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# Vector Control of Three-Phase Induction Motor with Two Stator Phases Open-Circuit

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**ABSTRACT**

Variable frequency drives are used to provide reliable dynamic systems and significant reduction in usage of energy and costs of the induction motors. Modeling and control of faulty or an unbalanced three-phase induction motor is obviously different from healthy three-phase induction motor. Using conventional vector control techniques such as Field-Oriented Control (FOC) for faulty three-phase induction motor, results in a significant torque and speed oscillation. This research presented a novel method for vector control of three-phase induction motor under fault condition (two-phase open circuit fault). The proposed method for vector control of faulty machine is based on rotor FOC method. A comparison between conventional and modified controller shows that the modified controller has been significantly reduced the torque and speed oscillations.



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## 1. INTRODUCTION

Three-phase induction motors are utilized in wide range of applications as a means of transforming electric power to mechanical power. The alternating current is provided to the stator winding directly whereas supply the voltage to the rotor winding is by induction; consequently it is named induction machine. The induction machine has the ability to function as a motor and as a generator. Nevertheless, it is rarely employed as a generator providing electrical power to a load. The overall performance features as a generator are not good enough for most usage. The induction machine is broadly applied as a motor in many applications. The induction motor is employed in different sizes. Small single-phase induction motors are applied in many domestic appliances, such as lawn mowers, juice mixers, blenders, washing machines, stereo turntables, and refrigerators. Large three-phase induction motors (in 10's or 100's of horsepower) are applied in fans, compressors, pumps, textile mills, paper mills and so forth. The linear type of the induction machine has been created mainly in order to use in transportation systems [1].

Over the past decades, many control techniques have been proposed for induction motors drive system. One of the most well-known control method for controlling the speed and torque of the induction motor is Field-Oriented Control (FOC) [2]. Modeling and control of faulty induction motor, is obviously different from the conventional balanced three-phase induction motor. As such, new modeling and control approaches have to be applied at the instance the faulty is detected. By applying the conventional balanced three-phase induction motor control strategy, such FOC to faulty induction motor, significant oscillations in the torque output will be presence; this is because of the unequal inductances in the d and q axis of the unbalanced induction [3], [4]

Important works has been developed concerning the implementation of vector control methods for electrical machines under open-phase fault [5]-[18]. Most of the pervious works have focused on developing vector control methods of faulty multi-phase induction motors (five and six phases) [5]-[9], faulty Permanent Magnet Synchronous Motors (PMSMs) [10]-[12], and three-phase induction motor under 2-phase condition (one-phase open circuit fault) [3], [4], [13]-[18] but none of them presented in the case of vector control method for three-phase induction motor drive with two stator phases open-circuit.

This research presented a new method for vector control of three-phase induction motor under fault condition. Main objectives of this research are as follows: (1): To develop a model of a faulty three-phase induction motor when two-phases of the stator are open circuit, which can be controlled using rotor FOC technique, (2): To modify a conventional rotor FOC of induction motor, so that it can be applied for unbalanced three-phase induction motor (while two-phase of stator are open circuit).

## 2. THREE-PHASE INDUCTION MOTOR MODEL WITH TWO STATOR PHASES OPEN-CIRCUIT

In this section the d-q model of three-phase induction motor when two phases of stator are open-circuit is presented. Figure 1 shows the d-q axes and stator a-axis.

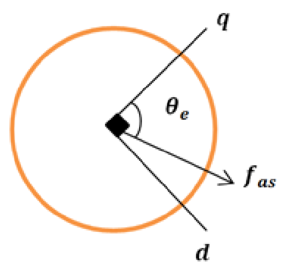



Figure 1. d-q axes and stator a-axis

In Figure 1, $f_{as}$ can be current, voltage or flux and $\theta_e$ is the angle between q-axis and a-axis variable of stator. Based on Figure 1, stator a-axis variable is formulated in terms of d and q axes as follows:

$$f_d = f_{as} \sin\theta_e, f_q = f_{as} \cos\theta_e \tag{1}$$

Considering that the d and q axes are orthogonal, consequently their dot product has to be equal to zero. As a result, $\theta_e$ can be equal to zero or (π/2). In this study it is assumed, $\theta_e$ is equal to zero then d and q axes can be written as equation (2):

$$f_d = 0, f_q = f_{as} \tag{2}$$

Therefore, the stator transformation matrix in the fault situation (two stator phases open-circuit) can be obtained as equation (3):

$$[f_q] = [T_s^{fault}][f_{as}] \rightarrow [T_s^{fault}] = [1] \tag{3}$$

The rotor transformation matrix is the same as rotor transformation matrix in the balanced condition. In equation (5), $\gamma$ is the angle between rotor a-axis variable and d-axis.

$$[T_r] = \sqrt{\frac{2}{3}} \begin{bmatrix} cos(\gamma) & cos(\gamma + 120) & cos(\gamma - 120) \\ sin(\gamma) & sin(\gamma + 120) & sin(\gamma - 120) \end{bmatrix} \tag{4}$$

By applying stator and rotor transformation to voltage equation of the motor, the voltage equation of faulty motor in stationary reference frame can be shown as follows [14]:

$$\begin{bmatrix} V_{ds}^s \\ V_{qs}^s \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} r_{sd} + L_{sd}\frac{d}{dt} & 0 & M_{srd}\frac{d}{dt} & 0 \\ 0 & r_{sq} + L_{sq}\frac{d}{dt} & 0 & M_{srq}\frac{d}{dt} \\ M_{srd}\frac{d}{dt} & \omega_r M_{srq} & r_r + L_r\frac{d}{dt} & \omega_r L_r \\ -\omega_r M_{srd} & M_{srq}\frac{d}{dt} & -\omega_r L_r & r_r + L_r\frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_{ds}^s \\ i_{qs}^s \\ i_{dr}^s \\ i_{qr}^s \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} \lambda_{ds}^s \\ \lambda_{qs}^s \\ \lambda_{dr}^s \\ \lambda_{qr}^s \end{bmatrix} = \begin{bmatrix} L_{sd} & 0 & M_{srd} & 0 \\ 0 & L_{sq} & 0 & M_{srq} \\ M_{srd} & 0 & L_r & 0 \\ 0 & M_{srq} & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{ds}^s \\ i_{qs}^s \\ i_{dr}^s \\ i_{qr}^s \end{bmatrix} \quad (6)$$

where, the parameter of the model are defined as the values of (7):

$$L_{sd} = 0, L_{sq} = L_{ls} + L_{ms},\ L_r = L_{ls} + \frac{3}{2}L_{mr},\ M_{srd} = 0, M_{srq} = \sqrt{\frac{3}{2}}L_{ms}, r_{sd} = 0, r_{sq} = r_s \quad (7)$$

The electromagnetic torque of faulty three-phase induction motor can be shown as follows:

$$T_e = \frac{pole}{2}\left(M_{srq} i_{qs}^s i_{dr}^s - M_{srd} i_{ds}^s i_{qr}^s\right) \quad (8)$$

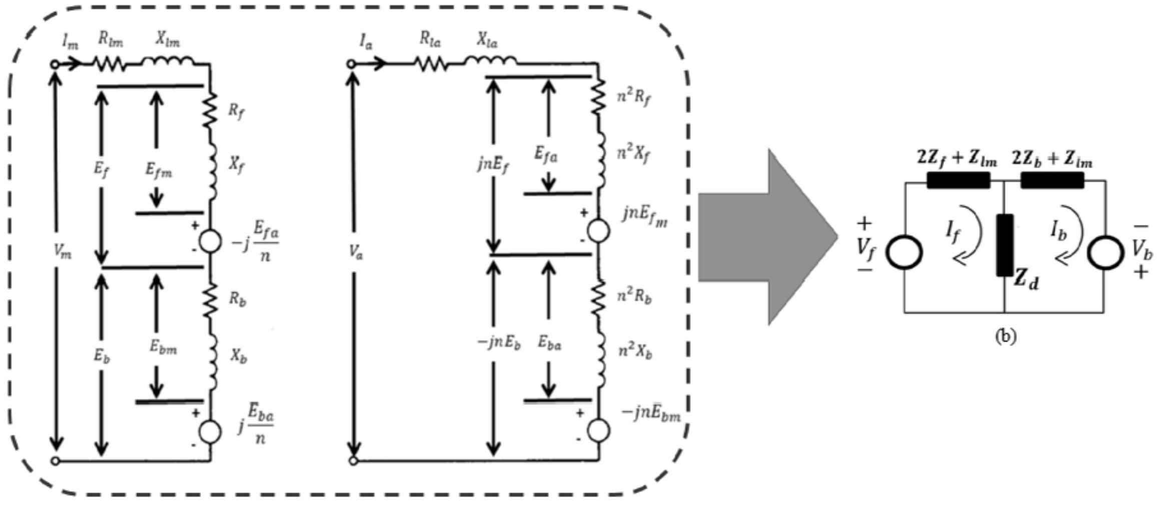
In (5)-(8), $V_{ds}^s$ and $V_{qs}^s$ are stator d and q axes voltages $i_{ds}^s$, $i_{qs}^s$, $i_{dr}^s$ and $i_{qr}^s$ represent the stator and rotor d and q axes currents $\lambda_{ds}^s$, $\lambda_{qs}^s$, $\lambda_{dr}^s$ and $\lambda_{qr}^s$ denote the stator and rotor d and q axes $L_{ms}$, $L_{mr}$, $L_{ls}$ and $L_{lr}$ represent the stator and rotor, mutual and leakage inductances. $r_{sd}$, $r_{sq}$ and $r_r$ are the stator and rotor d and q axes resistances. As presented, the model of three-phase induction motor with two phases open-circuit has the same structure of equations compared with balanced three-phase induction motor except the value of the parameters of the model.

## 3. ROTOR FOC OF THREE-PHASE INDUCTION MOTOR MODEL WITH TWO STATOR PHASES OPEN-CIRCUIT

To apply the rotor FOC strategy, the equations of the induction motor should be transformed to the rotor reference frame. For this purpose, the rotational transformation matrix as shown in (9) should be applied to the variables of the motor [19].

$$[T_s^{mr}] = \begin{bmatrix} \cos\theta_{mr} & \sin\theta_{mr} \\ -\sin\theta_{mr} & \cos\theta_{mr} \end{bmatrix} \quad (9)$$

In this transformation matrix, $\theta_{mr}$ is the angle between rotational reference frame and the stationary reference frame. Also the superscript "$mr$" shows that the variables are expressed in rotational reference frame. In the open phase fault, this transformation matrix cannot be applied to the motor variables, since the motor is unbalanced ($M_{srd} \neq M_{srq}$ and $L_{sd} \neq L_{sq}$). Applying this matrix generates forward and backward components in the motor equations [4]. To solve this problem, in this research, it is proposed unbalanced transformation matrices. The purpose of using these transformation matrices is changing the unbalanced faulty motor equations to the balanced equations. So it is possible to control the faulty induction motor by using some changes in the conventional controller. The idea of using these transformation matrices is adapted from equivalent circuit of single-phase induction motor. This motor is typically unbalanced with two stator windings, main and auxiliary windings which are actually displaced orthogonal. Figure 2(a) shows the equivalent circuit of main and auxiliary windings of stator for single-phase induction motor [2]. The voltage equations of the main and auxiliary windings are defines by (10) and (11).



(a)

(b)

Figure 2. (a) Equivalent circuit of main and auxiliary windings of stator for single-phase induction motor, (b) Simplified equivalent circuit of main and auxiliary windings of stator for single-phase induction motor

$$V_m = Z_{lm}I_m + Z_f I_m - j\frac{E_{fa}}{n} + Z_b I_m + j\frac{E_{ba}}{n} \quad (10)$$

$$V_a = Z_{la}I_a + n^2 Z_f I_a + jnE_{fm} + n^2 Z_b I_a - jnE_{bm}, \;\; n = \frac{N_a}{N_m} \quad (11)$$

In (10) and (11), $Z_{lm}$, $Z_{la}$, $Z_f$ and $Z_b$, are the leakage impedance of main winding, the leakage impedance of auxiliary winding, the impedance of forward direction and the impedance of backward direction respectively. $E_{fa}$, $E_{ba}$, $E_{fm}$ and $E_{bm}$ are the voltage induced by its own fluxes $\lambda_{fa}$, $\lambda_{ba}$, $\lambda_{fm}$, and $\lambda_{bm}$, which are forward and backward fluxes for main and auxiliary windings respectively. Moreover, the variables of $N_a$ and $N_m$ are the auxiliary and main windings number of the stator. By using some change of variables, the simplified equivalent circuit of single-phase induction can be obtained. The defined variables are $V_f$, $I_f$, $V_b$ and $I_b$ which are the forward voltage, forward current, backward voltage and backward current respectively.

$$V_f = \frac{1}{2}\left(V_m - j\frac{V_a}{n}\right), I_f = \frac{1}{2}(I_m - jnI_a), V_b = \frac{1}{2}\left(V_m + j\frac{V_a}{n}\right), I_b = \frac{1}{2}(I_m + jnI_a) \quad (12)$$

To get the simplified equivalent circuit of the single-phase induction motor, it is necessary to define $V_m$, $I_m$, $V_a$ and $I_a$ as follows:

$$V_m = V_f + V_b, I_m = I_f + I_b, V_a = (V_b - V_f)\frac{n}{2j}, I_a = (I_b - I_f)\frac{1}{j2n} \quad (13)$$

by substituting (13) in (10), (11), it can be concluded that:

$$V_f = \frac{1}{2}(\frac{Z_{la}}{a^2} - Z_{lm})(I_f - I_b) + (2Z_f + Z_{lm})I_f, \;\; V_b = \frac{1}{2}(\frac{Z_{la}}{n^2} - Z_{lm})(I_b - I_f) + (2Z_b + Z_{lm})I_b,$$
$$V_f + V_b = (2Z_f + Z_{lm})I_f + (2Z_b + Z_{lm})I_b, \quad \frac{1}{2}\left(\frac{Z_{la}}{a^2} - Z_{lm}\right) = Z_d \quad (14)$$

Based on the (14), the simplified equivalent circuit of main and auxiliary windings of stator for single-phase induction motor can be shown as Figure 2(b). According to Figure 2(b), if we neglect $Z_d$, then the equivalent circuit will be divided into two circuits, which both of them indicate a balanced motor with forward direction and backward direction. Therefore, based on $V_f$ and $I_f$ in (12), it is easy to write:

$$\begin{bmatrix} jV_f \\ V_f \end{bmatrix} = \begin{bmatrix} \frac{N_m}{N_a} & j \\ -j\frac{N_a}{N_m} & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_m \end{bmatrix}, \quad \begin{bmatrix} jI_f \\ I_f \end{bmatrix} = \begin{bmatrix} \frac{N_m}{N_a} & j \\ -j\frac{N_a}{N_m} & 1 \end{bmatrix} \begin{bmatrix} I_a \\ I_m \end{bmatrix} \tag{15}$$

In fact (15), demonstrates a transformation matrix from unbalanced situation (i.e. $V_m$ and $V_a$) to balances situation (i.e. $V_f$ and $jV_f$). Based on these equations we are able to use some substitutions as follows:

$$(j \leftrightarrow \sin\theta_{mr}), (1 \leftrightarrow \cos\theta_{mr}), (jV_f \leftrightarrow V_{ds}^{mr}), (V_f \leftrightarrow V_{qs}^{mr}), (V_a \leftrightarrow V_{ds}^{s}), (V_m \leftrightarrow V_{qs}^{s}),$$
$$(jI_f \leftrightarrow i_{ds}^{mr}), (I_f \leftrightarrow i_{qs}^{mr}), (I_a \leftrightarrow i_{ds}^{s}), (I_m \leftrightarrow i_{qs}^{s}), (\frac{N_m}{N_a} \simeq \frac{M_{srq}}{M_{srd}} \simeq \sqrt{\frac{L_{sq}}{L_{sd}}}) \tag{16}$$

Based on these substitutions, the stator rotational transformation for the variables from stationary to rotor reference frame is as follows:

$$[T_{vs}^{mr}] = \begin{bmatrix} \frac{M_{srq}}{M_{srd}}\cos\theta_{mr} & \sin\theta_{mr} \\ -\frac{M_{srq}}{M_{srd}}\sin\theta_{mr} & \cos\theta_{mr} \end{bmatrix}, [T_{is}^{mr}] = \begin{bmatrix} \frac{M_{srd}}{M_{srq}}\cos\theta_{mr} & \sin\theta_{mr} \\ -\frac{M_{srd}}{M_{srq}}\sin\theta_{mr} & \cos\theta_{mr} \end{bmatrix} \tag{17}$$

In order to transform the model of the faulty induction motor to rotor reference frame, first the new transformation matrices for the stator variables (17) are applied. As a result the stator voltage equations in rotor reference frame can be as follows:

$$\begin{bmatrix} V_{ds}^{mr} \\ V_{qs}^{mr} \end{bmatrix} = \underbrace{\begin{bmatrix} \left(r_{sq} + L_{sq}\frac{d}{dt}\right) & -\omega_{mr}L_{sq} \\ \omega_{mr}L_{sq} & \left(r_{sq} + L_{sq}\frac{d}{dt}\right) \end{bmatrix} \begin{bmatrix} i_{ds}^{mr} \\ i_{qs}^{mr} \end{bmatrix} + \begin{bmatrix} M_{srq}\frac{d}{dt} & -\omega_{mr}M_{srq} \\ \omega_{mr}M_{srq} & M_{srq}\frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_{dr}^{mr} \\ i_{qr}^{mr} \end{bmatrix}}_{Forward} + \underbrace{\begin{bmatrix} -r_{sq} & 0 \\ 0 & -r_{qs} \end{bmatrix} \begin{bmatrix} i_{ds}^{-mr} \\ i_{qs}^{-mr} \end{bmatrix}}_{Backward} \tag{18}$$

where, $i_{ds}^{-mr}$ and $i_{qs}^{-mr}$ are the backward components of the stator currents that are obtained from:

$$\begin{bmatrix} i_{ds}^{-mr} \\ i_{qs}^{-mr} \end{bmatrix} = \begin{bmatrix} (\cos\theta_{mr})^2 & -\sin\theta_{mr}\cos\theta_{mr} \\ -\sin\theta_{mr}\cos\theta_{mr} & (\sin\theta_{mr})^2 \end{bmatrix} \begin{bmatrix} i_{ds}^{mr} \\ i_{qs}^{mr} \end{bmatrix} \tag{19}$$

To transform the rotor voltage equation to rotor reference frame the rotor transformation matrix (9), must be applied to rotor voltage equation. As a result the rotor voltage equations in rotor reference frame can be as follows:

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} M_{srq}\frac{d}{dt} & -(\omega_{mr} - \omega_r)M_{srq} \\ (\omega_{mr} - \omega_r)M_{srq} & M_{srq}\frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_{ds}^{mr} \\ i_{qs}^{mr} \end{bmatrix} + \begin{bmatrix} r_r + L_r\frac{d}{dt} & -(\omega_{mr} - \omega_r)L_r \\ (\omega_{mr} - \omega_r)L_r & r_r + L_r\frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_{dr}^{mr} \\ i_{qr}^{mr} \end{bmatrix} \tag{20}$$

The electromagnetic torque of the faulty motor in rotor reference frame will be as follows:

$$T_e = \frac{Pole}{2} M_{srq}(i_{qs}^{mr} i_{dr}^{mr} - i_{ds}^{mr} i_{qr}^{mr}) \tag{21}$$

The rotor flux equation in rotor reference frame can be shown as follows:

$$\begin{bmatrix} \lambda_{dr}^{mr} \\ \lambda_{qr}^{mr} \end{bmatrix} = \begin{bmatrix} M_{srd} & 0 \\ 0 & M_{srq} \end{bmatrix} \begin{bmatrix} i_{ds}^{mr} \\ i_{qs}^{mr} \end{bmatrix} + \begin{bmatrix} L_r & 0 \\ 0 & L_r \end{bmatrix} \begin{bmatrix} i_{dr}^{mr} \\ i_{qr}^{mr} \end{bmatrix} \tag{22}$$

In order to apply rotor field-oriented control strategy, the d-axis of the rotational frame must be situated on rotor flux, its means:

$$\begin{bmatrix} \lambda_{dr}^{mr} \\ \lambda_{qr}^{mr} \end{bmatrix} = \begin{bmatrix} |\lambda_r| \\ 0 \end{bmatrix} \tag{23}$$

therefore:

$$i_{dr}^{mr} = \frac{|\lambda_r|}{L_r} - \frac{M_{srd}}{L_r} i_{ds}^{mr},\ i_{qr}^{mr} = -\frac{M_{srq}}{L_r} i_{qs}^{mr} \quad (24)$$

By substituting (23) and (24) in (18), the stator voltage equations for rotor field-oriented control strategy can be obtained as follows:

$$V_{ds}^{mr} = r_{sq} i_{ds}^{mr} + L_{sq}' \frac{d}{dt} i_{ds}^{mr} - \omega_{mr} L_{sq}' i_{qs}^{mr} + \left(L_{sq} - L_{sq}'\right) \frac{d}{dt}\left(\frac{|\lambda_r|}{M_{srq}}\right) - r_{sq} i_{ds}^{-mr} \quad (25)$$

$$V_{qs}^{mr} = r_s i_{qs}^{mr} + L_{sq}' \frac{d}{dt} i_{qs}^{mr} + \omega_{mr} L_{sq}' i_{ds}^{mr} + \omega_{mr}\left(L_{sq} - L_{sq}'\right)\left(\frac{|\lambda_r|}{M_{srq}}\right) - r_{sq} i_{qs}^{-mr} \quad (26)$$

where,

$$T_r = \frac{L_r}{r_r}, L_{sq}' = L_{sq} - \frac{{M_{srq}}^2}{L_r} \quad (27)$$

The rotor voltage equations for rotor field-oriented control strategy can be obtained as follows:

$$T_r \frac{d}{dt}|\lambda_r| + |\lambda_r| - M_{srq} i_{ds}^{mr} = 0,\ T_r(\omega_{mr} - \omega_r)|\lambda_r| - M_{srq} i_{qs}^{mr} = 0 \quad (28)$$

and the electromagnetic torque equation will be as follows:

$$T_e = \left(\frac{pole}{2}\right)\left(\frac{M_{srq}}{L_r}\right)\left(|\lambda_r| i_{qs}^{mr}\right) \quad (29)$$

The stator voltage equations can be divided into decoupling, reference and backward components as:

$$V_{ds}^{mr} = V_{ds}^{d} + V_{ds}^{ref} + V_{ds}^{b},\ V_{qs}^{mr} = V_{qs}^{d} + V_{qs}^{ref} + V_{qs}^{b} \quad (30)$$

$$V_{ds}^{d} = -\omega_{mr} L_{sq}' i_{qs}^{mr} + \left(L_{sq} - L_{sq}'\right)\frac{d}{dt}\left(\frac{|\lambda_r|}{M_{srq}}\right), V_{ds}^{ref} = r_{sq} i_{ds}^{mr} + L_{sq}' \frac{d}{dt} i_{ds}^{mr}, V_{ds}^{b} = -r_{sq} i_{ds}^{-mr} \quad (31)$$

$$V_{qs}^{d} = \omega_{mr} L_{sq}' i_{ds}^{mr} + \omega_{mr}\left(L_{sq} - L_{sq}'\right)\left(\frac{|\lambda_r|}{M_{srq}}\right), V_{qs}^{ref} = r_s i_{qs}^{mr} + L_{sq}' \frac{d}{dt} i_{qs}^{mr}, V_{qs}^{b} = -r_{sq} i_{qs}^{-mr} \quad (32)$$

Defining these variables help us to design the control blocks. For this purpose, ${V_{ds}}^{d}$ and ${V_{qs}}^{d}$ can be generated by the decoupling circuit and ${V_{ds}}^{b}$ and ${V_{qs}}^{b}$ can be generated by backward block. Moreover, ${V_{ds}}^{ref}$ and ${V_{qs}}^{ref}$ can be generated by two PI control blocks as follows:

$$V_{ds}^{ref} = K_{P1}\Delta i_{ds}^{mr} + K_{P1}\int \Delta i_{ds}^{mr}, V_{qs}^{ref} = K_{P2}\Delta i_{qs}^{mr} + K_{P2}\int \Delta i_{qs}^{mr} \quad (33)$$

Consequently, the rotor field-oriented control block diagram of faulty three-phase induction motor is represented in Figure 3. According to this figure the red blocks show the parts in the conventional vector control that must be changed for in order to be used for the unbalanced or faulty three-phase induction motor.

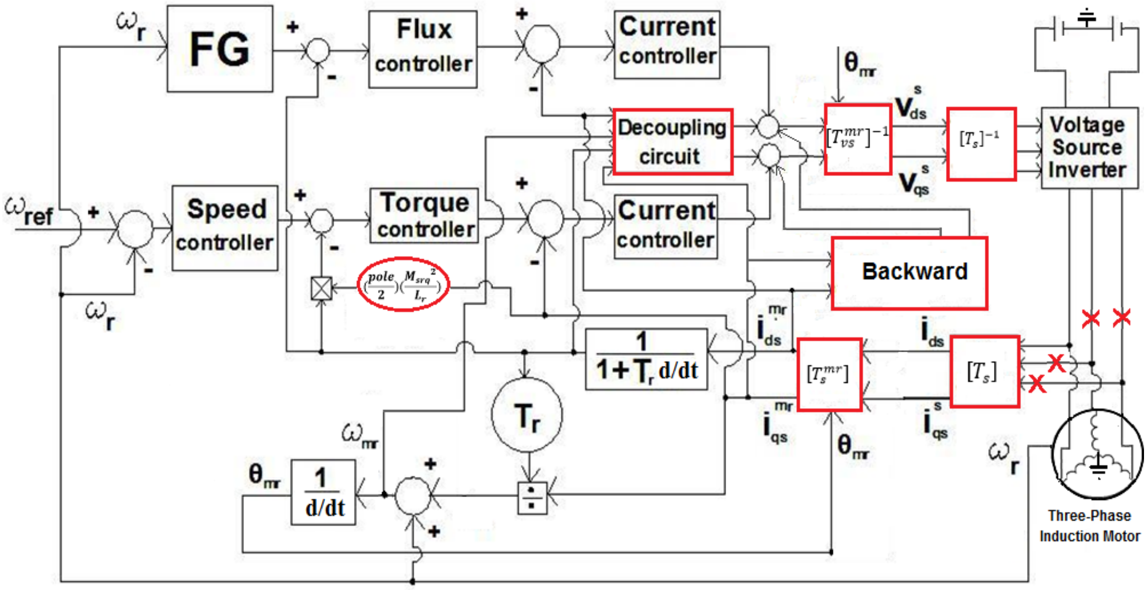



Figure 3. Block diagram of proposed rotor FOC of faulty three-phase induction motor

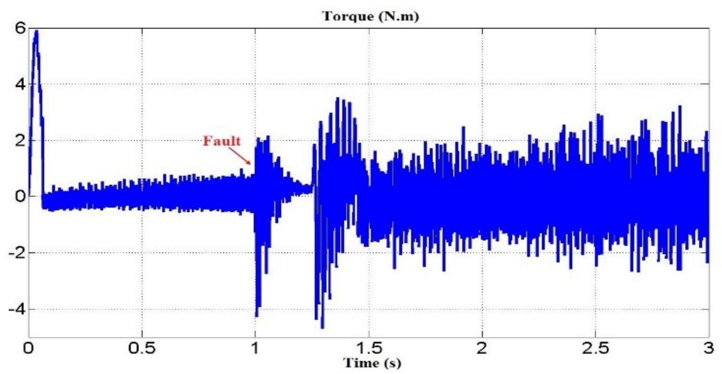
## 4. SIMULATION RESULTS

In this section, simulation results are discussed in order to verify the effectiveness of the proposed control method for a faulty three-phase induction motor. To show the dynamic behavior of faulty motor, simulation is conducted by using MATLAB (M-File) software. The fourth order Runge-Kutta algorithm is used for solving the balanced and faulty induction motor equations. The parameters and ratings of the simulated motor are as Table 1.

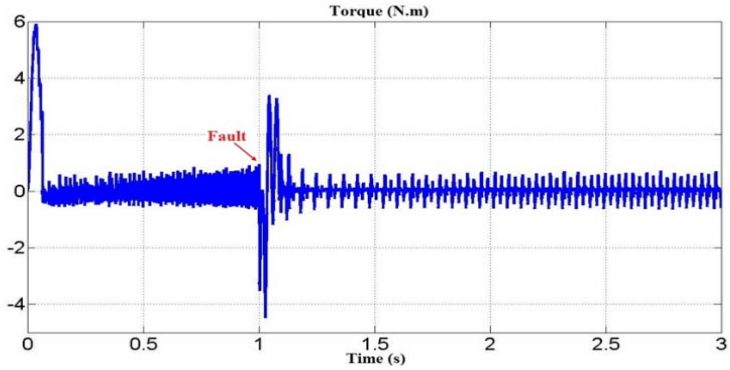
Table 1. The Parameters and Ratings of the Simulated Motor

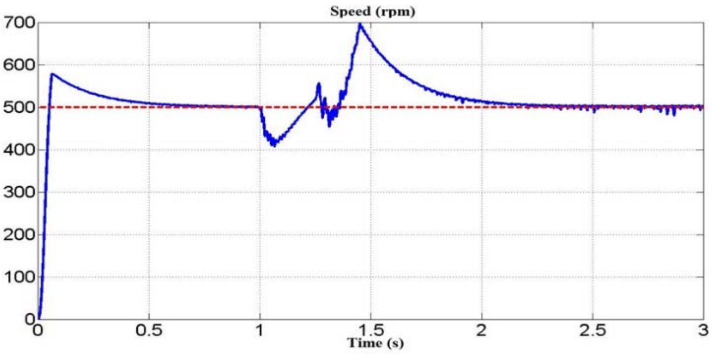
| Voltage=125 v | f=50 Hz | Pole=4 | $r_s = 20.6\ \Omega$ |
|---|---|---|---|
| $r_r = 19.15\ \Omega$ | $L_{ls} = L_{lr} = 0.0814$ H | $L_{ms} = 0.851$ H | J =0.0038 $kg.m^2$ |

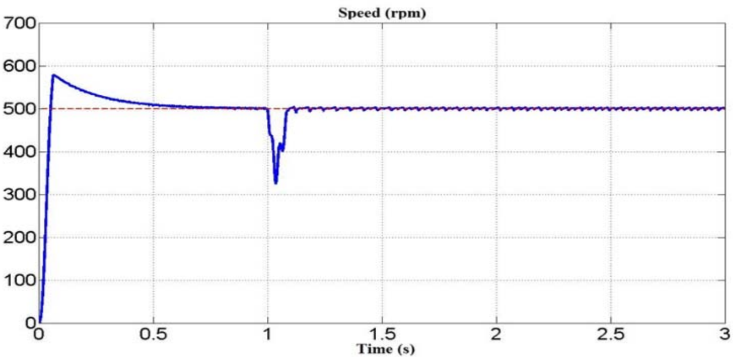
Figure 4 shows the comparison between conventional and modified vector controller for faulty three-phase induction motor under no-load condition. In this case the speed reference is set at 500rpm. According to this Figure, the reference speed is set at 500rpm. From t=0s to t=1s, motor is working under healthy condition and from t=1s to t=3s motor is working under faulty condition. This Figure shows using modified controller in comparison with conventional controller the torque and speed oscillation has been reduced.

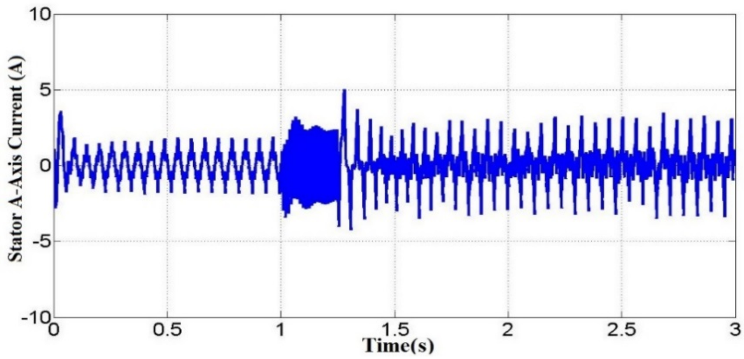


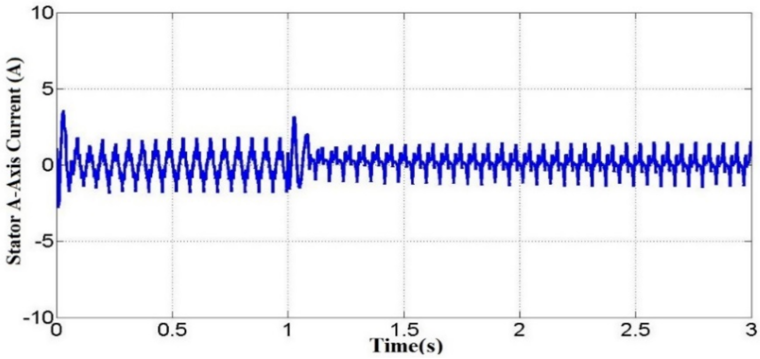

(a)


Torque (N.m)
Fault
Time (s)
(b)


Speed (rpm)
Time (s)
(c)


Speed (rpm)
Time (s)
(d)

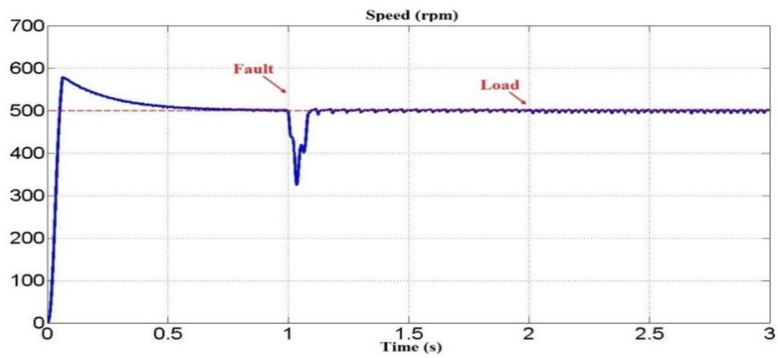

Stator A-Axis Current (A)
Time(s)
(e)



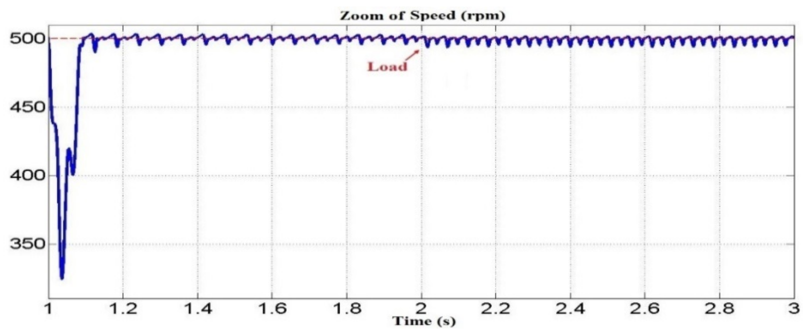

(f)

Figure 4. Simulation results of the three-phase induction motor vector control under faulty condition (no load condition); (a): Torque (conventional), (b): Torque (modified), (c): Speed (conventional), (d): Speed (modified), (e): Stator A-Axis Current (conventional), (f): Stator A-Axis Current (modified)

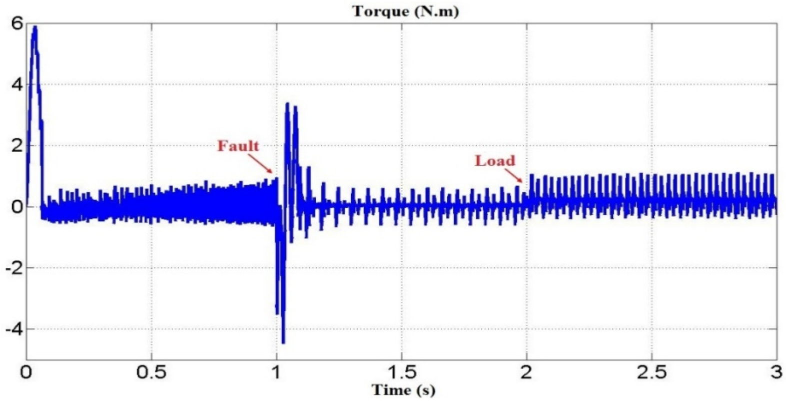
Figure 5 shows vector control of three-phase induction motor based on modified controller and under load condition. According to this Figure from t=0s to t=1s motor is working under healthy condition and from t=1s to t=3s motor is working under faulty condition. The speed reference is set at 500rpm. While the motor is working under faulty condition at t=2s a load equal to 0.2N.m is applied. Figure 5 shows the good performance of the proposed controller for vector control of faulty induction motor even under load condition.



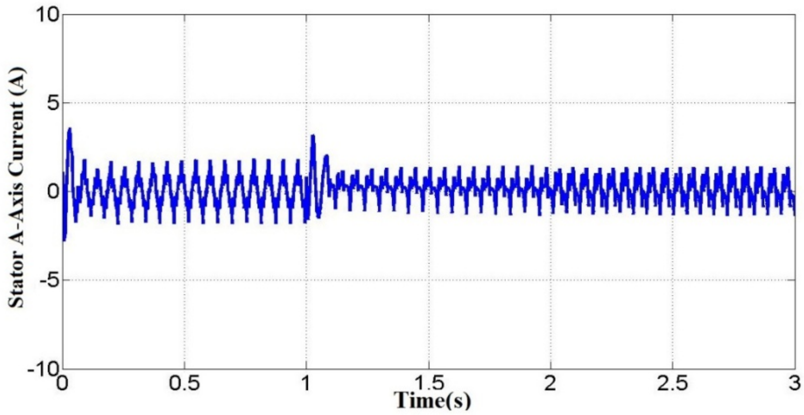

(a)




(b)




(c)




(d)

Figure 5. Simulation results of the three-phase induction motor vector control under faulty condition (load condition); (a): Speed, (b): Zoom of Speed, (c): Torque, (d): Stator A-Axis Current

## 5. CONCLUSION

This paper has presented a vector control method for faulty three-phase induction motor (three-phase induction motor when two phases of the stator are open circuit). It is shown the d-q model of faulty three-phase induction motor has the same structure of equations as the balanced three-phase induction motor. In this study, by using some modifications to the conventional controller, a novel technique for three-phase induction motor while two phases of the stator are open circuit has been presented. A comparison between conventional and modified controller indicated that, the modified controller has significantly reduced the torque and speed oscillations. Beside the implementation of this control strategy for three-phase induction motor, this method can be also used for vector control of single-phase induction motor when works with just main winding and vector control of asymmetrical two-phase induction motor under open-phase fault.

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