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Advance Protection for Three Phase Induction Motor using Microcontroller Atmega32

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Abstract— **A low cost and reliable protection scheme has been designed for a three phase induction motor against unbalance voltages, under voltage, over voltage, short circuit and overheating protection. Taking the cost factor into consideration the design has been proposed using microcontroller Atmega32, MOSFETs, relays, small CTs and PTs. However the sensitivity of the protection scheme has been not compromised. The design has been tested online in the laboratory for small motors and the same can be implemented for larger motors by replacing the i-v converters and relays of suitable ratings.**

Keywords— **Induction Motor Protection; Overvoltage; Undervoltage; Unbalance Voltage; Single Phasing; Over Current**

I. INTRODUCTION

The protection of induction motor plays an important role in its long life service. Many researchers have done work in this area but their protection scheme is costly and unfeasible in our Indian condition. Three phase induction motor can continue to run when one phase of the supply goes out of service due to any fuse blowing or opening of phase by protective device. The heat produced by the motor under single phasing condition needs to be taken care of in adequate time. When phase opens at distribution transformer or at feeder end, the stator and rotor losses increases to ten times and the shaft output power decreases to negligible. But if the single phasing occurs at motor terminals the losses increases twice and the shaft power reduces to nearly 70%. Motor life shortens as the temperature increases[1]. To protect the motor all the terminals should be open [2]. On distribution feeders, majority of faults are single phase. On an average single phase fault occurs 70%, double phase fault 20% and symmetrical fault 10%[3].

Voltage at motor terminals may be higher than nominal value in a complex industrial system and can be well below from nominal value in a heavily loaded industrial system. IEEE, NEMA and other power communities have different definitions about voltage unbalance. These definitions only give an idea about the voltage unbalance. The complex algebra is avoided in these definitions to make paper calculations easy[4]. Unbalance voltages have negative impact on the performance of three phase induction motors[5]. Under voltage in all the three phases adversely effects the efficiency of the motor as compared to three phase over voltage condition. Positive sequence voltage and negative sequence voltage effects the motor’s power factor and its efficiency.NEMAMG1 standard has suggested de-rating of the motor under voltage unbalance condition [6].

Starting of the motor also has a role of overheating in the rotor. If the starting of the motor is slow then the motor heats up quickly because it draws more current till it achieves the rated speed. This may be due to under-voltage condition. So at the time of starting of motor the voltage should be appropriate as mentioned on the name plate of motor. Due to global business competition, manufacturers have reduced the cost of the machine by reducing the size for same output motor. In the last century the power to weight (W/kg) ratio has increased 14 times. The rate of failure of the motors manufactured by the top companies in the last ten years has also shown an increasing trend in the last few decades[7].

Microcontroller or microprocessor can protect the motor from under/over voltages, over current etc. Low voltage output from the step down transformer has been fed to the ADC converter. ADC converter converts the analog values to digital values. Microcontroller has been used to compare the instantaneous digital values with the reference values. If the instantaneous values go beyond the prescribed limit, microcontroller trips the relay circuit[8]. Protection of the three phase induction motor based on voltage measurement is not enough if the fault occurs at distribution transformer or at substation feeder because the faulted phase will draw negative sequence current and voltage if developed nearly close to line voltage. If fault occurs at motor terminals then the voltage measurement can protect the motor very well. The current measurement device should be implemented within the protective device [9]. Protection can be enhanced by zero crossing detection method by using 8085 microprocessor [10].

II. FAULT DIAGNOSIS FOR THREE PHASE INDUCTION MOTOR

A. *Single Phasing Condition*

Two phases of three phase induction motor will get power supply in single phasing condition and they produce negative sequence current in the faulted phase because the three phases are connected to each other in the motor. Single phasing fault may arise at three locations [2]:

1) *Primary side of substation transformer*
2) *Primary side of distribution transformer*
3) *At motor terminals*

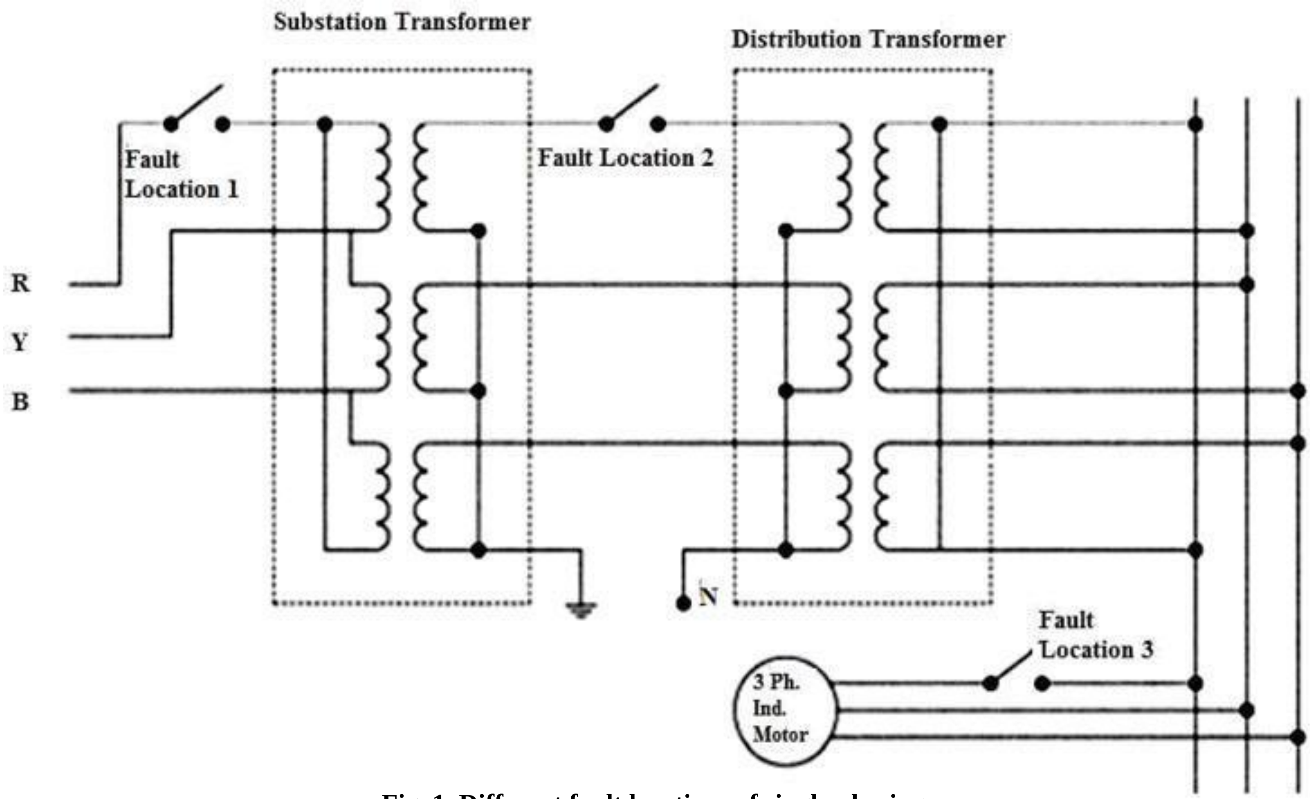

Fig. 1. Different fault locations of single phasing

As shown in fig. 1, out of these three fault locations, the most severe condition is when phase opens at distribution transformer or at substation transformer. Current increases almost ten times the nominal value while the shaft output power becomes negligible. If any overload protective device has been provided to isolate the motor from the main supply during single phasing condition and if it later attempts to start under the same condition, the motor draws locked rotor current which is 6-8 times the normal rated current. It can also damage the motor permanently. Single phasing is worse than the unbalance voltages[8].

When the fault occurs at the substation end or at distribution transformer, then the third phase of the motor will draw the negative sequence current and the torque will be produced by the remaining two phases. The winding of the faulted phases will behave like a generator and the generated voltage is nearly the same as of line voltage. The high current damages the winding insulation and the voltage sensing protective devices.

As shown in fig. 2 two three phase induction motors are connected with the three phase line and some single phase loads are also connected with the line. Whenever the single phasing occurs other than the motor terminal, then the faulted phase will receive the generated voltage from the other two phases because the three phase are connected with each other. The negative sequence current flows in the third phase and the generated voltage is near to the line voltage. The generated voltage is not in phase and can be detected by the phase measurement device. Now, if the protection devices are based on voltage magnitude sensing then they will sense the magnitude of voltage and will not trip the circuit. Hence as shown in the figure 2, the other loads which are connected to the same phase will draw the current through the motor winding and a large current is drawn from the three windings of the motor. This large current will damage the motor windings. If any voltage and current protection device is placed at the single phase load, which is connected to the faulted phase, will not respond because the current required by that load is drawn from the motor and the voltage is also at nominal level. Therefore, protective devicefor single phase load based on sensing of voltage and current will not function, if the fault occurs at substation transformer or at distribution transformer [9].

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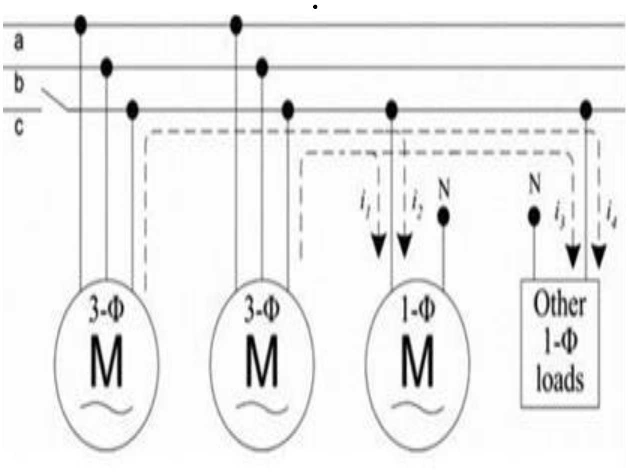

Fig. 2. Single phasing before motor terminals

If any single phasing fault occurs at any of these three fault locations i.e. at motor terminals, at substation end, at distribution transformer, then the current profile will surely change. Hence, the current sensing device along with the voltage sensing provides better protection. If single line to ground fault occurs at primary of star-star transformer then the secondary windings how's the single phasing condition. In case of delta-star transformer the line to ground fault on the primary is reflected as unbalance voltages in three phases on the secondary. Therefore the voltage sensing devices will be able to detect the single phasing in case of star-star transformer but will fail in case of delta-star connection. If single phasing occurs at the time of running of the motor, the stator current increases by two to three times and shaft output decreases to 70 percent approximately.

B. Unbalance voltages and frequency

When the magnitude of three phase voltages is not same or the phasor difference is not 120^0, it is called unbalanced voltage. According to NEMA MG1-2009 standard the limit for voltage and frequency variations are $\pm$10% and $\pm$5% respectively[12]. However, more than 5% unbalance in phase voltage is not recommended by NEMA MG1 (National Electrical Manufacturer Association Motor and Generator Standard) guidelines [4]. This affects the insulation life of winding, reduced efficiency, increased losses and increased temperature with in the motor.

1) Definitions of Unbalance voltages :

As per NEMA and IEEE guidelines the voltage unbalance can be defined as:

Voltage Unbalance %age = Maximum deviation of voltage from average voltage

As per NEMA guidelines the voltages are line voltages while IEEE guidelines use the phase voltages. It may be seen that both guidelines does not mention the phase angle between the voltages [5]. The reason may be to remove the complexity in the calculations [4].

Positive sequence voltage and negative sequence voltage can be calculated by [4]:

$$V_p = \frac{V\ a}{3}$$

$$V_n = \frac{V\ a}{3}$$

Where a = -0.5 + j0.866 and a^2 = -0.5 - j0.866

During the unbalanced condition we have to consider the positive sequence current and the negative sequence current. The positive sequence current is same as the normal running condition of the three phase induction motor but the negative sequence current arises due to unbalanced voltages. The negative sequence current produces reverse field.

Another definition of voltage unbalance by the IEC is as follows :

$$\text{VUF VUF} = \frac{\text{Negative Sequence Voltage}}{\text{Positive Sequence Voltage}} \times 100\%$$

2) Derating of motor during voltage unbalance :

When there is an unbalance in the supply voltages, according to NEMA guide lines, there should be derating of the motor due to introduction of negative sequence currents and as a result the temperature of the winding also rises. If the load on the motor remains same, then to develop the rated torque also, the current drawn by the motor increases than the rated value. The amount of derating of the motor with respect to percentage unbalance of supply voltage has been shown in figure 3. The derating chart for overvoltage has been also given by NEMA[13]. For a 90% under voltage the derating should be 0.92 [4].

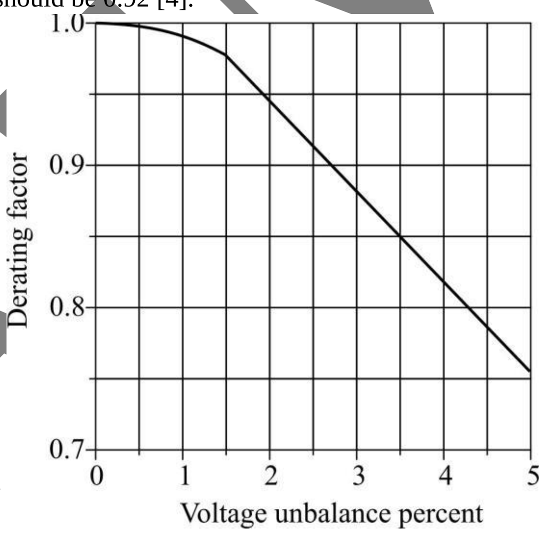

Fig. 3. De-rating of motor during unbalance voltage by NEMA MG1 standard

3) Effect of voltage unbalance on power factor and efficiency of motor :

The voltage unbalance also affects the power factor and efficiency of the induction motor. As the voltage increases the power factor decreases and the efficiency increases. But the efficiency given on the name plate is always higher whether the case is under voltage and over voltage. The efficiency decreases very fast in case of 3 Ø under voltage.If the capacitors are installed to improve the power factor under balance conditions results in increase of VUF under unbalance condition [6]. There is a sharp increase in the temperature of the motor due to under voltage in all the three phases as compared to over voltage and normal rated voltage.

C. Overloading effects :

Overloading of the three phase induction motor can produce hot spots within the winding, which may exceed the thermal limits of the motor. Time is an important factor for heat dissipation. Induction motor has a relatively large heat storage capacity, and these heat pockets are the core, conductors and the structural mass. For short period overloads and locked rotor condition, large amount of heat gets trapped in the motor windings and is not transferredto other parts in this small duration, hence get damaged[12]. According to NEMA MG1 Standard the stator current of the induction motor should be capable of withstanding 1.5 times of rated current for not less than 2 minutes [13]. If motor is designed for different frequency systems then its horse power and voltage ratings should be altered according to volts per hertz of the given system. Themotor should have the capability towithstand the locked rotor current upto 12 seconds. National Electric Code (NEC) (NPFA 70-2011) has defined the trip for the 125% of rated current for the continuous rating motors. There are several NEMA designs depending upon the speed, voltage, horsepower rating, service factor etc. for low and medium voltage motors.

D. Maintenance, environmental and manufacturing effects :

1) Ventillation effects :

Ventilation is necessary for the smooth operation of the motor because clogged or partially clogged ventilation will cause increase in the temperature of the motor. A small motor with clogged ventilation can get damaged. Ventilation inadequacy detecting devices like airflow detector, temperature sensing device etc. may help to protect the motor.

2) Manufacturing effects :

Manufacturing and selling of the machines are now a global business and have increased the competition between the manufacturers. This has put pressure on the designers to reduce the cost of the machine. The reduction of cost has negatively affected the life of a machine. The cost reduction has been done by[7]:

- *a) Reducing conductor cross sectional area*
- *b) Reducing insulation thickness*
- *c) Reducing amount of steel core material*
- *d) Developing fast manufacturing techniques to reduce labour cost .*

III. CAPABILITIES OF MICROCONTROLLER ATMEGA32

Microcontroller ATmega32 has 40 pins and is an 8 bit device. 32 pins can be used for data i/o. Its internal frequency is 1 MHz and can be upgraded to a maximum frequency of 16 MHz by using crystal oscillator. Operating voltage for this microcontroller should be between 4.5V and 5.5 V.

A. Data Port

Microcontroller has 4 data ports of 8 pins each. All the ports can be used for data i/o but they can only read or write 5V or 0V. Only ADC port can read between 0V to 5V.

B. ADC Port

The digital output has 10 bit resolution, which means it can read a change of 5mV. ADC port can be used for lower resolution. At a time, microcontroller can read only one ADC pin. It samples and holds the analog input of first pin till conversion into digital output and then it reads the next pin. Its internal frequency of 1 MHz is sufficient to read all the 8 inputs effectively.

C. Arithmetic Logic Unit

Arithmetic Logic Unit can be divided into three general categories of arithmetic, logic and bit-functions. It supports the signed/unsigned multiplications and other arithmetic mathematical operations.

IV. PROTECTION OF THREE PHASE INDUCTION MOTOR USING MICROCONTROLLER ATMEGA32 Protection of three phase induction motor can be done effectively and economically by using microcontroller

ATmega32.8 analog voltage inputs are converted into digital values by the ADC within the microcontroller. Hence external requirement of ADC converter has been eliminated. The ADC conversion, comparison and decision making are done within the microcontroller which makes the protection more reliable. Step down transformers and i-v converters are used for giving the instantaneous phase voltages and phase current to the microcontroller. It protects the motor from under voltage, over voltage, unbalance voltage, over current and single phasing. Microcontroller samples the values, compare it with reference values and make the decision. Schematic Block diagram is shown in fig. 4:

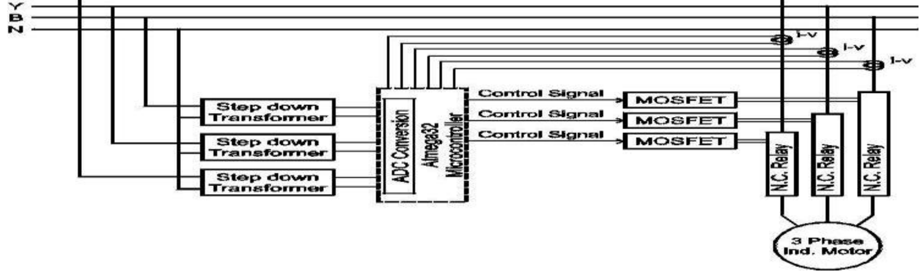

Fig. 4. Block diagram of Protection unit for three phase induction motor

A. Stepdown transformer unit

Three 240V/6V center tapped step down transformer has been used for the measurement of the phase voltages. The center tapped rectifier circuit has been used to rectify the low voltage signal and the capacitors are used to reduce the ripples in the dc output.For discharging of the capacitor the resistor has been used in parallel to the circuit. The output is calibrated across the potentiometer as per the requirement of the microcontroller. The variation in the dc input of the microcontroller is proportional to the variation in the supply voltage. There may be some normal fluctuation in the power system which can exist for few cycles, and tripping of motor for these fluctuations is not required [11]. Taking this into consideration, the value of resistor across the capacitor has been chosen accordingly. Three sets of the setup mentioned above have been used for the three phases of the supply given to the motor. Schematic diagram of step down transformer unit is shown in fig. 5:

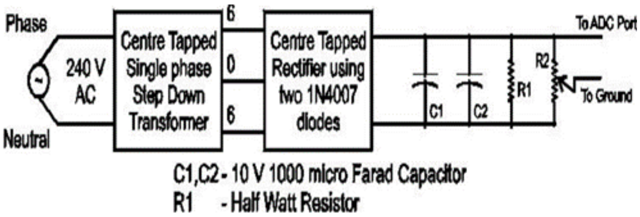

Fig. 5. Transformer unit of protection scheme

B. i-v converter unit

The overcurrent protection for three phase induction motor has been done using three i-v converters of 20A/20V in individual phases. The wire of the supply terminals of the motor has been used as the primary for these converters. When the motor is in running condition, the magnetic flux developed around the phase wires induces voltage on the secondary side of the converters. This voltage is given as an input to the microcontroller using ADC port. These voltages are calibrated with rated current value and programmed into the microcontroller when the motor is running in the healthy condition. The starting current of the motor is normally 6-8 times higher than the running condition [13], hence time delay has been provided. Delay time can be increased for different type of motors. The output of the i-v converter increases as the current through the motor increases.

C. Relay unit with MOSFET

1) Working of Relay : The relays implemented in this protection scheme are capable to pass 7A current at 300V AC. 6V are minimum required to operate the relay. The relays are connected across the battery and one MOSFET is connected between them. When the MOSFET recieves the high signal from the microcontroller, the supply to the relay is given for its operation. The relay is in normally closed condition and opens the circuit when it is energized. All the three relays are connected in the three phases in same configuration for its operation. All the MOSFETs get the high signalfrom same pin of the microcontroller to enhance reliability of the whole protection scheme.

2) Working of MOSFET : The driving power of the microcontroller is not sufficient to energize the relay and operate it.Hence the MOSFET is used as a controlled switch and for energization of the relay a separate DC source has been used. The other reason is that even the higher ratings of relays can be controlled using the same circuitryof the protection scheme. So the MOSFET implementation in the design makes the protection system more versatile for different range of three phase induction motor ratings.

3) Battery : Battery is required in this operation for giving the supply to the relays. The relays are in normally closed mode so we do not require power all the time from the battery but under the faulty condition, the power will be supplied from the battery to energize the relay. The battery Ah rating is taken accordingly to the power requirement of the relay. Rechargeable batteries can be used and the batteries can be changed during the running of the motor and without disturbing the whole protection system. Batteries connected with the rectifier system can also be implemented.

4) Working of relay with MOSFET : Values of the Voltage and Current are taken from the Voltage transformer andi-v converter respectively. These values are given to the input of the ADC port of the microcontroller. Microcontroller converts the analog input into calibrated digital values. Microcontroller compares the values of voltages and current with the prescribed limits. If the value goes beyond the prescribed limit, the respective MOSFET will get the supply after certain delay as prescribed by NEMA MG1 or required by the consumer. In case of any unbalance of voltages, under or over voltage in any of the phases, and over current all the three phase relays will open simultaneously to disconnect the motor from the supply. Schematic diagram is shown in fig. 7:

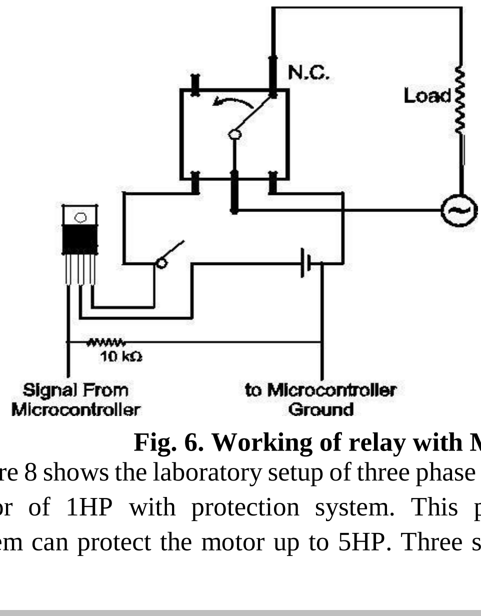

Fig. 6. Working of relay with MOSFET

V. LABORATORY SETUP OF PROTECTION SYSTEM

Figure 8 shows the laboratory setup of three phase induction motor of 1HP with protection system. This protection system can protect the motor up to 5HP. Three step down transformers of 220V/6V and three i-v converter of 20A/20V are used. Three relays of 230V/7A capacity are connected with three MOSFETs across 9V battery.

Fig. 7. Protection setup of three phase induction motor

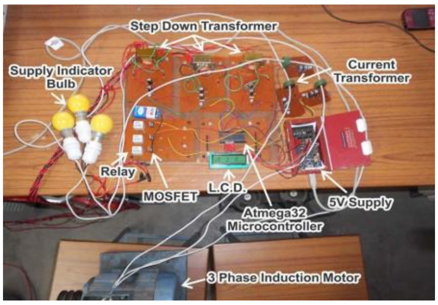

Fig. 8. Close view of protection system

By changing higher current handling CT and relay, the protection system can also protect motor of higher ratings. Figure 8 gives a closer view and figure 9 shows the components of the protection system. Bulbs are the indicators for three phase supply given to the motor.

Fig. 9. Protection system components

Fig. 11. LCD display with phase voltage and phase current

LCD has been used to display the digital values of the voltages and currents as converted by the microcontroller. Figure 10 shows the phase voltages in the upper row and phase current in the lower row on the LCD. When any phase voltage or phase current goes beyond its limit, microcontroller disconnects the motor from power supply. At this instant, LCD displays zero current and the present supply voltages of the three phases. In case of under/over voltage, even after disconnecting the supply to the motor the microcontroller keeps monitoring the voltage and reconnects the supply as soon as the voltages are within the limits. In case of over current, motor is disconnected from the power supply for longer duration and can be restart earlier by the user.

VI. CONCLUSION

This protection system is an improved method because it is a very low cost device as compared to other protective devices. The system is tested in the laboratory for many times on Three phase induction motor under faulty condition and it gives desirable results. The system is reliable and rugged. It is designed in a manner that by changing CT and relay within the same circuit, it can be used for higher rating motors. The MOSFET is preferred instead of IGBT because the current rating to control the relay is very small. This is a prototype for the protection of motor for under voltage, over voltage, unbalance voltage, over current and single phasing

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