Implementation of over-voltage & under-voltage protection system

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ABSTRACT

Overvoltage and undervoltage are quality problems, they happen due to many reasons. The effects of overvoltage and undervoltage can be severe and can cause insulation failure in case of overvoltage and overheating and burning of motors coils in case of undervoltage.

To solve the problem a tripping mechanism is designed to disconnect the load when subjected to overvoltage, undervoltage or imbalance operation in case of three phase equipments. The design is first simulated in a virtual environment using a simulation program, and then a hardware design is made according to the simulated circuit. Two designs are made single phase and three phase, only the single phase is designed as hardware.

The circuits responded effectively to voltage variations whether it's under or over voltage in case of single phase circuit, and overvoltage, undervoltage, phase failure and imbalance operation in case of three phase circuit.

The liquid crystal display shows the operation status of the system whether it is operating normally or under faulted condition.

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LIST OF SYMPOLS

V_{ip}	Peak full wave rectified voltage at the filter input
V_p	Peak transformer secondary voltage value
V_{dc}	DC voltage value
f	frequency
R_B	Base resistor
V_N	Microcontroller output voltage
V_{BE}	Base emitter voltage
I_B	Base current
I_C	Collector current
h_{FE}	DC current gain

CHAPTER ONE

INTRODUCTION

1.1 Overview

As the demand of electrical energy increases more generating units, transmission lines are added to the system, which in turn increases its complexity, making the system more prone to faults and disturbances.

Now-a-days, greater demands have been placed on the transmission network, and theses demands will continue to rise because of the increasing number of nonutility generators and greater competition among utilities themselves. Increased demands on transmission, absence of long-term planning, and the need to provide open access to generating companies and customers have resulted in less security and reduced quality of supply [1].

Several types of power enhancement devices have been developed over the years to protect equipments from power disturbances, but these devices can also fail or malfunction sometimes. Thus the need for more security is always wanted.

1.2Problem Statement

The effects of overvoltage and under voltage to electric equipments in general and motors specifically are serious and can’t be ignored. Overheating and insulation failure might happen when electric equipments are subjected to under or over voltage conditions.

Moreover the condition maybe hazardous, Depending on its duration, it is more serious in the case of domestic appliances like fridges and air conditioners. If a fridge is operated on low voltage, excessive current flows through the motor, which heats up and gets damaged.

The economic loss from premature motor failure is devastating. In most cases, the price of the motor itself is trivial compared to the cost of unscheduled shutdowns of processes. Both high and low voltages can cause premature motor failure, as will voltage imbalance.

1.3Objectives

- To develop a tripping mechanism to protect the load from over voltage and under voltage in general.
- To develop a tripping mechanism to protect three phase motors from under voltage, overvoltage, imbalance operation and phase failure.

1.4Methodology

- Circuit simulation program is used to test the equipments to be used in a virtual environment; the program is *Proteus 8 Professional.*
- Then a simple single phase prototype is built to stimulate the results in real time environment.

1.5Project Layout

This project contain five chapters, Chapter One includes the introduction, problem statement, objectives, methodology and project layout. Chapter Two includes causes of overvoltage and under voltage, their effects on various types of loads and the solutions normally adopted to solve them. Chapter Three includes the various components used in this project by great details. Chapter Four includes the single phase and three phase circuits, the simulation and hardware implementation of the single phase circuit, program code used and the three phase circuit, its simulation and the code used. Chapter Five includes conclusion and the recommendations of the project.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

As the demand of electrical power increases, more generating units, transmission lines, power and distribution transformers etc. are added to the system. Which in turn will increase its complexity; faults and quality problems will increase as well. Undervoltage and overvoltage are common quality problems. The overvoltage causes number of effect in the power system. It may cause insulation failure of the equipments, malfunction of the equipments. Overvoltage can cause damage to components connected to the power supply and lead to insulation failure, damage to electronic components, heating, flashovers, etc. Over voltages occur in a system when the system voltage rises over 110% of the nominal rated voltage.

Voltage sags are brief reductions in voltage, typically lasting from a cycle to a second, or tens of milliseconds to hundreds of milliseconds. Longer periods of voltage sags are harmful especially to induction motors,

(Longer periods of low or high voltage are referred to as "under-voltage" or "over-voltage”).

A transient event is a short-lived burst of energy in a system caused by a sudden change of state.

The source of the transient energy may be an internal event or a nearby event. The energy then couples to other parts of the system, typically appearing as a short burst of oscillation.

2.2 Over-voltage:

The main causes due to which over-voltages are produced in the power systems can be generally classified into two categories as follows:

- **Internal over-voltages**

  This is classified to:

  - Switching over-voltages.
  - Insulation failure.
  - Arcing ground: can be prevented by earthing the neutral.
  - Resonance.
- **External over-voltages:** due to lighting [2].

2.2.1 Switching over-voltages:

There is a great variety of events that would initiate a switching surge in a power network. The switching operations of greatest relevance to insulation design can be classified as follows:

- Energization of transmission lines and cables. The following specific switching operations are some of the most common in this category:
- Energization of a line that is open circuited at the far end.
- Energization of a line that is terminated by an unloaded transformer.
- Energization of a line through the low-voltage side of a transformer.
- Reenergization of a line**.** This means the energization of a transmission line carrying charges trapped by previous line interruptions when high-speed reclosures are used.
- Load rejection. This is affected by a circuit breaker opening at the far end of the line. This may also be followed by opening the line at the sending end in what is called a line dropping operation.
- Switching on and off of equipment. All switching operations involving an element of the transmission network will produce a switching surge. Of particular importance, however, are the following operations:
- Switching of high-voltage reactors.

- Switching of transformers that are loaded by a reactor on their tertiary winding.
- Switching of a transformer at no load.
- Fault initiation and clearing.

2.2.2 Lightning over-voltages:

An electric discharge between cloud and earth, between clouds or between the charges centers of the same cloud is known as lightning.

Lightning is a huge spark and takes place when clouds are charged to such a high potential (+ve or −ve) with respect to earth or a neighboring cloud that the dielectric strength of neighboring medium (air) is destroyed [2].

The most severe lightning stroke is that which strikes a phase conductor on the transmission line as it produces the highest overvoltage for a given stroke current. The lightning stroke injects its current into a termination impedance Z, which in this case is half the line surge impedance $Z_o$since the current will flow in both directions as shown in Figure (2-1). Therefore, the voltage surge magnitude at the striking point is:

$V = \left(\frac{1}{2}\right) I \times Z_o$ .... (2-1)

The lightning current magnitude is rarely less than 10 kA and thus, for typical overhead line surge impedance Z_o of 300, the lightning surge voltage will probably have a magnitude in excess of 1500 kV.

Equation (2-1) assumes that the impedance of the lightning channel itself is much larger than (1/2) Z_o; indeed, it is believed to range from 100 to 3000 Ω. Equation (2-1) also indicates that the lightning voltage surge will have approximately the same shape characteristics. In practice, however, the shapes and magnitudes of lightning surge waves get modified by their reflections at points of discontinuity as they travel along transmission lines Lightning strokes represent true danger to life, structures, power systems, and communication networks. Lightning is always a major source of damage to power systems where equipment insulation may break down under the resulting overvoltage and the subsequent high-energy discharge.

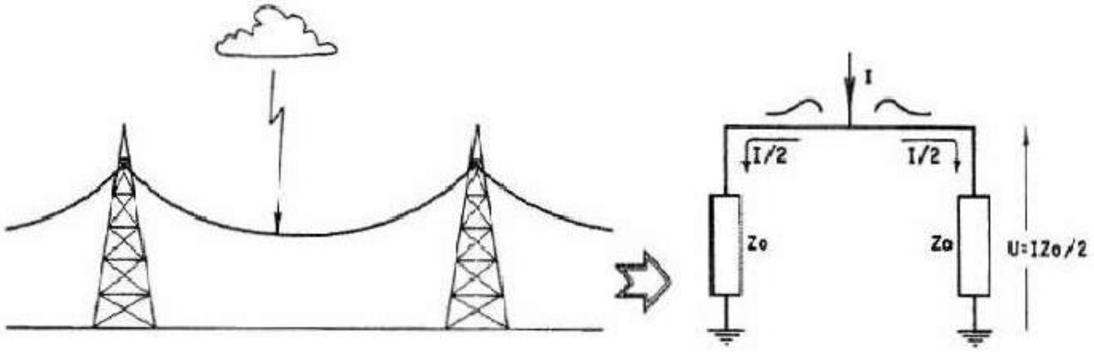


Figure 2.1: Development of lightning overvoltage

2.3 Under-voltage:

Sag or under-voltage is a temporary decrease in power lasting up to over a minute. Sag or an under-voltage typically happens whenever heavy machinery is turned on. A great amount of power is used by the heavy machinery during startup, leaving a small amount or power available for other equipment to use.

Voltage sags also happen when the main source of power is affected by natural events like lightning strikes, strong winds and power lines getting hit by falling tree branches. Sag or an under-voltage may affect equipment within 100 miles of the main power grid of a utility company.

Voltage sags are caused by abrupt increases in loads such as short circuits or faults, motors starting, or electric heaters turning on, or they are caused by abrupt increases in source impedance, typically caused by a loose connection.

Voltage sags are the most common power disturbance. At a typical industrial site, it is not unusual to see several sags per year at the service entrance, and far more at equipment terminals.

Voltage sags can arrive from the utility; however, in most cases, the majority of sags are generated inside a building. For example, in residential wiring, the most common cause of voltage sags is the starting current drawn by refrigerator and air conditioning motors.

Sags do not generally disturb incandescent or fluorescent lighting Motors or heaters; however some electronic equipment lacks sufficient internal energy storage and, therefore, cannot ride through sags in the supply voltage. Equipment may be able to ride through very brief, deep sags, or it may be able to ride through longer but shallower sags.

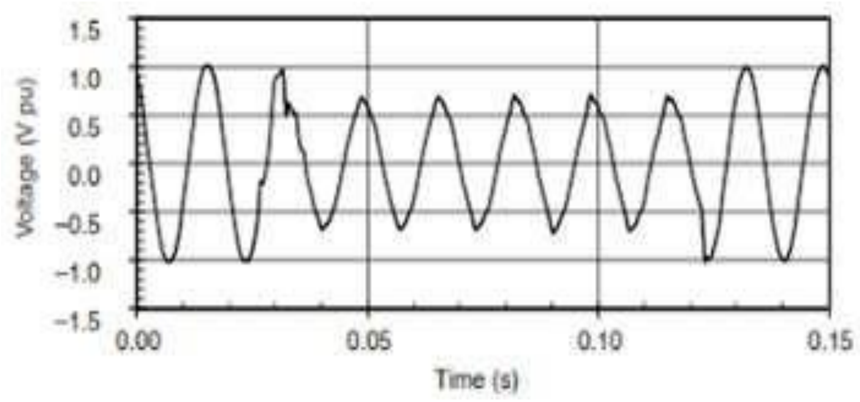


Figure 1.2: Typical voltage sag

2.4 Effects of voltage fluctuations:

2.4.1 Appliances without motors and their behavior on voltage fluctuations: Appliances like luminaries (bulbs, tube lights and CFLs) and heaters (like room heaters and water heaters) do not need voltage stabilizers. When the voltage is less, less current will flow through them. When voltage is more, more current will flow through them. So when voltage is less, the output of these appliances will be less or the bulb will give less light, room heater will heat less, water heater will heat slowly. And as the bulb will give lesser light the power consumption of the bulb will be less. In fact many municipalities reduce the voltage of street lights at times when the light requirement is less to reduce the power consumption of the bulbs. However when the voltage is higher than normal, more current will flow through these appliances. And if the high voltage is consistent, it may result in burning of the bulb or the appliance.

2.4.2 Appliances with motors and their behavior on voltage fluctuations:

All appliances with motors have an operating voltage range. Appliance like a ceiling fan has much larger operating voltage range and thus they are able to work even at lower voltages. But appliances like air conditioners have very small operating voltage range and thus they do not work at low voltages. If the voltage provided to them is lower than their operating voltage range, then either they will not start at all, and if they are already running, they will start producing a humming sound. This humming sound happens as these motors draw more current to run the system. This can lead to overheating and burning of the motor if persistent. Thus saving induction motors from voltage fluctuations is very important. At high voltages these appliances draw more current only at the time of starting, but once they reach steady state the current is much less. But still, the high starting current can damage the system and thus appliances with motors need to be protected both from high as well as low voltages.

.2.5 Effects of low voltage on motors

When a motor is subjected to voltages below the nameplate rating, some of the motor's characteristics will change slightly and others will change dramatically. To drive a fixed mechanical load connected to the shaft, a motor must draw a fixed amount of power from the line. The amount of power the motor draws has a rough correlation to the voltage and current (amps). Thus, when voltage gets low, the current must increase to provide the same amount of power. An increase in current is a danger to the motor only if that current exceeds the motor's nameplate current rating. When amps go above the nameplate rating, heat begins to build up in the motor. Without a timely correction, this heat will damage the motor, the more heat and the longer the exposure to it, the more damage to the motor.

The existing load is a major factor in determining how much of a decrease in supply voltage a motor can handle. For example a motor that carries a light load. If the voltage decreases, the current will increase in roughly the same proportion that the voltage decreases. For example, a 10% voltage decrease would cause a 10% amperage increase. This would not damage the motor, if the current stays below the nameplate value.

In the case of heavy loaded motors the motor is already drawing high current, so voltage is already lower than it would be without the load. It might even be close to the nameplate's lower limit for voltage. When there is a voltage reduction, the current would rise to a new value, which may exceed the full-load rated amps.

Low voltage can lead to overheating, shortened life, reduced starting ability, and reduced pull-up and pullout torque. The starting torque, pull-up torque, and pullout torque of induction motors all change, based on the applied voltage squared. Thus the torque is very sensitive to any changes in the supply voltage. For example a change of 5% in supply voltage will produce a change of approximately 10% in the rotor torque.

On lightly loaded motors with easy-to-start loads, reducing the voltage will not have any appreciable effect, except that it might help reduce the light load losses and improve the efficiency under this condition. This is the principle behind some add-on equipment whose purpose is to improve efficiency [3].

2.6 Effects of high voltage on motors

High voltage on a motor tends to push the magnetic portion of the motor into saturation. This causes the motor to draw excessive current in an effort to magnetize the iron beyond the point where magnetizing is practical.

Motors will tolerate a certain change in voltage above the design voltage. However, extremes above the design voltage will cause the amperage to go up with a corresponding increase in heating and a shortening of motor life.

For example, manufacturers previously rated motors at 220/440V, with a tolerance band of 10%. Thus, the voltage range they can tolerate on the high- voltage connections is 396V to 484V. Even though this is the so-called tolerance band, the best performance would occur at the rated voltage. The extreme ends (either high or low) put unnecessary stress on the motor.

The purpose of these bands is to accommodate the normal hour-to-hour swings in plant voltage. Operation on a continuous basis at either the high or low extreme will shorten the life of the motor.

Such sensitivity to voltage is not unique to motors. In fact, voltage variations affect other magnetic devices in similar ways. The solenoids and coils found in relays and starters tolerate low voltage better than they do high voltage. This is also true of ballasts in fluorescent, mercury, and high-pressure sodium light fixtures. And it's true of transformers of all types. Incandescent lights are especially susceptible to high voltage. A 5% increase in voltage results in a 50% reduction in the life of the lamp. A 10% increase in voltage above the rating reduces incandescent lamp life by 70%.

2.7 Single Phasing Fault:

This is a power supply-related electrical fault in case of an induction motor. For a Three-phase motor when one of the phases gets lost then the condition is known as single phasing.

2.7.1 Causes of Single Phasing Fault

Single phasing fault in an induction motor may be due to

- A downed line or a blown fuse of the utility system.
- Due to an equipment failure of the supply system.

- Due to short circuit in one phase of the star-connected or delta-connected motor.

2.7.2 Effects of Single Phasing Fault

Effects of single phasing fault are as follows:

- For single phasing fault motor windings get over heated, primarily due to flow of negative sequence current.
- If during running condition of the motor single phasing fault occurs motor Continues to run due to the torque produced by the remaining two phases and this torque is produced as per the demand by the load—as a result healthy phases may be over loaded and hence over heated resulting in critical damage to the motor itself.
- A three-phase motor will not start if a single phasing fault already persists in the supply line.

2.8 Voltage unbalance

A voltage variation in a three-phase system in which the three voltage magnitudes or the phase angle differences between them are not equal, causes are large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault). Consequences are Unbalanced systems imply the existence of a negative sequence that is harmful to all three phase loads. The most affected loads are three-phase induction machines. [3]

2.9 Adopted solutions

- Transient Voltage Surge Suppressors (TVSS):

It provides the simplest and least expensive way to condition power. These units clamp transient impulses (spikes) to a level that is safe for the electronic load. Employing an entire facility protection strategy will safeguard the electrical system against most transients. Multi-stage protection entails using TVSS at the service entrance, sub-panel a at the point of use. This co-ordination of devices provides the lowest possible let through voltage to the equipment. Transient voltage surge suppressors are used as interface between the power source and sensitive loads, so that the transient voltage is clamped by the TVSS before it reaches the load. TVSSs usually contain a component with a nonlinear resistance (a metal oxide varistor or a zener diode) that limits excessive line voltage and conduct any excess impulse energy to ground. [3]

- Voltage regulators :

Voltage regulators maintain output voltage at nominal voltage under all but the most severe input voltage variations. Voltage regulators are normally installed where the input voltage fluctuates, but total loss of power is uncommon. There are three basic types of regulators:

- Tap Changers: Designed to adjust for varying input voltages by automatically transferring taps on a power transformer. The main advantage of tap changes over other voltage regulation technology is high efficiency. Other advantages are wide input range, high overload current capability and good noise isolation. Disadvantages are noise created when changing taps and no waveform correction.
- Buck Boost: Utilize similar technology to the tap changers except the transformer is not isolated. Advantages are the units withstand high in-rush currents and have high efficiency. Disadvantages are noise created when changing taps, poor noise isolation and no waveform correction.
- Constant Voltage Transformer (CVT): Also known as ferroresonant transformers. The CVT is a completely static regulator that maintains a nearly constant output voltage during large variations in input voltage. Advantages are superior noise isolation, very precise output voltage and current limiting for overload protection. The lack of moving parts mean the transformer

requires little or no maintenance. Disadvantages are large size, audible noise and low efficiency.

Constant voltage transformers (CVT) were one of the first PQ solutions used to mitigate the effects of voltage sags and transients. To maintain the voltage constant, they use two principles that are normally avoided: resonance and core saturation. When the resonance occurs, the current will increase to a point that causes the saturation of the magnetic core of the transformer. If the magnetic core is saturated, then the magnetic flux will remain roughly constant and the transformer will produce an approximately constant voltage output. If not properly used, a CVT will originate more PQ problems than the ones mitigated. It can produce transients, harmonics (voltage wave clipped on the top and sides) and it is inefficient (about 80% at full load). Its application is becoming uncommon due to technological advances in other areas [4].

- Static VAR Compensators (SVCS):

Static VAR compensators (SVR) use a combination of capacitors and reactors to regulate the voltage quickly. Solid-state switches control the insertion of the capacitors and reactors at the right magnitude to prevent the voltage from fluctuating. The main application of SVR is the voltage regulation in high voltage and the elimination of flicker caused by large loads (such as induction furnaces). It is normally applied to transmission networks to counter voltage dips/surges during faults and enhance power transmission capacity on long. [3]

CHAPTER THREE CIRCUITS COMPONENTS

3.1 Transformer

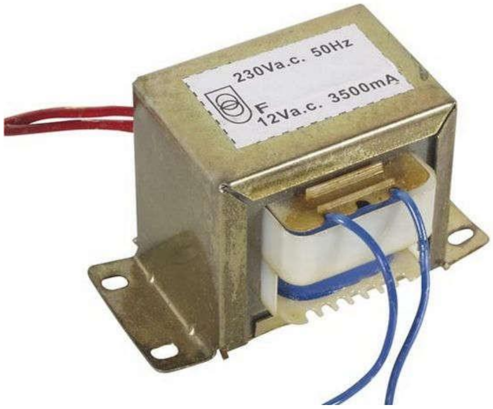


Figure 3.1: 12V 3500mA transformer

A transformer is a static piece of apparatus by means of which electric power in one circuit is transferred into electric power of the same frequency in another circuit. It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in current. [5] The physical basis of a transformer is mutual induction between two circuits linked by common magnetic flux. In its simplest form, it consists of two inductive coils which are electrically separated but magnetically linked through a path of low reluctance. The two coils posses high mutual inductance. If one coil is connected to a source of alternating voltage, an alternating flux is set up in the laminated core, most of which is linked with the other coil in which it produces mutually induced e.m.f. if the second coil circuit is closed, a current flows in it and so electric energy is transferred (entirely magnetically) from the first coil to the second coil. The first coil, in which electric energy is fed from the AC supple mains, is called primary winding and the other from which energy is drawn out, is called secondary winding.

3.2 Rectifier

Figure 3.2: Diode Bridge, rated at 1000 volts, 4 amperes.

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification, since it "straightens" the direction of current. Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems.

Because of the alternating nature of the input AC sine wave, the process of rectification alone produces a DC current that, though unidirectional, consists of pulses of current. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a steady constant DC current (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter (usually a capacitor) to produce a steady current.

3.2.1 Full-wave rectification

A full-wave bridge rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to pulsating DC (direct current), and yields a higher average output voltage. Two diodes and a center tapped transformer, or four diodes in a bridge configuration and any AC source (including a transformer without center tap), are needed [6]. Single semiconductor diodes, double diodes with common cathode or common anode, and four-diode bridges, are manufactured as single components.

The average and RMS no-load output voltages of an ideal single-phase full- wave rectifier are:

$$V_{dc} = V_{av} = \frac{2 * V_{peak}}{\pi} \quad (3.1)$$

3.2.2 Rectifier output smoothing

While half-wave and full-wave rectification can deliver unidirectional current, neither produces a constant voltage. Producing steady DC from a rectified AC supply requires a smoothing circuit or filter. In its simplest form this can be just a smoothing capacitor, placed at the DC output of the rectifier. There is still an AC ripple voltage component at the power supply frequency for a half-wave rectifier, twice that for full-wave, where the voltage is not completely smoothed.

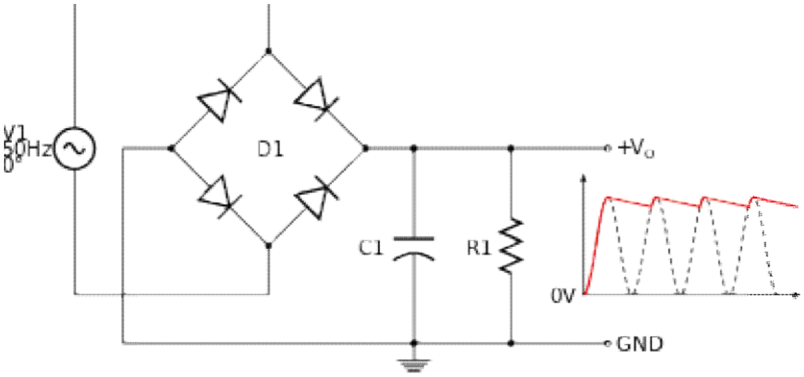


Figure 3.3: RC filter circuit.

Sizing of the capacitor represents a tradeoff. For a given load, a larger capacitor reduces ripple but costs more and creates higher peak currents in the transformer secondary and in the supply that feeds it. The peak current is set in principle by the rate of rise of the supply voltage on the rising edge of the incoming sine-wave, but in practice it is reduced by the resistance of the transformer windings. In extreme cases where many rectifiers are loaded onto a power distribution circuit, peak currents may cause difficulty in ma0intaining a correctly shaped sinusoidal voltage on the ac supply.

To limit ripple to a sp the ecified value the required capacitor size is proportional to load current and inversely proportional to the supply frequency and the number of output peaks of the rectifier per input cycle. The load current and the supply frequency are generally outside the control of the designer of the rectifier system but the number of peaks per input cycle can be affected by the choice of rectifier design.

3.3 Voltage regulator

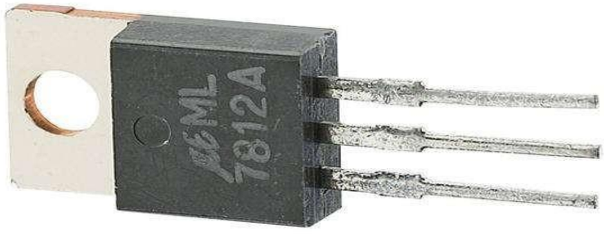


Figure 3.4: 12V Voltage regulator

A voltage regulator is designed to automatically maintain a constant voltage level. Electronic voltage regulators are found in devices such as computer power supplies where they stabilize the DC voltages used by the processor and other elements.

Due to low-cost fabrication technique, many commercial integrated-circuit (IC) regulators are available since the past two decades. These include fairly simple, fixed-voltage types of high-quality precision regulators. These regulators have much improved performance as compared to those made from discrete components. They have a number of unique build-in features such as current limiting, self-protecting against over temperature, and remote control operation over a wide range of input voltages.[5]

3.3.1 Types of IC voltage regulators

- Fixed positive linear voltage regulators.
- Fixed negative linear voltage regulators.
- Adjustable positive linear voltage regulators.
- Adjustable negative linear voltage regulators.

- **Fixed positive linear voltage regulators**

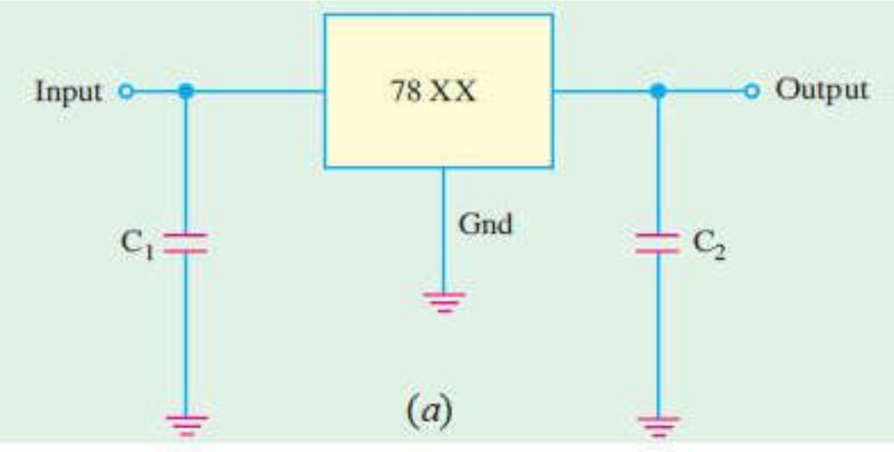


Figure 3.5: Standard configuration of a fixed positive voltage IC regulator of 7800 series.

There are many IC regulators available in the market that positive produces a fixed output voltage. But 7800 series of IC regulators is representative of three terminal devices that are available with several fixed voltages positive output making them useful in a wide range of applications.

Fig (2) shows a standard configuration of a fixed positive voltage IC regulator of 7800 series. The last two digits (marked xx) in the part number designate the output voltage. The capacitor C_1 is required only if the power supply filter is located more than 3 inches from the IC regulator [5].

3.4 RESISTOR

Figure 3.6: A typical axial-lead resistor

A resistive is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.

Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment. Practical resistors as discrete components can be composed of various compounds and forms. Resistors are also implemented within integrated circuits.

The electrical function of a resistor is specified by its resistance: common commercial resistors are manufactured over a range of more than nine orders of magnitude. The nominal value of the resistance falls within the manufacturing tolerance, indicated on the component.

3.5 POTENTIOMETERS

Figure 3.7: A typical single-turn potentiometer

A potentiometer is a three-terminal resistor with a sliding contact that forms an adjustable voltage divider [7]. Two terminals are connected to both ends of a resistive element, and the third terminal connects to a sliding contact, called a wiper, moving over the resistive element. The position of the wiper determines the output voltage of the potentiometer. The potentiometer essentially functions as a variable voltage divider. The resistive element can be seen as two resistors in series (potentiometer resistance), where the wiper position determines the resistance ratio of the first resistor to the second resistor.

A potentiometer is also commonly known as a potmeter or pot. The most common form of potmeter is the single turn rotary potmeter. This type of pot is often used in audio volume control (logarithmic taper) as well as many other applications. Different materials are used to construct potentiometers, including carbon composition, cermets, wire wound, and conductive plastic or metal film. For theory of operation see appendix A.

3.6 Operational Amplifier

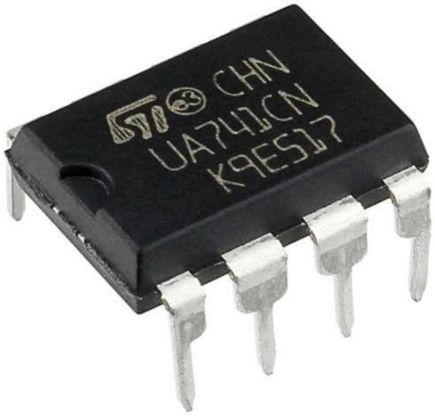


Figure 3.8: General purpose operational amplifier.

Operational amplifiers are linear devices that have all the properties required for nearly ideal DC amplification and are therefore used extensively in signal conditioning, filtering or to perform mathematical operations such as addition, subtraction, integration and differentiation.

An **Operational Amplifier**, or op-amp for short, is fundamentally a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals. These feedback components determine the resulting function or "operation" of the amplifier and by virtue of the different feedback configurations whether resistive, capacitive or both, the amplifier can perform a variety of different operations, giving rise to its name of "Operational Amplifier".

An *Operational Amplifier* is basically a three-terminal device which consists of two high impedance inputs, one called the Inverting Input, marked with a negative or "minus" sign, (–) and the other one called the Non-inverting Input, marked with a positive or "plus" sign (+).

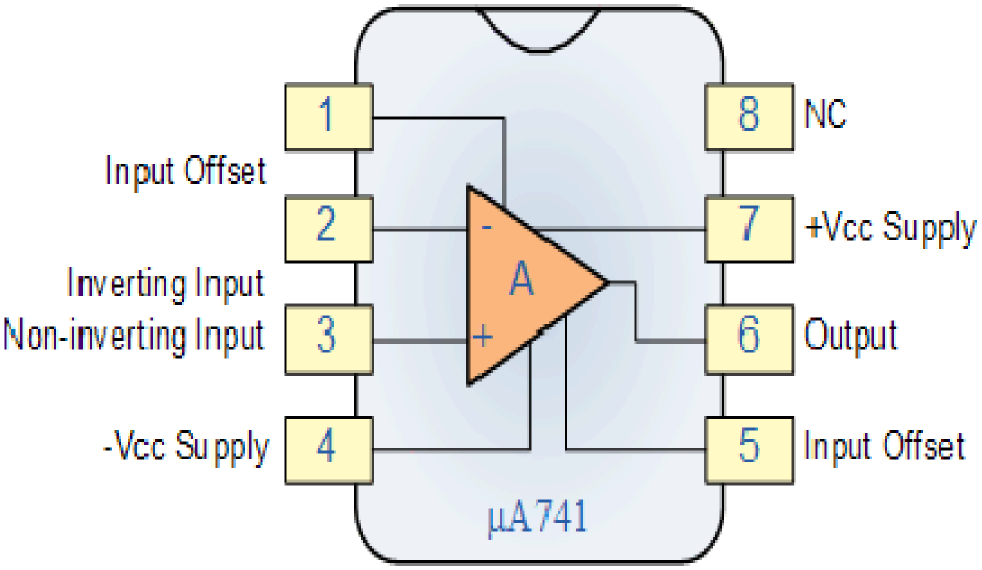
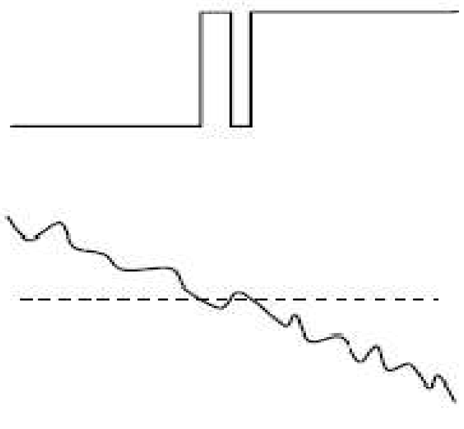


Figure 3.9: Internal pins configuration

3.6.1 : Signal Comparator:

That is, the op-amp is being used as a voltage comparator. A device designed primarily as a comparator may be better if, for instance, speed is important or a wide range of input voltages may be found, since such devices can quickly recover from full on or full off ("saturated") states.



.10: A noisy signal on V- (bottom) generates multiple transitions (top) as 3Figure it goes above and below the threshold on V+ (dashed line).

We often refer to the V+ voltage as the reference voltage and connect the input to V-. Comparators are supposed to determine:

- If the input (V-) is less than the reference (V+) then the output rails high.
- If the input (V-) is greater than the reference (V+) then the output rails low.

However, when a comparator looks at a real input signal it will always be faced with some small variations in the signal that make it hard to determine which input is greater. Even worse, this electrical "noise" could drive your comparator through many transitions when you really wanted your signal to show only one transition. Figure 3.10 shows how a little noise added to a slowly decreasing signal can cause multiple transitions in the output. The top curve shows the comparator output, while the bottom curve shows the V– input. The dashed line represents the V+ input.

When V– drops below the threshold (dashed line) the output changes state. When noise makes the input voltage briefly go back above the dashed curve the output "bounces" to low and back to high accordingly.

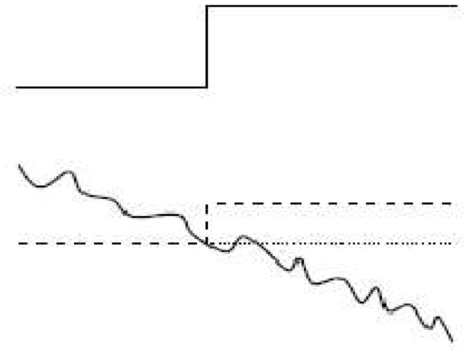


Figure 3.11: When the output makes a transition (top), the reference level can be shifted (dashed) using positive feedback to prevent extra transitions as the input on V- (bottom) makes multiple transitions across the original reference voltage on V+ (dotted line).

The solution to this problem is to use positive feedback to simultaneously shift the reference voltage (V+) as the output changes states. This is illustrated in Figure 3.11. If the shift is large enough, then the output will be less likely to bounce between the two output states during the transition. This shift, which is called a “hysteresis”, depends on the design of the feedback network that ties V+ to the output level.

3.7 ZENER DIODES

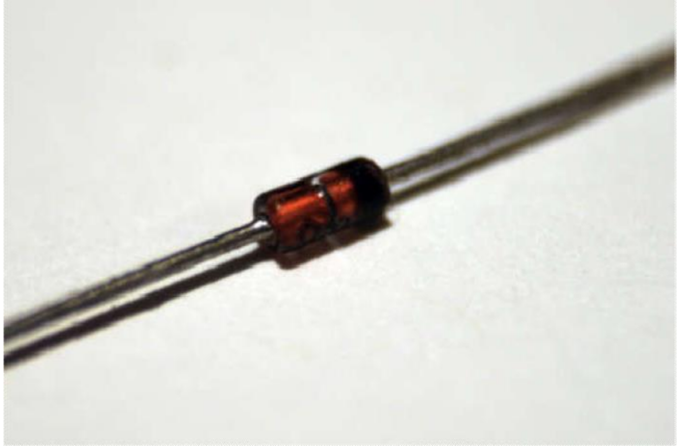


Figure 3.12: Zener diode

A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage". The device was named after Clarence Melvin Zener, who discovered the Zener effect. A Zener diode exhibits almost the same properties, except the device is specially designed so as to have a greatly reduced breakdown voltage, the so-called Zener voltage. A Zener diode contains a heavily doped p-n junction allowing electrons to tunnel from the valence band of the p-type material to the conduction band of the n-type material. In the atomic scale, this tunneling corresponds to the transport of valence band electrons into the empty conduction band states; as a result of the reduced barrier between these bands and high electric fields that are induced due to the relatively high levels of doping on both sides.A reverse-biased Zener diode will exhibit a controlled breakdown and allow the current to keep the voltage across the Zener diode at the Zener voltage. For example, a diode with a Zener breakdown voltage of 3.2 V will exhibit a voltage drop of 3.2 V if reverse bias voltage applied across it is more than its Zener voltage.

However, the current is not unlimited, so the Zener diode is typically used to generate a reference voltage for an amplifier stage, or as a voltage stabilizer for low-current applications.

The breakdown voltage can be controlled quite accurately in the doping process. While tolerances within 0.05% are available, the most widely used tolerances are 5% and 10%. Breakdown voltage for commonly available Zener diodes can vary widely from 1.2 volts to 200 volts.

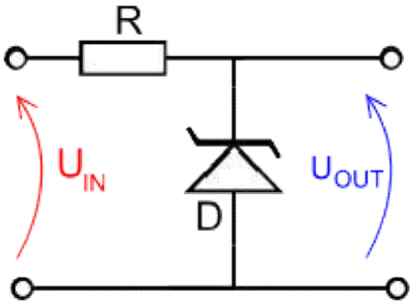


Figure 3.13: Zener diode voltage regulator

In this circuit, a typical voltage reference or regulator, an input voltage, U_{IN}, is regulated down to a stable output voltage U_{OUT}. The intrinsic voltage drop of diode D is stable over a wide current range and holds U_{OUT} relatively constant even though the input voltage may fluctuate over a fairly wide range. Because of the low impedance of the diode when operated like this, Resistor R is used to limit current through the circuit.

The value of *R* must satisfy two conditions see appendix B.

3.8 Capacitor

Figure 3.14: A typical electrolytic capacitor

A capacitor or condenser is a passive electronic component consisting of a pair of conductors separated by a dielectric. When a potential difference exists across the conductors, an electric field is present in the dielectric. This field stores energy and produces a mechanical force between the conductors. The effect is greatest when there is a narrow separation between large areas of conductor; hence capacitor conductors are often called plates.

An ideal capacitor is characterized by a single constant value, capacitance, which is measured in farads. This is the ratio of the electric charge on each conductor to the potential difference between them. In practice, the dielectric between the plates passes a small amount of leakage current. The conductors and leads introduce an equivalent series resistance and the dielectric has an electric field strength limit resulting in a breakdown voltage.

Capacitors are widely used in electronic circuits to block the flow of direct current while allowing alternating current to pass, to filter out interference, to smooth the output of power supplies, and for many other purposes. They are used in resonant circuits in radio frequency equipment to select particular frequencies from a signal with many frequencies.

See appendix B for the choice of rating of the capacitor and its relation to breakdown voltage.

3.8.1 Capacitor types

Capacitors are divided into two mechanical groups: Fixed capacitors with fixed capacitance values and variable capacitors with variable (trimmer) or adjustable (tunable) capacitance values.

The most common kinds of capacitors are:

- Ceramic capacitors
- Film capacitors
- Power film capacitors
- Electrolytic capacitors

Electrolytic capacitors derive a large part of their capacitance from the formation of a gaseous layer on one plate when proper polarity is applied. This gaseous layer and greater dielectric effect gives an electrolytic capacitor a much larger capacitance by volume than other types of capacitors can achieve.

Because of their higher capacitance values, electrolytic capacitors are most often used in lower-frequency applications such as in power supply filters. Because of their construction and polarity-sensitive operation, electrolytic capacitors require more careful use than other capacitors. If installed improperly (reverse polarized), electrolytic capacitors will not achieve correct capacitance and may build internal gas pressure, leading to an (minor) explosion.

- **Supercapacitors**

3.9 Diode

Figure 3.15: Diode

In electronics a diode is a two-terminal electronic component that conducts electric current in only one direction. The term usually refers to a semiconductor diode, the most common type today, which is a crystal of semiconductor connected to two electrical terminals, a P-N junction. A vacuum tube diode, now little used, is a vacuum tube with two electrodes; a plate and a cathode.

The most common function of a diode is to allow an electric current in one direction (called the forward direction) while blocking current in the opposite direction (the reverse direction). Thus, the diode can be thought of as an electronic version of a check valve. This unidirectional behavior is called rectification, and is used to convert alternating current to direct current, and remove modulation from radio signals in radio receivers.

A P-N junction diode is one-way device offering low resistance when forward biased and behaving almost as an insulator when reverse biased.[5]

Hence, such diodes are mostly used as rectifiers *i.e.* for converting alternating current into direct current.

3.10 Transistor:

Figure 3.16: Assorted discrete transistors

A transistor is a semiconductor device commonly used to amplify or switch electronic signals. A transistor is made of a solid piece of a semiconductor material, with at least three terminals for connection to an external circuit. A voltage or current applied to one pair of the transistor's terminals changes the current flowing through another pair of terminals. Because the controlled (output) power can be much more than the controlling (input) power, the transistor provides amplification of a signal. Some transistors are packaged individually but most are found in integrated circuits.

3.10.1 Simplified operation:

The essential usefulness of a transistor comes from its ability to use a small signal applied between one pair of its terminals to control a much larger signal at another pair of terminals. This property is called gain. A transistor can control its output in proportion to the input signal, that is, can act as an amplifier. Or, the transistor can be used to turn current on or off in a circuit as an electrically controlled switch, where the amount of current is determined elements. by other circuit The two types of transistors have slight differences in how they are used in a circuit. A bipolar transistor has terminals labeled *base*, *collector*, and *emitter*. A small current at the base terminal (that is, flowing from the base to the emitter) can control or switch a much larger current between the collector and emitter terminals. For a field-effect transistor, the terminals are labeled gate, source, and drain, and a voltage at the gate can control a current between source and drain.

3.10.2 Transistor as a switch:

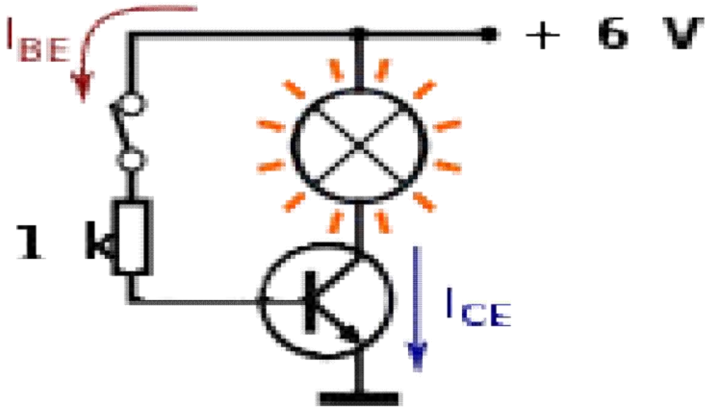


Figure 3.17: BJT used as an electronic switch, in grounded-emitter configuration.

Transistors are commonly used in digital circuits as electronic switches which can be either in an "on" or "off" state, both for high-power applications such as switched-mode power supplies and for low-power applications such as logic gates. Important parameters for this application include the current switched, the voltage handled, and times. the switching speed, characterized by the rise and fall In a grounded-emitter transistor circuit, such as the light-switch circuit shown, as the base voltage rises, the emitter and collector currents rise exponentially. The collector voltage drops because of reduced resistance from collector to emitter. If the voltage difference between the collector and emitter were zero (or near zero), the collector current would be limited only by the load resistance (light bulb) and the supply voltage. This is called *saturation* because current is flowing from collector to emitter freely. When saturated, the switch is said to be on [9].

Providing sufficient base drive current is a key problem in the use of bipolar transistors as switches. The transistor provides current gain, allowing a relatively large current in the collector to be switched by a much smaller current into the base terminal. The ratio of these currents varies depending on the type of transistor, and even for a particular type, varies depending on the collector current. In the example light-switch circuit shown, the resistor is chosen to provide enough base current to ensure the transistor will be saturated.

In a switching circuit, the idea is to simulate, as near as possible, the ideal switch having the properties of open circuit when off, short circuit when on, and an instantaneous transition between the two states. Parameters are chosen such that the "off" output is limited to leakage currents too small to affect connected circuitry; the resistance of the transistor in the "on" state is too small to affect circuitry; and the transition between the two states is fast enough not to have a detrimental effect.

Transistor is the proper arrangement of different semiconductor materials. General semiconductor materials used for transistor are silicon, germanium, and gallium-arsenide. Basically the transistors are classified depending on their structure. Each type of transistors has their own characteristics, advantages and disadvantages.

Some transistors are designed primarily for switching purpose, other side some are designed for amplification purpose and some transistors are designed for both amplification and switching purposes. Depending on the structure the transistors are classified into BJT and FET.

3.10.3 Junction transistors

Bipolar junction transistors can operate in three regions, they are:

- Cut-off region: Here the transistor is in ‘OFF’ state i.e. the current flowing through the transistor is zero.
- Active region: Here the transistor acts as an amplifier.
- Saturation region: Here the transistor is in fully ‘ON’ state and also works as a closed switch.

3.11 Relay

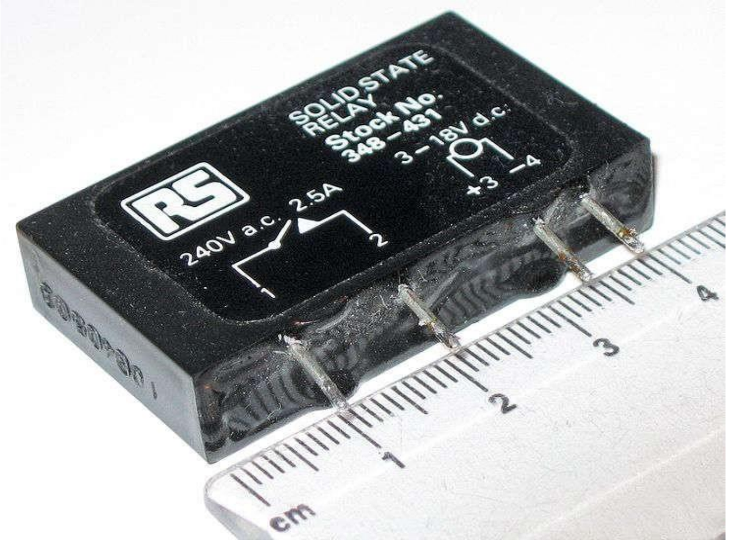


Figure 3.18: Solid state relay

A relay is an electrically operated switch. Many relays use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as solid-state relays. Relays are used where it is necessary to control a circuit by a separate low-power signal, or where several circuits must be controlled by one signal.

A type of relay that can handle the high power required to directly control an electric motor or other loads is called a contactor. Solid-state relays control power circuits with no moving parts, instead using a semiconductor device to perform switching.

3.11.1 Basic design and operation

A simple electromagnetic relay consists of a coil of wire wrapped around a soft iron core (a solenoid), an iron yoke which provides a low reluctance path for magnetic flux, a movable iron armature, and one or more sets of contacts. The armature is hinged to the yoke and mechanically linked to one or more sets of moving contacts. The armature is held in place by a spring so that when the relay is de-energized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed, and the other set is open. Other relays may have more or fewer sets of contacts depending on their function.

When an electric current is passed through the coil it generates a magnetic field that activates the armature and the consequent movement of the movable contact either makes or breaks (depending upon construction) a connection with a fixed contact. If the set of contacts was closed when the relay was de- energized, then the movement opens the contacts and breaks the connection, and vice versa if the contacts were open. When the current to the coil is switched off, the armature is returned by a force, approximately half as strong as the magnetic force, to its relaxed position. Usually this force is provided by a spring, but gravity is also used commonly in industrial motor starters. Most relays are manufactured to operate quickly. In a low-voltage application this reduces noise; in a high voltage or current application it reduces arcing.

When the coil is energized with direct current, a diode is often placed across the coil to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a voltage spike dangerous to semiconductor circuit components.

3.12 Microcontroller:

Figure 3.19: PIC 18F8720 microcontroller.

A microcontroller is a small computer on a single integrated circuit. In modern terminology, it is a system on a chip.

A microcontroller contains one or more CPUs (processor cores) along with memory and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems.

3.12.1 Embedded Design:

A microcontroller can be considered a self-contained system with a processor, memory and peripherals and can be used as an embedded system. The majority of microcontrollers in use today are embedded in other machinery, such as automobiles, telephones, appliances, and peripherals for computer systems.

While some embedded systems are very sophisticated, many have minimal requirements for memory and program length, with no operating system, and low software complexity. Typical input and output devices include switches, relays, solenoids, LED's, small or custom liquid-crystal displays, radio frequency devices, and sensors for data such as temperature, humidity, light level etc. Embedded systems usually have no keyboard, screen, disks, printers, or other recognizable I/O devices of a personal computer, and may lack human interaction devices of any kind.

3.12.2 Programming Environment:

Microcontrollers were originally programmed only in assembly language, but various high-level programming languages, such as C, Python and JavaScript, are now also in common use to target microcontrollers and embedded systems[10].These languages are either designed especially for the purpose, or versions of general purpose languages such as the C programming language. Compilers for general purpose languages will typically have some restrictions as well as enhancements to better support the unique characteristics of microcontrollers.

Simulators are available for some microcontrollers. These allow a developer to analyze what the behavior of the microcontroller and their program should be if they were using the actual part. A simulator will show the internal processor state and also that of the outputs, as well as allowing input signals to be generated.

3.13 LIQUID CRYSTAL DISPLAY

Figure 3.20: LCD

A liquid crystal display (LCD) is a thin, flat display device made up of any number of color or monochrome pixels arrayed in front of a light source or reflector. Each pixel consists of a column of liquid crystal molecules suspended between two transparent electrodes, and two polarizing filters, the axes of polarity of which are perpendicular to each other. Without the liquid crystals between them, light passing through one would be blocked by the other. The liquid crystal twists the polarization of light entering one filter to allow it to pass through the other. Many microcontroller devices use 'smart LCD' displays to output visual information.

For an 8-bit data bus, the display requires a +5V supply plus 11 I/O lines. For a 4-bit data bus it only requires the supply lines plus seven extra lines. When the LCD display is not enabled, data lines are tri-state and they do not interfere with the operation of the microcontroller.

SIGNALS TO THE LCD:

The LCD also requires 3 control lines from the microcontroller:

- Enable (E)

This line allows access to the display through R/W and RS lines. When this line is low, the LCD is disabled and ignores signals from R/W and RS. When (E) line is high, the LCD checks the state of the two control lines and responds accordingly.

- Read/Write (R/W)

This line determines the direction of data between the LCD and microcontroller. When it is low, data is written to the LCD. When it is high, data is read from the LCD.

- Register select. (RS)

With the help of this line, the LCD interprets the type of data on data lines. When it is low, an instruction is being written to the LCD. When it is high, a character is being written to the LCD.

CHAPTER FOUR

CIRCUITS IMPLEMENTAION AND HARDWARE IMPLEMENTAION

4.1 Single phase

To protect single phase loads from fluctuations, overvoltage and over voltage disturbances, a device consisting of discrete electronic and electrical components is built to act as a voltage sensor and measure the voltage at all times and make sure the device to be protected is operating under nominal voltage value.

Block diagram

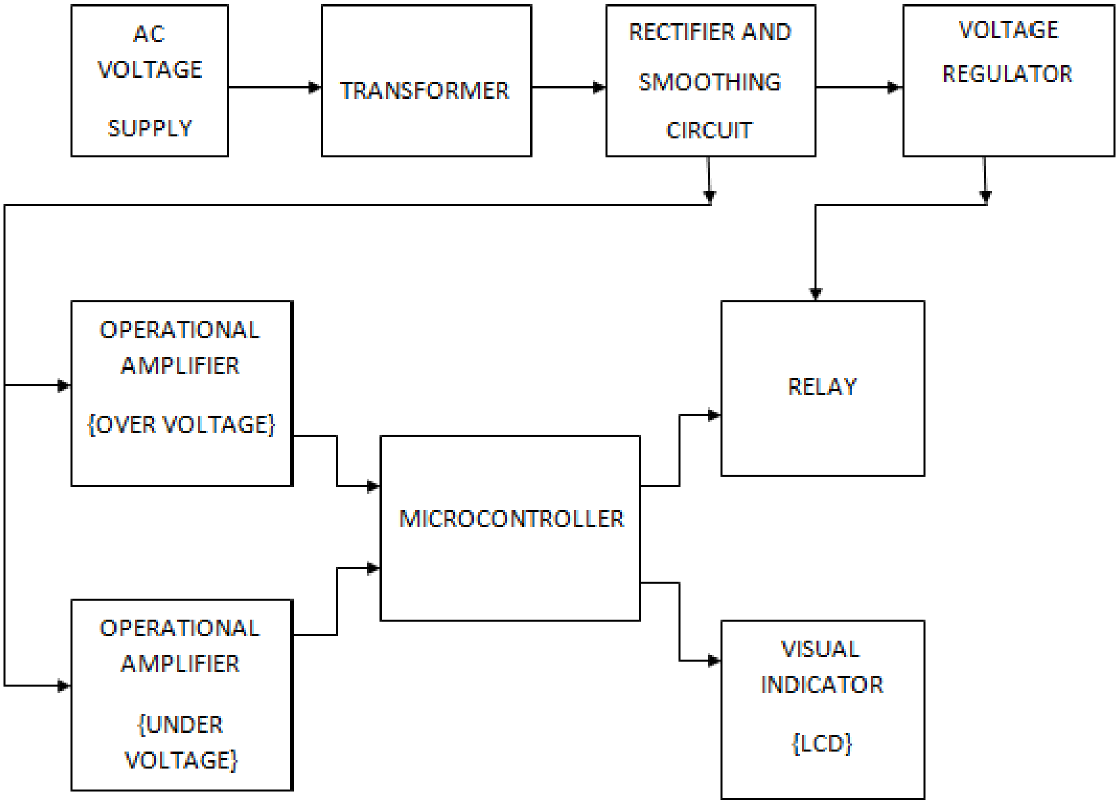


Figure 4.2: Single phase block diagram

4.1.1 Simulation design:

The simulation is done by using Proteus 8 Professional; it is a circuit simulation program, used to simulate electric circuits in a virtual environment.

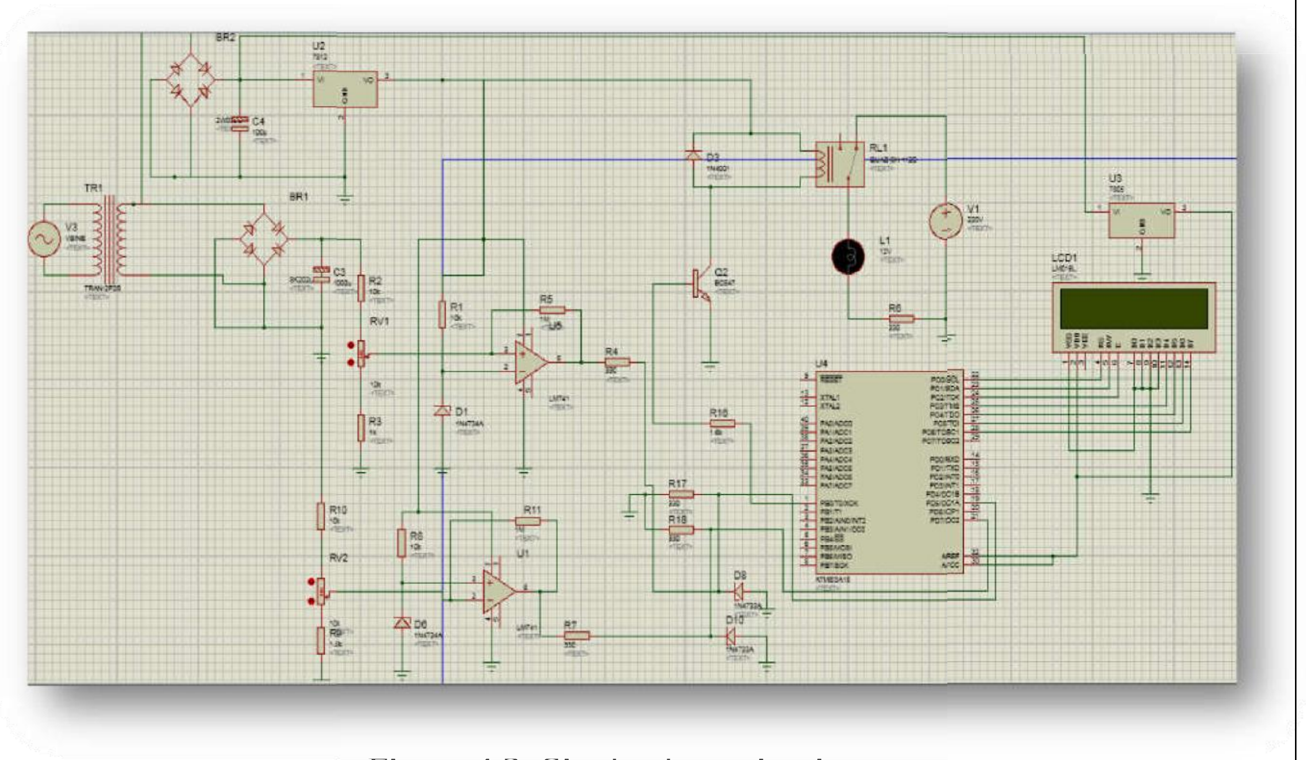


Figure 4.2: Single phase circuit

- **Rectifier circuit:**

The AC main supply is fed to the circuit through a step down transformer (220/12) V, two full wave rectifiers are used to convert the AC to DC voltage (unregulated 12V) one rectifier is connected to two voltage regulator (12 and 5) V, the other one’s output is smoothed with a smoothing capacitor (1000µf) and fed to the two operational amplifiers variable inputs.

$V_{ip} = V_p - (2\times0.7)$ ……………………………………………………………………………(4.1)

$V_{dc} = \frac{V_{ip}}{1+\frac{1}{4fCR_l}}$ ……………………………………………………………………..(4.2)

R_S is assumed to be 12Ω.

Equations (4.1) and (4.2) are used to determine the smoothing the capacitor value, value is approximated to 1000μf.

- **Voltage regulator:**

The 12 V (7812) is supplied with unregulated DC voltage from the full wave bridge rectifier; its output is fed to the positive supply rail of the two operational amplifiers, and to the relay.

The 5 V (7805) is supplied from the same unregulated DC voltage, and its output is fed to the microcontroller and the LCD, because the microcontroller's voltage should be 5Vto operate properly.

- **Operational amplifier:**

The primary method of determining the voltage status depends on the operational amplifier, basically it acts as voltage sensor. Two amplifiers are used, one for over voltage and the other for under voltage.

- **Over voltage amplifier:**

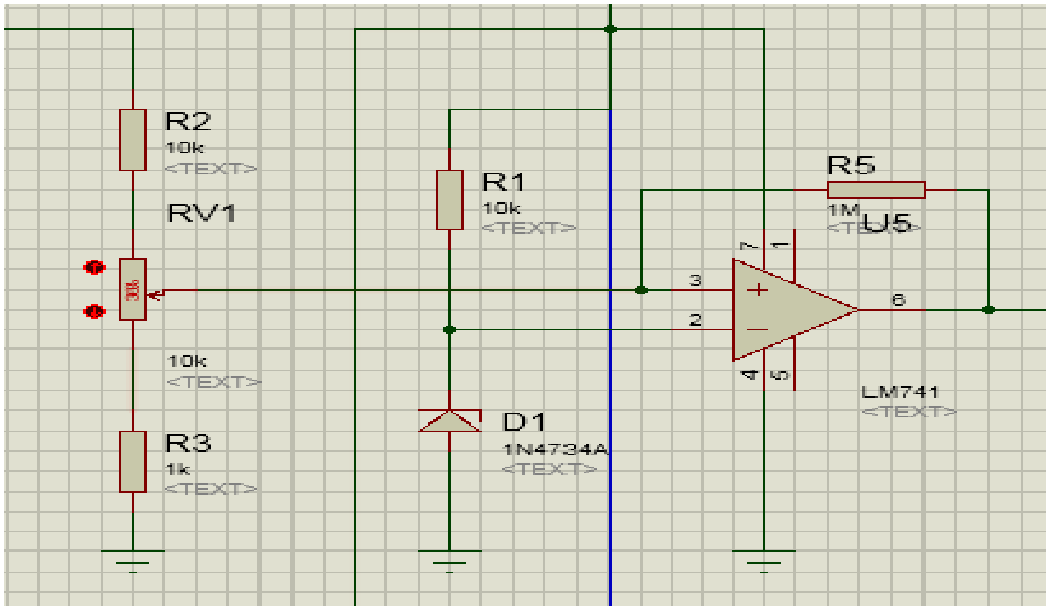


Figure 4.3: Over voltage circuit

The unregulated voltage is fed to the non-inverting input of the operational amplifier (LM741), and the inverting input is supplied with (12v) regulated voltage, and then is reduced to constant (5.6v) through a zener diode.

The inverting input is the reference in the over voltage sensing case. When the non-inverting input's voltage is higher than the reference voltage the output of the amplifier will go high. And that is the case of over voltage, when the supply voltage increases it will only increase the voltage on the non-inverting pin _the inverting pin is fixed to 5.6V _ and that will drive the output to high value.And in normal operation the voltage at the non-inverting pin is made close to the reference voltage. However, when a comparator looks at a real input signal it will always be faced with some small variations in the signal that make it hard to determine which input is greater. That's why a feedback of (1MΩ) is fed to the variable input to reduce the noise.

- **Under voltage amplifier:**

The same unregulated voltage is fed to the inverting input, and the non-inverting input is supplied with constant (5v) through a zener diode.

The same course of action will happen here only in reverse, the non-inverting pin is at constant voltage value (5v) and the inverting pin varies with the supply voltage. At normal operation the voltage at the inverting pin is made slightly higher than that of the non-inverting pin, so when the supply voltage reduces the inverting input reduces as well while the non-inverting is fixed at all times, and when the voltage at the inverting pin reduces to a value below of the reference value the output of the operational amplifier will go high, the (1MΩ) feedback is introduced for the same reason stated above.

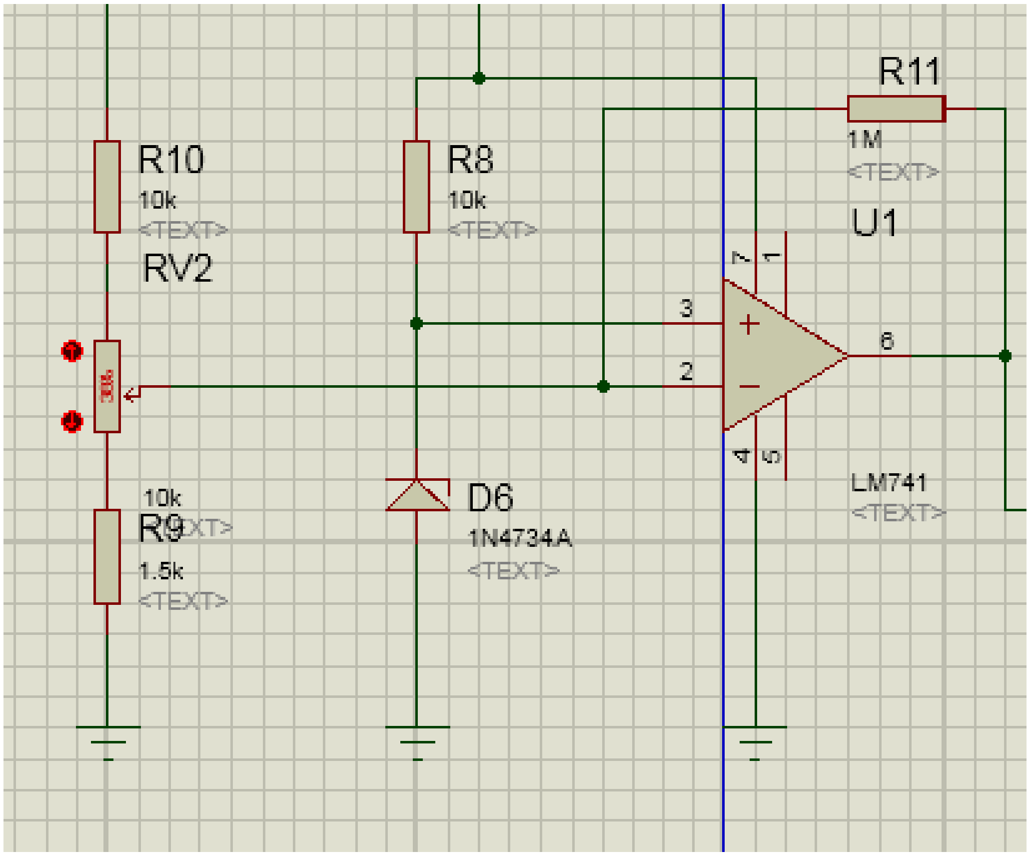


Figure 4.4: Under voltage circuit

- **Microcontroller and LCD:**

The code is written using C language, and compiled using CodeVisionAVR program. Microcontroller atmega16 is used to control the relay based on the output signal from the operational amplifier, and to control the LCD.

Pin (D5) and (D6) are used as the input port, and pin (B0) as the output. Pin (D5) receives over voltage signal and pin (D7) receives under voltage signal. Port(C) is connected to the LCD to give visual indicator based on the inputs to the microcontroller.

When pin (D5) or (D7) is high the output (B0) will go high after a preset time delay to ensure the persistence of the fault, and the status of the operation will appear on the LCD if (D5) is high then it is over voltage, and if (D7) is high then it is undervoltage. The output of the microcontroller will reset to its original value after both pin (D5) and (D7) are low, and that is also after some time delay to eliminate the fluctuations possibility.

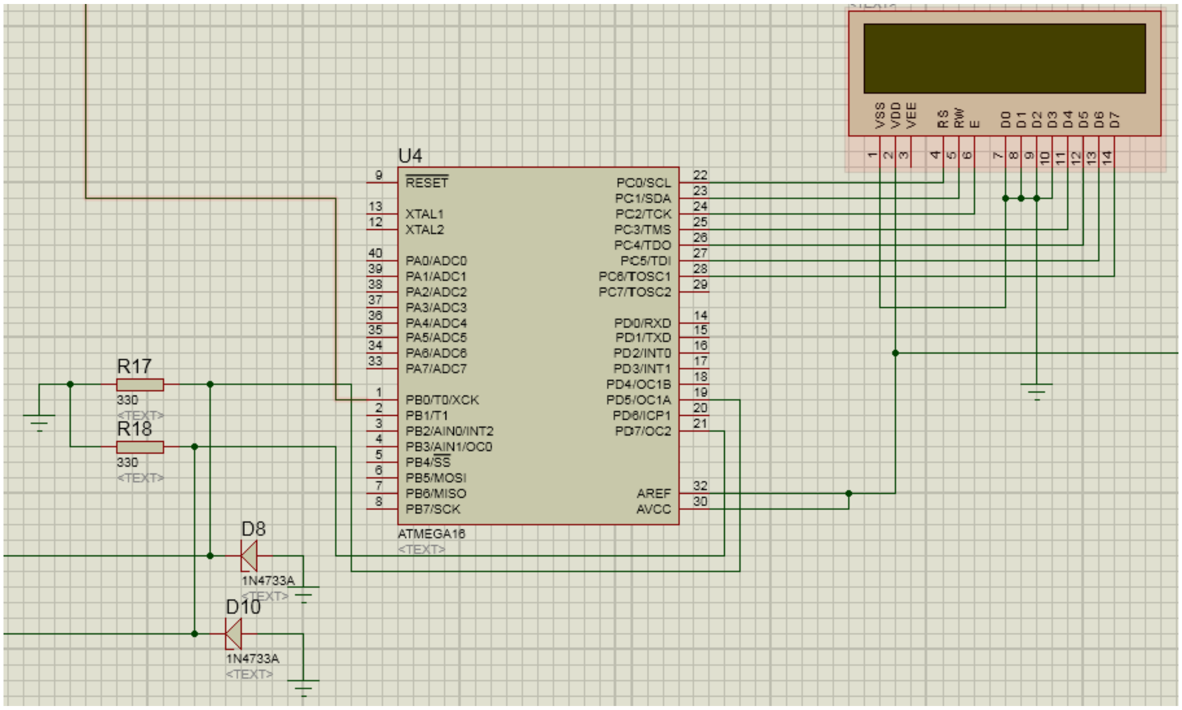


Figure 4.5: Microcontroller connection

The output from the operational amplifiers is connected to zener diodes (5v) to reduce the voltage to (5v); if not then the output will be more than 5v theoretically will reach the positive rail supply voltage (12v) and that will burn the microcontroller. Resistors (R17) and (R18) act as pull down resistor to prevent the input from floating, which is a state where the microcontroller can’t define its input state whether it’s high or low.

- **Flow chart**

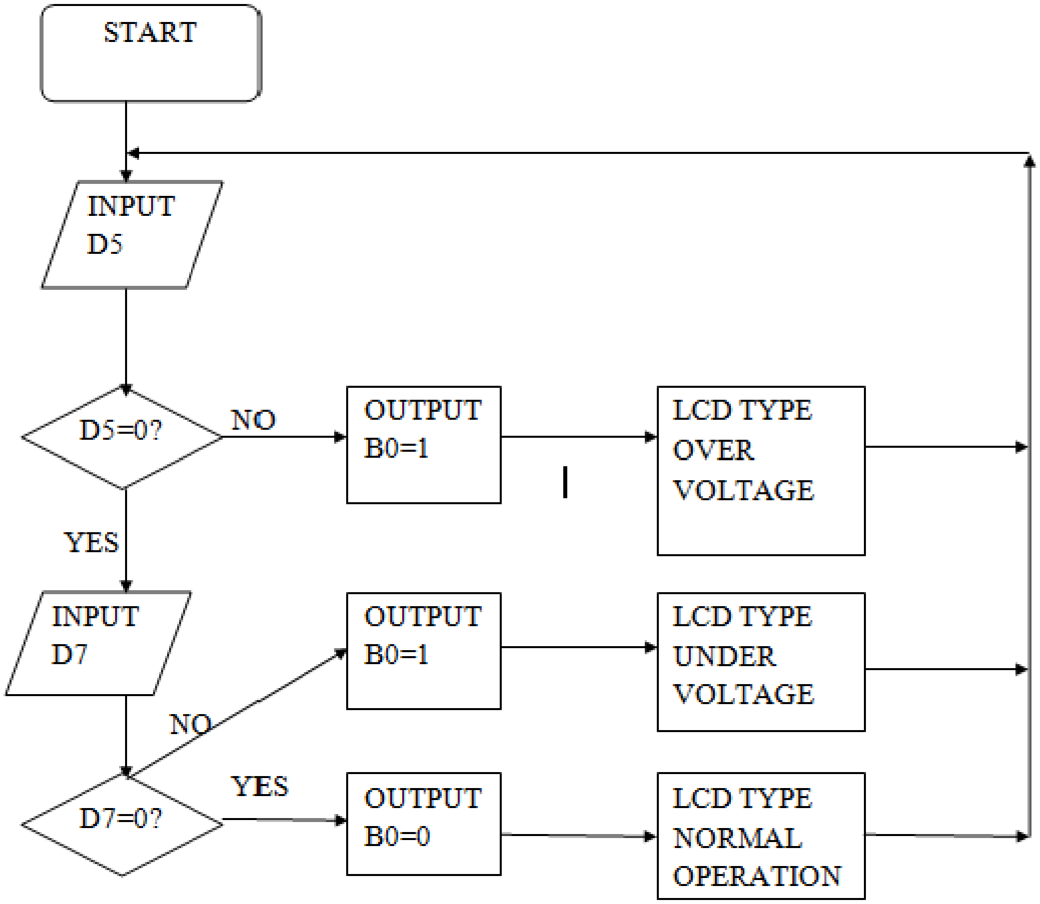


Figure 4.6: microcontroller flow chart

For the microcontroller program see appendix C

- **Relay driver**

The output from the microcontroller cannot directly drive the relay and hence the relay driver is used.

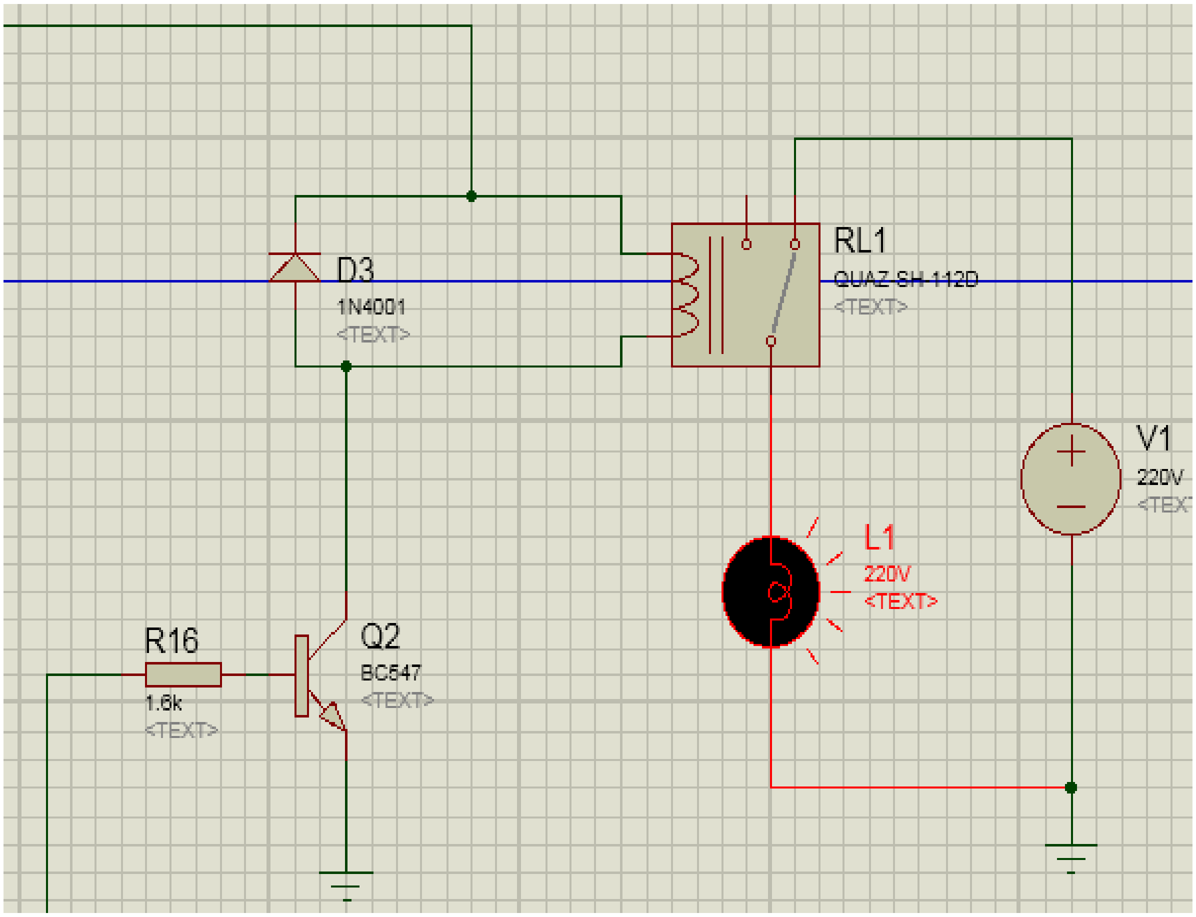


Figure 4.7: Relay driver circuit

A 12V relay is used; its coil's terminals are connected to the collector of the NPN transistor and to the output of 12V voltage regulator, and the load is connected to the normal close contact. At normal operation when the main voltage at safe value the transistor is in OFF state and the relay is not activated, but when the output from the microcontroller goes high the activated transistor will be driving the relay and switching the load off.

Calculations for the base resistor:

$$R_B = \frac{V_N - V_{BE}}{3 I_B} \quad (4.3)$$

The value of I_B is the value that makes the transistor runs in the saturation mode,

$$I_B = \frac{I_C}{h_{FE}} \qquad (4.4)$$

$R_B$is found to be 1600KΩ.

4.1.2 Hardware design

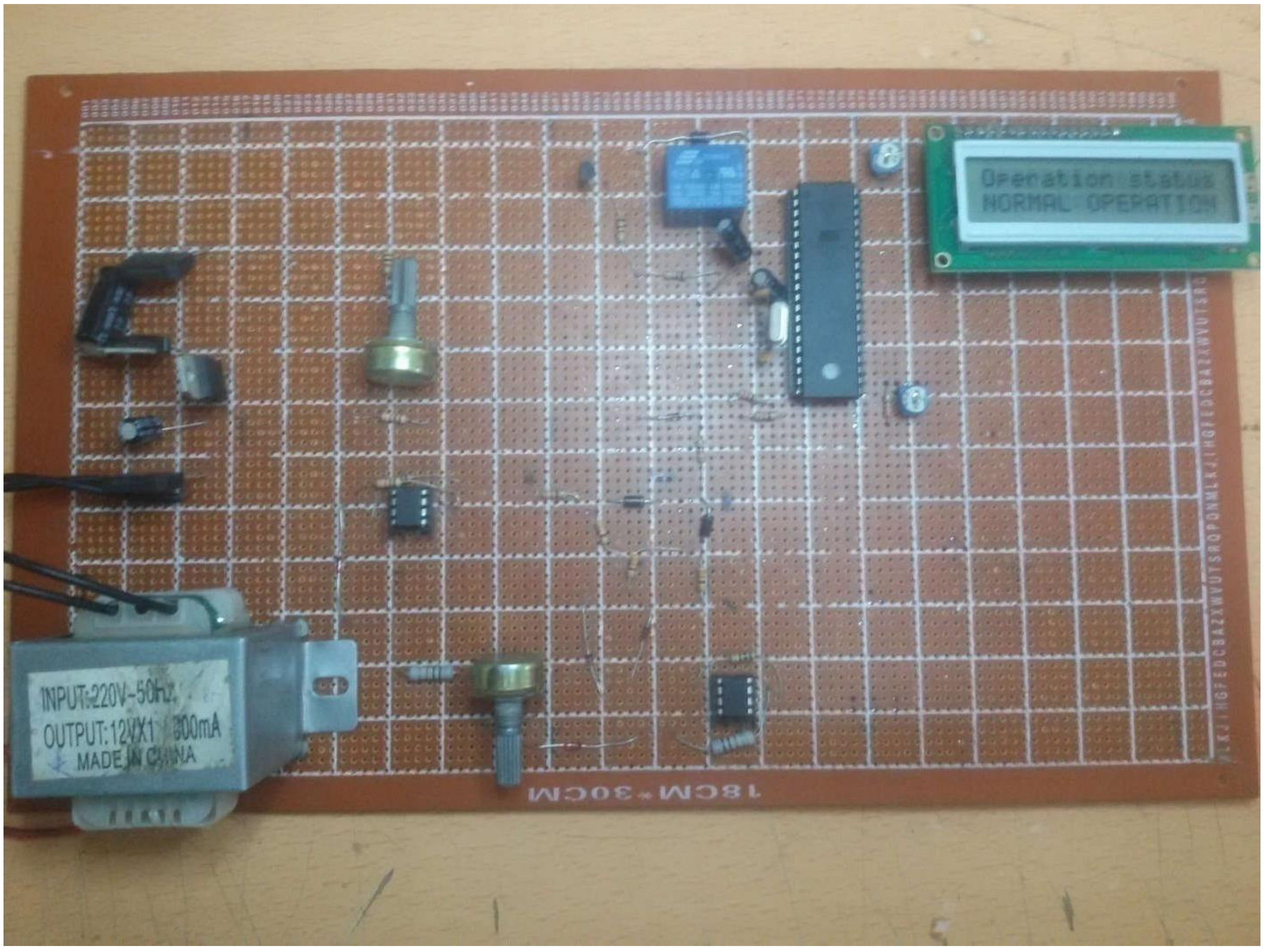


Figure 4.8: hardware connections

The same components are used in the hardware design, LM741 operational amplifier, atmega16 microcontroller, 12V relay.etc

The overvoltage and under voltage situations are simulated by varying the two potentiometers, for an instance by varying the overvoltage potentiometer, the input to the operational amplifier non-inverting terminal will increase, when increased to a value higher than that of the inverting terminal the operational amplifier’s output will go high ultimately triggering the relay and disconnecting the load.

The same approach is done with the under voltage situation.

4.2 Three phase

To protect a 3 phase load, three single phase circuits is built with the same configuration as before; each circuit continuously senses one line at a time. If any disturbance is sensed from any line, the microcontroller will send a signal to the relay and disconnect the load from power. Thus the condition for proper operation of the load is that all the lines are balanced.

4.2.1 Simulation design

Some components are omitted from the simulation to save space and because they are insignificant compared to the other ones shown.

The components are three separate single phase transformers. A 3 separate 12V AC source is used in their place each displaced 120° from the other, each connected to a full wave bridge rectifier.

Voltage regulators 12V and 5V are also omitted and replaced with 12V and 5V DC supply

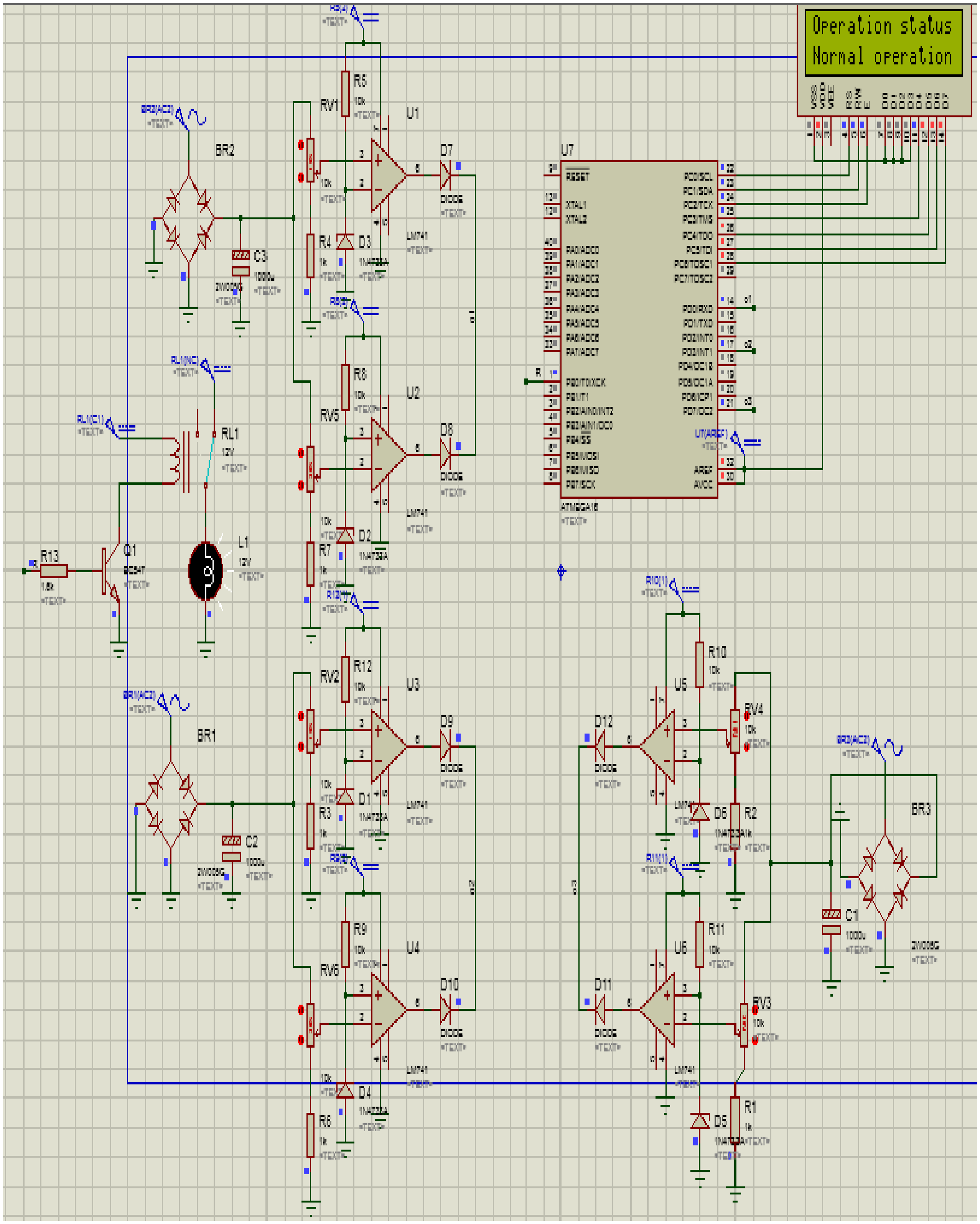


Figure 4.9: Three phase circuit

Table 4.1: RELAY OPERATION TRUTH TABLE

PHASE A	PHASE B	PHASE C	RELAY OUTPUT
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

0 means healthy phase, no under or over voltage, 1 means unhealthy phase, under or over voltage situation is happening. Basically the relay will remain inoperative if there is no disturbance at any line, and will operate if there is a disturbance at any phase. For the Microcontroller program see appendix D

CHAPTER FIVE CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The circuits presented respond effectively to voltage variations whether it’s under or over voltage in case of single phase circuit, and overvoltage, undervoltage, phase failure and imbalance operation in case of three phase circuit.

The liquid crystal display shows the operation status of the system whether it’s operating normally or under faulted condition.

The range of normal voltage can be adjusted with the variable resistors (potentiometers), it can be made very sensitive to over or under voltage, or it can be less sensitive.

5.2 Recommendations

Further developments can be added to the project, to increase the accuracy of voltage sensing devices i.e. operational amplifiers.

Also further indicating devices can be added to show the results of operation, like GSM interface.

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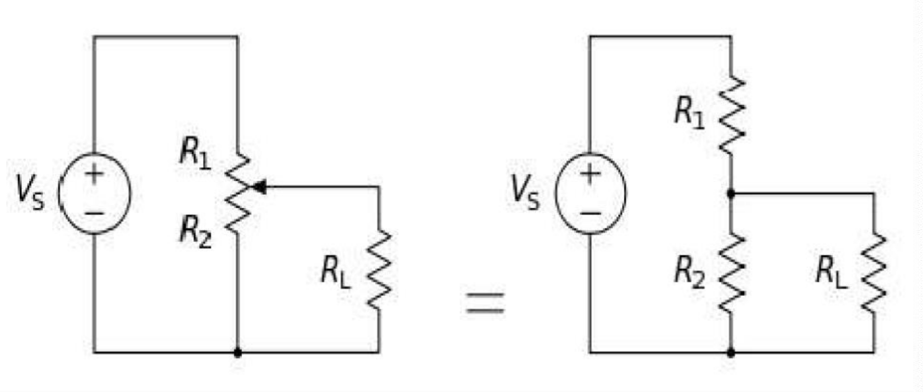
APPENDIX A



A potentiometer with a resistive load, showing equivalent fixed resistors for clarity.

The potentiometer can be used as a voltage divider to o adjustable b tain a manually output voltage at the slider (wiper) from a fixed inp u t voltage applied across the two ends of the potentiometer. This is their most common use. The voltage across R_L can be calculated by:

$$V_L = \frac{R_2}{R_1+R_2} * V_S$$

One of the advantages of the potential divider compared to a variable resistor in series with the source is that, while variable resistors have a maximum resistance where some current will always flow, dividers are able to vary the output voltage from maximum (V_S) t ground (zero volts) as the wiper moves from one end of the potentiometer to of the other. There is, however, always a small amount contact resistance.

In addition, the load resistance is often not known and therefore simply placing a variable resistor in series with the load could have a negligible effect or an excessive effect, depending on the load.

APPENDIX B

- *R* must be small enough that the current through D keeps D in reverse breakdown. The value of this current is given in the data sheet for D. For example, the common BZX79C5V6 device, a 5.6 V 0.5 W Zener diode, has a recommended reverse current of 5 mA. If insufficient current exists through D, then U_{OUT} will be unregulated, and less than the nominal breakdown voltage (this differs to voltage regulator tubes where the output voltage will be higher than nominal and could rise as high as U_{IN}). When calculating *R*, allowance must be made for any current through the external load, not shown in this diagram, connected across U_{OUT}.
- *R* must be large enough that the current through D does not destroy the device. If the current through D is I_D, its breakdown voltage V_B and its maximum power dissipation P_{MAX}, then $I_D V_B < P_{MAX}$.

A load may be placed across the diode in this reference circuit, and as long as the Zener stays in reverse breakdown, the diode will provide a stable voltage source to the load.

Breakdown voltage

Typical ratings for capacitors used for general electronics applications range from a few volts to 1KV. As the voltage increases, the dielectric must be thicker, making high-voltage capacitors larger per capacitance than those rated for lower voltages.

The breakdown voltage is critically affected by factors such as the geometry of the capacitor conductive parts; sharp edges or points increase the electric field strength at that point and can lead to a local breakdown. Once this starts to happen, the breakdown quickly tracks through the dielectric until it reaches the opposite plate, leaving carbon behind and causing a short circuit. The results can be explosive as the short in the capacitor draws current from the surrounding circuitry and dissipates the energy, [8] because of this the operating voltage is lower than the breakdown voltage. The operating voltage is specified such that the voltage may be applied continuously throughout the life of the capacitor.

APPENDIX C

```
lcd_init(16);
lcd_clear; DDRB =
0x01;
//set port B as output DDRD =
0x00;
//set port D as input

while (1)
{
if (PIND.5 == 1 && PIND.7 == 0)
//check if the over voltage pin is high and the other is low
delay_ms(100);//delay for 0.1 sec to see if the fault is still happening if
(PIND.5 == 1 && PIND.7 == 0)
//check for the fault again
{
lcd_clear; PORTB.0
= 1;
//activate the output and drive the relay
lcd_gotoxy(0,0);
lcd_puts("Operation status");
lcd_puts("OVER VOLTAGE    ");
```

```
delay_ms(500);
//delay for fluctuations possibility
}
if (PIND.7 == 1 && PIND.5 == 0)
//check if under voltage pin is high and the other is low
delay_ms(100);//delay for the same purpose as before if
(PIND.7 == 1 && PIND.5 == 0)
//check the pin again
{
PORTB.0 = 1;
//activate the output and drive the relay
lcd_clear;
lcd_gotoxy(0,0); lcd_puts("Operation
status"); lcd_puts("UNDER VOLTAGE
                                            ");
delay_ms(500);
//delay for fluctuations possibility
}
if (PIND.5 == 0 && PIND.7 == 0)
//chck if there is no under voltage or over voltage
{
PORTB.0 = 0;
//output off andrelay is off
lcd_clear; lcd_gotoxy(0,0);
lcd_puts("Operation status");
lcd_puts("NORMAL OPERATION");
}}}
```

APPENDIX D

```
lcd_init(16); DDRB
= 0x01; DDRD =
0x00;
while (1)
{
if (PIND.0 == 1 && PIND.3 == 0 && PIND.7 == 0)
delay_ms(100);
if (PIND.0 == 1 && PIND.3 == 0 && PIND.7 == 0){
PORTB.0 = 1;
//activate the output and drive the relay
lcd_gotoxy(0,0);
lcd_puts("Operation status");
lcd_puts("phase 1 fault   ");
delay_ms(100);
//delay for fluctuations possibility
}
if (PIND.0 == 0 && PIND.3 == 1 && PIND.7 == 0)
delay_ms(100);
if (PIND.0 == 0 && PIND.3 == 1 && PIND.7 == 0){
PORTB.0 = 1;
//activate the output and drive the relay
```

```
lcd_gotoxy(0,0);
lcd_puts("Operation status");
lcd_puts("phase 2 fault   ");
delay_ms(100);
//delay for fluctuations possibility
}
if (PIND.0 == 0 && PIND.3 == 0 && PIND.7 == 1)
delay_ms(100);
if (PIND.0 == 0 && PIND.3 == 0 && PIND.7 == 1){
PORTB.0 = 1;
//activate the output and drive the relay
lcd_gotoxy(0,0);
lcd_puts("Operation status");
lcd_puts("phase 3 fault   ");
delay_ms(100);
//delay for fluctuations possibility
}
if (PIND.0 == 1 && PIND.3 == 1 && PIND.7 == 0)
delay_ms(100);
if (PIND.0 == 1 && PIND.3 == 1 && PIND.7 == 0){
PORTB.0 = 1;
//activate the output and drive the relay
lcd_gotoxy(0,0);
lcd_puts("Operation status");
lcd_puts("phase 1&2 fault   ");
delay_ms(100);
//delay for fluctuations possibility
}
```

```
if (PIND.0 == 1 && PIND.3 == 0 && PIND.7 == 1)
delay_ms(100);
if (PIND.0 == 1 && PIND.3 == 0 && PIND.7 == 1){
PORTB.0 = 1;
//activate  the  output  and  drive  the  relay
lcd_gotoxy(0,0);
lcd_puts("Operation        status");
lcd_puts("phase   1&3   fault   ");
delay_ms(100);
//delay for fluctuations possibility
}
if (PIND.0 == 0 && PIND.3 == 1 && PIND.7 == 1)
delay_ms(100);
if (PIND.0 == 0 && PIND.3 == 1 && PIND.7 == 1){
PORTB.0 = 1;
//activate  the  output  and  drive  the  relay
lcd_gotoxy(0,0);
lcd_puts("Operation        status");
lcd_puts("phase   2&3   fault   ");
delay_ms(100);
//delay for fluctuations possibility
}
if (PIND.0 == 1 && PIND.3 == 1 && PIND.7 == 1)
delay_ms(100);
if (PIND.0 == 1 && PIND.3 == 1 && PIND.7 == 1){
PORTB.0 = 1;
//activate  the  output  and  drive  the  relay
lcd_gotoxy(0,0);
```

```
lcd_puts("Operation status");
lcd_puts("3 phase fault   ");
delay_ms(100);
//delay for fluctuations possibility
}
if (PIND.0 == 0 && PIND.3 == 0 && PIND.7 == 0)
delay_ms(100);
if (PIND.0 == 0 && PIND.3 == 0 && PIND.7 == 0)
{
PORTB.0 = 0;
//output off and relay is off
lcd_gotoxy(0,0); lcd_puts("Operation
status"); lcd_puts("Normal
operation");}}}
```