Simulation Analysis of Fully Protected Induction Motor

Raheel Muzzammel, M. Nauman Akram, Muhammad Shehzad Ahmed, Abubakr Saleem and Muhammad Umair Muqeem

Abstract—With the passage of time, induction motor is becoming essential for both home appliances and industrial drives. Most of the industry depends on induction motor. Therefore, reliable operation of induction motor is much necessary for long term continuity of services associated with it. For reliability purposes, different types of protection relays are used such as over-current relay, under-current relay, over-voltage relay, under-voltage relay and thermal relay. In this research, induction motor is simulated in Matlab / Simulink and different types of protection circuits are attached with it. Effects of protection system on induction motor working and under faults are analyzed in this research work.

Index Terms— Induction motor, power system protection, over-current relay, under-current relay, over-voltage relay, under-voltage relay, Matlab/ Simulink

1 Introduction

An electrical motor converts electrical energy into mechanical energy. Most of the electric motors operate through the dealings of magnetic field of electric motor and winding currents to generate force. Induction motor is one of them. An asynchronous or induction motor is an AC electric motor in which electric current in the rotor, needed to produce torque, is obtained by electromagnetic flux from the magnetic field of the stator winding. In such machines the rotor voltage is induced in the rotor windings [1] –[4].

The main feature of an induction motor is that no external supply is required to rotate the rotor. There are two types of rotor of induction motors. Wound or slip ring rotor motor is a type of induction motor where the rotor windings are connected through slip rings with the external resistance. Speed of the rotor can be controlled by adjusting the resistance. Squirrel-cage rotor motor consists of a cylinder of steel laminations, with aluminium or copper conductors combined in its surface [1]. Squirrel-cage induction motor is widely used due to its simple construction. Therefore, its protection is also easy as compared to wound motor. Induction motor consists of following parts [5]:

Stator: Stator is a stationary part of induction motor. Stator winding is placed in the stator of induction motor and three phase supply is given to it.

Rotor: Rotor is a rotating part of induction motor. Rotor is connected to the mechanical load through the shaft.

Drive Shaft: Shaft is made up of steel. This shaft is used for transmitting the torque to the load.

Terminal Box: Terminal box is used for receiving the external electrical connection.

Cooling Fan: Cooling fan is used for the constant temperature for the motor.

Bearings: Bearings are used for supporting the rotating shaft.

More commonly, induction motor in use is a squirrel cage induction motor. A cage induction motor rotor consists of a series of conducting bars laid into slots carved in the face of the rotor and shorted at either end by large shorting rings. Rotor is made from punched laminations of steel or iron core with slots to provide rotor windings while bars are made of aluminium or copper metal. The conductors are often skewed slightly along the length of the rotor to reduce noise and smooth out torque fluctuations.

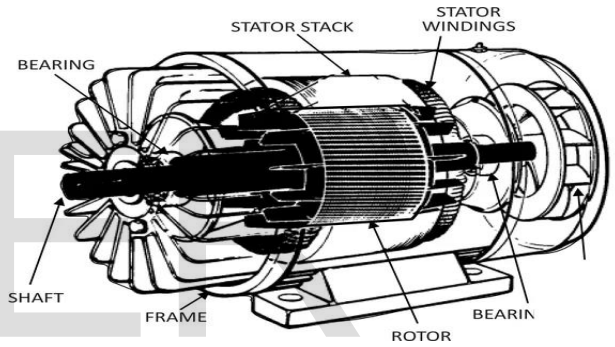

Fig.1. Squirrel Cage Induction Motor [6]

When a three phase voltage is supplied to stator winding, a three phase ac current flows through this winding which induces EMF in the stator and helps in the rotation of the rotor. This is the main advantage of squirrel cage induction motor over wound induction motor. It means no other external supply is required for rotor. Speed of induction motors depends on the magnitude of current in the stator. If current is high, then the speed of induction motor is high.

Induction motor is becoming an essential part of business. The most important advantage of an induction motor is that its construction is quite simple.

The working of motor is independent of conditions of an environment. This is because of that fact that the induction motor is strong and robust. With the protection of Induction motor, it is necessary to monitor and control induction motor [6] - [10].

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Industry depends on induction motor. Therefore, it is essential to make motor protection and control more efficient [11]. The control of monitoring of induction motor with programmable conditions must be well aware about voltages, currents, speed and temperature values of the induction motor with commercial or industrial appliances [9].

A squirrel-cage induction motor does not contain brushes, slip rings or commutators. Due to this advantage, the cost of this motor is quite low. Due to absence of brushes, there are no sparks in the motor. This motor has high speed torque and good speed regulations [4].

Power system is very much sensible of faults [12]. When an error occurs in a power system, protection module does not go for unwanted tripping of lines and distribution system, In this way, power system remains healthy and can maintain the stability [13].

Single-phase induction motor is used in home appliances while three-phase induction motor is used in industrial drives. Therefore, highly efficient protection is required against abnormal conditions [14].

Power system protection deals with the protection of electrical machines such as induction motor from the faults.

For the safety and longer life of induction motor, protection is essential for motors. So, different types of protection relays are used for different types of faults [7]. The power system protection agreement is mandatory for the reliability and security of the electrical system [15].

Over-current relay operates when current exceeds its predetermined value. Under-current relay operates when current remain low than its lowest bearing value. Over-Voltage relay operates when voltage exceeds its predetermined value. Under-Voltage operates when voltage remain low than its lowest bearing value. These are some important relays which are used for the protection of a machine. These relays should be sensitive because when a fault occurs, relays should operate quickly before motor gets damage.

Another type of relay is thermal relay. It is used in abnormal temperature conditions. Due to over-speeding or over-heating, the temperature increases which affects rotor and stator winding, in result, it causes great damage [8]. For avoiding this damage, thermal relay should be used in protection system [3].

Some electrical induction motors without enough protection devices are not disconnected but they are damaged by the thermal effect of a relatively high negative sequence current component [14].

2 Mathematical Formulation Of Induction Mototr

An induction motor depends for its operation on the induction of voltages and currents in its rotor circuit from the stator circuit. The equivalent transformer model of an induction motor is shown in fig. 2.

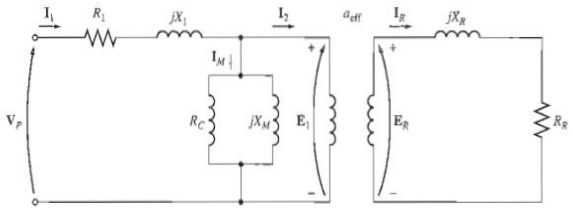

Fig. 2. Transformer model on an induction motor [1]

Rotor circuit is helpful in measuring voltages and currents of induction motor and is shown in fig. 3.

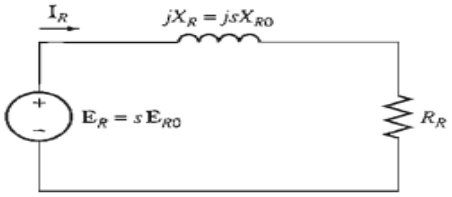

Fig. 3. Rotor circuit [1]

Where

I*R* is the rotor current

jXR + RR is the total impedance of the rotor

ER is the voltage which induces from the stator.

So from the circuit, the equation of current and voltage can be written as:

$$I_R = \frac{E_R}{R_R + jX_R} \quad (1)$$

Voltage can be measured from:

$$E_R = I_R \times (R_R + jX_R) \quad (2)$$

When the current in rotor increases temperature increases and when current decreases temperature decreases. So, torque T has directly relation to the current I and voltage V [1].

3 Mathematical Formulation of Protection System

As discussed four type of relays above for the protection, so, there are four different types of conditions that must be applied for the operation of relays. Ipick-up current takes as a reference current and I takes as source current.

- Over-current relay: I > IPick-up
- Under-current relay: I < Iminimum

Similarly, Vpick-up voltage takes as reference voltage and V takes as source voltage:

- Over-voltage relay: V > VPick-up
- Under-voltage relay: V < Vminimum

3 Test System Of An Induction Motor

Simulation model of three phase induction motor is developed in Matlab/ Simulink. Voltage and current waveforms are observed under healthy and normal conditions. Different types

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of protection modules are developed for protection system for induction motor. These modules are tested under normal and faulty conditions to ensure reliable operation of induction motor. Induction motor with over current protection module is shown in fig. 4.

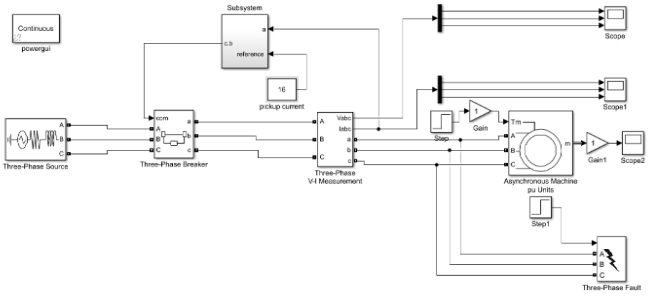

Fig. 4. Connection of over-current protection with induction motor

Over-current limit for this system is set at 16A which means that this relay will operate when the value of current exceeds from pick up value (16 A) of current. The subsystem which is handling this operation is shown in fig. 5. Pick-up value of any voltage and current is set as reference value. When high current (more than pick-up current) is supplied from the source, relational operator compares it to pick-up value and for over-current relay condition, it becomes true so 1 receives on S flip flop. Output Q=0 terminates and Q! = 1 receives on AND gate. If all inputs on AND gate are 1, then over-current relay operates and cut off the circuit from the source voltage.

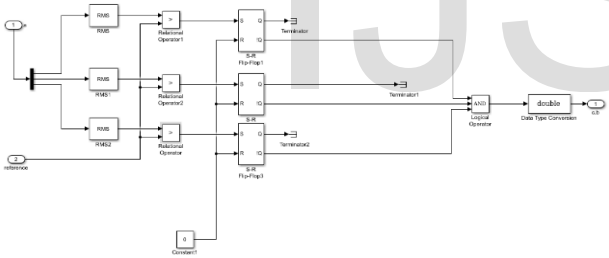

Fig. 5. Subsystem of over-current relay

Under- current relay protection module is connected to induction motor and is shown in fig. 6. Under-current limit for this system is set at 12A which means that this relay will operate when the value of current remains below from reference current. The subsystem which is handling this all operation is shown is fig. 7.

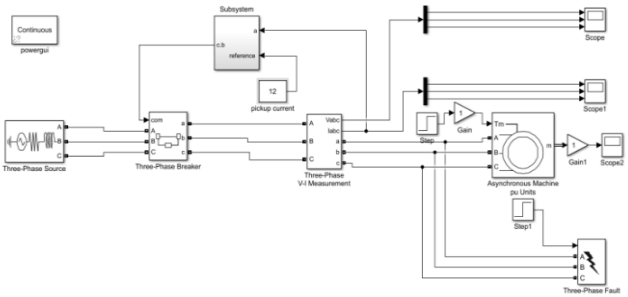

Fig. 6. Connection of under-current relay with induction motor

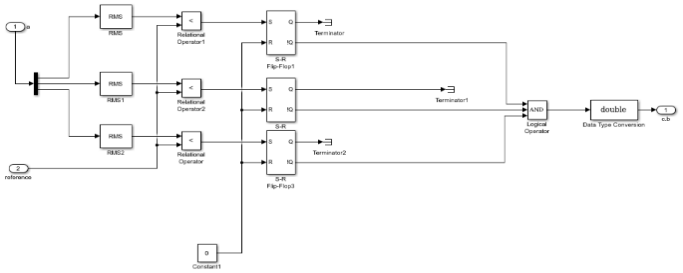

Fig.7. Subsystem of under-current relay

Over-voltage relay protection module is connected to induction motor and is shown in fig. 8.

Over-voltage limit for this system is set at 240V which means that this relay will operate when the value of voltage exceeds from reference voltage. The subsystem which is handling this operation is shown in fig. 9.

Under- voltage relay protection module is connected to induction motor and is shown in fig. 10.

Under-voltage limit for this system is set at 180V which means that this relay will operate when the value of voltage remains below from reference voltage. The subsystem which is handling this all operation is shown in fig. 11.

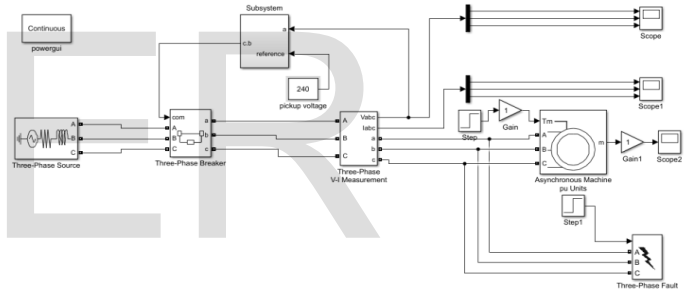

Fig. 8. Over-voltage relay

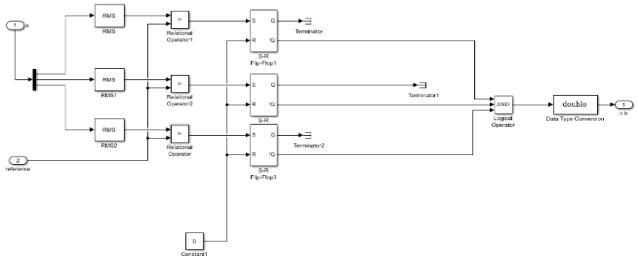

Fig. 9. Subsystem of under-voltage relay

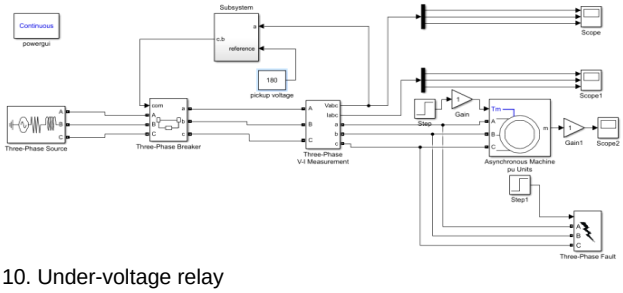

Fig. 10. Under-voltage relay

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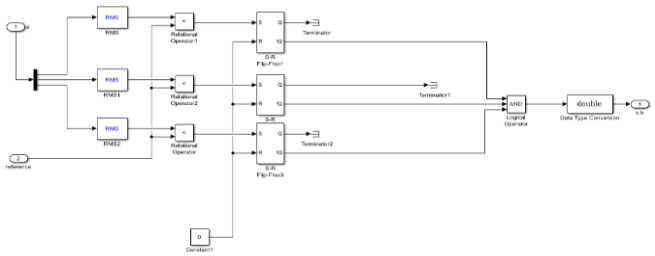


Fig. 11. Subsystem of under-voltage relay

All the protection modules are simultaneously applied on three phase induction motor in order to check the reliability of modules. It is required that for a specific condition of fault, specific protection module designed should operate only. Circuit diagram of fully protected three-phase induction motor model is shown in fig. 12.

Subsystem of protection module works for this system. This subsystem consists on all relays which are using for the protection system. This is shown in fig. 13.

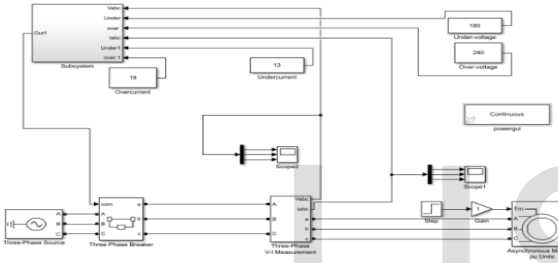


Fig. 12. Circuit diagram of fully protected three-phase induction motor model

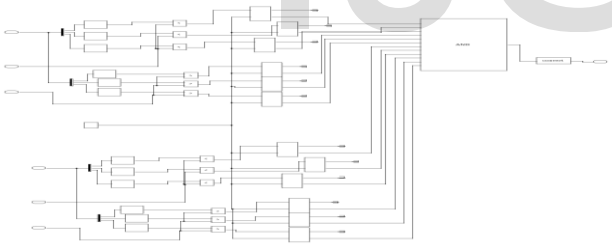


Fig. 13. Subsystem of relay module

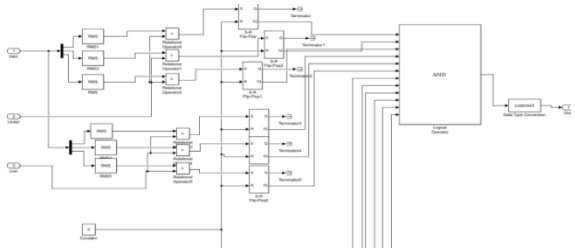


Fig. 14. Under and over-voltage relay

This upper half part of under and over voltage relay system is shown in fig. 14. If over-voltage condition happens, then only over-voltage relays will work. All other relays will be disconnected from the circuit. If over-current relay works them all remaining relays will be disconnected from the circuit and so on. Other lower half part of this subsystem consists on over and under current relay and it is shown in fig. 15.

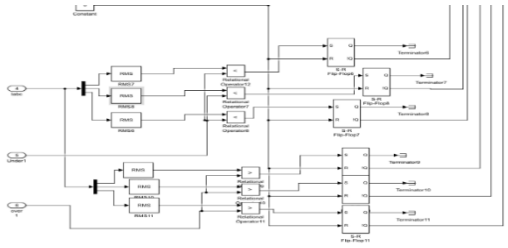


Fig. 15. Under and over-current relay

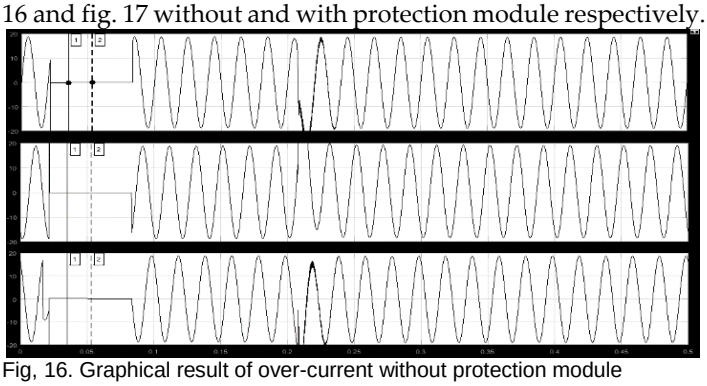
4 Graphical Results

Voltage and current values are used for analyzing operation of protection modules for three phase induction motor graphically. Table 1 shows the values of components that is incorporated for simulation.

TABLE 1
SELECTED VALUES FOR CIRCUIT ELEMENTS OF INDUCTION MOTOR TEST SYSTEM MODEL

Serial Number	Element	Value
1	RMS Voltage	230V
2	Source Voltage	230Vrms
3	System Frequency	50Hz
4	System Time Period	0.5s
5	Over-Current (Reference)	12A
6	Under-Current (Reference)	16A
7	Over-Voltage (Reference	240V
8	Under-Voltage (Reference)	180V

When a current increases from the pick-up value (16A) set in the relay, relay will respond to the abnormality happened in the system in order to protect induction motor. Such type of behaviour is known as over-current protection and it is shown in fig. 16 and fig. 17 without and with protection module respectively.



Fig, 16. Graphical result of over-current without protection module

When a current decreases from minimum (12A) value set in the relay, relay will respond to the abnormality happened in the system in order to protect induction motor. Such type of behaviour is known as under-current protection and it is shown in fig. 18 and fig. 19 without and with protection module respectively.

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Fig. 17. Graphical result of over-current with protection module

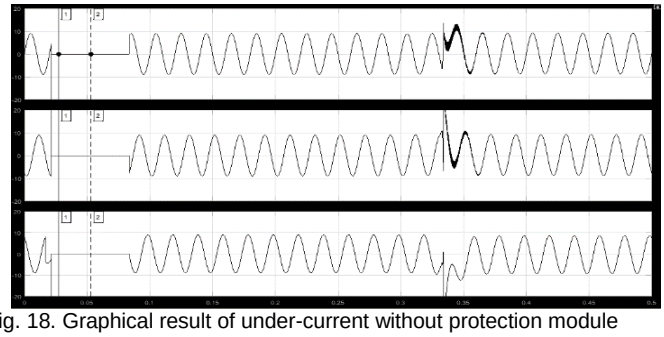

Fig. 18. Graphical result of under-current without protection module

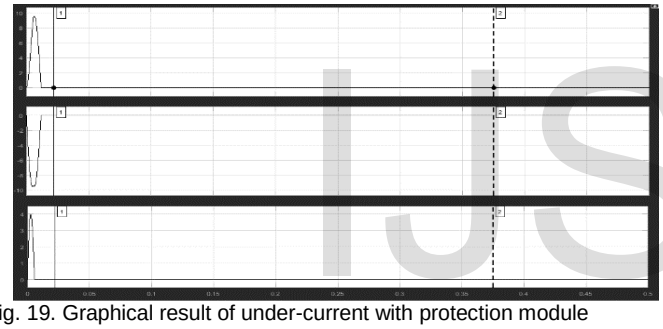

Fig. 19. Graphical result of under-current with protection module

Value of source is changed from 230V to 270V, then relay operates at time of 12.43ms and circuit breaker cuts off the supply. Sensing and sending tripping command time of protection module is about 13ms. Circuit breaker operating time is 0.5s. Such type of behaviour is known as over-voltage relay and it is shown in fig. 20 and fig. 21 without and with protection module respectively.

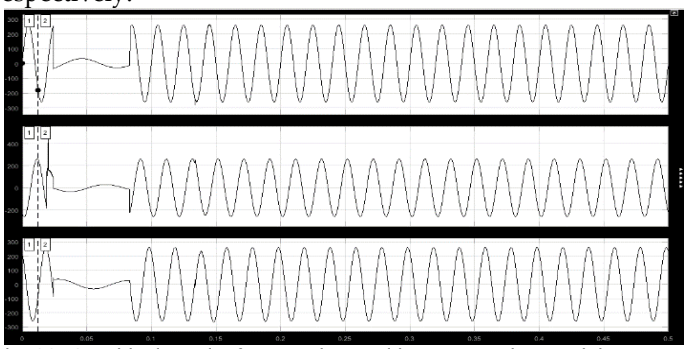

Fig. 20. Graphical result of over-voltage without protection module

Fig. 21. Graphical result of over-voltage with protection module

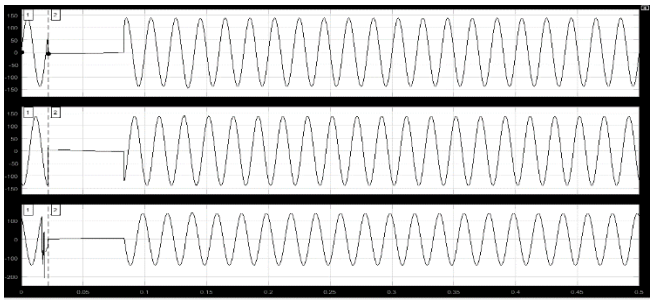

Fig. 22. Graphical result of under-voltage without protection module

Fig. 23. Graphical result of under-voltage with protection module

For under-voltage, value of voltage source is changed from 230V to 140V. At time period of 12.43ms, the relay operates quickly to sends a command of disconnection. Circuit breaker cuts off the circuit in a time period of 0.5s. In this situation, only under-voltage relay operates and other remains off and it is shown in fig. 22 and fig. 23 without and with protection module respectively.

5 Conclusion

Induction motors are the favourite candidates of industries and home appliances. Most of the applications installed that have rotary component are equipped with induction motor. Because of its large scale usage, there is a need to ensure continuous and non-interruptible operation. For this, different type of protection system must be mounted on motor. In this research, four type of protection system are simulated to make induction motor highly protected. It is noticed in the simulations and results that abnormalities and faults are fully rectified with developed protection system for induction motor.

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