Analysis and Simulation of Three-phase Induction motor using Clarke's transformation

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***Abstract*— Condition monitoring of induction motors is a fast emerging technology in the field of electrical equipment maintenance and has attracted more and more attention worldwide as the number of unexpected failure of a critical system can be avoided. Online motor diagnosis is the most efficient way to retain motors operating continuously under healthy conditions. To simplify analysis of a polyphase system, Clarke's transformation is appied. The induction motor model operation and performance is simulated using Matlab. It demonstrates the operational characteristics of faulty as well as healthy motors. This paper presents the advantages of simulation softwares such as Matlab, and use of Clarke's transformation to simplify analysis of a three-phase system.**

Keywords—Induction motor, Stator and rotor faults,clarke's transform.

I. INTRODUCTION

Various test can be performed to investigate the steady-state and dynamic operation of electrical machines and to determine their modeling parameters. Performing such tests helps to acquire a clear understanding of the motor performance. Nevertheless, constraints in some cases make it impossible to do these tests, or only allow them to be done to a limited degree. Such constraints include: the high costs of some of the tests; the lack of appropriate measuring instruments or test rigs; the destructive nature of some of the tests. The risk of equipment damage from repeated tests in a short time period. These limitations prevent from performing some useful tests, repeating other test procedures, and employing a trial-and-error approach to get a better understanding of the machine performance. Simulations place no limitations on the duration of tests, such virtual tests are therefore perfectly cost-effective.

The simulation of rotor bar failure and dc, no-load, of induction motors (IMs) using MATLAB/Simulink was proposed in [1]-[3] to improve the fundamental concepts of electric machines. Computer simulation has sometimes been
(5)
employed as a complement to an electrical machine performance and its practical tests [3]. Computer programshave also been used to obtain the steady-state performance of IMs under different operating conditions, using its equivalent circuit and plotting various characteristics.

II. ELECTRICAL EQUIVALENT CIRCUIT OF IM

An induction motor can be represented as a generalized transformer (fig 1), with stator being fixed and behaving as the primary, while rotating rotor behaves as the secondary. Since we are dealing with a 3 phase motor therefore per phase equivalent circuit of the stator can be represented as shown below (fig 2).

Applying KVL per phase to the equivalent circuit gives;

$$Vsa = Isa\ Rsa + \frac{d}{dt}\Phi a \quad (1)$$

$$Vsa = Isa\ Rsa + ((\ Lsa\ Isa + Lm\ Isb + Lm\ Isc) + Lsr\ Ir) \quad (2)$$

Similarly;

$$Vsb = Isb\ Rsb + ((\ Lsb\ Isb + Lm\ Isa + Lm\ Isc) + Lsr\ Ir) \quad (3)$$

$$Vsc = Isc\ Rsc + ((\ Lsc\ Isc + Lm\ Isa + Lm\ Isb) + Lsr\ Ir) \quad (4)$$

Using matrix notation, the above equations can be written as;

$$\begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix} = \begin{bmatrix} Isa \\ Isb \\ Isc \end{bmatrix} \begin{bmatrix} Rsa & 0 & 0 \\ 0 & Rsb & 0 \\ 0 & 0 & Rsc \end{bmatrix} + \frac{d}{dt} \left\{ \begin{bmatrix} Lsa & Lm & Lm \\ Lm & Lsb & Lm \\ Lm & Lm & Lsc \end{bmatrix} \begin{bmatrix} Isa \\ Isb \\ Isc \end{bmatrix} + (Lsr)Ir \right\}$$

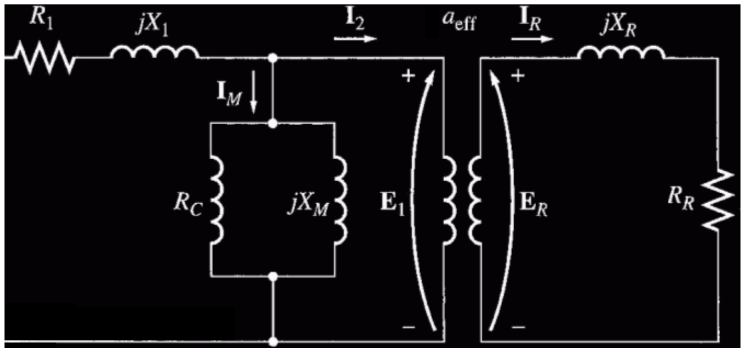

Fig 1 Electrical equivalent circuit of IM

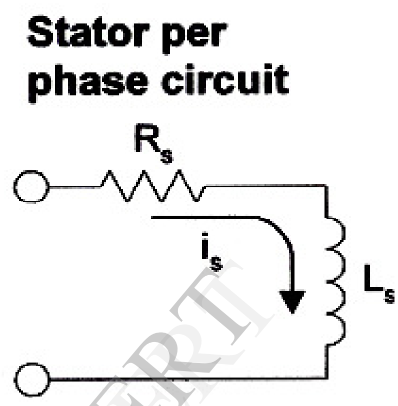

Fig 2. Stator equivalent circuit

In a more generalised form; the above equation can be written as;

$$[Vs] = [Is][Rs] + \frac{d}{dt}([Lss][Is] + [Lsr][Ir]) \quad (6)$$

i.e $\quad Vs = IsRs + \frac{d}{dt}\Phi s \quad (7)$

where;

$$\Phi s = Lss\ Is + Lsr\ Ir \quad (8)$$

Thus from the above equations we get;

$$[Vs] = \begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix};\ [Is] = \begin{bmatrix} Isa \\ Isb \\ Isc \end{bmatrix};\ [Rs] = \begin{bmatrix} Rsa & 0 & 0 \\ 0 & Rsb & 0 \\ 0 & 0 & Rsc \end{bmatrix};$$

$$Lss = \begin{bmatrix} Lsa & Lm & Lm \\ Lm & Lsb & Lm \\ Lm & Lm & Lsb \end{bmatrix};\ \Phi s = \begin{bmatrix} \Phi sa \\ \Phi sb \\ \Phi sc \end{bmatrix}; \quad (9)$$

It is to be noted that [Lsr] and [Ir] are also in the form of matrices, which is derived during the analysis of rotor circuit.

The inductance due to space fundamental component of the air gap flux produced by a stator phase current can be given as;

$$Lsa = Lsb = Lsc = Ls + Lls\ ; \text{ and } Lm = -\frac{Ls}{2} \quad (10)$$

Where;

$$Ls = \frac{\mu\pi Nc^2\ Rgd}{4gp^2} \quad (11)$$

Using a three phase quantity, the analysis of induction machine becomes quiet complex. Therefore to simplify calculations Clarke's transformation also called as dqo transformation can be applied.

III. CLARKE'S TRANSFORMATION

Clarke's transformation is a mathematical transformation to simplify analysis of a three-phase circuit; given as;

$$Xdqo = \sqrt{2/3} * \begin{bmatrix} Xa \\ Xb \\ Xc \end{bmatrix} * u\ ; \quad \text{where}$$

$$U = \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ -sin\theta & -\sin(\theta - 2\pi/3) & -\sin(\theta + 2\pi/3) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}$$

Thus ;

$$Xd = \sqrt{2/3}\ [\cos\theta * Xa + \cos(\theta - 2\pi/3) * Xb + \cos(\theta + 2\pi/3) * Xc] \quad (12)$$

$$Xq = -\sqrt{2/3}\ [\sin\theta * Xa + \sin(\theta - 2\pi/3) * Xb + \sin(\theta + 2\pi/3) * Xc] \quad (13)$$

$$X0 = \sqrt{2/3}\ \left[\frac{Xa+Xb+Xc}{\sqrt{2}}\right] \quad (14)$$

.

Generally the value X0 is used to indicate the amount of imbalance in a 3Φ system. Since the system is balanced ,therefore Xo tends to zero, indicating that the system is perfectly balanced.

Thus we will be implementing the clarke's transformation only to derive the d and q axis, which are referred as the direct and quadrature axis.

Dq transformation can be applied to any 3 phase quantity e.g. voltage, current, flux linkage, etc. Thus to convert 3Φ supply to dq-axis the converter (transformation circuit) can be implemented as shown in fig 3.

Thus Vd or Vq represents Vs. The value of stator flux can be calculated if Vs, Is and Rs are known. In the same way stator current for a 3 Φ system, can be converted to a 2 Φ quantity using the same transformation

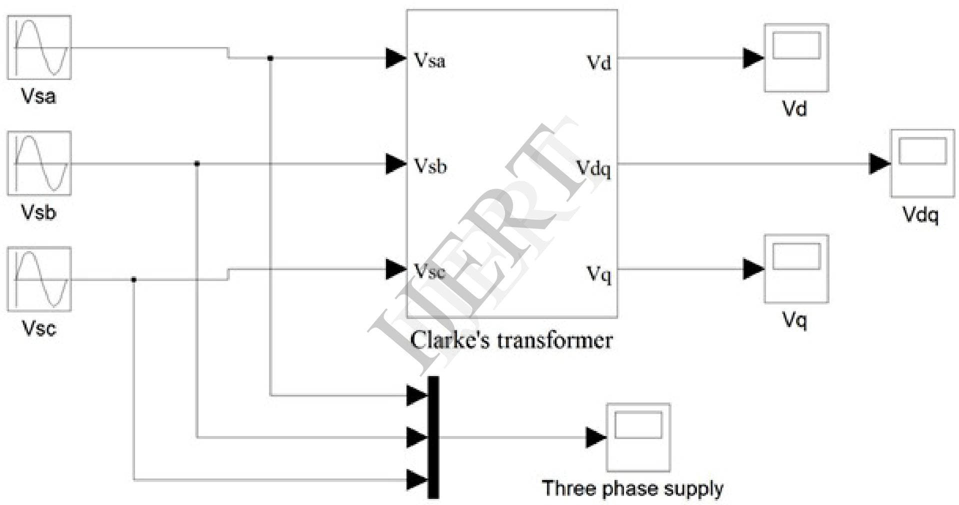

Fig 3. Clarke's transformer

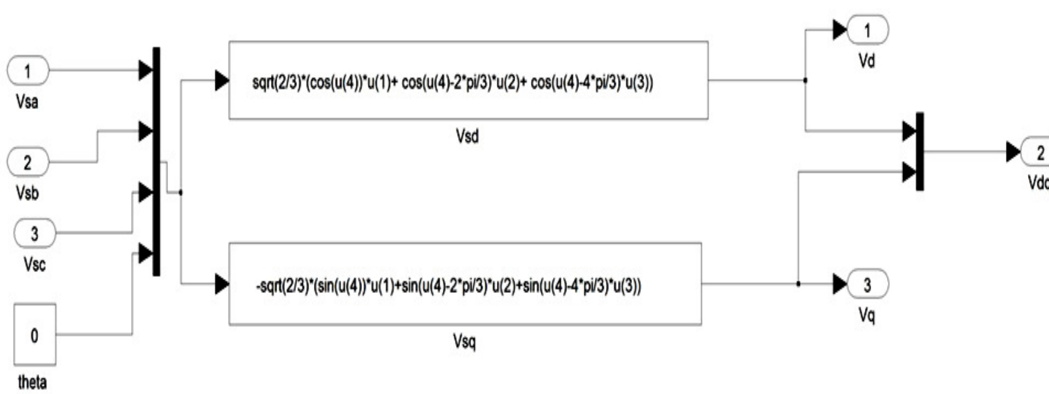

Fig 4 Internal blocks of Clarke's transformet

IV. RESULTS

The use of clarke's transformation helps to convert a three phase quantity into a two phase quantity abbrievated as direct and quadrature quantities. The observations for each scope is presented to justify the clarke's transformer. Fig 5 represents a three phase supply which is converted to two phase (in quadrature to each other) using clarke's transformation as depicted in fig 6.

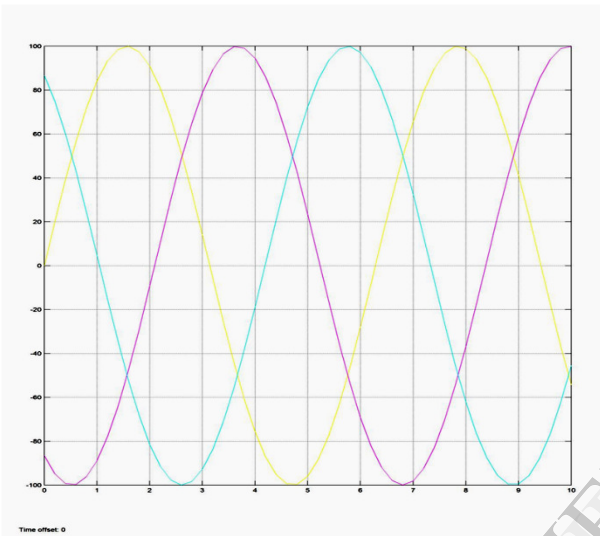

Fig 5 Three phase supply

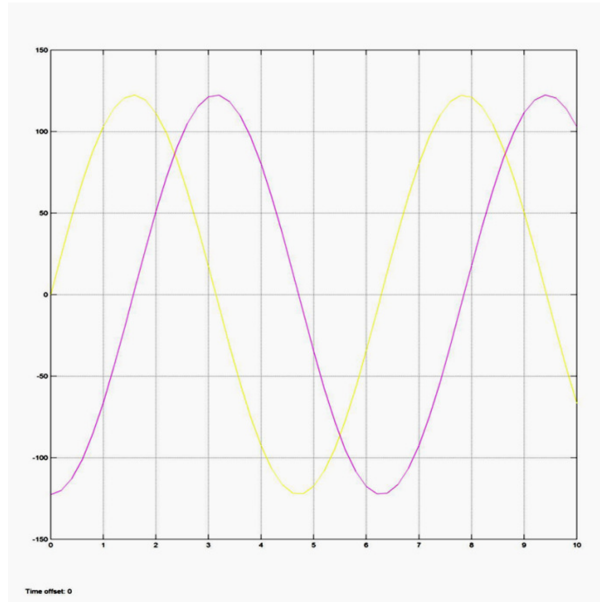

Fig 6 Two phase quantity

This analysis can be further extended to calculate the values of stator and rotor currents by making using of the clarke's transformation. Fig 7 and fig 8 represent the equivalent matlab models for estimating stator and rotor currents in a three phase induction motor by the application of clarke's transformation. Fig 9 depicts the two currents represented as single phase quantities

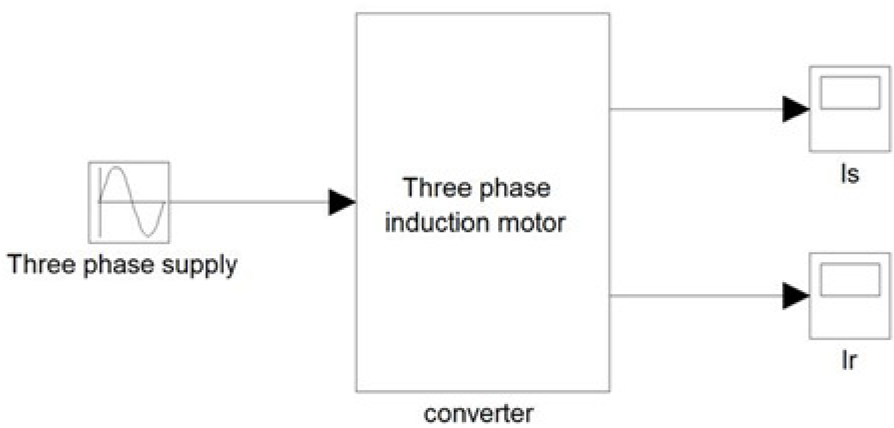

Fig 7 Estimating stator and rotor current per phase

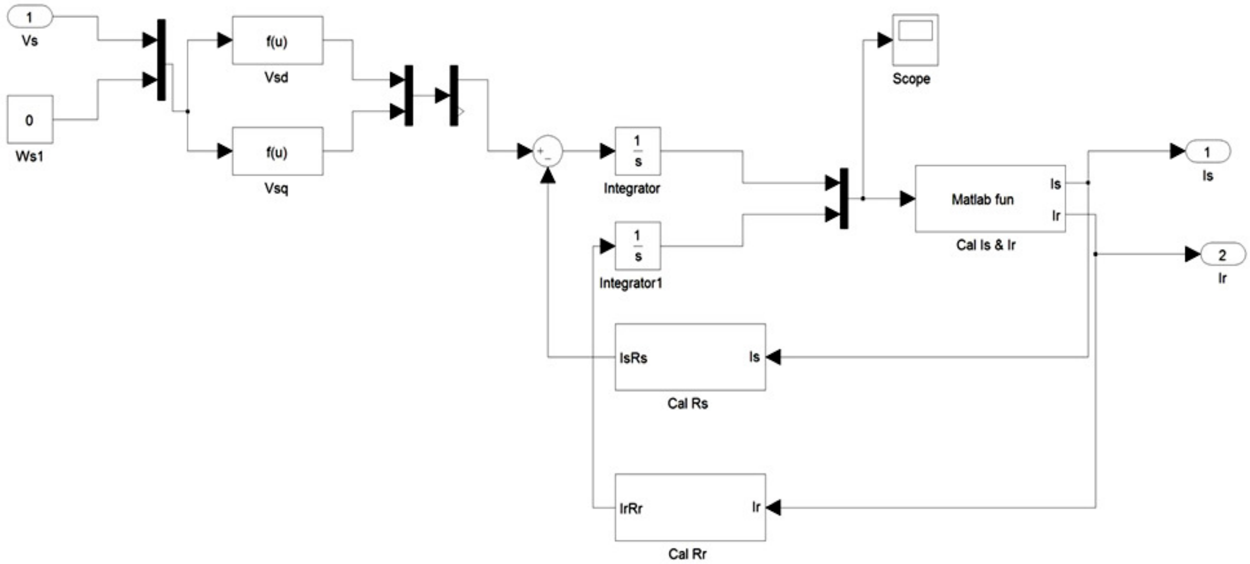

Fig 8 Internal blocks for measurement of stator and rotor currents

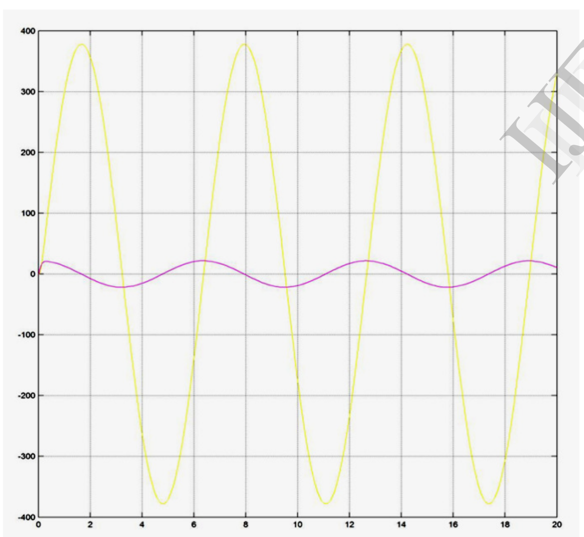

Fig 9 Representation of stator and rotor currents as single phase quantities

TABLE I

Observations	Amplitude	Phase (deg)
Vsa	100	0
Vsb	100	-120
Vsc	100	+120
Vd	120	0
Vq	120	-90
Is	123	0
Ir	7	90
Φs	6 wb/m	0
Φr	4wb/m	0

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