Concept Development of 3-Phase Under Voltage Release For Air Circuit Breaker

Major Project Report

Submitted in Partial Fulfillment of the requirement for

the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Electrical Power Systems)

By

Pooja M. Patel

14MEEE16

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

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I **Pooja Patel** , **Roll No 14MEEE16** , give undertaking that the Major Project entitled **Concept development of 3-Phase under voltage release for Air Circuit Breaker** submitted by me , towards the partial fulfillment of the requirements for the degree of Master of Technology in **Electrical Power Systems, Electrical Engineering** , under the Institute of technology of Nirma University , Ahmadabad is the original work carried out by me and I give assurance that no attempt of plagiarism has been made . I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere , it will be in severe disciplinary action.

Signature of student

Date:

Place:

Endorsed by:

Project Guide(Industry)
Mr.Hardik Vyas
Asst. Manager-Design
L&T ,EBG.
Vadodara.

Project Guide (Institute)
Prof. Sarika S. Kanojia
Asst. Professor
Electrical Engg. Department
Nirma University
Ahmedabad.

Certificate

This is to certify that the Major Project Report (Part-2) entitled **"Concept development of 3-Phase under voltage release for Air Circuit Breaker"** submitted by **Ms. Pooja M Patel (14MEEE16)**. towards the partial fulfillment of the requirement for Degree of Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by her under supervision and guidance.The work submitted has in our opinion reached a level required for being accepted for examination.The result embodied in this major project work to the best of our Knowledge have been Submitted to any other University or Institute for award of any degree or diploma.

Project Guide(Industry)
Mr.Hardik Vyas
Assistant Manager-Design
L&T,EBG
Vadodara.

Project Guide (Institute)
Prof.Sarika S. Kanojia
Assst. Professor
Electrical Engg. Department
Nirma University
Ahmedabad.

Head of the Department
Department of Electrical Engineering
Institute of Technology,
Nirma University, Ahmedabad

Director
Institute of Technology,
Nirma University, Ahmedabad

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Pooja M. Patel

14MEEE16

Abstract

Air Circuit Breaker is an upstream device to make and break the current even in case of any abnormality in system. ACB can sense the abnormal system conditions like short circuit, earth fault and overload etc. Also in some cases like high inrush current may cause drop in system voltage and to sense this fault Under Voltage Release is used. UVR trips circuit breaker if voltage falls between 35 to 70 percentage of its rated voltage. Current UVR can operate only on 1-Phase under voltage fault. In order to sense under voltage fault in 3-Phase system, 3-Phase UVR has to be developed. Additionally UVR has time delay controller which trips the breaker after pre-defined time delay.To provide the solution for three phase voltage dip sensing 3-Phase UVR, 3-Phase controller has to be developed.

Abbreviations

1)UVR ——— under voltage release

2)ACB ——— Air Circuit Breaker

3)SMPS ——— Switched mode power supply

4)PSim ——— Power Simulation

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Chapter 1

Introduction to Air Circuit Breaker

1.1 Principle of operation of Air Circuit Breaker

A circuit breaker is a device capable of making and breaking electrical circuit under normal and abnormal conditions. ACBs are the circuit breakers which use atmospheric pressure as an arc extinguishing medium.The working principle of ACB is rather different from other types of circuit breaker. The main aim of circuit breaker is to prevent re-establishment of arcing after current zero where the contact gap will withstand the system recovery voltage. It does same work in a different manner.

These breakers normally have two pairs of contacts. The main pair of contacts carries the current at normal load and these contacts are made of copper. The additional pair is the arcing contact and is made of carbon. When circuit breaker is being opened, the main contacts open first and during opening of main contacts the arcing contacts are still in touch with each other. As the current gets, a parallel low resistive path through the arcing contact during opening of main contacts, there will not be any arcing in the main contact. The arcing is only initiated when finally the arcing contacts are separated. The each of the arc contacts is fitted with an arc chute which helps the arc discharge to move upward due to both thermal and electromagnetic effects . As the arc is driven upward it enters in the arc chute, consisting of D-ION plates as splitters. The arc in chute will become colder, lengthen and split hence arc voltage becomes much larger than system voltage at the time of operation of air circuit breaker, and therefore the arc is quenched during the current zero.

In operation, a circuit breaker is opened by energizing a trip coil associated with the

circuit breaker. Once the trip coil is energized, the main contacts are opened and then auxiliary contacts are opened to prevent damage to the trip coil.Circuit breakers may include an electronic trip unit that senses electrical current to the protected equipment. If the sensed electrical current indicates an over current situation, the electronic trip unit provides a trip signal to a trip actuator. In response to the trip signal, the trip actuator actuates a mechanical operating mechanism. Actuation of the mechanical operating mechanism by the trip actuator causes the mechanical operating mechanism to separate the electrical contacts, stopping the flow of current to the protected equipment.

1.2 Features of Air circuit breaker

- It can make and break at higher capacity
- It can withstand fault for short time about 1 sec. ACBs are provided with Icu,Ics,Icw capacities. **Icu** is the rated ultimate short circuit breaking capacity at which breaker can clear the fault but could be risky to operate.**Ics** is the rated service short circuit capacity at which breaker can clear fault and safe to operate but for longer fault we need to inspect the breaker. **Icw** is the rated short time withstand capacity at which breaker need withstand stress developed by the fault current.
- In air circuit breaker dielectric strength develops very rapid,so it requires very lesser space for final contact gap for arc extinction.it reduces the size of the circuit breaker and it's design is robust.Due to rapid growth of dielectric strength arcing time is very less.
- Due to lesser arcing energy it can operate for frequent operations.So it is having higher mechanical and electrical life.
- Air circuit breaker is highly resistive to electrodynamics force developed by short circuit.
- Built in ampere metric release with wide range of setting. The ampere metric release in the thermo magnetic release for overload and short circuit protection, volt metric releases are the under voltage and shunt release.

- Mechanism ,control devices ,accessories and contacts are easily accessible.So its maintenance is easy.
- Air circuit breaker are provided with accessories for trip signaling and interlocking.

1.3 Applications of Air circuit breaker

- In Sub-station.
- In cement and steel manufacturing plant etc.
- In industry for high current equipment.
- Some machines such as blowers, large motors, conveyors and cooling plants themselves require a separate ACB.
- A large residential complex, big shopping centers, commercial buildings ,resorts where biasing is essential.

Chapter 2

Introduction to U-Power Omega Air Circuit Breaker

2.1 Classification of U-Power Air Circuit Breaker

Larsen and Toubro has developed air circuit breaker on the basis of two different mounting arrangement and with different current carrying capacity with classified into three different frame sizes and breaking capacities.

2.1.1 According to mounting arrangement

Larsen and Toubro has designed two types of air circuit breaker according to mounting arrangement are fixed type and draw out type.

- **Fixed Air Circuit Breaker**:Mostly air circuit breaker is mounted in panel as main circuit breaker .Fixed air circuit breaker are mounted directly to the terminal adapters which are connected with bus-bar . Because it does not require cradle to mount it .its cost is lesser than draw out type air circuit breaker.If we need to take breaker for maintenance on the cost of supply cut off which is main drawback over draw out breaker.

- **Draw out Air Circuit Breaker**:This type of circuit breaker are mounted in panel on D-rails through cradle.Breaker terminals are connected to bus-bar through spring loaded jaw which are mounted on cradle and make electrical contact and for that need breaker to be racked in cradle. We can racked out breaker for maintenance

without loss of supply cut off .This is the major advantage of draw out circuit breaker but due to cradle cost of breaker increases.

2.1.2 According to current carrying capacity and breaking capacity

According to current carrying capacities, breaking capacity and numbers of pole U-Power ACBs are differentiated in three frame sizes as per below table:

Frame	Frame-1	Frame-2	Frame-3
Rated uninterrupted current(In)	400-2500 A	400-3200 A	400-6300 A
versions	N,S,H	S,H,V	H,V

N: 50 kA ,S: 65 kA , H: 80 kA , V:100 kA

2.1.3 Construction of U-Power Omega Air Circuit Breaker

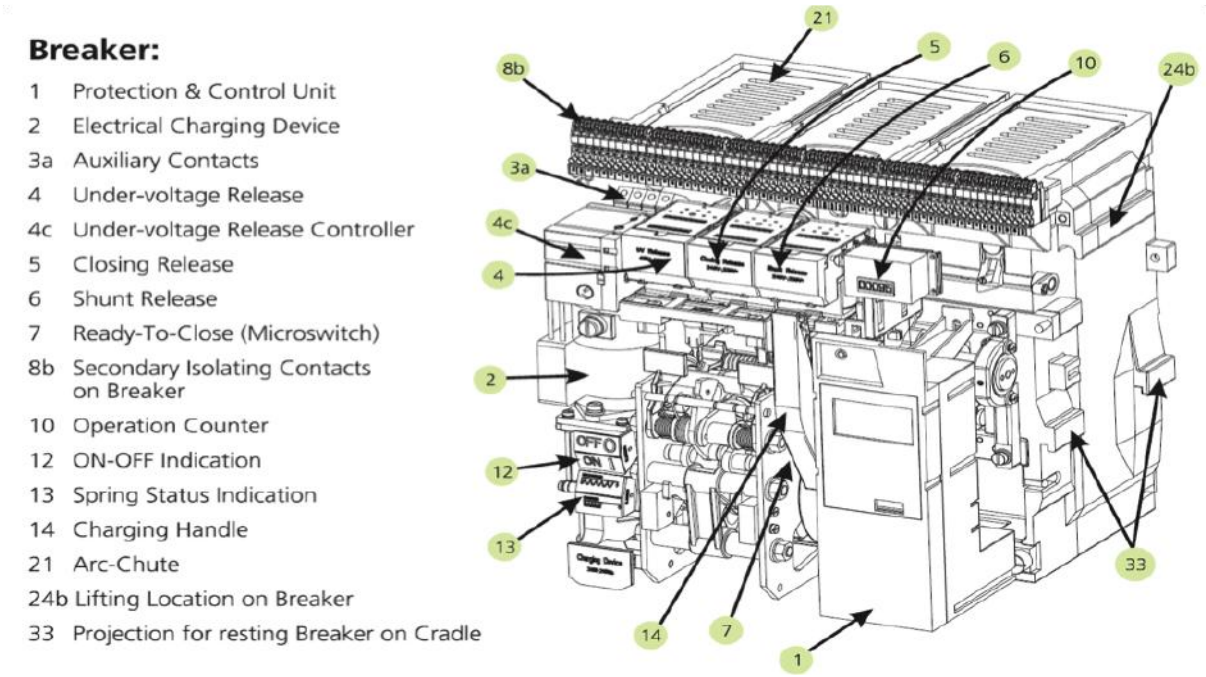

Figure 2.1: internal construction diagram

2.1.4 Components of Air Circuit Breaker

1. Cradle Assembly

2. Breaker Shaft Assembly
3. Accessories

1. **Cradle Assembly**

- Cradle rails
- Cradle shaft assembly
- Racking Handle
- Cradle terminals
- Cradle adapters
- Jaw Contacts

2.Breaker Shaft Assembly

- Contact fingers
- Lower terminals
- Copper braids
- Spring cover
- Main spring
- Charging handle
- Arc chute

3.Accessories

- Auxiliary contacts
- Electrical charging device
- Shunt release
- Closing release

- Under voltage release
- Counter
- Electrical indication

Figure 2.2: U-Power Omega ACB

2.1.5 Problem identification

The main cause of voltage sag is increase in current for short duration in power system.Voltage dip occurs due to starting of motors, energizing of capacitor bank and transformers.It also occurs due to short circuit fault and earth fault in line also .Air circuit breakers are supplied with single phase under voltage release to protect the system against voltage dip .Under voltage release open circuit breaker if operational voltage falls between the value 35 to 70 percentage of rated voltage.And it will allow the circuit breaker to close with 85 to 110 percentage of rated voltage.

In market three phase voltage monitoring relays are available .But relay will only sense the voltage dip and will indicate it. It will actuate contactor and perform some suitable functions according to customers requirement. Where UVR is mechanically coupled to ACB which senses the voltage dip and open circuit breaker immediately.

Existing UVR consisting of micro controller based controller and coils.Controller will actuate coil to trip the circuit breaker.But existing UVR has been designed to monitoring single phase only.If UVR is connected between phase to phase or one phase and neutral it monitor concern phase only.Actually need to actuate coil when voltage dip occurs in all three phases simultaneously . Larsen and Toubro does not have that feature in

their portfolio.We also need to detect Phase loss.As Phase loss is mostly undetectable by measuring devices at the terminal of device and other two phases draw current to run the device which cause heat and can be caused to damage the device.

In three phase system there are two different supply voltage configuration and effect of under voltage on all phase voltages and why three phase UVR is required in three phase system can be understood as per below figure:

star connection	single phase fault	only faulty phase will be affected,no other phases will be affected in 3 phase 3 wire system, and in case of 3 phase 4 wire system current will return through neutral.
	phase to phase fault	two phase will be affected ,one healthy phase will be affected
Delta connection	single phase fault	two phases will be affected and one phase will be unaffected
	phase to phase fault	Large drop in one phase and small drop in two phase

Figure 2.3: Supply system configuration

2.1.6 Objective

The main objective of this project is to develop a 3-Phase circuit of new under voltage release for ACB so it will monitor all three phases simultaneously and will give protection against under voltage fault occurs in any phase.

Key objectives are listed below:

- Develop new power supply circuit
- Develop phase loss detection circuit
- To achieve three phase monitoring circuit
- To expand the portfolio of Larsen and Toubro by developing 3-Phase Under Voltage Release

2.1.7 Methodology

- Study specification list
- Concept development for three phase under voltage release circuit
- Simulate developed under voltage monitoring circuit
- Proto-typing
- Testing and validation

Chapter 3

Literature Survey

For the better understanding of project literature survey plays a very important role. Literature survey consists of papers , patents and IEC standards referred which gives basic idea of how three phase voltage monitoring relays work and have knowledge regarding voltage dip fault.

[1].SERBIAN JOURNAL OF ELECTRICAL ENGINEERING ,Factor Affecting Characteristic of Voltage Sag Due to Fault in the Power System,Vol. 5, May 2008

This paper gives the importance of occurrence of power quality problem ,voltage sag in the system.Problem occurrence to sensitive and sophisticated control at modern devices at industries and at residential level due to voltage dips .It also gives the knowledge of characteristics of voltage sags.

[2].Helerea Elena,Ciobanu Anca Faculty of Electrical Engineering and Computer Science Transilvania University of Brasov,Brasov, Romania,"Impact of Three-Phase Voltage Dips on the Induction Motors"

This paper deals with the investigation of the effects of three-phase voltage dips on the induction motors.

[3].Ying Wang, Math H. J. Bollen, Fellow, IEEE, and Xian-Yong Xiao,"Calculation of the Phase-Angle-Jump for Voltage Dips in Three-Phase Systems"IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 30, NO. 1, FEBRUARY

2015

The phase-angle-jump is defined in this paper as an- other single-event characteristic of voltage dips, besides residual or characteristic voltage and duration.

[4].United state patent no.:4238811,Dec.9,1980 By Warren C. Fry, Connellsville,Pa

This patent is for three phase voltage monitoring,which monitor separately converts the voltage on each phase to a D.C voltage ,compare each D.C voltage with reference voltage and operates an output signal whenever voltage drops below the reference voltage.

[5].United state patent no.:3001100,Sept.19,1961 By NILES f. Schuh and Lewis R. Lowry

This pattern relates to under voltage sensing circuit and particularly lowest the voltage in phase of poly phase alternating current system.

[6].United state patent no.:4027204,May 31,1977 By Dean King Norbeck

This pattern provides indication of trouble on a three phase line voltage when a voltage drop or brown out condition occurs .It also provide protection to load from damage.

[7].United state patent no.:4823227,April.18,1989 By James E. Grant, Orlando,Fla.

This pattern relates to phase monitor device designed to protect electrical equipment powered by three phase voltage changes in phase and voltage.

[8].United state patent no.:3242383,March 22,1966 By Henry L. Opad ,245 Bennett Ave., New York, N.Y

This pattern relates to multiphase electrical system ,particularly to three phase power supply systems and has for its principle object to protect electrical equipment served thereby in the event of voltage failure on one or more phases of power supply system.

Chapter 4

Existing single phase Under Voltage Release

Single phase under voltage release supplies with U-Power Omega Air Circuit Breaker consist of :

1. Analog /Micro controller based controller circuit
2. Clutch coil and trip coil

Single phase under voltage release is supplied with phase voltage which is given to controller circuit in which circuit is divided in three parts power supply circuit, Voltage sensing circuit and micro controller based time delay circuit.Output of controller circuit will actuate clutch coil and trip coil which will cause to trip circuit breaker under fault condition.

4.1 UVR Controller

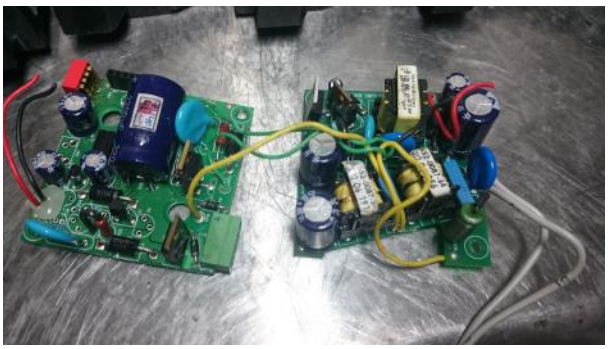

Figure 4.1: Controller

UVR controller having three sub part as per below:

4.1.1 Power supply circuit

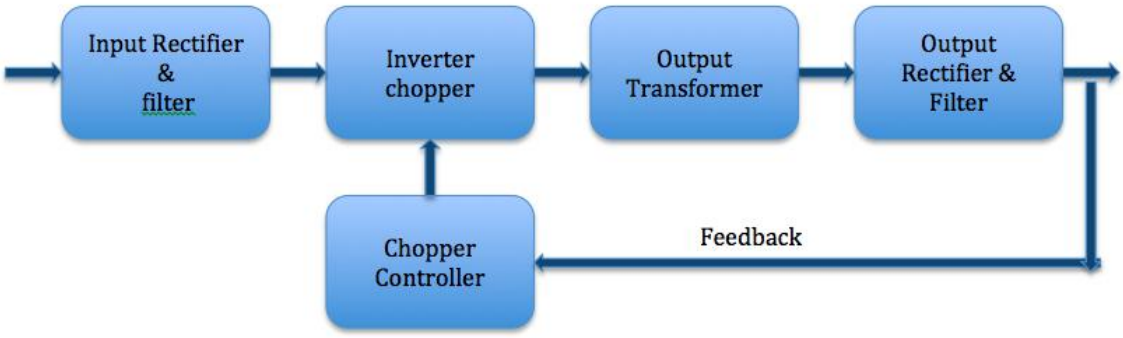

Figure 4.2: Block diagram of SMPS

Switched mode power supply provides constant DC output voltage over wide range.In SMPS circuit A.C supply first rectifies and filtered by capacitor ,it generates rough D.C supply.But generated D.C supply could fluctuate due to changes in input supply. Input capacitor is large enough to hold up the supply to rectifier circuit in case of a severe drop in the supply side. This unregulated D.C output is fed in to switching section .In this section MOSFET switches on and off and switch the voltage across primary of power transformer so it will induced E.M.F on the secondary side and will generate

rectified output and smoothed by the filter depending upon the inductors/capacitors arrangement.These pulses are very high 20 kHz to 100 kHz which reduces the power transformer size. To provide constant D.C output feedback control loop is provided.This output voltage is compared with reference voltage and error voltage will produce by the logic (IC- TOP245Y) and drives the MOSFET by providing pulses .This is providing constant D.C voltage.

4.1.2 Voltage sensing circuit and Micro controller based time delay circuit

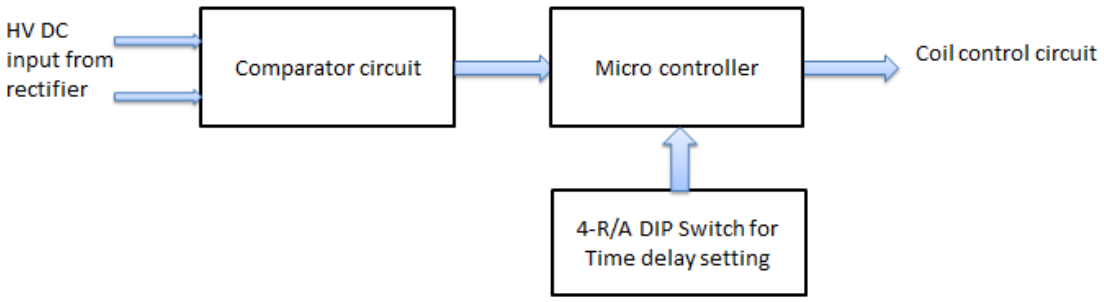

Figure 4.3: Micro controller Circuit

In voltage sensing circuit HVDC input is taken from the rectified out of SMPS circuit.Which is given to the comparator .Under healthy condition input to the non inverting terminal of OP-AMP is high and high out of OP-AMP will be given to the micro controller. Micro controller runs the logic and give high output to main coil control circuit and at the same time provides low output to clutch coil control circuit .Therefor during healthy condition clutch coil remains de-energized and main coil in energized . When voltage reach above 70 % micro controller logic runs and supplies 6A for 100 mSec to main coil and plunger actuated.Circuitry senses the under voltage again micro controller logic runs and provide supply to clutch coil for 100 mSec to energize it.

4.1.3 Control Circuit

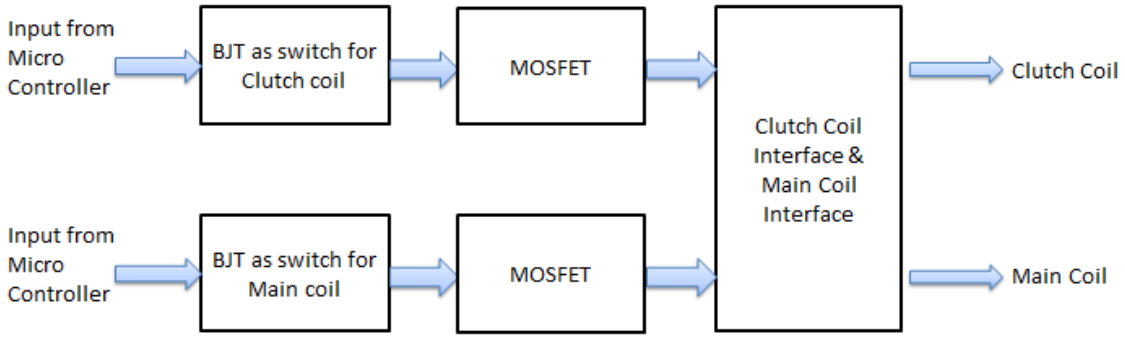

Figure 4.4: Coil Control Circuit

Micro controller outputs is given to the coil control circuit which switched on or off the transistor .Output of transistor switched on or off to MOSFET according to it through which output is given to clutch coil and main coil.Even in above shown figure 30V SMPS output is regulated to 5V to supply micro controller and transistors.In case of power cut off (0V) capacitor of 2200 uF supplies enough current to micro controller to trip circuit breaker.

4.1.4 Coil Design

Single phase UVR having two coils:

- Clutch Coil
- Trip Coil

4.1.5 Clutch Coil

Under normal condition clutch coil de-energized to hold the trip coil which blocks the circuit breaker to open.When voltage dip occurs it energized followed by the micro controller logic and allow the circuit breaker open.

Figure 4.5: Clutch Coil of single phase UVR

4.1.6 Trip Coil

Initially when voltage reaches above 75% of rated voltage it energized for 100 mSec by following micro controller logic and plunger of trip coil actuated and hold by clutch coil.When voltage dip occurs input to the trip coil gets low and plunger gets pop out.

Figure 4.6: Trip Coil of single phase UVR

Chapter 5

Testing of existing three phase relay

For the development of the concept of three phase voltage monitoring relay for air circuit breaker one existing three phase relay was being tested on the test bench following results was being achieved and two concept has been developed.Technical Specifications of three phase monitoring relay are as under:

Supply Voltage	415VAC; 3-Phase 4-wire
Frequency	47 to 53 Hz
Power consumption	10VA(Max.)
Trip level of Under voltage	55% to 95% of supply voltage
Trip time for under voltage	5 Sec +/- 1 Sec (Fixed)
Operating Temperature	-10°C to + 60°C
Electrical life expectancy	100000 operations

5.1 Reading of test performed on relay

5.1.1 Trial : 1

%Setting Volt.	Claimed Line volt.	Claimed Ph. Volt.	Not trip Value	Trip Value
		For each Phase		
55%	228.25	131.93	133	131
60%	249	143.76	144	143
65%	269.75	155.74	156	155
70%	290.5	167.7	168	166
75%	311.25	179.7	179	178
80%	332	191.68	192	190
85%	352.75	203.66	204	201
90%	373.5	215.64	215	214
95%	394.25	227.62	227	225

Above table shows as per given specification if voltage falls between 55% to 95% in each phase relay gives the under voltage indication .It shows it works very accurately if voltage drops in all three phases. e.g if 55% of Claimed phase voltage is 131.93V . During test 131 volt was set in each phases which was indicating under voltage and when 133 volt was set it was not indicating under voltage.It shows how accurately it check three phase under voltage .

5.1.2 Trial : 2

In second trial two phases were set to healthy condition 230Volts and one phase was set to 80% of phase voltages 110,110,115,120 Volts and so on respectively.If all the phases are healthy the voltage is 690Volts and total summation of 80% in all three phases are 576volts. When one phase drops total of all three phases are 560,570,575,580 volts and so on respectively. So after taking trials for different set values and at different percentage during initial reading logic was concluded that summation of all three phase voltages must be less than total summation of respective % setting voltage of phase voltage.e.g Under voltage relay should indicate under voltage for 560,570,575 volts but it was also showing indication on 580 volts. But some time Same trial was taken for 85 % of phase voltage.According to logic it should indicate when total summation of all three phases are 612volts.But it was also showing indication above 612volts (e.g 615,620,622 volts).But sometimes it was also showing indication on 635volts. Trials were taken for 55% to 95%

.Results shows it is not satisfied the concluded logic.So it was not able to sense accurately individual phase voltage drop.

5.1.3 Trial : 3

In third trial any two phase voltages were set to down and one phase has been kept healthy.It was taken for 80% of phase voltage .Total of summation should be 576 volts. Reading were set according to below.

230,220,165 = 615	Trip
230,220,170=620	Trip
230,220,175=625	Trip
230,180,160 = 570	Trip
230,215,192 = 637	Non Trip
230,220,190 = 570	Non Trip

So Concluded from above table that when voltage drops 80% and in phase c (190v,192v and so on)it was not indicating under voltage.So clearly indicates that it will not sense the individual phase drop .It will sense phase drop in all three phases .So it is not satisfying as per our requirement of detection of individual phase voltage drop .Based on taken trials two concept has been recommended as per below .

Chapter 6

Developed concept : 1

6.1 Basic introduction to concept

As per requirement of three phase under voltage detection below concept has been recommended .Concept is explained using shown block diagram.Three phase supply system has two configuration star and delta according to that Concept has been developed for 3-Phase 3-Wire.

6.1.1 3-Phase 3-Wire System:

Figure 6.1: Block dia. 3-phase 3-wire

Three phase rectifier will convert AC voltage to DC voltage .Capacitor will be used to filter the output of DC rectifier.DC rectified output will be scaled down to lower voltage for comparison. In Comparator circuit voltage will be compare with pre specified reference voltage. Output of comparator circuit will be either high or low according to Variable input voltage to comparator.Transistor will be used as switch which will ON -OFF according to input voltage at base from comparator circuit. Transistor will supply

specified voltage given to its V_{cc} to Driven circuit .Driven circuit will supply the coil control circuit. Coil control circuit consist of micro controller and switching circuits.Coil control circuit will control the two coils clutch coil and trip coil.

6.2 Three Phase Rectifier

Rectifier is the electrical device which converts AC voltage to DC voltage. In three phase Diode bridge rectifier is having three legs, each leg consist of two diode .Diodes D1,D3,D5 will conduct when they are subjected to positive voltage and at same time D2,D4,D6 will conduct when they subjected to negative voltage . DC average output voltage for three phase is as per below equation.

$$V_{DC} = \frac{3\sqrt{2}V_{rms}}{\pi} \tag{6.1}$$

Vrms = RMS value of line voltage

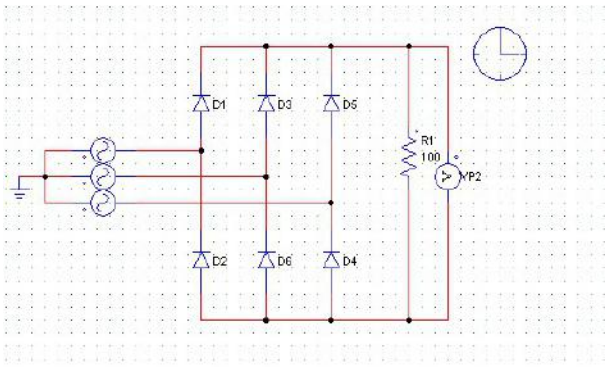

Figure 6.2: 3-Phase Rectifier circuit

6.3 Voltage Divider:

Voltage divider circuit is used to decrease the magnitude of voltage using two resistor R1 & R2 connected in series .Input voltage is given across series connection of resistor and Output is taken across the resistor R2. Voltage divider will give output as per below equation:

$$V_{out} = \frac{V_{in}R_2}{R_1 + R_2} \tag{6.2}$$

6.4 Comparator Circuit

Generally comparator circuit compares magnitude of two voltages levels.It compares variable voltage with one reference voltage and generates high or low output .Here Comparator circuit consist of op-amp .it is having two terminals inverting terminal and non inverting terminal.Reference voltage sets at inverting terminal and variable input at non inverting terminal. So op-amp comparator is also known as positive voltage comparator.

6.5 Switch

In re commanded concept NPN transistor is used to provide voltage to Driven circuit and Coil control circuit by switch ON OFF.Transistor is current controlled device.Transistor has two regions while using as switch.

- **Cut off Region**:When base voltage is getting low ,base current I_b becomes zero and collector current I_C also becomes zero.At that time transistor does not allow current to flow from collector to emitter .Therefor transistor acts as Fully OFF switch.So both the junction V_{BE} & $V_{CE}$are reversed bias.(V_{BE} <0.7 volt, I_C=0)
- **Saturation Region**:When both junction V_{BE} & V_{CE} are forward biased ,high current will conduct and will flow through collector to emitter.Therefore NPN transistor acts as Fully ON switch. ((V_{BE} >0.7 volt)

6.6 Driven circuit and Coil control circuit

In driven circuit voltage sensing circuit is available which sense the input voltage which is supplied by transistor switch .Micro controller will be used to control the supply to coils . Micro controller will be programmed as per requirement with time delay logic.CMOS Micro controller 12F675 has been used to run the logic. 12F675 micro controller having 8 pin,operating voltage range is 2 to 5.5 volts.Time delay setting is given by 4-R/A DIP Switch and it will be given to PIN 2,3,4. PIN diagram of 12F675 controller is as given below.

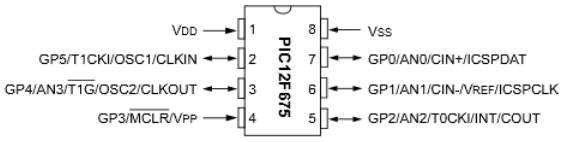

Figure 6.3: PIN diagram of micro controller

In coil control circuit , two different switching circuit is used to control supply of clutch coil and main coil.PNP transistor and MOSFETs are used as switch to control coils .

6.7 Internal lab trail using 1-Phase circuit

To check weather concept is working or not for three phase ,trials were taken using single phase rectifier.All parameters were taken randomly. First circuit has been simulated in PSim software. Figure and waveform of circuit of simulation is as per below:

6.7.1 Circuit using 1-Phase Rectifier

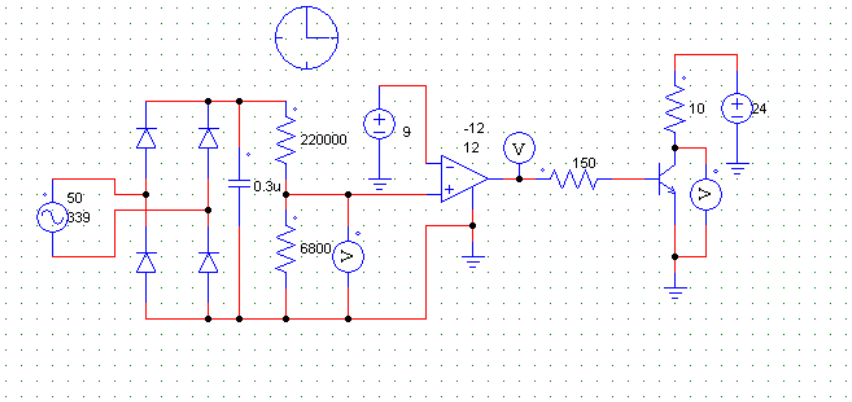

Figure 6.4: Single Phase Circuit

1. Rectifier Circuit
2. Voltage Divider Circuit
3. Comparator Circuit
4. Switching Circuit

5. Driven circuit and coil control circuit(24VDC)

6. coil

6.7.2 Waveform of Circuit Under Healthy Condition

When supply voltage above 80% of rated voltage condition has been considered to healthy condition. Here reference voltage taken as 9v from battery.As per condition if voltage is healthy V2 is variable input to comparator circuit is above 9volt. For same condition comparator circuit gives high output and input to base of transistor. As transistor has been used as switch .Voltage to base of transistor is high so it acts as fully ON switch.it supply V_{cc} to load circuit connected across V_{ce}.

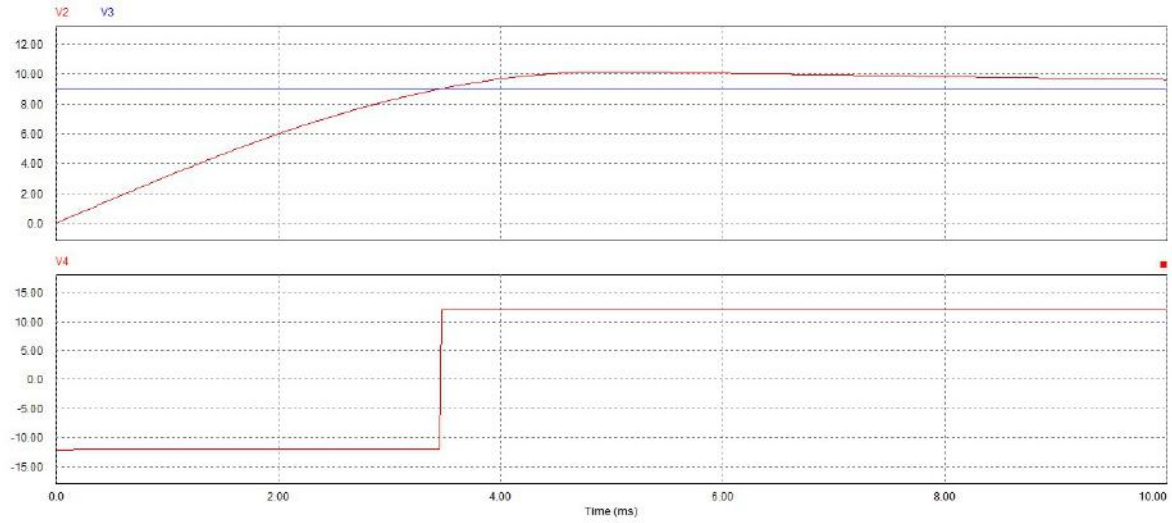

Figure 6.5: Output waveform under Healthy Condition

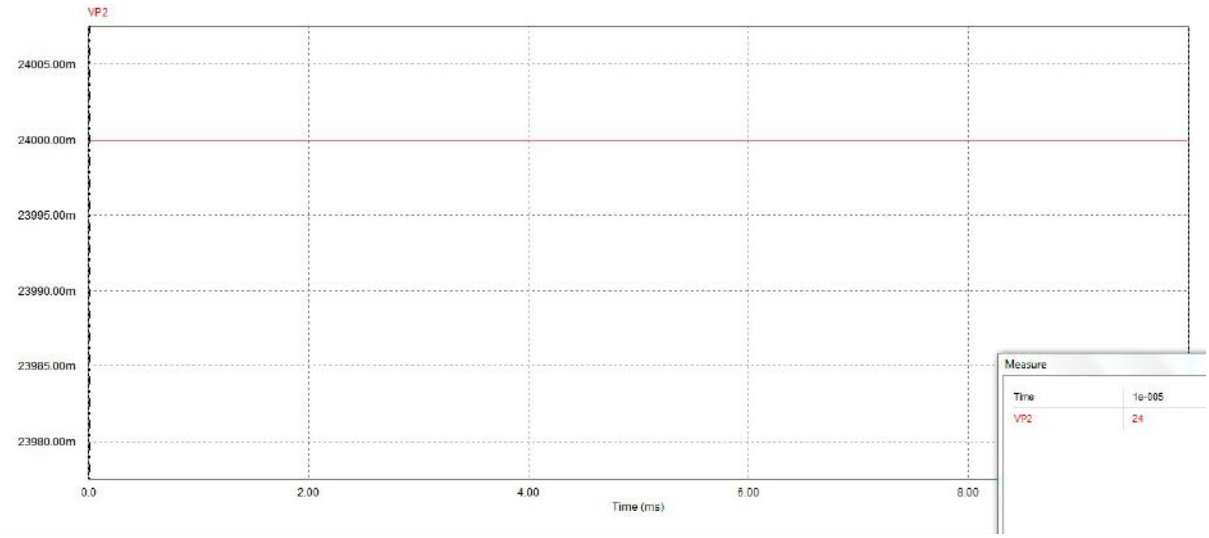

Figure 6.6: Output waveform under Normal Condition

V2 = Single Phase Rectifier and Voltage divider output (V_{in})

V3 = Reference Voltage (9V battery)(V_{ref})

V4 = Comparator Output (When $V_{in} > V_{ref}$)

V_{P2} = Output of Transistor switch between V_{ce}

6.7.3 Waveform of Circuit Under Faulty Condition

When supply voltage falls below 80% of supply voltage ,this condition has been considered as faulty condition. As voltage falls below 80% output voltage to rectifier circuit reduces and voltage divider value also decreases which has been given to input to comparator circuit.Which is below 9v of reference voltage.So comparator circuit gives lower output which makes transistor switch as fully OFF . And voltage to load circuit is equal to V_{ce} on which driven circuit can not operate .

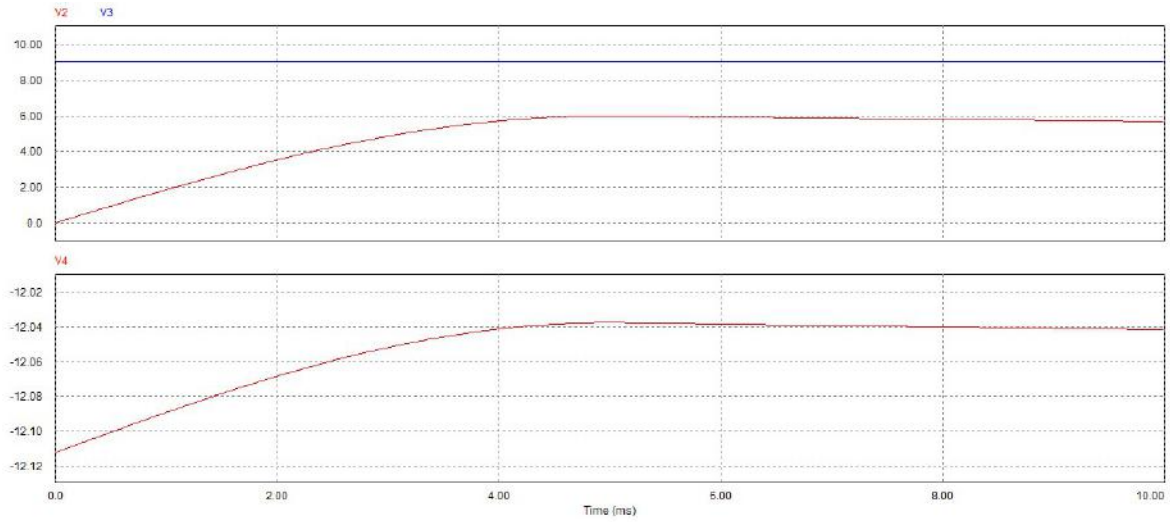

Figure 6.7: Output waveform under fault Condition

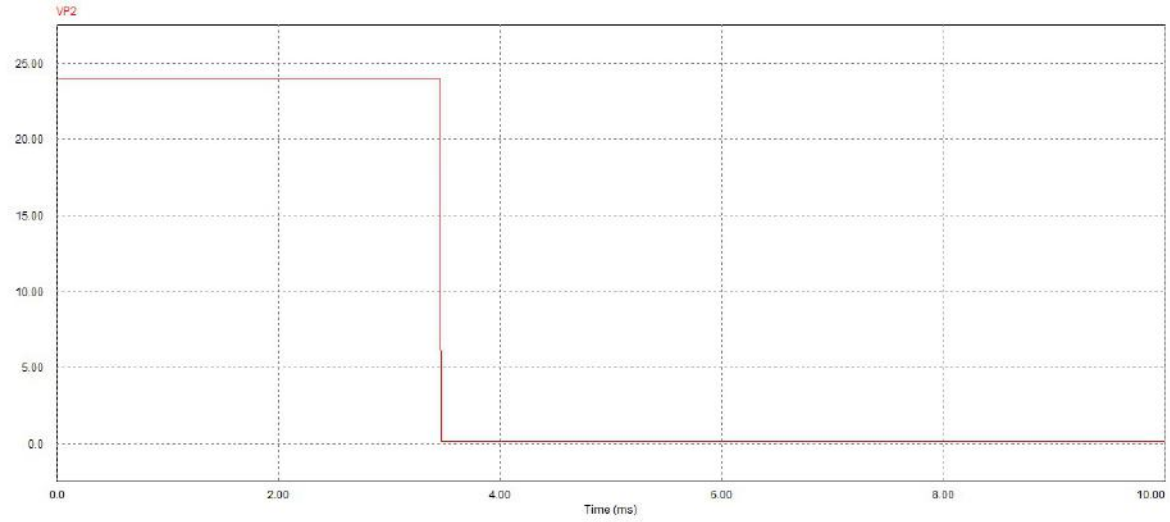

Figure 6.8: Output waveform under faulty Condition

V2 = Single Phase Rectifier and Voltage divider output (V_{in})

V3 = Reference Voltage (9V battery)(V_{ref})

V4 = Comparator Output (When V_{in} <V_{ref})

V_{P2} = Output of Transistor switch between V_{ce}

6.7.4 Hardware of Circuit

1. Rectifier & Voltage Divider Circuit

2. Voltage Regulator Circuit

3. Comparator Circuit

4. Switching Circuit (Transistor)

5. 24VDC Driven circuit

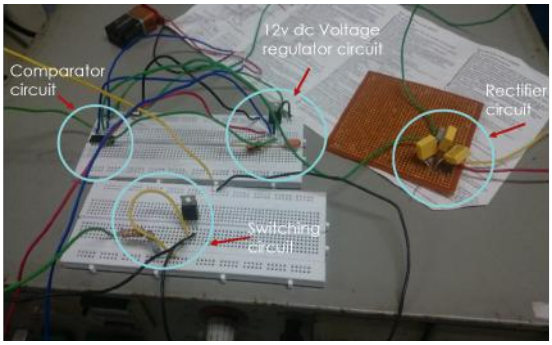

Figure 6.9: Hardware

6.7.5 Rectifier And Voltage Divider Circuit

Parameters of rectifier and voltage divider circuit has been selected according to reference voltage .Reference voltage has been set 9 volt. Voltage divider circuit is consist of two resistor R1 & R2 . Value of R1 & R2 has been selected such that output of voltage divider circuit will be greater than 9 volt reference voltage under healthy condition and as voltage will drop below 80% output of voltage divider will be less than reference voltage and comparator circuit will detect the voltage drop and comparator will give low output.

1. Diode Bridge Rectifier :
    - 14N007 Diode (4 Nos.)
2. Capacitor as filter
    - 0.3 Micro-Farad Capacitor (400V)
3. Voltage divider
    - R1 = 220000 OHM (2 Watts)
    - R2 = 6800 OHM (2 Watts)

V_{ac}	$V_{rectifier}$	$V_{divider}$
240	310.9	10.1
230	297.9	9.20
220	284	8.81
210	272.9	8.45
200	260.6	8.01
190	246.8	7.59
180	232.2	7.18

Waveform of Rectifier & Voltage divider Circuit

Below waveform shows Voltage divider circuit output with ripples . Ripple voltage is 2.8Volts.when capacitor is used of 0.1 Micro-Farad.

Figure 6.10: Rectifier output with ripples

Below waveform shows Voltage divider circuit output with reduced ripples . Ripple voltage is reduced to 0.2Volts from 2.8Volts .when capacitor is used of 0.3 Micro-Farad.

Figure 6.11: Rectifier output with reduced ripples

6.7.6 Comparator Circuit

In comparator circuit LM324 IC is used as comparator IC. LM324 is 14 pin IC having four OP-AMP. Its PIN diagram is shown below.

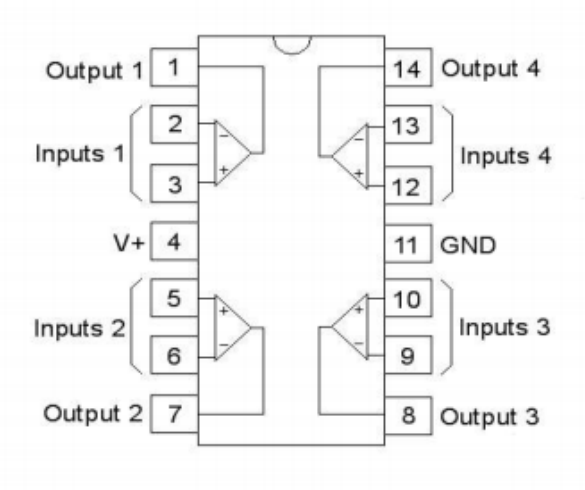

Figure 6.12: LM324 Pin Diagram

Below figure shows the IC LM324N and description of IC Pins and its input and output.

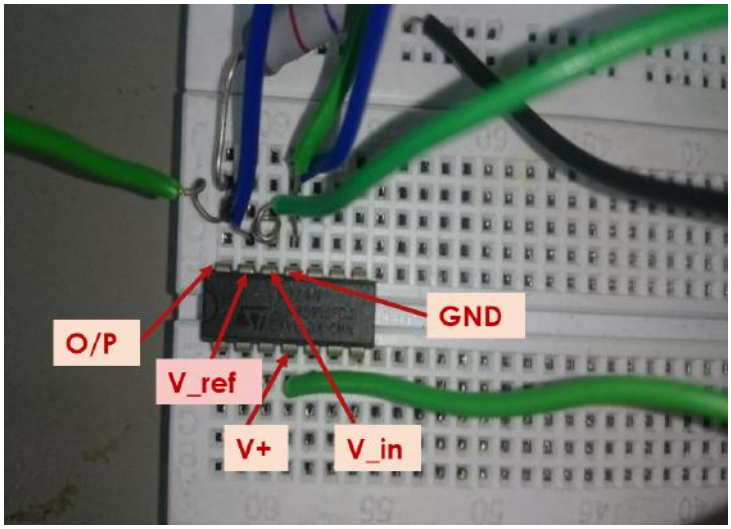

Figure 6.13: Comparator IC

Input Waveform of Comparator IC:

- When $V_{in} > V_{ref}$

Figure 6.14: Comparator waveform

- When $V_{in} < V_{ref}$

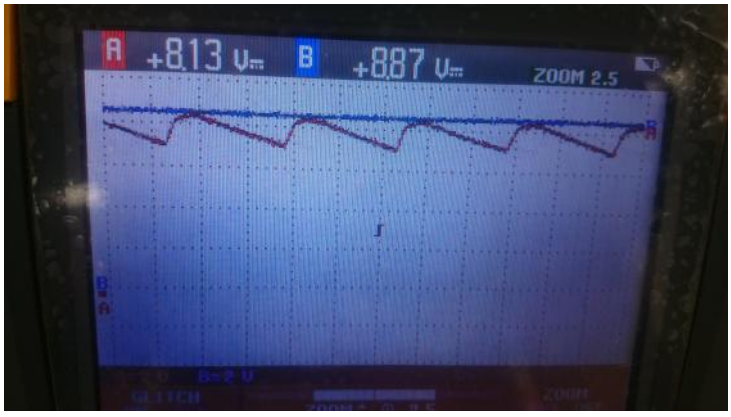

Figure 6.15: Comparator waveform

Output Waveform of Comparator IC:

- When $V_{in} > V_{ref}$

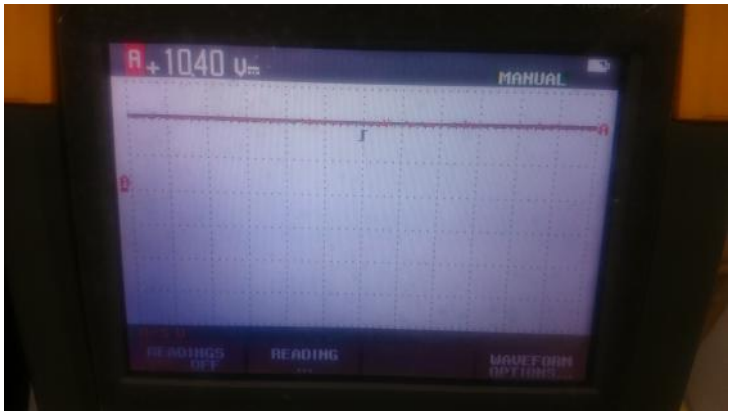

Figure 6.16: Comparator output waveform

- When $V_{in} < V_{ref}$

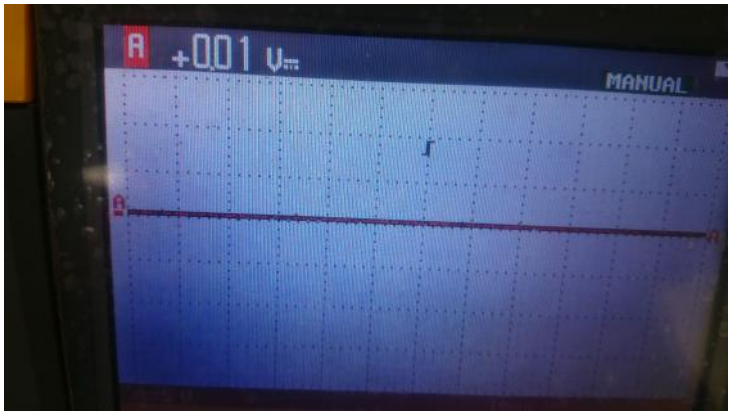

Figure 6.17: Comparator output waveform

6.8 Switching Circuit (Transistor Switch)

As base voltage will be low transistor will be in off state and transistor will be act as open switch and supply to 24VDC UVR will be cut off and UVR will be trip. And as base voltage will be high transistor will be act as on switch and will supply 24V DC to UVR and UVR will be actuated.

Transistor circuit hardware has been shown below:

Terminal 1 : Base

Terminal 2: Collector

Terminal 3: Emitter

Collector Current $I_c = 3$ Amp

$V_{(ce)sat} = 1.2$ Volt

$h_{FE} = 50$

$R_b = 136.6$ Ohm(As per Calculation)

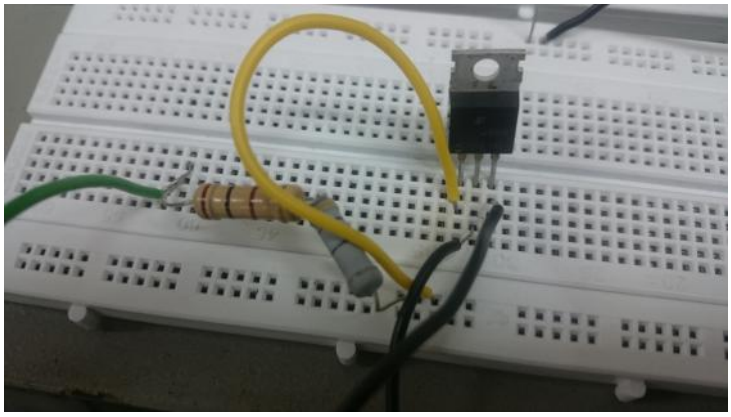

Figure 6.18: IC TIP31C

- When $V_{in} > V_{ref}$

  When Base voltage will be Higher than 1.8 volts transistor IC TIP31C will be act as close switch and it will supply the 24V DC to 24V DC UVR.

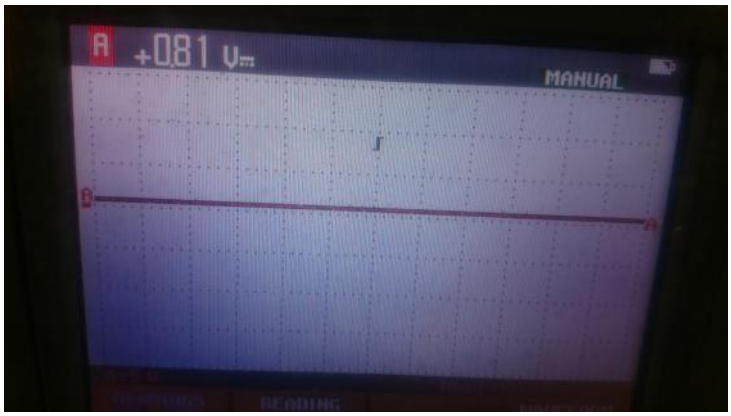

Figure 6.19: Transistor output waveform

- When $V_{in} < V_{ref}$

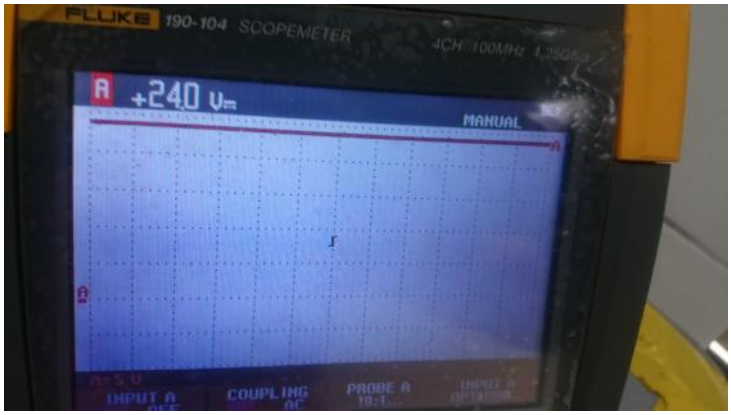

Figure 6.20: Transistor output waveform

6.9 Conclusion for 1-Phase Circuit

After taking trials of 1-phase circuit ,it has been concluded that concept is working ,When voltage drops below 80% of rated voltage transistor is able to supply 24volt to driven circuit.Driven circuit has been design on 24 volt and it makes the coils trips according to logic runs in driven circuit.Which makes the circuit breaker open under faulty condition.Now it required to design three phase circuit which is able to sense three phase voltage drop and operate 24vDC driven circuit.

Chapter 7

Design circuit for three phase Under voltage sensing

7.1 Three phase simulation circuit

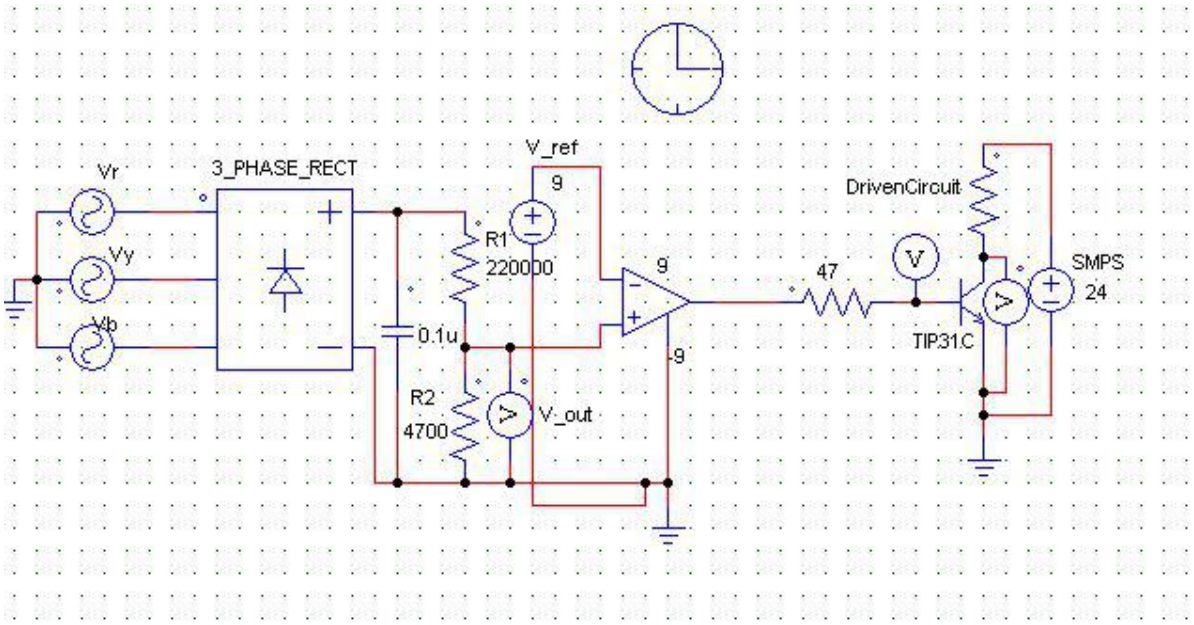

Figure 7.1: Simulation circuit

Three phase voltage sensing circuit which has been simulated in PSim is shown in figure 30.Parameters of different component and work has been explained below.

7.2 Three phase voltage sensing circuit

Voltage detector circuit is provided to supply 24VDC to driven circuit to produce output signal which operate the coils.Voltage detector circuit will sense the three phase voltage drop, as well as single phase and two phase voltage drop.It is also able to sense the phase loss of poly phase system.To achieve requirement of voltage sensing circuit parameters of circuit has been calculated as per below.

7.2.1 Specification:

Rated Voltage	240v AC ,3-Phase 3- Wire
Supply Frequency	50 Hz
Trip level	35% to 75%
Pick up level	80% and above
Time delay setting	Instantaneous,0.1,0.3,0.5 Sec

7.2.2 Calculation of parameters

- **Three Phase Rectifier & Voltage Divider Circuit** : Three phase rectifier is used to concert AC supply voltage to DC.This DC value has an average value with ripple content.In three phase rectifier ripple contents are little as compare to single phase rectifier .This DC supply is reduced to amplitude over a voltage divider circuit.Parameters of rectifier and voltage divider has been decided such that voltage divider reduces voltage to value which senses voltages when falls below 70 % of rated voltage .Simulation has been done in PSim software and readings have been taken for different conditions. Three Conditions when voltage drops in all three phases, in two phases and only in one phase has been considered.Readings are taken by simulating circuit shown below:

When all three phases down						
% drop	Line Volt.	Phase Volt.(RMS)	V_{avg}	R1	R2	Voltage divider value(V_{out})
100%	415	239.88	559.061	220000	4700	11.6937
90%	373.5	215.90	503.154	220000	4700	10.5243
85%	352.75	203.90	475.201	220000	4700	9.9396
80%	332	191.91	447.248	220000	4700	9.3549
75%	311.25	179.91	419.295	220000	4700	8.7703
70%	290.5	167.92	391.342	220000	4700	8.1856
60%	249	143.93	335.436	220000	4700	7.0162

When two phases down						
% drop	Line Volt.	Phase Volt.(RMS)	V_{avg}	R1	R2	Voltage divider value(V_{out})
100%	415	239.88	559.061	220000	4700	11.6937
90%	373.5	215.90	522.459	220000	4700	10.9281
85%	352.75	203.90	504.051	220000	4700	10.5431
80%	332	191.91	485.741	220000	4700	10.1601
75%	311.25	179.91	467.537	220000	4700	9.7793
70%	290.5	167.92	449.448	220000	4700	9.4010
60%	249	143.93	413.548	220000	4700	8.6500
55%	228.25	131.94	395.865	220000	4700	8.2802

When single phase down						
% drop	Line Volt.	Phase Volt.(RMS)	V_{avg}	R1	R2	Voltage divider value(V_{out})
100%	415	239.88	559.061	220000	4700	11.6937
90%	373.5	215.90	541.526	220000	4700	11.3269
85%	352.75	203.90	532.43	220000	4700	11.1367
80%	332	191.91	523.433	220000	4700	10.9485
75%	311.25	179.91	514.542	220000	4700	10.7625
70%	290.5	167.92	505.765	220000	4700	10.5789
60%	249	143.93	488.546	220000	4700	10.2188
55%	228.25	131.94	480.177	220000	4700	10.0437
50%	207.5	119.94	471.962	220000	4700	9.8719

After analysis of above table it has been concluded that if V_{out} will be higher than 9 volt comparator will give higher output as per our requirement during healthy condition. In above tables V_{avg} & Voltage divider output(V_{out}) is calculated theoretically as per below equation:

$$V_{avg} = \frac{3\sqrt{2}V_{rms}}{\pi} \tag{7.1}$$

Vrms = RMS value of line voltage

$$V_{out} = \frac{V_{in}R_2}{R_1 + R_2} \tag{7.2}$$

R1 = 220000

R2 = 4700

- **Comparator Circuit**:LM324 operational amplifier is used as comparator to compare two voltage magnitude .Here LM324 compares regulated V_{out} with reference voltage (V_{ref})9 volt. 9 volt value is decided after studying above tables.9 volt of Reference value has been set using 7809 IC . LM324 IC is supplied with 9 volt using same IC 7809. Output of LM324 is fed to transistor switch using base resistor at base terminal .Typical value of LM324 output current is 20 mA . Voltage output dependent of supply voltage .

Condition	V_{com}
V_{ref} <V_{out}	high
V_{ref} >V_{out}	low

- **Switching Circuit**:In this circuit NPN transistor has been used as switch to supply 24 volt. to driven circuit when three phase supply voltage is healthy and switch should be able to cut off 24v DC to driven circuit when voltage drops in any of the poly phase system or in all three phases. TIP31C NPN transistor has been selected to satisfied required power rating of circuit.Base resistor value is calculated as per below equation.

$$R_b = \frac{V_{com} - V_{be}}{I_b} \tag{7.3}$$

$$I_c = \beta I_b \tag{7.4}$$

$$R_c = \frac{V_{cc} - V_{ce}}{I_c} \tag{7.5}$$

properties of TIP31C NPN transistor is as per below:

V_{CE} = Collector Emitter Voltage(V_{CC})=60 volt.

I_c = Collector Current(DC) = 3 Amp.

I_b = Base Current(DC) = 1 Amp.

h_{FE} = 10 to 50

$V_{CE(sat)}$ = 1.2 volt

$V_{BE(sat)}$ = 1.8 volt

After calculating value of R_b using above equations 47 ohm is getting . And driven circuit is connected across collector to emitter. V_{CC} is supplied to collector through new designed 24VDC ,5 Amp SMPS.

When V_{com} at base is higher than 1.8 volt ,transistor is in forward biased and base current is flowing .At same time transistor act as fully ON switch and will supply V_{cc} to driven circuit connected across collector emitter of transistor. Further driven circuit will run according to its design.

7.3 SMPS design

SMPS design provides stable DC output independent of input supply. SMPS is designed on the base of main coil design . Main coil is designed on rated voltage of 24V DC ,5 amp current. SMPS is also used to supply comparator circuit ,reference voltage using voltage regulator IC .In 3-Phase 3-wire system SMPS is connected across two phases. SMPS input supply is 240 VAC. and in star connected 3-Phase 4-wire system SMPS is connected across phase to neutral.SMPS is switched mode power supply which provide regulated DC output . Working of SMPS is as per below block diagram:

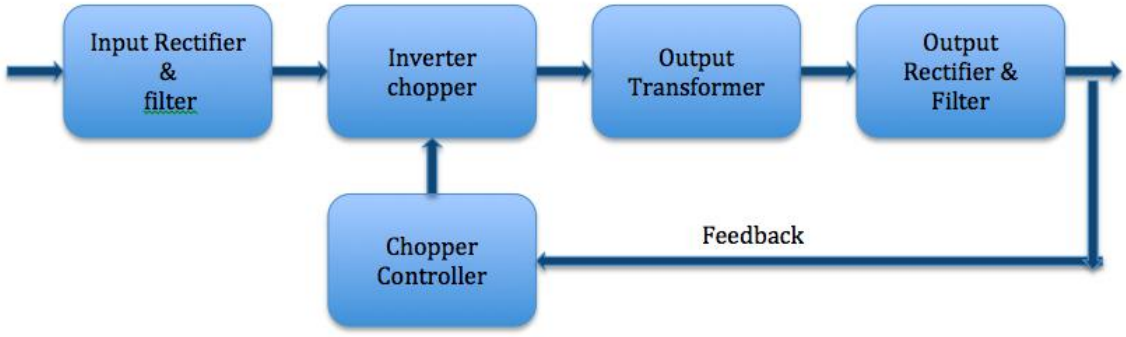

Figure 7.2: Block diagram of SMPS

When SMPS connected to supply voltage ,First AC voltage is converted to DC voltage using single phase rectifier . Rectified output content ripples which will be filtered using capacitor filter.Filtered output is fed to inverter chopper ,which convert rectified DC output to AC using power oscillations.Output transformer is designed at high frequencies about 10 to 20 kHz Which is switching ON OFF using MOSFET switch.MOSFET switch regulated the switching of transformer by taking output feedback to chopper controller . Output of transformer is again converted and filtered out using rectifier and filter circuit. Output of this rectifier is regulated DC voltage.If input supply voltage vary then after it gives constant 24 VDC supply as its output is independent of input voltage.

7.4 Driven circuit

Driven circuit is supplied by 24VDC ,5 Amp SMPS .Driven circuit consist of power circuit,voltage sensing circuit,micro controller circuit .

- **Power Circuit**: Power circuit is designed for input voltage of 24v to 30vDC.Which gives regulated DC output of 30vDC , 1 Amp.In this power circuit DC to DC converter .DC to DC converter convert one DC voltage level to another constant DC voltage with different power rating.DC to DC converter is referred as switching converter. In DC to AC converter output voltage of converter is controlled in both amplitude and frequency using control circuit. Transformer or inductor is used to store energy or to isolate the input and output. Transformer or inductors is designed

within 300kHz to 10MHz. MOSFET has been used to switch the transformer at very high frequencies .As its ON resistor is very lower so MOSFET having very less switching losses. Rectifier and filter circuit is followed by the transformer which provides regulated 30VDC ,1Amp. Power circuit provides 30VDC ,1 Amp to clutch coil directly and also used to supply micro controller ,LM324 IC of voltage sensing circuit and transistor switch of coil control circuit after converting to 5 volt using 7805 voltage regulator IC. Block diagram of power circuit is shown below:

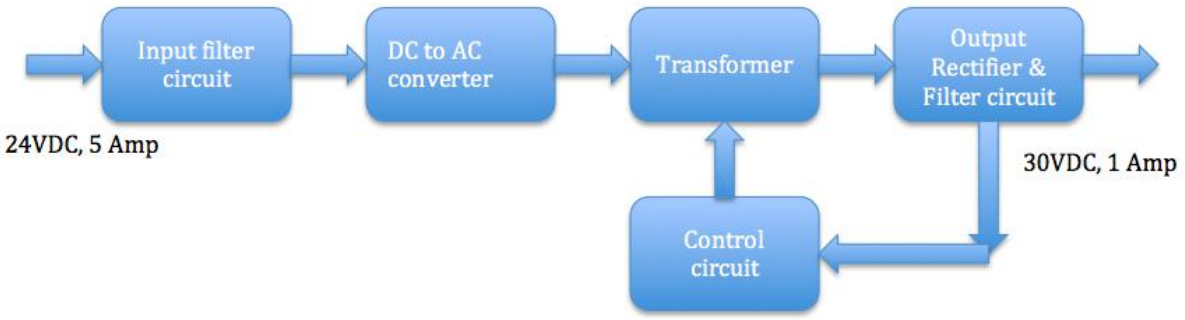

Figure 7.3: Block diagram of DC to DC converter

- **Voltage sensing circuit & Micro controller** :In driven circuit voltage sensing sense the only input voltage 24VDC .24VDC is used to scaled down using voltage divider resistor value of R1=80000 & R2=6800 ohm to approximately 2.45 volt(V_{in}). And reference voltage has been set 2.45 volt (V_{ref}) with scaling down of 5 volt using voltage divider resistor value R1=20000 & R2=100 ohm.LM324 operational amplifier has been used as comparator . LM324 having two terminals inverting terminals and non inverting terminals.Here V_{ref} is set at 2.45 volts at inverting terminals.And comparator works as positive comparator. At non inverting terminal V_{in} has been set.Under healthy condition input to voltage divider is 24 volt and under fault condition input to voltage divider is 0 volt. As $V_{ref} > V_{in}$,positive comparator gives high output(V_{com}) .High output has been given to AN0 (PIN 7) terminal of micro controller . Here PIC 12F675 micro controller is used. Micro controller program run as it gets high input and give high output to GP2 terminal (PIN 5) and low output to GP1 terminal (PIN 6). PIN 5 & 6 give input to coil control circuit for main coil and clutch coil respectively .Simultaneously time delay logic is given us-

ing 4-R/A DIP Switch to GP5,GP4,GP3(PIN 2,3,4 resp.) Terminal.PIN diagram of micro controller has been shown below. When $V_{in} < V_{ref}$,comparator gives low output .Low input to AN0 (PIN 7) gives higher output to GP1 (PIN 6) .

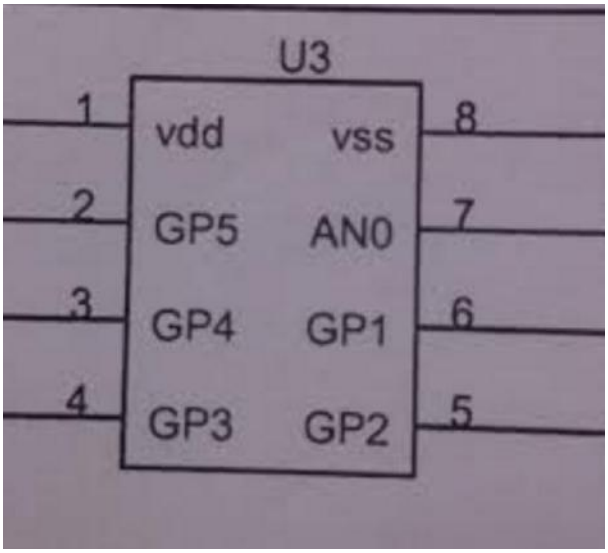

Figure 7.4: PIN diagram of micro controller

7.5 Coil control circuit & Coil Design

Main Coil Design :

Main coil is designed such that it gets energized on 17volt to 24volt .It is having plunger ,spring and actuator. It is supplied directly through 24VDC when supply given to driven circuit. As coil is energized magnetic field is generated and attracts the plunger which actuates the actuator .Actuator is mechanically latched with clutch coil actuator.When main coil is supplied clutch coil is not supplied at that time.

Rated Voltage	17 to 24 Volts
Rated Current	5 Amp
No of Turns	2407
Resistance	123.4

Main Coil Control Circuit:

As driven circuit is supplied with 24VDC,5 Amp directly given to main coil by switching ON MOSFET switch.When driven circuit senses the healthy 24VDC ,micro controller

give high output to its PIN 6 .High input voltage to base of transistor which switched ON the transistor . Transistor gives control signal to gate terminal of MOSFET to switch ON and MOSFET is allowed to Flow current from drain to source .Main coil is connected across the drain and source terminal of MOSFET.V_{CC} to drain terminal of MOSFET is 24VDC,5 Amp.

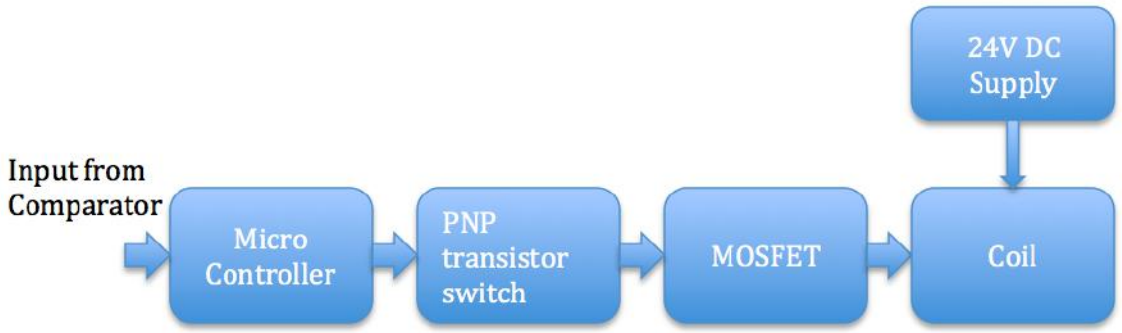

Figure 7.5: Block Diagram of Main coil control circuit

Clutch Coil Design:

Clutch coil is designed such that it gets energized on 30VDC ,1 Amp .It is having actuator with spring. Power circuit of driven circuit supplied energized voltage to clutch coil while three phase voltage drops.As it gets energized it actuates the actuator which have been mechanically latched with main coil actuator . As actuator actuates it drops the main coil actuator and plunger of main coil makes circuit breaker open.

Rated Voltage	30 Volts
Rated Current	1 Amp
No of Turns	320
Resistance	2.1 ohm

Clutch Coil Control Circuit:

When voltage to driven circuit gets 0 volts as three phase voltage drop occurs or any phase voltage drop occurs of poly phase system. Voltage sensing circuit sense 0volts less than reference voltage 2.45 volts and give comparator output lower. Lower input run logic in micro controller and it gives higher output to PIN 7 . Output of micro controller fed to base of transistor of clutch coil control circuit. Higher voltage to base switches on

the PNP transistor of control circuit. Transistor provides control signal to gate terminal of MOSFET. Which makes MOSFET fully ON switch and allow to flow 1 Amp current through clutch coil to energized it. Clutch coil is connected across drain -source terminal of MOSFET.

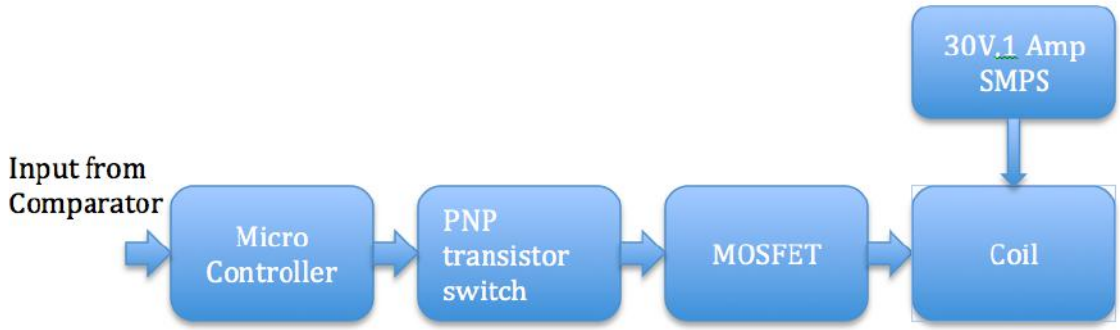

Figure 7.6: Block Diagram of clutch coil control circuit

Below table shows the output voltages at PIN 6 & PIN 5 of micro controller at Higher and lower output of comparator .

V_{com}	V_5	V_6
2.79	4.9	0
0	0	4.9

Chapter 8

Testing of Three Phase Circuit

8.1 Three Phase Circuit Trials

Above mention concept has been applied and implemented hardware for same circuit. Testing of hardware has been performed on three phase test bench . On test bench three phase supply voltage is controlled .Three phase four wire system is configured on test bench.Phase R, Y and B voltages have been given to respective input of three phase rectifier circuit. 24VDC,5 Amp rating SMPS is connected between one phase and neutral. Test have been perform for three conditions with single phase voltage drop, with two phase voltage drop and with three phase voltage drop.Phase voltage has been given 240 VAC to each leg of rectifier circuit with 120 degree phase shift.Observation has been taken as per below table for different conditions.

- **Single Phase Voltage Drop**:
  In this case voltage has been gradually decreased manually in B phase first.Observation taken till coil gets tripped . Voltage has been decreased by 10 voltages at each observation.After taking observations for B Phase same trials have been taken for Phase R & Y . Observations were approximately same for each phase.

Single phase voltage drop				
V_R	V_Y	V_B	V_{out}	Observation of Coil
240	240	240	11.96	Not tripped
240	240	200	11.37	Not tripped
240	240	190	11.14	Not tripped
240	240	180	11.02	Not tripped
240	240	170	10.85	Not tripped
240	240	160	10.66	Not tripped
240	240	150	10.50	Not tripped
240	240	149	10.49	Not tripped
240	240	145	10.46	Not tripped
240	240	144	10.42	Tripped
240	240	142	10.40	Tripped
240	240	140	10.38	Tripped

From above observation table ,it has been analyzed that when voltage falls below 145 volt in single phase coil gets tripped . So it is analyzed that when voltage falls below **60%** of rated voltage 240 volts , circuit sense the voltage drop and it makes the coil tripped . Here voltage divider value is 10.42 and below ,on which coil gets tripped .Here observed value 10.42 recorded by digital multimeter shows average value. But in actual when voltage drops in one phase of poly phase system only one phase output voltage waveform gets reduced while waveform of other phases are healthy . So waveform of affected voltage gets below 9 volts (V_{ref}) Comparator considered it as lower value and provide the signal to further circuit to trip the coil.

- **Two Phase Voltage Drop**:

  In this case voltage has been decreased in phase R & B simultaneously and taken trials.Observation have been taken till main coil gets tripped.Observation table is shown below.

Two Phase Voltage Drop				
V_R	V_Y	V_B	V_{out}	Observation of Coil
240	240	240	11.92	Not tripped
210	240	210	10.92	Not tripped
198	240	198	10.51	Not tripped
192	240	190	10.35	Not tripped
192	240	192	10.23	Not tripped
180	240	180	9.94	Not tripped
170	240	180	9.92	Not tripped
170	240	170	9.59	Not tripped
168	240	168	9.58	Not tripped
167	240	166	9.52	Tripped
167	240	170	9.56	Tripped
166	240	166	9.46	Tripped
165	240	166	9.48	Tripped
154	240	158	9.25	Tripped

From above observation table it has been analyzed that voltage divider output (V_{out}) falls below 9.58 comparator sense it as voltage drop and it makes coil tripped. 9.58 volt observed is average value by digital multimeter .It has been observed that when voltage drops in two phases falls below **70%** of rated voltage 240volt three phase under voltage circuit sense it as fault and makes coil tripped.Same trials were taken for phase R& Y and phase B & Y.

- **Three Phase Voltage Drop**:

  In this case voltage have been decreased in all three phases simultaneously .And observations taken at different percentage falls in rated voltages.Observation table shown below.

V_R	V_Y	V_B	V_{out}	Observation of Coil
240	240	240	11.92	Not tripped
200	200	200	10.92	Not tripped
190	190	190	9.34	Not tripped
185	185	185	9.01	Not tripped
182	182	182	8.97	Not tripped
180	180	180	8.95	Not tripped
179	179	179	8.81	Not tripped
178	178	178	8.78	Tripped
176	176	176	8.72	Tripped
175	175	175	8.64	Tripped
170	170	170	8.35	Tripped

Above observation table shows as voltage drops occurs **75%** in each phase circuit sense it as fault and it provide signal to coil and coil gets tripped.

8.2 Observation

After taking trails of three phase under voltage circuit ,it is concluded that circuit works properly for different percentage drop in single phase ,two phase and three phase. Designed circuit can able to sense **60%** and below of rated voltage drop in one phase only .it is able to open circuit breaker below 60% of rated voltage sensed . Designed circuit can able to sense **70%** voltage drop in any two phases of three phase system and circuit can be able to sense **75%** voltage drop in all three phases simultaneously. So for different condition **drop off voltage** as per standard.As per standard drop off voltage should be below **75%** of rated voltage which has been achieved in taken trials.

8.3 Circuit to Achieve Pick up Voltage

As per standard ,pick up voltage of under voltage release should be **80%** and above. Which was not achieved in above circuit .Only drop off voltage has been achieved. So some modification required in above circuit so it can achieve pickup voltage also.80% of

rated voltage 240volt is 192 volts. If phase voltage will be above 80% (192 VAC) then only main coil should be picked up and should latch mechanically with clutch coil actuator.

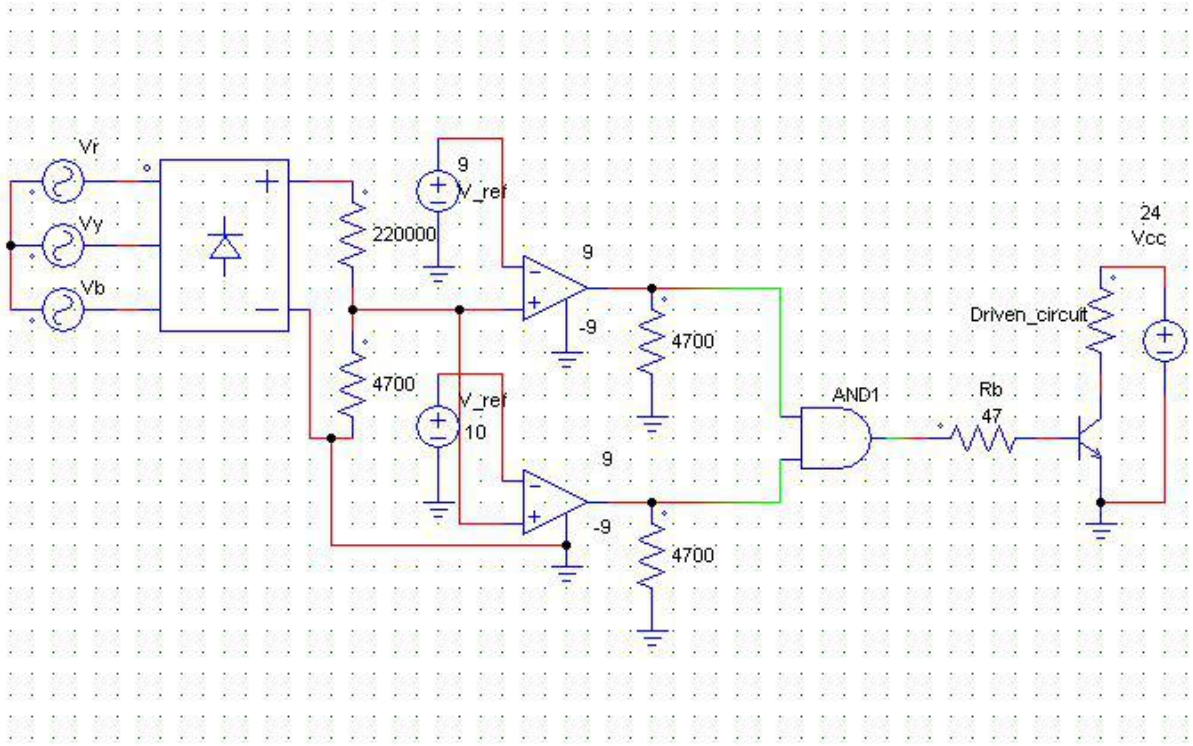

Figure 8.1: Circuit diagram of pickup voltage

In figure 34 two comparator has been used .Reference voltage set to their inverting terminals are different. In one comparator reference voltage has been set to 9 volt and in second comparator 10 volt. AND gate IC is followed by comparator .AND IC is two input IC .Output of comparator will fed to gate IC .AND gate IC will give high output when both comparator output goes high. When both input to AND IC is high it gives high output and one of two input goes low AND gate will give lower output. High output of AND IC will transistor ON and lower output will make transistor OFF. Further driven circuit ,coil control circuit will be same.Trials have been taken for same circuit for different condition.

Chapter 9

Conclusion

After taking trials of three phase under voltage circuit ,it is concluded that circuit senses voltage drop in three phase system.It is able to sense 60% of drop in any one phase of three phase system.It can sense 70% of drop in any two phase simultaneously of poly phase system.And it can sense 75% of drop in all three phases simultaneously. So drop voltage is achieved .Pick up voltage is also achieved 80% and above.

Chapter 10

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