AN IMPROVED METHOD FOR PROTECTION OF INDUCTION MOTOR USING MICROCONTROLLER

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Submitted By

Gagan Garg

Regn. No. 801241009

Under the supervision of

Dr. Amrita Sinha

Assistant Professor, EIED

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ELECTRICAL AND INSTRUMENTATION ENGINEERING DEPARTMENT

THAPAR UNIVERSITY

PATIALA (PUNJAB)-147004

CERTIFICATE

I hereby certify that the work which is being present in the dissertation entitled "**An Improved Method for Protection of Induction Motor using Microcontroller**" in partial fulfillment of the requirements for the award of degree of Master of Engineering in Power Systems submitted in the Electrical and Instrumentation Engineering Department of Thapar University, Patiala is an authentic record of my own work carried out under the guidance of **Dr. Amrita Sinha**, Assistant Professor, EIED.

The matter presented in the dissertation has not been submitted for the award of any other degree of this or any other university.

Gagan Garg 18/7/14

(Gagan Garg)

(Regn. No. 801241009)

It is certify that the above statement made by the student is correct to the best of my knowledge & belief.

18/7/14

(Dr. Amrita Sinha)

Electrical & Instrumentation Engineering Department

Thapar University, Patiala

Countersigned by:

(DR. RAVINDER AGARWAL)

Professor & Head, EIED

Thapar University, Patiala

(DR. S.K. MOHAPATRA)

Sr. Professor & Dean of Academic Affairs

Thapar University, Patiala

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Gagan Garg

Regn. No. 801241009

ABSTRACT

Protection of three phase induction motor has been done using the microcontroller, current transformer and step down transformer. This protection scheme protects the three phase induction motor from single phasing, under voltage, over voltage and over current. The overall process is monitored by ATmega32 microcontroller. Microcontroller sends signal through MOSFET to relay for operation. This microcontroller can sense 8 analog inputs up to 5V. Six analog inputs of microcontroller have been used for three phase voltages and currents individually for conversion to digital signal. The remaining inputs can be used for receiving the information from motor such as temperature, speed etc. The current transformer is an i-v converter (20A/20V), which gives output in terms of voltage and can be fed to the microcontroller directly. Step down transformer is (220V/6V). The output of these transformers will vary proportionately with respect to its input. The microcontroller senses the voltage, compares with the reference value and sends control signals to the respective protective relays. The overall system is cheap and reliable. It has been tested several times and gives the good results. A three phase inverter is designed to run the motor in emergency cases. In the event of single phasing the rectifier is connected to remaining two phases and the output is given to three phase inverter which converts the dc power into three phase ac supply. Six pulses are designed to give control signals to six MOSFETs of the inverter through the ATmega32 microcontroller. The output of the six gate pulses for the inverter have been checked on the CRO and the results are satisfactory. In this protection system, the limits for the voltages and currents have been taken as $\pm$10% and $\pm$30% respectively for 3 seconds. If any phase voltage or current goes beyond its limit, the microcontroller will send trip signal to all the three relays simultaneously so that the motor is disconnected from the power supply. In case of single phasing, the relays gives the supply to the rectifier and the power is given to the motor through inverter circuit. RCD snubber circuit is used to protect the MOSFET against voltage transients.

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LIST OF ABBREVATIONS

NEMA	National Electrical Manufacturer Association
IEEE	Institute of Electrical and Electronics Engineering
IEC	International Electrotechnical Commission
NEC	National Electric Code
Vp	Positive Sequence Voltage
Vn	Negative Sequence Voltage
1-ϕ UV	Single Phase Under Voltage
2-ϕ UV	Two Phase Under Voltage
3-ϕ UV	Three Phase Under Voltage
1-ϕ OV	Single Phase Over Voltage
2-ϕ OV	Two Phase Over Voltage
3-ϕ OV	Three Phase Over Voltage
1-ϕ A	Single Phase angle displacement
2-ϕ A	Two Phase angle displacement
RTD	Resistance temperature detector

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CHAPTER – 1
INTRODUCTION

1.1 Overview

Induction motor is the most widely used motor in the industry due to its simple and rugged construction. It requires least maintenance as compare to the other electrical motors. Induction motor speed control is nowadays more easy and versatile due to the advancement in the field of power electronics and hence is easy to replace other costly and controllable motors. The protection of induction motor plays an important role in its long life service.

Researchers have done costly and limited protection for the stator windings protections, broken rotor bars protection, thermal protection etc. Mainly the induction motor needs protection from the variation of the input supply for small motors which is in common use not only in big industry but also in small scale industries. The small scale industries are not able to provide costly protection to the drives in use as it will increase their capital cost. Hence a cheap and compact design has been done for protection of induction motor against unbalance voltages, under voltage, over voltage, short circuit and thermal protection. It has been also designed for critical loads which need to be run even under single phasing condition. Due to the poor power quality the damage of induction motors in small scale industries needs to be taken care of.

The proposed design can be also used for speed control, improvement of efficiency under poor power quality service manually by introduction of a single two way switch. Many researches has been done in this area but they are costly and unfeasible in our Indian condition. The overall cost of the protection equipment should not be more than 15% of the total cost of the actual machine. Keeping this in mind the design has been proposed using 16-bit microcontroller, MOSFETs, relays, small CTs and PTs, so that the overall cost is low. But the efficiency of the protection scheme should not be compromised.

1.2 Literature Review

William H. Kersting [1] stated that three phase induction motor can continue to run when one phase of the supply gone out of service. This may be due to any fuse blowing or opening of protective device of the motor, at step-down transformer or at feeder end. At this condition the three-phase induction motor continue to run but the motor will heat up quickly and it should be protected by removing it from the service at the instant of single phasing. When phase opens at step down 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 as compare to steady state losses and the shaft power reduces to nearly 70%. To protect the motor all the terminal should be open.

Sutherland P. E. and Short T.A. [2] described that the for single phase fault the three phase reclosers are widely employed on distribution feeders. The majority faults are single phase. Its negative effect occurs on the other two phase customers, because the distribution line is mainly supplying the load to single phase customers. If three phase reclosers did not open from the service, and the problem arises for three phase industry. On an average single phase fault occurs at 70%, two phase fault occurs at 20% and three phase fault occurrence is 10%.

Sudha M. and Anbalagan [3] proposed a technique to save the three phase induction motor from single phasing. In this technique, PIC16F877 microcontroller has been used to sample the values of each phase and converted them to low voltage ac by means of transformer. The signals are converted to digital value using ADC converter. The controller continuously compare the digital value with the reference value and when the fault occurs, it opens the normally close contactor and disconnects it from the power supply. Single phasing, under voltage and over voltage protection is done practically on a 2kW motor and the motor is isolated if any of these condition occurs.

Pragasen Pillay *et.al.* [4] examines the three phase induction motor under the influence of under voltage and over voltage. The voltage at motor terminals may be higher than the 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 defined the voltage unbalance. The complex algebra is avoided in these definitions. In this paper calculation of the unbalance of voltage have been done on true basis with complex algebra and compared with NEMA standards.

Faiz J. *et.al.* [5] has studied the negative impact of the unbalanced voltages on the performance of three phase induction motor. In this paper the comparison of the voltage unbalance definitions of NEMA, IEEE and IEC (International Electrotechnical Commission) has been done. The studies showed that the definition given by the NEMA, IEEE are simple to calculate as compared to IEC. But all the three give only an idea about the percentage unbalance and needs to be modified.

Javed A. and Izhar T. [6] have proposed the protection of three phase induction motor based on voltage measurement and is not enough to protect the motor if the fault occurs at distribution transformer or at substation feeder. 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. They have also proposed a phase measurement device which can measure the phase difference of the voltages because when the fault occurs at any other location rather than the motor terminals, then the faulted phase will draw negative sequence current and work as a voltage generator. The voltage developed is close to line voltage but the measurement scheme is not able to detect the fault, however the phasor difference of the faulted phase changes.

Chattopadhyay *et.al.* [7] analysed the stator current of three phase induction motor by using different techniques. The single phasing can also be measured by the zero crossing detection method and has proposed to use 8085 microprocessor for doing this work. The accuracy can be increased by increasing the sampling time. The phase shift can also be measured by the use of microprocessor. The phase shift helps to protect the motor from any increased or decreased phase difference.

Lee Ching-Yan [8] described the effect of unbalanced voltages on the three phase induction motor. All the possible under voltage and over voltage effects are discussed. The worst cases of 3 phase under voltages affect the efficiency of motor. Positive sequence voltage and negative sequence voltages effects the power factor and efficiency. The derating of the motor is suggested incase of the voltage unbalance according to the NEMA MG1 Standards.

Ransom D. L. and Hamilton R. [9] studied the effect of thermal issues. Thermal effect can shorten the life of motor. The starting and running of motor with reduced voltage affects the thermal insulation of the motor. Thermal relay settings are described according to the different type of starting.

Stone G.C. *et.al.* [10] stated the numerous problem related to the design of the electrical machines. Due to global business, it increases the competition between the manufacturers. They have reduced the cost of the machine by reducing the size of the motor for same output. In the last century the W/kg. ratio is increased 14 times. The failure of the motors which had manufactured by the top companies in the last ten years has also shown increased failure rate as compared from the previous 50 years.

Cunkas A. *et.al.* [11] described the protection of the induction motor under various conditions like over voltage, under voltage, voltage unbalance and over current using PIC16C84 microcontroller . Potential transformer and current transformer are used for this process. Later the values from these transformer are converted into digital values using ADC converter. The tripping circuit has been given some delay.

Venkataraman B. *et.al.* [15] presented the thermal protection algorithm for the induction motor. Motor failure rate has been shown in IEEE and EPRI study. Different protection methods has been discussed. Technique to protect the motor from overheating for high load inertia has been described with real case example. For a complete motor protection system the designer should review the electrical, mechanical and physical properties of the motor.

Lin B.R. *et.al.* [16] described the ZVS converter with center tapped rectifier. Secondary side of the center tapped rectifier is used to get full wave rectified output. Voltage stress and current stress on converter are studied. Clamped circuit has been used to improve the effectiveness of converter.

Rao G.S. *et.al.* [20] stated the technique to run a three phase squirrel cage induction motor with single phase supply with higher speeds or with variable speed using electronic circuits. The induction motor are more efficient at light loads and the power factor correction method is an efficient method which is given by NASA in 1978. PWM control has been explained to run the three phase motor by three phase inverter and phase correctection method has been used to improve the power factor of the motor.

Basu K.P. and Mukerji S.K. [21] described connection for running a three phase induction motor with zig-zag transformer in case of single phasing condition. This paper presented that the three phase induction motor does not start in the case of single phasing, because negative sequence current does not allow to start the motor. For this, zig-zag transformer is suggested to connect with the motor.

Das J.C. [22] presented the effect of voltage dips on the induction motor. Induction motors may be stable on a certain magnitude of voltage dip for finite duration and it may be desirable to delay the trip circuit which may isolate the motor from supply. The various factors and effects of the voltage dips on the induction motor are described. Different type of protection scheme for induction motor are also explained and their tripping delay is described for finite duration of voltage dips.

Bayindir Ramazan [23] explained the three phase induction motor protection using sesnsors. PLC based protection has been employed and compared with PIC based protection. PLC has proved to be cost efficient. Need of ADC card has been eliminated by using PLC. PLC can be implemented on different kind of motors by applying small changes.

Kastha D. and Bose B.K. [24] investigated the faults of voltage fed inverter system for the three phase induction motor. Different fault modes has been discussed that can occur in PWM inverter system employed for the induction motor. Different types of fault probabilities regarding to fault in inverter system, has studied in this paper. The fault tolerant level is discussed to improve the reliability of the inverter system.

Maier Reinhard [25] presented the protection of squirrel cage induction motor and utilization the instantaneous power for the motor. Protection scheme for starting condition and running condition has been discussed. The method presented the ground faults, short circuits, interim fault and phase failure. It is sensitive to small deviations in voltage and load changes.

Kernstock Harald and Plassneggar Bernd [26] proposed that efficiency of the motor can be increased with low conduction and switching losses during inverter operation. Resonant circuit has been employed for the soft-switching of the MOSFET. The technique has been employed on a three level inverter. Result of hard switching and soft switching has been compared. Soft-switching shows less conduction and switching loss.

Bellini A. *et.al.* [27] discussed the previous ten years papers published on protection schemes for three phase induction motor. Research activity completed the study of electric faults, mechanical faults, signal processing for monitoring the induction motor and artificial intelligence approach for decision making. It has been suggested that the induction motor should be fully diagnosed for good protection.

Gomez J.C. *et.al.* [28] stated the effect on three phase induction motor of short interruption of power supply and voltage sags. Extremely deep voltage sag proves the worst case for the three phase induction motor. In most cases the short time voltage sags donot effect on the induction motor. The protection system should be designed in a way that the motor should not restart in a non-interfering fault.

Christopher W.I. and Ramesh R. [29] presented the hardware design of a nine-level inverter controlled by microcontroller. This technique has been employed to reduce the overall system cost. Microcontroller capabilities reduced the number of components required and made the system small in size and cost effective.

Julian A.L. *et.al.* [30] presented a scheme to apply a standby system for VSI controller. A secondary standby system can make the system reliable when primary VSI controller fails during operation. The controller has been implemented on different FPGA boards. Two boards communicate with each other during normal process and during fault on the primary board, secondary board override the primary board.

Lai J.S. *et.al.* [31] described the soft-swtiching technique for the inverter to overcome the over-voltage and over-current problem. In this inverter a single auxiliary switch and an inductor per phase is employed to produce zero voltage across main switch. Various techniques has been described to protect the MOSFET from switching voltages spikes. MOSFET protection is described with use of inductors for single phase and three phase inverter.

Li Tin-ho *et.al.* [32] investigated the Gate drive ON resistance losses of MOSFET snubber diode. Switching losses and different characterstics of the snubber circuit for the MOSFET protection has been studied. The experimental results are shown on 1kW, 230 V motor. On a single phase inverter, the sequence step are followed to describe the each part of the inverting process.

Al-Nasseir J. *et.al.* [33] described the RCD and RLD snubber circuit for the inverter circuit. RCD and RLD snubber circuits are designed on a three-level inverter. The results are compared with and without these snubber circuit. According to results, circuit without snubber circuit has many switching states and with snubber circuit the switching are reduced. This helps to reduce the false triggering of MOSFET and it helps to reduce switching losses.

Hanna R. and Schmitt D.W. [34] presented the failure analysis on a 7500 HP induction motor. Study shows that the small mechanical damages may not interrupt the motor normal operation. Comparison has been done between direct on line starting and soft starting. Historical data of the motors has been studied to show the various electrical and mechanical fault.

U-Yaison C. *et.al.* [35] presented the RCD, RLD, RCD-RLD snubber circuit for the MOSFET to reduce the spike voltages, di/dt during turn on period, over voltage, power loss and EMI emission during conduction. RCD, RLD and RCD-RLD snubber circuit are explained and compared. RCD-RLD circuit gives satisfactory results for inductive load and the switching losses are reduced. RCD can also be used to protect the MOSFET for low frequency switching pulses.

1.3 Objectives of the Thesis Work

The main objective of the work is to make a cheap and reliable protection system for three phase induction motor. The protection system should protect the motor from voltage unbalancing, single phasing, under voltage, over voltage and thermal protection. Further to improve the technique to run the motor under single phasing.

1.4 Organization of the Thesis

The thesis is organized into six chapters. The contents of these chapters are summarized as:-

Chapter 2 introduces the fault diagnosis for three phase induction motor.

Chapter 3 covers the protection techniques of the three phase induction motor.

Chapter 4 summarizes the implementation of protection of three phase induction motor.

Chapter 5 covers the technique to run the motor under single phasing fault.

Chapter 6 summarizes the conclusion of the work.

CHAPTER - 2

FAULT DIAGNOSIS FOR THREE PHASE INDUCTION MOTOR

2.1 Different kinds of Fault :

Induction motors are the workhorse for the industry because of its versatility, ruggedness and low manufacturing cost. Induction machines are the reliable machines but their failure rate is approximately 3% and it can be as high as 12% in pulp and paper industry. Downtime of the machine in industssstry may be expensive. The protection system may enhance the reliability, personal safety and protect the motor from over heating. The external motor troubles are described in four groups :

i) Single phasing effect [1]

ii) Unbalanced voltages and frequency

iii) Overloading and Starting effect

iv) Maintenance, environmental and manufacturing effect [3]

2.2 Single phasing condition :

If the condition of single phasing arises during the running of motor, the winding of motor gets heated due to the negative sequence current in the faulted phase. 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 internal connection of three phase motor are connected with each other. Single phasing fault may arise at three locations :

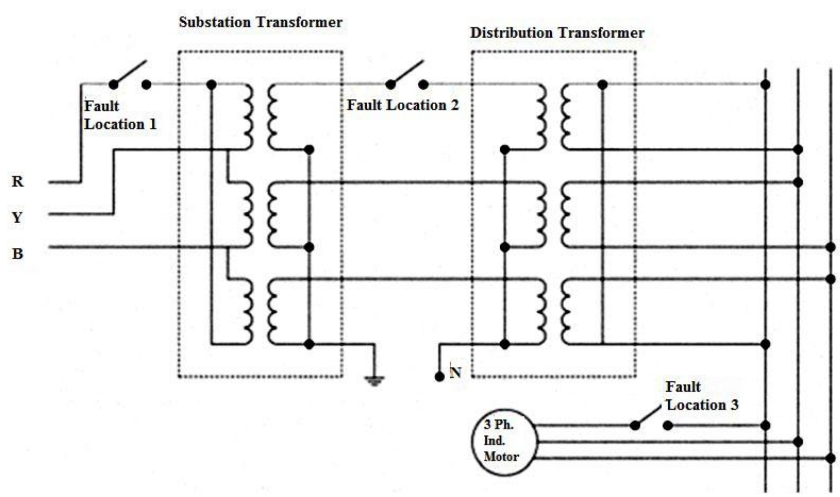


Fig. 2.1 Fault locations of single phasing

Fault Location 1 : Opening one phase of the primary side of substation transformer

Fault Location 2 : Opening one phase of the primary side of distribution transformer

Fault Location 3 : Opening one phase at the motor terminals [1]

2.2.1 Phase opening at substation or distribution transformer

Out of these three fault locations, the most severe condition is when phase opens at distribution step down transformer or at substation feeder end. The current goes to ten times higher. The shaft output power also approaches to negligible.

If the condition of single phasing arises when the motor is in running condition, the motor continues to rotate but it is not capable of starting under single phasing condition. If we allow the run the motor in this condition, then the motor will heat up very fast and we should remove the motor from the service. If any overload protective device is provided to isolate the motor from the main supply during single phasing condition and if it later attempts to start the motor during single phasing then it will draw locked rotor current which is 6-8 times of normal running current. It will permanently damage the motor. Single phasing is worst than the unbalance voltages[3].

When the fault occur at the substation end or at distribution transformer, it raises one more problem for the voltage magnitude fault detection devices located at the motor terminals. As when the fault occur at any one phase at substation 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 same of the line voltage[6]. The high current will damage the winding insulation and the motor will permanently damage. This makes a problem for the voltage sensing protective devices. A schematic diagram is shown if the Single phasing occurs at feeder end or distribution secondary winding :

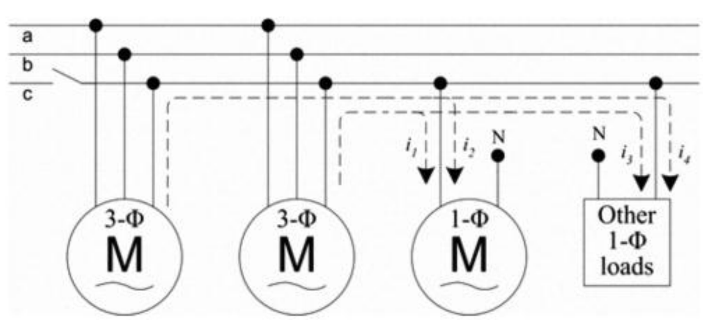


Fig. 2.2 Single phasing at feeder end or at distribution secondary winding

As shown in the figure 2.2, 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 fault occurs other then 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. Third phase will get negative sequence current and the voltage is generated nearly to the line voltage. The generated voltage is not in the 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, 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. The 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. So no protection device with voltage and current sensing will work at single phase load, if it is connected to the faulted phase [6].

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. So with the voltage sensing protection device, the current sensing protection proves better protection.

If fault occurs at primary of wye-wye transformer then the secondary winding line to ground voltages of one phase will show 0 p.u. and the rest two winding will show 1 p.u. but in case of delta-wye line to ground voltages will be 0.58 p.u., 1 p.u. and .58 p.u. This means that in case of delta-wye transformer, all the three phase will show voltages but the two phases will give lower voltages. In wye-wye transformer, the secondary of two phases will give rated voltage but the faulted phase will show zero voltage.

If the distribution transformer of wye-wye winding then the single phasing condition can be easily measured because one phase will show 0 p.u. But in case of delta-wye transformer the single phasing condition cannot be measured efficiently because two of the three phases of the secondary winding will show .58 p.u. voltage. Current measuring device with voltage measuring device can protect the motor effectively.

2.2.2 Phase opening at motor terminals

If fault at motor terminals is not much severe as compare to previous case. The current rises two to three times if the phase opens at motor terminal and shaft power output decreases to nearly 70 percent. The windings will heat up quickly and all the phases should be isolated from the power supply.

2.2.3 Basic protection from single phasing

Motors are extremely sensitive to voltage unbalance. The negative sequence stator current sets up counter rotating flux field in the motor and causes the local heating in rotor iron. The motor heats up rapidly about 25-30% as compared to balanced condition, due to negative sequence currents. It is recommended that the protective relay time delay set under single phasing conditions should be 4 seconds. Multilin 469, a typical relay trips at a current imbalance of 40% or greater than nominal value with 2 seconds delay [22]. In three phase rectifier, during single phasing the current in the remaining two phases may increase to two to three times [2]. In DC drives, which uses controlled rectifier, the mis-firing of the SCR, commutation failure etc. occurs. Ferroresonance can occur due to single phasing in transformers due to capacitance in the cable fed line and results high voltage as much as 5 p.u. can occur on the open terminals of the transformer which can damage metal-oxide surge arrestors. Ferroresonance also occurs at low core loss transformer because capacitance power is not fully dissipated in core resistance when single phase fault occurs. Ferroresonance in transformer can be avoided by grounded wye transformer.

2.2.4 Advantages and disadvantages of single phasing prevention recloser

If any single phase fault occurs on the distribution transformer, we have one option to trip the single phase and allow the other two phase because all the three phases are connected to the different single phase customers and some three phase customers. The second option is to close all the three phases. Both of them have some advantages and disadvantages. If we close the one phase, the single phase consumer connected to other two phases will not be interrupted but the three phase customer will face adverse effect on its three phase machine. The three phase load will get damaged if it is not disconnected from main supply. On the other side, if all the three phases are closed, then the both single phase customer and three phase customer will face power outage till the fault is not cleared [2].

2.3 Unbalanced voltages and frequency :

When the three phase voltages have different magnitude and phase angle is not accurate with 120 degree difference, it is called unbalanced voltage. According to NEMA MG1-2009 standard the voltage variation should be in limit of $\pm$10% and $\pm$5% for frequency variation[12]. However more than 5% voltage is not recommended by NEMA (National Electrical Manufacturer Association Motor and Generator Standard) guidelines [4]. This effects the insulation life of winding, reduce efficiency, increase losses and increase temperature with in the motor.

2.3.1 Definitions of Unbalance voltages :

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

$$\text{Voltage Unbalance \%age} = \frac{\text{Maximum deviation of voltage from average voltage}}{\text{Average voltage}} \quad \text{….. (2.1)}$$

In equation 2.1. as per NEMA guidelines the voltages are line voltages. IEEE guidelines uses the phase voltages with this same formula. It may be seen that both guideline did not mention the phase angle between the voltages [5]. This may be due to remove the complexity in the calculations [4].

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

$$Vp = \frac{V_{ab} + a^*V_{bc} + a^{2*}V_{ca}}{3} \quad \text{….. (2.2)}$$

$$Vn = \frac{V_{ab} + a^{2*}V_{bc} + a^*V_{ca}}{3} \quad \text{….. (2.3)}$$

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. We can calculate the positive and negative sequence current by :

$$Ip = \frac{Vp}{\sqrt{\left[\left\{r_1 + \left(\frac{r'_2}{s}\right)\right\}^2 + (x_1 + x'_2)^2\right]}} \quad \text{….. (2.4)}$$

$$I_n = \frac{V_n}{\sqrt{\left[\frac{r_1 + r'_2}{(2 - s)}\right]^2 + (x_1 + x'_2)^2}} \quad \text{….. (2.5)}$$

I_p = positive sequence current | I_n = negative sequence current

V_p = positive sequence voltage | V_n = negative sequence voltage

x_1 = stator reactance | x'_2 = rotor reactance

r_1 = stator resistance | r'_2 = Rotor resistance

s = slip

Another definition of voltage imbalance by the IEC is as follows [5] :

$$VUF = \frac{\text{Negative Sequence Voltage}}{\text{Postive Sequence Voltage}} \times 100\ \% \quad \text{…..(2.6)}$$

2.3.2 Derating of motor during voltage unbalance

When there is any unbalance in the voltage, according to NEMA guide lines, there should be derating of the motor. The motor should be derated, because unbalance voltage introduce the negative sequence current and the current heats up the winding. If the motor is allowed to the rated torque, it will draw more current then the rated current. So to avoid te over heating, the motor should be derated. For example, if the unbalance voltage reaches the value of 5% then the motor should be derated to 77% of its original value. For a 90% undervoltage the derating should be 0.92 [4]. The derating chart is also drawn by NEMA for the under voltage condition and the over voltage condition. The figure for derating of motor during unbalance voltages is given below [13] :

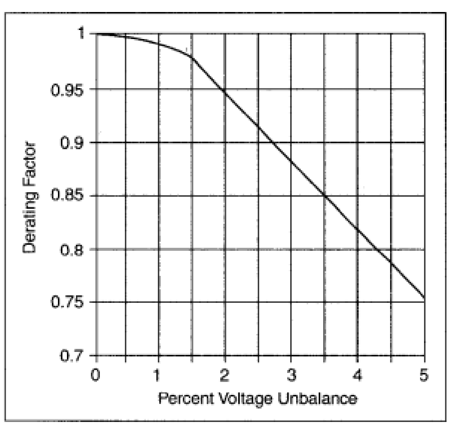


Fig. 2.3 Derating of motor during unbalance of voltages

2.3.3 Effect of voltage unbalance on power factor and efficiency of motor

When VUF occurs, Undervoltage and overvoltage also effects the power factor and efficiency of the induction motor. Power factor decreases as the voltage increases and the efficiency increases as the voltage increases.

But the efficiency described on the name plate is always higher whether the case is under voltage or over voltage. For the customer's view if there is any efficiency reduction due to voltage unbalance, he has to pay more electricity bills for the same work and for the utility point of view, they have to generate more power. The efficiency decreases very fast in the case of 3-phase under voltage.

Table 2.1 Comparison for eight unbalance voltages in terms of efficiency and power factor

	VUF	**Efficiency (%)**	**Power factor (%)**
Balanced condition	0	83.8	83.1
3-ϕ UV	4	80.532	85.3
2-ϕ UV	4	81.382	84.7
1-ϕ UV	4	81.506	83.89
2-ϕ A	4	82.254	83
1--ϕ A	4	83.041	82.9
1-ϕ OV	4	83.225	81.6
2-ϕ OV	4	83.402	81.2
3-ϕ OV	4	83.584	80.8

The efficiency decreases negligible in case of 3-phase over voltage. Under-voltage reduce the efficiency and cost increases. However in some cases, lower VUF may result into lower efficiency. The customer installs capacitors to improve the power factor in balanced condition and in under voltage condition the power factor improves higher than required, it may result in over voltage [8].

In case of three phase under voltage the power factor increases and efficiency decrease. This means that the customer have to run the motor for extra time for same kind of work. This will cost him extra. For example, a survey in Taiwan on three phase induction motors by ministry of economic administration shows that there were approximately 2 lakh induction motors running with power capacity of 1-5 HP. The calculation is done by taking 3HP motor an average in table 2.2. VUF is taken as 4% & cost is taken as 7 Rs./kWh.

Table 2.2 Cost increase for same work due to decrease in efficiency

Voltage unbalance cases	Total installed capacity(kW)	Motor efficiency (%)	Load increase rate (LdIR)	Extra power consumption per year (kW/yr)	Average running time per year (Hour)	Extra electricity consumption per year (kW/yr)	Extra electricity charge per year (Rs.M/yr)
balanced	534000	83.8	1	0	2500	0	0
3-ϕ UV	534000	80.532	1.04058	21669.72	2500	54174300	379.22
2-ϕ UV	534000	81.382	1.029701	15860.33	2500	39650825	277.55
1-ϕ UV	534000	81.506	1.023816	12717.74	2500	31794350	222.56
2-ϕ A	534000	82.254	1.018786	10031.72	2500	25079300	175.55
1-ϕ A	534000	83.041	1.009132	4876.48	2500	12191200	85.33
1-ϕ UV	534000	83.225	1.0069	3684.65	2500	9211625	64.48
2-ϕ UV	534000	83.402	1.004763	2543.44	2500	6358600	44.51
3-ϕ UV	534000	83.584	1.002578	1376.65	2500	3441625	24.09

According to British Standard BS-4999, general requirements for the electrical rotating machine for giving optimum output is to keep below the VUF from 2% where as for NEMA MG1 the VUF must be below 5% [13].

The negative sequence voltage has very little effect on the power factor as compare to the efficiency of the motor. If we maintain the positive sequence voltage at 127 degrees and vary the negative sequence voltage from 1% to 7%. The effect is shown below [8]:

Table 2.3 Effect on negative sequence voltage on power factor and efficiency of 3 ϕ induction motor

VUF	Vp	Vn	efficiency	Power factor
0 %	127	0	83.8	83.1
1 %	127	1.27	83.63	83.04
2 %	127	2.54	83.55	82.98
3 %	127	3.81	83.3	82.95
4 %	127	5.08	82.97	82.91
5 %	127	6.35	82.72	82.86
6 %	127	7.62	82.38	82.74
7 %	127	8.9	81.96	82.62

However the efficiency reduces significantly with negative sequence voltage. The efficiency has a great impact on the cost because efficiency reduction means more time to complete the same work. So the negative sequence voltage should be as low as possible. Overheating also occurs when there is any unbalance in voltages. The worst case is when the voltage is unbalance with 3 phase under voltage. The rise in temperature is very fast in 3 phase under voltage and very low in case of 3 phase over voltage unbalance [8].

2.4 Overloading Effects :

Overloading of the three phase induction motor can produce hot spot within the winding, which may exceed the thermal limits of motor. Time is a very important factor in case of over temperature. Induction motor has a relatively large heat storage capacity, so a short period overload cannot damage the motor windings because a large part of heat is stored in the core, conductor mass and in structural members [12]. But in the case of locked rotor condition the current rises very rapidly and a very little amount of heat transmits to the other parts of the motor. The winding insulation thermal level may reach to its limit within seconds.

2.4.1 Design of polyphase induction motor according to NEMA MG1 standard :

According to NEMA :

i) The stator current of the induction motor should be capable of withstanding 1.5 times of rated current for not less then 2 minutes[13].

ii) If motor is designed for different frequency system then it can be used to some another frequency system only if its horsepower and voltage ratings are set according to volts/hertz.

iii) The locked rotor current should be withstanding capability upto 12 seconds by the motor.

National Electric Code (NEC) (NPFA 70-2011) has defined the trip for the 125% of rated current for the continuous motors. There are several NEMA design depending upon the speed, voltage, horsepower rating, service factor etc. for low and medium voltage motors. The designs are A, B, C, D and E. Locked rotor current, Pull up torque, Break down torque, slip, Locked rotor torque, Slip, Efficiency and typical applications for the polyphase induction motors are given in table 2.4 [13].

Table 2.4 Typical characteristics for the polyphase induction motors according to NEMA

Polyphase characterstics	Locked rotor torque (% rated load torque)	Pull-up torque (% rated load torque)	Break-down torque (% rated load torque)	Locked rotor current (% rated load current)	Slip (%)	Typical applications	Relative effici-ency
Design A Normal locked rotor torque and high locked rotor current	70-275*	65-190*	175-300	Not defined	0.5 - 5	Fans, centrifugal pumps, blowers and motor generator sets, compressors etc., where starting torque requirements are relatively low	Medium or high
Design B Normal locked rotor torque and high locked rotor current	70-275*	65-190*	175-300*	600-800	0.5 - 5	Fans, centrifugal pumps, blowers and motor generator sets, compressors etc., where starting torque requirements are relatively low	Medium or high
Design C High locked rotor torque and normal locked rotor current	200-285*	140-195*	190-225*	600-800	1 - 5	Conveyors, crushers, reciprocating pumps, compressors and stirring machines etc., where starting under the load is required	Medium
Design D High locked rotor torque and high slip	275	Not defined	275	600-800	$\geq$5	High peak load with or without flywheels like shears, punch presses, hoises, elevators, winched, extractors, weire-drawing machines and oil-well pumping	Medium
IEC Design H High locked rotor torque and high locked rotor current	200-285*	140-195*	190-225*	800-1000	1 - 5	Conveyors, crushers, reciprocating pumps, compressors and stirring machines etc., where starting under the load is required	Medium
IEC Design N Normal locked rotor torque and high locked rotor current	70-190*	60-140*	160-200	800-1000	0.5 – 3	Fans, centrifugal pumps, blowers and motor generator sets, compressors etc., where starting torque requirements are relatively low	Medium or high
* Higher values for lower HP ratings.							

2.4.2 Effect of starting to avoid overheating :

Starting of the induction motor also effects the insulation deterioration of the winding. For medium to large induction motors the motors should be start at reduced voltages. Reduced voltage helps to reduce the starting current [12]:

Table 2.5 Different types of reduced voltage starter and its effects

Starter Type	**% Motor Voltage During Start**	**% Motor current at locked rotor**	**% line current at locked rotor**	**% torque at locked rotor**
Primary Reactor				
80% Tap	80	80	80	64
65% Tap	65	65	65	42
50% Tap	50	50	50	25
Auto Transfomer				
80% Tap	80	80	64	64
65% Tap	65	65	42	42
50% Tap	50	50	25	25
Wye/Delta Start				
Wye Start	58	58	33	33

Generally the motors are equipped with wye start because it has the nearly same effect as from the 50% tap from primary reactor and auto transformer. But the cost of wye starter is very less compared to auto transformer and primary reactor.

The starting of the motor also has a role of overheating of the rotor. If the starting of the motor is slow then the motor heats up quickly because it draw more current till it achieve the rated speed. This may be due to under-voltage condition. At zero speed, all the energy which crosses the air gap becomes heat. This is according to the law of conservation of energy. As the rotor speeds up the heat decreases [9]. So at the time of starting of motor the voltage should be appropriate as mentioned on the name plate of motor.

As per typical current and voltages from IEEE 620-1996, starting the motor at reduced voltages and continue to run at reduced voltages will achieve the rated current in large time [14]. This is shown in the figure 2.4 given below :

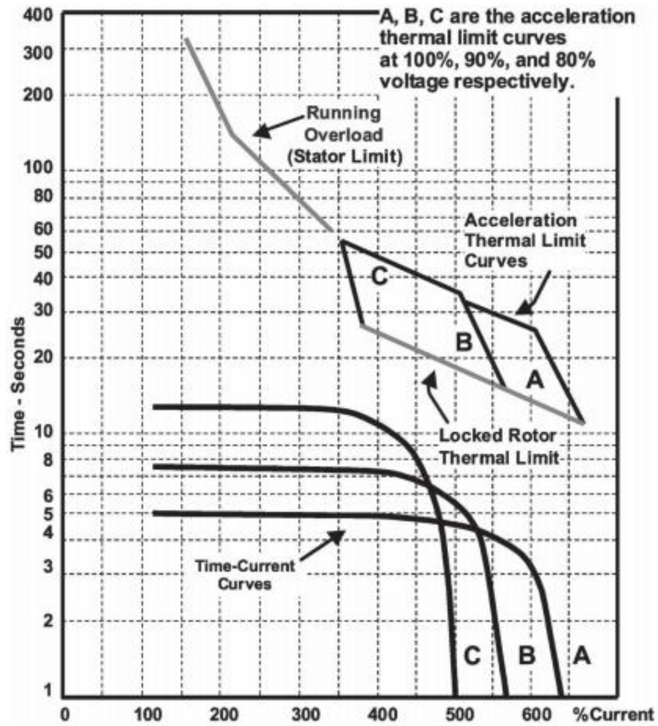


Fig. 2.4 Starting time at reduced voltage starter

As we know that the heat losses are directly proportional to the time and we have to reduce the time of low voltage starting. The starting current is 4 to 6 times of the full load current and the heat produced at starting is 16 to 36 times the full load thermal limit. If the rotor takes to much time to take the full speed, it will crosses the thermal limit. This makes the stator winding heat up beyond thermal limit.

2.5 Maintenance, environmental and manufacturing effects :

2.5.1 Ventilation effects :

Ventilation is necessary for the smooth operation of the motor because a 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.

2.5.2 Manufacturing effects :

Manufacturing and selling of the machines are now a global factor. This has increase the competition between the manufacturer. This has put pressure on the designers to reduce the cost of the machine. Some of the methods which they applied are :

i) Reducing conductor cross section area

ii) Reducing insulation thickness

iii) Reducing amount of steel core material

iv) Developing fast manufacturing techniques to reduce labour cost [10]

The data of previous years shows that the machine have more problems which are manufactured in the last ten years as compared to previous fifty years. We see the manufacturing designs of electrical machine as W/kg. W/kg. can be defined as the wattage of machine divided by the weight of machine. The W/kg. is 14 times increased in the last century, which shows that the manufacturers have reduced the weight of machine for the same power rating. Figure 2.5 shows the W/kg of the motors in the previous century [10] :

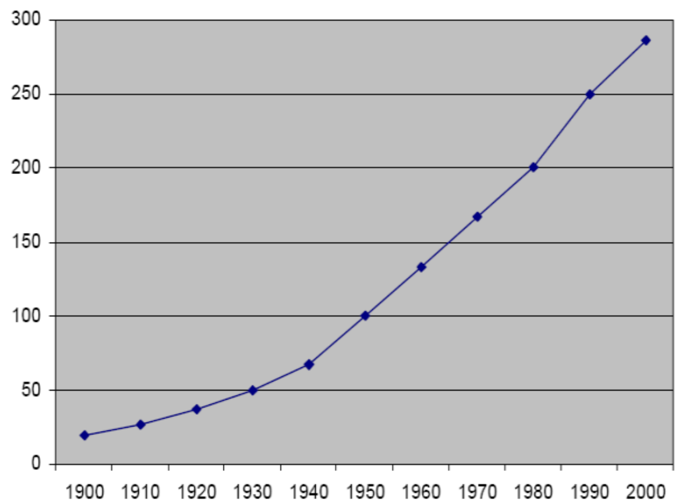


Fig 2.5 W/kg. of the motor v/s year of manufacturing

CHAPTER - 3

PROTECTION FOR INDUCTION MOTORS

3.1 Reason of failure

Stator winding insulation deterioration is the main cause of the failure of the motor. The insulation may be damage by dielectric stress, mechanical stress, thermal stress or excessive moisture in the winding. The dielectric and physical properties of the insulation system deteriorate with respect to time and it accelerates if the working temperature increases. As the thumb rule, for every increase in 10 degree Celsius temperature the life of the insulation decrease to half and if the operating temperature decreases to 10 degree Celsius then life increases two times [12].

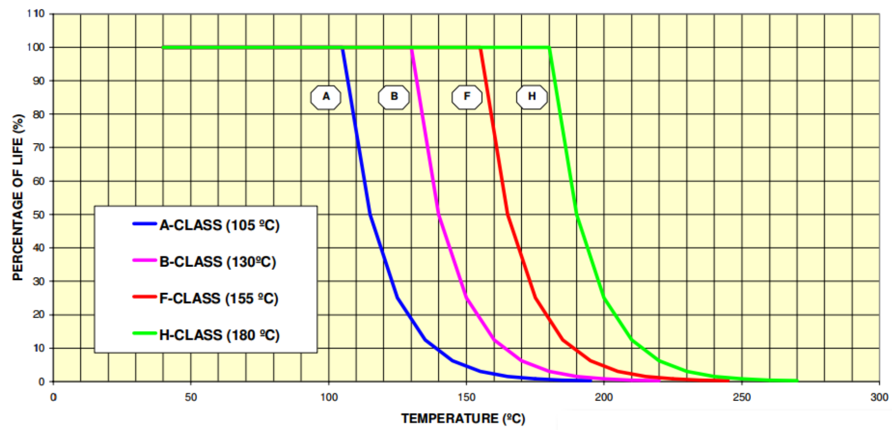


Fig. 3.1 Effect of temperature on the life of A, B, F and H class insulation [15]

There may be different type of reason for increasing the temperature in the winding like impulse switching, moisture, thermal degradation etc. But regardless of the reason, the motor should be protected by the elevated temperature that causes the insulation of winding.

3.2 IEEE Standard for insulation of squirrel cage induction motors

There are four classes according to IEEE-Std. 1-2000 standard for motors i.e. Class A, B, F and H. External air is used for cooling the motor and insulation table is given below at the maximum cooling air temperature of 40 degree Celsius. Cooling and external air for the three phase induction motor is necessary to remove the heat. If the heat increases beyond the thermal limit of the motor then it may damage the winding permanently. Excess heat also effect the insulation ageing. The insulation also deteriorate in case of motor overloading.

Three phase induction motor normally runs on overload for few times. Two tables are given with service factor 1 and service factor 1.15.

Table 3.1 Machine with 1.0 service factor at rated load

Item	Machine part	Method of temperature determination	Temperature rise (degree Celsius) Class of insulation system			
			A	B	C	D
a	Insulated windings					
	1. All horsepoert (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 insulation of the machine should not effected by any means due to the heat from cores, collector rings, squirrel-cage windings, brushes and brushholders etc.					

* Embedded detectors are located in the slot of motor and can be either thermocouples or resistance elements.

Table 3.2 Machine with a 1.15 service factor at rated load

Item	Machine part	Method of temperature determination	Temperature rise (degree Celsius) Class of insulation system			
			A	B	C	D
a	Insulated windings					
	1. All horsepoert (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 insulation of the machine should not effected by any means due to the heat from cores, collector rings, squirrel-cage windings, brushes and brushholders etc.					

* Embedded detectors are located in the slot of motor and can be either thermocouples or resistance elements.

3.3 Thermal Protection :

Report on industrial motor failures done by IEEE and EPRI shows that the most of the motor failures occur due to the overheating [15]. The reasons for motor failure is given in table 3.3 :

Table 3.3 Study on reason of failure by IEEE, EPRI

IEEE Study		**EPRI Study**		**Average%**
Electrical Related	30.6 %	Electrical Related	36 %	33%
Mechanical Related	30.7 %	Mechanical Related	32 %	31%
Abnormal frequency Abnormal voltage High Ambient Temp. Abnormal Moisture Poor Ventilation Abrasive chemicals Other reasons Total	0.6 % 1.5 % 3 % 5.8 % 3.9 % 4.2 % 19.7 % 38.7 %	Bearing Seals Frame Wedges Oil Leakage Other components Total	6 % 3 % 1 % 1 % 21 % 32 %	Maintenance, environmental and other related failure reasons 36 %

Modern techniques are making motor more efficient and compact in size. Using of fiber glass and silicon resins has improved dielectric capabilities as compare to cotton and varnish. But they are also more vulnerable to excessive heating. The overheating can also be avoid by setting the correct thermal limit of the relay. Sometimes the thermal limit is overestimated. The algorithm for designing the relay protection system can be achieved more precisely by using the microprocessor or microcontroller based protection system. The ideal device for looking the heating in the motor is the thermal image unit. We cannot use the sensors in the rotor part because of technical difficulties, cost and reliability. An additional reason is resistance temperature detector (RTD) has slow response in rotor unit as compare to stator unit. RTD does not give good results in fast thermal transients[21-23].

Alternatively current is the measurement tool for the heat measurement in the motor. Current and time gives the heat produced in the motor. For avoid over heating, NEMA MG1 Standard has given a derating of the motor in case of voltage unbalance. The derating is a tool to protect the motor effectively.

3.4 Protection techniques :

Three phase induction motor should be protected by different types of problem occurred in the power system. Some of these are sensed by the protective devices and trip the motor. This protection process can be done by different ways. Some of the techniques are discussed below [11]:

i) Step down transformer to detect the phase voltages

ii) Current transformer to detect the current

iii) Thermal senser to detect the temperature of winding

iv) Zero crossing to detect the phase difference between voltages and current

This can be done by using microcontroller [11] and microprocessors[7]. The protection device should be capable of voltage and current detection[6]. There are several other techniques which uses wavelet for finding the time difference between zero crossing and this helps to check the phase angle difference between them. The current measure protection is important because any phase fault occurance is detectable by measuring the current but there is a chance when voltage measurement device will not able to detect the phase failure. So voltage and current measurement made the protection reliable, if the motor is influenced by the fault, which may occurs at any location [6]. If the fault occurs at motor terminals then voltage measurement device may be suitable.

We should select the protection schemes based on the following factors [12]:

i) Horsepower rating and type of motor

ii) Motor supply characteristics like phases, voltage, grounding method, available short circuit current etc.

iii) Motor controller type

iv) Functioning and process nature which determine the importance of drive

v) Frequency of motor starting

vi) Environment of switching device, protecting device and motor

vii) Cost of protection unit compared to associated equipment

viii) Time vs current curve during starting

ix) Protection devices monitoring load process, like torque, vibration and some other mechanical limits

The requirement of different type of protective relay according to the voltage and power rating of motor is given below. The data is taken from IEEE guide for motor and NEMA standards and given in table 3.4 :

Table 3.4 Requirement of relay for low voltage motors by IEEE, NEMA

Ratings	**Range of ratings**	
Continuous amperes	9-250	…
Nominal Voltage (V)	240 - 600	…
Horsepower	1.5 - 250	…
Starter size (NEMA)	…	00 – 9
Types of protection	**Quantity**	**NEMA designation**
Overload : overload relay elements	3	OL
Short circuit: circuit breaker current trip elements	3	CB
Fuses	3	FU
Undervoltage : inherent with integral control supply and three phase wire control circuit	…	…
Ground fault (when specified) : ground relay with toroidal CT	…	…

Table 3.5 Requirement of relay for medium level voltage

Ratings	**Class E1 (without fuses)**	**Class E2 (with fuses)**
Nominal Voltage (V)	2300 - 6900	2300 - 6900
Horsepower	0 - 8000	0 - 8000
Symmetrical MVA interrupting capacity at nominal voltage	25-75	160-570
Types of protection devices	**Quantity**	**NEMA designation**
Overload : or locked rotor, or both :		
Thermal overload relays	3	OL
TOC relays	3	OC
IOC relay and time delay	3	TR/OC
Short circuit :		
Fuses, class E2	3	FU

IOC relay, class E1	3	OC
Ground fault :		
TOC residual relay	1	GP
Overcurrent relay with toroidal CT	1	GP
Phase Balance :		
Current balance relay (per motor), or	1	BC
Negative-sequence voltage relay (per bus) or both	1	…
Undervoltage :		
Three wire control circuit connected with control supply and trip the circuit when voltage falls sufficiently low	…	UV
Temperature :		
Temperature relay using thermocouple or resistance sensor	…	OL

CHAPTER - 4

IMPLEMENTATION OF THE 3 PHASE PROTECTION

4.1 Objective of protection

The objective of dissertation is to protect the three phase induction motor under single phasing fault. Block diagram of the protection technique is given below in fig. 4.1 :

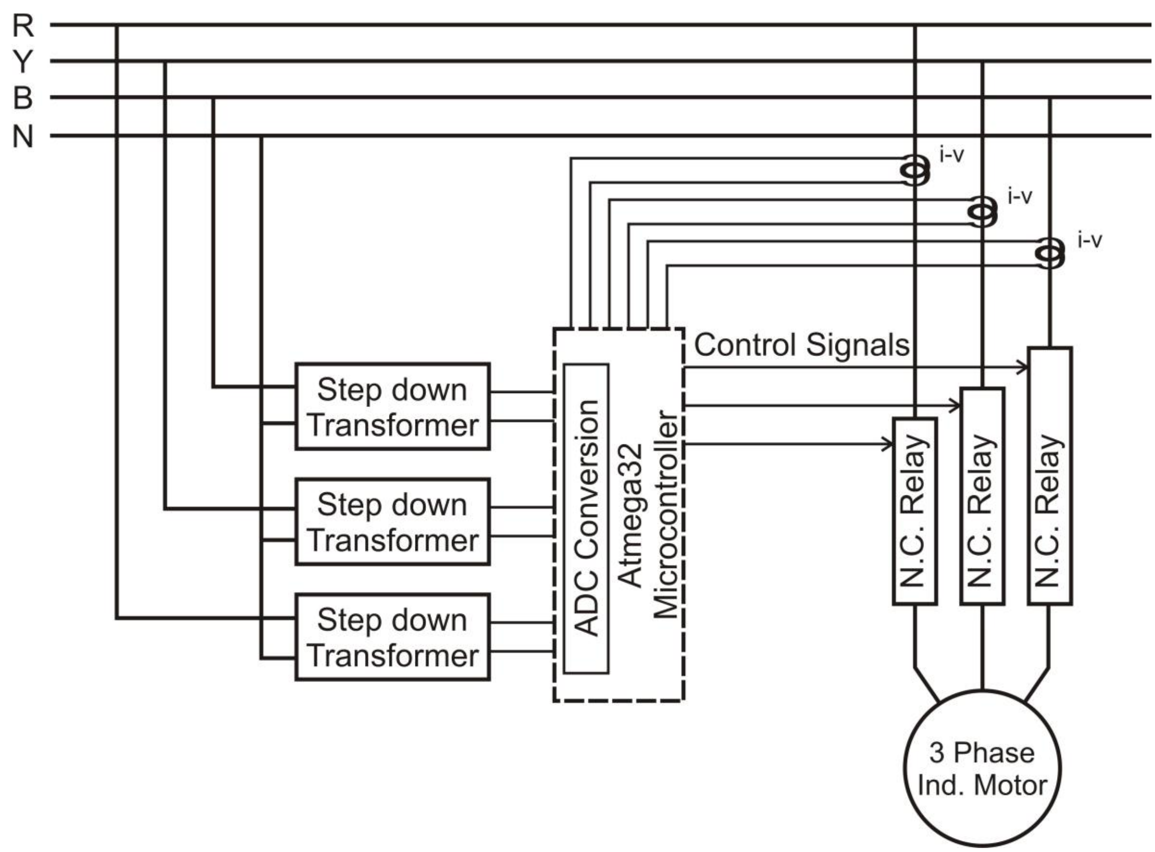


Fig. 4.1 Block diagram of Protection Technique for 3 Phase Induction Motor

In this protection technique we have :

i) 3 Step down transformers 6-0-6

ii) 3 Current transformers

iii) 1 Atmega32 Microcontroller

iv) 3 Normally Closed Relay

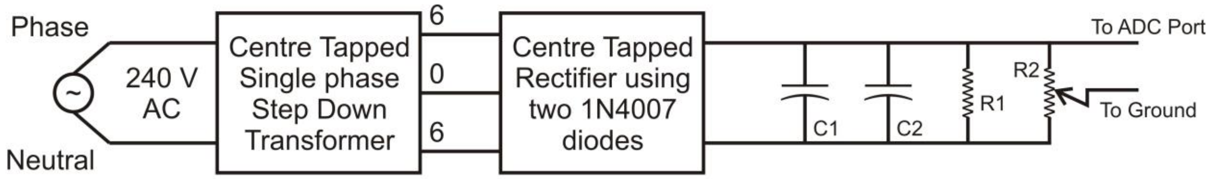
v) 3 MOSFET

vi) 1 9V Battery

vii) 5V Supply for microcontroller

4.2 Description and working of Step down transformer Unit :

Step down transformer unit gives the DC voltage to the microcontroller. The output of this unit changes proportionally to the input. Schematic Diagram of step down transformer unit is given in fig 4.2 :



C1,C2 - 10 V 1000 micro Farad Capacitor
R1 - 800kΩ, Half Watt Resistor
R2 - 20kΩ Potentiometer

Fig. 4.2 Schematic diagram of Step down transformer unit

4.2.1 Construction of Step down transformer unit :

Components used :

i) One centre tapped step down transformer from 240 V to 6-0-6 V

ii) Two 1N4007 diodes

iii) Two 10V 1000 micro Farad capacitors

iv) One half Watt resistor (800k Ohm)

v) One 20k Ohm potentiometer

a) Data sheet description of the centre tap transformer :

Input Voltage	240 V
Output Voltage	6 V
Current Rating	500 mA

b) Data sheet description of the 1N4007 diode [18] :

Peak reverse breakdown voltage	1000 V
RMS reverse breakdown voltage	700 V
Average rectified output current	1 A
Peak forward surge current for 8.3 ms	30 A
Peak reverse current	5 A

c) Data sheet description of the 10V 1000 micro Farad capacitor :

Maximum voltage	10 V
Capacity	1000 micro Farad

d) Data sheet description of the half watt resistor :

Resistance	800 k Ohm
Power dissipation	Half Watt

e) Data sheet description of the 20k ohm potentiometer :

Resistance	20 k Ohm
Type	PCB mounted

4.2.2 Working of Step down transformer unit

Three 240 V to 6 V centre tapped step down transformer has been used for the measurement of the phase voltage. Step down transformer is used because the microcontroller can only read voltages up to 5 V. The step down voltage is further rectified through centre tapped rectifier [16]. The centre tapped rectifier has ripples. We have use two 1000 micro Farad capacitor to reduce the ripples. One half watt resistor is also used across the terminal output of the rectifier to discharge the capacitor quickly. The output is connected across the potentiometer because the microcontroller can only receive the input below 5V. The output taken from the potentiometer is nearly 3V and multiplying factor taken as 80 to make it readable as 240V. This value is programmed into the microcontroller. When the input voltage of the step down transformer varies from 240 V, the input of the microcontroller will also vary proportionally. 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]. By taking this into account, the value of resistor across the capacitor is taken as half watt. Higher value of the resistor will discharge the capacitor fast and response of the input value for the microcontroller will fast accordingly to the change of voltages in the input of transformer. Output of the potentiometer is given to the ADC of the microcontroller.

4.3 Description and working of the i-v converter :

Manufacturer	Electroohms
Part No.	SCT 1052
Turns Ratio	1 : 2500
Ampere range (input)	0.25 – 20 Ampere
Output range	20V/20A

4.3.1 Working of the i-v converter:

Three current transformer are used for the protection of the three phase induction motor from over current. These current transformer are placed around the three phase windings of the motor. When the motor is in running condition, the magnetic flux is produced around the phase wires of the motor. These flux induces the voltage in the current transformer. This voltage is sensed by the microcontroller using ADC port. These voltages are compared with rated current value and programmed into the microcontroller when the motor is running in the healthy condition. The time delay is given 3 seconds in the programming because the starting current of the motor is normally 6-8 times higher then the running condition [13]. Delay time can be increased for different type of motors. The output of the current transformer is in mVs and it increases as the current through the motor increases. The output of the current transformer is directly coupled with the microcontroller ADC port.

4.3.2 Description and working of Atmega32 Microcontroller [17] :

Manufacturer	Atmel
Pins	40
Programmable Pins	32
ADC Channel	8 channels, 10-bit
Speed Grade	Up to 16 MHz
Operating Voltage	4.5 V – 5.5 V
Power consumption at 1 MHz	1.1 mA
Instructions execution per cycle	131
Timer	Two 8bit / One 16 bit

Working of Atmeaga32 microcontroller

Atmega32 Microcontroller has some good features as required for our project. It has 8 ADC inputs which can be used for our required 6 analog inputs [17]. There are two more ADC input left which can be used for further analog inputs. Inbuilt frequency of this microcontroller is 1 MHz and can be upgraded upto 16 MHz by using crystal oscillator. We can use 24 pins as output and 8 pins as ADC input. 8 pins are used for LCD display. 1 Pin is used controlling the relays.

4.4 Description and working of the relay:

Max. Voltage rating	300 V AC
Max. Current rating	7 A
Operation	N. O. / N. C.

4.4.1 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 will get the 5V signal from the microcontroller, it will connect the relay and the battery and relay will operate. The relay is connected in normally closed condition and it will open the circuit when it is energized. The energization takes place when the MOSFET will get 5V from the microcontroller. All the three relays are connected with this same description. All the MOSFET get the 5V from same pin of the microcontroller for enhance reliability. Schematic diagram of the relay is given in fig. 4.3

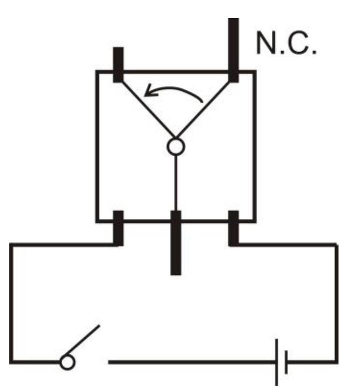


Fig. 4.3 Schematic diagram of Relay

4.5 Description and working of protection MOSFET :

Gate on voltage	3-5 V
Maximum Drain Source Voltage	55 V
Maximum Continuous Drain current	16 A
Power dissipation	5 W
Maximum Turn-on rise time	140 ns
Maximum Turn-off fall time	85 ns

4.5.1 Working of MOSFET :

MOSFET are used to remove the power supply through the microcontroller for the relay operation. The relay operation is done through the MOSFET and relay is isolated from the microcontroller. When MOSFET will get the signal from the microcontroller it will connect the power across relay and relay energizes. This is done because the current rating across the microcontroller is very small it cannot give the enough power to relays. The other reason is that the relays up to 50V DC can be used across the same design using this protection technique. So the MOSFET implementation in the design makes the protection system versatile for different range of three phase induction motor ratings. Layout of the MOSFET is given in fig, 4.4

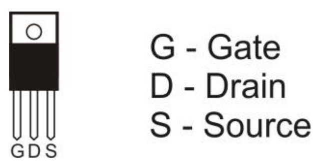


Fig. 4.4 Layout of MOSFET

4.6 Description of the battery :

Battery is required in this operation for giving the supply to the relays. The relays are in normally closed so we do not require power all the time from the battery but in the fault condition, the power will be supplied from the battery to energize the relay. The battery Ah rating is taken accordingly to the 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. In this protection system we have used the small 9V battery.

4.7 Description of 5V Supply for microcontroller :

Atmega32 Microcontroller needs 4.5V – 5.5V DC supply [17]. For this a 5V DC adaptor can be used to supply the microcontroller. The supply should be ripple free for the reliability and safety of the microcontroller.

4.8 Relay Protection with MOSFET :

MOSFET is used as a switch for the relay. MOSFET will get the signal from the microcontroller. Schematic diagram of the protection using Relay and MOSFET is given in fig, 4.5

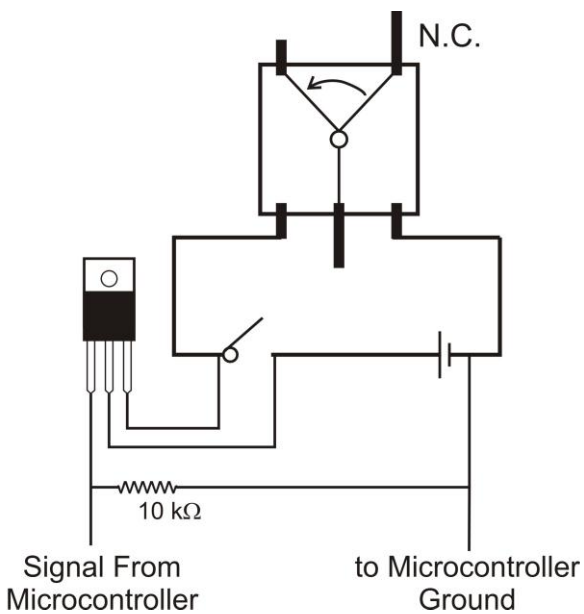


Fig. 4.5 Schematic diagram of protection using relay and MOSFET

Steps are given below of protection unit :

Step 1 : Values of the Voltage and Current are taken from the Voltage transformer and Current transformer respectively.

Step 2 : This values are given to the input of the ADC port of the microcontroller.

Step 3 : Microcontroller convert the ADC input into calibrated programmed values.

Step 4 : Microcontroller compares the values of voltages and current with the prescribed limits.

Step 5 : If the value goes beyond the prescribed limit, it will wait 500 ms and then again check the ADC input values.

Step 6 : If the values are still beyond the prescribed limit, it will send 5V signal to the MOSFETs else 0V to MOSFETs.

Step 7 : When MOSFETs will get the 5V signal, they close the circuit across the relay and battery. It energize relay.

Step 8 : When the relay energize, they will open the circuit between 3 phases R, Y, B and three phase induction motor.

Step 9 : Start from Step 1.

4.9 Results of the Protection system :

Fig. 4.6 Protection setup of Three Phase Induction motor

Fig. 4.7 Three Phase Induction motor running with protection system

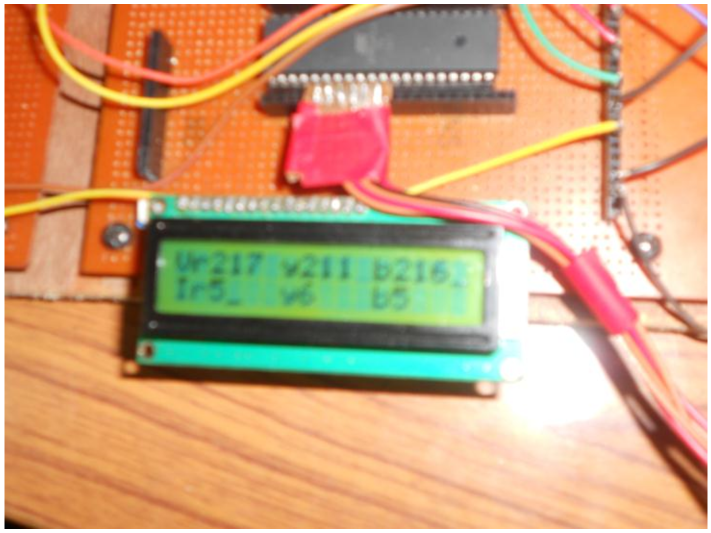


Fig. 4.8 LCD display showing the motor voltage and current

CHAPTER - 5

THREE PHASE PROTECTION WITH THREE PHASE INVERTER

5.1 Overciew

This technique is developed to protect the three phase induction motor from single phasing, under voltage, over voltage, over current etc. and to run the motor in case of single phasing condition by converting the available 2 phase supply into 3 phase supply using three three phase inverter. Microcontroller protect and control the whole system. Gate pulses for the inverter is given by microcontroller. The protection scheme is same as discussed in the previous chapter. Running the three phase motor from rest two phase supply is discussed in this chapter. Block diagram of this protection scheme is given in fig. 5.1 :

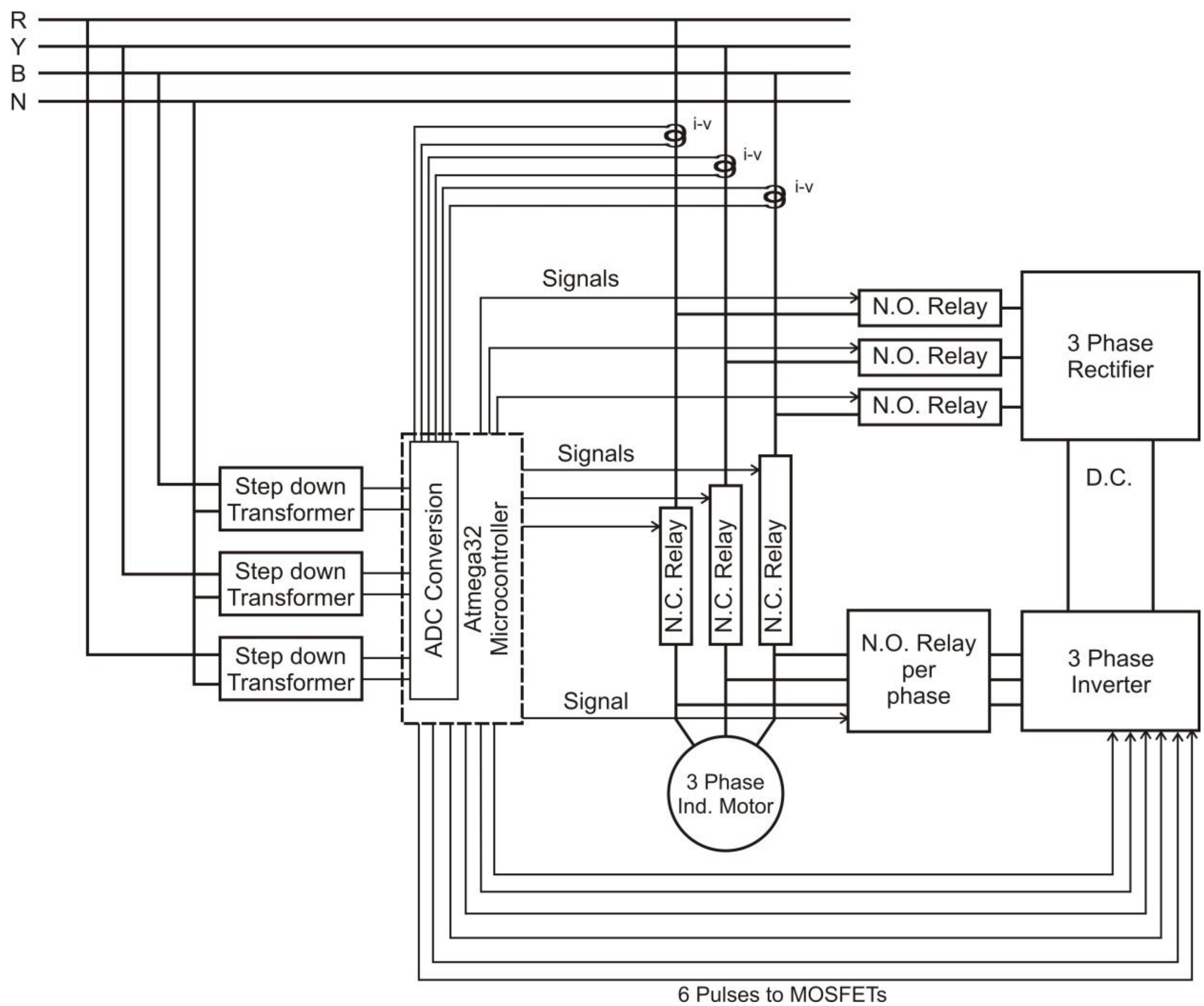


Fig. 5.1 Protection and running of three phase induction motor during single phasing

5.2 Description of the system :

Step down Transformer	3
i-v converter	3
Atmega32 Microcontroller	1
Relay N.C. / N.O.	9
3 Phase Rectifier	1
3 Phase Inverter	1
MOSFET P55NF06	6
MOSFET FQP6N40	6
Snubber Circuit	6

5.3 Protection of Three Phase Induction Motor :

The protection of three phase induction motor during various faults is same as discussed in previous chapter. In this technique reliability of the three phase motor is enhanced during fault condition. This is done by using the supply from left two phases during single phasing condition. Whenever a fault arises in one phase, the three phases are disconnected from the motor and the two phases are connected with the three phase rectifier. When two phases are connected with the three phase rectifier, it will rectify the two phases. The rectified output is connected with capacitors to remove the ripples. Then the DC output is given to the three phase controlled inverter. The inverter is designed with 6 MOSFET and the MOSFET are getting gate signals from the microcontroller. The output of the three phase inverter is connected across the motor after controlled relay. The gating signals for the inverter are programmed in the ATMEL Studio. The inverter design is based on 180 conduction [19]. Power requirement for the three phases of the induction motor will be provided by the two phases. Snubber circuit is also designed to protect the MOSFET from voltage spikes. Voltage spikes can easily damage the MOSFET. The other effect of the voltage spikes is false triggering. False triggering can result in short circuit. If both the MOSFET of same leg get signals at the same time, inverter will face short circuit. RCD snubber circuit is employed to reduce the voltage spikes. It also reduces the switching losses and protect the MOSFET from overheating. RLD snubber circuit can also be employed to reduce the current spikes[29].

5.4 3 Phase Inverter :

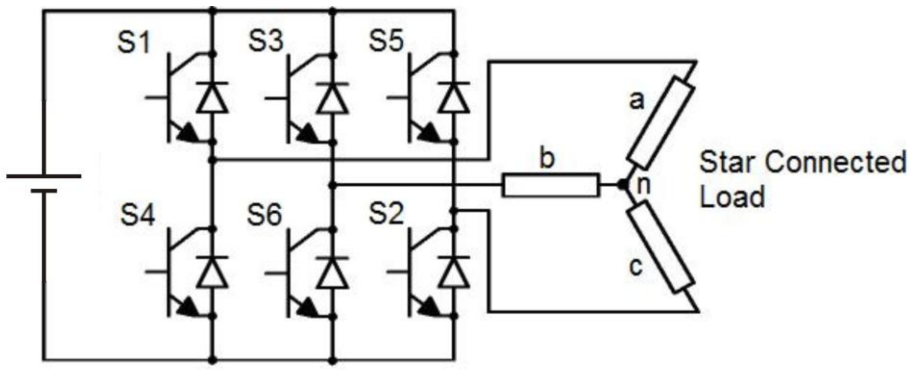


Fig. 5.2 Three phase inverter

S1, S2, S3, S4, S5, S6 – Switching devices

There are six switching devices in this 3 phase inverter. This inverter is controlled by external gate signals. These gate signals are programmed in microcontroller.

The gating signals are designed in a manner that both the switches in the same column does not get pulse at the same time. If they get the pulse at the same time then the circuit will get short circuited because the current will get minimum resistance path from positive end supply to negative end supply. If both the switches in one column do not get pulse at any time in a complete cycle then one of the star connected load will not get supply at all. So the gate pulses are designed in a manner that one of the two switches in a column will get a pulse at a time. It means at any time three switches will work and one in a column.

5.4.1 180 Degree Conduction :

There are six switching devices and the sequence of switching should be repeated after 360 degrees. For every positive half cycle the upper three switches S1, S3, S5 should work for 180 degrees and for every negative half cycles the lower three switches S4, S6, S2 should work for 180 degrees. This is given in fig. 5.3 :

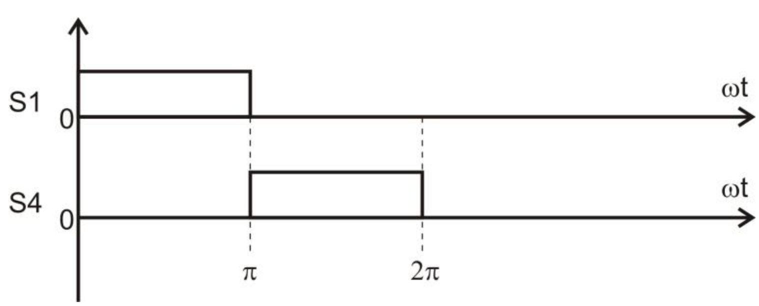


Fig. 5.3 Schematic conduction of one complete cycle of one phase

When switch S1 work for 180 degrees the conduction across load ‘a’ will be through ‘a’ to ‘n’ and when S4 work for 180 degrees the conduction across load ‘a’ will be ‘n’ to ‘a’ coming from load ‘b’ or ‘c’. All the switches will work for 180 degrees. All the three phases are 120 degrees apart from each other. According to this the switches S1, S3 and S5 should conduct after 120 degrees. The figure 5.4 given below consists of the conduction of the upper half switches for the positive 180 degree conduction.

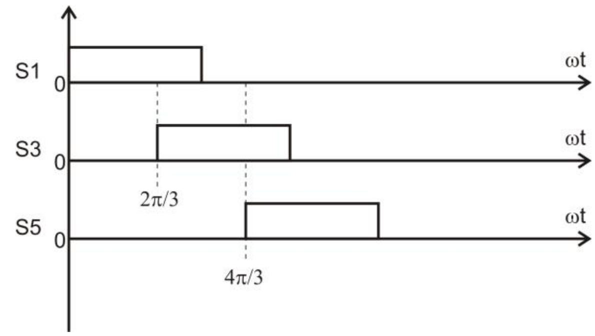


Fig. 5.4 Three phases 120 degrees apart from each other

For negative 180 degree conduction the lower half switches S4, S6, S2 should work immediately after the switching off of upper half switches S1, S2, S5 respectively. The schematic diagram is given in figure 5.5 :

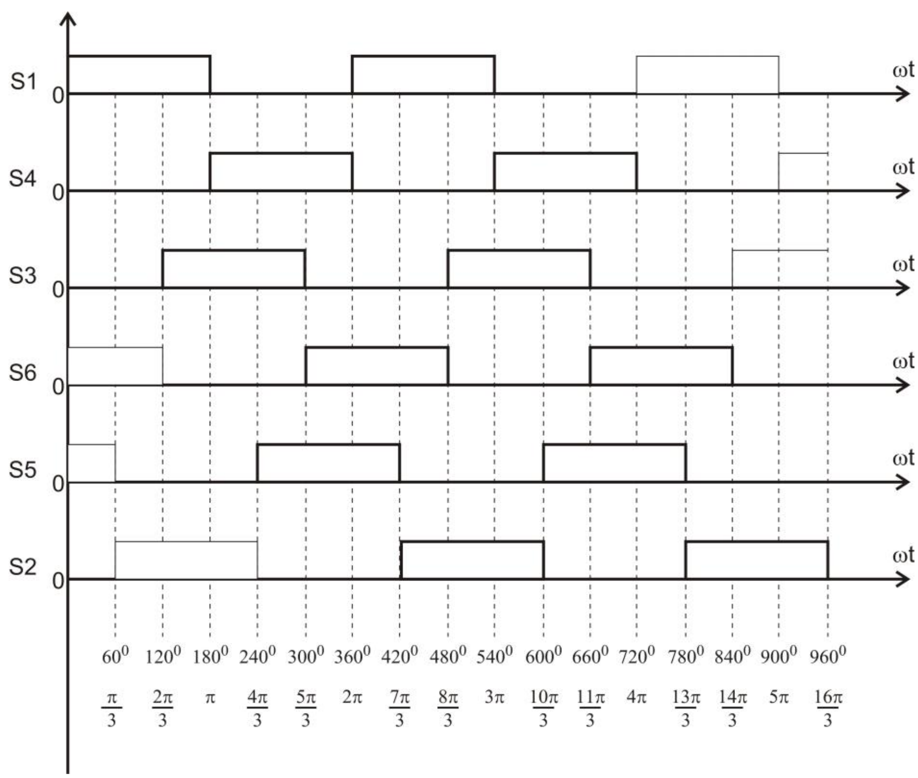


Fig. 5.5 180 degree conduction for three phase inverter

5.4.2 Switching of MOSFET :

As shown in the fig. 5.5 , after every 60 degrees, one switch is getting off and another switch is getting on. Every switch is conducting for 180 degrees. For the first 60 degree conduction S1, S6, S5 are conducting and for next 60 degree conduction S5 is getting off and S1, S6, S2 are conducing. The schematic switching is given in table 5.1 :

Table 5.1 Switching sequence of six MOSFET

Switch ON	Switch OFF	Time
S1, S6, S5	S4, S3, S2	0 – 60 degree
S1, S6, S2	S4, S3, S5	60 – 120 degree
S1, S3, S2	S4, S6, S5	120 – 180 degree
S4, S3, S2	S1, S6, S5	180 – 240 degree
S4, S3, S5	S1, S6, S2	240 – 300 degree
S4, S6, S5	S1, S3, S2	300 – 360 degree

5.4.3 Working of 3 Phase inverter :

In the first 60 degree conduction, S1 and S5 will work from upper half of the inverter circuit and S6 will work in the lower half of the circuit. S1 is connected to load ‘a’, S5 is connected to load ‘c’ and S6 is connected to load ‘b’. Load ‘a’ will recieve supply from ‘a’ to ‘n’ and ‘c’ will receive supply from ‘c’ to ‘n’ but load ‘b’ will recieve supply from ‘n’ to ‘c’. This means load ‘a’ and ‘c’ will face positive supply and ‘b’ will face negative supply. Schematic circuit for the first 60 degree conduction is shown in fig. 5.6 :

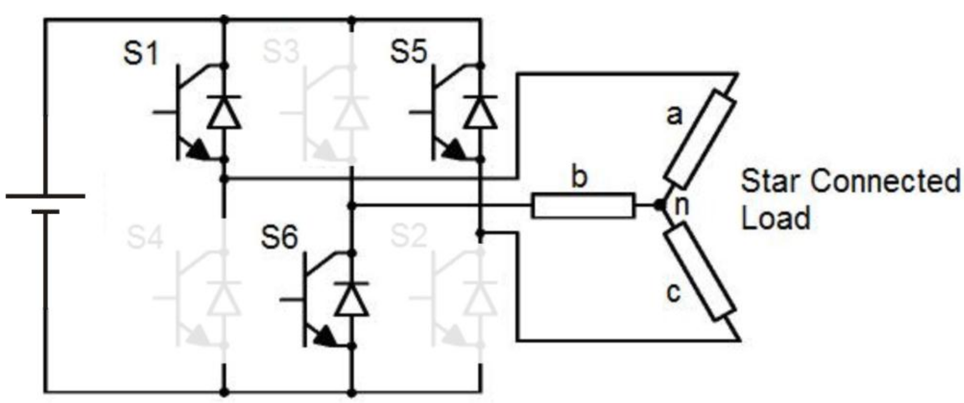


Fig. 5.6 First 60 degree conduction of 3 Phase inverter

Its equivalent circuit is given below in fig. 5.7 :

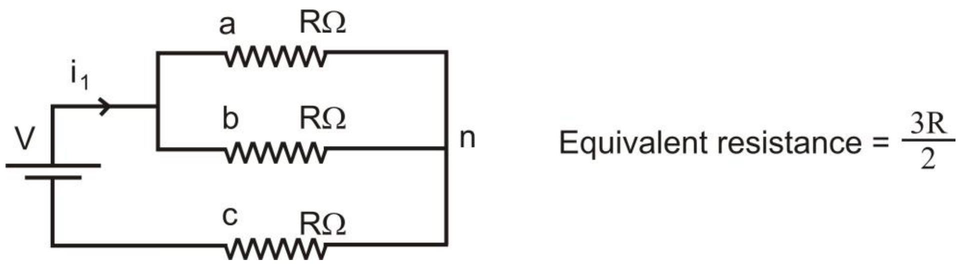


Fig. 5.7 Equivalent circuit of first 60 degree conduction of 3 phase inverter

When Switch S1, S5 and S6 will conduct, load 'a' and 'b' will face positive of the the dc supply and load 'c' will face the negative of the dc supply. The load is taken as balanced and star connected. Voltage across the load 'a', 'b' and 'c' can be calculated as :

$$\text{Equivalent resistance (Req.)} = \frac{3R}{2} \quad \ldots\ldots (5.1)$$

$$\text{Current } i_1 = \frac{V}{\text{Req.}} = \frac{2V}{3R} \quad \ldots\ldots (5.2)$$

Equivalent resistance of the upper branch is given below in fig. 5.7 :

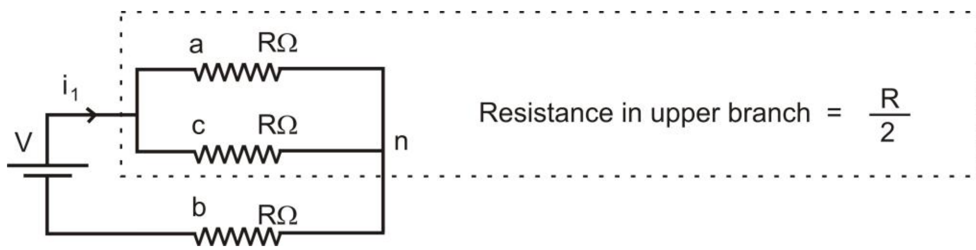


Fig. 5.8 Equivalent resistance of the upper branch

$$Van = Vcn = \frac{i_1 R}{2} \quad \ldots\ldots (5.3)$$

Putting the value of eq. 5.2 in equation 5.3, we get voltage across the load 'a' and load 'c' :

$$Van = Vcn = \frac{V}{3} \quad \ldots\ldots (5.4)$$

Voltage across load 'b' can be calculated by measuring the resistance of the lower branch :

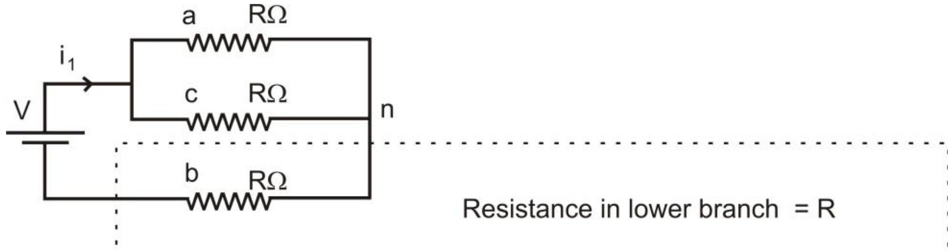


Fig. 5.9 Equivalent resistance of the lower branch

According to figure 5.8, voltage across load 'c' :

$$Vnb = i_1 R \quad .... (5.5)$$

Equation 5.5 can be rewritten as :

$$Vbn = -i_1 R \quad ..... (5.6)$$

Putting the value of i1 in the above equation, we get :

$$Vbn = \frac{-2V}{3} \quad ..... (5.7)$$

In the first 60 degree conduction we have ,

$$Van = Vcn = \frac{V}{3} \quad .... (5.8)$$

$$Vbn = \frac{-2V}{3} \quad .....(5.9)$$

Phase to neutral voltages of the next five conduction modes is given below :

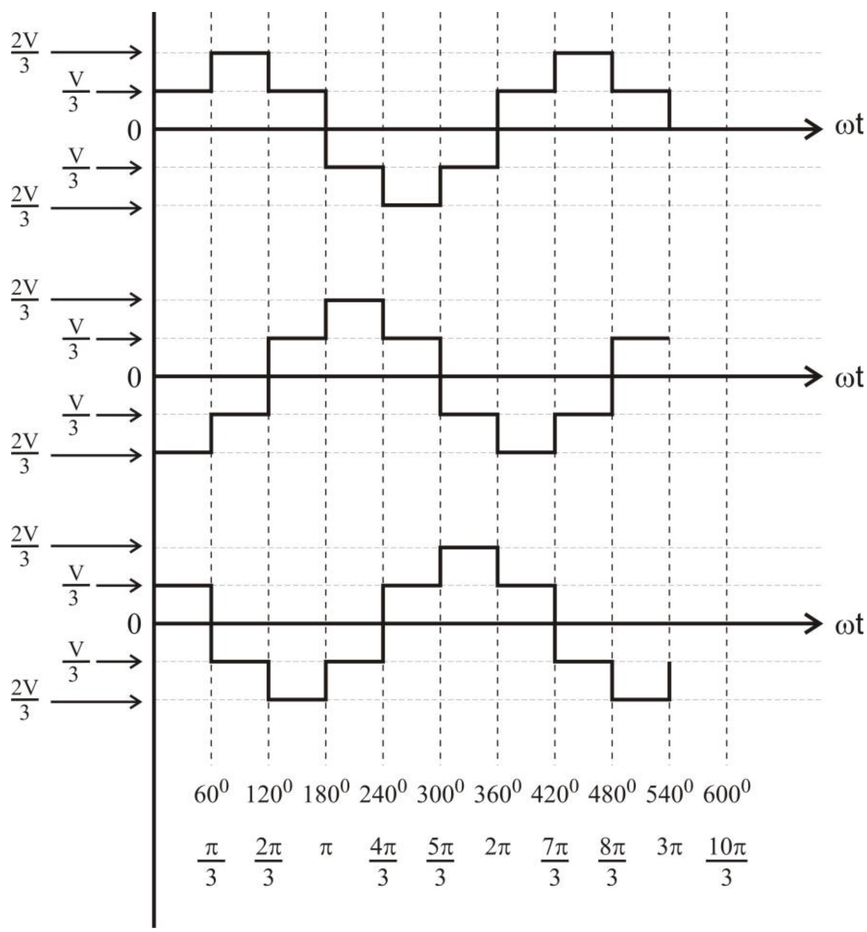


Fig. 5.10 Phase to neutral voltages of 3 phase inverter

5.4.4 Application of 3 Phase inverter design to microcontroller:

The above schematic diagram shows the conduction of the six switches. MOSFET is a good candidate for high speed switching but in this 180 degree conduction method, switching speed is not so high. MOSFET has low conduction and switching losses [26]. Every MOSFET conduction period is 180 degrees at different time intervals. For implementing this procedure in the microcontroller we need 6 different timers. But due to the limitations of the no. of counter in the microcontroller, a different approach is established. A single counter is used and 6 pulses are generated each after 60 degree. There is some turn on and turn off time between each pulses. The schematic diagram is given in fig. 5.10 :

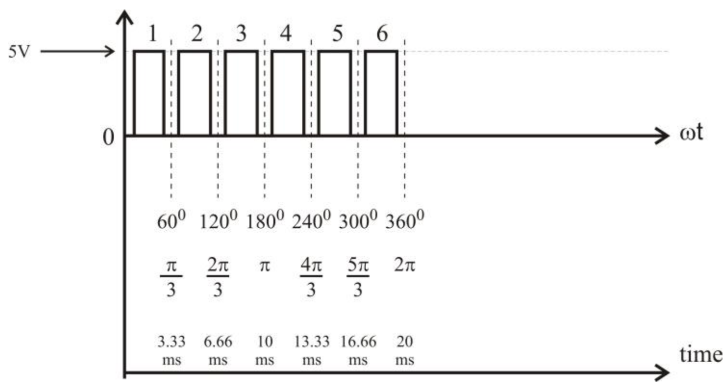


Fig. 5.11 Single counter output of microcontroller

A single counter timer is used to generate these pulses. By using the logical conditions, we can give these pulses to all the six MOSFETs. The pulses are generated for 50 Hz operation so the time duration for 1 cycle is 20 ms. All the six pulses are divided in equal time i.e. the duration of one pulse will be 3.33 ms. The steps for generating the 6 pulses for 6 MOSFETs are given below in table 5.2 :

Table 5.2 Steps of switching of six MOSFET using single counter of microcontroller

Pulses	Switches	Time
1	S1, S6, S5	0 – 3.33 ms
2	S1, S6, S2	3.33 – 6.66 ms
3	S1, S3, S2	6.66 – 10 ms
4	S4, S3, S2	10 – 13.33 ms
5	S4, S3, S5	13.33 – 16.66 ms
6	S4, S6, S5	16.66 ms – 20 ms

5.5 MOSFET Snubber ckt. :

Snubber circuit is required for the protection of the MOSFET [31]. MOSFET Snubber diode are used in the power converter[32]. RCD and RLD snubber circuit are employed to protect the MOSFET from over current and overt voltage[33]. Three types of snubber circuit can be employed [35] :

i) RLD ii) RCD iii) RCD and RLD

5.5.1 RLD Snubber circuit :

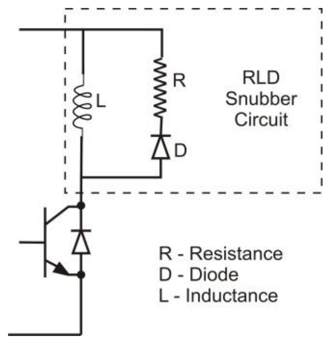


Fig. 5.12 RLD snubber circuit

RLD snubber circuit is used to protect the MOSFET from high *di/dt* rating. RLD snubber circuit reduces the current spikes and switching losses. Current spikes are highly reduced and heat loss during switching can be avoided by using RLD snubber circuit[35].

Value of L can be calculated by [19] :

$$L = \frac{V\,t_r}{I_L} \quad \text{..... (5.11)}$$

I_L = Load current

t_r = Turn on rise time, V = Voltage of the DC source

Value of R can be calculated by :

$$R = 2\sqrt{\frac{L}{C}} \quad \text{.... (5.12)}$$

C = Capacitance, L = Inductance

Value of C can be calculated by :

$$C = \frac{I_L\,t_f}{V} \quad \text{..... (5.13)}$$

t_f = Turn off rise time

Formula for calculating the capacitance given above is the same for RCD snubber circuit.

5.5.2 RCD Snubber circuit :

RCD snubber circuit consist of the Resistance, Capacitance and diode. It is connected in parallel with the MOSFET.

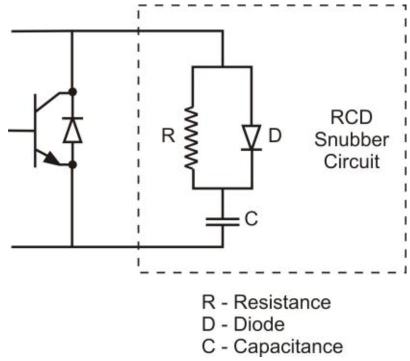


Fig. 5.13 RCD snubber circuit

As shown in the fig. 5.12, Value of R and C can be calculated by its *dv/dt* rating [19].

RCD snubber circuit protects the MOSFET from the voltage spikes [35] but the current spikes are not much reduced. RCD snubber circuit is required to protect the MOSFET from false switching because voltage spikes can turn on the MOSFET and can result into short circuit. Switching losses are alse reduced by using the RCD snubber circuit.

5.5.3 RLD and RCD snubber circuit :

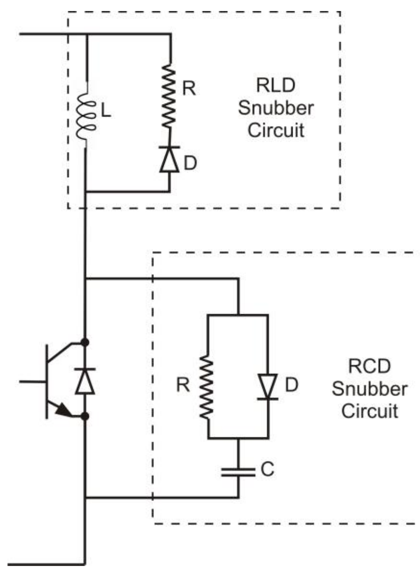


Fig. 5.14 RLD and RCD snubber circuit

RCD and RLD snubber circuit both provide the protection from *di/dt* and *dv/dt*. MOSFET is protected from voltage spikes and current spikes. Switching losses can be minimized by using RCD and RLD circuit.

In the three phase inverter design, we have implemented the RCD snubber circuit design to protect the MOSFET from voltage spikes and false triggering.

5.6 Results of three phase inverter

The sequence as given in the above table will switch on the switches as will give the desirable output across the phase to neutral load. The experimental results are taken on C.R.O. and given in figure 5.14 :

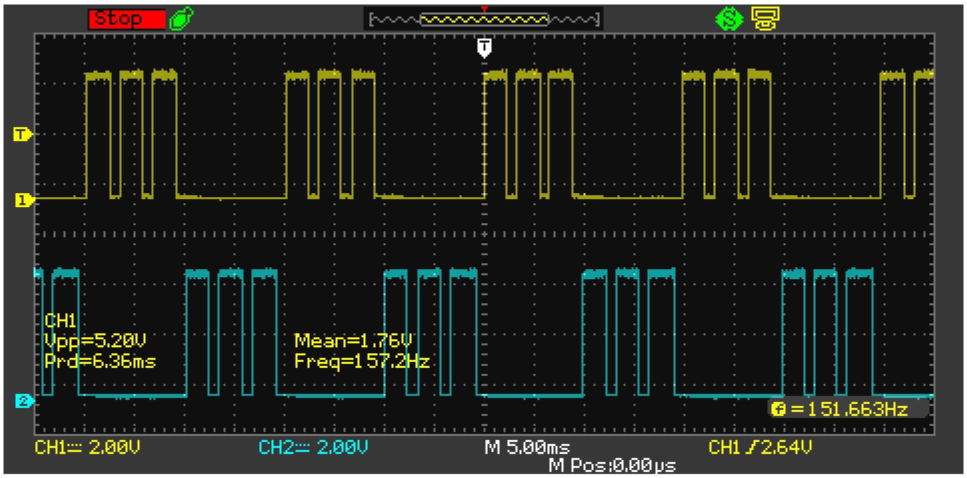


Fig. 5.15 Output of conduction across S1 and S4

Switch 1 Input – Yellow, Switch 4 Input – Blue

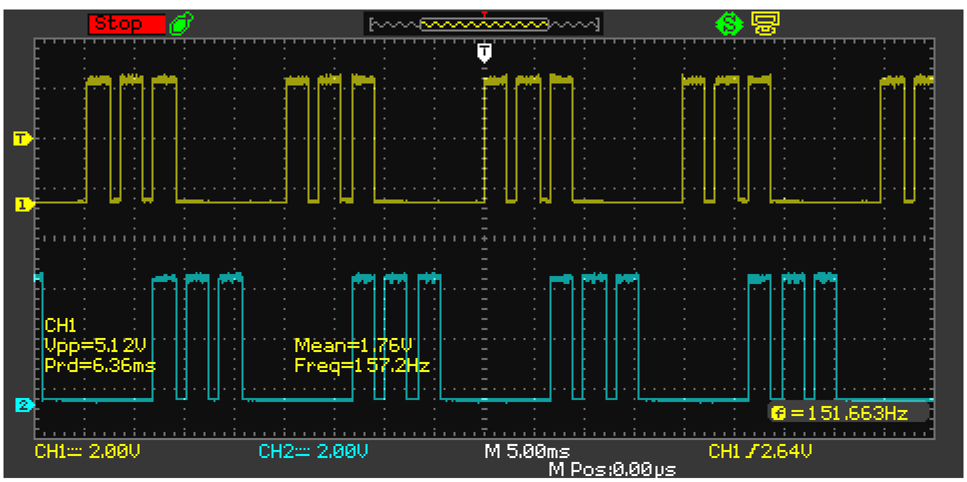


Fig. 5.16 Output of conduction across S1 and S3

Switch 1 Input – Yellow, Switch 3 Input – Blue

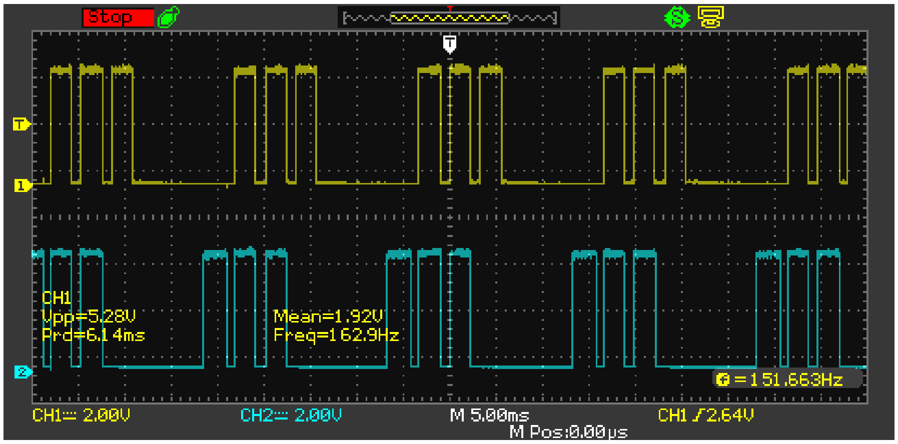


Fig. 5.17 Output of conduction across S1 and S6

Switch 1 Input – Yellow, Switch 6 Input – Blue

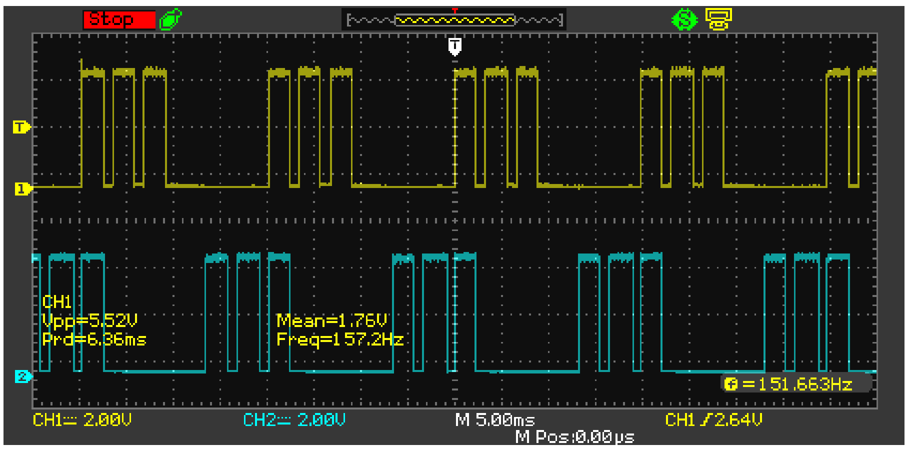


Fig. 5.18 Output of conduction across S1 and S5

Switch 1 Input – Yellow, Switch 5 Input – Blue

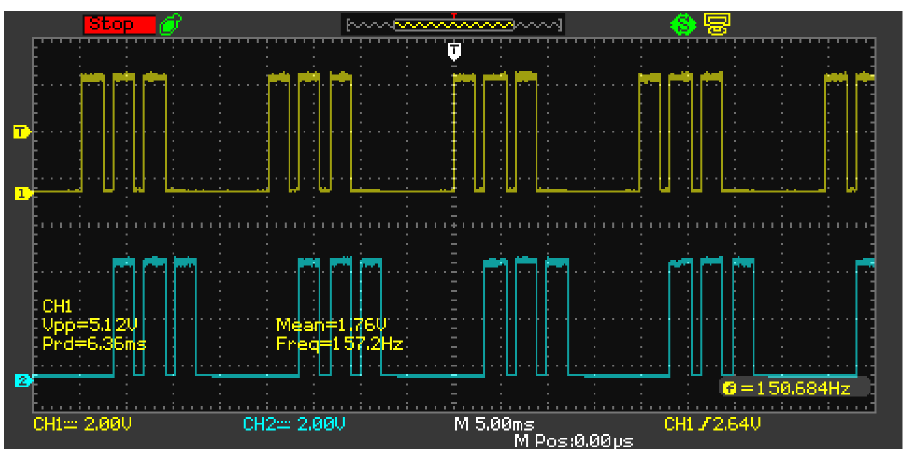


Fig. 5.19 Output of conduction across S1 and S2

Switch 1 Input – Yellow, Switch 2 Input – Blue

Switching input for the first 60 degree are taken on two CROs. In the first CRO input of S1 and S6 are shown on second CRO input of S1 and S5 are shown. These input are similar as described for the three phase inverter for 180 degree conduction.

5.6.1 Pulses of the Six MOSFET are given below on three CROs :

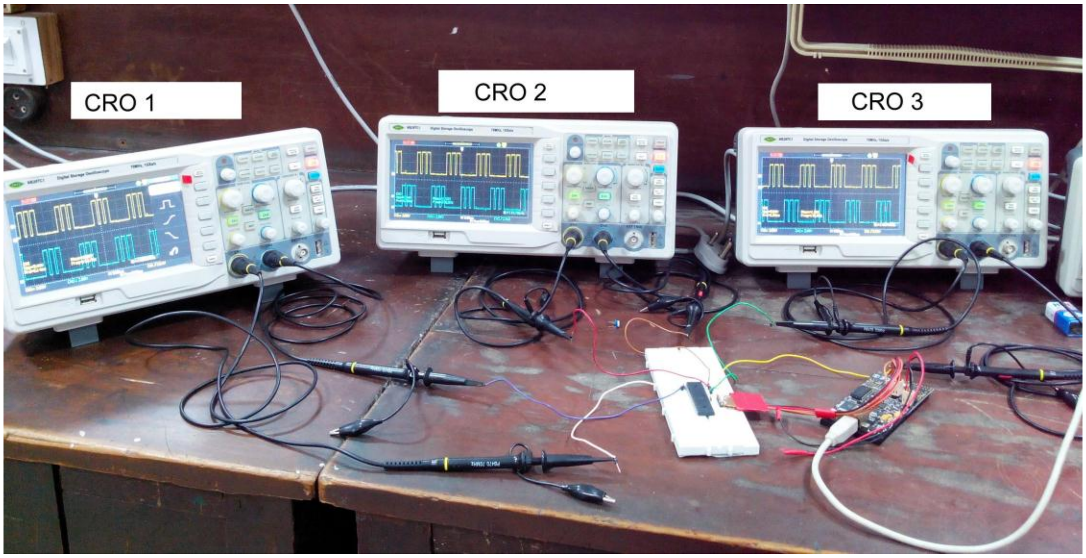


Fig. 5.2 Output of conduction of 6 MOSFET on three CROs
Switch 1 Input – Yellow, Switch 6 Input – Blue
CRO 1 output : S1, S4 input
CRO 2 output : S3, S6 input
CRO 3 output : S5, S2 input

5.6.2 The result of the output across load a is given below :

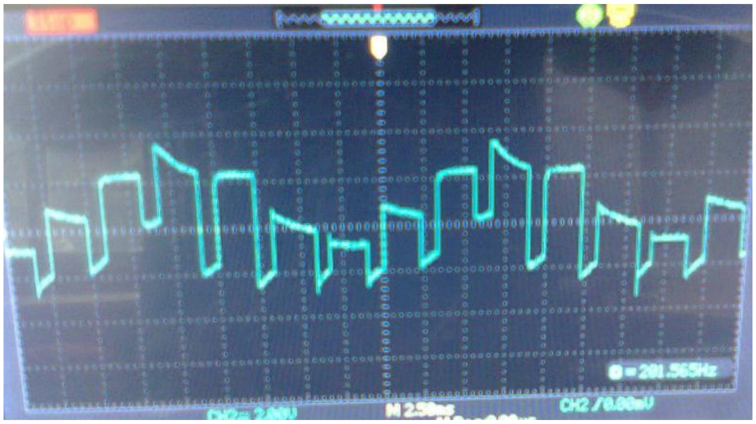


Fig. 5.21 Inverter output across load

CHAPTER - 6
CONCLUSIONS

6.1 Conclusion

The dissertation is based on the protection of three phase induction motor under single phasing condition and it is implemented using microcontroller, MOSFET, step down transformers, current transformers and protective relays. The system is very cheap as compared to present protective devices available. The protection system can protect three phase induction motor from under voltage, over voltage, over current and unbalance voltages. The inverter is also designed to make the three phase motor running under two phase supply. Three phase inverter will be pulsed from the microcontroller output and the output are also shown, which are satisfactory. The MOSFET which are used in protection system are easily available in the market and can be also used to large protection system.

6.2 Future Scope of work

Future scope the dissertation is to implement the inverter system on the large capacity three phase induction motors. In control circuit only the ratings of C.T. and P.T. has to be chosen accordingly while the power circuit has to be designed independently as per the rating of the motor.

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