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Detection of Stator and Rotor Winding Faults in Induction Motor using Park's Vector Approach

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Abstract

The Induction Motors in every rotating machine's heart and it's a very important component in a much. Almost 90 percent of the Induction Motor use in industry as a prime mover. So Induction Motor is necessary to Condition Monitoring for Economic Running Cost. Condition Based Monitoring of Induction Motor has become an important and difficult task for Engineers and Researchers mainly in Industrial applications. Several Condition Monitoring Methods (Technique) including Motor Current Signature Analysis Monitoring, Vibration Monitoring, Acoustic Emission Monitoring, Stray Flux Analysis, Shock Pulse Monitoring, Instantaneous Output Power Variation Analysis, Thermograph but all of these techniques required expensive specialized tools and sensors where Motor Current Signature Analysis method does not necessary any expensive sensors. The Motor Current Signature Analysis technique helps to effectively diagnose faults such as Rotor and Stator winding, Unbalanced Voltage and Load Fault are all examples of faults. The Stator Current Park's vector analysis is an easy and popular methodology for online discerns between healthy condition and faulty condition Induction Motors and it also tells about different faults. In this paper, Park's vector Patterns of 3-phase stator current is analyzed for Stator and Rotor winging Fault of Induction Motor. In the presence of multiple faults, the current in the supply stator contains sideband components, causing the circular pattern to be distorted. A three-phase induction motor with 7.5 HP was used to test this technique. The simulation result validated the experimental analysis.

Keywords: Stator Current Park's vector Approach, Analysis of Motor Current Signature, Stator and Rotor winging Fault.

INTRODUCTION

Induction Motor is commonly used in the Industrial Process for the reason that safety, arduous, reliability, efficiency, performance and cost-effective. The Induction Motor is 1-phase and 3- phase depending on the requirements of the machine. The Induction Motor consists of Electrical and Mechanical Components such as rotor, stator, winding, bearing and end rings, etc. Induction Motor works in harsh environmental and industrial conditions and the presence of various types of stress. These presences of Faults occur as a result of stress Induction Motors which are classifiable in three different types such as electrical, mechanical, and environmental faults as known in Figure 1 [23]. The basic region for these faults as (a) unbalance voltage and current (b) bed environmental conditions (c) unbalanced and overload (d) weak and improper installation (e) weak and improper stator winding insulation (f) corrosion (g) contamination.

The theory of different for every fault which give parameter such as vibration, current and acoustics, with the help of these parameters to be monitored and the detection of these faults.

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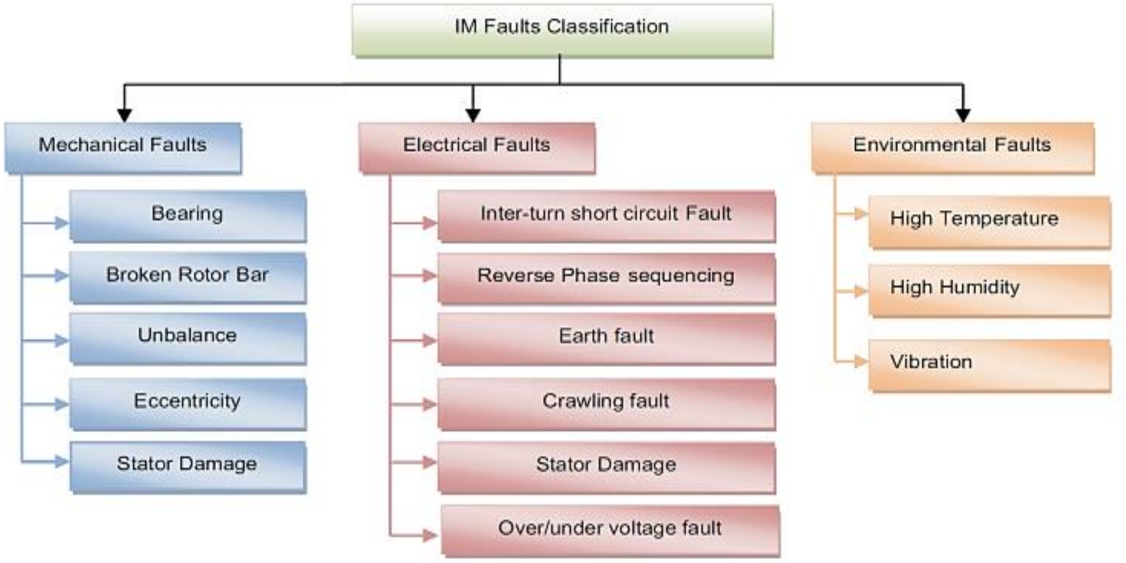

Figure 1. Classified in Three Different Types such as Electrical, Mechanical and Environmental Faults

Condition monitoring technique	A physical variable	Motor Component
Acoustic monitoring	Acoustic output	Bearings [3-5]
Instantaneous output power variation analysis	Instantaneous power	Stator winging [6,7]
Motor current signature analysis	Current signal	Stator winding [8-11], broken rotor bar [12, 13], bearing [14]
Shock pulse monitoring	Vibration and shock pulse	Bearing [15]
Stray flux analysis	Stray flux	Rotor eccentricity [16]
Vibration monitoring	Levels and frequencies of vibration	Bearings [17-19]

Table 1. condition monitoring methods and physical parameters.

The various condition monitoring methods and physical parameters, as well as the monitoring of major induction motor components, are shown in Table 1 [24-29].

STATOR FAULT

The stator is the most important part, as it generates the rotating magnetic flux that causes the rotor to experience induced electromagnetic force (emf). Stator faults are responsible for 30-40% of induction motor failure [2]. Figure 2 depicts a complex representation of a stator winding with a fault in the phase winding, where sa_2 represent stator fault winding for α (the stator winding's number of turns that have been shortened / In the winding of the stator, the sum number of phases per turn) fraction of turn sorted. For healthy conditions, α is nil (zero) [31-36]. For fault condition, α is not nil (zero).

The stator current is expressed mathematically in terms of flux linkage and voltage. [35]

$$[i_s] = [R_S]^{-1} + [v_S] - \rho[\lambda_s] \quad (1)$$

Where:

$[v_S]$ = Stator voltage $=[v_{sa1}\ v_{sa2}\ v_{sb}\ v_{sc}]^T$

$[R_S]$ = Stator resistance $=R_S$ diag

$[1-\alpha \quad \alpha \quad 1 \quad 1]$

$[i_S]$ = Stator current $=\left[i_{sa1}\ (i_{sa}-i_f)\ i_{sb}\ i_{sc}\right]^T$

$[\lambda_s]$ = Stator Flux linkage $= L_{ss}\, i_s = \mu_o A\pi l N_S^2 i_s / 2g$

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$\mu_o = Permeability\ of\ air$
A = the air-average gap's radius

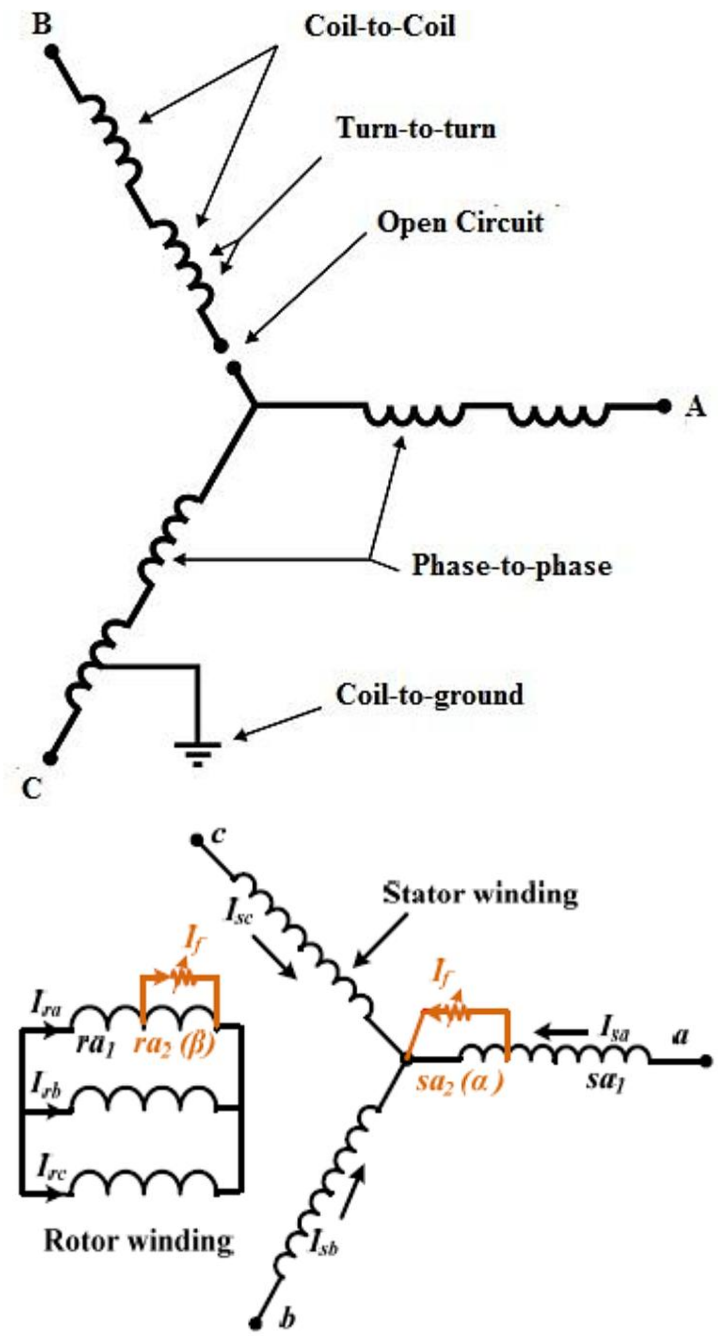

Figure 2. Induction motor winding faults on the stator and rotor.

l = Rotor's length
N_s = The stator winding's number of turns.
g = Air gap distance (length)

An induction motor has electromagnetic and mechanical stresses. In healthy conditions, the stator impedance and stator current are balanced. These balance conditions, frequency component at f and sf exist. If the stator is faulted, the stator unsymmetrical of induction motor and a reverse magnetic field that rotates produced. Therefore, from equation (1), the current in the stator is a function of the stator winding's number of turns. The induction motor frequency propagation of

$$i_s = f_1(N_s) \quad (2)$$

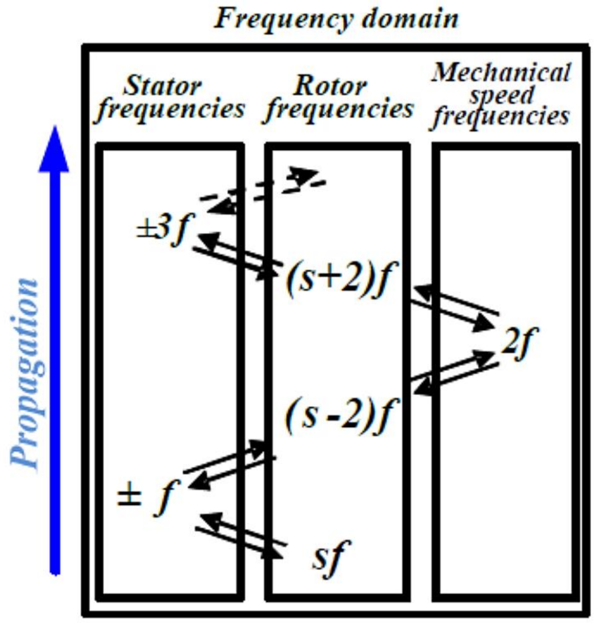

Figure 03.1: A stator winding's frequency domain propagation Induction motor faults.

The 3rd order harmonic portion is the characteristic fault for a stator winding fault, there is a frequency component caused by an induction motor's stator unsymmetrical current and a magnetic field that rotates backwards is formed.

ROTOR FAULT

The winding representation of the winding is depicted in Figure 2, where ra_2 represents rotor fault winding for β (the number of turns in the rotor winding that have been shortened / in the winding of the rotor, per-turn total number of phases) fraction of turn sorted. For healthy conditions, β is nil (zero). For fault condition β is not nil (zero).

The stator current is expressed mathematically in terms of flux linkage and voltage.

$$[i_S] = [R_S]^{-1} + [v_S] - \rho[\lambda_s] \quad (3)$$

Where:

$[v_S]$ = Stator voltage $=[v_{sa1}\ v_{sa2}\ v_{sb}\ v_{sc}]^T$

$[R_S]$ = Stator resistance $=R_S$ diag

$[1-\alpha \quad \alpha \quad 1 \quad 1]$

$[i_S]$ = Stator current $=\left[i_{sa1}\ (i_{sa}-i_f)\ i_{sb}\ i_{sc}\right]^T$

$[\lambda_s]$ = Stator Flux linkage $= L_{ss}\, i_s + L_{sr}\, i_r = \left(\mu_o A\pi l N_S^2 i_s/_{2g}\right) + \left(\mu_o A\pi l N_s N_r i_r/_{4g}\right)$

$\mu_o = Permeability\ of\ air$

A = the air-average gap's radius

l = Rotor's length

i_r = Rotor Current

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N_s = Number of turns on a stator winding.
N_r = Rotor winding's number of turns.
g = Air gap distance (length)

The Induction motor has electromagnetic and mechanical stresses. In healthy conditions, the stator impedance and stator current are balanced. These balance conditions, frequency component at f and sf exist. If the rotor is faulted, the rotor unsymmetrical of induction motor and a reverse rotating magnetic field produced. Therefore, from equation (3), The stator current is determined by the number of turns in the rotor winding. The induction motor frequency propagation of

$$i_r = f_2(N_r) \quad (5)$$

The characteristic fault frequency components for an induction motor's rotor winding failure as a result of rotor unsymmetrical current, which is reflected as the stator current and a reverse rotating magnetic field produced, are the slip frequency's 3rd order harmonic component.

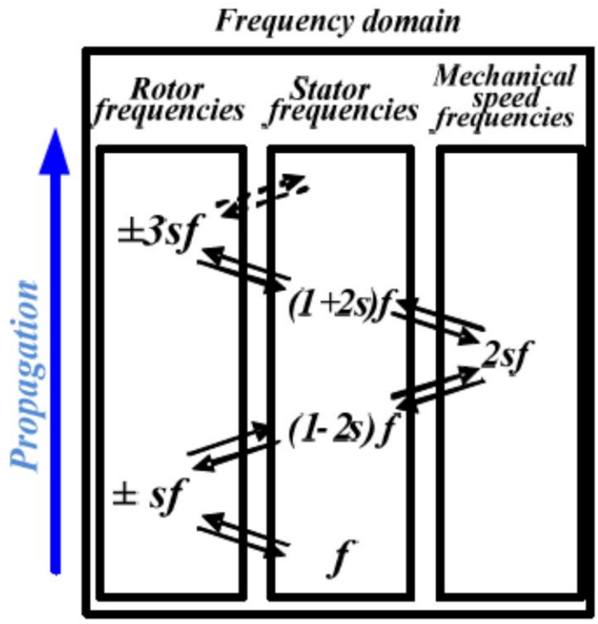


Figure 03.2: Frequency domain propagation of a rotor winding Faults of induction motor.

The 3 – phase stator current is balanced in a healthy condition, as shown below.

$$\begin{aligned} i_{sa} &= I_m \sin(wt) \\ i_{sb} &= I_m \sin(wt-120^0) \\ i_{sc} &= I_m \sin(wt-240^0) \end{aligned} \quad (6)$$

The 3rd order harmonic characteristic fault frequency components of 3 – phase stator current to winding asymmetry under the stator winding fault condition are:

$$\begin{aligned} i_{sa_{sf}} &= I_{ma_{sf}} \sin 3(wt) \\ i_{sb_{sf}} &= I_{mb_{sf}} \sin 3(wt-120^0) = I_{mb_{sf}} \sin 3(wt) \\ i_{sc_{sf}} &= I_{mc_{sf}} \sin 3(wt-240^0) = I_{mc_{sf}} \sin 3(wt) \end{aligned} \quad (7)$$

From equation (7) it has been observed that the amplitude and phase shift of the harmonic of the 3rd order characteristic fault all of the phases have different frequency components. As a result, a faulty stator the vector pattern used by Park is not circular. in the form under these conditions.

Likewise, (1±2s) order harmonic component represents characteristic fault frequency components for rotor faults.

Frequency of Characteristic fault components for rotor faults are described by the (1±2s) order harmonic component.

$$i_{sa_{rf}} = I_{ma_{rf}} sin\ (1 \pm 2s)\ wt$$
$$i_{sb_{rf}} = I_{mb_{rf}} sin\ (1 \pm 2s)\ wt\ sin\ (1 \pm 2s)\ wt \quad (8)$$
$$i_{sc_{rf}} = I_{mc_{rf}} sin\ (1 \pm 2s)\ wt$$

Connection between Park's Vector Stator Current and Algorithm Proposed

The three-phased stator current system of a safe induction machine is perfectly symmetric:

$$i_a = \sqrt{2}I \sin(w_s t)$$
$$i_b = \sqrt{2}I \sin\left(w_s t + \frac{2\pi}{3}\right) \quad (9)$$
$$i_c = \sqrt{2}I \sin\left(w_s t + \frac{4\pi}{3}\right)$$

Converting a three-phased system to a two-phased orthogonal system is possible:

$$\begin{vmatrix} f_d \\ f_q \\ f_0 \end{vmatrix} = [p_{dqo}] \begin{vmatrix} f_a \\ f_b \\ f_c \end{vmatrix} \quad (10)$$

Where *f* denotes the transformed function (it can be the current, voltage or magnetic flux).

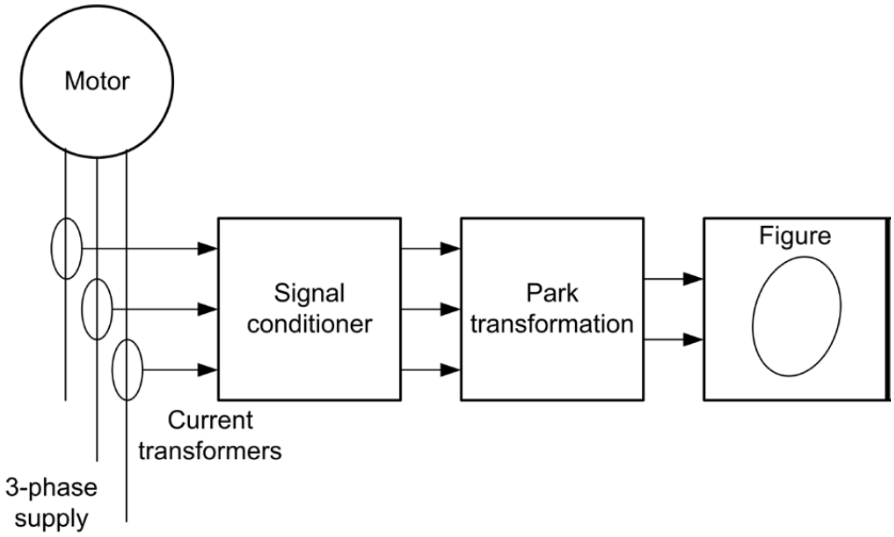


Figure 4. The MCSA Block Diagram using Park's Vector approach

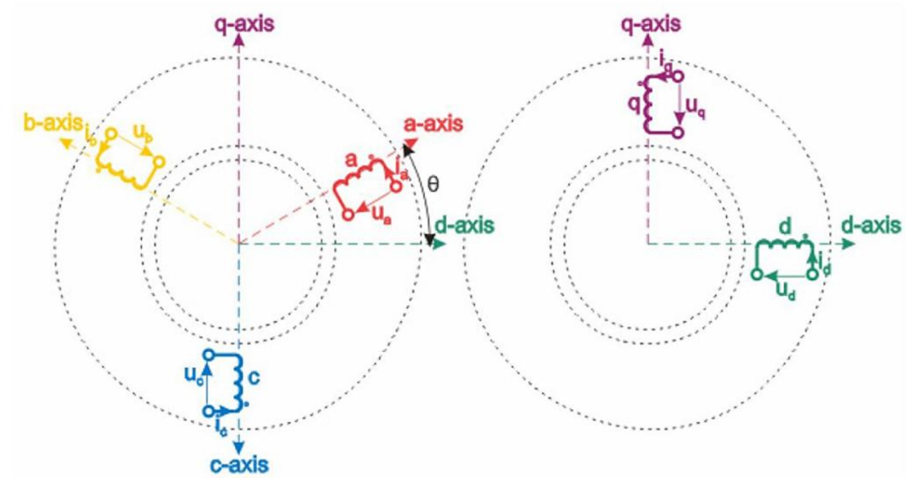


Figure 5. Park's Transformation

Park's transformation matrix is as follows:

$$|P_{dqo}|\sqrt{\frac{2}{3}}\begin{vmatrix} \cos(\theta) & \cos(\theta-\frac{2\pi}{3}) & \cos(\theta-\frac{4\pi}{3}) \\ -\sin(\theta) & -\sin(\theta-\frac{2\pi}{3}) & -\sin(\theta-\frac{4\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{vmatrix} \quad (11)$$

The orthogonal elements of Park's current vector can be computed using the above transformation from a three-phased current symmetrical structure with the components: i_a, i_b, and i_c:

$$i_d = \sqrt{\frac{2}{3}}\left[i_a \cos\theta + i_b \cos\left(\theta - \frac{2\pi}{3}\right) + i_c \cos\left(\theta + \frac{2\pi}{3}\right)\right] \quad (12)$$
$$i_q = -\sqrt{\frac{2}{3}}\left[i_a \sin\theta + i_b \sin\left(\theta - \frac{2\pi}{3}\right) + i_c \sin\left(\theta + \frac{2\pi}{3}\right)\right]$$

If the relation is set in the stator of the machine ($\theta = 0$) the equation becomes:

$$i_d = i_a - \frac{i_b}{2} - \frac{i_c}{2} \quad (13)$$
$$i_q = \frac{\sqrt{3}}{2}(i_b - i_c)$$

In this case, by replacing (12) with (13) in the case of a healthy induction machine, for two orthogonal components of Park's current vector, the following equation can be obtained:

$$i_d = \frac{3}{2} I_M \sin(wt) \quad (14)$$
$$i_q = \frac{3}{2} I_M \cos(wt)$$

According to equation (14) a healthy induction machine shows a complete perfect circle in Park's vector representation, as shown in Figure 6.

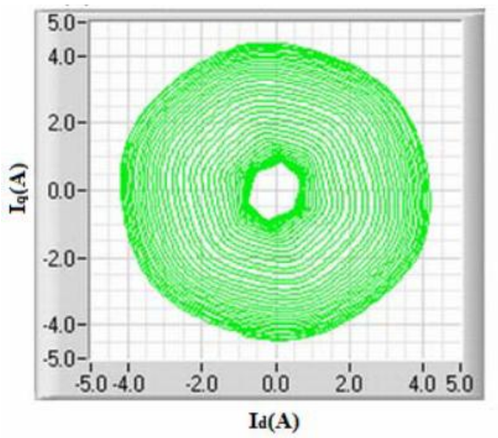


Figure 6. Stator Current Park's Vector for ideal conditions

EXPERIMENTAL RESULTS

On a four-pole, 400-volt, 50-hertz 3-phase induction motor, in laboratory, the proposed technique is experimentally validated.

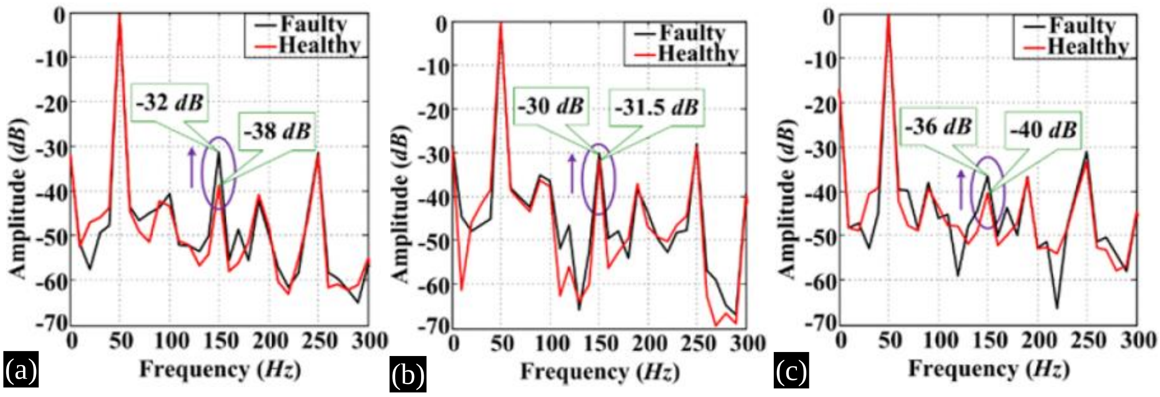
The specifications of the experimental 3-phase induction motor are given in below Table 2:

Parameter	Particulars
Rating of power	7.5 hp
Turns/coils of the stator	57 (342 turns/phase)
Rotor turns/coil	22 (220 turns/phase)

Table 2. Specifications of the experimental 3-phase induction motor

Fault study of the stator windings

One of the most typical faults in induction motors is the stator winding fault. Figures 4(a, b and c) display the stator current in three phases FFT spectrums in a healthy and a phase winding condition with 12 turns shorted in the stator [34-38].



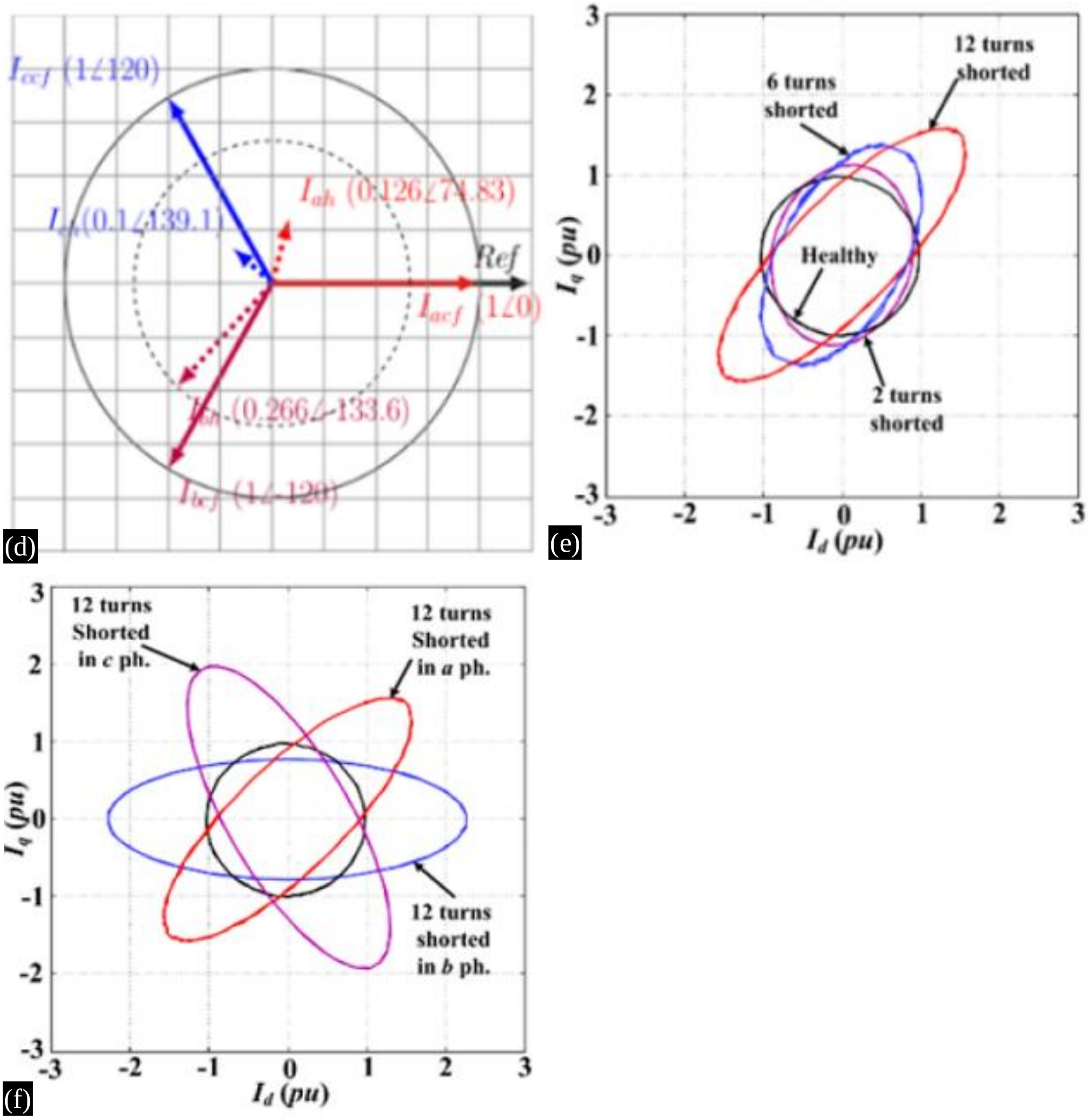


Figure 4. (a) *a* phase, (b) *b* phase, (c) *c* phase, (d) Phase diagram, (e) Stator fault Park's vector pattern of stator (f) Stator fault Park's vector pattern of stator with three phases induction motor current.

The characteristics of faults frequency components for stator faults are represented by the 3rd order frequency component in the diagrams above.

Figure 4(d) depicts a 3rd Three-phase order frequency component phasor diagram stator current in a healthy condition. The dotted line in the phasor diagram represents a stable condition, while the straight line represents a defective condition.

Figure 4(e), Stator fault Park's vector pattern of stator with three phases induction motor current 3rd order frequency component in the category of healthy and 2, 6, 12 turns shorted in the stator 'a' phase winding and Figure 4(f), Stator fault Park's vector pattern of stator with three phases induction motor current 3rd order frequency component in the category of healthy and 12 turns shorted in the stator each phase winding at rated load and voltage conditions.

Fault study of the Rotor windings

One of the most common faults in induction motors is the rotor winding fault. Figures 5(a, b and c) show the current in three phases of a stator FFT spectrums in the category of healthy and 8 turns shorted in the rotor *a* phase winding conditions.

The characteristics of faults frequency components for stator faults are represented by the 3rd order frequency component in the diagrams above.

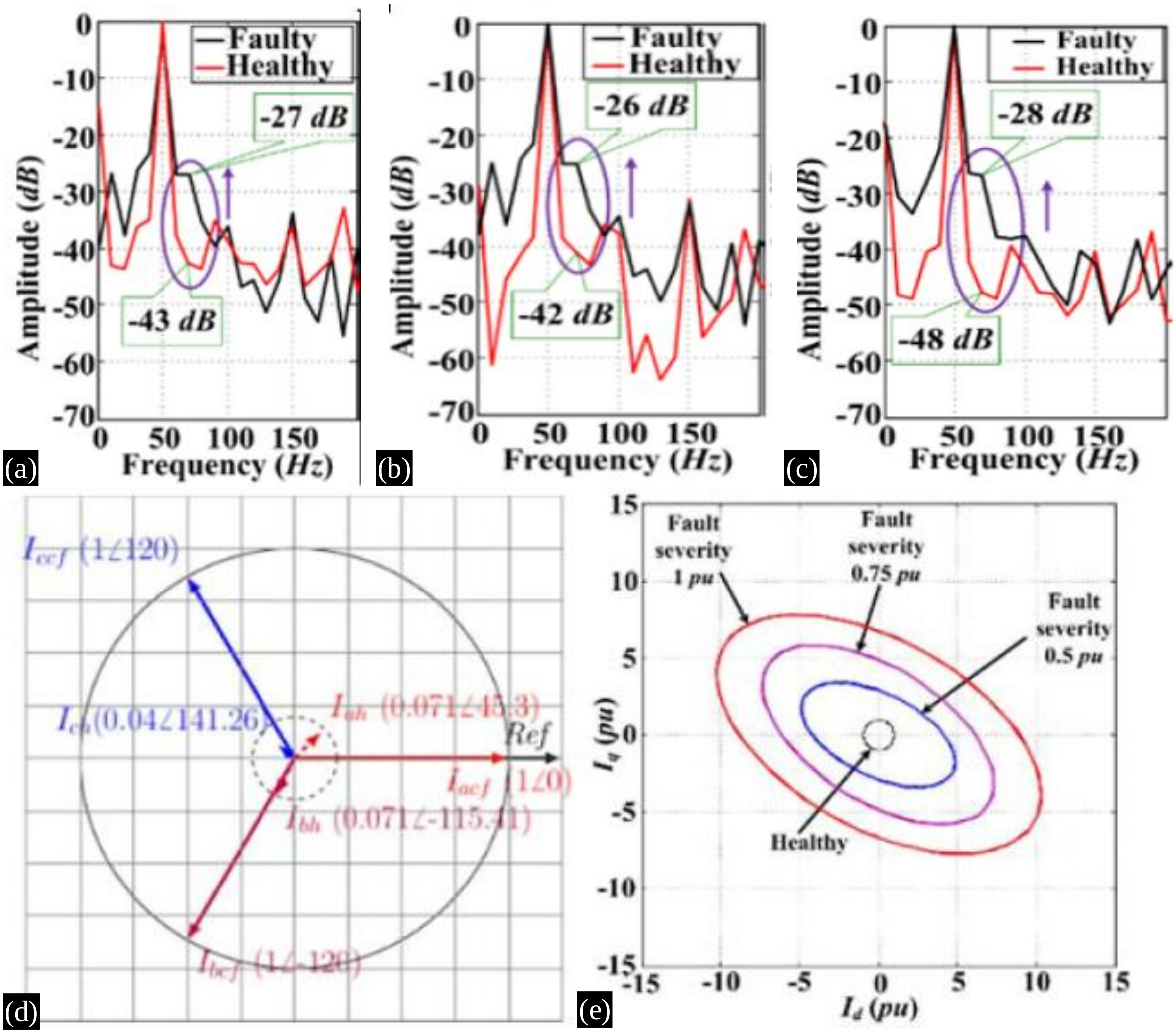


Figure 5. (a) *a* phase, (b) *b* phase, (c) *c* phase, (d) Phase diagram

Figure 5 depicts a 3rd order frequency component phasor diagram of current in three phases of a stator in a category of healthy state (d). The phasor diagram, it should be noted, reflects the defective conditions.

Figure 5(e), Rotor fault Park's vector pattern of stator with three - phases induction motor current Frequency of the 3rd order component 8 turns shorted and under healthy conditions in the rotor 'a' phase winding, rotor fault Park's vector pattern of three - phase stator induction motor current 3rd order frequency component 8 turns shorted and under healthy conditions in the rotor each at rated load and voltage conditions, phase winding is used.

CONCLUSIONS

This paper described a new non-invasive online method for detecting rotor and stator winding faults. The Rotor fault under healthy and defective operating conditions, the vector of Park, and Stator fault the vector of Park have been analyzed, experimentally, and simulated. The reference rotor fault The vector of Park and stator fault The vector of Park are compared to the instantaneous rotor fault The vector of Park and stator fault The vector of Park, respectively. The severity level of the fault is determined by the amount of deviation. The stator winding fault is located based on the inclination the Stator fault the vector of Park. When the experimental outcomes are compared to simulation results, it is found that experimental results' pattern is virtually identical to the simulation results. As a result, the suggested method has been proven. The proposed fault detection technique has the advantage of being immune to unbalanced voltage and multiple faults.

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