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A Protection Scheme for Three-Phase Induction Motor from Incipient Faults Using Embedded Controller

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Abstract: This study presents a protection scheme for three-phase induction motor from incipient faults using embedded microcontroller. The induction motor experiences several types of electrical faults like over/under voltage, over load, phase reversing, unbalanced voltage, single phasing and earth fault. Due to these electrical faults, the windings of the motor get over heated which lead to insulation failure and thus reduce the life time of the motor. To analyze the behavior of induction motor during electrical faults, the induction motor is modeled using arbitrary reference frame theory in MATLAB/Simulink environment; the faults are created and the variation of the induction motor parameters under faulty conditions are observed. Based on the analysis, embedded controller is developed to protect the motor from incipient faults.

Key words: MATLAB/Simulink, over/under voltage, over load, phase reversing, unbalanced voltage, single phasing, earth fault, microcontroller

INTRODUCTION

The three-phase induction motors are used in many industrial applications due to their reliability, low cost and high performance. Whereas this popular ac motor performance is affected by following type of faults:

- **Electrically related faults (33%):** The faults come under this classification are over/under voltage, over load, phase reversing, unbalanced voltage, single phasing and earth fault
- **Mechanically related faults (32%):** The rotor winding failure, stator winding failure and bearing faults are most occurring mechanical fault in three-phase induction machine
- **Environmentally related faults (15%):** The external moisture, contamination and ambient temperature also affect the induction motor performance. The vibration of machine also affects the performance of induction machine under various operations

Electrical related faults are frequently occurring faults in three-phase induction machine which will produce more heat on both stator and rotor winding. This leads to reduce the life time of induction machine (Wang, 2001; Kersting, 2001). This study presents the behavior of three-phase induction machine under the unbalanced supply voltage, single phasing and over load condition. In contrast to the conventional methods, the Simulink and Power System Block set of MATLAB is much easier to simulate the dynamic behavior of electrical faults than the traditional method (Masahiro and Hiyama, 2007; Delmotte *et al*., 2003).

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To protect the machine from more heating due to these electrical faults, a reliable protection scheme is to be applied (Chen and Peiming, 2001; Colak *et al*., 2005). In the existing protection scheme, each and every individual faults require separate protective relay like earth fault relay and over current relay, etc. (Dai *et al*., 2003) which will be more costlier. To overcome this, a low cost, reliable, integrated protection scheme for three-phase induction motor is developed using PIC 16F877 micro controller.

MATERIALS AND METHODS

The protection scheme of three phase induction machine using embedded micro controller is developed as per flow chart shown in Fig. 1. Simulation and testing was done in Electrical Machines laboratory of Kumaraguru College of Technology, Coimbatore during October 2006.

INFLUENCE OF ELECTRICAL FAULTS ON MOTOR PERFORMANCE

Unbalanced voltage comprises of two opposing components, a positive sequence component that produces the wanted positive torque, a negative sequence component that produces unwanted negative torque (Saffet and Nwankpa, 2005). As the amount of unbalance in the supply voltage increase, the positive sequence voltage decreases and negative sequence voltage increases. The percentage of unbalance defined by NEMA:

$$\text{Unbalance (\%)} = \frac{\text{Max. deviation from average voltage}}{\text{Average voltage}} \times 100 \tag{1}$$

Causes and Effects of Unbalanced Supply Voltage

Causes

Open delta transformers, unbalanced loading, unequal tap settings, high resistance connections, Shunted single phase load, unbalanced primary voltage and defective transformer (Lee, 1999; Wang, 2000; Kersting, 2001; Woll, 1975; Pragasan *et al*., 2002).

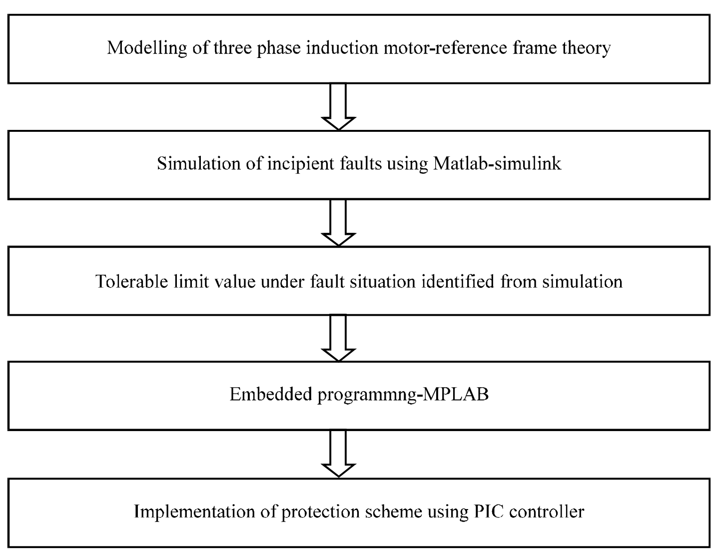


Fig. 1: Design steps

Effects

Reduction in motor efficiency, increase in stator and rotor copper losses, temperature rise, serious reduction in starting torque, nuisance and overload tripping, premature failure of motor winding, excessive and unbalanced full load current.

High voltage unbalance factor leads to lower efficiency and higher power factor. Negative sequence voltage component has little effect on the power factor when compared to positive sequence voltage. From customer viewpoint, the efficiency reduction of an induction motor due to supply voltage unbalance results in a higher electricity charge for same work done (Paul and Robert, 1985).

Single phasing occurs when one phase of the three-phase supply is open. Single-phasing condition is the worst case of voltage unbalance. If a three-phase motor is running with the single phase condition, it will attempt to deliver its full horsepower of the load. The motor continuously trying to drive the load, until the motor burns out or until the properly sized overload elements make the motor off.

Cause and Effects of Single Phasing

Causes

Open winding in motor, any open circuit in any phase anywhere between the secondary of the transformer and the motor, primary fuse open (Kersting, 2005).

Effects

The effects of single phasing on three-phase motor vary with service conditions and motor thermal capacities. When single-phased, the motor's temperature rise is greater than the increase in current.

Causes and Effects of Phase Reversal

The phase reversal occurs when two of the three phases (RYB) of supply line reverses. Most of motor will react very badly to such a situation. Motor could suddenly begin to turn in the wrong direction, causing major collateral damage.

Cause and Effects of Over/Under Voltage

Under Voltage

The under voltage occurs when a reduced supply voltage with a rated mechanical load on the motor (Thomson, 1994).

Effects

Increased currents, excess heating of machine, Stator and Rotor losses increase.

Over Voltage

Any one of the line voltage is greater than 110% of rated value, over voltage fault occur.

Effects

Harmful effects on machine insulation.

Cause and Effects of Overload Condition

When there is increase in mechanical load on the motor beyond the rated value, the overload situation occurs. Due to high load torque, motor begins to draw more current (Nandi and Toliyat, 2005).

Effects

Increase in phase currents and overheating of machine.

Cause and Effects of Earth Fault

Ground faults are more prevalent in motors than other power system devices, because of the violent manner and frequency with which they are started. The ground fault is monitored and detected by measuring leakage current. The two types of faults occur in a motor are turn to turn and turn to ground (Marcus *et al*., 1998; Li *et al*., 2003).

The amount of phase current unbalance is a very good indication of the turn-turn insulation conditions. Turn-turn insulation failure is a prelude to most insulation failure in motors and normally occurs before a fault propagating to a turn to ground failure. Ground fault current leads to insulation failure in motor; therefore, a considerable amount of attention is given to the ground current levels available in the system.

Effects of Ground Fault

Hazards for human safety, thermal stress due to fault current, voltage stress, interference with telecommunication, interruption of power supply.

DYNAMIC MODELING OF INDUCTION MACHINE

The induction machine d-q or dynamic equivalent circuit is developed by using arbitrary reference frame theory as shown in Fig. 2. Voltage equations of induction machine in arbitrary reference variables are follows:

$$\overline{V}_{abcs} = \overline{r}_s i_{abcs} + p\lambda_{abcs} \tag{2}$$

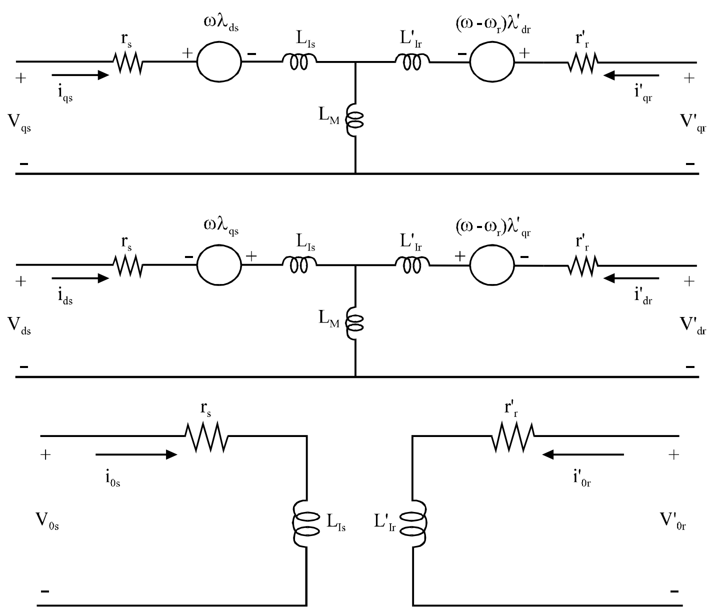


Fig. 2: Equivalent circuits of a 3-phase, symmetrical induction machine with rotating q-d axis at speed of ω

$$V'_{abcr} = r'_r\, i'_{abcr} + p\lambda_{abcr} \tag{3}$$

$$\lambda_{abcs} = (\bar{L}_s)i_{abcs} + (L'_{sr})i'_{abcr} \tag{4}$$

$$\lambda'_{abcr} = (\bar{L}'_{sr})^T i_{abcs} + (L'_r)i'_{abcr} \tag{5}$$

$$\bar{V}_{abcs} = K_s \bar{V}_{qd0s}, \quad i_{abcs} = K_s \bar{i}_{qd0s} \tag{6}$$

$$V'_{abcr} = K_r \bar{V}'_{qd0r}, \quad i'_{abcr} = K_r \bar{i}'_{qd0s} \tag{7}$$

Hence, both stator and rotor resistance are diagonal matrices each with equal nonzero elements. Using the above transformation equations, we can transform the voltage equations to an arbitrary reference frame rotating at speed of ω.

$$V_{qd0s} = r_s\, i_{qd0s} + \omega\lambda_{qds} + p\lambda_{qd0s} \tag{8}$$

$$V'_{qd0r} = r'_r i_{qd0r} + (\omega - \omega_r)\lambda'_{qdr} + p\lambda'_{qd0r} \tag{9}$$

Flux linkage equations in abc reference frame can be transformed to qd axes using K_s and K_r transformation matrices:

$$\begin{bmatrix} \lambda_{qd0s} \\ \lambda'_{qd0r} \end{bmatrix} = \begin{bmatrix} K_s L_s (K_s)^{-1} & K_s L'_{sr} (K_r)^{-1} \\ K_r L'_{sr} (K_s)^{-1} & K_r L'_r (K_r)^{-1} \end{bmatrix} \begin{bmatrix} i_{qd0s} \\ i'_{qd0r} \end{bmatrix} \tag{10}$$

Where:

$$K_s L_s (K_s)^{-1} = \begin{bmatrix} L_{1s} + M & 0 & 0 \\ 0 & L_{1s} + M & 0 \\ 0 & 0 & L_{1s} + M \end{bmatrix}, \; M = \frac{3}{2}L_{ms}$$

$$K_r L'_r (K_r)^{-1} = \begin{bmatrix} L'_{lr} + M & 0 & 0 \\ 0 & L'_{lr} + M & 0 \\ 0 & 0 & L'_{lr} + M \end{bmatrix}, \; M = \frac{3}{2}L_{ms}$$

$$K_s L'_{sr} (K_r)^{-1} = K_r (L'_{sr})^T (K_s)^{-1} = \begin{bmatrix} M & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{bmatrix}$$

Voltage equation is:

$$\begin{aligned} V_{qs} &= r_s i_{qs} + \omega\lambda_{ds} + p\lambda_{qs} \\ V_{ds} &= r_s i_{ds} - \omega\lambda_{qs} + p\lambda_{ds}, \\ V_{0s} &= r_s i_{0s} + p\lambda_{0s} \end{aligned} \tag{11}$$

$$\begin{aligned} V'_{qr} &= r'_r i'_{qr} + (\omega - \omega_r)\lambda'_{dr} + p\lambda'_{qr} \\ V'_{dr} &= r'_r i'_{dr} - (\omega - \omega_r)\lambda'_{qr} + p\lambda'_{dr} \\ V'_{0r} &= r'_r i'_{0r} + p\lambda'_{0r} \end{aligned} \tag{12}$$

Flux linkage equations are:

$$\begin{aligned} \lambda_{qs} &= L_{ls} i_{qs} + M\left(i_{qs} + i'_{qr}\right) \\ \lambda_{ds} &= L_{ls} i_{ds} + M\left(i_{ds} + i'_{dr}\right) \\ \lambda_{0s} &= L_{ls} i_{0s} \end{aligned} \tag{13}$$

$$\begin{aligned} \lambda'_{qr} &= L'_{lr} i'_{qr} + M\left(i_{qs} + i'_{qr}\right) \\ \lambda'_{dr} &= L'_{lr} i'_{dr} + M\left(i_{ds} + i'_{dr}\right) \\ \lambda'_{0r} &= L'_{lr} i'_{0r} \end{aligned} \tag{14}$$

Since, machine and power system parameters are nearly always given in ohms or percent or per unit of base impedance, it is convenient to express the voltage and flux linkage equations in terms of reactance rather than inductances. Let,

$$\varphi = \lambda \omega_b \tag{15}$$

Then,

$$\begin{aligned} V_{qs} &= r_s i_{qs} + \frac{\omega}{\omega_b}\varphi_{ds} + p\varphi_{qs} \\ V_{ds} &= r_s i_{ds} - \frac{\omega}{\omega_b}\varphi_{qs} + \frac{p}{\omega_b}\varphi_{ds}, \\ V_{0s} &= r_s i_{0s} + \frac{p}{\omega_b}\varphi_{0s} \end{aligned} \tag{16}$$

$$\begin{aligned} V'_{qr} &= r'_r i'_{qr} + \frac{(\omega - \omega_r)}{\omega_b}\varphi'_{dr} + \frac{p}{\omega_b}\varphi'_{qr} \\ V'_{dr} &= r'_r i'_{dr} - \frac{(\omega - \omega_r)}{\omega_b}\varphi'_{qr} + \frac{p}{\omega_b}\varphi'_{dr} \\ V'_{0r} &= r'_r i'_{0r} + \frac{p}{\omega_b}\varphi'_{0r} \end{aligned} \tag{17}$$

And flux linkages become flux linkages per second with the units of volts.

$$\begin{aligned} \varphi_{qs} &= X_{ls} i_{qs} + X_m\left(i_{qs} + i'_{qr}\right) \\ \varphi_{ds} &= X_{ls} i_{ds} + X_m\left(i_{ds} + i'_{dr}\right), \\ \varphi_{0s} &= X_{ls} i_{0s} \end{aligned} \tag{18}$$

$$\begin{aligned} \varphi'_{qr} &= X'_{lr} i'_{qr} + X_m\left(i_{qs} + i'_{qr}\right) \\ \varphi'_{dr} &= X'_{lr} i'_{dr} + X_m\left(i_{ds} + i'_{dr}\right) \\ \varphi'_{0r} &= X'_{lr} i'_{0r} \end{aligned} \tag{19}$$

Electromagnetic torque in terms of arbitrary reference frame variables may be obtained by substituting the equations of transformation in:

$$\begin{aligned} T_e &= \frac{P}{2}(i_{abcs})^T \frac{\partial}{\partial\theta_r}(L'_{sr})i'_{abcr} \\ &= \frac{P}{2}\left[(\mathbf{K}_s)^{-1} i_{qd0s}\right]^T \frac{\partial}{\partial\theta_r}(L'_{sr})(\mathbf{K}_r)^{-1} i'_{qd0r} \\ T_e &= \left(\frac{3}{2}\right)\left(\frac{P}{2}\right) M(i_{qs} i'_{dr} - i_{ds} i'_{qr}) \end{aligned} \tag{20}$$

where, T_e is electromagnetic torque.

$$T_{em} = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\lambda_{ds}\, i_{qs} - \lambda_{qs}\, i_{ds}) \tag{21}$$

SIMULINK IMPLEMENTATION OF INDUCTION MACHINE

MATLAB/Simulink is a tool used to simulate dynamic systems. The Sim Power system is one of the toolbox in Simulink, used to analyze the three-phase induction machine performance under different electrical fault conditions. The solver used for simulation of induction machine performance is ODE113. The dynamic model of Three Phase induction motor is implemented using MATLAB/ Simulink environment as shown in Fig. 3. The inputs of a squirrel cage induction motor are the three-phase voltages (V_a, V_b, V_c), their fundamental frequency and load torque. The outputs are stator current, rotor currents, d-q stator currents, rotor d-q currents, electrical torque and Rotor Speed (Sri and Varatharasa, 1999).

EQUIVALENT CIRCUIT PARAMETER CALCULATION

The parameters for the equivalent circuit are determined from no load test, DC test and blocked rotor test. During the DC test a DC voltage is applied across two terminals while machine is at standstill.

Thus:

$$r_s = (V_{DC}/I_{DC}) \times (1/2) \tag{22}$$

Where:

V_{DC} = Input DC voltage applied
I_{DC} = DC current obtained from DC test

The power input during this test is snm of the stator ohnic losses, the core losses due to hysteresis and eddy current losses and rotational losses due to friction and windage.

The stator ohnic losses are:

$$P_{ohmic} = 3 \times I^2_{nl} \times r_s \tag{23}$$

Where:

I_{nl} = No-load phase current
r_s = Stator resistance

Therefore, the power loss due to friction and windage losses and core losses is:

$$P_{fWC} = P_{nl} - P_{ohmic} \tag{24}$$

Where:
P_{nl} = No-load power
P_{ohmic} = Ohmic losses

The no-load impedance is highly inductive and its magnitude is assumed to be sum of the stator leakage reactance and the magnetizing reactance. Thus:

$$X_{ls}+X_m = (V_{nl})/(1.732\times I_{nl}) \qquad (25)$$

During the Blocked rotor test, the rotor is locked by some external means and balanced three phase stator voltages are applied. The frequency of the applied voltage is often less than rated value.

From this test,
$$P_{br} = 3\times I^2_{br}\times(r_s+r'_r) \qquad (26)$$

From which,
$$r'_r = (P_{br})/(3\times I^2_{br})-r_s \qquad (27)$$

Where:
P_{br} = Blocked rotor power
r'r = Rotor resistance

The magnitude of the blocked rotor input impedance is:

$$|Z_{br}| = (V_{br})/(1.732\times I_{br}) \qquad (28)$$

Now,

$$|\,(r_s+r'_r)+j\,(fbr/f_{nl})\times(X_{ls}+X'_{lr})\,| = Zbr \qquad (29)$$

Where:
f_{br} = Frequency during Blocked rotor test
f_{nl} = Frequency during No-load test
X_{ls} = Stator Leakage reactance
X'_{lr} = Rotor Leakage reactance

From above equation the values of X_{ls} and X'_{lr} are calculated. Table 1 shows equivalent circuit parameters for dynamic model of 3 hp, 3 pole and 415 volts, 3-phase, 50 Hz and 1440 rpm induction machine.

The induction machine model shown in Fig. 3, consists of following major subsystems:

- Subsystem 1 : Three phase to two phase variable conversion (stator)
- Subsystem 2 : Three phase to two phase variable conversion (rotor)
- Subsystem 3 and 4 : Implementation of dynamic modeling equation

Table 1: Induction machine parameters

Machine variables	Obtained value (pu)
Stator resistance (r_s)	0.435
Rotor resistance (r'_r)	0.815
Mutual inductance (X_m)	26.130
Stator leakage reactance (X_{ls})	0.754
Rotor leakage reactance (X'_{lr})	0.754

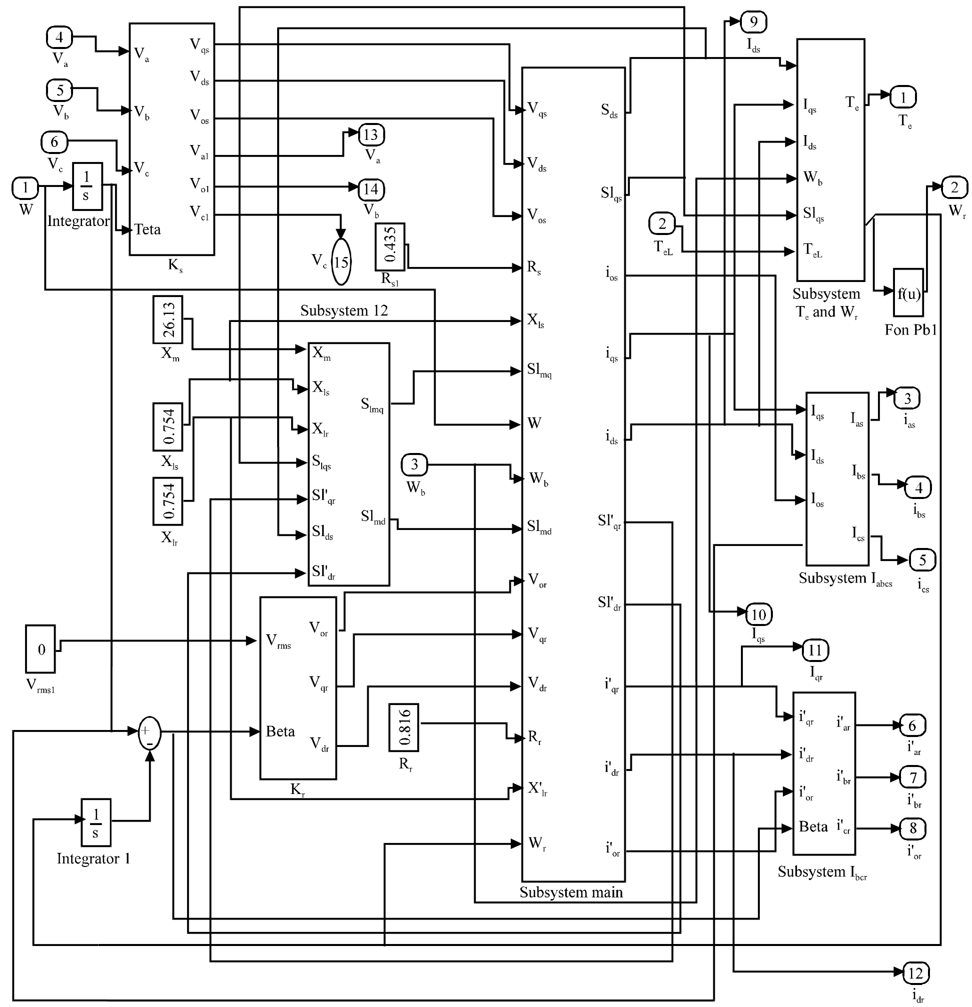


Fig. 3: Overall dynamic model of three-phase induction machine

- Subsystem T_e and ω_r : Implementation torque and speed equation
- Subsystem I_{abcs} : Two phase to three phase conversion (stator)
- Subsystem I_{abcr} : Two phase to three phase conversion (rotor)

RESULTS AND DISCUSSION

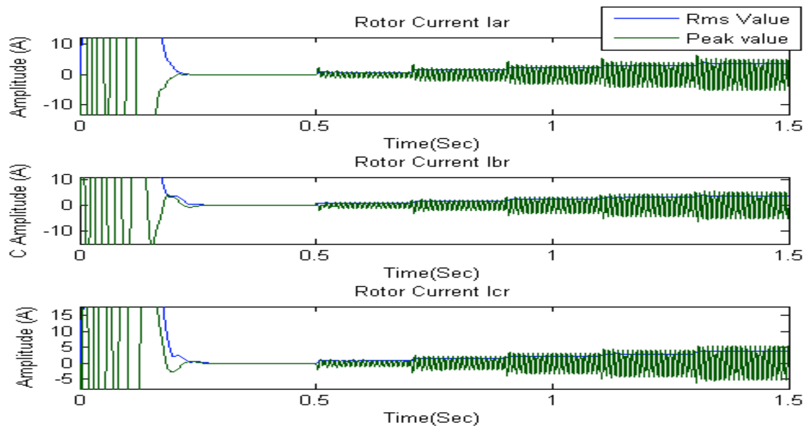
Unbalanced Supply Voltage

Unbalanced supply voltage fault is created in simulation environment based on Eq. 1 and the performance plots are obtained at no-load and full load conditions as shown in Fig. 4 and 5.

Single Phasing

The single phasing fault is a worst condition of unbalanced case. This fault is simulated by any one of the three phase voltage is kept as zero and performance plots are obtained for different load

(a)



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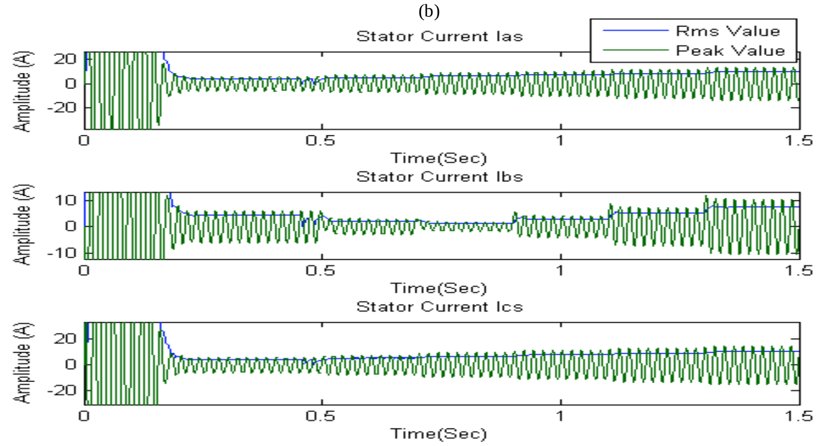

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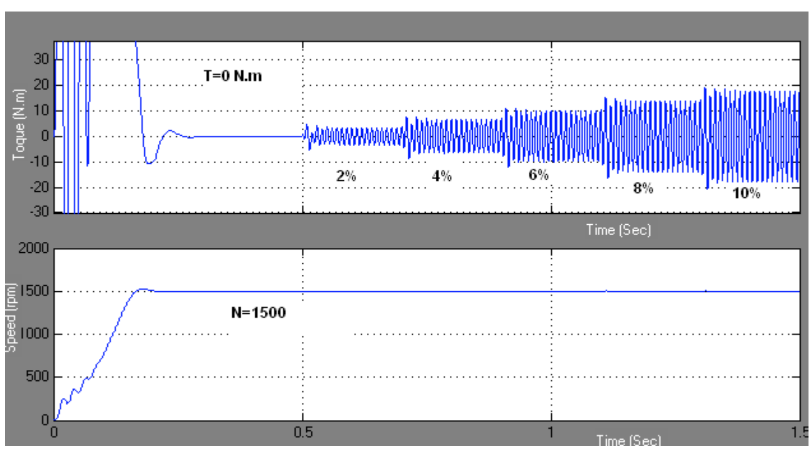


Fig. 4: (a) Rotor currents, (b) Stator currents and (c) Speed and torque during different unbalanced conditions at no-load (T = 0 Nm)

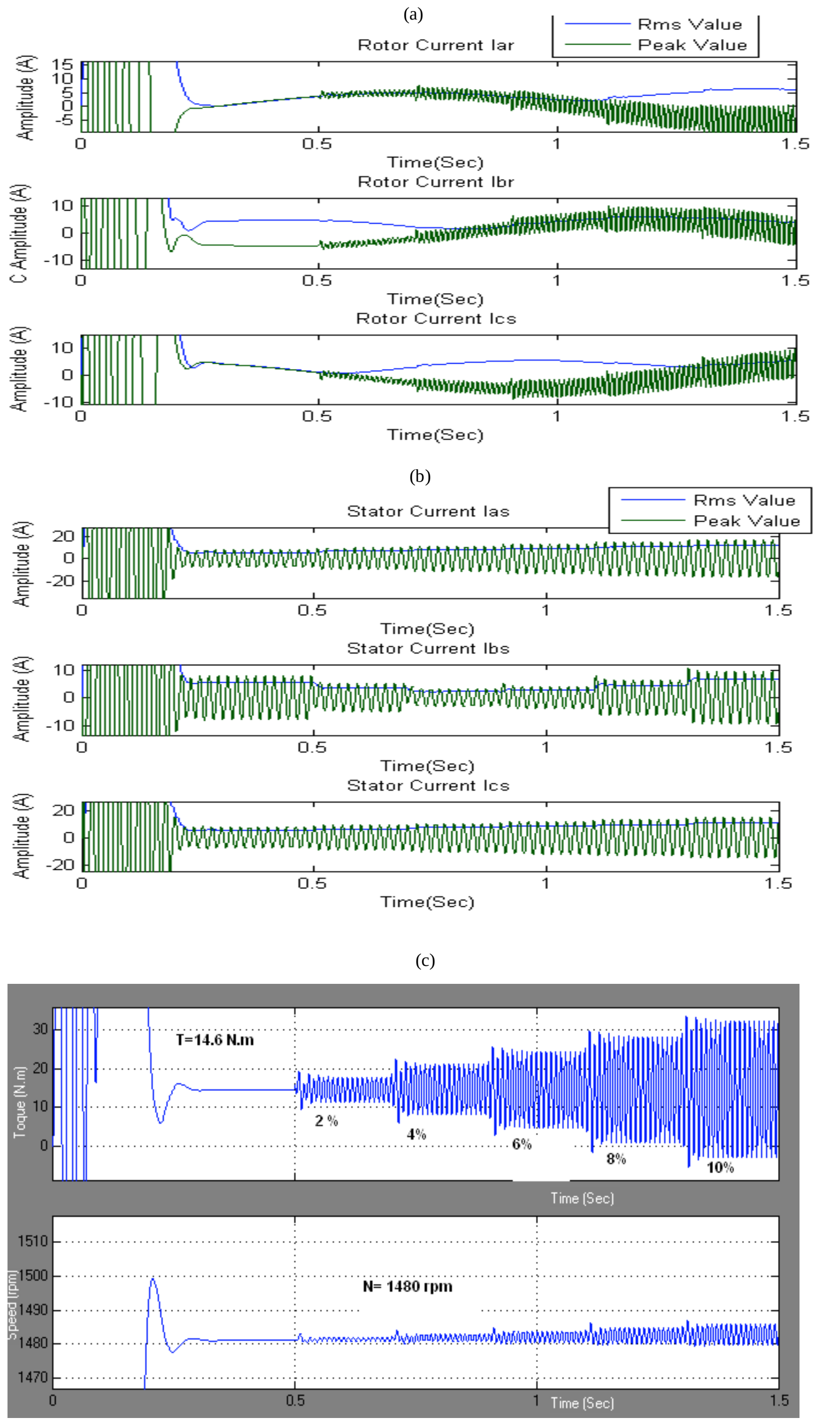


Fig. 5: (a) Rotor currents, (b) Stator currents and (c) Speed and torque during different unbalanced condition at full load (T = 14.6 Nm)

conditions. By analyzing the simulation results shown in Fig. 6, it is observed that during single phasing; (i) More current will flow through cut down phase and (ii) More heat will be generated in stator winding.

Phase Reversing

The phase reversing fault is simulated by changing any two phases like RBY from normal RYB sequence. From simulation results of phase reversing shown in Fig. 7, it is observed that the motor will rotate in opposite direction, i.e., simply the motor runs with negative speed.

Over Load Condition

This fault is created by increasing mechanical torque on the motor by changing T_L (Load Torque) value in simulation environment. Stator currents, rotor currents, speed and torque during different over current situations are shown in Fig. 8. The speed versus Torque performance under different over current situations are shown in Fig. 9. From simulation results of overload fault condition, the following observation are made; (i) increase in phase currents, (ii) overheating of machine and (iii) machine rotates opposite direction when torque exceeded to 75 Nm, i.e., stator current is greater than 4 times the rated current which is shown in Fig. 9e.

Ground Fault

The phase to ground fault is simulated as given below. During running condition of the motor, at 0.5 sec any one of the phases kept as zero and the performance plots of single phase to ground fault is observed as shown in Fig. 10.

Over Voltage/Under Voltage Fault

The over/ under voltage fault are simulated as given below:

Under Voltage

Under voltage fault is simulated by reducing the maximum voltage on all three phases by a certain percentage when the motor is running under normal condition. Figure 11 shows the performance characteristics during under voltage condition at full load.

Over Voltage

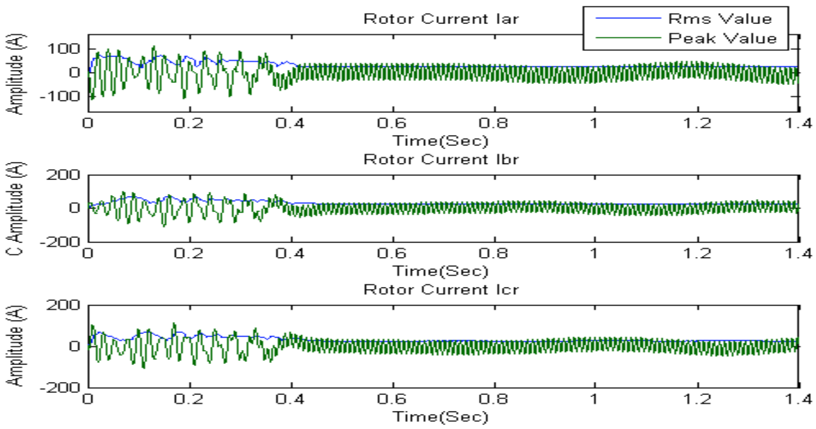
When the motor is operating at normal condition with load, the three phase voltages are increased by a certain percentage. Figure 12 shows the performance characteristics during over voltage condition at full load. Due to increase in the phase voltages, the current increases further from normal rated value.

Table 2 shows the observations of all electrical fault analysis, which is used for hardware implementation of protection system.

Table 2: Observation from fault analysis

Faults	Tolerable value	Permissible value
Unbalanced supply voltage	1 to 5%	1 to 5%
Current unbalance	Up to 45%	Up to 40%
Over current	2 times rated current (10 A)	1.5 times rated current (8 A)
Single phasing	Motor will run up to 75% of its rated load	Not permitted
Phase reversing	Motor will run in reverse direction	Not permitted

(a)



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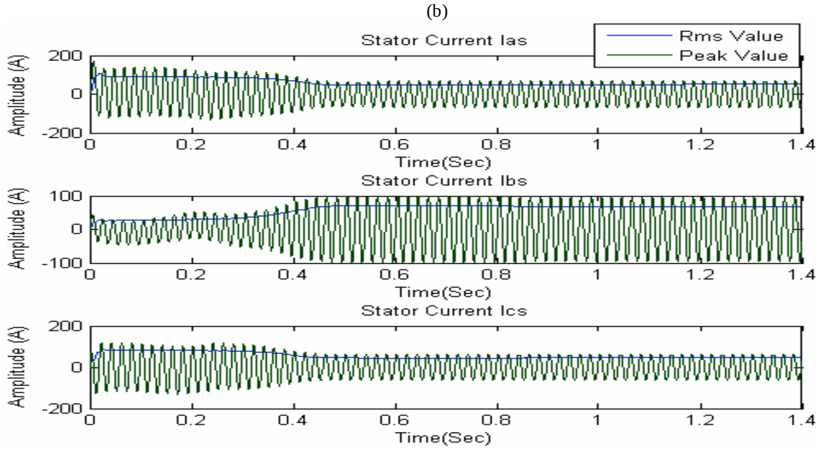

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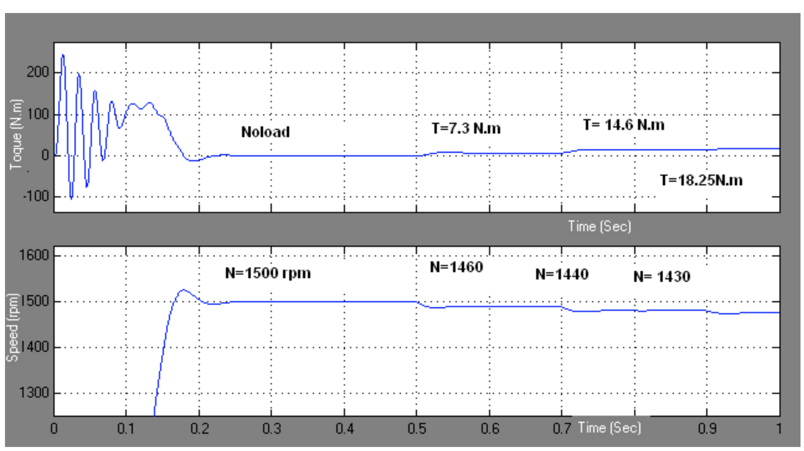
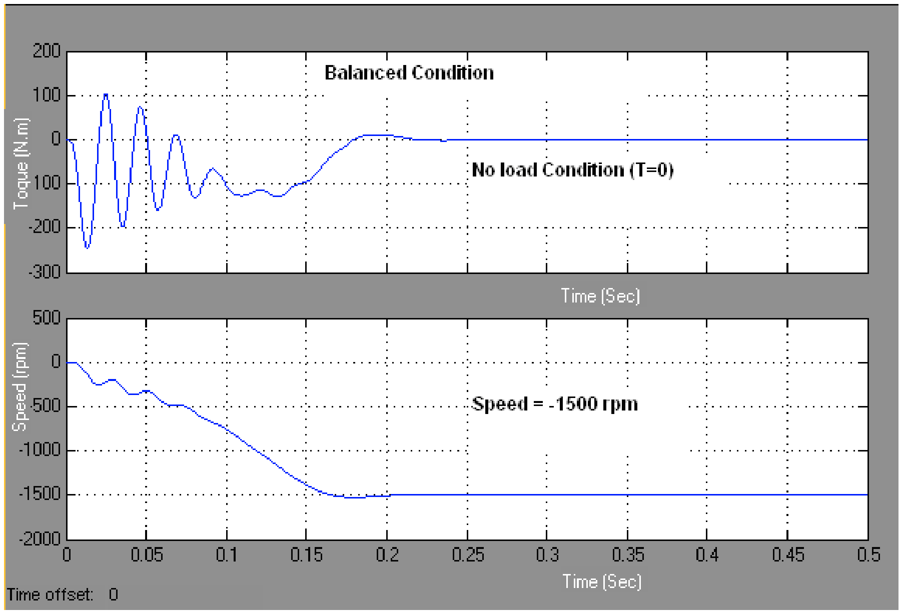


Fig. 6: (a) Rotor currents, (b) Stator currents and (c) Speed and torque during single phasing

(a)



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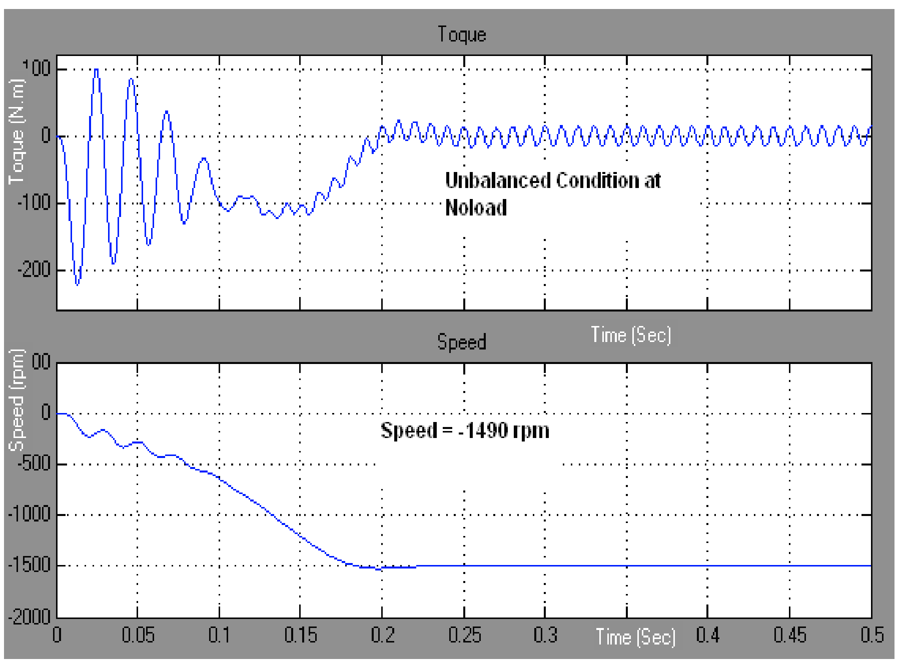
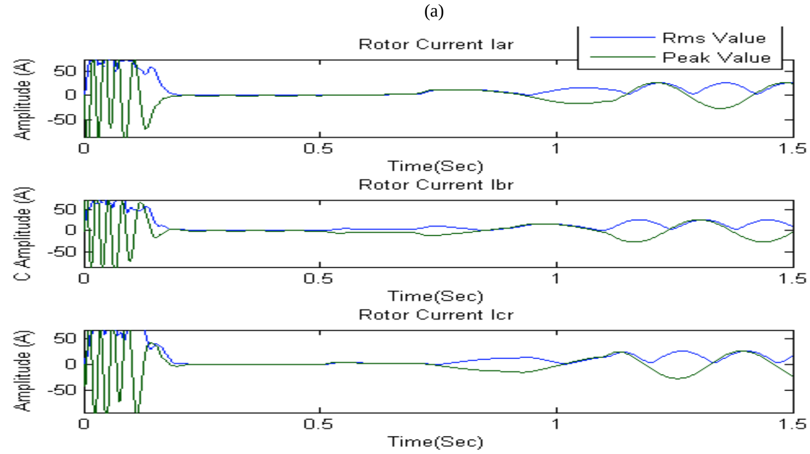


Fig. 7: (a) Torque and speed characteristics during phase reversing at no load (a) Balanced and (b) Unbalanced

(a)



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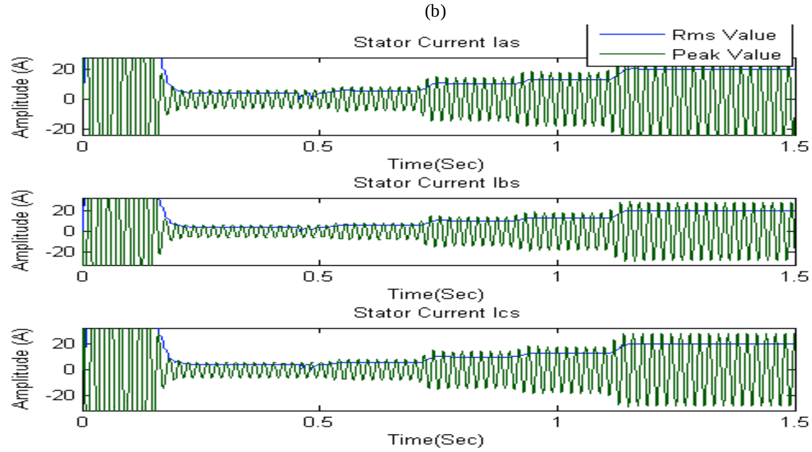

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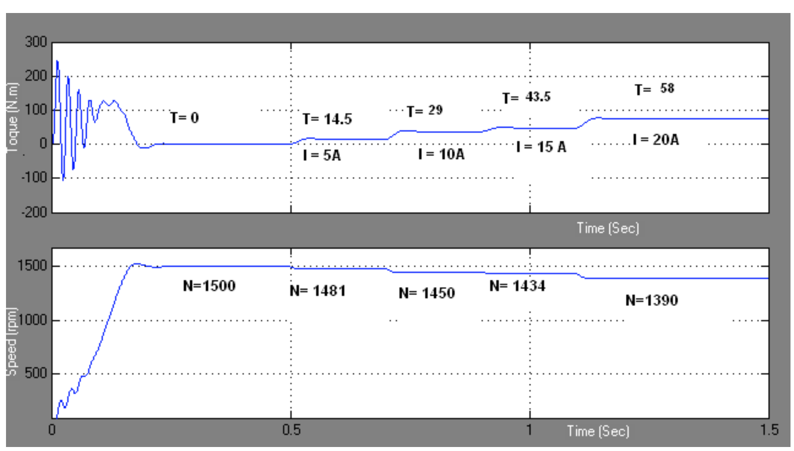
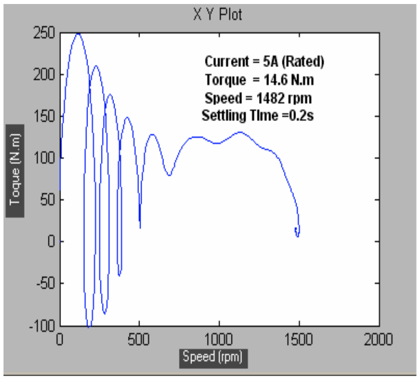


Fig. 8: (a) Stator currents, (b) Rotor currents and (c) Speed and torque during over load



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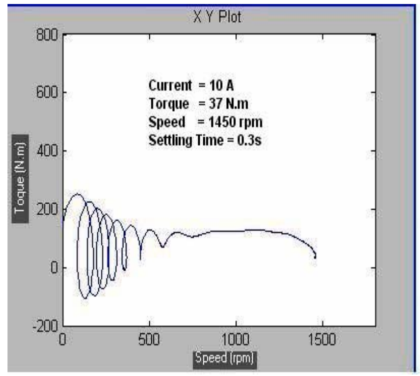

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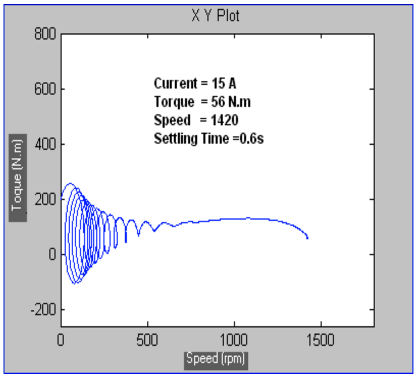
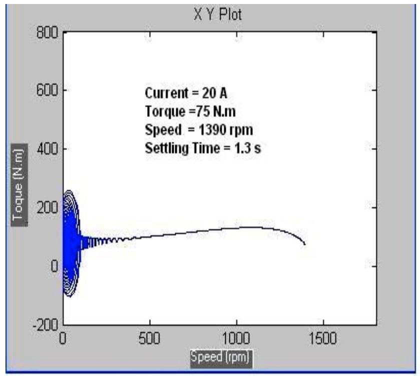


(c)



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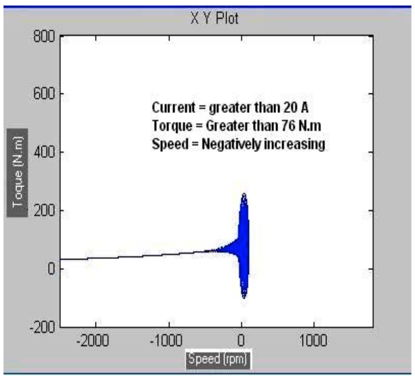
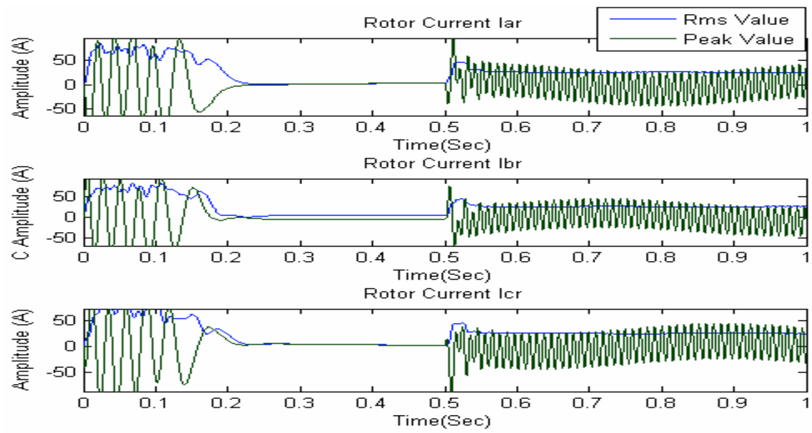


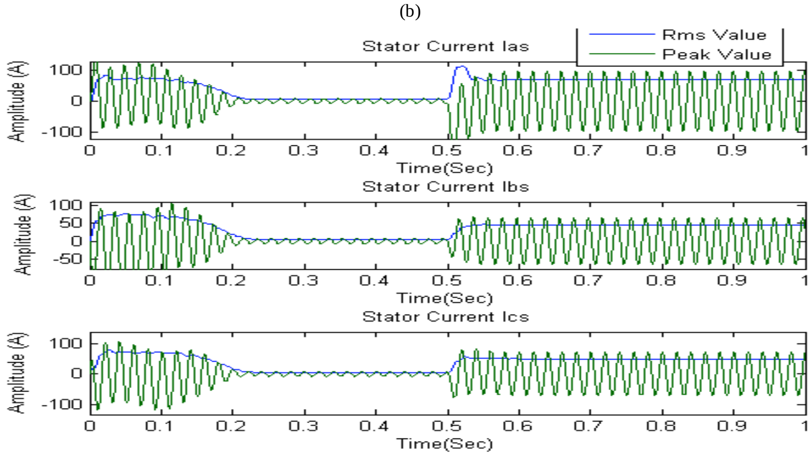
(e)

Fig. 9: Speed versus torque performance during different over current condition (a) Rated current (I = 5 A), (b) Two times rated current (10 A), (c) Three times rated current (15 A), (d) Four times rated current (20 A) and (e) Five times rated current (25 A) at T = 73 Nm

(a)



(b)



(c)

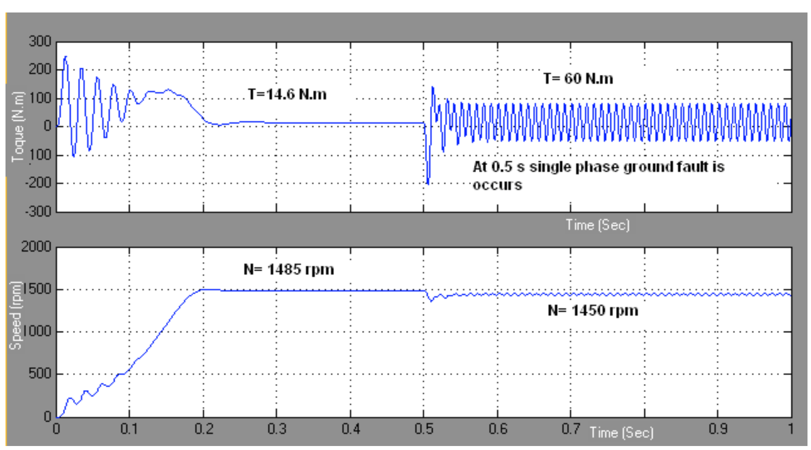
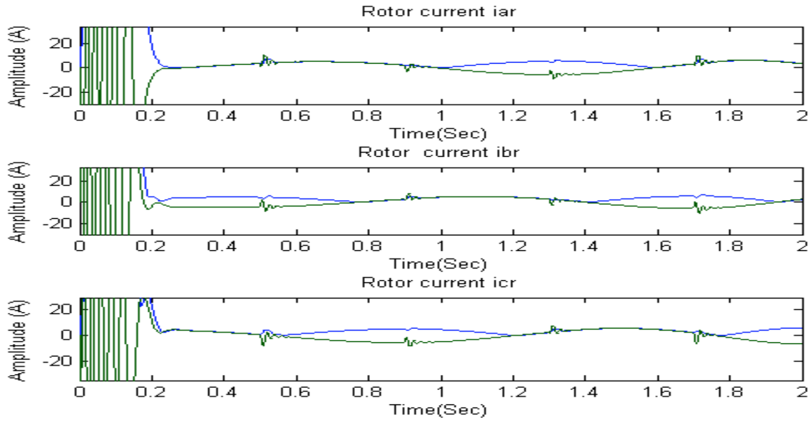
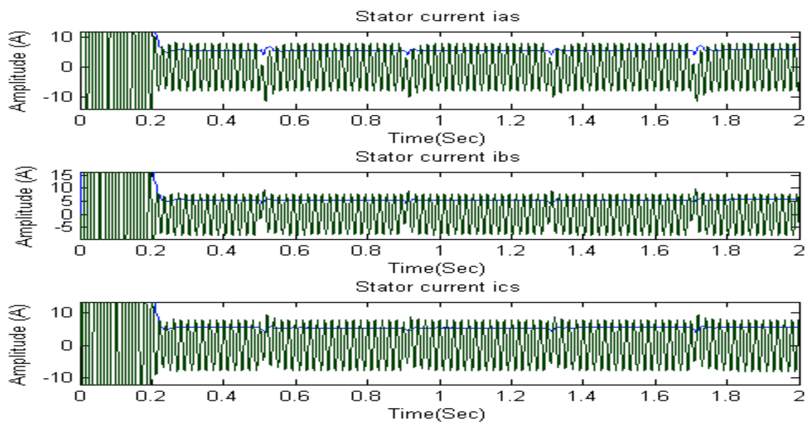


Fig. 10: (a) Stator currents, (b) Rotor currents and (c) Speed and torque during phase to ground fault

(a)



(b)



(c)

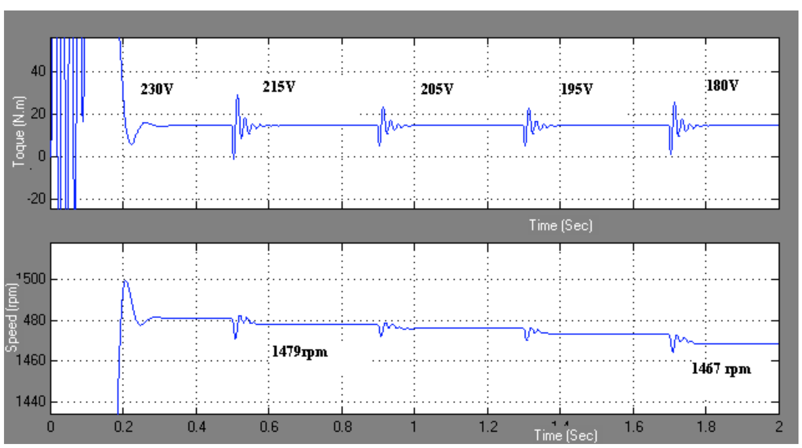
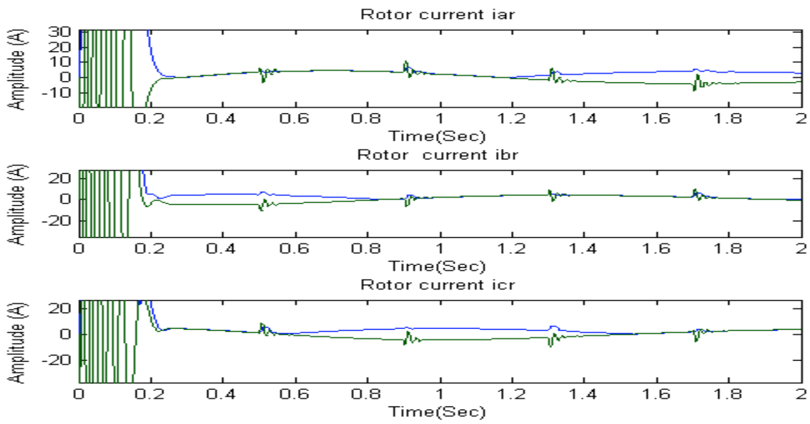
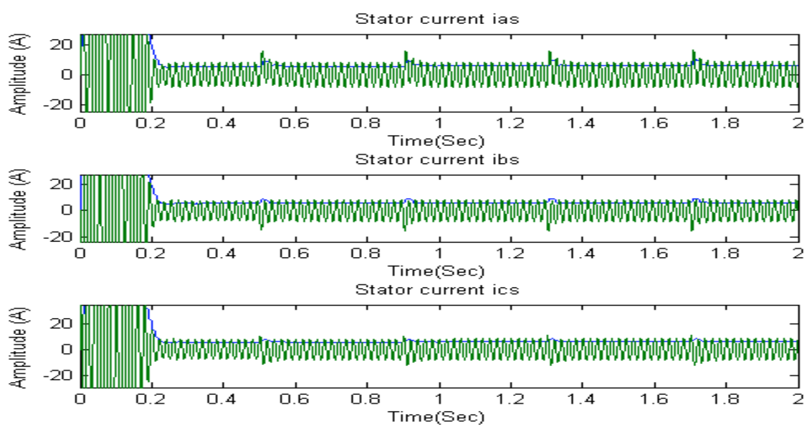


Fig. 11: (a) Stator currents, (b) Rotor currents and (c) Speed and torque during different under voltage condition at full load (T = 14.6 Nm)

(a)



(b)



(c)

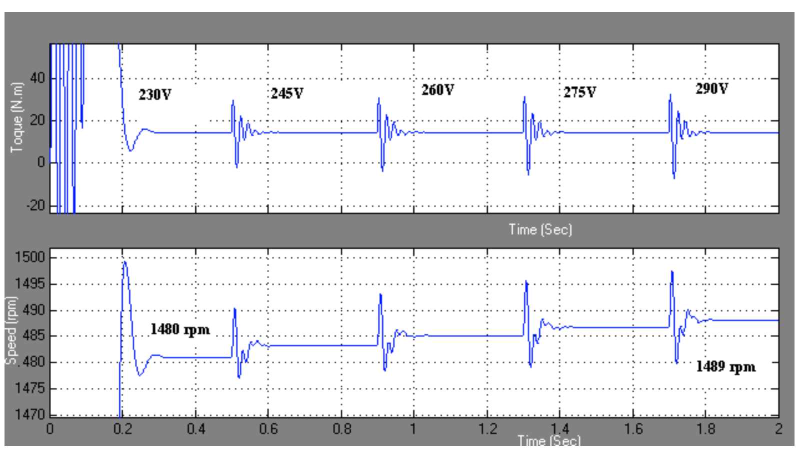


Fig. 12: (a) Stator currents, (b) Rotor currents and (c) Speed and torque during different over voltage condition at full load (T = 14.6 Nm)

IMPLEMENTATION OF PROTECTION SYSTEM

The micro controller based motor protection system combines control, monitoring and protection function of induction motor from incipient faults in one assembly. The overall block diagram of the motor protection system is shown in Fig. 13. The system does not require special sensors. Ouly conventional Current Transformers (CT) and Potential Transformer (PT) are used for monitoring line current and line voltage under running condition. The data gathered from Current Transformer (CT) and Potential Transformer (PT) is transferred to the micro controller digitally by passing through the current and voltage measuring circuits. The PIC 16F877 micro controller having in build analog to digital (ADC) converter.

The needed comparisons are made in micro controller according to limit values, which are earlier entered and when an unexpected situation is encountered, the motor is being stopped by means of the control signal. The system provides protection schemes for unbalanced supply voltage, over current/overload, phase reversing, single phasing, under/over voltage and ground fault. The controller of the system is implemented using PIC 16F877 microcontroller using MPLAB development tool based on the value obtained from simulation results, which is shown in Table 2. The input data (limit values) to the system is given through the keypad. LED Seven Segment display unit is used as an output device to display the output data, warning message and fault condition. The system works with any motor design with high degree of accuracy. The method is very sensitive, fast and detects faults while running and before start. The prototype model is developed and tested on a 3 phase induction motor with rated current of 5 A and the test results are satisfying the design criteria. The motor parameters like the full load current in amperes, service factor and class of motor, etc., are needed to be entered into the relay programming unit to automatically calculate the correct motor protection curve.

Specification of Induction Machine

The three-phase squirrel cage induction machine under test has the following specifications:

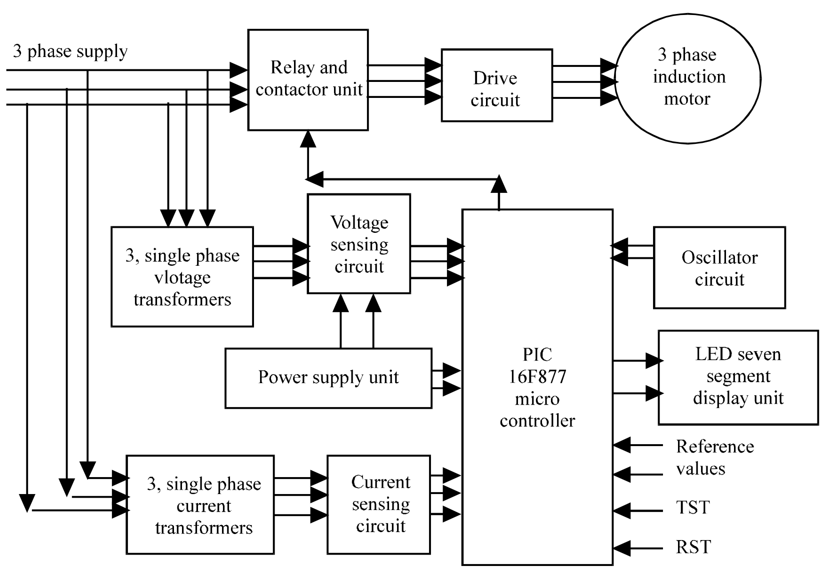


Fig. 13: Overall block diagram of protection system for 3 phase induction machine

Power rating	=	2.2 kW
Line voltage	=	415 V
Rated current	=	5 V
Frequency	=	50 Hz
No. of poles	=	4
Rated speed	=	1440 rpm
Counection	=	Delta
Class type	=	K

ALGORITHM

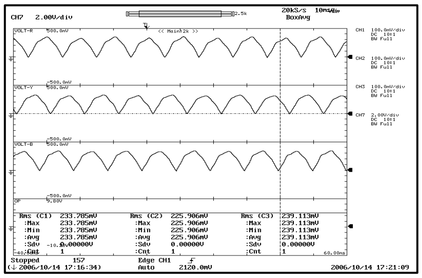
The algorithm used for developing embedded programming as follows:

(1) Implement the microcontroller based integrated protection system
(2) The permissible value obtained from simulation results are entered as reference value in Microcontroller unit
(3) Start the machine at rated condition
(4) Monitor supply voltage (V_a, V_b, V_c) and stator currents (I_a, I_b, I_c) through Potential Transformer (PT) and Current Transformer (CT)
(5) Measured voltages and currents are digitally passed to microcontroller unit via voltage and current sensing circuits
(6) Comparisons are made between measured values with reference value
(7) If ($\angle R \sim \angle Y = 240°$) then stop the motor and display message as phase reversing. Otherwise
(8) If ($V_a \mid V_b \mid V_c = 0$) then generate trip signal to stop the motor and display message as single phasing. Otherwise
(9) If (% of voltage unbalance >=5%) then stop the motor and display message as voltage unbalance condition. Else
(10) If (% of current unbalance >40%) then stop the motor and display message as current unbalance condition. Else
(11) If ($I_a \mid I_b \mid I_c$) > 10A) then stop the motor and display error message as over current. Otherwise,
(12) If phasor addition of I_a, I_b, I_c is greater than 1 A i.e., ($I_a+I_b+I_c$)>1 A) then stop the motor and display error message as Earth fault in LCD display. Otherwise
(13) Go to step 4

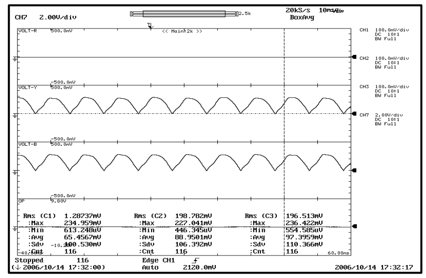
A prototype model is developed and tested on a 3 phase, 440 V, 50 Hz, 2 kW, 5 A induction motor. The microcontroller based multifunction motor protection system responded to all types of faults perfectly by tripping the motor after the specified time delay and displayed the corresponding error message in the LED seven segment display unit. The waveforms for various fault conditions are observed using Digital Storage oscilloscope and shown in Fig. 14a-e.

CONCLUSION

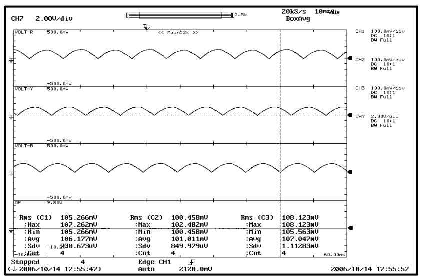
This study presents the simulation of the three-phase induction motor performance during incipient faults using MATLAB/Simulink tool. From simulation analysis, limit values are obtained to implement a low cost, reliable integrated protection system of induction machine



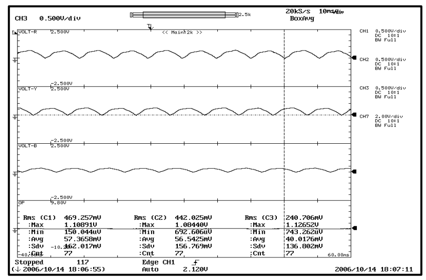
(a)



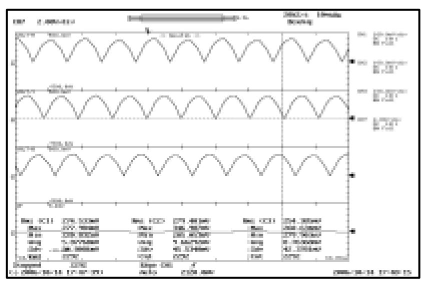
(b)



(c)



(d)



(e)

Fig. 14: Output signals from the voltage sensing circuit and input signal to the relay and contactor unit under various fault conditions (a) Normal operating condition, (b) Single phasing condition, (c) Under voltage condition, (d) Unbalanced voltage condition and (e) Overload condition

using PIC embedded controller. This protection system detects the voltage unbalance, single phasing, overload, over/under voltage, phase reversal and earth fault thus provides efficient protective scheme.

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