“DESIGN AND ANALYSIS OF PROTECTIVE RELAYS FOR PROTECTION OF THREE PHASE INDUCTION MOTOR”

A Dissertation submitted in partial fulfilment for the Degree of

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Submitted By

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CERTIFICATE

I, Devvrat, Roll No. 2K14/PSY/21 student of M. Tech. (Power System), hereby declare that the dissertation/project titled "Design and Analysis of Protective Relays for Protection of Three Phase Induction Motor" under the supervision of Dr. J N Rai of Electrical Engineering Department, Delhi Technological University in partial fulfilment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

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ABSTRACT

Every electrical equipment has to be monitored to protect it and provide human safety under abnormal operating conditions. Electric motors play a vital role in everyday life from electricity generation plants, industries and domestic uses. Majority of the industrial loads are induction motors and electric motors are used in electrically powered rail vehicles such as electric multiple units and long distance trains. It shows how much important it is to protect induction motor from various abnormal conditions. Simulation software are very useful for educational and industrial purpose where you can simulate a system and check its performance under various condition before creating the actual system. Here various protective relays are simulated in MATLAB and Proteus professional software and various results were obtained.

In this dissertation, overcurrent relay, undervoltage relay, thermal relay and digital negative sequence relay are simulated and under various operating conditions the operation of relay is studied. Microcontroller based relay is used to protect the motor from over temperature. A motor can be slightly overloaded only if the temperature of the motor is not high and if the temperature of the induction motor is high it should not be overloaded as it will further increase the temperature of the motor and it will reduce the lifetime of the motor. Overcurrent relay will operate if the current in any phase of the motor will increase and it will protect the motor against various faults. Further, digital negative sequence relay is simulated and its operation is studied under line to ground fault and it is successfully operated under the fault condition. Now a days a major research is going in the field of digital relays. These relays are more capable in detecting faults and they have fast operation.

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INTRODUCTION

Majority of the loads in power system are induction motor type loads. It shows how much important it is to protect a three phase induction from various faults and various abnormal operating conditions. In this thesis work protection scheme for three phase induction motor is developed and its operation under various fault condition is examined. For the functional dependability and security of power system network it is very important to protect induction motor from various faults. Now a days a major research is going on in the field of digital relay to protect industrial plants and power system. A variety of approaches were introduced and tested in actual power system and various promising results were demonstrated.

Basically a good protection scheme should have good features. These features include high speed of operation, dependability, security, accuracy. A protection system consist of various current transformer, potential transformer, relays, circuit breakers etc. Relay is basically a sensible element which takes input from the system and issues a tripping signal if there is any fault in the system. There is a basic algorithm which determine whether there is any fault in the system or not. The input to the relay could be current, voltage, temperature. To examine the status of the system current from the current transformer, voltage from the potential transformer and other electrical from various transducers are used. These inputs are necessary to determine the instantaneous state of the system. The relay will process the signal received and then make decision according to the algorithm provided in the relay. In digital relays the threshold is provided in the program so that above the threshold current and below the threshold voltage the relay will send the trip signal to the circuit breaker. The functional security is of the grid is dependent upon successful operation of thousands of relay.

1.2 INDUCTION MOTORS

The stator winding (armature windings) of an induction motor is connected to the power supply. The winding in the rotor slots is not connected to any power supply, but receives its current by the phenomena of induction. Energy is transferred to the rotor through the magnetic field. Depending on the type of power supply, the stator winding is either poly-phase or single-phase. The rotor winding is designed as either a poly-phase winding or a squirrel-cage winding. In the wound rotor induction motor, the conductors of the rotor winding are insulated and are taken out through slip rings, which are connected to external resistance. These external resistance are used for high starting torque and once the motor has started the resistance is reduced to lowest value possible to achieve higher efficiency. In the squirrel-cage induction motor, the conductors of the rotor are not insulated, but consist of bare conductors fitted into the slots of the rotor. These conductors are solidly connected together by a conducting metallic ring at each end that is compatible with the conductor alloy. Three phase induction motor has a robust construction. Approximately 80% of the industrial load is three phase induction motor. So it is very important to protect these induction motors. It is extensively used in industries for various functions. In case these induction motors goes out of service the production of the industry is seriously affected.

Due to the commonly harsh industrial environments, each part of electric motors is potentially exposed to the high risk of unexpected mechanical, chemical, and electrical system failures. The reasons why electric motors fail in industry have been commonly reported as follows:

1 Operating after standard lifetime

2 Wrong-rated power, voltage, and current

3 Unstable or unbalanced supply voltage or current source

4 Overload or unbalanced load

5 Electrical stress from fast switching power electronic devices or unstable ground

6 Residual stress from manufacturing

7 Mistakes during repairing

8 Harsh application environment (dust, water leaks, environmental vibration, chemical contamination, high temperature)

1.3 MOTIVATION

The population of electric motors has greatly increased in recent years in the world. The world market was expected to be around $16.1 billion in the year 2011, which is assumed more than 50% growth within 5 years. The electric motors consume more than 50% of whole electrical energy demand in the United States. The annual electrical energy demand in the United States was 3,873 billion kilowatt-hours in 2008, which is expected to be further increased in every year depending on population and economic growth. This data indicates that more than 1,900 billion kilowatt-hours is consumed by electric motors every year in the United States of America, which is the highest energy consumption by any single electric device in the present scenario.

Table 1.1 Number of motors by application (US-2002)

Application	Population
Fans and pumps	3,847,161
Air compressor	632,731
Others	7,954,438
TOTAL	12,434,330

Table 1.1 shows the number of motors in USA in the year 2002. The data is provided by the US department of energy. It is evident from the table how much it is important to protect the motor in power system network.

Table 1.2 Motor system energy usage by application (US-2002)

Application	GWh / Yr
Fans and pumps	221,417
Air compressor	91,050
Others	262,961
TOTAL	575,428

Table 1.1 shows the amount of energy consumed by the motors according to their application in USA in the year 2002. The data is provided by the US department of energy. It is evident from the table how much it is important to protect the motor in power system network.

Table 1.3 Failures of various components in large motors

Failed component	**Induction motors**	**Synchronous motors**	**Wound rotor motor**	**Direct current motors**	**Total (all types) number**	**Total (all types) percentage**	**Protection**
Bearings	152	2	10	2	1	43.7%	38, 39
Windings	75	16	6	-	97	25.56%	26, 46, 49, 50, 50N, 51, 51N, 51R, 59, 87
Rotor	8	1	4	-	13	3.4%	21, 26, 46, 49, 50, 50N, 51, 51N, 51R, 59, 87
Shaft or coupling	19	-	-	-	19	5.0%	37, 39
Brushes or slip ring	-	6	8	2	16	4.2%	40, 53, 55
External devices	10	7	1	-	18	4.7%	27, 32, 40, 47, 53, 55, 60, 63, 64, 78, 81
Not Specified	40	9	-	2	51	13.4%	
Total	304	41	29	6	3	100%	N/A

* Denotes protections applied for various failure detection.

Table 1.3 provides information on failure of various components in large motors and is based on Table 10-19 in IEEE Standard 493-2007. The information is based on data reported for 380 failures on 1141 large motors in industrial and commercial facilities. However, the information is also expected to give a good idea of failures in power plant motors. Generally applied protections for these failures have been added to Table 1.3.

In this work, the main focus is kept on the protection of three phase induction motor from various faults and abnormal conditions. The fault should be cleared as soon as possible and the motor should also be protected from higher temperatures. High temperature may create hot spots in the windings and may decrease the lifetime of the motor. Further, various conventional as well as modern methods are applied to improve the existing protection system for the induction motors.

1.4 TYPES OF PROTECTION IN THREE PHASE INDUCTION MOTOR

There are several different kinds of faults in three phase induction motor. These faults or abnormal conditions are listed as follows:

I. Induction motor stalling.

II. Stator winding protection.

III. Motor Overloading.

IV. Abnormal power supply conditions.

V. Surge protection.

VI. Negative Sequence protection.

VII. Rotor fault Protection.

VIII. Ground Fault Protection.

1.4.1 INDUCTION MOTOR STALLING

An induction motor stalls when the load torque is more than the breakdown torque and causes its speed to decrease to zero, or to some other stable operating point well below rated speed. This occurs when the applied shaft load is more than the motor torque supplied. This is typically due to a reduction of voltage at the motor terminal. A stall condition can also occur when a high mechanical load is applied beyond the capability of motor torque. For an induction motor to stall during normal operation, the load torque needs to be more the breakdown torque as described earlier. During this stalling process, the current of motor will increase rapidly until the breakdown torque is reached. Beyond breakdown torque, the motor current continues to increase nearly locked-rotor current. Along with the increase in current, the speed of the motor reduces and motor impedance approaches the locked-rotor impedance.

There are two types of stall causes:

- Excess shaft load torque prior to a motor start up (e.g., failure to open the pump'sdischarge gate)

- Sudden change of increased shaft load torque during normal operation (e.g., bearing failures)

Overcurrent relay is used to detect stall in an induction motor, with an inverse characteristic set to detect current above the breakdown torque level.

1.4.2 STATOR WINDING PROTECTION

As the insulation of the winding of the machine reduces the life of the motor also decrease.

The physical and dielectric strength of an insulation system deteriorate with age, this process is catalysed by an elevation in temperature. A rule of thumb has been made from tests and experience to indicate that the life of an insulation system is approximately halved for every 10 °C incremental increase of winding temperature, and approximately doubled for every 10 °C decrease. Thus, insulation life is related to the length of time the insulation is maintained at a giventemperature.

1.4.2.1 CLASSIFICATION OF INSULATION SYSTEMS

Insulation systems are divided into four classes according to the thermal endurance of the system for temperature rating purposes. Four classes of insulation systems are used in motors and generators, namely Classes A, B, F, and H. These classes have been established in accordance with the IEEE Standard 1-2000.

1.4.2.2 TEMPERATURE RISE

The observable temperature rise under rated-load conditions of each of the various parts of the induction machine, above the temperature of the cooling air, should not be more the values given in Table 1.4 and Table 1.5. The temperature of the air cooling is the temperature of the external air as it enters the ventilating space of the machine, and the temperature rises given in the tables are for a maximum temperature of 40 °C for this external air.

Temperatures should be determined according to IEEE Standard 112-2004. Allowable winding temperature rise is basically used to determine alarm and trip thresholds for rotor and stator over temperature.

Table 1.4 Machine at rated load with service factor 1.0

Item	Machine part	Method of temperature determinatio	Temperature rise (°C) Class of insulation system			
			A	B	F	H
a	Insulated windings					
	1. All horsepower (kW ratings)	Resistance	60	80	105	125
	2. 1500 hp and less	Embedded detector	70	90	115	140
	3. Over 1500 hp (1120 kW)					
	a) 7000 V and less	Embedded detector	65	85	110	135
	b) Over 7000 V	Embedded detector	60	80	105	125
b	The temperatures attained by cores, squirrel-cage windings, collector rings, and miscellaneous parts (such as brush holders and brushes, etc.) shall not injure the insulation or the machine in any respect.					

Table 1.4 Machine at rated load with service factor 1.15

Item	Machine part	Method of temperature determinatio	Temperature rise (°C) Class of insulation system			
			A	B	F	H
a	Insulated windings					
	1. All horsepower (kW ratings)	Resistance	70	90	115	135
	2. 1500 hp and less	Embedded detector	80	100	125	150
	3. Over 1500 hp (1120 kW)					
	a) 7000 V and less	Embedded detector	75	95	120	145
	b) Over 7000 V	Embedded detector	70	90	115	135
b	The temperatures attained by cores, squirrel-cage windings, collector rings, and miscellaneous parts (such as brush holders and brushes, etc.) shall not injure the insulation or the machine in any respect.					

1.4.3 MOTOR OVERLOADING

Overloads can increase the temperature of the machine which will cause hot spots in the winding and further it will reduce the lifetime of the motor. In case of over temperature time factor should also be taken into consideration. The heat storage capacity of an induction motor is relatively large. Small overloading for short periods of time does not result in damaging winding insulation, because the extra heat is stored in the mass of the conductor, core, and structural members of the motor. In contrast, for locked-rotor conditions, the rate of rise of temperature is very rapid due to the large currents flowing in the windings of the motor.

1.4.4 ABNORMAL POWER SUPPLY CONDITIONS

Motors are generally expected to operate normally under running conditions at rated load with a variation of ±10% in rated voltage, ±5% variation in rated frequency, for a combination of these two, provided the summation of the absolute values of the deviations should not be more than 10% and the frequency variation does not exceed ±5%.

Variation in voltage or frequency, or both, usually increase the temperature of the stator winding which will reduce the lifetime of the motor.

EFFECT ON MOTOR PERFORMANCE DUE TO VARIATIONS IN MOTOR POWER SUPPLY

In general, the following changes in motor performance will occur due to variations in the motor power supply:

- Torque will change approximately as the square of the applied voltage.
- Speed will change directly with frequency and increase slightly with a voltage increase.
- Operating temperature rise will change as the square of the motor current.
- Efficiency is directly proportional to motor losses; any increase in motor current will decrease efficiency.
- Power factor is directly related to motor magnetization (no-load) current; an increase in magnetization current results in a decrease in motor power factor.
- Most motors can be considered constant kVA devices i.e., as voltage

decreases, current increases proportionately.

Although each of these performance characteristics may affect the process of which the motor is used, only operating temperature is of primary concern with respect to protection of motor. Operating temperature will determine the life of the motor insulation. Each occurrence of increased temperature beyond rated temperature will effectively reduce the lifetime of the motor. Therefore, it is desirable to detect these conditions as soon as possible to save the motor life.

CATEGORIES OF CURRENT THAT AFFECT OPERATING TEMPERATURE OF MOTOR

Seven categories of current directly affect motor operating temperatures:

- Starting (locked rotor) current
- Magnetization (no load) current
- Load current
- Conductor eddy currents
- Stray loss currents
- Negative-sequence currents or current unbalance flowing in rotor bars, rotor wedges, or damper windings
- Nonlinear loads

The magnitude of each of these currents will be affected by abnormal voltages and/or abnormal frequency.

1.4.4.1 ABNORMAL VOLTAGE

Operating voltages that deviate from rated voltages more than the tolerance given in NEMA MG-1-2009 may subject the motors to hazards for which special forms of protection may be required [2]. In the present context, abnormal voltage are of following types:

- Undervoltage
- Overvoltage
- Unbalanced voltage and phase failure

UNDERVOLTAGE PROTECTION

Undervoltage conditions may last for only a few cycles or may continue in steady-state. The effect the undervoltage condition will vary depending on the type of motor, the driven load, and whether the motor is running or being started. The overcurrent protection may provide satisfactory motor protection for excessive steady-state undervoltages. That being the case, when a long-term undervoltage condition occurs, the overcurrent devices operate to protect the motor. So overcurrent protection will also provide protection against undervoltage.

OVERVOLTAGE PROTECTION

Overvoltage causes an increase in no load or magnetization current due to an increase in iron losses of the machine. For a given shaft load, the overvoltage also causes a drop in load current. Since the no load or magnetisation current is a lesser percentage (typically 20% to 30%) of the total current in large motors, the resulting total current will be less than the motor current at rated voltage. Therefore, higher stator winding temperatures at higher operating voltages are improbable. This is not the case for smaller rating motors, because the magnetization current is a much higher percentage of the total motor current. However, if motor load current were to remain constant, and the motor magnetization current increased due to the overvoltage, then there will be increase in motor operating temperatures. Therefore, overcurrent devices with their individual current pick-up level permit a higher winding temperature to occur on overvoltage than at rated voltage. Only a device that senses winding temperature of the motor can adequately protect against such an abnormal overvoltage operating condition.

UNBALANCE PROTECTION AND PHASE FAILURE

Unbalanced voltage and phase failures are similar phenomena, only difference is the degree of unbalance. While unbalanced phase voltages or currents are identified, it is the negative-sequence component that actually harm the motor. Hence, simple unbalance measurements may not provide the degree of motor protection required.

When the voltages provided to an operating motor become unbalanced, the positive-sequence current remains essentially unchanged, and a negative-sequence current flows because to the unbalance. If, for example, the cause of the unbalance is an open circuit in any phase, a negative-sequence current flows that is equal and opposite to the previous load current in that phase. The combination of positive- and negative- sequence currents produces phase currents of approximately 1.7 times the previous load in each sound phase and zero current in the open phase. This is illustrated in Figure 1.1, and Figure 1.2. Due to additional motor losses, the actual magnitude of the motor phase current in each phase is closer to twice the previous load current when the motor was under normal condition.

Three-phase voltages will still be noticed at the motor terminals with one supply phase open. The actual values depend on the shaft load of the motor and on whether any other loads or capacitors are connected in parallel.

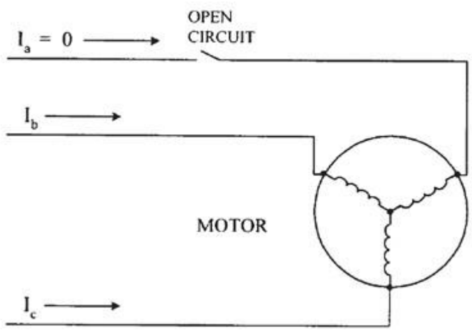


Figure 1.1 Current in motor windings with one phase open circuited

A small-voltage unbalance produces a large negative-sequence current flow in either a synchronous or induction motor. The per unit negative-sequence impedance of either type of motor is approximately equal to the reciprocal of the rated voltage per unit locked-rotor current. When, for example, a motor has a locked-rotor current of six times rated, it has a negative-sequence impedance of approximately 0.167 per unit on the motor-rated input kilovolt ampere base [1]. When voltages having 0.05 per unit negative-sequence components are applied to the motor, negative-sequence currents of 0.30 per unit flow in the windings. Thus, a 5% voltage unbalance produces a stator negative-sequence current of 30% of full-load current [1]. The severity of this condition is indicated by the fact that with this extra current, the motor may experience a 40% to 50% increase in temperature rise [1].

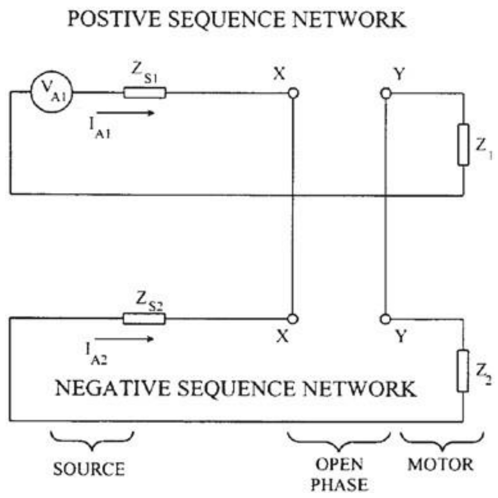


Figure 1.2 Connection of sequence networks for open-phase condition

The increase in loss is largely in the rotor. Negative-sequence phase currents produce a flux that rotates in a direction opposite to the rotor rotation. This flux cuts the rotor bars at a very high speed and generates a pronounced voltage, resulting in a large rotor current. In addition, the 100-Hz nature of the induced current produces a marked skin effect in the rotor bars, greatly increasing rotor resistance. Rotor heating is considerable for minor voltage unbalance. Immoderate heating may occur with phase current less than the rated current of the motor.

1.4.4.2 ABNORMAL FREQUENCY

Motor speed varies directly with the supply frequency. Motors are generally designed for constant volts per hertz operation. Frequency in excess of the rated frequency but not in excess of 5% over the rated frequency without a corresponding voltage rise is not considered a hazardous condition for synchronous or induction motors, on the condition that the driven equipment does not overload the motors at the higherfrequency.

At decreased frequency without a corresponding voltage reduction, the flux density is increased within the motor core, thus increasing the hysteresis and eddy-current losses and heating. Sustained operation at reduced frequency and rated or overvoltage is not permitted if the effect of the voltage and frequency is more than the standard tolerances. Protection against this type of operation is usually allocated to the thermal protective equipment; however, more refined protection is possible using a frequency-sensitive relay or a volts per Hertz relay, which measures the actual abnormality.

1.4.5 SURGE PROTECTION

Rotating machines may require surge protection. The coil insulation of the stator winding of ac rotating machines has a relatively low impulse strength. The insulation consists of groundwall insulation and turn insulation. The groundwall insulation surrounds all the turns of a coil, insulating the coil and the stator iron. Turn insulation is around each turn so as to provide insulation between the several turns in a coil. Stator winding insulation systems of ac machines are exposed to stresses due to the steady-state operating voltages and to steep-fronted voltage surges of high amplitudes.

The steep-fronted voltages are caused by lightning strikes, normal circuit breaker operation, switching of power factor correction capacitors, starting, aborted starts, bus transfers, and switching speed (or speeds) in two-speed motors. Turn insulation testing itself also imposes a high stress on the insulation system. Both types of voltages stress the ground insulation. The steep-fronted surges also stress the turn insulation. If the rise time of the surge is steep enough (0.1 ms to 0.2 ms), most of the surge can appear across the first coil, the line-end coil, and its distribution in the coil can be non-linear. This can damage the turn insulation even though the magnitude of the surge is limited to a value that can be safely withstood by the ground wall insulation. Wave fronts of duration longer than 5 μs generally produce uniform turn-to-turn stresses on multi-turn machine insulation systems and are less severe than steep wave fronts. However, the crest magnitude of voltage, whether fast or slow front, must be controlled to below the machine ground wall insulation withstand strength

The test voltage for steady-state voltage withstand is one minute of fundamental frequency at twice rated (line-to-line) voltage plus 1000 V. The surge voltage test consists of two tests, one to test the ground insulation and the other to test the turn insulation.

1.4.6 PHASE OVERCURRENT PROTECTION

When the motor kilovolt ampere (kVA) rating is less than half that of the transformer, instantaneous relays can be used for phase protection. Where the starting current value approaches the fault current (motor kVA greater than half of the transformer rating), differential relays should be used.

Two over current relays, with different time-current characteristics, have occasionally been applied to obtain a better match to the motor thermal limits during start-up and locked rotor. The two relays are applied when the characteristic of a single relay cannot provide overall protection for the motor thermal damage curves for both starting and running conditions. As shown in Figure 1.4, the pickup of the (51-1) relay is set to provide overload protection for the majority of the motor's running thermal damage curve. The purpose of the (51-2) relay is to provide specific protection near the motor's allowable locked-rotor thermal limits and, therefore, has a much higher pickup and a more inverse characteristic.

For types of motors where starting currents are quite low, the use of extremely inverse or inverse over current relays gives substantially improved protection for short circuits in the ranges immediately above the starting current.

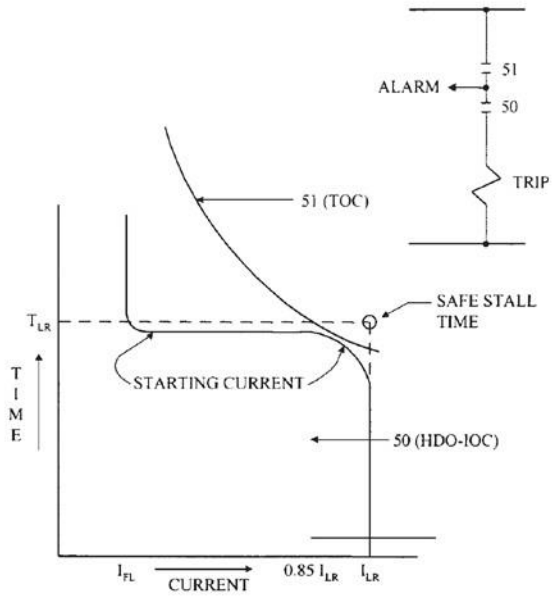


Figure 1.3 —Locked-rotor protection with over current element supervised by a high-dropout inverse over current element

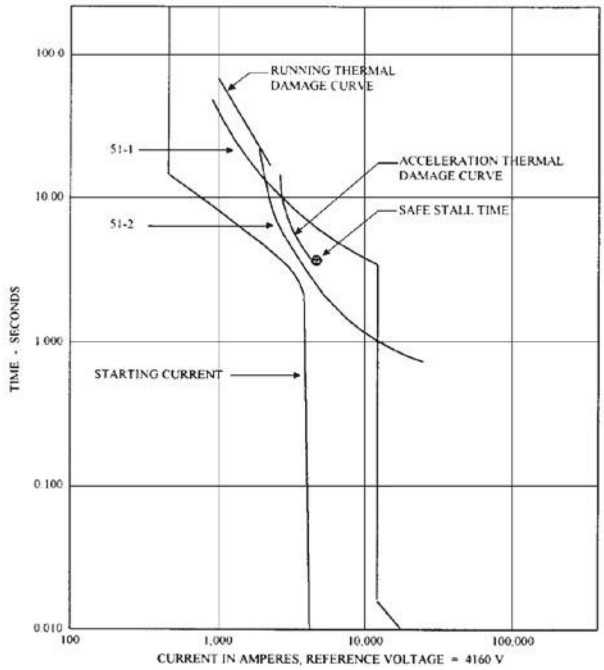


Figure 1.4 —Thermal damage protection utilizing two overcurrent relays with different pickups and timing characteristics

1.4.7 NEGATIVE SEQUENCE PROTECTION

Negative-sequence current is contributed by the motor or system when

- An unbalanced voltage condition exists (e.g., open-phase conditions, single-phase faults, or unbalanced load)
- Stator coil cut-out occurs during a repair
- There are shorted turns in the stator winding

These negative-sequence currents induce double line-frequency currents that flow in the damper or rotor parts. The magnitude of the double line-frequency current depends on the location of the fault, number of turns shorted, mutual induction, and system and motor impedance. The danger to the rotor parts is a function of the unbalance in the stator current.

1.4.8 ROTOR FAULT PROTECTION

Because of the construction of squirrel-cage induction motors, protection of the rotor circuit is not considered necessary. Wound-rotor motors may be protected for slip-ring and rotor flashover to ground by the circuit in Figure 1.5. For wound-rotor motors, relays with constant V/Hz characteristics should be used because of the changing slip frequency experienced by the rotor. This protection is not effective at or near synchronous speed, because the rotor-induced potential is greatly reduced. Many wound-rotor installations depend on the stator inverse over current device to provide rotor flashover protection.

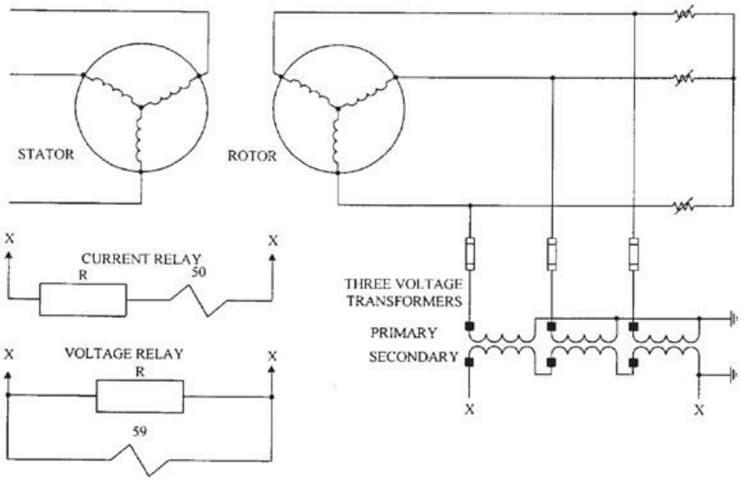


Figure 1.5 —Wound-rotor motor rotor ground protection

1.4.8 GROUND FAULT PROTECTION

On solidly grounded systems, phase overcurrent relays, direct-acting trip devices, and fuses afford a certain measure of ground-fault protection. For motors where greater sensitivity to ground faults is required, ground relays should be used. Ground relays can be connected residually or to a ground sensor by using a toroidal current transformer that encircles all three-phase conductors.

1.4.8.1 RESIDUALLY CONNECTED GROUND RELAY

Figure 1.6(b) shows a residually connected ground over current relay (51N). Theoretically the 51N relay operates only on the zero-sequence current due to ground faults. In practice, however, current may flow through this residual circuit because of the unequal outputs of the phase-current transformers. This may be due to unequal burdens on the current transformers, the difference in the current transformer characteristics caused by variations in manufacturing, or current transformer saturation caused by high motor-starting currents. Because these unbalanced currents are present, it often becomes necessary to use time-delay residual relays so that undesired tripping on starting does not occur with sensitive current settings on the relay. If instantaneous residually connected relays (50N) are used, they may trip due to the false residual that may occur during motor starting, or from feedback for an external fault unless they are set fairly high. Where a large ground-fault current exists, this presents no problem; however, where high-impedance grounding is used, these relays may be of little value. False residual current can be decreased markedly by increasing residual burden using a lower tap value, or by adding a series resistance. However, the former also increases sensitivity to ground-fault currents.

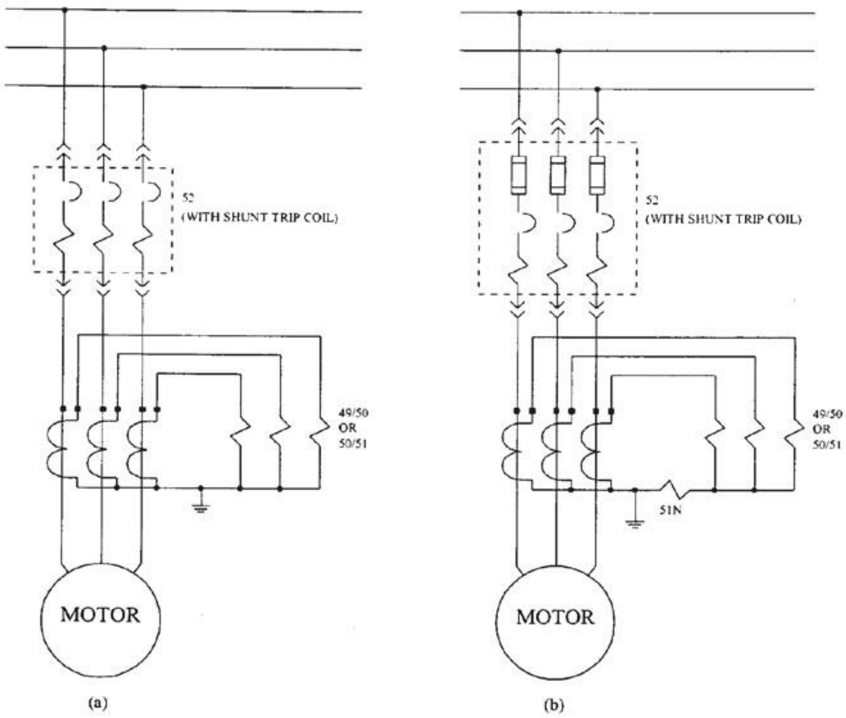


Figure 1.6 —Low-voltage power circuit breaker with protective relays

The combination of three (3) phase relays and one residually connected ground relay connected to three CTs is often used to provide phase- and ground-fault protection as shown in Figure 1.6(b).

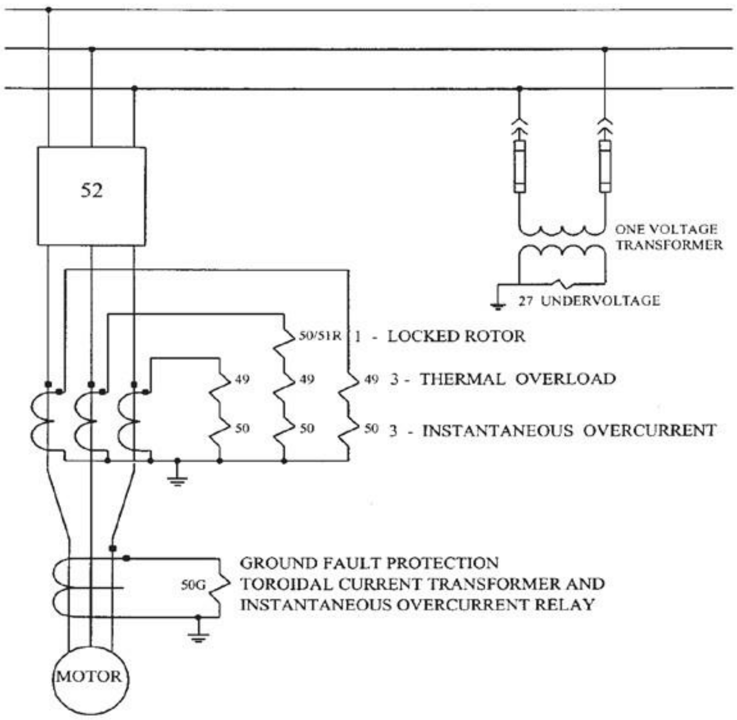


Figure 1.7 —Power circuit breaker motor controller—typical protection

Figure 1.7 illustrates a method of obtaining sensitive ground-fault protection with an inverse over current relay (50G). The toroidal current transformer encircles the three-phase conductors, summing the flux produced by the current passing through the conductors within the current transformer. This arrangement allows all positive- and negative-sequence currents, including their dc components, to be magnetically cancelled out within the current transformer, so that only the zero-sequence ground-fault current appears in the relay. This means that under all balanced conditions, including single-phase loading, all currents leave and return through the toroidal current transformer. The net flux within the current transformer will be zero. It is only when the current returns by a path outside of the current transformer that a flux imbalance will occur within the current transformer, resulting in a proportional current flow to the ground relay.

When using a grounded conductor, the toroidal CT should encompass only the phase conductors and not the grounded conductor. Figure 1.8 shows two methods of grounding the cable sheath when using a toroidal CT. Note that the cable shield ground is established on the load side of the CT in Figure 1.8(a) and, therefore, does not contribute to the flux within the CT.

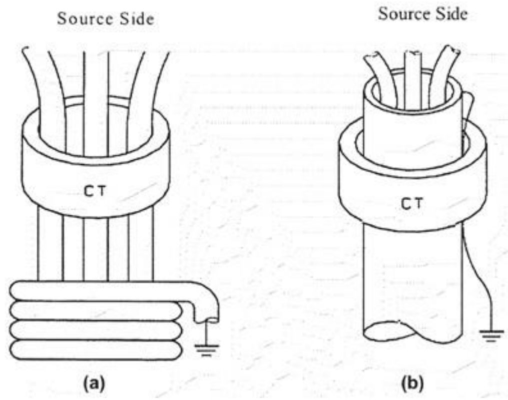


Figure 1.8 —Toroidal current transformer cable sheath grounding

In Figure 1.8(b), the shield lead is doubled back from the source side to the load side of the CT, resulting in magnetic flux due to current in the shield summing to zero within the CT. If the cables in Figure 1.8(b) have individual shielding tape or braiding, they can be jumpered together on the source side with a shield lead brought back through the CT.

1.5 DISSECTION OF THESIS

Chapter 1 presents the basic introduction of three phase induction motor and its application in various fields and the energy consumption by the motor system in various application according to the US department of energy. The chapter includes the various factors due to which the motors in the industry fails and a brief introduction to the importance of the three phase induction motor protection system.

Chapter 2 contains the literature review of the various protection system used in the power system with special emphasis on three phase induction motor protection system. The literature review also have various conventional as well as modern protection techniques and algorithms to detect various types of faults and to clear these faults in short time.

Chapter 3 explains the design and simulation of microcontroller based relays to protect three phase induction motor from under voltage and over temperature. This chapter shows the result obtained from the simulation of microcontroller based relay before and after the fault condition.

Chapter 4 explains the MATLAB model for protection of induction motor using a overcurrent relay. The relay is realised by digital components for protecting a motor of

4kW, 400V, 1430 RPM induction motor.

Chapter 5 explains the MATLAB Simulink model for digital negative sequence relay for the protection of three phase induction motor against unbalance, line to ground, line to line and three phase fault.
Chapter 6 gives the conclusion and future scope of work.

1.6 CONCLUSION

In this chapter, a brief introduction basic introduction of three phase induction motor and its application in various fields and the energy consumption by the motor system in various application according to the US department of energy in the year 2002 . The chapter includes the various factors due to which the motors in the industry fails and a brief introduction to the importance of the three phase induction motor protection system. Further, the overview of each chapter is given.

CHAPTER 2
LITERATURE REVIEW

INTRODUTION

Three phase induction motor is widely used in the industries because of its robust construction and various performance advantages. Induction motors are the electromechanical devices used in the most industries for the conversion of electrical energy to mechanical energy. Induction Motors are utilized worldwide as the workhorse as a part of mechanical provisions. Such motors are robust machines utilized for general purposes, as well as in risky areas and serious situations. Broadly useful provisions of induction motors incorporate pumps, transports, machine instruments, diffusive machines, presses, lifts, and bundling supplies. Then again, requisitions in unsafe areas incorporate petrochemical and common gas plants, while serious environment provisions for induction motors incorporate grain lifts, shredders, and gear for coal plants.

Induction motors are vulnerable to numerous sorts of issue in industrial requisitions. A motor failure that is not distinguished in an introductory stage may get cataclysmic and the induction motor may endure serious harm. Accordingly, undetected motor faults may course into motor failure, which may cause production shutdowns. Such shutdowns are excessive as far as lost processing time, support takes, and squandered crude materials.

2.2 INDUCTION MOTOR PROTECTION SYSTEM

IEEE guide for AC motor protection [1] is concerned primarily with the relay protection of three phase induction motor and synchronous motor. This guide also summarizes the uses of relays and devices, individually and in combination, so the user may select the necessary equipment, to obtain adequate motor protection. It contains terminology definitions, information on insulation class of motors and various techniques to detect and clear various faults.

NEMA motor-generator standards for three phase induction motors [2] contains information that is often referred to in the application of induction motor protection. It contains various standards of name plate ratings, frame dimensions, voltage ratings, routine tests, shaft vibration limits, starting conditions and various starters used to start three phase induction motors and their performance followed by the electrical manufacturers.

Muhammad Mohsin Aman [3] presents the modelling and simulation of digital negative sequence relay. The paper describes the various data conversion steps included in the designing of digital negative sequence relay. The detection of negative sequence current and appropriate action is needed for the protection of power system. The operation of relay should be reliable and fast for minimum outage of power system in case of electrical fault or abnormal condition. Symmetrical component method is used for the calculation of negative sequence current and positive sequence current and their ratio is examined in this paper and trip signal is given if the ratio is greater than a specific value. The output of the negative sequence element is given to the over current element, which trips the circuit in case of fault or any abnormal condition.

M Sudha [4] presents designing and implementation of protection system for faults due to single phasing, voltage unbalance and undervoltage in a three phase induction motor. The system uses microchip PIC16F877 microcontroller to continuously compare the measured value with the reference value. Whenever there is any single phasing, voltage unbalance and undervoltage is sensed a trip signal is issued by the system and the respective fault is displayed in the 7 segment display.

The conventional electromechanical and static protective devices used for the protection of three phase Induction motors in Industrial applications normally employ separate and Independent overload, short circuit, earth fault and single phasing protective devices in the circuit breaker to take care of motor protection [5]. The proposed all-In-one protection scheme Integrates these Into a single static protective device and operates by sensing the positive, negative and zero sequence components of motor currents derived through three current transformers and a solid-state sequence components After which provides fast and real-time separation of these components of motor currents.

A comprehensive list of non-directional overcurrent relays would include thermal overload. Inverse-time, definite time, and instantaneous relays. The list could be further classified by operating quantities including individual phase, residual, and negative-sequence current. Taken collectively and depending on the characteristic shape, pickup and time range, and dynamics, these relays span the applications for motor, feeder, and breaker failure protection [6].

Yin Lee Goh [7] discussed the modelling of overcurrent relay for inverse definite minimum time (IDMT) type using DSP board TMS320F2812. The results obtained from

MATLAB/Simulink simulation and execution from TMS320F2812 will be presented. From these results, it proves the capability of TMS320F2812 processor act as a modelling and computational hardware for the IDMT overcurrent relay.

H. H. Zeineldin [8] dual setting directional over-current relays are proposed for protecting meshed distribution systems with DG. The proposed protection coordination scheme with dual setting relay can significantly reduce the overall relay operating time, making it an attractive option for distribution systems with DG.

Computer models of relays play an important role in evaluating the performance of protection systems during system faults and other disturbances. The use of relay models would enable us to investigate the relays with closed-loop simulations and approximate actual relay's characteristics so that their performance can be evaluated for a variety of operation conditions. The model is employed for testing the performance of the relay with a variety of simulation tests [9].

Large numbers of microprocessor based devices are being applied to distribution systems. They include: computer controlled tap changers, digital voltage line regulators and of course a large selection of microprocessor based protection relays. This new generation of equipment thrown together with older equipment such as mechanical reclosers, a variety of fuses and electromechanical protection relays, at times creates co-ordination situations that are difficult to say the least [10].

Numerical relays are the result of the application of microprocessor technology in relay industry. Numerical relays have the ability to communicate with its peers, are economical and are easy to operate, adjust and repair. Modelling of numerical relay is important to adjust and settle protection equipment in electrical facilities and to train protection personnel [11].

Christos A. Apostolopoulos [12] presented an integrated environment for real-time simulation, analysis and validation of digital relay models, based on MATLAB/SIMULINK and RTDS, is presented. A detailed analysis and discussion for this environment is given an example cases are used to illustrate its implementation. Software models for protective relays offer an economic and feasible alternative to studying the performance of protective relays. Relay models have been long used in a variety of tasks, such as designing new relaying algorithms, optimizing relay settings and training personnel.

There appears to be different philosophies involved in the application of protection for industrial and utility motors. Where the industrial users prefer magnetic and thermal devices for both short-circuit and overload protection, the utility users tend to relays [14].

The use of a speed proportional control current in the secondary saturable reactors of a wound-rotor motor gives nearly constant torque and current values at all motor speeds from standstill to above half speed, with nearly normal breakdown torque and full-load slip values, without any secondary contactors or control devices [15].

When a fault occurs on the auxiliary generator, or the auxiliary transformer, or their leads, the operation of the differential relays or other protective relays on this equipment is an indication that the source is lost [16].

Replacement of existing electromagnetic relays with solid-state relays can be one important option for the existing installations, where the short-circuit currents have increased or low ratio CT's of poor accuracy classification are in use. A solid-state relay will significantly reduce the CT burden [20].R. E. Bedford [21] presented the complete solution of the voltage equation for constant speed of the motor. T. Bach [23] presented the paper which introduces a new approach for calculating the flow of negative sequence currents.

Ramchanndra Hasabe [24] presented paper based on novel wide area backup protection system using Phasor measurement units (PMU) as an alternate to the conventional distributed backup protection in substation. Synchronized Measurement technology is a key element and empower the wide area protection, control and monitoring system. Working of Phasor measurement unit is based on GPS system and it gives accurate verdicts. In this system, overall communication is done through optical fiber. And it is expected that wide area protection, control and monitoring (WAPCAM) system reduce the number of disastrous blackouts and improve the reliability and security of the power system. The new backup protection system is based on phasor measurement unit obtained from studies on five bus test system using Matlab Simulink.

Negative-sequence overcurrent elements do not respond to balanced load and can thus be set to operate faster and more sensitively than phase overcurrent elements for phase to phase faults. A.F. Elneweihi [26] demonstrated that on a radial distribution system, negative sequence overcurrent elements need only be coordinated with downstream phase overcurrent devices for phase-to-phase faults. Coordination for other fault types is then achieved with no further analysis required. The effects of negative-sequence load current and open phase conductors on negative-sequence overcurrent elements are also discussed.

2.3 CONCLUSION

This chapter presents the literature review of the different type of protection system of Three Phase Induction motor, fault detection algorithm and various relays used to protect the induction motor. Latest advancements and research in the field of three phase induction motor protection system are enlightened. It helps in enhancing the knowledge of the system and provides guidance in the thesis work.

CHAPTER 3
MICROCONTROLLER BASED RELAY:

INTRODUCTION

For modelling a microcontroller based relay, we can use both hardware and software simulation. Keil µvision software is used to link and program the microcontroller and Proteus 8 Professional is used to simulate components like microcontroller, ADC, relay and all other electrical equipment. The code is written in Keil µvision software and its hex file is attached to the microcontroller in the Proteus 8 Professional.

3.2 8051 FAMILY

Intel introduced 8051, referred as MCS- 51, in 1981. The 8051 is an 8-bit processor. The CPU can work on only 8 bits of data at a time.

The 8051 has:

i. 128 bytes of RAM,
ii. 4K bytes of on-chip ROM,
iii. Two timers,
iv. One serial port,
v. Four I/O ports, each 8 bits wide,
vi. 6 interrupt sources.

The 8051 became widely popular after allowing other manufactures to make and market any flavour of the 8051, but remaining code-compatible.

The 8051 family has the largest number of diversified (multiple source) suppliers

i. Intel.
ii. Atmel.
iii. Philips/Signetics.
iv. AMD.
v. Infineon (formerly Siemens).
vi. Dallas Semiconductor/Maxim.

3.2.1 INTERFACING OF ADC804

ADCs (analog-to-digital converters) are among the most widely used devices for data acquisition. We need an analog-to-digital converter to translate the analog signals to digital numbers, so microcontroller can read them ADC804 IC is an analog-to-digital converter. It works with +5 volts and has a resolution of 8 bits. Conversion time is another major factor in judging an ADC. Conversion time is defined as the time it takes the ADC to convert the analog input to a digital (binary) number. In ADC804 conversion time varies depending on the clocking signals applied to CLK R and CLK IN pins, but it cannot be faster than 110 µs.

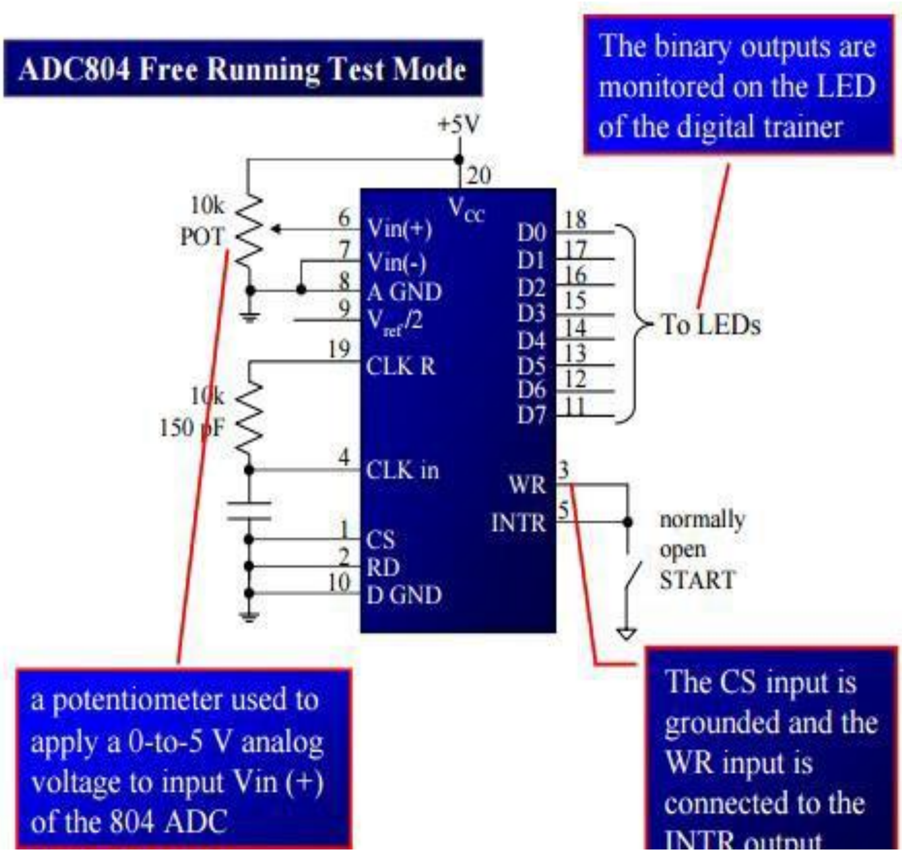


Figure 3.1 Pin diagram of ADC804

3.2.2 DATA CONVERSION IN ADC804

The following steps must be followed for data conversion by the ADC804 chip:

i. Make CS = 0 and send a low-to-high pulse to pin WR to start conversion
ii. Keep monitoring the INTR pin
iii. If INTR is low, the conversion is finished
iv. If the INTR is high, keep polling until it goes low
v. After the INTR has become low, we make CS = 0 and send a high-to-low pulse to the RD pin to get the data out of the ADC804.

3.2.3 8051 C CODE

The following code is written in Keil µ vision software to continuously read the output of the analog to digital converter and if the value is above the threshold it will issue trip the signal. The following converted and saved in the HEX file by the compiler. This hex file is fed into the microcontroller in the Proteus professional software to simulate the microcontroller based relay.

```
#include <REGX51.H>

#define adc_port P2          //ADC Port

#define rd P1_0              //Read signal P1.0

#define wr P1_1              //Write signal P1.1

#define cs P1_2              //Chip Select P1.2

#define intr P1_3            //INTR signal
P1.3 sbit relay1=P1^7;
void conv();                 //Start of conversion function

void read();                 //Read ADC
function unsigned char adc_val;

void main() {

while (1)
```

```
{                                   //Forever loop

conv();                             //Start conversion

read();                             //Read ADC
P3 = adc_val;                       //Send the read value to P3

}

}

void conv()

{

cs = 0;                   //Make CS low

wr = 0;                   //Make WR low

wr = 1;                   //Make WR high

cs = 1;                   //Make CS high

while (intr==1);          //Wait for INTR to go low

}

void read ()

{

cs = 0;                    //Make CS low

rd = 0;                   //Make  RD  low

adc_val = adc_port; //Read ADC port

rd =1;                    //Make RD high
cs = 1;                   //Make CS high

}
```

3.3 Proteus Simulation

The following model is simulated in Proteus professional software. This software consist of various toolbox with electrical and electronics components. This software is used to simulate as well as for printing the PCB. A microcontroller from 8051 family is selected and HEX file from the KEIL µ vision is fed into the microcontroller. The microcontroller will continuously read the output of the ADC804 and if the value is greater than the threshold value defined in the microcontroller program section, the relay will generate a trip signal to the transistor array which will open the circuit and provide protection to the device. The microcontroller section is powered by a DC power source. Figure 3.2 shows the working of the equipment under normal condition. This concept can be used for the protection of induction motor. This microcontroller based relay can be used as under voltage and thermal protection relay. For using this concept as thermal relay the output of the transducer is fed into the ADC804. For using the same concept as under voltage relay the output of the potential transformer is given to the rectifier and the filtered DC signal is given to the ADC804.

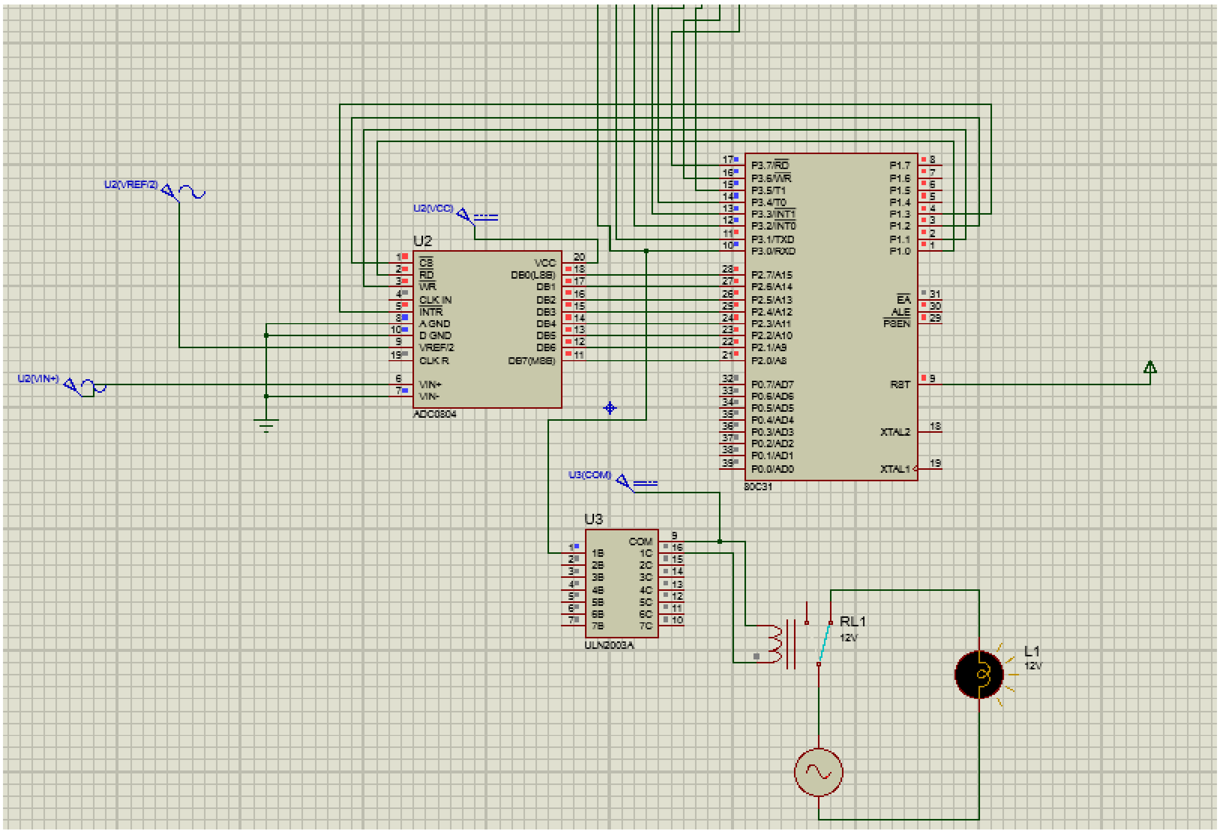


Figure 3.2 Proteus model (under normal condition)

In case the value of the input to the ADC804 changes, the microcontroller will sense the change and it will trip the device to save it from any abnormal condition. The threshold value can be changed easily by just changing the value in the microcontroller program. If heating occurs in the device, the voltage across the RTD will increase and the microcontroller will read the value and if the value is more than the threshold value it will give the trip signal to the transistor array and the device will switch off.

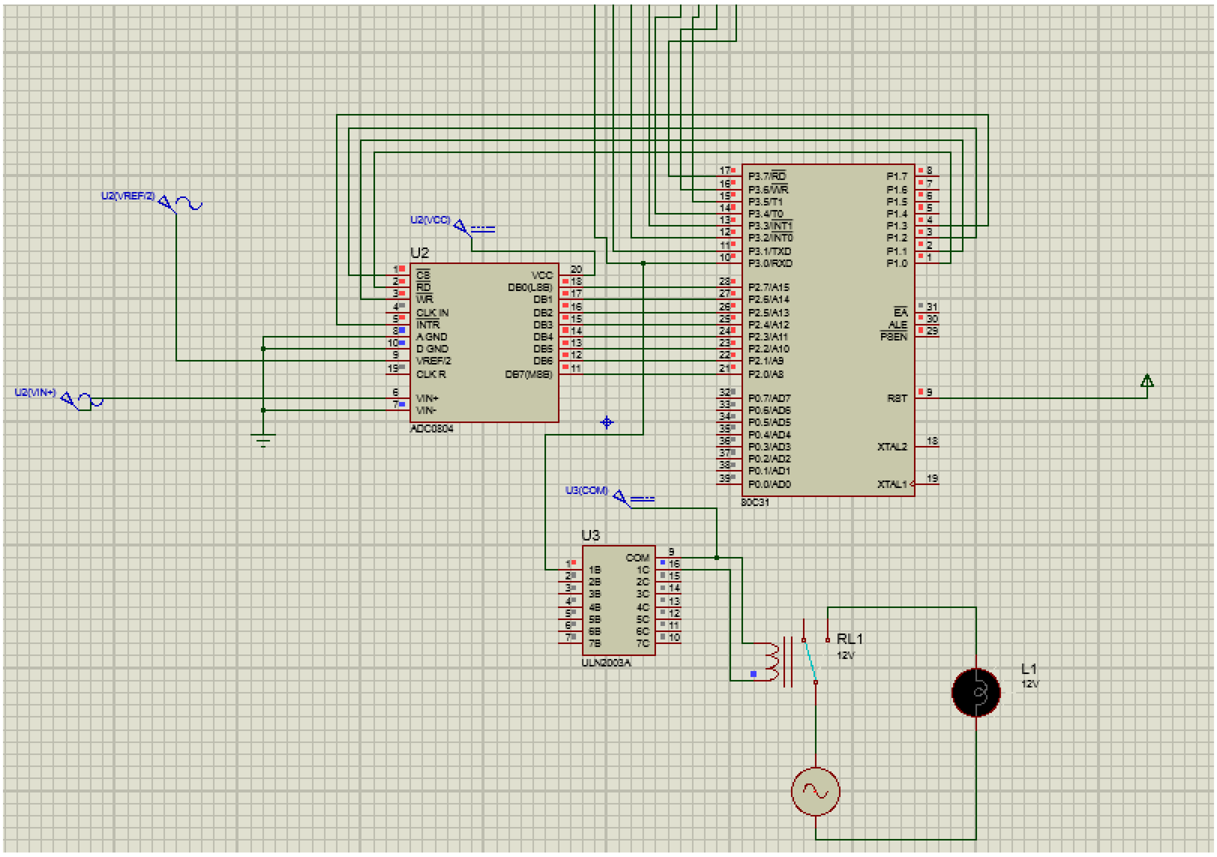


Figure 3.2 Proteus model (after fault condition)

Figure 3.2 shows that if the device is overheated or if the voltage is under the specified threshold the relay will issue a trip signal and device is turned off and no current will flow to the device and it can be saved from overheating. This overheating can cause hot spots in the winding of three phase induction motor which will reduce the lifetime of the motor. So we have to prevent the motor from overheating. For this purpose microcontroller based relay are very fast and accurate. The RTD will provide a voltage according to the temperature of the RTD which are embedded in the stator winding of the motor while construction. This voltage is converted into digital form by using ADC804 and is microcontroller will continuously read the digital signal from the microcontroller and will issue a trip signal in case the value input signal is greater than the specified threshold in the program. The advantage of microcontroller based relay is that this specified threshold can be easily changed by modifying the code.

3.4 CONCLUSION

In this chapter, microcontroller based relay is studied for thermal relaying purpose and under voltage purpose. The relay is designed and simulated in this chapter and its testing is done for both normal operation condition as well as faulty condition. The relay will trip for the faulty or abnormal conditions. These studies will help designer to practically make a microcontroller based relay in hardware. By using microcontroller based relay we can protect the induction motor from overheating and under voltage condition. These relay are accurate, fast and reliable as compared to the conventional relays.

CHAPTER 4

MATLAB SIMULATION OF OVER CURRENT RELAY

INTRODUCTION

In this chapter MATLAB model of over current relay is explained. The over current relay is designed for a motor rating of 5.4HP (4KW) 400V 50Hz 1430RPM. In case there is any fault in the induction motor and if the fault current is more than the relay setting, then the relay will generate a trip signal and the three phase breaker will cut off the supply to the three phase induction motor. This over current relay will save the motor from various abnormal or faulty conditions like line to ground (LG) fault, line to line (LL) fault, three phase fault. In the above mentioned faults the current in the phase will increase and ion that case the fault will be detected by the over current relay and will trip the motor.

4.2 Implementation of over current relay using Simulink

Simulink is a tool which provide engineers a facility to first model and simulate their work and find the out the results before doing it physically. One can find feasibility of ones work on the MATLAB. In MATLAB model the current data are given to the digital relay which will compare the data to the reference value and if the current exceeds the reference value it will generate the trip signal. The three phase circuit breaker is controlled by external control. If the external trip signal is there the three phase breaker will cut off the motor from the mains supply and save it from any dangerous consequences. In figure 4.1, the MATLAB Simulink model of digital over current relay is shown to protect the three phase induction motor of 4KW ,400V rating. The three phase fault is simulated by three phase fault block which is predefined in the Simulink library and it can be used to simulate line to ground and line to line fault as well. Three phase breaker is used with external control is used to isolate the motor in case any fault is detected by the relay. From the bus B1, the data of current are taken and fed to the relay. The relay will convert the current value into root mean square value and the root mean square value is compared to the reference value by using the relational operator. After the relational operator the signal is fed to the S-R flip flop. If the current increase in any phase the relay will generate a trip signal to the three phase circuit breaker. In normal running condition the output of the flip flop is 1, and if there is any fault the output will become 0 and the conditional operator AND is used to generate trip signal to the circuit breaker. The relay will operate if there is any increase in current and breaker will open its contacts and isolate the three induction motor from the healthy part of the power system.

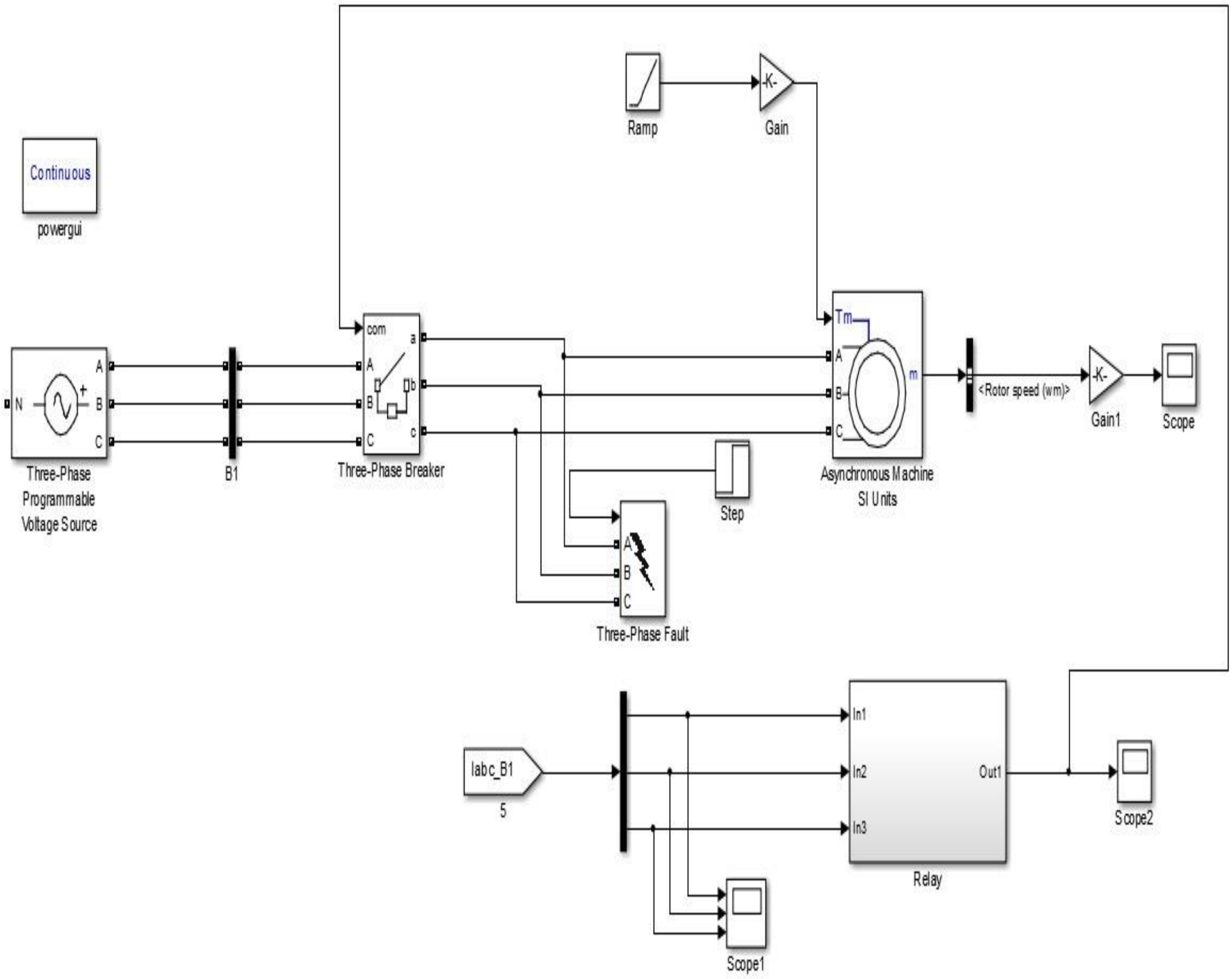


Figure 4.1 Over current protection of induction motor

4.3 OVER CURRENT RELAY

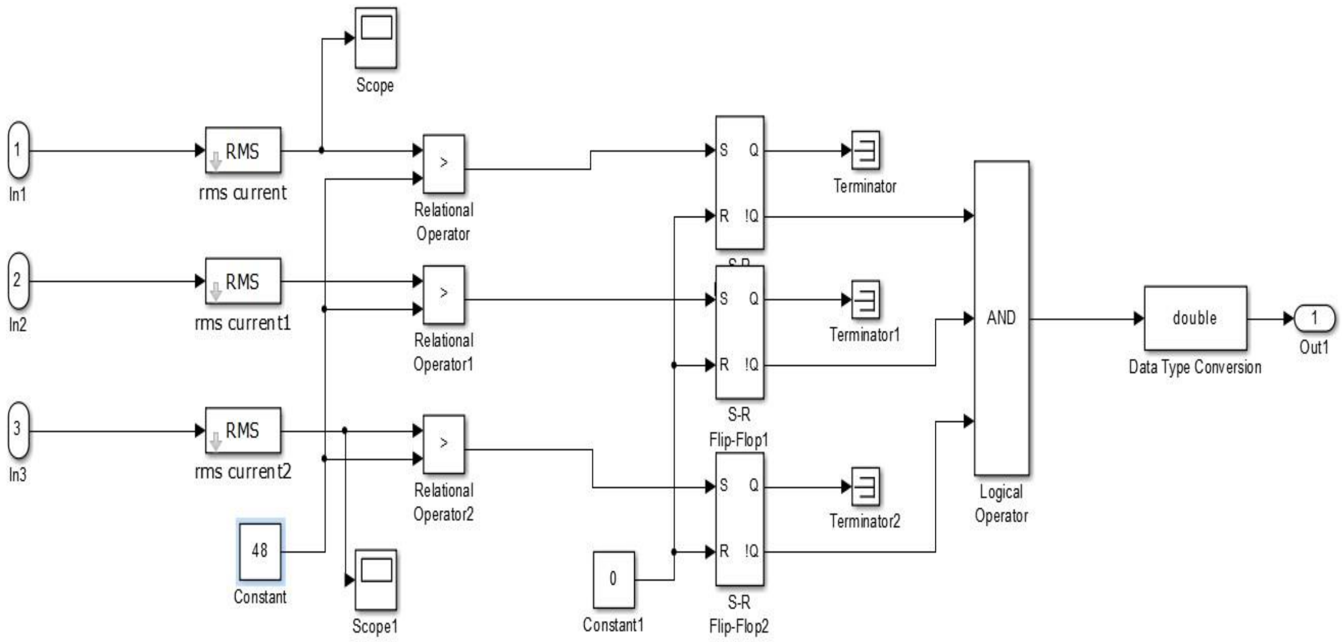


Figure 4.2 Over current Relay

In order to study the over current relay it is digitally simulated in the Simulink. Figure 4.1 shows digital over current relay. It uses digital components like relational operator, S-R flip flop, and conditional operator. From the bus B1, the data of current are taken and fed to the relay. The relay will convert the current value into root mean square value and the root mean square value is compared to the reference value by using the relational operator. The reference value can be changed according to the load. If the load increase the reference value can be increased according to the load. After the relational operator the signal is fed to the S-R flip flop. If the current increase in any phase the relay will generate a trip signal to the three phase circuit breaker. In normal running condition the output of the flip flop is 1, and if there is any fault the output will become 0 and the conditional operator AND is used to generate trip signal to the circuit breaker. The relay will operate if there is any increase in current and breaker will open its contacts and isolate the three induction motor. The overcurrent relay block simulated here can be used to protect other equipment also. It can sense increase in current and can detect fault and it will generate trip signal to isolate the equipment under protection.

4.4 RESULTS

In the previous sections, the over current relay is simulated and now its performance will be analysed in this section. Various results are taken to analyse the performance of the relay. The results are taken for both normal and faulty condition. First the MATLAB results for normal condition are analysed and then the results for the faulty condition are analysed.

4.4.1 Normal Condition

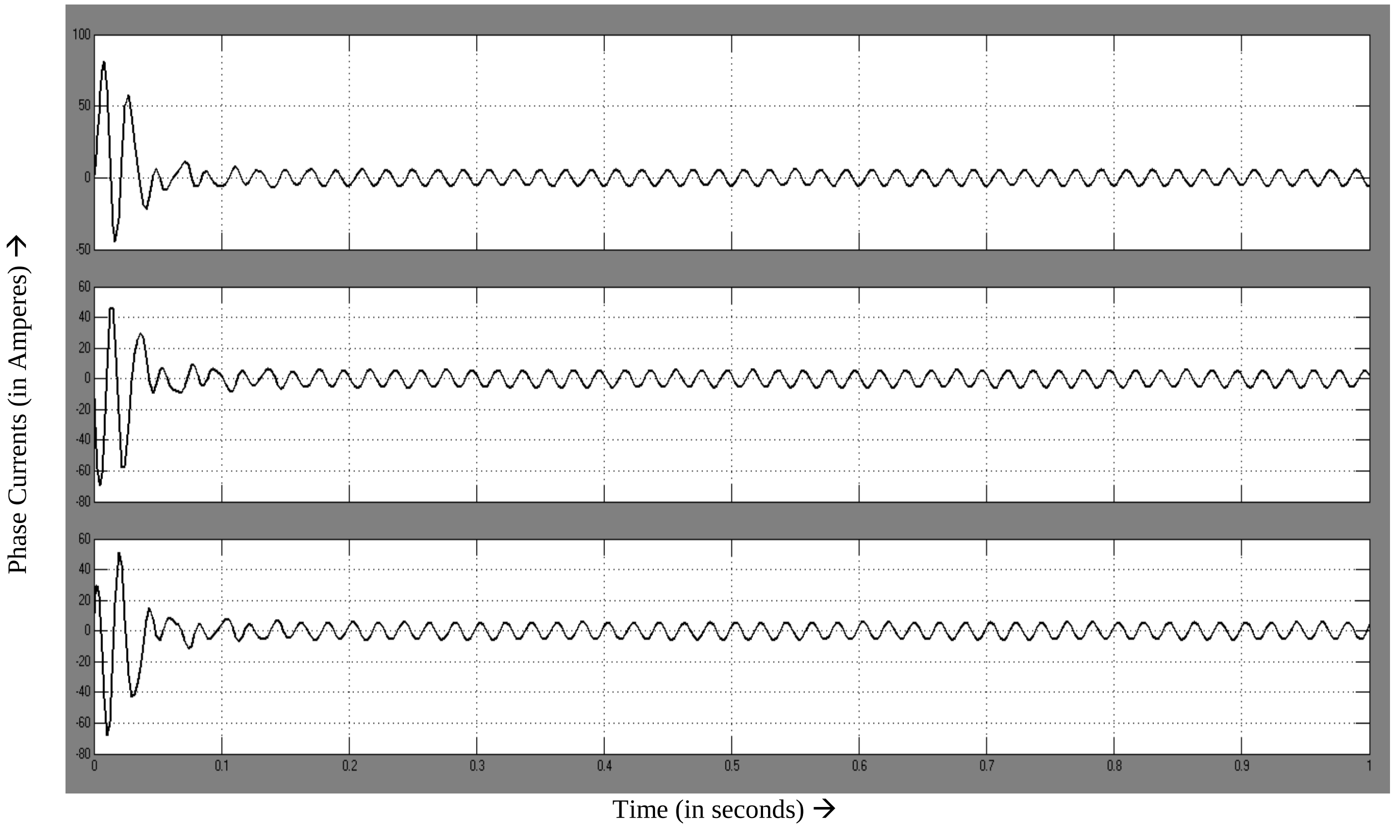


Figure 4.3 Motor Current for normal operation

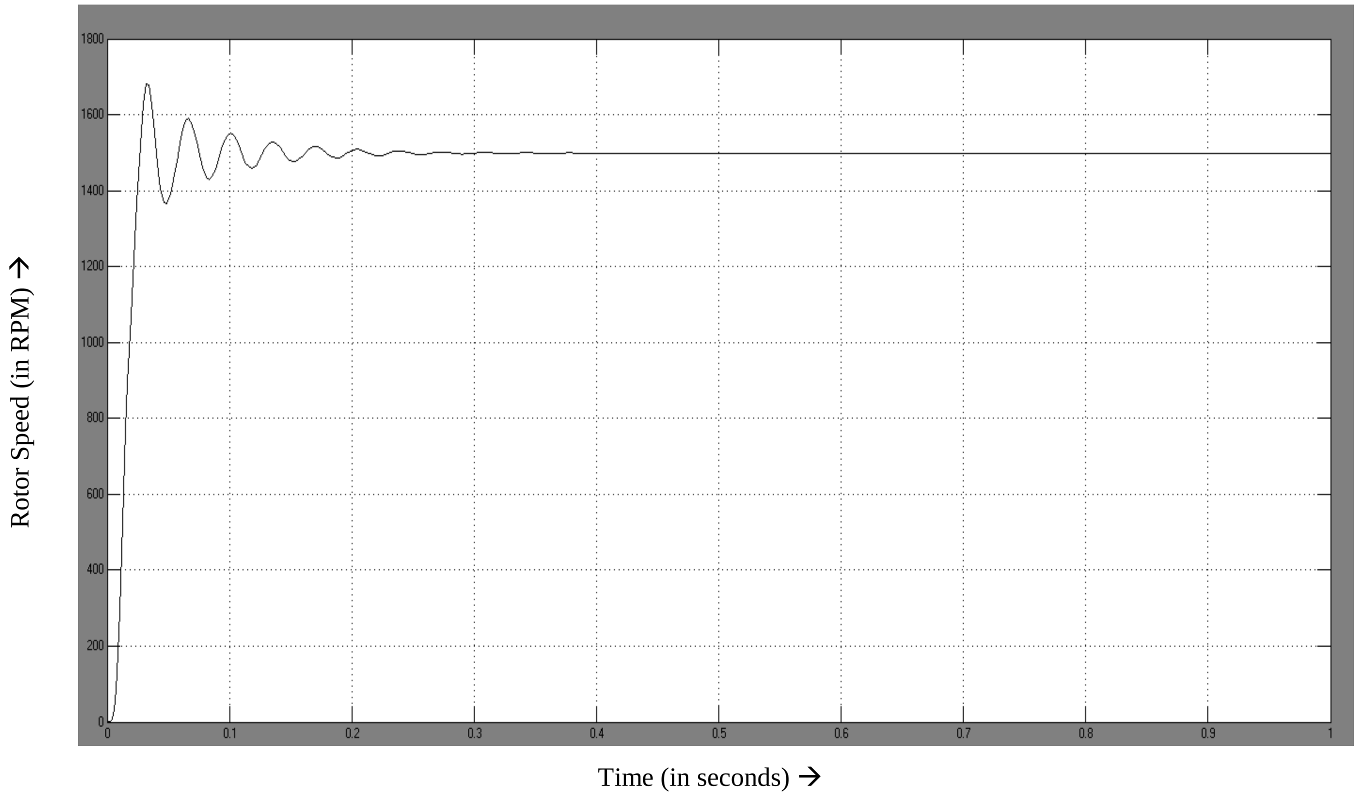


Figure 4.4 Rotor Speed for normal operation

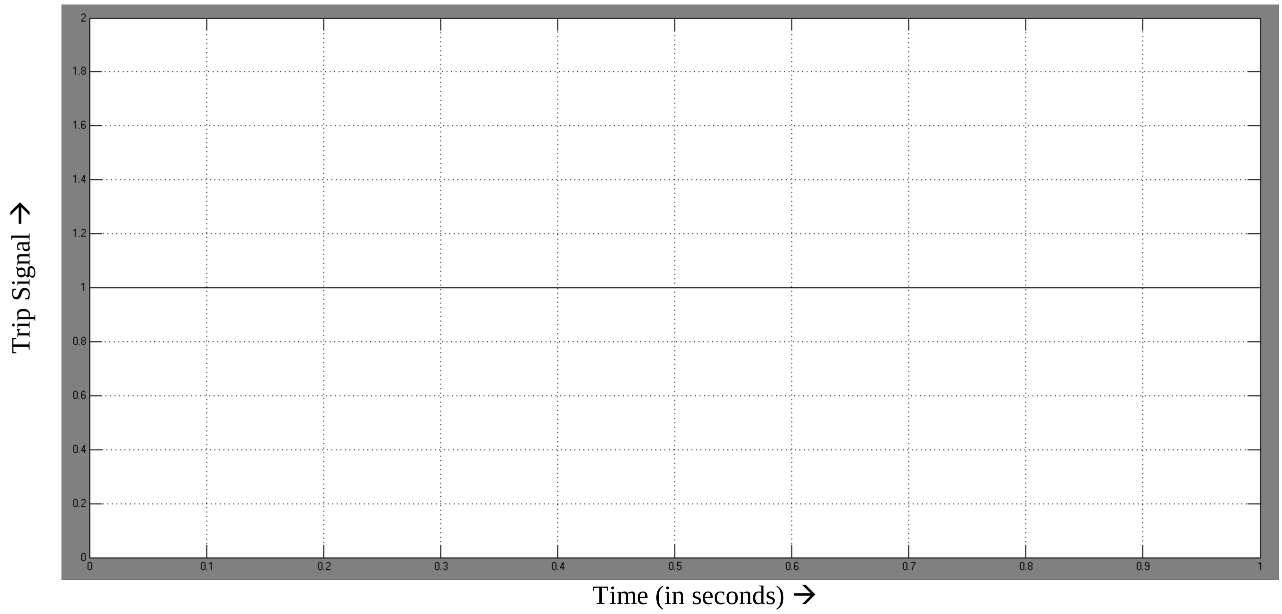


Figure 4.5 Trip Signal for normal operation

4.4.2 Fault condition

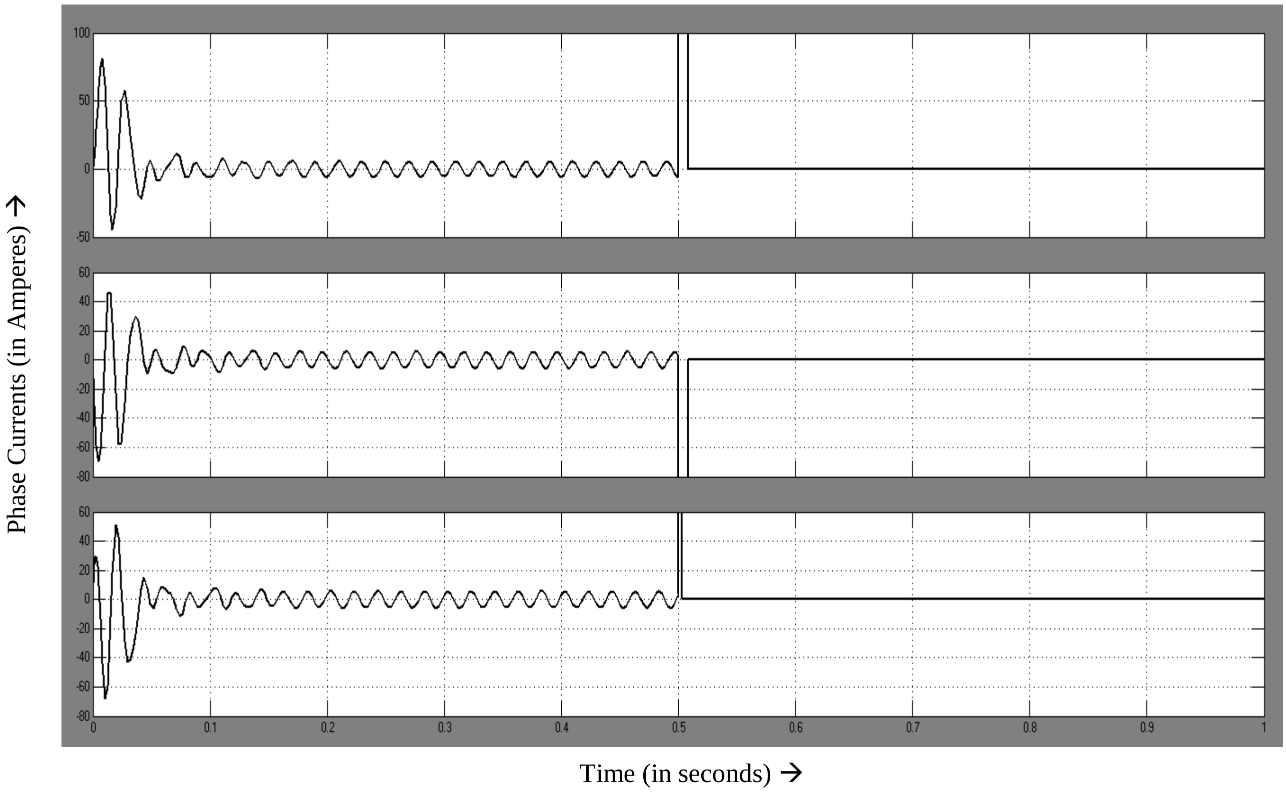


Figure 4.6 Motor Current for three phase fault

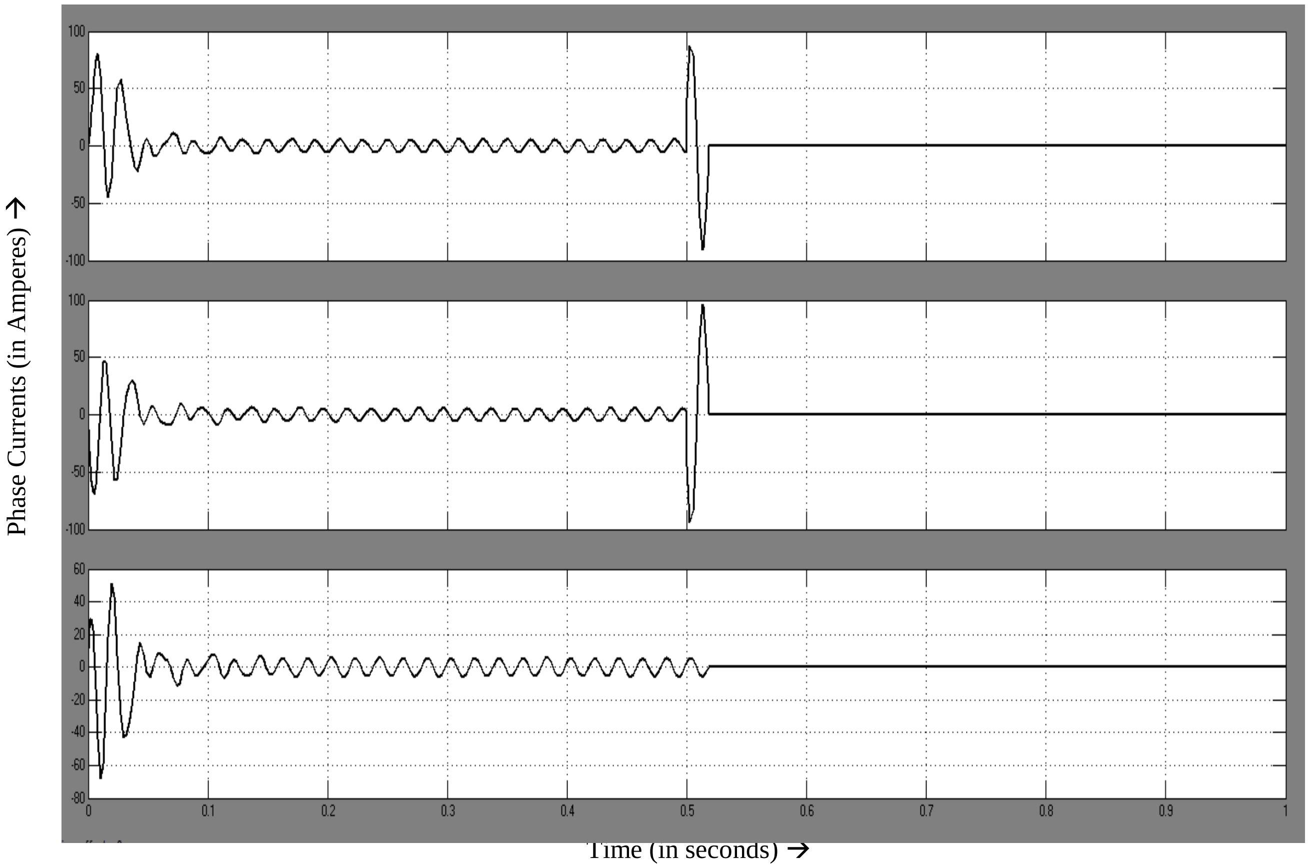


Figure 4.7 Motor Current for line to line fault

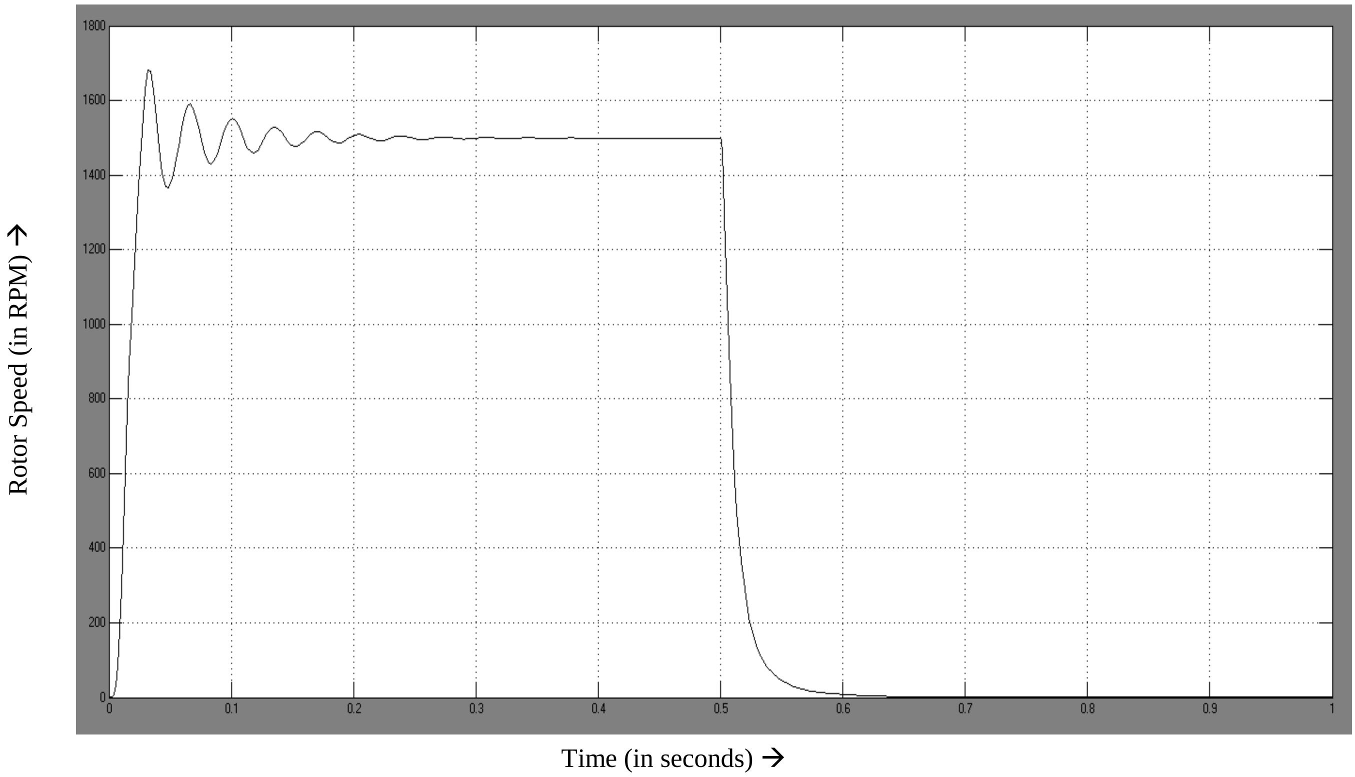


Figure 4.8 Rotor speed for three phase fault condition

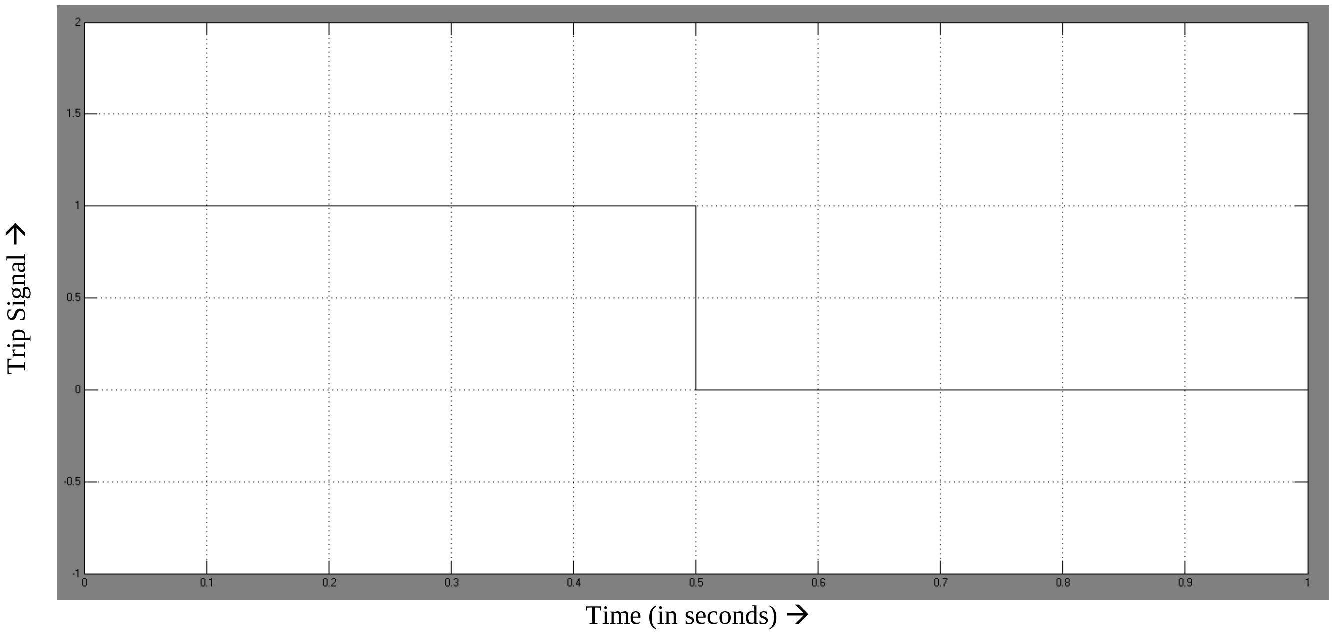


Figure 4.9 Trip signal for fault condition

4.5 CONCLUSION

In this chapter, over current relay is tested on a three phase induction motor. A three phase fault and a line to line fault is simulated on the terminals of a three phase induction motor. And various results are obtained. Results are taken for normal running conditions and results are also taken for the two faults discussed above. The relay successfully detected both the faults and isolated the three phase induction motor from the power supply.

CHAPTER 5

DIGITAL NEGATIVE SEQUENCE RELAY FOR THE PROTECTION OF INDUCTION MOTOR

Introduction

Negative sequence relay are generally used for detecting faulty conditions in power system protection. Negative sequence relay are based on symmetrical components method. Negative sequence component is present in large value under faulty or unbalanced conditions. Negative sequence component are used to detect line to ground (LG), line to line (LL) and double line to ground (LLG) faults. The advantage of negative sequence relay is that only three phase current is required as inputs and neutral current is not required. It can be used to detect unbalance in the power supply which can cause intolerable vibrations in the motor. It is also used in transmission line to detect unbalance and asymmetrical faults. Negative sequence component cause a counter flux which rotate in opposite direction. Eddy current induced with double frequency cause temperature rise in the motor and cause mechanical stress in the motor. Figure 5.1 shows the system used to simulate the performance of digital negative sequence relay for protection of induction motor.

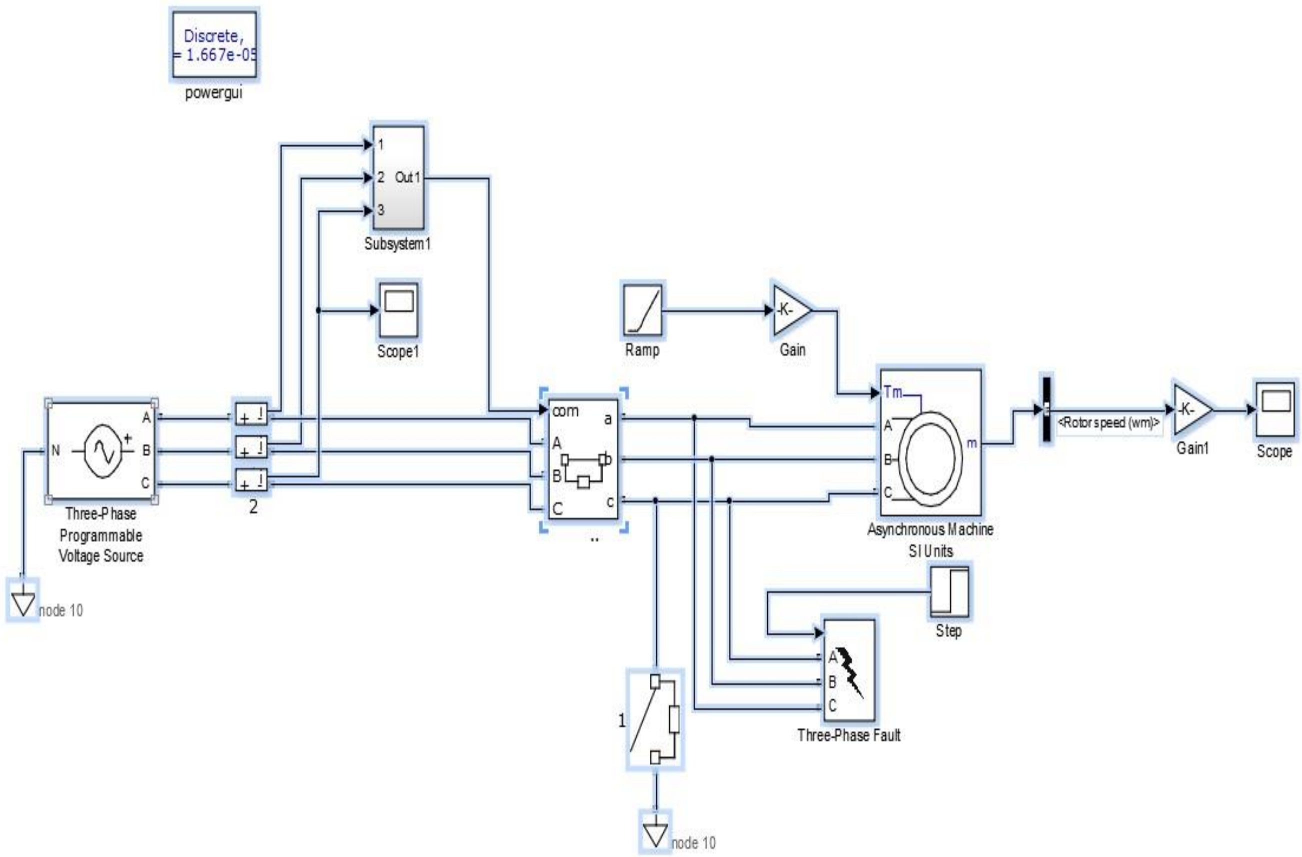


Figure 5.1 Simulation of Digital negative sequence relay

5.2 NEGATIVE SEQUENCE RELAY

The unbalanced current affects the operation of the electrical motors, especially induction motors. A relatively small unbalance in the supply voltage to a motor can give rise to an appreciable negative sequence load current. A negative sequence voltage of 2% may give rise to a negative sequence motor current of up to 10-15% [3]. Thus the negative phase sequence components will lead to the enormous heating of motor and reduction in motor output torque. These relay are more sensitive than over current relay for line to line fault.

The relay can also be used in the other applications such as:

i. Phase interruptions e.g. a broken conductor.
ii. Failure on one or two poles of a breaker or disconnect switch at opening and closing
iii. Earth-fault detection in solidly earthed system.
iv. A short circuit between two-phases will give a large negative sequence current, but these faults are normally cleared by the short circuit protection in much shorter time than the operate time of the negative sequence relay.

Negative sequence relay follow inverse characteristics given by the equation 5.1

$$I_R^2 T = K \tag{5.1}$$

Where I_R is the ratio of between negative to positive sequence current component (I^-/I^+).

And K is a constant that represents the characteristics of a motor or generator. This constant shows the time for which the generator or motor will permit negative sequence current. And T is the time in which relay will trip. I_R is given by the equation 5.2.

$$I_R = \frac{I^-}{I^+} \tag{5.2}$$

5.2.1 Simulation of Negative Sequence relay

It consist of two parts. The first part is negative sequence element and the second part is over current element. The negative sequence element will compute the ratio of I^- to I^+. and the over current element will take the action according to the characteristics.

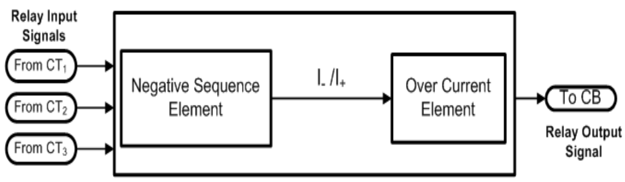


Figure 5.2 Block diagram of Digital negative sequence relay

The negative sequence is based on the ratio of I^- to I^+. For the digital sequence relay the continuous current signal of I_a, I_b and I_c from the current transformer by selecting an appropriate sampling frequency F_s, then the number of samples per cycle of the signal will be F_s/f.

Table 5.1 Samples delayed for negative and positive sequence components

FS	Negative Sequence			Positive Sequence		
	0	240	120	0	120	240
	Delayed Samples per cycle					
12000	0	80	160	0	160	80
60000	0	400	800	0	800	400

To detect the unbalance in the system, the output ratio of the negative sequence element is measured by over current element. The I_R value is compared to a pre-set value I_P and if the value of I_R is more than that of I_P then the relay will generate a trip signal. The signals from the CT are delayed by sample values and then these values are added and then this value is divided by 3 to obtain negative sequence current. The signal so obtained is then quantized to a desired level of accuracy and then buffered. By using fast fourier transform this signal is then converted into frequency domain. The magnitude can be obtained by complex to magnitude and angle block available in MATLAB. By using the embedded MATLAB function block, the signal is extracted. The output of the negative sequence tells the over current element to take appropriate action in case unbalancing is detected by the negative sequence element.

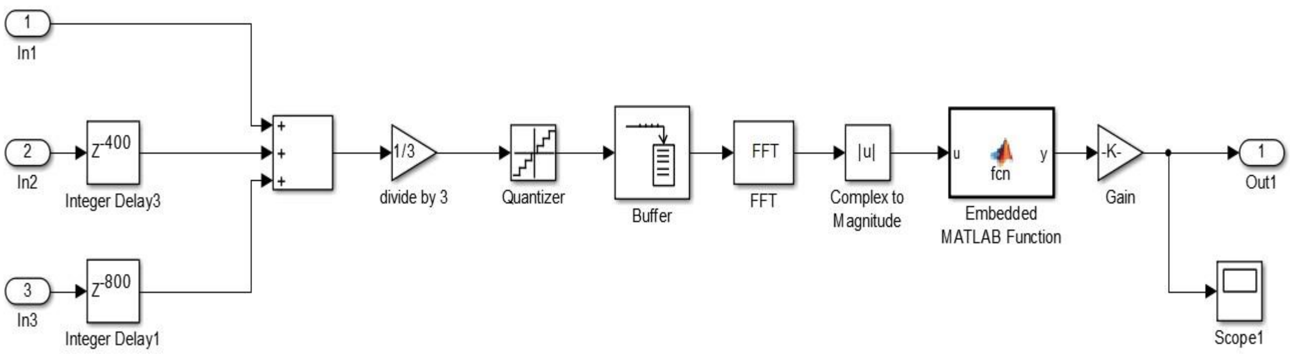


Figure 5.3 Negative sequence component calculation subsystem

Figure 5.3 shows the subsystem used for the calculation of negative sequence component. The inputs are of line current from the current transformers.

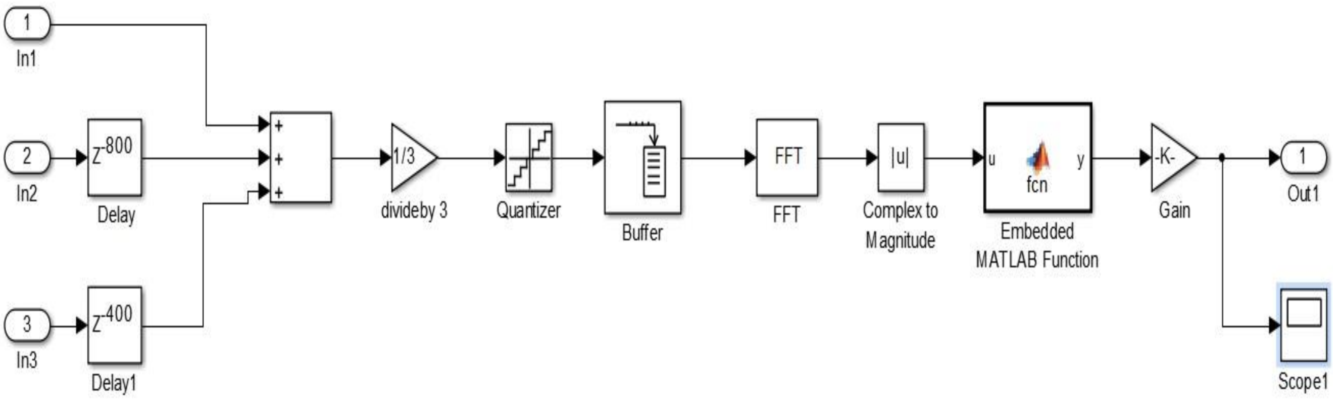


Figure 5.4 Positive sequence component calculation subsystem

Figure 5.3 shows the subsystem used for the calculation of positive sequence component. The inputs are of line current from the current transformers. By using these currents and symmetrical components method negative sequence current is calculated.

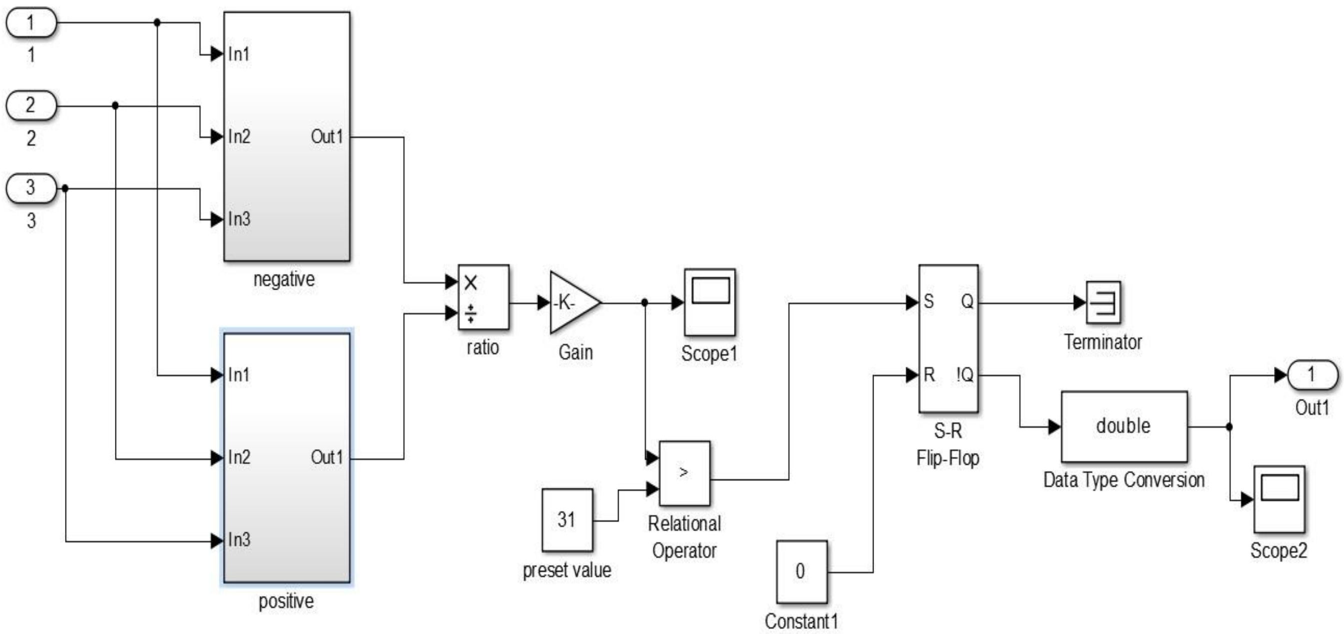


Figure 5.5 Relay logic subsystem

Figure 5.3 shows the subsystem used to find out the ratio of negative and positive sequence current and this subsystem will give trip signal to the circuit breaker if the ratio of these sequence current is more than the pre-set value. The circuit breaker is externally controlled and the trip signal will control the circuit breaker in case of unbalancing.

5.3 RESULTS

5.3.1 Normal Condition

Under normal running condition the ratio of negative and positive sequence component is less than the pre-set value. So the negative sequence element will not give trip signal as the value is less than the pre-set value.

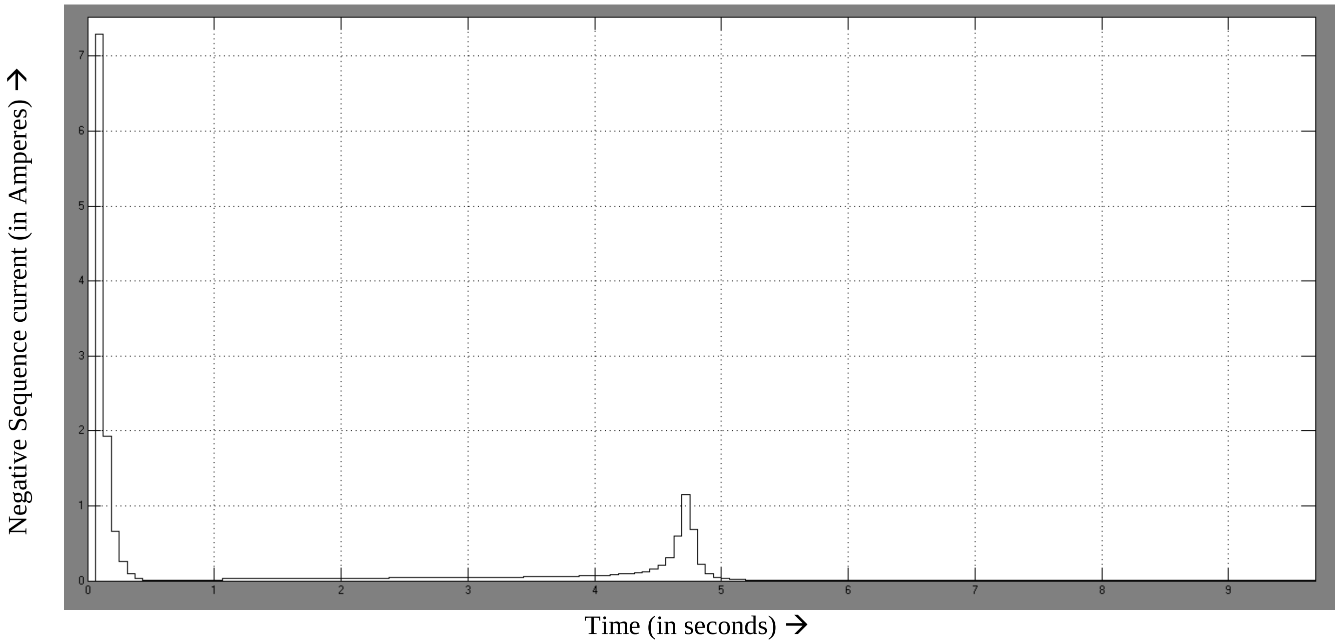


Figure 5.6 Negative sequence component for normal running condition

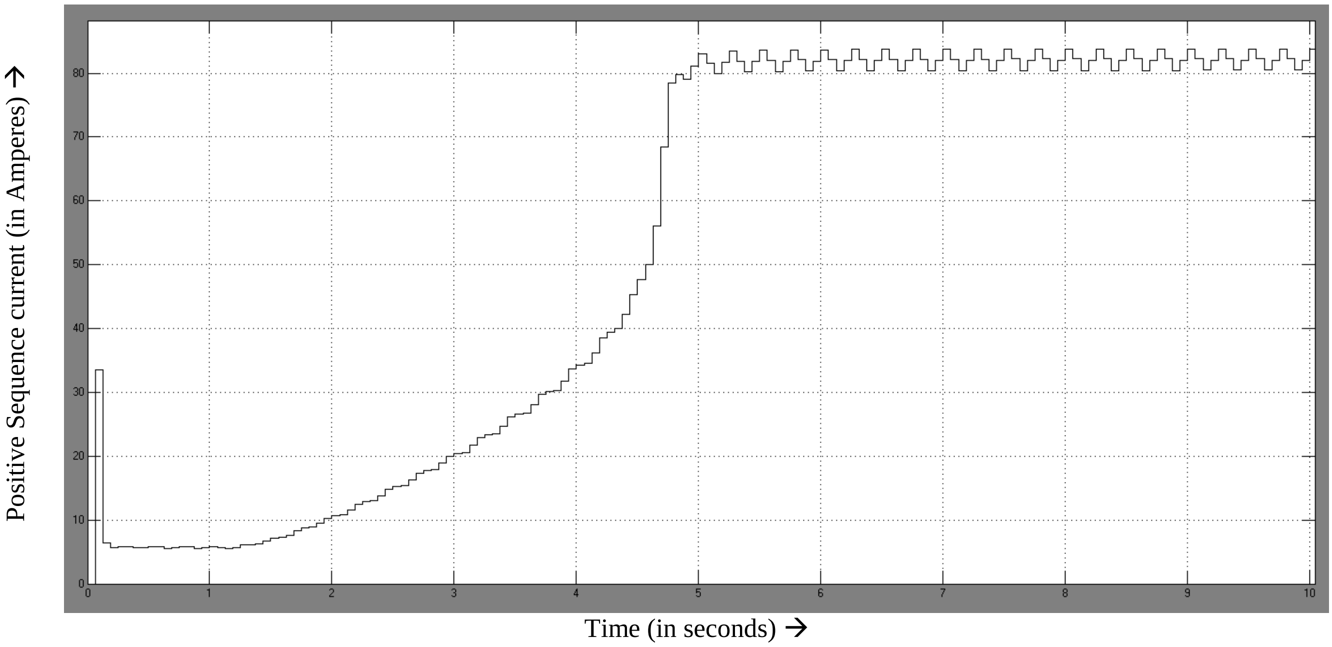
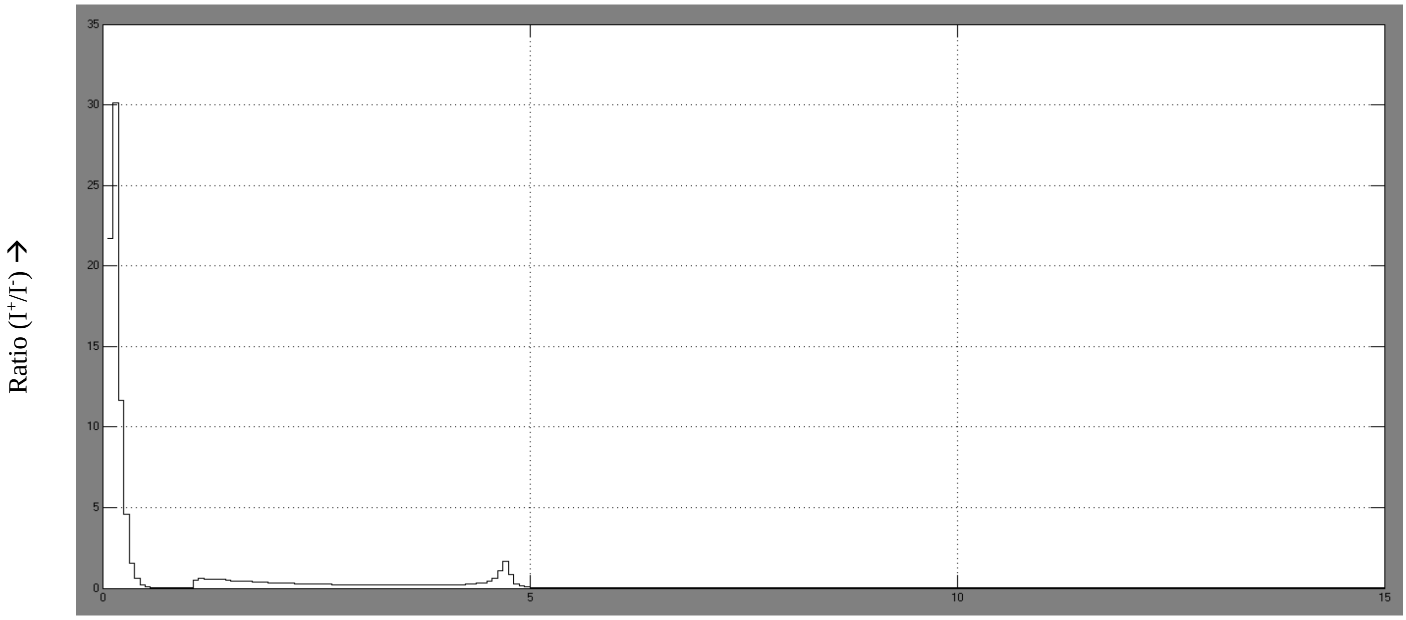


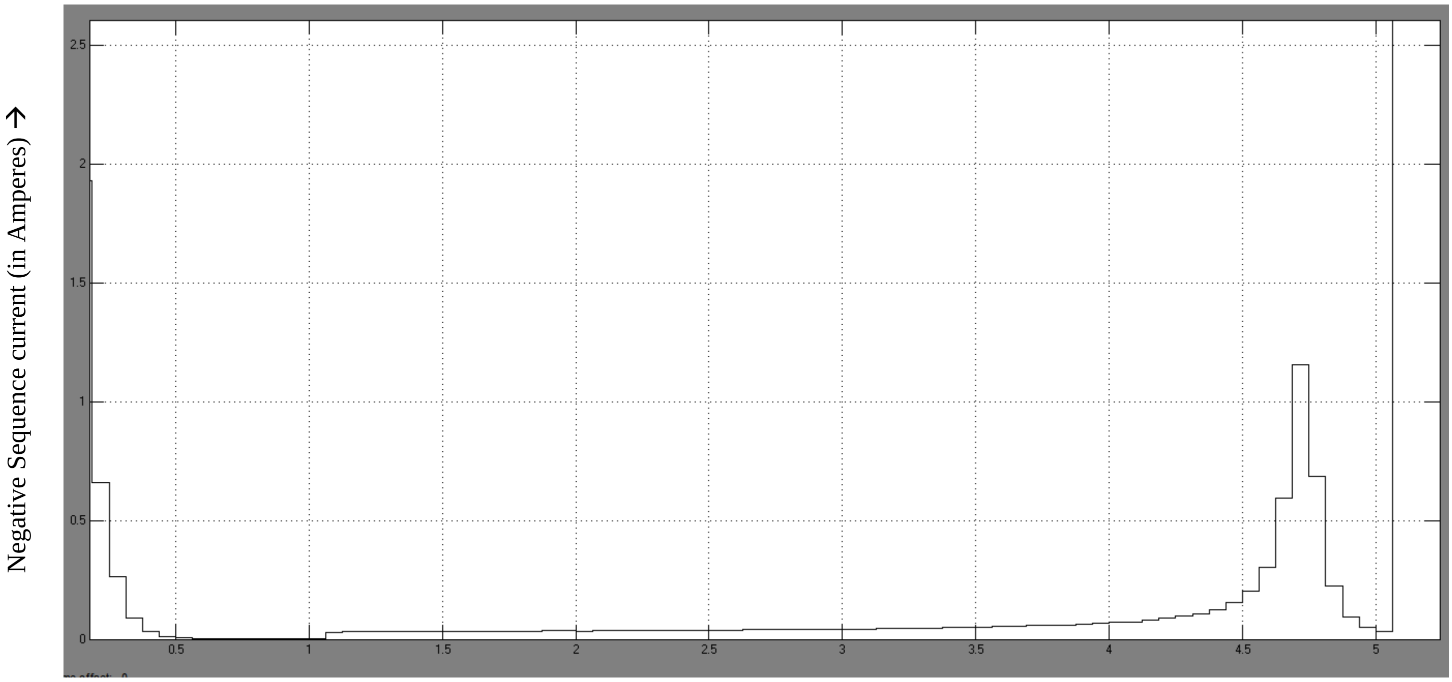
Figure 5.7 Positive sequence component for normal running condition



Time (in seconds) →
Figure 5.8 Ratio (I+/I-) for normal running condition

Figure 5.6 shows the negative sequence component for the normal running condition and figure 5.7 shows the positive sequence component for the normal running condition. The ratio of I^- and I^+ is shown in the figure 5.8. As it is visible that the value of this ratio is smaller than that of the pre-set value the relay will not generate the trip signal.

5.3.2 Fault condition



Time (in seconds) →
Figure 5.9 Negative sequence component for fault condition

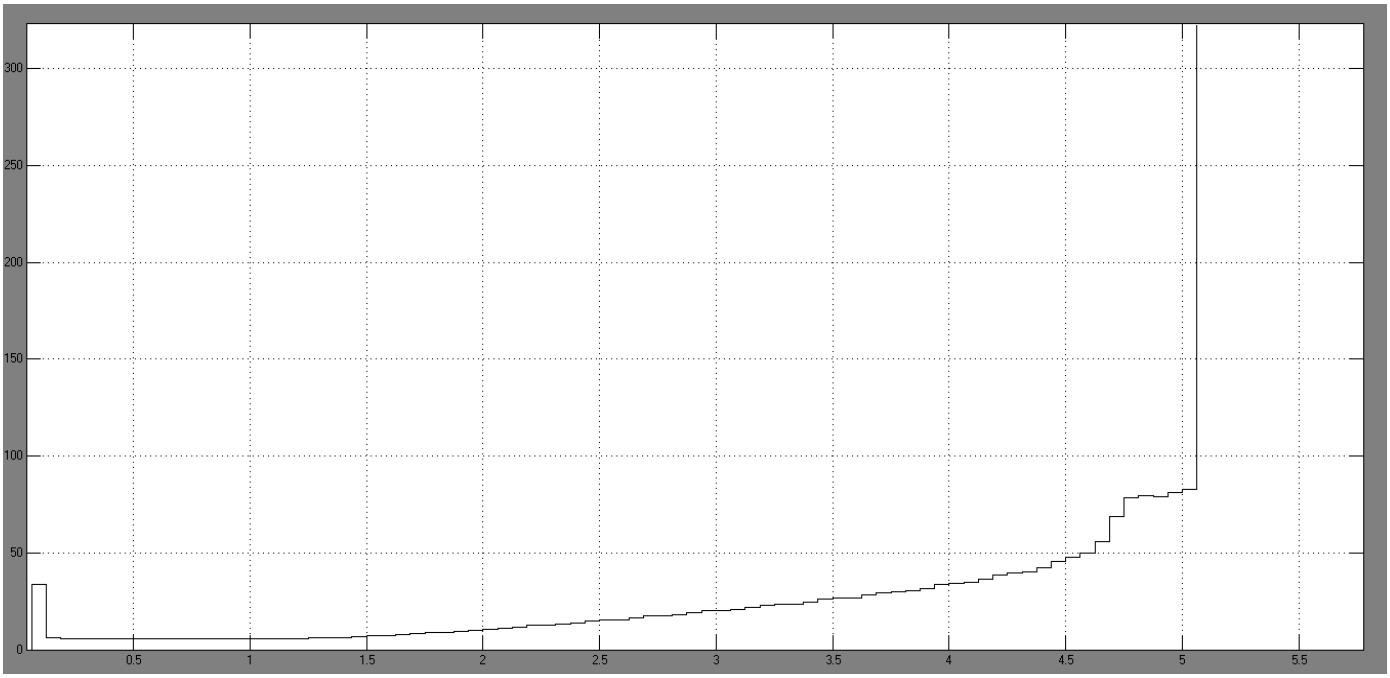


Figure 5.10 Positive sequence component for fault condition

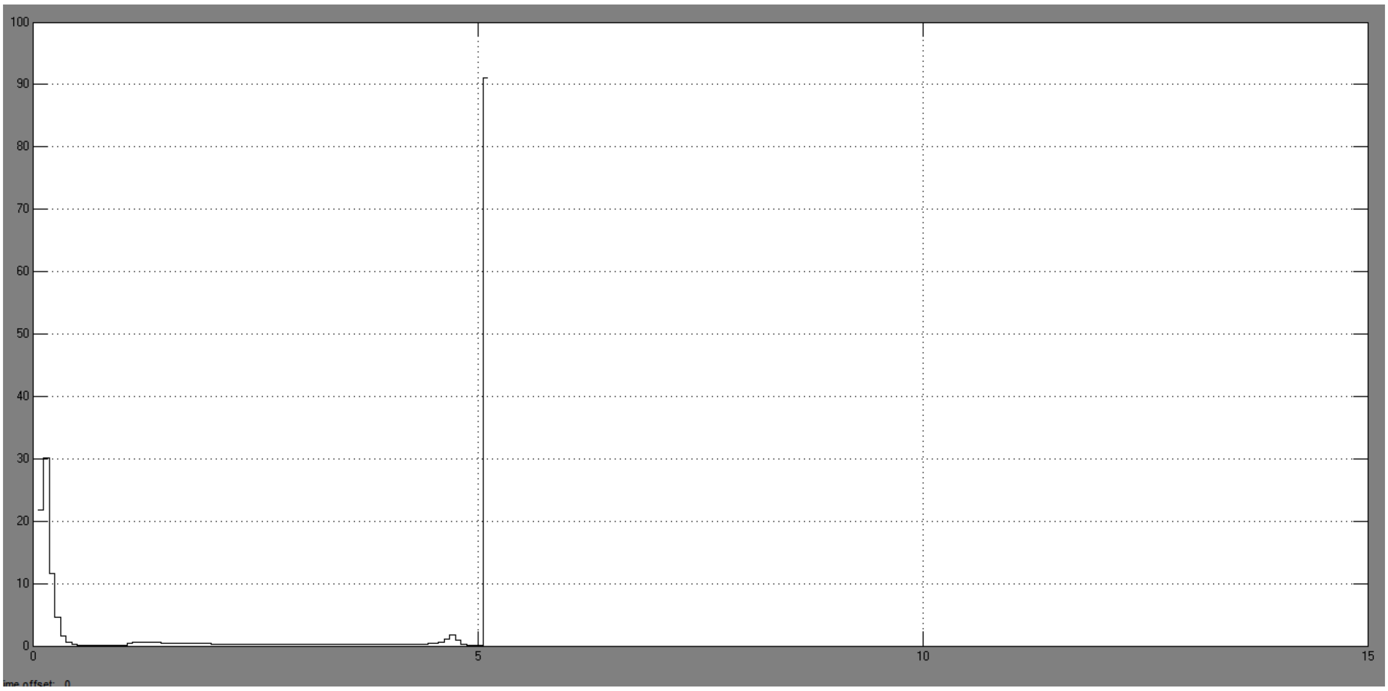


Figure 5.11 Ratio (I+/I-) for fault condition

Figure 5.9 shows the negative sequence component for the fault condition and figure 5.10 shows the positive sequence component for the fault condition. The ratio of I^- and I^+ is shown in the figure 5.11. As it is visible that the value of this ratio is greater than that of the pre-set value the relay will not generate the trip signal.

5.4 CONCLUSION

This chapter presents the simulation of digital negative sequence relay. In this chapter the logic for the negative sequence relay is studied. Negative sequence relay consist of negative sequence element and over current element. If the ratio of I^- to I^+ is greater than pre-set value over current element will take appropriate action according to its characteristics. Various results show that in case of any fault the ratio of I^- to I^+ is greater than pre-set value and relay will issue trip signal and it will switch off the motor.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE OF WORK

6.1 CONCLUSION

Initially the various types of faults in three phase induction motor has been studied in detail and a types of relay for particular type of fault has been described. Relay required for protection of three phase induction motor has been studied and Further, the microcontroller based relay were studied and its performance was examined. Microcontroller based relay can be used for making various types of relay algorithm like overcurrent, under voltage and thermal relay. Microcontroller based relays are now in recent trends and they can be easily used for other equipment just by modifying the program. Then, over current relay is tested on a three phase induction motor. A three phase fault and a line to line fault is simulated on the terminals of a three phase induction motor. And various results are obtained. Results are taken for normal running conditions and results are also taken for the two faults discussed above. The relay successfully detected both the faults and isolated the three phase induction motor from the power supply. Further, digital negative sequence relay is simulated and various results were taken and it is found that the relay will trip if there is any fault or unbalancing in the machine. It can be concluded that the overcurrent relay will provide protection to induction motor to a large extent. But it cannot sense the unbalancing which will overheat the machine. Overheating will cause hot spots in the winding which will reduce lifetime of the motor. So, thermal relay should also be used with over current relay.

6.2 FUTURE SCOPE OF WORK

There are several points which may further be investigated but couldn't be covered in this work due to limited time frame. The main points are described below.

1) Motor can be overloaded if its temperature is not high for a short period of time. But it cannot be over loaded if its temperature is high. So in future relay logic should be designed taking the above point into consideration.

2) The studies done in this work are based on various simulation software. In future this work can be implemented on hardware. The 8051 C code can be fed into microcontroller 8051 family and PCB can be made by using Proteus Professional software.

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