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Research Article

MODELING AND SIMULATION AND ANALYSIS OF THREE-PHASE SQUIRREL-CAGE INDUCTION MOTORS BEHAVIOR IN THE CONDITIONS OF TYPES OF SHORT CIRCUIT IN THE STATOR TERMINAL

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ABSTRACT
Induction motors are the main components of many industrial and commercial systems, so their correct and reliable performance is inevitable and also today, error detection has considerable importance. Error detection has valuable advantages during performance and in early stages of motor performance and preventing from being damaged of motor. Stator fault which constitutes 30 to 40 percent of total motor errors has relatively considerable importance. These errors involve reel-to-reel errors, skein-to-skein errors, and phase-to-phase errors and in the case of lack of identification the errors and on-time developed performance can result in more destructive errors. Consequently, at first a suitable method was chosen for modeling of induction motors in its normal mode and analysis of behavior and performance and modeling of other errors has been presented and then the behavior of the induction motors' parameters has been analyzed to achieve methods for error detection and motor protection.

Keywords: *Induction Motors, Simulation, Short Circuit in the Stator Terminal*

INTRODUCTION
Main characteristic which distinguishes induction machines from other types of electrical motors is that secondary currents caused only by induction; for example, it is assumed that a transformer is fed by an exciter and or an external source. The use of induction motors is widespread due to some reasons such as: simple design, simple and safe exploitation, resistant buildings, low initial cost, simple maintenance, and high efficiency in industry. Squirrel cage rotors are the most commonly used among induction motors because they have some priorities such as higher efficiency, less maintenance, better size factor in limited space, and decrease in cost in comparison to the wound-rotor motors. Attempts have been made to evaluate the effects of short circuits on induction motors based on computational methods and also based on simulation done by different software which can be mentioned as follows:
(1) Experiments are related to identification the parameters of a simulated three-phase induction motor and the analysis of results from these experiments has been described. Then, the values of the sample motor's parameters has been found through expressed formulas and at last, machine equivalent circuit has been shown based on these values and the characteristics of machine have been traced. The behavior of a squirrel-cage induction motor in the case of open-circuit (no-load) and short circuit with math equations are analyzed (2) the characteristics of machine are extracted. Precise concept of these equations and the way of using them require spending too much time and using other references. (3) a method has been presented to analyze the transient behavior of the squirrel-cage three-phase of induction motors based on math equations in the desired reference system that simulation has been carried out by using the results of equations; and then existing simulation has been used in Matlab→Simulink→demo. It is obvious that expressed explanations are not enough to understand the subject. A general model of three-phase induction motor has been presented and its simulation has been carried out by using sub-blocks. Construction of any part of the motor separately has caused that reader cannot communicate suitably with the subject because there is no enough information about the way of constructing these blocks in this context. Tests of an asynchronous machine and also efficiency computations of these machines have been presented in mathematical model. Then, simulation of this machine has been described by sub-blocks and

used math equations in them that analyzing the model and conclusion is difficult due to complexity of model and multiplicity of existing sub-blocks in presented block diagram. The joint point about previous carried out works is the use of solutions based on math calculations and lack of enough explanation about simulations and also the way of simulations and required information has not been described well to do them. In this article, it has been tried that the block structure of stimulated diagrams is simple possibly and the circuit is compared with the real state of system in order to understanding the subject becomes simple from the reader's point of view. Displaying outputs as diagrams caused the state of motor is studied easily under various conditions such as: before, during, and after connection error of short circuit.

Concepts and Mathematical Relationships

A short circuit in energy supply source network can expose induction motor to severe mechanical and electric pressures. At this time, magnetic energy which is saved in motor can flow to the place of error like electric energy, so the power of short circuit increases in the network. After occurring short circuit in the network after a short while, this network will feed error like a source.

Short-circuit current at the moment are as follows according to IEEE standards:

(1) $I_{peak, asym}= M F_p I_{rms, sym}$

In which symmetrical short-circuit current is as follows:

(2) $I_{rms, sym}= U_n / \sqrt{3}Z_m$

(3) $M F_p= \sqrt{2} (1+ e^{-\pi R/x})$

(4) $R= R_M$, $X= X$ or $X= 1.2 X$

Peak ofthe short-circuit current is also calculated by following relation:

(5) $I_p= K\sqrt{21}_k$

(6) $K= 1.02 + 0.98 e-3R_M / X_M$

As we will see later, most stress is entered into the system at the moment of short circuit, so it is necessary to calculate primitive shot-circuit current which system should be able to tolerate it.

Primitive shot-circuit current is equal to:

(7) $I_k= CU_n / \sqrt{3}Z_M$

In which:

Rated voltage of the system is 230 to 400 Volts for low voltage

C= 1.00

For other low voltages C= 1.05

For medium voltage 1 KV≤ C= 1.10

1- Block Parameters of Three-Phase Induction Motor

We regulate the parameters of induction machine as follows:

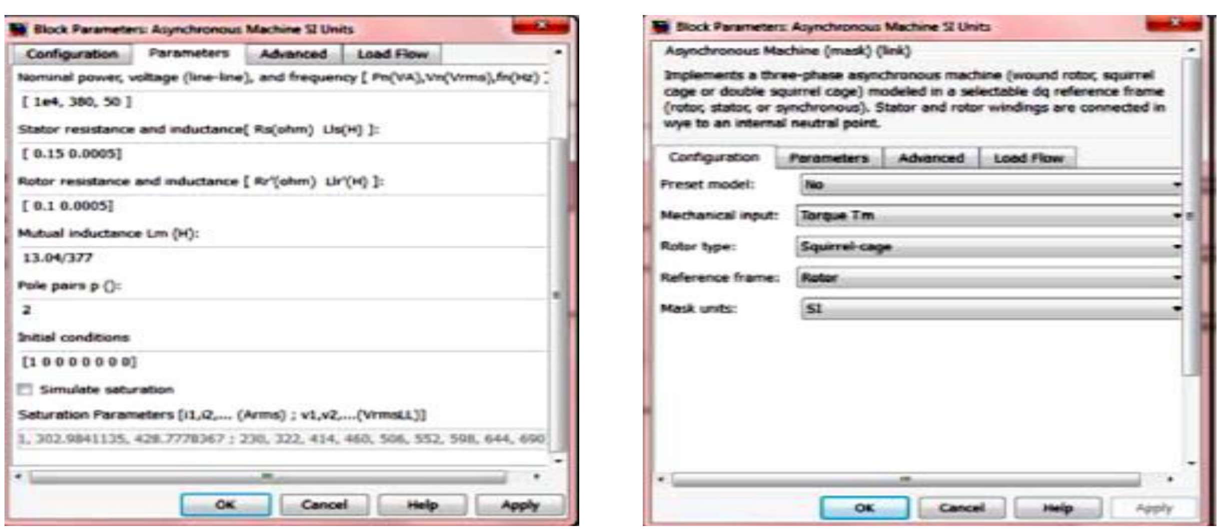

Figure 1: Parameters of Squirrel-Cage Induction Motor

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And also we involve parameters of motor input voltages, UrbcR and Urab, as it has been shown in the following figure. We should be careful that the phase of voltage is -120 Urab degrees.

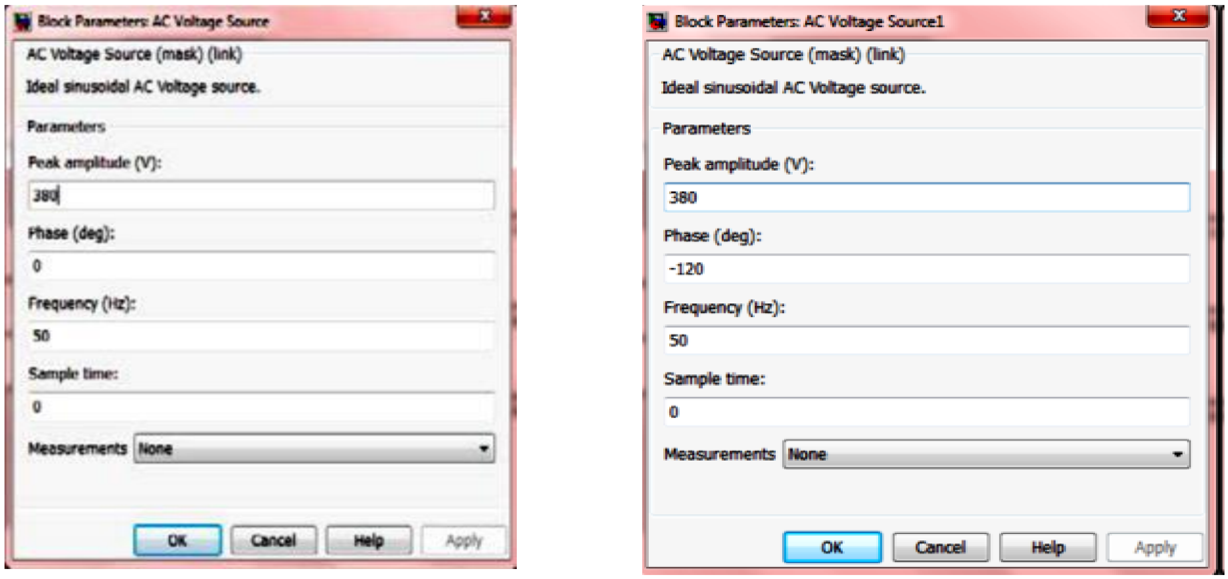

Figure 2: The Parameters of Power Supply

1- We have calculated the values of torque machine based on the power and speed of synchronous and we apply 50 percent of these values to induction machine as input torque. We run the model and observe the starting of motor and diagram it and also we identify the speed of motor in steady state.

2- We do above simulation for zero input torque and observe and diagram the results.

1-3 Determine the Torque-Speed Characteristic

In this section, we change Torque Tm to Speed W from Configuration in the characteristics of induction machine of Mechanical Input as it has been shown in the following figure.

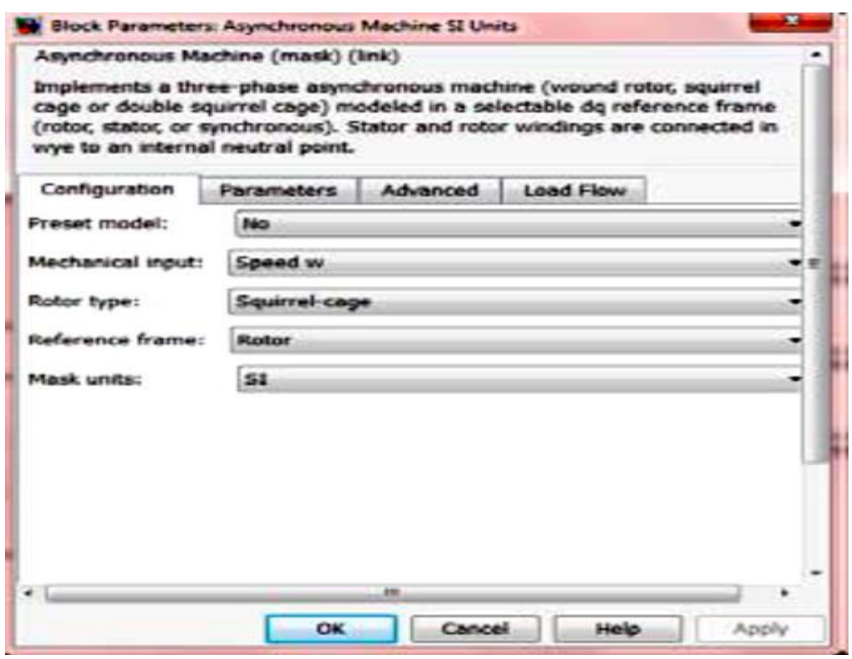

Figure 3: The Characteristics of Induction Machine

We have changed this section of the speed of motor from 2 π / 60 to 3000 * 2π / 60 which has been identified as input for simulation and we recognize the machine's steady state torque and stator current in each stage. We draw torque graph by speed and also stator current by speed in various work regions. We should consider in this section that if the speed of machine becomes close to zero, transient state torque had been swung and we should spend more time on simulation to observe steady-state torque.

2-3 Extracting Parameters of Motor

We do simulation in no-load state. We note down the speed of no-load, no-load current, and its relation with rated current, the power factor, and no-load power. Then, we also simulate locked rotor state. In this case, once we do simulation by rated voltage and once again we apply a voltage which is motor's rated stator current and we note down the characteristics of short circuit motor.

3-3 Theory of Experiment

Three coils are placed on the stator of squirrel-cage three-phase induction motor which they have phase difference with each other 120 degrees. If a set of three-phase current is added to these three coils, rotating field is created in air gap which rotates with suitable speed with frequency of the applied current. The rotors of these types of motors have been constituted from short circuit threads which are like squirrel-cage. The rotor bars have seen the changes of rotating field voltage are induced in them with consideration to Faraday's law and because the circuit has become short, a current is created in them according to Lenz's law which wants to weaken its creator factor. The field resulted from this current becomes rotating field which moves by the speed of stator's rotating field. Consequently, torque is produced and it move rotor in the direction of stator's rotating field (if productive torque is more than load torque).

The difference speed of rotor and the speed of stator's rotating field are expressed by slip, so that:

(8) $S = n_s - n_r / n_r$

At the time of starting rotor which it is in static state, the value of slip is 1 and the speed of slip rated velocity will be close to zero, but it becomes never zero; In this case, rotor sees stator's rotating field to be static and voltage is not induced in it. In the following figure (4), circuit which is equal to induction motor has been shown such as: resistance, stator leakage reactance, parallel branch model of core losses, and inductance of the magnetic circuit, resistance, and rotor leakage reactance.

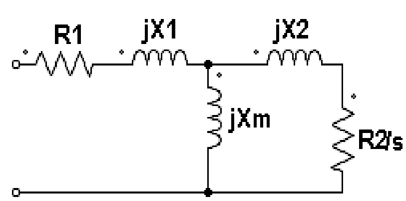

Figure 4: Circuit which is equal to induction motor

Stators current is achieved by dividing its voltage on impedance of equivalent circuit. The value of slip had been large in starting and resistance of rotor is small and because of this the current of starting induction motors is usually high. Power transmission through air gap should be divided on velocity of synchronous angles to identify torque in various slips. In this case, the torque- speed characteristic of an induction motor will be as follows.

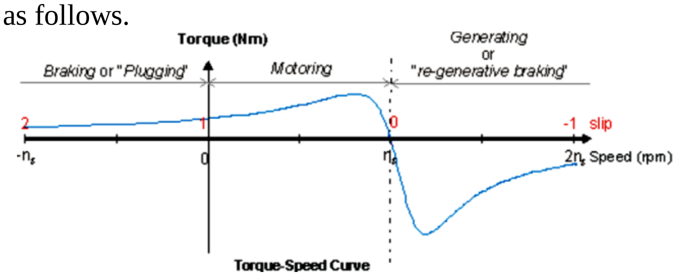

Figure 5: Induction Motor Torque-Speed Curve

(5) In above torque-speed curve, engine, generator, and brake work areas are recognized. If torque enters into oriented induction machines in a way that the speed of machine has more speed than the speed of synchronization, induction machine works in generator mode. If the speed is less than zero (reverse revolution), induction machine works in brake mode. Three experiments, locked rotor, no-load rotor, and identification of dc resistance are used to obtain the parameters of the equivalent circuit of an induction machine. In experiment of locked rotor, the rotor of machine is kept constant and it is tried to produce rated current in stator by applying a voltage. In this case, s=1 and the equivalent circuit will present in the form below by skipping parallel branch:

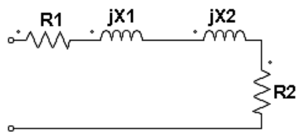

Figure 6: Equivalent Circuit in Locked Rotor Experiment

In this case, current, voltage, and input power of motor are measured. In no-load experiment, motor works without mechanical load and current, voltage, and input power are measured again. In this case, the speed of machine is close to the synchronous speed and s=0. Equivalent circuit of machine is as follows in this case. It is necessary to say that in this case, measured resistance will introduce rotational losses and also stator resistance.

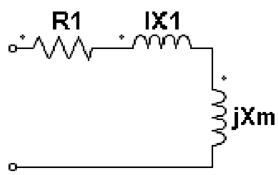

Figure 7: Equivalent Circuit in No-Load Experiment

Parameters of induction machine and quantity of rotational losses can be calculated with consideration to iron losses and no-load mechanical losses as rotational losses by using measured values in these experiments and with consideration to equivalent circuit in both cases.
Stator resistance can be measured by measuring DC resistance of the coil with applying DC voltage and measuring current.

4-3Determine the Torque-Speed Characteristic of Squirrel-Cage Induction Motor in Star Connection

(6) We connect connections based on following figure.

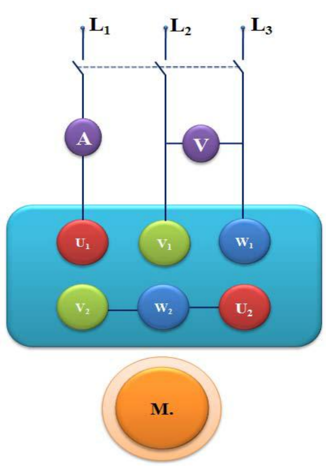

Figure 8: Circuit related to the experiment of torque-speed characteristic

(Voltmeter and ampere-meter servo control are used to measure power and power factor). We select the direction. In this stage, the objective is that in pc identification of torque-speed characteristic, we change again speed mode from higher than synchronous speed to negative speed and we observe torque curve, yield, and stator current depending on engine speed. We open a new diagram. We connect induction motor to the network. We should be careful that the direction of motor rotation is equal to the positive direction of servo. Then in this case, we set parameters of servo speed control similar to figure 6 so that it reaches 1550 speeds in 5 seconds and then reaches -50 speeds in 30 seconds at the time engine testing. We observe and interpret obtaine4d curves.

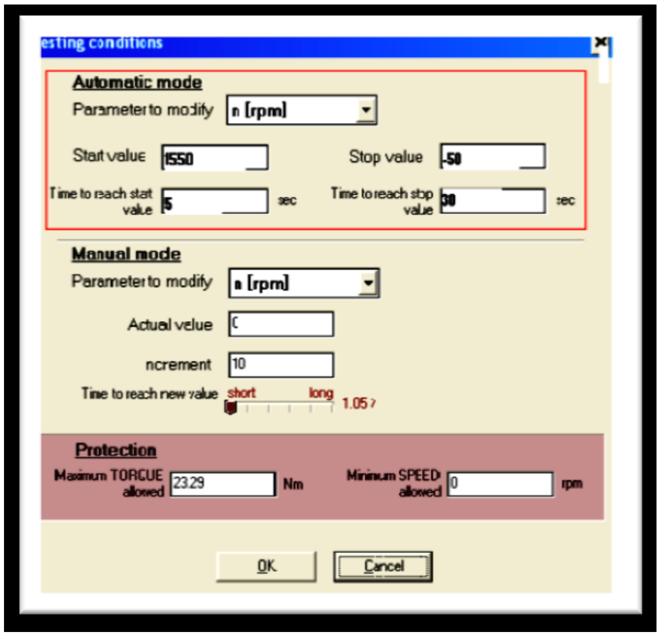

Figure 9: Set the Speed Control to Obtain Torque-Speed Curve

5-3 Determine the Equivalent Circuit Parameters of an Induction Motor

Locked rotor experiment, no-load experiment, and DC test can be used to determine the equivalent circuit parameters of an induction motor.

6-3 No-Load Experiment

We shut down the circuit of figure 8 by using variable tree-phase power supply. We increase voltage power supply gradually to rated voltage. We keep constant the torque on zero from servo speed control of motor in pc mode and we measure the voltage values, current, and electrical power of induction motor.

7-3 Locked Rotor Experiment

In this section, we should have calculated suitable voltage to have rated current in locked rotor and apply it to the machine by using the characteristic of current-speed which we have obtained before. We keep constant the speed on zero for this reason from servo speed control of motor in pc mode.

Figure (1): Block Parameters of Induction Motor

(Locked rotor experiment) Then, we increase variable voltage and source voltage slowly so that stator current becomes equal to rated values. We should consider that necessary voltage to do this experiment is low. We also measure current values, power, and voltage in this case.

8-3 DC Test

We will also need stator resistance to obtain equivalent circuit. We connect three-phase terminals two by two to DC voltage of controllable power supply to measure the resistance of stator and measure the current. Please, calculate parameters of equivalent circuit by using measured values (We suppose once motor is class A and once again it is class B).

After doing above experiments, required values are obtained as follows to simulate:

Phase	**3**	**Rotor Resistance**	**3.16 Ohm**	**Phase**
The Number of Poles	4	Used Resistance For Core Losses	701 Ohm	The Number of Poles
Frequency	50 Hertz	Mutual inductance	0.26 Henry	Frequency
Linear Voltage	380 Volt	Stator leakage inductance magnetic properties	6.9073 Midi Henry	Linear Voltage
Stator Resistance	3.5 Ohm	Rotor leakage inductance magnetic properties	6.8118 Midi Henry	Stator Resistance

Simulation and Analysis of Results

In this experiment, after motor reaches its rated mode, suddenly a short circuit occurs in its stator terminal which its block diagram will have been presented later. Modeling short circuits are carried out by block error. Each of the errors of short circuit, Single-phase short circuit to ground, two-phase, and three-phase short circuits can be modeled easily by arrangement of this block. (The time of error has been considered since 11.5 seconds to 2.5 seconds.)

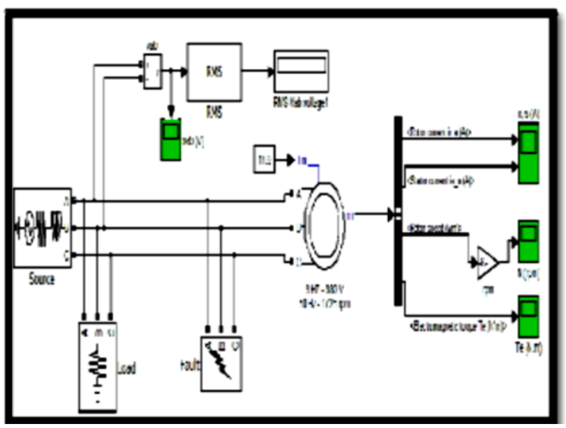

Figure 10: Block Diagram of Induction Motor Accompanied by modeling the Block Error

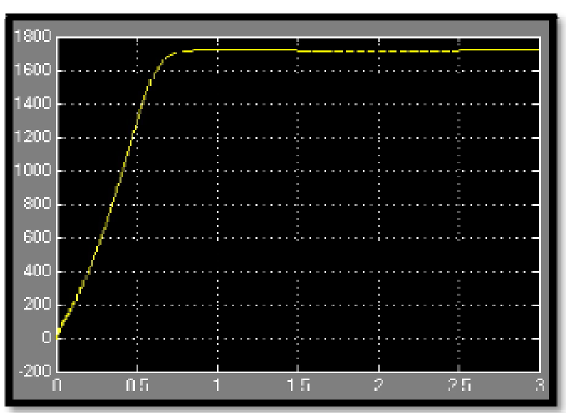

Figure 11: The Rotor Speed of Three-Phase Induction Motor at the Time of Single-Phase Short Circuit to Ground

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Single-phase Short-Circuit to Ground in Stator Terminal of Three-Phase Induction Motor

After motor has reaches to its rated values, suddenly single-phase short circuit to ground occurs in terminal which the figure of resulted waves has been presented.

It is observed that single-phase short circuit to ground is observed only a little and single-phase short circuit to ground has affected rotor speed of this induction motor only a little and has caused to decrease it.

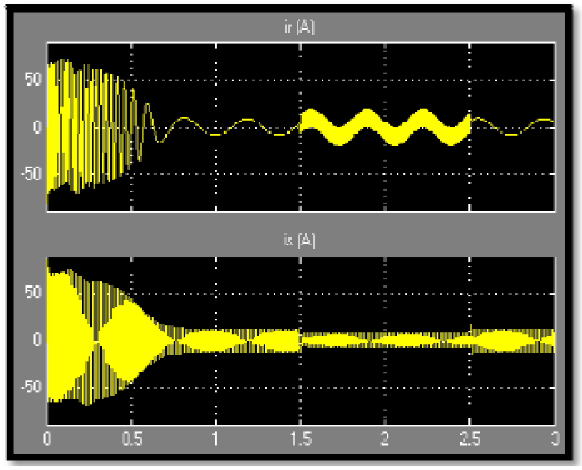

Figure 12: Rotor Currents and Stator of Three-Phase Induction Motor at the Time of Single-Phase Short Circuit to Ground

As it is obvious from the figure of waves, the rotor current has increased at the time of error, but stator current has decreased and returns to its rated mode after error repair.

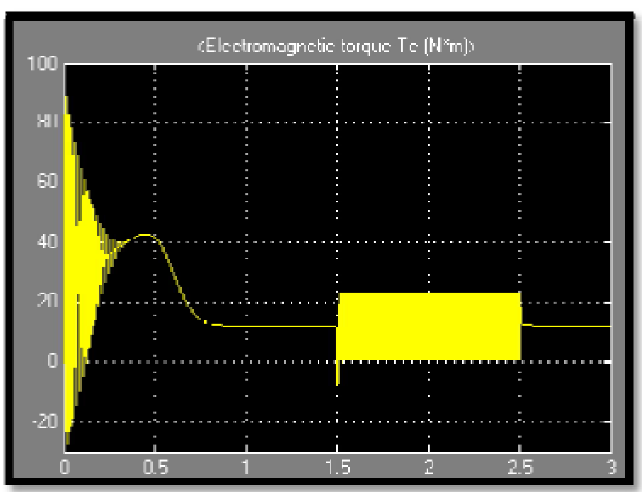

Figure 13: Electromagnetic Torque of Three-Phase Induction Motor at the Time of Single-Phase Short Circuit to Ground

At first, torque value decreases at the time of error, but it is accompanied by constant increase during error which it is continued until error repair and torque returns to its rated value after error repair.

Two-Phase Short-Circuit to Each Other and to ground in Stator Terminal of Three-Phase Induction Motor

After motor reaches to its rated values, suddenly two-phase short circuit to each other and to ground occurs that the figure of related waves to it has been presented.

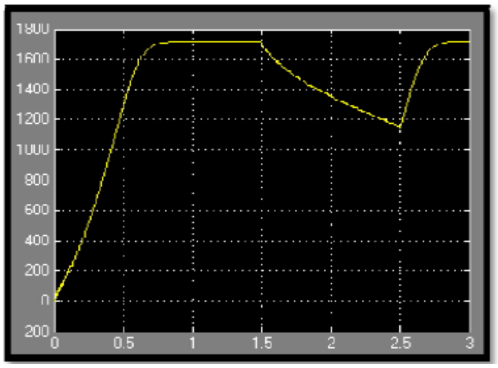

Figure 14: The Rotor Speed of Three-Phase Induction Motor at the Time of Two-Phase Short-Circuit to Each Other and to ground

It is observed that rotor speed in single-phase short circuit to ground does not change a lot, but the speed decreases considerably at the time of error in Two-Phase Short-Circuit to Each Other and to ground which will cause to apply pressure on motor. The speed of motor returns to its rated value again with a little delay after error repair.

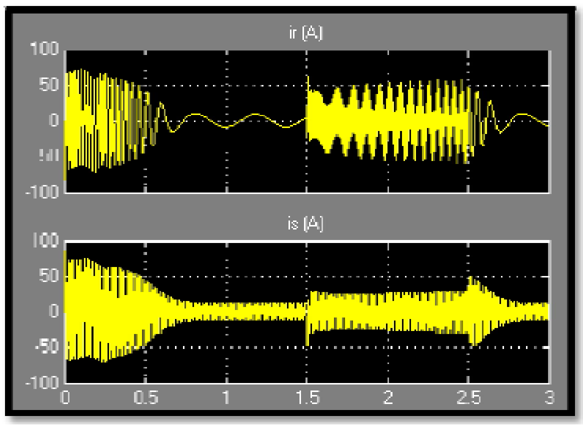

Figure 15: three-phase induction motor stator's rotor currents at the Time of Two-Phase Short-Circuit to Each Other and to ground

In this short circuit, at first rotor current also increases considerably like single-phase short circuit to ground and stator current decreases considerably that it returns to usual mode after error repair.

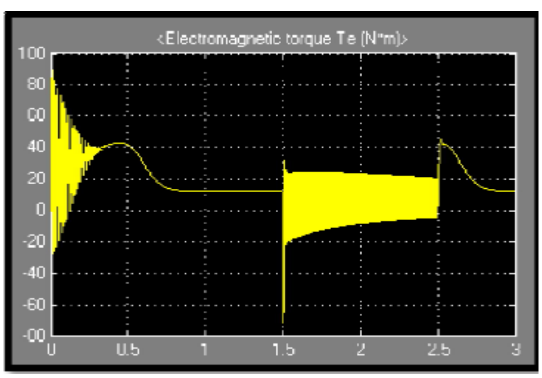

Figure 16: Electromagnetic Torque of Three-Phase Induction Motor at the Time of Two-Phase Short-Circuit to Each Other and to Ground

In this error, torque decreases considerably and or more transients is accompanied until the time of error repair and it also confronts with considerable increase at the time of error repair.

Three-Phase Short Circuit to Each Other and to Ground in Stator Terminal of Three-Phase Induction Motor

After motor reaches to its rated values, suddenly three-phase short circuit to each other and to ground occurs in terminal the figure of related waves to it has been presented.

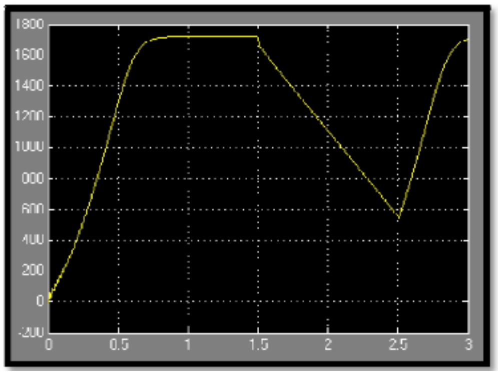

Figure 17: The Speed of Three-Phase Induction Motor at the Time of Three-Phase Short Circuit to Each Other and To Ground

Rotor speed decreases considerably until the time of error repair in this error, too that it is much more in comparison to previous mode.

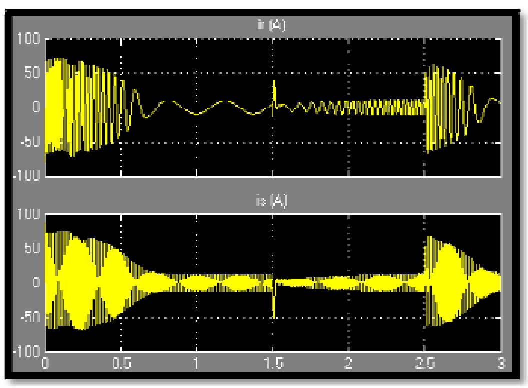

Figure 18: Rotor Currents of Three-Phase Induction Motor at the Time of Three-Phase Short Circuit to Each Other and to Ground

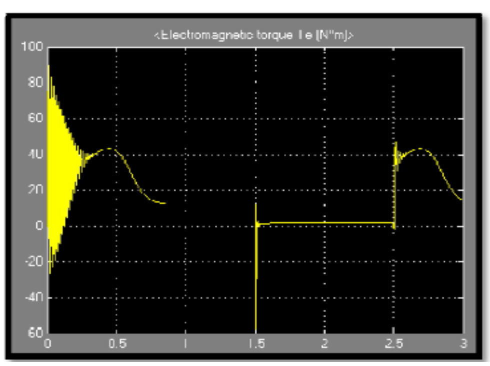

Figure 19: Electromagnetic Torque of Three-Phase Induction Motor at the Time of Three-Phase Short Circuit

In this mode, rotor and stator currents are changed less in comparison to previous mode at the time of error, but the values of currents increase considerably at the time of error repair which returns to rated values again after a short while. Torque also decreases considerably in this error, but it is established in a fixed value at the time of continuity error and it confronts with considerable increase after error repair that it returns to its rated value after a short while.

RESULTS AND DISCUSSION

As it is obvious from observing the figure of various waves, short circuits cause to create difficult conditions and mechanical and electrical shocks on motor which lead to efficiency loss and damage to the motor and also will cause to apply shock to other equipment which are connected to the network and the network becomes unbalanced. At the time of short circuit, motor which receives electrical energy from this network and moves it and transforms it to torque before has behaved as an energy source (rotating rotor) now and the speed of this rotating source will decrease by passing time. Speed of motor decreases that this decrease will overcome merely on energy losses and speed diagrams confirm this claim. It is obvious that the greater the intensity of short circuit, the energy has lost faster and motor will be stopped faster. Most stresses enter into motor at the time of continuity error in two-phase short circuit to each other and to ground. An important point in this short circuit is that motor has changed into generator in a moment depending on the intensity of the connection and if this event is repeated, it leads to damages to motor itself and system. The most pressures enter into motor at the moment of applying error and error repair in three-phase short circuit to each other and to ground that machine has changed into generator and vice versa in these two periods of time. Of course, motor has almost fixed conditions at the time of continuity of error except about rotor speed. It should be considered that transients occur in stator and rotor currents at the moment of occurring short circuit that (the ratio of leakage reactance to the resistance in both rotor and stator circuits becomes more) by increasing the power of motor and or turbulence intensity increases. Of course, the intensity of this turbulence is less in rotor due to lowering frequency of rotor than stator. Finally, each of above errors will cause applying pressure on motor and also the network which should be prevented from those errors by selecting suitable motor to supply intended load and also by using appropriate controllable tools.

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