltage, speed & stator currents, etc.

VII. CONCLUSION

We have given the simulation model and results of simulation of the source induction motor. This method has been tailored to direct rotor flux field oriented controlled drives in transient conditions. During transient operations, torque and speed vary, avoiding the use of the MCSA and traditional spectral analysis for an effective diagnosis of rotor faults.The obtained analytical frequencies in the stator spectrum can be related to the experimental ones for normal operation and under rotor bar faults. The fact that the frequency components induced by rotor asymmetry are present in normal operation can be assumed as the inherent unbalance of the induction machine rotor cage reflected in the stator current spectrum.The proposed method will be tested on large power three phase induction machines in order to observe the sensitivity of the different frequency components affected by the introduced dissymmetry when a rotor bar or an end-ring is broken. This will be also extended for variable-frequency power supply in order to apply the same technique to adjustable-speed drives.

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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