UNIVERSITY OF NAIROBI

FINAL YEAR PROJECT

DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

MICROCONTROLLER BASED POWER TRANSFORMER PROTECTION SYSTEM

PROJECT NO: 009

By

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A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF BACHELOR OF ELECTRICAL AND ELECTRONIC ENGINEERING OF THE UNIVERSITY OF NAIROBI

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DECLARATION OF ORIGINALITY FORM

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Title of the work DESIGN OF A MICROCONTROLLER BASED POWER TRANSFORMER PROTECTION

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Acknowledgement

First and foremost, I thank the Almighty God for His guidance throughout my studies in the University of Nairobi and the completion of this project.

I am very grateful to my supervisor Professor Elijah Mwangi for his guidance throughout this project. The sessions that I had with professor inspired me to work harder every time we met.

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Dedication

This project is dedicated to my family for their support throughout my academic life. I am grateful to my brothers Paul, Dan and Ken for always providing a listening ear whenever I was in need. Lastly to my friend Joy for always being the supportive friend that God gave me.

ABSTRACT

The main intention of this project is to design a microcontroller based system that can be used in power transformer protection. The system checks the operating parameters of the transformer i.e. current and reports the quantity that is flowing through the transformer. The system is designed such that it is able to detect currents above the normal operating level and isolate the power transformer from the distribution line. This isolation process is to ensure that the transformer is safe from any excess current levels that can make it to overheat thus get damaged. It gives a solution to the need to reduce cost of maintenance and ensure that supply of electricity to consumers is not interrupted for long periods taken while repairing or replacing destroyed transformers.

A current sensor ACS712x series has been used in this project as the interfacing instrument between the power transformer and the PIC16F690 microcontroller. The PIC16F690 controls all operations that the device does. A relay and a contactor have been used as the switching gears to isolate the transformer from the power system in case a fault occurs. A monochrome LCD has been used to show system current readings and indicate cases of over-current fault. To warn an operator of a fault occurrence, LEDs and a piezoelectric buzzer have been used. All these peripheral devices depend on the microcontroller to make them operate or otherwise. Some of the tools used in this project include MPLAB - programming software used to write the program for the microcontroller used in this project. Proteus- simulation software has also been used to test whether the design works appropriately before its implementation on hardware. Pickit3- has been used to load program into the microcontroller using MPLAB.

ACRONYMS AND ABBREVIATIONS

PIC	Programmable Intelligent Controller
LCD	Liquid crystal Display
GND	Ground
ASCII	American Standard Code for Information Exchange
LED	Light emitting diode
MOS	Metal oxide semiconductor
GSM	Global System for Mobile
PCB	Printed circuit board
CT	Current transformer
RAM	Random access memory
ROM	Read only memory
AC	Alternating Current
DC	Direct Current
ADC	Analogue to Digital Converter
CPU	Central Processing Unit
CMOS	Complementary metal oxide semiconductor
IC	Integrated circuit
ACS	Allegro current sensor
MSB	Most significant bit
LSB	Least significant bit

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

In the design of electrical power transmission and distribution system, there are various factors that need to be considered in the quest to satisfy the needs of electricity consumers. Electrical power systems experience faults at various times due to various reasons. These faults must be foreseen and safety precautions applied to the power system. The power systems engineer must include in his design, safety measures in order to avert any destructive occurrences that the system may undergo at any given time. Power system protection is very essential and necessary for a dependable electrical power supply. It ensures that the system is protected from itself and that the consumer is also safe as he benefits from the electrical power supply. An electrical power system consists of various components such as generators, switches, transmission cables, transformers, capacitor banks among other components. It cannot therefore operate without an effective protective device to keep these components safe and the system stable. Faults in a power system refer to the undesired conditions that occur in the electrical power system. These conditions may include short circuit, over current, overvoltage, high temperatures among others.

It is clear that over time, there has been an increase in human population, economic growth and technological advancement. This has continuously made the demand for electrical power to go high because as technology, human population and economy grows; there is an increase in demand for power as many more electrical loads are introduced into the supply line. An increase in load leads to a lot of current drawn from the power line. At times the demand goes above what the power distributor can supply. The consequence of this is that electrical power overload cases φφbecome common thus posing danger to power system components. This therefore throws in the need for devices that can monitor the rate of power consumption in accordance with the level that a given system is designed to sustain. Such a device must be designed to cut off consumption if the system oversteps its ability thus being dangerous to users and the components. In this project, we look at the protection of power transformer from various faults that may occur and may be destructive to the component if left undetected. The transformer is a very important component in an electrical power system as distribution of electrical power to consumers is more efficiently effected. Every transformer is designed to comfortably supply a given load. Cases of overload or short circuits can lead to transformer being damaged. To combat such occurrence, an elaborate system that monitors these excesses in supply parameters needs to be built. Such a device controls the flow of electrical power to the load so that the transformer is not overworked. Over current relays and overvoltage relays have been used for a long period of time and have been electromechanically controlled. In this system, a microcontroller is used to monitor cases of electrical faults and communicate to a switch to isolate the transformer from the system.

1.2 PROBLEM STATEMENT

Power system protection is a very important consideration in the design of an electrical power system. There is need to protect electrical power components from dangerous faults. This is warranted by the need to increase the life of the components, avoid unnecessary expenditure in frequent replacement of obsolete components and to ensure that there is a continuous supply of power to serve the needs of the ever growing economy. This project therefore seeks to design a microcontroller based system that will intelligently monitor faults and prompt a safety measure to protect the power transformer in case of power overload.

1.3 OBJECTIVES

The main objective of this project is to design and implement a system that uses microcontroller and other peripheral devices to protect power transformer. To achieve this the following must be done.

a) Design and build an over current relay using PIC microcontroller and a current sensor
b) Development, analysis and calibration of the current sensor.
c) Development of the ADC program to convert the analogue sensor output to equivalent digital form within the PIC microcontroller.
d) Development of the LCD program to display the sensed levels.
e) Development of warning (audio and visual) and relay control system program.

1.4 SCOPE WORK

The investigation carried out in this project is limited to power transformer protection methods. The extent of the work is to build a device that detects current spikes/overload in the primary and secondary sides of a single phase transformer and isolate it from the power system.

CHAPTER 2: LITERATURE REVIEW

2.1 Electric Power system

An electric Power system refers to a network that constitutes electrical components/machines used in the supply, transmission and consumption of electric power [1]. The diagram below illustrates a complete electric power system. It involves generation, transmission and distribution of electric power to various categories of consumers. The generation plant is normally located far from the load centre. There are different levels of electric power consumption depending on the purpose for which a consumer uses electricity. Electrical power consumers may be industrial, commercial or domestic. These consumers require different levels of electric power supply. In order to meet their specific needs, certain devices that adjust the voltage levels accordingly have to be used. Some of those components include: step up and step down transformers, capacitor banks, protective devices etc.

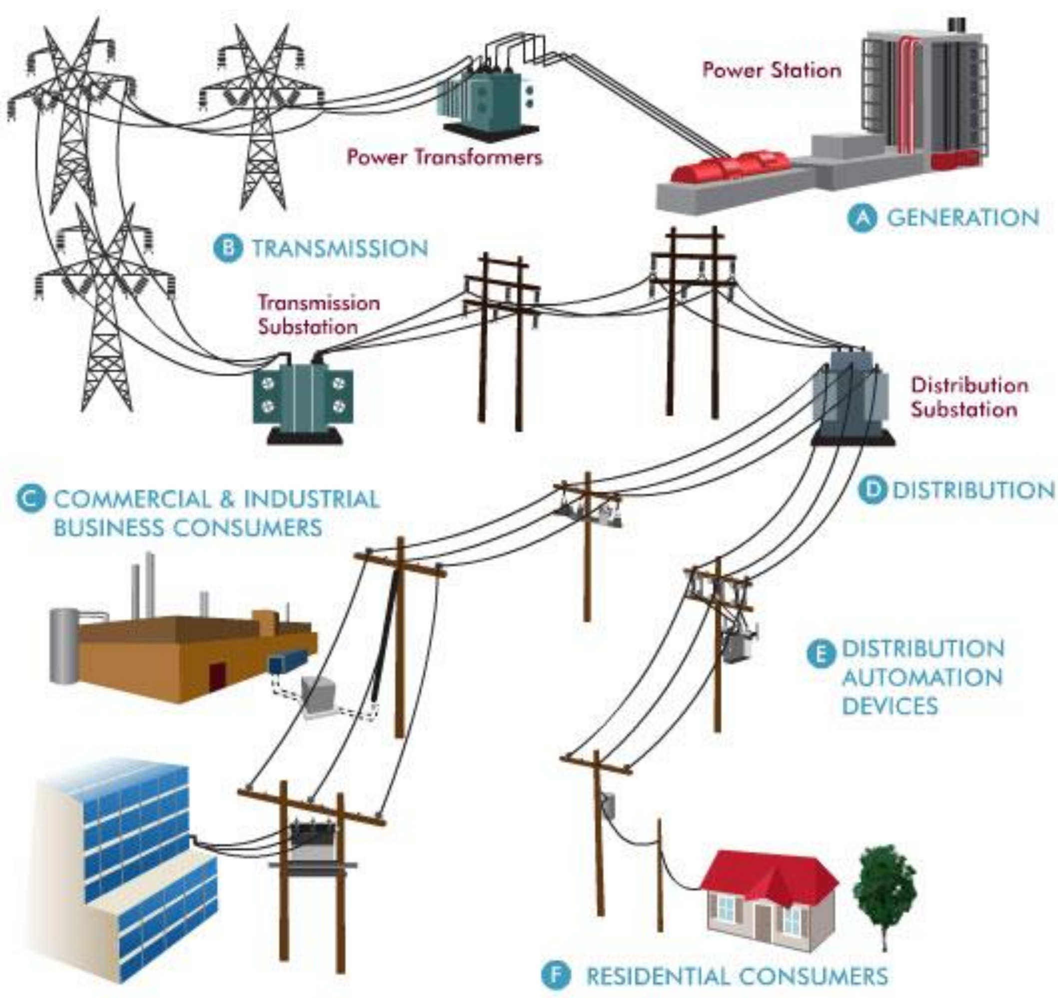


Figure2.1 Generation, transmission and distribution of electrical power [2].

2.2 Power system protection

A branch of electrical power engineering that deals with protection of Power system from faults is known as power system protection. It does this by isolating the faulted parts of the system from the rest of healthy electrical network [3]. The diagram below shows a model of a power protection system.

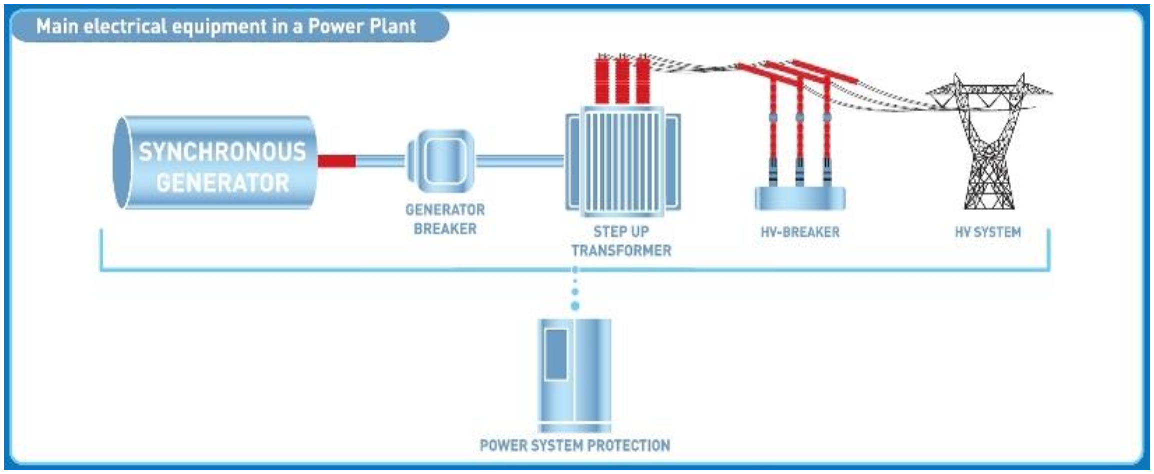


Figure2.2 power system protection [3]

The main aim of power system protection scheme is to switch off a section that is faulty in the system from the remaining live system. This ensures that the remaining portion is able to function satisfactorily locking out chances of damage that may be caused by fault current.

A circuit breaker closes automatically as a result of trip signals it receives from the relay whenever a fault is detected. The basic philosophy of a power protection system is that system faults cannot be prevented from flowing in the system but can be stopped from spreading in the system.

2.2.1 Importance of power system protection

Occurrence of fault is hazardous to both electric power user and the electric system itself. To the user, life is of most important concern. The main concern of the system is to ensure a stable supply of electric power to consumer and to ensure that the electrical components do not get destroyed. In summary, power protection is necessary to:

a) *User/Personnel*- ensure safety i.e. Prevent injury/accident.
b) *Electrical equipment* - to protect the equipment from cases of over current, overvoltage and frequency drift that can destroy the equipment.
c) *General Safety* -Prevent secondary accidents that occur as a result of system fault like fire.

d) *Power Supply Stability*- Ensures a continuous and stable supply of electrical power.
e) *Operation Cost* -Ensure optimal operating efficiency so as to reduce equipment maintenance/replacement cost

2.2.2 Types of protection systems

Implementation of power system protection can be done in two ways. These are: the unit protection and non-unit protection [1].

Unit Protection

The unit protection scheme protects a definite\discrete zone bounded by the protection system. Differential relay protection is normally employed in this scheme. This is illustrated in Figure 2-3

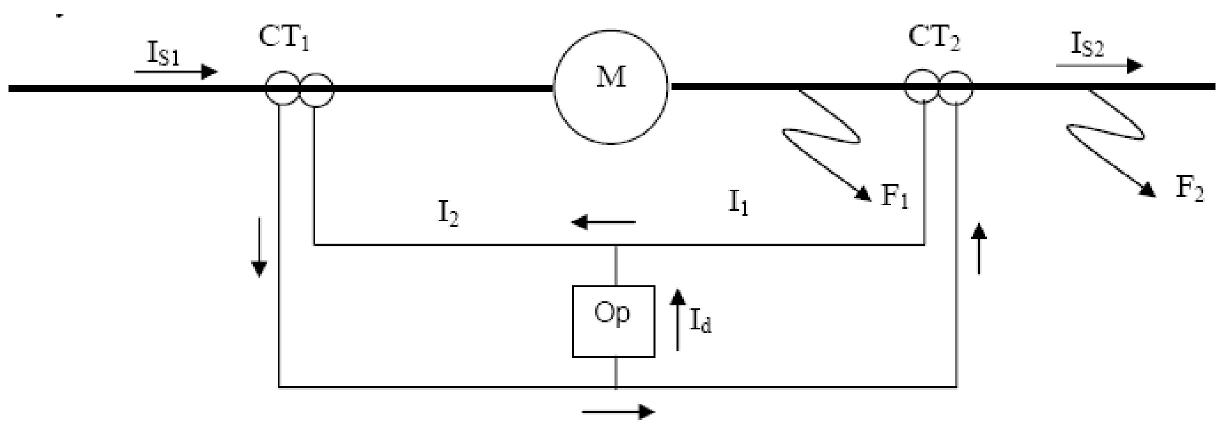


Figure2.3 Unit protection [4]

Non-Unit Protection

The Non-Unit protection protects a system\zone and can overlap with another protection zone in the system. This scheme ensures an isolation of the entire circuit (a larger area) in case a fault occurs as illustrated in figure 2-4

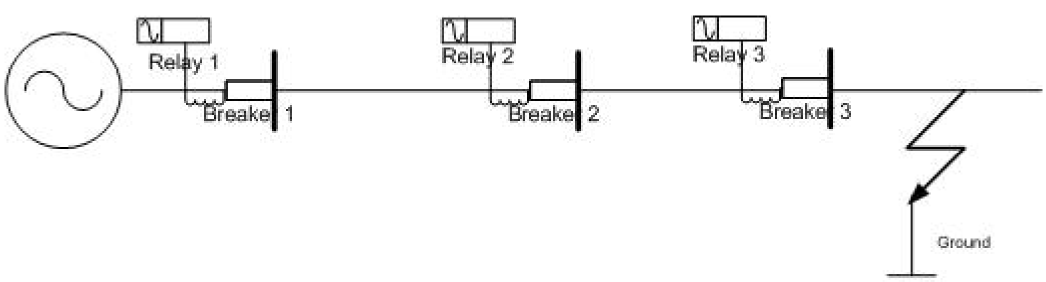


Figure2.4 Non-unit protection [4]

2.2.3 Power Protection elements

There are 4 types of these elements, namely instrument transformers, switchgears, protective gears and station batteries.

Instrument transformers: these include current transformers and voltage transformers. Instrument transformers step down current and voltage from the power line to level that can be measured safely.

Switchgears: switchgears basically include circuit breakers. Circuit breakers are the main part of a protection system. They break contacts of the system in case of a fault. They include minimum oil, bulk oil, SF_6 , vacuum and air blast circuit breakers. Mechanisms of operation of circuit breakers include: hydraulic, solenoid, spring and pneumatic [1].

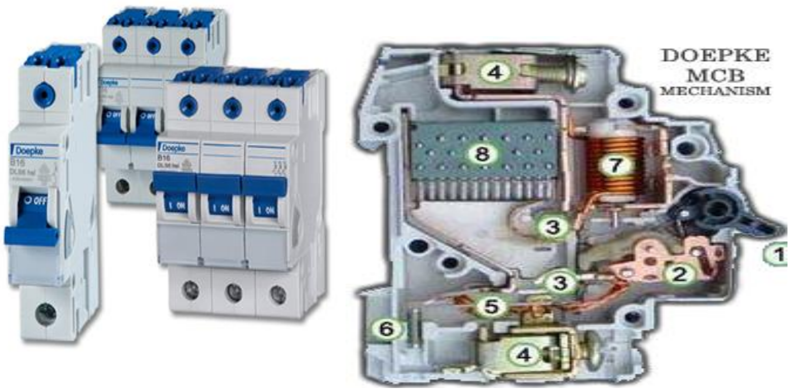


Figure2.5 circuit breaker [4]

Protective gear: consists of protective relays like voltage, current, impedance, frequency and power relays, based on operating parameter, definite time, inverse time, and stepped relays, classified according to operating characteristic, differential and over fluxing relays classified according to logic. When a fault occurs, relay sends signal to relay to the circuit breaker completing its circuit thus making it to trip [1].

Station batteries: all circuit breakers in a power system operate using direct current. The current is provided by battery banks that are installed together with the circuit breaker. It is thus an essential element in a power protection system.

Figure2.6 Station battery [1]

2.2.4 Functional requirement of a protection relay

In order for a protection relay to operate effectively, it must have the following qualities[5].

a) Reliability: power protection relays should remain inoperative always as long as a fault does not occur. But when a fault occurs, they should respond as quickly as possible.
b) Selectivity: it must only operate on the section that has experienced a fault to avoid unnecessary power outs due to wrong detections. It should also respond only when a fault occurs.
c) Sensitivity: The relaying equipment should be highly sensitive so that it can be relied on to provide the required detection.
d) Speed: the relaying equipment must operate at the required speed. It should not delay so as to give time for system equipment to get destroyed. It should also not be too fast to cause undesired operation.

2.3 Transformer protection

Electrical power systems have various devices that aid in the transmission and distribution of electrical power. One such component is the power transformer. A transformer can be described as an electrical device used in electric power system to transmit power between different circuits, applying the principle of electromagnetic induction. The transfer of energy from one circuit to another makes use of basic magnetic fields. The flow of electric current in a conductor induces magnetic field around that particular conductor. If another conductor is brought within the effect of the first conductor, such that they are linked, voltage induction takes place in the second conductor. Transformer theory and application is based on the principle where magnetic field in one coil causes voltage induction into another coil. Sizes of transformers vary according to their applications from the tiny ones used in microphones to the ones weighing hundreds of tones used system grid. Transformers are used in electronic appliances and in electrical power networks. Transformers are therefore very important in transmission, distribution and consumption of electrical power[6].

There are two basic principles that explains the operation of a transformer

Magnetic field can be caused by electric current.
A varying magnetic field linked to a coil induces voltage across the ends of the coil by means of electromagnetic induction.

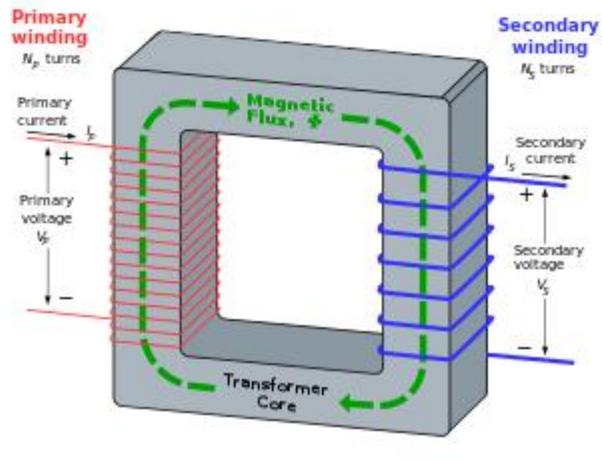


Figure2.7 Electro-magnetic induction [6]

As shown in the diagram above, as current passes through the primary coil, it causes magnetic field. The primary and the secondary windings are woven around a core whose magnetic permeability is very high. This is to ensure that a large percentage of the magnetic flux pass through the primary windings and the secondary windings.

Power transformers are transformers used in transmission networks for example in transmission substations. Their power rating is normally more than 200KVA [4]. Substation transformer is used to step down the utility service voltage. Some of the characteristics of power transformers include;

33kv and above voltage rating
High operating efficiency close to 100%
They are big in size compared to distribution transformers
Low energy loss due to very little load fluctuations
Operating temperature dependent on the power output rating
Power rating- over 200KVA

Figure2.8 Photo of a power transformer [4]

2.3.1 Causes of fault in power transformer

There are many faults that can occur in a transformer owing to a variety of reasons as follows[5]:

a) Winding and core fault is the most frequent type of fault in a power transformer. This can be attributed to weakening of conductor insulation. Phase faults rarely occur in the transformer, they may however occur at the terminals of that are found within the transformer protection zone.
b) Most power transformers use oil for cooling and insulation, oil leakage can also be a cause of fault in a transformer.
c) The inrush current that occurs momentarily when a transformer is energized can also be treated as a fault unless conditions are set for its detection.
d) Inter-turn faults may occur and cause rise in hot spots within the transformer winding.
e) Transformer may experience over fluxing which may be as a result of transformer operating at low frequency at rated voltage. Over fluxing may also be caused by overvoltage operation at rated frequency.
f) Sustained overload can also be a cause of fault in a transformer

Transformer Protection Schemes

There are several schemes used in transformer protection. A few are presented below.

Percentage differential protection

This protection scheme is used to protect transformers against internal short circuits. It is an effective method to protect transformer against internal faults. It may however not be effective in protecting the transformer against ground fault in case of ungrounded or high impedance grounding. The following factors affect differential current in a transformer and should be taken into consideration while using differential protection scheme to protect a transformer [5].

Magnetizing inrush current: this is the maximum instantaneous current that a transformer draws when it is first switched on. Power transformers can draw as high as 8-30 times its rated current depending on its resistance. Inrush current if not taken care of can thus be detected by the system as a fault and thus cause unwanted response. The diagram below shows a typical waveform of inrush current.

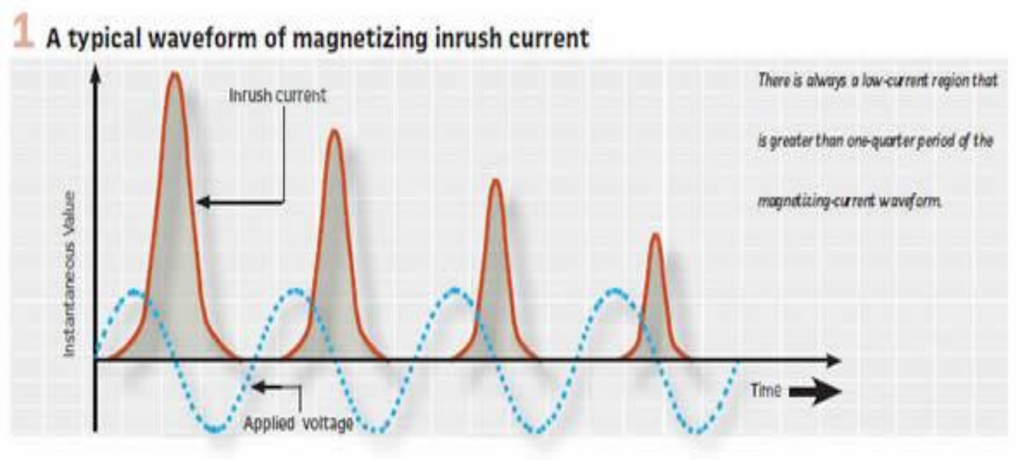


Figure2.9 Waveform of a magnetizing inrush current [4]

Over excitation: Over excitation when referring to a transformer means an increase in magnetic flux in the core above allowable/normal levels. This causes the magnetizing current to increase. It can lead to destruction of the transformer if the situation is not taken care of. Over excitation in transformers is caused by overvoltage I the network.

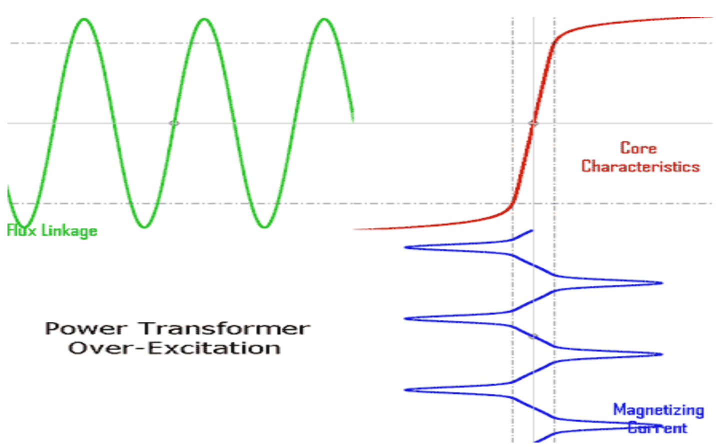


Figure2.10 Over-excitation waveform (4)

CT saturation: this is a phenomenon where a CT is no longer able to produce an output that is proportional to its primary current as per the transformation ratio. The main reason for this is the property of the core to go into magnetic saturation due to high currents or large burden at the secondary side. His can cause relay operating current to flow as a result of distortion of the CT current [7].

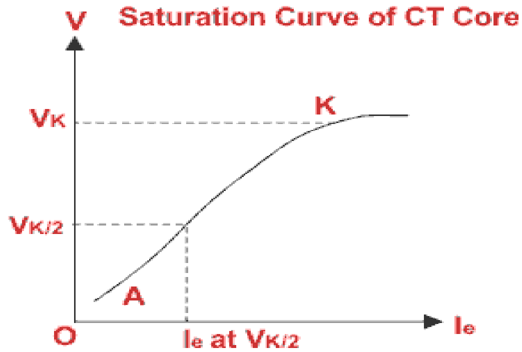
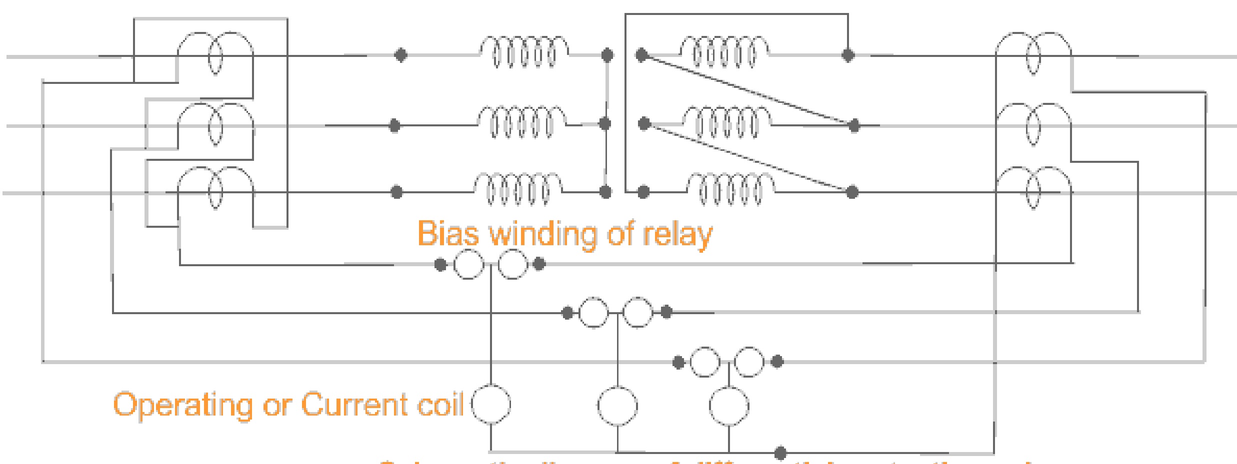


Figure2.11 CT Saturation curve [7]

Different primary and secondary voltage levels: that is the secondary and voltage CTs are of different ratios
Phase displacement in delta wye transformers.

Transformer differential relay

In order to take care of the above variables, a differential transformer relay that is less sensitive (in the range of 15%-60%) is applied.



Schematic diagram of differential protection scheme

Figure2.12 Differential protection Scheme [7]

Harmonic restraint relay

Differential relay can fail due to magnetizing inrush current. The magnetizing inrush current waveform normally consists of several harmonics while the internal fault current consists of the fundamental component. To solve the problem of inrush current, a harmonic restraint relay is used. It is only effective during inrush current and remains inactive the remaining times.

Restricted Earth Fault

Restricted earth fault protection is used in power transformer to detect the transformer's internal earth fault. This scheme is connected as shown below. It is restricted to the transformer winding; otherwise, it may operate for any ground fault anywhere in the system. It detects faults with values below pick up of differential relay.

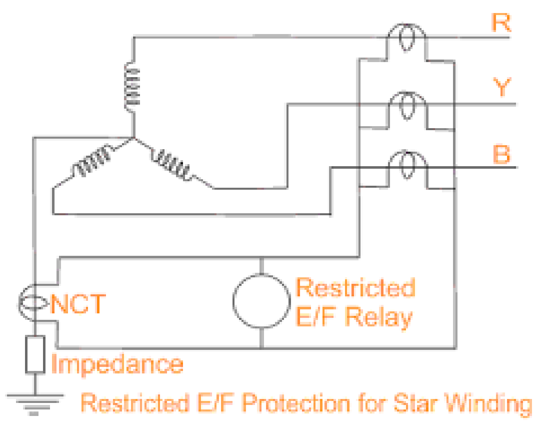


Figure2.13 Restricted Earth Fault Protection [5]

Over current protection

Over current protection scheme ensures that the transformer is protected from momentary excess current caused by overload, power surge etc.

In electric power system, over current refers to a situation where more than current intended flows through a conductor. This leads to excessive heat generation and thus the risk of causing fire or causing destruction to electrical equipment. Over current is caused by short circuit, overloading or wrong design.

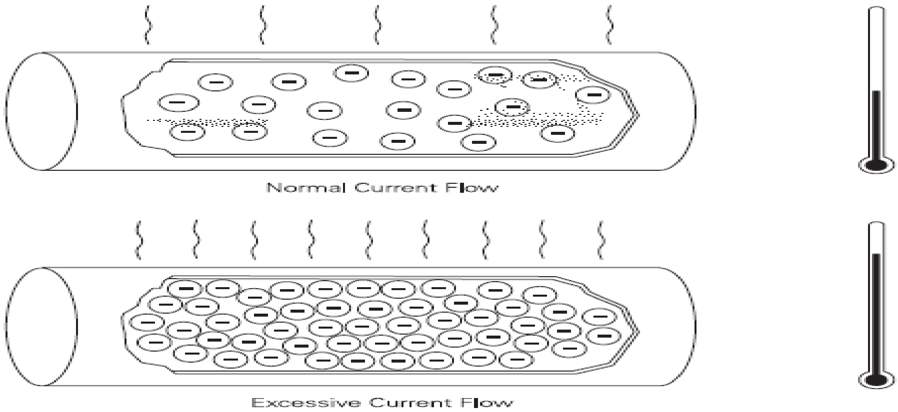


Figure2.14 Over current Phenomenon [9]

This phenomenon can be prevented using over current protection. This scheme is normally used for large transformers (over 5MV)

Over current protection protects the transformers against currents that rise beyond its rated value. Over current relay isolates the transformer in case of a fault in the system. This relay is the focus of this project. It can be implemented using analogue circuitry or digitally using microcontrollers. This project seeks to apply microcontroller and appropriate software program to design an over current relay. The diagram below illustrates an over current relay scheme [1].

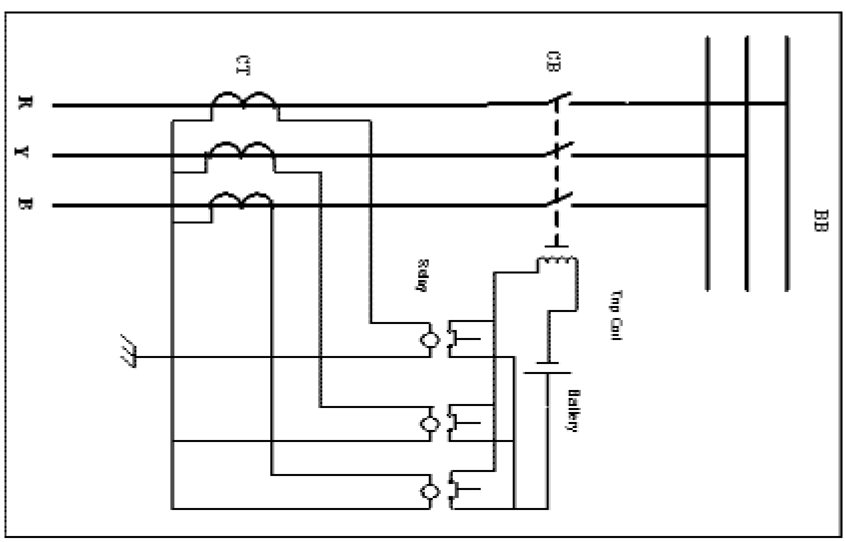


Figure2.15 Over current Protection Relay [9]

CHAPTER 3: REVIEW OF COMPONENTS USED

3.1 The PIC16f690 microcontroller

Microcontroller is basically a computer on a chip. It is a compact microcomputer, designed to control the operation of embedded electronic systems in various applications such as motor vehicles, home appliances, office machines, robots, medical devices, vending machines, mobile radio transceivers, and other electronic devices. Typically, a microcontroller comprise of a processor, timers, memory, clock/oscillator, and other peripherals. The difference between a microcontroller and a microprocessor is that a microprocessor is an integrated circuit that only has CPU but no memory as in the microcontroller. They are used in general purpose applications.

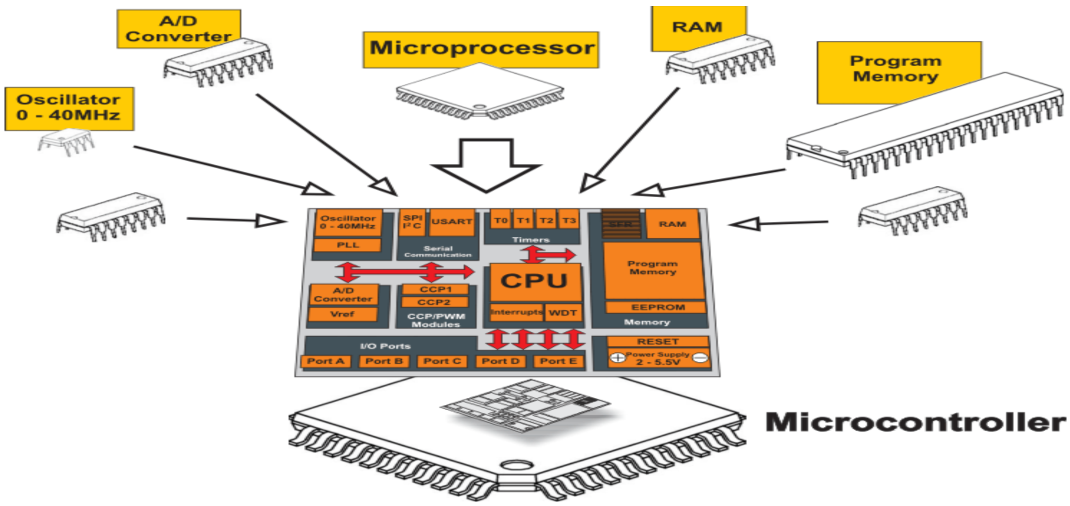


Figure3.1 microcontroller architecture [5]

As shown in figure 2-16, it can be noted that the microprocessor is actually constituted inside the microcontroller.

There are two architectures used to organize computers; Harvard architecture and Von Neumann architecture. Harvard architecture has the data memory separate from program memory while Von Neumann has both data and program in the same memory location. The advantage of Harvard architecture over Von Neumann architecture is that the CPU can fetch both data and instruction simultaneously [11]. This relationship is depicted in figure 2-17.

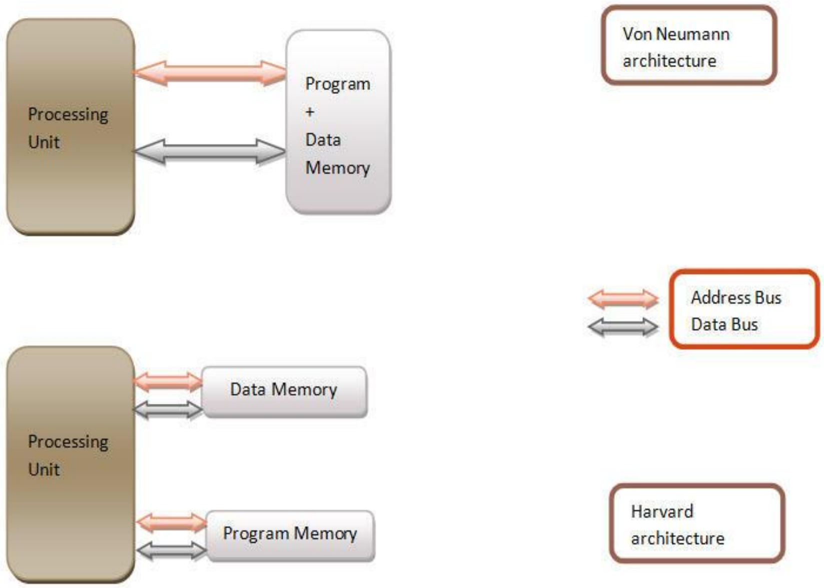


Figure3.2 microcomputer memory organization [11]

The PIC16F690 is a 20 pin, 8-bit microcontroller, with a modified Harvard architecture. It is manufactured by Microchip Technology. PIC stands for programmable interrupt controller. The PIC16F690 has a central processing unit, working memory (RAM), program memory (EPROM) and 20 input/output ports [13]. The work of the CPU is to execute instructions stored in the program memory. It can also store and retrieve data from the working memory. The diagram below illustrates the pin arrangement of the PIC16F690. The pins of PIC16F690 can be used for multiple functions as indicated on the pin diagram in figure 2-18. Pin 1 (VDD) is used for positive power supply while Pin 20 (VSS) is used as a ground reference. Pins on PORTA can be used for input/output purposes except pin RA3 which is solely an input pin. All PORTB and PORTC pins can be used for either input or output functions [14].

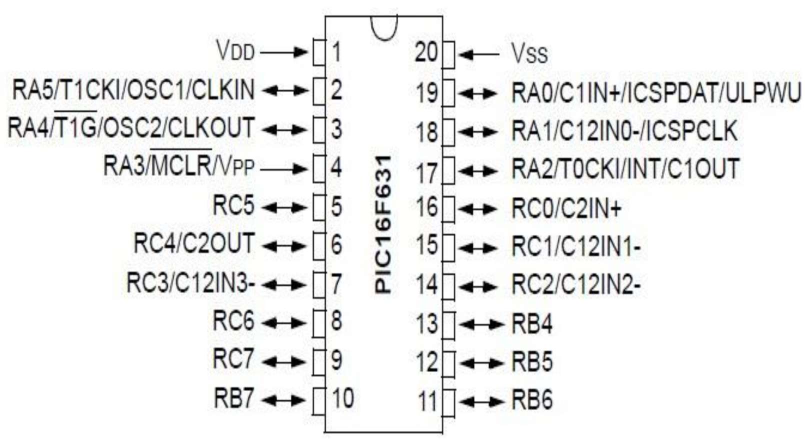


Figure3.3 PIC16F690 Pin diagram [6]

This microcontroller has the following features that made it an appropriate choice for carrying out this project.

TABLE 3.1Properties of PIC16F690

Property name	Value/description
Program memory type	Flash 4x14
Data memory	EEPROM 256bytes
RAM	256bytes
Interrupts stack	13bit 8level
Internal oscillator-software selectable	8MHz-32KHz
3 input/output ports	PORTA=6pins(6-bit wide) PORTB=4pins(4-bit wide) PORTC=8pins(8-bit wide)
A/D converter	12 Channels of 10-bits
Analogue comparator	2 channels
Wide operating voltage	2 to 5V
Auto shut down and restart option	
Programmable on chip voltage reference	
Temperature range of operation	-40 to 125°C
Maximum output current sourced/sunk by any I/O pin	25mA
Maximum current sourced/sunk in all the ports combined	200mA
Pin count	20

3.2 Liquid Crystal Display

Liquid crystal display is a type of screen display often used in digital watches, calculators and computers. The LCD display makes use of two layers of polarising material having solution of liquid crystal between them [15]. When an electric current passes through the liquid crystal, it causes them to align and cause light not to pass through them. Each crystal acts like a shutter to either allow or not allow light to pass through. The principle is illustrated in figure 2-19

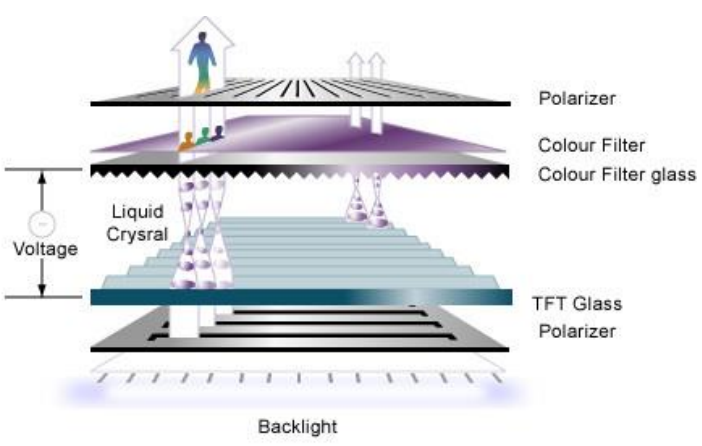


Figure3.4 The structure of an LCD [15]

Monochrome LCDs produce either dark or blue images while colour LCDs use passive matrix or thin film transistor to display many colours. In this project, a monochrome LCD is used because the aim of LCD usage is basically to display numerical figures and characters. LCDs consume little power thus they can be powered using battery.

This project makes use of HD44780 LCD. It is a 16x2 line LCD with 8-bit wide data bus (D0-D7). It has three power pins (pins1-3), and three control pins (pins 4-5). The LCD can be operated either in 4-bit or 8-bit interface. 8bit interface makes use of all the pins while 4-bit mode uses only 4 data lines plus the other remaining pins. In this project, 8-bit mode is used.

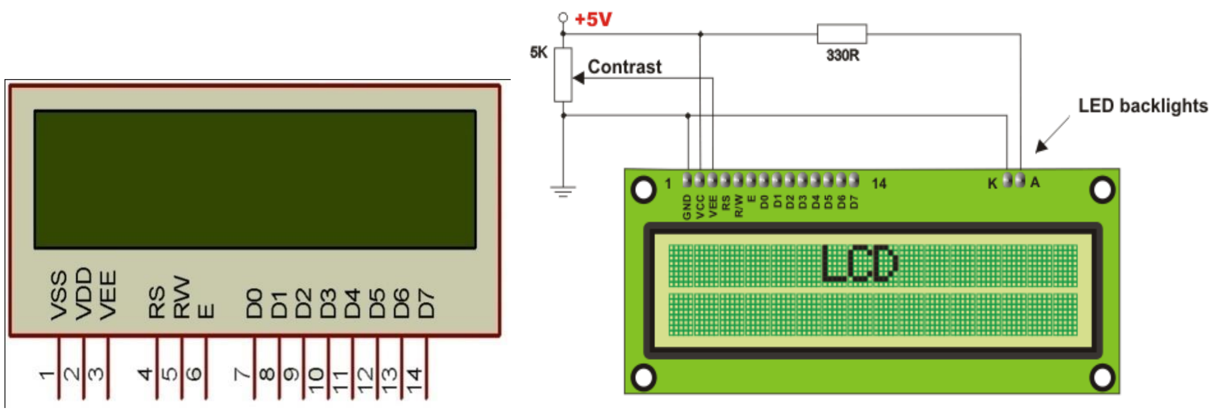


Figure3.5 LCD pin arrangement [5]

TABLE 3.2 LCD pins description

Pin number	Symbol	Function
1	VSS	Ground
2	VCC	Power supply (+5V)
3	VEE	Adjusting contrast
4	RS	Register select
5	R/W	Read/Write
6	E	Enable pin
7	DB0	Data line zero (LSB)
8	DB1	Data line 1
9	DB2	Data line 2
10	DB3	Data line 3
11	DB4	Data line 4
12	DB5	Data line 5
13	DB6	Data line 6
14	DB7	Data line 7 (MSB)

ENABLE PIN: This pin is key in the operation of the LCD. Data can only be latched into the LCD when high to low signal is passed into this pin. There should be at least 450ns delay between clearing and setting this pin, because of the higher frequency of the microcontroller relative to the LCD.

When: E = 0 LCD cannot be accessed

E = 1 LCD can be accessed

R/W: informs the LCD whether the information is supposed to be read or written on the LCD.When:

R/W = 0 Data is written to LCD
R/W = 1 Data is read from LCD
RS: helps the LCD to identify whether the information is data or command.

When: RS = 0:command

RS = 1: data

D0-D7: these are the data pins, information is sent/received via these pins.

TABLE 3.3 LCD Instructions [15]

Code(hex)	Command to LCD instruction register
1	Clear display screen
2	Return home
4	Shift cursor to left
5	Shift display right
6	Shift cursor to right
7	Shift display left
8	Display off, Cursor off
A	Display off, Cursor on
C	Display on, Cursor off
E	Display on, Cursor blinking
F	Display on, Cursor blinking
10	Shift Cursor position to left
14	Shift Cursor position to right
18	Shift the entire display to the left
1C	Shift the entire display the right
80	Force cursor to beginning of first line
C0	Force cursor to beginning of second line
38	2 lines and 5x7 matrix

TABLE 3.4 HD44780 instruction set

Instruction	Code							
	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
Clear display	0	0	0	0	0	0	0	1
Cursor home	0	0	0	0	0	0	1	*
Entry mode	0	0	0	0	0	1	I/D	S
Display ON/OFF & cursor	0	0	0	0	1	D	C	B
Cursor/display shift	0	0	0	1	S/C	R/L	*	*
Function set	0	0	1	DL	N	F	*	*
Set CGRAM address	0	1	A	A	A	A	A	A
Set display address	1	A	A	A	A	A	A	A

I/D: 1 = Increment, 0 = Decrement — S: 1 = Display shift ON, 0 = OFF
D: 1 = Display ON, 0 = OFF — C: 1 = Cursor ON, 0 = OFF
B: 1 = Cursor blink ON, 0 = OFF — R/L: 1 = Right Shift, 0 = Left shift
S/C: 1 = Display shift, 0 = Move cursor — DL: 1 = 8-bit interface, 0 = 4 bit
N: 1 = two lines, 0 = 1 line — F: 1 = 5x10 dots, 0 = 5x7 dots

Carrying out any operation on the LCD requires that instructions be sent via the data lines. This means that the RS pin has to be set low. The instructions in the tables above are used to write information to the LCD. The LCD can be used in either of the following configurations,

8-bit configuration: all the eight data pins are used (D0 – D7)
4-bit configuration: only four of the data lines are used (D4 – D7)

There are two more pins (anode and cathode) that enable data written when it is dark to be seen.

3.3 Current sensor

This is a device that detects electric AC or DC current flowing in a conductor and gives out a corresponding signal (analogue voltage/current/digital pulse). The detected signal can be used for various purposes like measuring the amount of current in the conductor, controlling of another device etc.

Figure3.6 Allegro Microsystems ACCS712 Series

The current sensor used in this project is Allegro ACS712ELCTR-30A-T. It is popularly used in diverse applications in motor control, electric vehicles and in power distribution. It has the following features [7];

- Low-noise analogue signal path
- Device bandwidth is set via the new FILTER pin
- 5 μs output rise time in response to step input current
- 80 kHz bandwidth
- Total output error 1.5% at T_A= 25°C
- Small footprint, low-profile SOIC8 package1.2 mΩ internal conductor resistance
- 2.1 kVRMS minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation
- 66 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis
- Ratiometric output from supply voltage [16]

The Allegro ACS712ELCTR-30A-T has a low-offset linear Hall sensor circuit that has a conduction path made of copper located next to the die. A magnetic field is caused by the current flowing through the copper conductor. This magnetic field is detected by the integrated Hall IC which converts it into a voltage proportional to the magnetic flux. A current of 1A flowing in a conductor produces 66mV. The close proximity of the magnetic signal to the Hall transducer optimizes the device accuracy. To attain precision, in terms of voltage produced, a low-offset, chopper-stabilized Bi-CMOS Hall IC is used. It is programmed for accuracy at the factory[16].

The sensor measures a maximum of 30A from the load current. This serves as its primary current. The sensor output voltage is fed into the microcontroller as the analogue input.

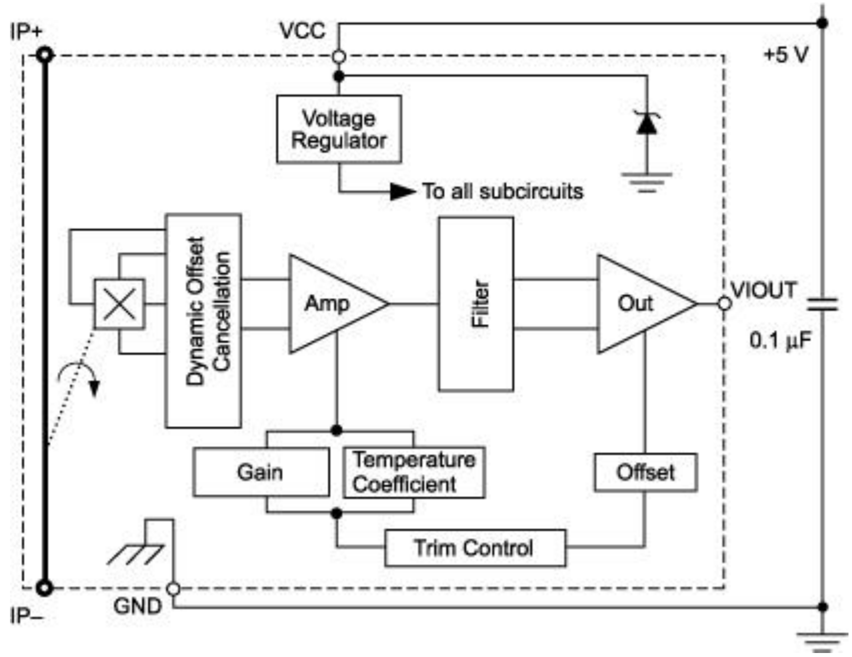


Figure3.7 Current sensor functional block diagram [16].

3.4 Relay

A relay is an electrically operated switch. It uses electromagnetic force to close or open contact. The relay employed in this project can be operated as normally closed or normally open. For this system, the normally closed mode was used. The relay circuit is illustrated in figure 2-25. The relay was used to de-energize the contactor coil in case of a fault thus isolating the transformer from the system.

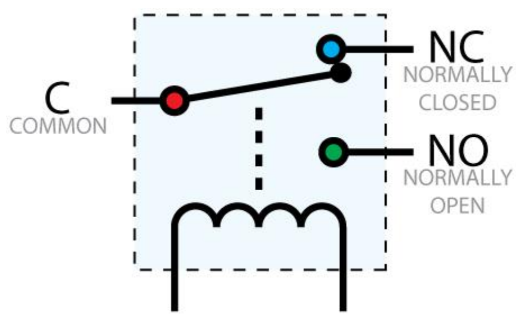


Figure3.8 Relay circuit [17]

3.5 Contactor

When a relay is used to switch a large amount of electrical power through its contacts, it is referred to as a *contactor*. Contactors basically have several contacts, and which are usually (but not always) normally-open, so that power to the load is shut off when the coil is de-energized [18]

CHAPTER 4: DESIGN

The ultimate objective of this project is to design an automatic over current relay that uses microcontroller to read transformer currents and automatically isolate the transformer from the power system in case of a fault. This design is therefore based on the programmable Interrupt Controller (PIC microcontroller) as the main control element in the system. The design of this system has been divided into the following sections;

Hardware design
Software design
PCB design

4.1 HARDWARE DESIGN

The PIC16F690 microcontroller has been used as the main device in the development of this system. Based on the number of input/output pins and the other functional features it was selected for use in this project. The 20 pins of the microcontroller have been distributed for use as follows

TABLE 4.1 Microcontroller Pin Usage

Pin function	Number of pins	Pin names
Power pin(VDD)	1	RA3
Sensor input pin	1	RA0
LEDS control	2	
Buzzer control	1	
Relay control	1	
LCD control	3	
LCD data lines	8	RC0-RC7
Reset pin	1	

4.1.1 Interfacing LCD to the microcontroller

The LM016L LCD display device has been employed in the system implementation. The LCD operates as a medium for communicating the amount of current flowing in the electric conductor at any given time. The logical process that avails the readings takes place within the microcontroller using a program and displayed on the LCD. The LCD operates in 8-bit mode, so 8 pins from the microcontroller have been connected to the 8 data pins on the LCD. Since PORTC of the PIC16F690 is 8-bit wide, it is used for this purpose. So, RC0- RC7 pins of PIC microcontroller have been connected to D0-D7 of the LCD as illustrated in figure 4-1.

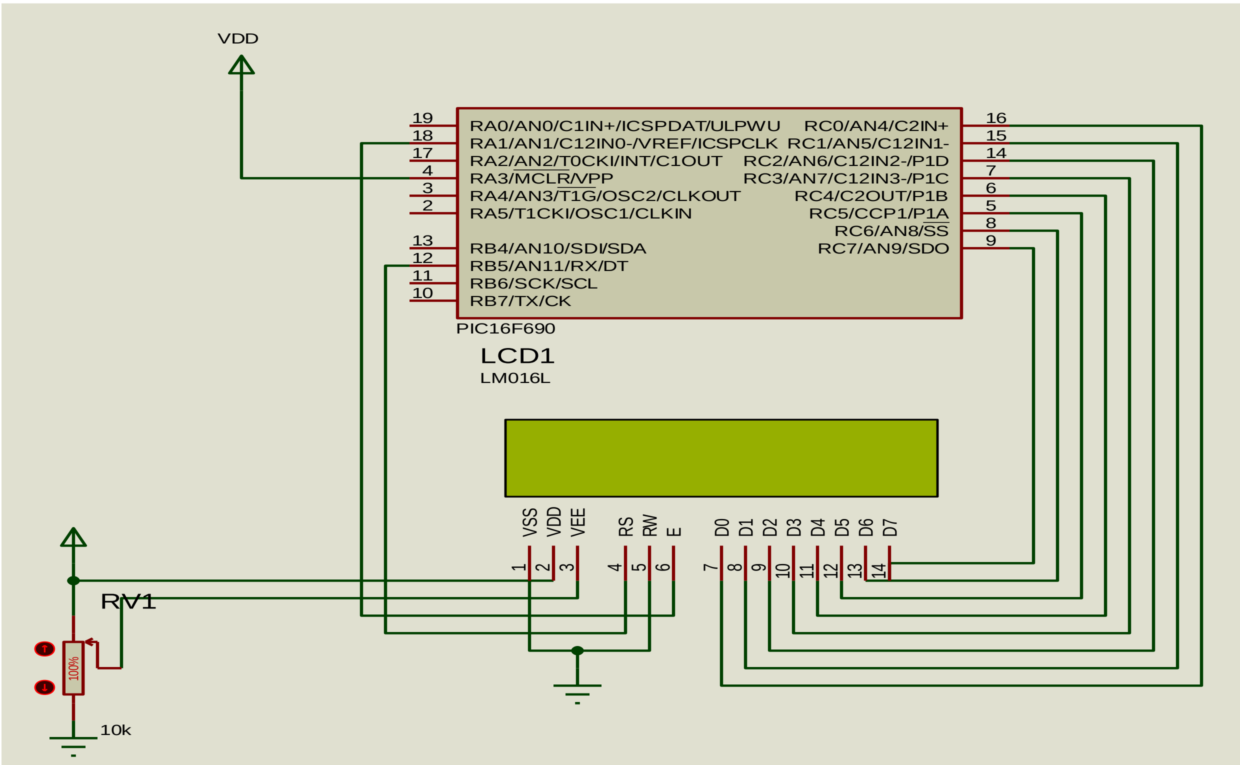


Figure4.1 Microcontroller-LCD interface as done in the simulation software

The register select (RS) pin has been connected to pin 12 (RB5) on the microcontroller. Enable pin has been connected to RA1 (pin 12). At all times, the R/W line is connected to ground (kept low) since data in this case is always written into the LCD. A potentiometer of 10KΩ has been used to vary the brightness contrast of the LCD.

4.1.2 Warning devices and relay control

a) LEDs

In order to indicate the state of the power line, two Light emitting diodes have been used. One LED emits red light and the other one green light. The green LED is set to blink when the current flowing through the power system is at a normal level. The red LED should blink at an interval of half a second whenever the current build up approaches the overload level through to the point when the relay gets energized. This acts as a visual warning when a fault occurs.

The green LED has been connected to the pin RB4 (pin 13) via a current limiting resistor (220Ω) to ground. The red LED has been connected to pin RA5 (pin 2) also through a current limiting resistor (220Ω) to ground. The microcontroller pins can give a maximum of 5.3V. LEDs typically have a forward voltage drop ranging between 1.8V and 3.3V subject to the LED colour. The value for red LED is about 1.8V. The forward voltage drop is a function of the LED colour frequency.

For the LED to light, it needs around 20mA of current. The calculation below justifies the resistor values chosen for the design of this system.

According to Ohms law, resistance is a function of voltage and current, as shown in the equation below

$$R = \frac{Vs - Vf}{Is}$$

$$R = (5.3 - 1.8) * \frac{1000}{20} = 175\Omega$$

$$Vs = supply\ voltage\ from\ the\ pin\ to\ the\ LED, \qquad Vf = forward\ voltage\ drop,$$
$$Is = LEDcurrent$$

175Ω is not a standard resistor value, so a value close to it can be chosen. In order to ensure that the current sourced is as little as possible, the 220Ω resistor has been chosen such that the maximum current sourced becomes;

$$\frac{5.3 - 1.8}{220} = 16mA$$

The figure 2-2 below illustrates the connection of LEDs to the microcontroller via current limiting resistors.

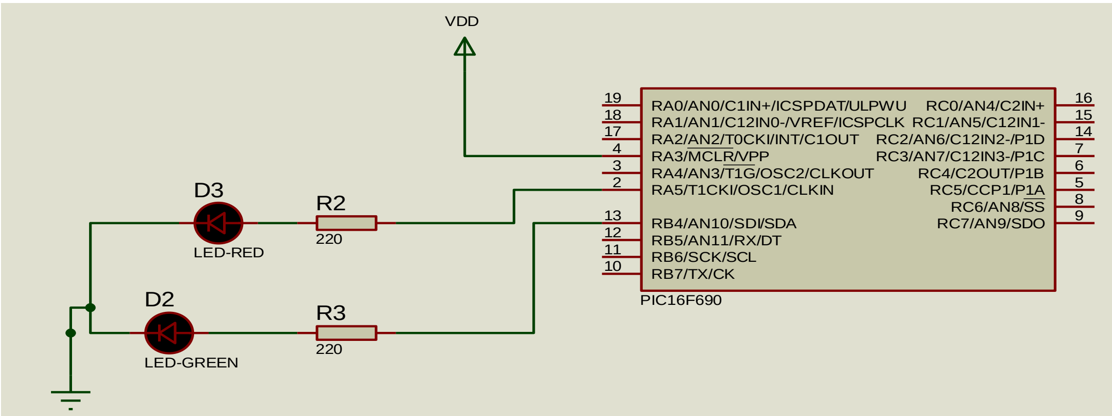


Figure4.2   Microcontroller-LED connection

b) Audio Alert

In order to provide an audio warning in case of a transformer overload, a piezoelectric buzzer has been used. The buzzer rating is between 2V-5V with a current rating of approximately 9mA. In order to achieve the 9mA rating, a resistor of value R= 5V/9mA = 550Ω is required. A standard 560Ω resistor has been used. In order to allow for varied range of buzzers to be used, a Darlington transistor is used as a switch. It is connected to pin RB6 of the microcontroller. The microcontroller produces 5V that drives the transistor thus allowing current flow in the transistor. The buzzer is connected between the transistor VDD and the collector. It goes on whenever the microcontroller pin controlling it is set to high. This results due to an instance of a fault occurring in the system which is unsuitable for the transformer. This piezoelectric buzzer serves to give a warning to users to cease overloading the transformer or for a mitigation process to be conducted.

c) Relay/contactor control

An electromagnetic relay has been employed as a switch to isolate the transformer from the power system in case a fault occurs. The rating of the relay used is in the model system is 5V. Due to the fact that the relay might draw a current of higher value than what the microcontroller can sink or source, a Darlington transistor is used as a switch to run it. It is connected between the transistor VDD and the Darlington transistor collector. When fault current is detected, the RB6 pin of the microcontroller is set high. This produces current that drives the Darlington transistor. The transistor in turn completes the relay coil circuit. The relay is energized through the principle of electromagnetic induction. It in turn de-energizes the contactor to isolate the transformer from the system. The relay is used alongside a contactor because; a power transformer uses high currents that the 5V relay cannot sustain. The relay sends signals to the contactor which in turn disconnects the circuit and isolates the transformer from the power system. The process is illustrated in the figure 4.3 below.

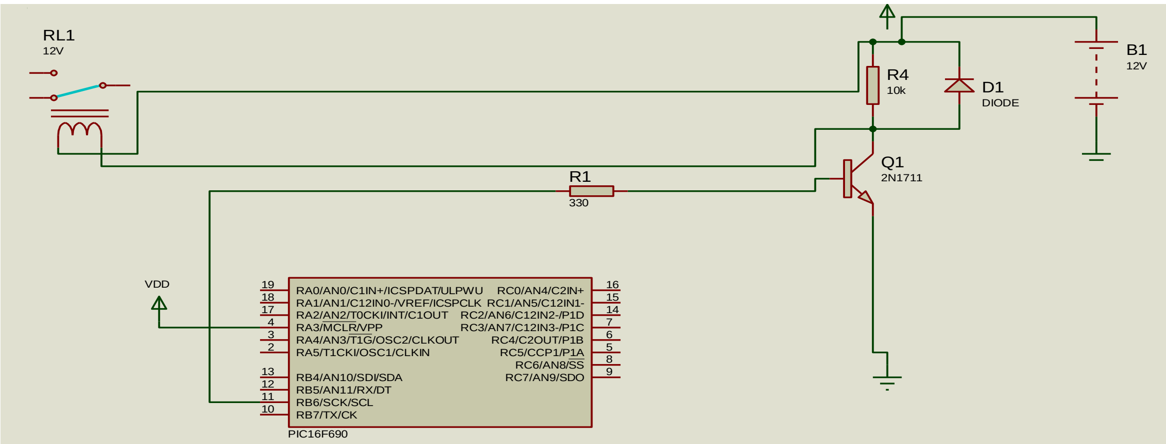


Figure4.3 Microcontroller-relay interface as done on the simulation software

4.1.3 Sensor interfacing to the microcontroller

Since the microcontroller can take a maximum of 5V DC input, it cannot be connected directly to an AC line with high voltages. A current transformer and anACS75x series sensor has been used. The current transformer stepped down the line current to measurable level of 25A. The current sensor converts the current to a maximum of 5V. The current transformer is connected to the pins 4 and 5 of the current sensor. The sensor output is connected to the pin RA0 of the microcontroller. A zener diode is used to protect the microcontroller from voltage spike. The figure 4.4 illustrates this process

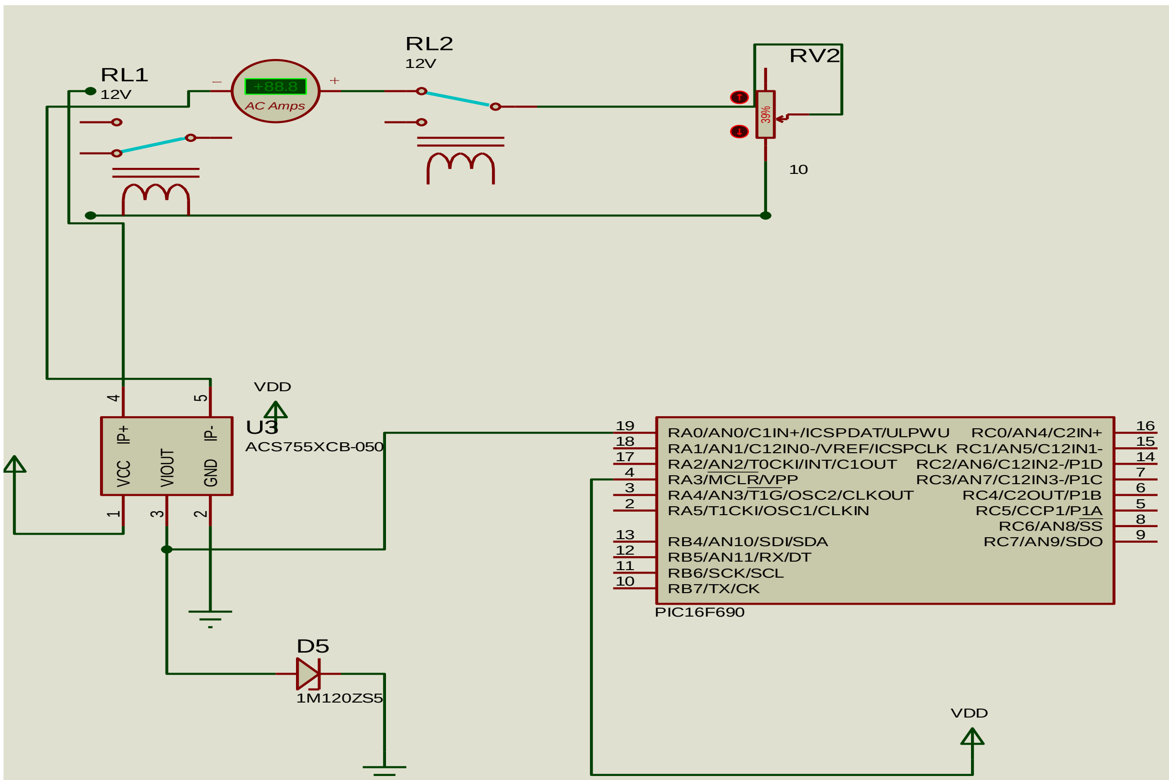


Figure4.4 Microcontroller-sensor interface as done on the simulation software

4.1.4 The Oscillator

The function of an oscillator in a microcontroller is to generate a clock signal. The clock signals are important because they help the parts of the microcontroller to function together. The clock makes it easier to know when the different parts of the microcontroller are going to change state. It is important to know how long a given operation takes to accomplish. An internal oscillator has been used in this design instead of an external crystal oscillator. It is selected in the program.

4.1.6 PCB design

After the circuit is successfully tested on the breadboard, it is transferred to a PCB. The process for designing the PCB is as follows

i. The circuit layout is drawn using software. In this project, proteus has been used. The components are confirmed to be well placed.
ii. The circuit design is printed on a transparent film. This is used to develop the circuit on a PCB through etching process.
iii. The needed holes are then drilled and then the components fitted into them.

4.2 SOFTWARE DESIGN

For the microcontroller to operate, it must be programmed, and thus the software design. Software design is divided into four parts as follows;

LCD Program
Analogue to Digital conversion
Protection program
The main program guide

The flow chart below illustrates the way the program worked. It was used as a guide while writing the code for the microcontroller.

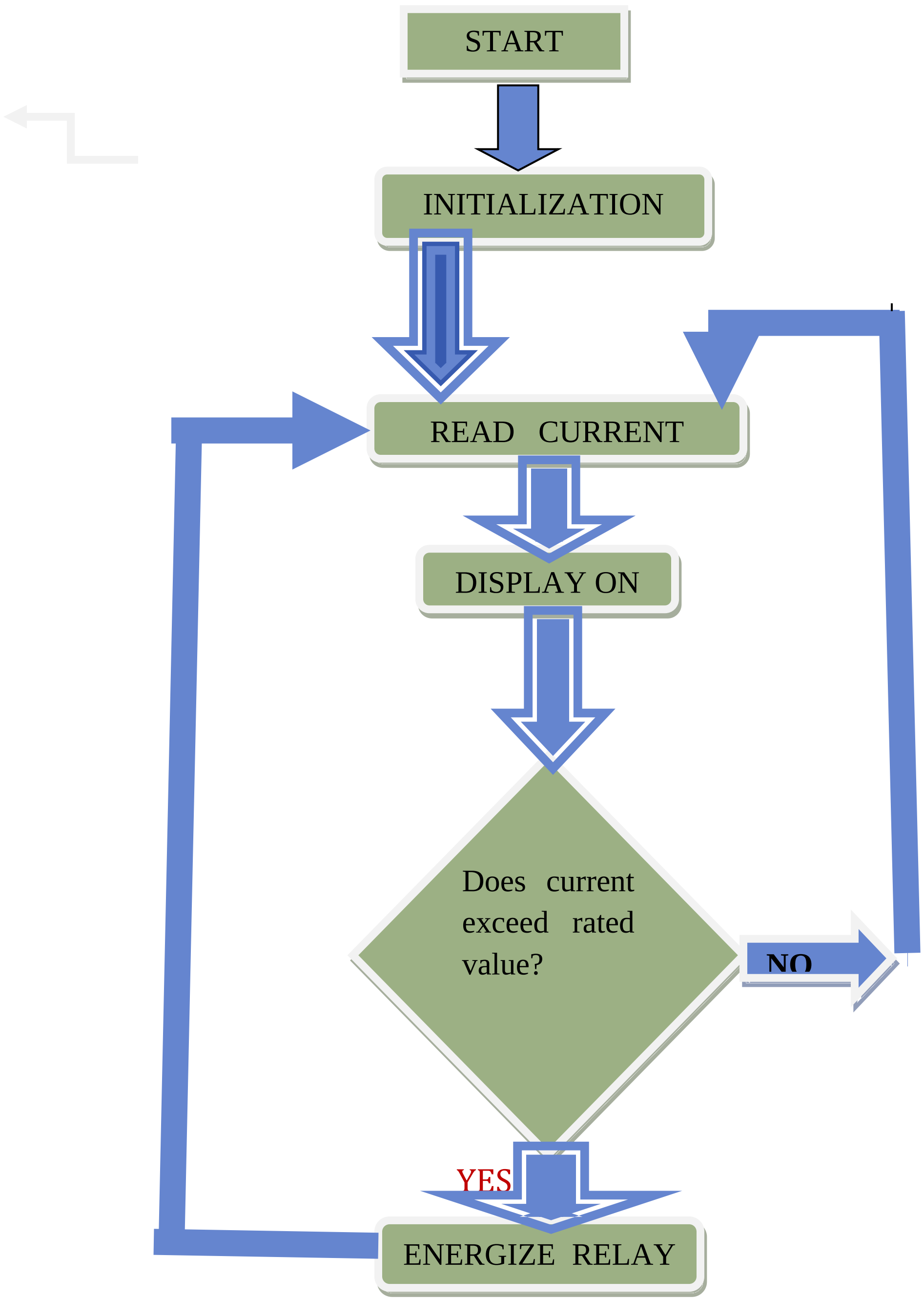


Figure4.5 Flow chart of the program

4.2.1 ADC Program

The PIC16F690 has an internal analogue to digital converter module that is 10 bit wide and has 12 channels. For this ADC to be used, it has to be programmed.

a. Bank selection

The data memory is partitioned into four banks which contain the General Purpose Registers (GPR) and the Special Function Registers (SFR). For a register to be used, the right bank that contains it has to be selected. The first register used in the ADC program is ADCON1 register. It is contained in bank 1. For bank 1 to be selected, the following instruction is used.

BSF STATUS, RP0

The STATUS register is used to select banks. Its arrangement is shown in figure 3-1. Bits 5 (RP0) and 6 (RP1) are used to select one of the four banks as appropriate.

So in order to select bank1, the RP0 bit is set high (1) while RP1 remains low (0).

BCF STATUS, RP0 ; clear bit 5 of STATUS register

BSF STATUS, RP1 ; set bit 6 of STATUS register.

IRP	RP1=1	RP0=0	TO	PD	Z	DC	C
Bit 7							Bit 0

Figure4.6 the Status register

TABLE 4.2 Bank selection bits

RP1	RP0	SELECTION
0	0	Bank 0 selected
0	1	Bank 1 selected
1	0	Bank 2 selected
1	1	Bank 3 selected

b. Clock setting

The ADCON1 register is used to select the A/D Conversion clock. Its selection bits are as illustrated in figure 4-7

U-0	R/W-0	R/W-0	R/W-0	U-0	U-0	U-0	U-0
-	ADCS2	ADCS1	ADCS0	-	-	-	-
BIT-7							BIT-0

Figure4.7 ADCON1 Register.

Bit 7 **Unimplemented:** Read as ‘0’

Bit 6-4 **ADCS<2:0>:** A/D Conversion Clock Select bits

000 = FOSC/2

001 = FOSC/8

010 = FOSC/32

X11 = FRC (clock derived from a dedicated internal oscillator = 500 kHz max)

100 = FOSC/4

101 = FOSC/16

110 = FOSC/64

Bit 3-0 **Unimplemented:** Read as ‘0’

An internal clock (FOSC/16) of 4MHz, is used, hence selection is **ADCS2 = 1, ADCS1 = 0** and **ADCS0 = 1** the relevant code segment is as follows.

```
MOVLW b'01010000'          ; ADC clock at 4MHz/16(TAD=4.0us)

MOVWF ADCON1
```

The time taken to complete one bit conversion is defined as T_{AD}. The choice of FOSC/16, 4MHz gives a T_{AD} of 4µs.

c. Input configuration

The input pin is selected by setting the TRIS and ANSEL bits. First, the right bank for TRIS is selected. In this case we are still in bank-1 and since the TRIS register is in bank-1, there is no problem. The following code segment is employed select pin RA0 as the input pin.

```
BSF TRISA, 0          ; Set RA0 to input
```

To set the input pin as an analogue input, we use the ANSEL register which is in bank-2. The bank is first selected as shown;

```
BCF STATUS, RP0       ; select  Bank -2

BSF STATUS, RP1       ;
```

Since RA0 has been used as an input, ANS0 is configured to analogue input using ANSEL.

ANS7	ANS6	ANS5	ANS4	ANS3	ANS2	ANS1	ANS0
Bit 7							Bit 0

Figure4.8 The ANSEL register

BSF ANSEL, 0 ; Set RA0 to analogue

d. Channel, reference voltage and result format selection

The ADCON0 register controls the microcontroller ADC operation such as channel selection, power on the ADC circuit, start converting, ADC voltage reference selection and ADC result format presentation selection.

RW/-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	VCFG	CHS3	CHS2	CHS1	CHS0	GO/DONE	ADON
BIT-7							BIT-0

Figure4.9 ADCON1 Register.

Bit 7 **ADFM:** A/D Conversion Result Format Select bit

1 = Right justified

0 = Left justified

Bit 6 **VCFG:** Voltage Reference bit

1 = VREF pin

0 = VDD

Bit 5-2 CHS<3:0>: Analog Channel Select bits

0000 = AN0

0001 = AN1

0010 = AN2

0011 = AN3

0100 = AN4

0101 = AN5

0110 = AN6

0111 = AN7

1000 = AN8

1001 = AN9

1010 = AN10

1011 = AN11

1100 = CVREF

1101 = 0.6V Reference

1110 = Reserved. Do not use.

1111 = Reserved. Do not use.

Bit 1 **GO/DONE:** A/D Conversion Status bit

1 = A/D conversion cycle in progress. Setting this bit starts an A/D conversion cycle.

This bit is automatically cleared by hardware when the A/D conversion has completed.

0 = A/D conversion completed/not in progress

Bit 0 **ADON:** ADC Enable bit

1 = ADC is enabled

0 = ADC is disabled and consumes no operating current

First the following code segment is used to select the bank-0 where the ADCON0 register is located.

BCF STATUS, RP0 ; Bank 0

BCF STATUS, RP1

The ADFM is used to select the result format; for this case, the conversion result formats are left justified, i.e. bit 7 (ADFM) is kept low.

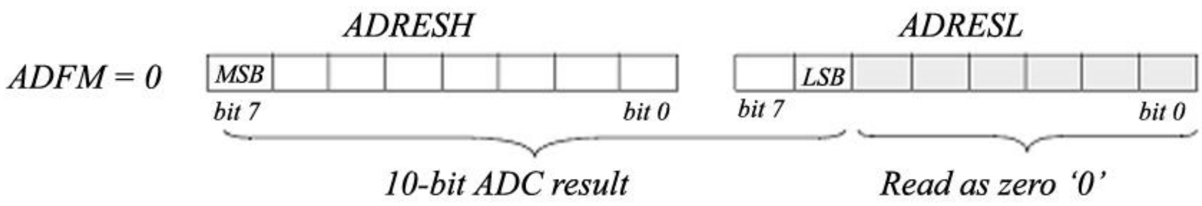


Figure4.10 Left justification format

VDD has been used as the voltage reference, thus bit 6 is also kept low. Since AN0 has been configured as the analogue input, bits 5 to 2 are kept low. The GO/DONE bit is kept low to show that the conversion is complete.

To enable ADC, BIT- 0 (ADON) BIT is set to 1. The code segment is as follows

MOVLW 0x01 ; Vdd Vref (bit 6), AN0 (0000 of bit 5-2), on (bit 0)

MOVWF ADCON0 ; also LEFT JUSTIFY

e. Acquisition time

Acquisition time is the amount time required to charge the holding capacitor on the front end of an analogue-to-digital converter. The holding capacitor must be given sufficient time to settle to the analogue input voltage level before the actual conversion is initiated. If sufficient time is not allowed for acquisition, the conversion will be inaccurate. The required acquisition time is based on a number of factors, two of them being the impedance of the internal analogue multiplexer and the output impedance of the analogue source. An increase in the source impedance will increase the required acquisition time[12].

To determine the minimum acquisition time, the following relationship is used.

T_{ACQ} = Amplifier Settling Time+ Hold Capacitor Charging Time + Temperature Coefficient

$= T_{AMP} + T_C + T_{COFF}$.............. (eq 4-1)

$= 5\mu s + T_C + [(\text{Temperature} - 25°C)(0.05\mu s/°C)]$...........(equ 4-2)

We can approximate the value of T_C using the following equation:

$T_C = -C_{HOLD}(R_{IC} + R_{SS} + R_S) \ln (1/2047)$.................. (equ 4-3)

$= -10pF(1k\Omega + 7k\Omega + 10k\Omega) \ln (0.0004885)$

$= 1.37\mu s$

Where, R_{SS}=sampling switch

R_{IC}=interconnect resistance

R_S=Input impedance

Assuming day temperature of 40°C

T_{ACQ} = 5μS + 1.37μS + [(40°C- 25°C)(0.05μS/°C)]

= 7.12μS

Thus a suitable minimum acquisition time is = 7.12μSec

f. Storing the data after conversion

Because left justification format has been selected, the ADRESH of the ADC takes the upper 8 bits of the conversion while the upper two bits of ADRESL are occupied by the lower two bits of the conversion. The following code segments show how data from the addresses are stored in the general purpose registers.

```
MOVF ADRESH, W          ; Read upper 8 bits
MOVWF OUTPUTH           ; move contents of ADRESH to OUTPUTH

BANKSEL   ADRESL        ; select the bank where ADRESL is located
MOVF ADRESL, W          ; Read lower 2 bits
BCF STATUS, RP1         ; bank- 0
BCF STATUS, RP0         ; select bank-0
MOVWF OUTPUTL           ; move contents of ADRESL to OUTPUTL
```

4.2.2 LCD DISPLAY

The pins of the LCD are connected to the microcontroller as follows; the 8 data lines are connected to PORTC since 8 bit configuration has been used. The R/W pin is connected to low (ground) since data is always written into the LCD. The RS pin is connected to pin 12 of the microcontroller and is used to control instructions or characters sent to the LCD. The Enable pin was connected to pin 18 of the microcontroller and it was used to enable the LCD to either feed instruct instruction into the register or write character into it. The following code segments are used to initialize the LCD;

For the LCD to power, it needs some time, thus a delay of 20milliseconds is created. This delay is called at the start of the initialization. The following code has been used.

```
CALL Delay20
```

After powering the LCD, the type of interface is set to 8-bit interface by setting, (**DL=1)** the number of line display and character font is also selected by setting **N=1** (two lines) and **F=0** (font of 5x7). Thus the instruction with **00111000 binary** or **38 Hex** on the data lines. A delay of more than 40µs is used then a subroutine is called to feed the instruction.

```
MOVLW    b'00111000'       ;select 8-bit interface,
CALL     Delay50           ; 50µSec used
CALL     LCDcom            ; instruction subroutine
```

The entry mode is set as follows; Cursor is made to move to the right and at the same time the register is incremented by 1- (**I/D=1**), no display shift (**S=0**). This results in **00000110 binary** or **06 Hex**. The code segment is as follows.

```
MOVLW b’00000110’                     ; Increments display
```

Display on/off control: the display is set on by setting D=1, while cursor and blinking are put off (C=0, B=0), resulting in **00001100 binary** or **0C Hex**. The code segment is as follows.

```
MOVLW 0Ch                  ; Display ON, cursor OFF & blink OFF
```

To take cursor home, **00000010** binary or **02Hex** is used. To clear the screen in readiness for writing, **00000001** binary or **01Hex** is used.

```
MOVLW    0x02              ;takes cursor home
MOVLW    0x01              ;clears LCD display
```

In order to write into the LCD, data is first taken to the PORTC, then both E and RS pins of the LCD are set. A small delay is then given to allow data to be written, then enable pin is cleared and a delay applied.

In order to write characters to the first row on the LCD, a code for the address of the first row first column is addressed to PORTC. The first row on the LCD starts from 80Hex**.** This is placed in a register and incremented up to the number of times equal to the number of characters to be displayed. In this design, the number of characters to be displayed is 16. In order to know that we have moved to the last column, the content of the counter is subtracted from 8F. This is done until the carry bit of the Status register is set. An XOR instruction is also used to identify the end of text. The entire program code is presented in the appendix.

Sending an instruction to the LCD requires that a code be written. First, the value is moved to the PORTC. For an instruction, **RS** is set to **0.** This is achieved by setting bit-5 of PORTB low. Then some small delay of 5µSec is applied to the LCD. It is then enabled, (**E=1**) then another short delay of 5µSec that gives it time to fetch data is used before clearing the enable bit (**E=0**) and calling another delay routine.

The values stored in ADC are in binary form. For them to be displayed on the LCD, they need to be converted to ASCII values. The 10 bits of the ADC are stored in two registers- ADRESH and ADRESL. The ADC can encode analogue input up to 1024 (2^{10}) different levels. On the other hand, the full scale analogue voltage from the current sensor is 5V. The resolution of the converter indicates the number of discrete values it can produce over the range of analogue values

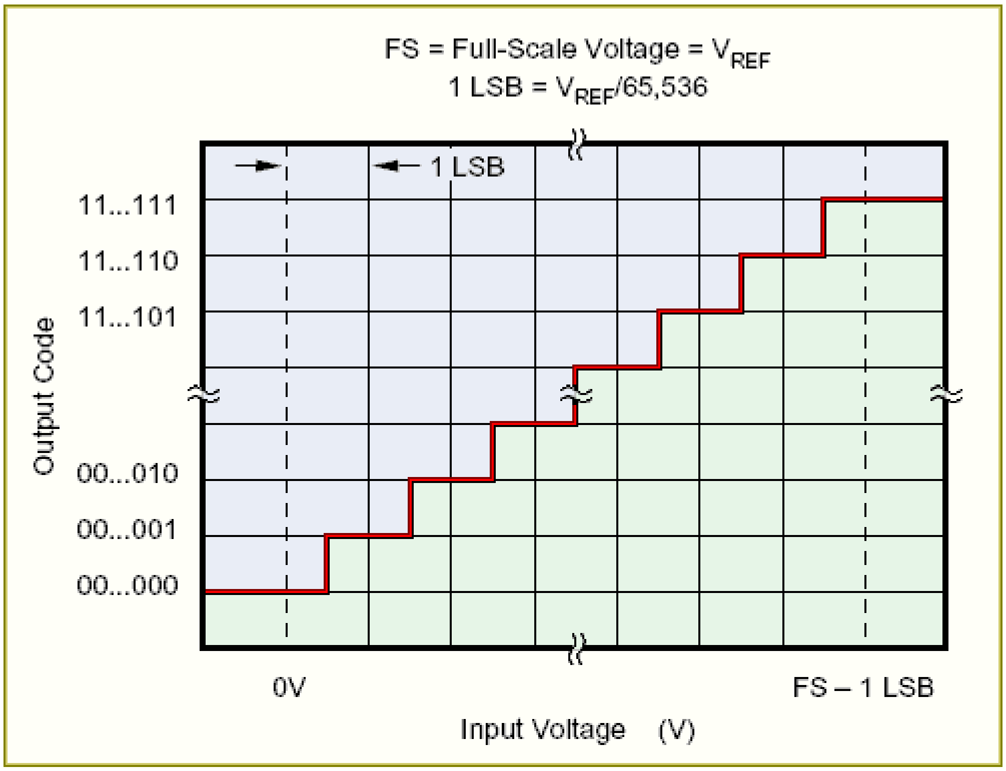


Figure4.11 ADC output against input voltage [12]

The resolution is the minimum voltage required to cause a change at the output level. It is also referred to as the least significant bit voltage. It is calculated as follows

$$Resolution = \frac{E}{N} \qquad Equ\ 4-4$$

Where: E = 5 V

N = (2^{10}- 1) = 1023

$$Resolution = \frac{5}{1023} = 4.9\text{mV}/bit \qquad Equation\ 3.4$$

The range of the sensor is 0 – 30A. The voltage output range is 0 - 5V

$$(\frac{0.0048875855}{5})30 = 0.029$$

The 10 bits and corresponding values of current were calculated as shown in the table below.

TABLE 4.3 Value of each bit in Volts and Amperes

Bit	Equivalent voltage (V)	Equivalent current (A)
Bit 0 (LSB)	0.005	0.29
Bit 1	0.010	0.059
Bit 2	0.020	0.117
Bit 3	0.039	0.234
Bit 4	0.078	0.469
Bit 5	0.156	0.938
Bit 6	0.313	1.877
Bit 7	0.626	3.754
Bit 8	1.251	7.507
Bit 9 (MSB)	2.502	15.014
TOTAL	5	30

To be able to display current values, six registers are declared; they included; hundreds, tens, ones, first_dec , sec_dec and third_dec. Each value is put in its respective register for all the bits upon testing whether or not each is set.

After assigning the values to the different registers, they are used when writing the values on the LCD. The upper and lower registers have to be tested as well to establish whether they contain any value or not so that only those that have values are written. E.g., if the tens register is zero its place is left blank. The same test is carried out for the ones position until the last decimal value.

4.2.3 Relay and Fault Signals

When the amount of current circulating through the transformer goes beyond the rated value, the relay is energized so as to isolate the transformer from the power system until the over current fault is cleared. The relay keeps testing automatically and in case the fault is still present, it keeps isolating the transformer until the conditions are safe. For the model, a 5V relay has been used and connected to the secondary side of the transformer. It is driven by pin RB6 of the microcontroller via a transistor. The need to send an alarm in case of a fault warrants the use of a 5V buzzer and a red LED. In case a fault occurs, the red LED blinks and at the same time, the buzzer goes on. The red LED and buzzer are controlled by pins RA5 and RB7 respectively.

For demonstration, a preset current value has been set in the program. The microcontroller sets the relay, buzzer and red LED pins on in case the current amounts reaches this value and off as long as the current value remains lower than the pre-set value. For the actual power transformer, current rating for a particular transformer is be used. The preset current value in this case has been set to 15Amperes. This in binary form is as follows;

ADC results = 200He

ADRESH = 80H

ADRESL = 00H

The exact amount of current at which the relay triggers is 15.015A since the binary value is 1000000000, which means that only bit 9 is set and bit 9 contains15.015A. So there is no need of checking the OUTPUTH register since it would contain zero.

CHAPTER 5: RESULTS AND ANALYSIS

5.1 Simulated results

The following results have been obtained after simulating the design on proteus. Table 5.1shows the state of the relay, LED and buzzer as current increases. A decrease in load resistance makes current circulating in the primary side of the transformer to increase.

TABLE 5.1SIMULATED RESULTS

% Load Resistance	Sensor output (V)	Display on LCD	State of the Relay	State of the buzzer	LED Blink	LCD DISPLAY
100	0.05V	0.352A	OFF	OFF	GREEN	
90	0.06V	0.381A	OFF	OFF	GREEN	
80	0.07V	0.44A	OFF	OFF	GREEN	
70	0.08V	0.498A	OFF	OFF	GREEN	
60	0.09V	0.586A	OFF	OFF	GREEN	
50	0.12V	0.704A	OFF	OFF	GREEN	
40	0.14V	0.88A	OFF	OFF	GREEN	
30	0.19V	1.143A	OFF	OFF	GREEN	
20	0.28V	1.701A	OFF	OFF	GREEN	
10	0.51V	3.079A	OFF	OFF	GREEN	
5	0.89V	5.337A	OFF	OFF	GREEN	
2	1.70V	10.234A	OFF	OFF	GREEN	
1	2.52V	15.132A	ON	ON	RED	OVERCURRENT FAULT
0	2.52V	15.161A	ON	ON	RED	OVERCURRENT FAULT

5.2 Analysis

It Is observed that as the current circulating in the transformer increases, the sensor output also increases. This is illustrated in the table above. An increase in the sensor output voltage led to a corresponding increase in the current value displayed on the LCD.

Current displayed on LCD

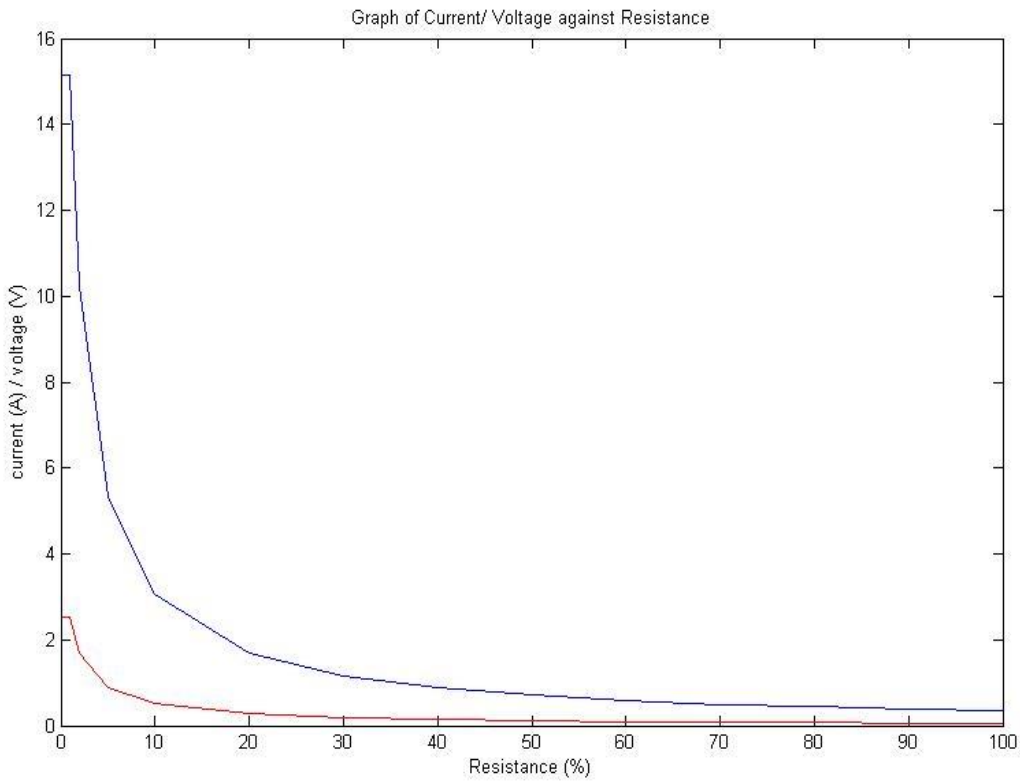


Figure5.1 Graph of current /Voltage against Resistance

A graph of line current against resistance drawn on matlab shows a trend of decrease in current as resistance increases. Little resistance means that the load has increased thus more current is drawn from the transformer. More resistance limits current flow, signifying reduced load. So as resistance is reduced by varying the rheostat, current increases up to a point where the relay trips the circuit. This confirms that the system has been designed well and thus it is able to read and record the current as it changes, and operate the switches at optimum current levels.

The ADC gave satisfactory results as expected. The input value from the sensor matches well with the displayed value on the LCD. For example a value of 3.07A displayed on the LCD corresponds to 0.51V from the sensor.

Proof

The value 3.07 calculated from the table will include the following bit values;
1.877+0.938+0.235+0.029=3.07
These values mean that the ADC bits were set as follows;
0001101001.
The above binary representation corresponds with the following sensor resolutions;

0.312+0.156+0.039+0.004=0.511
It can therefore be concluded that the ADC module has been well programmed.
It is also observed that during normal transformer operation, the green LED blinked. The normal operation range is between 0 and 15.132A. Within this range of, the relay contact remains intact, the buzzer remains quiet, the red LED remains off and the LCD displays varying current as the load current is varied from 0 – 20KΩ. The following figures illustrate the simulated device operation.

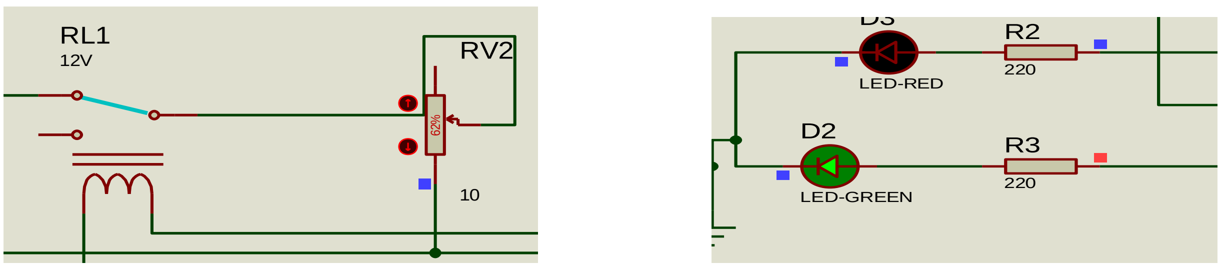


Figure5.2 Relay closed Green blinks

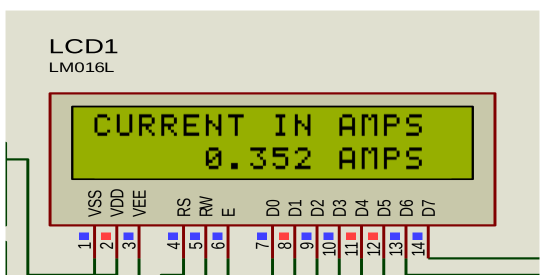


Figure5.3 LCD Display

Finally, it is observed that when the current is varied up to the pre-set level, of 15.015A, the relay, buzzer and the red LED are triggered. The buzzer sounds an alarm notifying the operators of the fault, the relay isolates the transformer from the system, the red LED blinks to signify that the current level is too much for the transformer to supply. The LCD displays a notification that there is an OVERCURRENT FAULT. The observations are as follows.

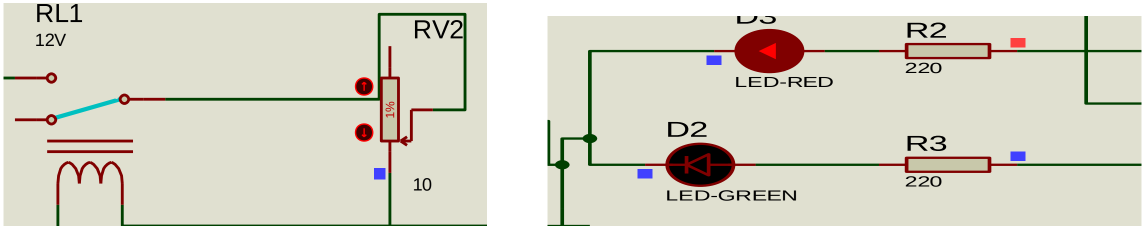


Figure5.4 Relay Open, Red LED blinking

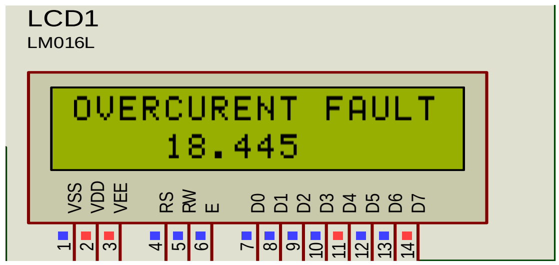


Figure5.5 Over current Fault

From the observations, the system achieves the function of an over-current relay that automatically detects over current fault and uses a microcontroller to record the fault, isolate the transformer from the affected zone and report the fault occurrence so that the system operator is aware that there is a problem. The advantage of this system over analogue over current relay is that it automatically recloses once the fault is cleared. The level of accuracy of the system is also super as compared to analogue operated over-current relay. To take care of inrush current, a delay of 255µSec x 4 has used. This delay allows the inrush phenomenon to clear so that the transformer comes back to normal operation before the relay starts its work.

5.3 Results after implementation

The following figures shows the outcome upon implementation on a breadboard.

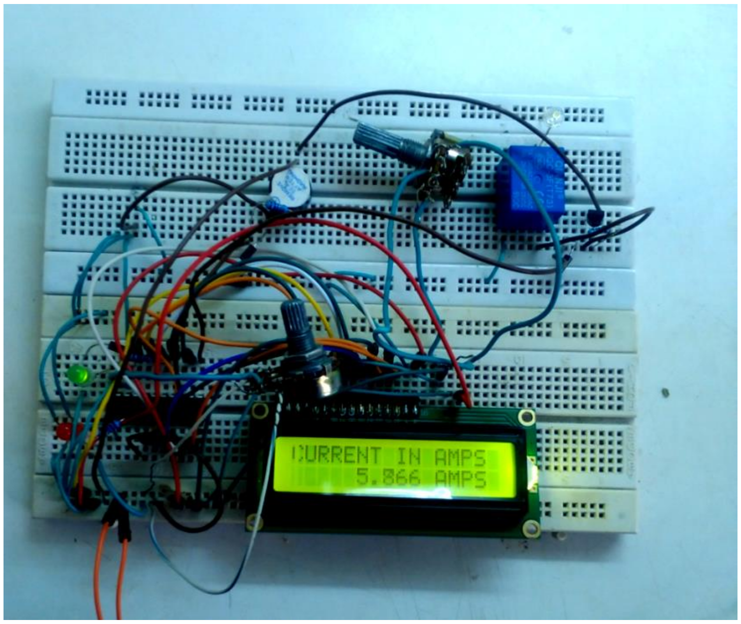


Figure5.6 Normal transformer operation

The figure 4.8 above shows the outcome when the transformer is operating under normal conditions. The LCD is operating normally and the green LED blinks to show that the system is responding accordingly. A 20KΩ variable resistor has been used as the load. Varying the resistor signifies the varying load connected to a transformer. The current reading on the LCD changes as the resistor is varied up to the preset fault point. The normal operation condition operates as expected and as depicted in the simulation.

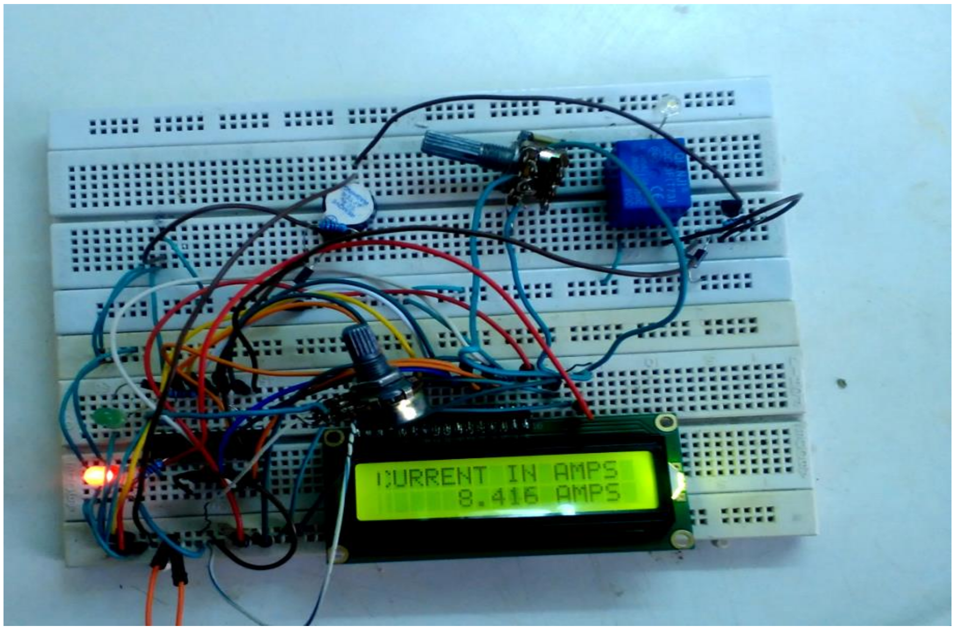


Figure5.7 current level approaching fault level

The system as shown in figure 4.9 shows the red LED blinking to warn that the load current is approaching the rated value of the transformer. This warning is triggered when the current exceed 7 - 8A. In actual power transformer protection, this visual warning would be triggered when the current circulating in the transformer is approaching the rated level.

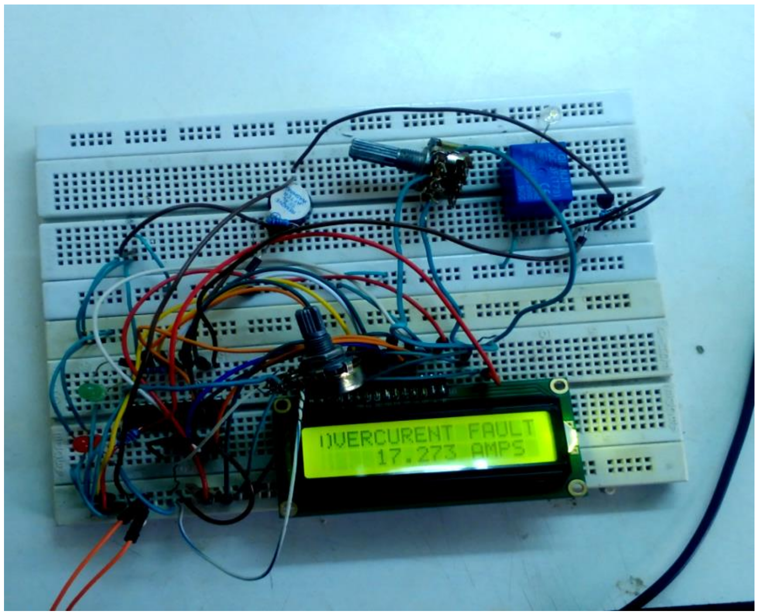


Figure5.8 Over current fault

The system as shown in the figure 5-0 above shows the LCD display when the current circulating in the transformer exceeds the rated value. The LCD displays “OVERCURRENT FAULT” and at the same time, the buzzer is activated to alert the system operator of the fault occurring in a given transformer. A signal is also sent to the relay to isolate the transformer from the power system. In this model, a relay and a contactor are used to carry out the process of transformer isolation from the system. The circuit design is in appendix A.

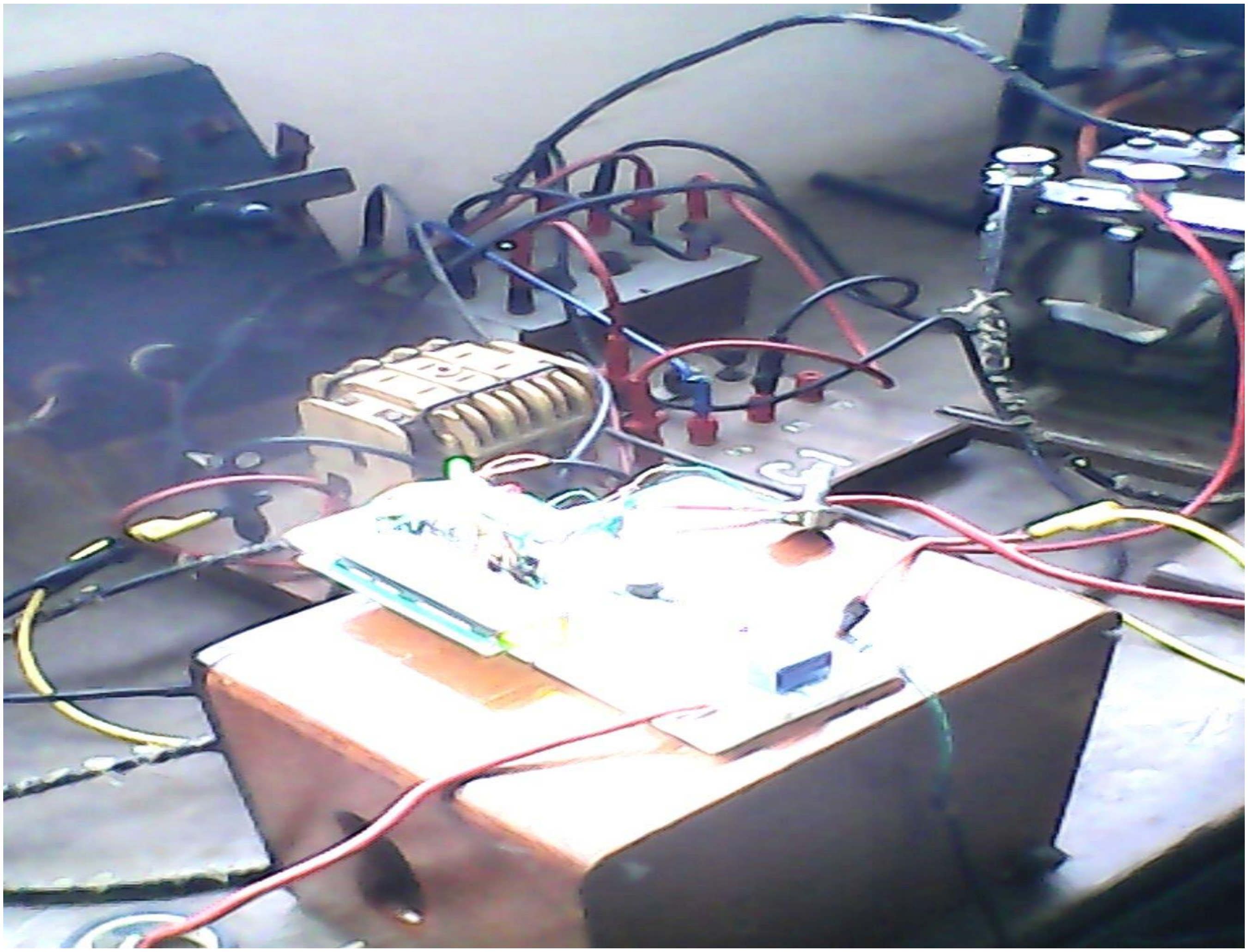


Figure5.9 Lab set up

CHAPTER 6: CONCLUSION and RECOMMENDATINS

The main objective if this project has been to design and implement a system that uses a microcontroller to protect a power transformer. This objective was achieved as the system works effectively. As the current circulating in the transformer coil varies, the LCD displays the readings. The relay is able to operate and isolate the transformer in case of an over current fault. The relay is the main switching element in the system. When energized, it opens its contacts and de-energizes the contactor thus isolating the transformer to safety in case of adverse current conditions. The other peripheral devices act as means of sending warning messages in case a fault occurs.

This system if put to use in power transformer protection can serve the purpose with greater advantages than the analogue over current relay. Its ability to automatically reclose the circuit after the fault is cleared warrants the system usability in remote areas that may be too far for an operator to reach easily and reconnect the transformer back to the supply line. The admirable fact about it is the accuracy with which it closes and recloses during either normal operation or fault occurrence.

Every customer desires to optimize the usage of a gadget yet at a low cost. The cost of implementing the system is relatively cheap as the components used are few and can be cheaply found in the market. The microcontroller can be used to drive multiple relays using the same program. The only thing that needs to be done is free more ports for multiple input and outputs. This will allow for more variables from different transformers and multiple outputs to different relays.

Owing to the fact that transformers are very important components of the electrical power system, their safety is paramount. Over current phenomenon can cause damage to transformers. Damage to a transformer puts interrupts electrical supply to consumers. Blackouts cause economic derailment and disorients consumers' work schedule. This explains why this system is needed and can help mitigate the effects of fault in a transformer.

In case an over current fault occurs, the power engineers should consider taking time to evaluate the possible cause of this phenomenon. For example, if there is an overload at the consumer end, there may be a call to install a new transformer that can withstand the increased load. The other mitigation option may be to add another supply line to the consumer so that the consumer demand is met.

This system comes with a power supply that can be directly plugged to 240V source and give the appropriate operating voltage. The 240V source can be easily cultivated in a power system line. It can be used in substations or in distribution trans

6.2 limitations and Future recommendations

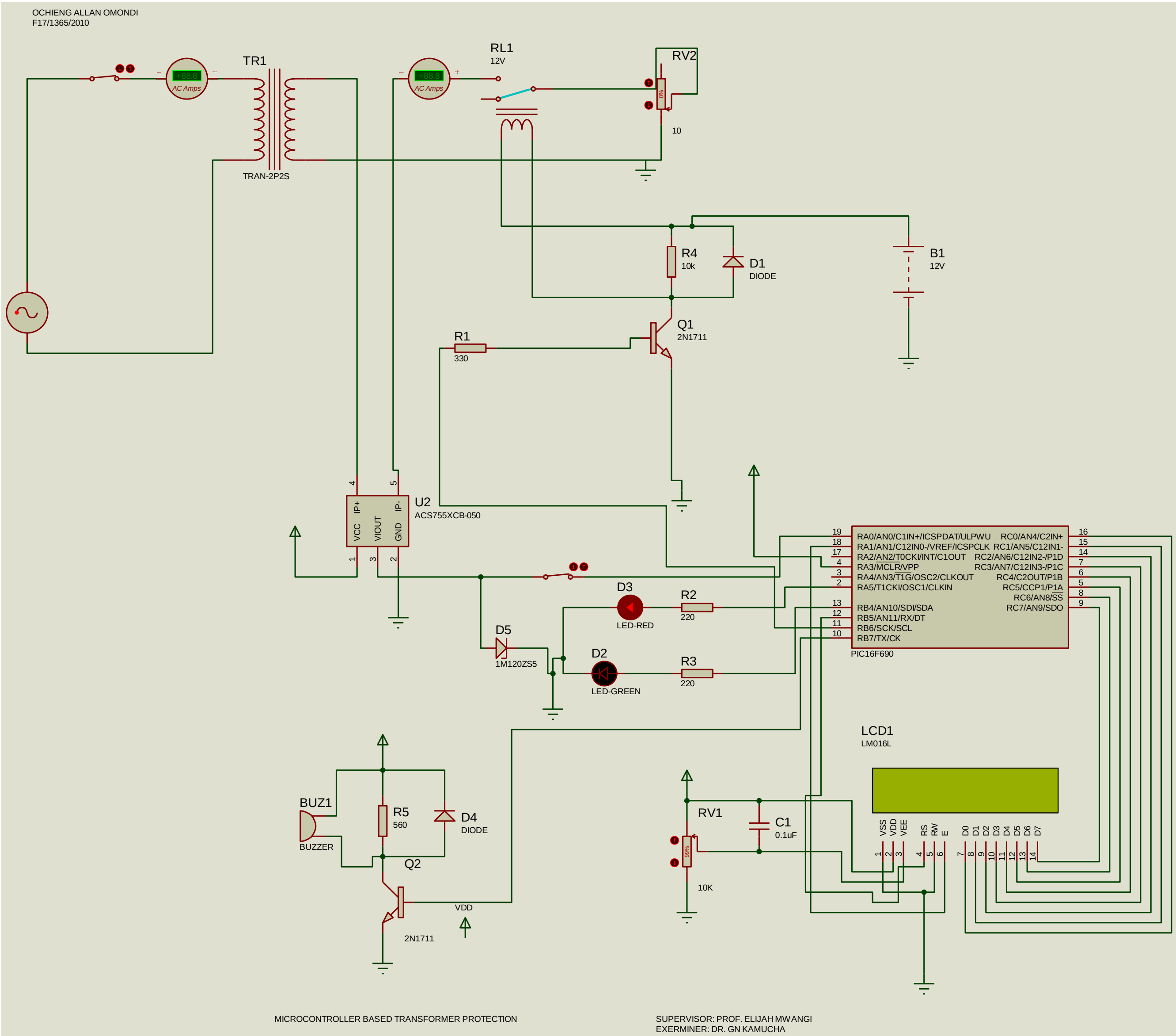
Transformer protection is a very crucial engineering principle. It is clear that the demand for electricity is increasing fast with increasing population and economic growth. This demands that more sophisticated transformer protection methods be used in the future in order to maintain a stable electrical power supply as will be demanded by the growing economy.

Based n the work done in this project, the future may demand that some improvements be made.

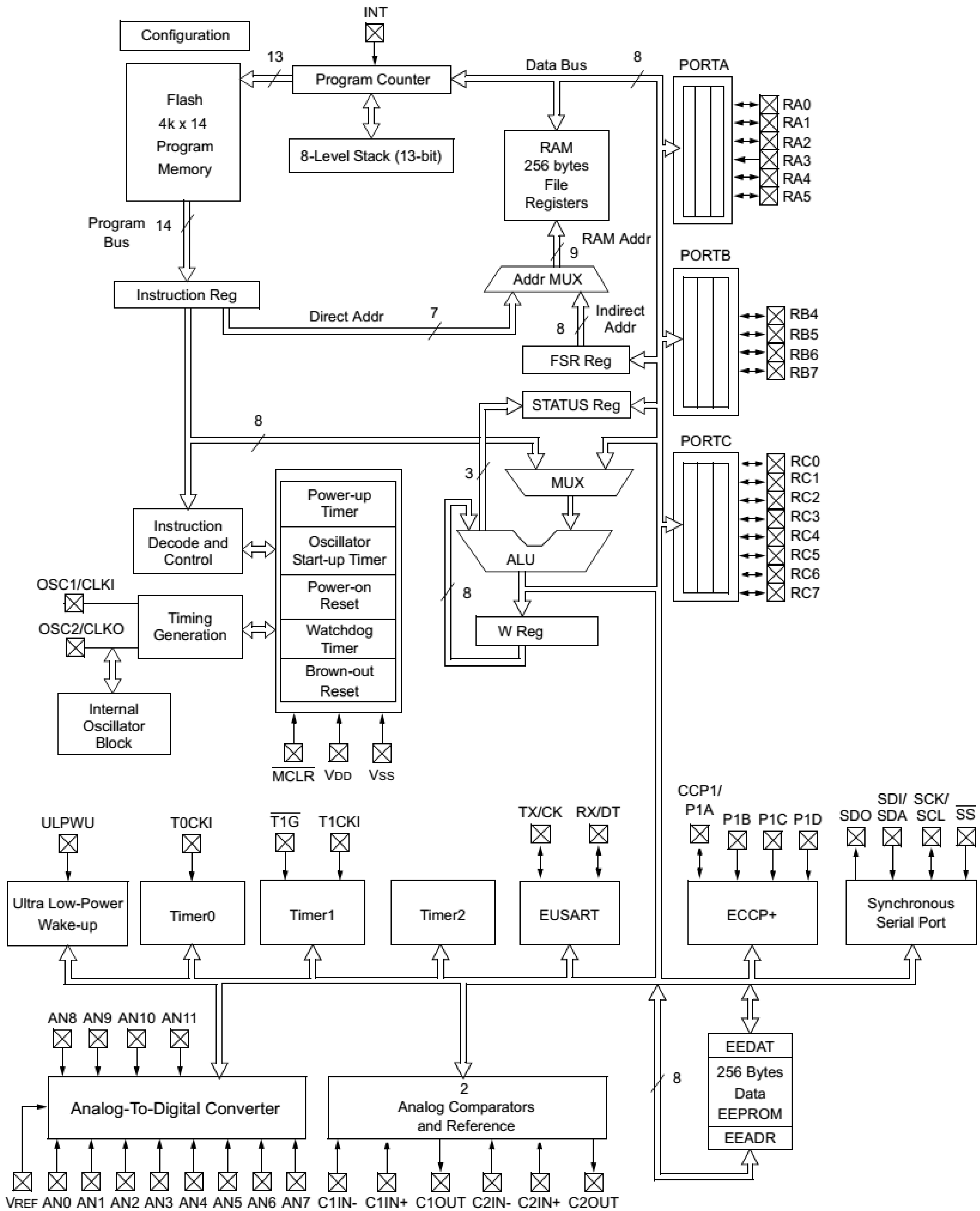
Some of the limitations faced in the design and future solutions include;

a) The current sensor does not offer a 100% sensing speed as needs some time do sense and transfer the signal to the microcontroller. A device with a faster sensing speed should be established.
b) Instead of using the relay as a switch, a semiconductor switching device such as a thyristor should be used.
c) Another limitation is that whereas the relay automatically recloses its contacts, the contactor used has to be restarted physically by an operator. Using a circuit that automatically recloses the system would be a great solution.
d) Lastly, the method of relaying the information to an operator in a control room far from the sub-station has not been explored in this project due to time constraint. An area for future study is how the system can automatically send a message to a control centre and notify the engineers of the exact location of a faulted transformer. A GSM module can be used in this case.

APENDIX A: Circuit Design



APENDIX B: PIC16F690 Architecture



Configuration
INT
13
Program Counter
Data Bus
8
PORTA
Flash
4k x 14
Program
Memory
8-Level Stack (13-bit)
RAM
256 bytes
File
Registers
RA0
RA1
RA2
RA3
RA4
RA5
Program
Bus
14
RAM Addr
9
PORTB
Addr MUX
Instruction Reg
Direct Addr
7
Indirect
Addr
8
RB4
RB5
RB6
RB7
FSR Reg
STATUS Reg
8
PORTC
3
MUX
RC0
RC1
RC2
RC3
RC4
RC5
RC6
RC7
Power-up
Timer
Instruction
Decode and
Control
Oscillator
Start-up Timer
ALU
OSC1/CLKI
Power-on
Reset
8
Timing
Generation
OSC2/CLKO
Watchdog
Timer
W Reg
Brown-out
Reset
Internal
Oscillator
Block
MCLR
VDD
VSS
CCP1/
P1A
ULPWU
T0CKI
T1G
T1CKI
TX/CK
RX/DT
P1B
P1C
P1D
SDO
SDI/
SDA
SCK/
SCL
SS
Ultra Low-Power
Wake-up
Timer0
Timer1
Timer2
EUSART
ECCP+
Synchronous
Serial Port
AN8
AN9
AN10
AN11
EEDAT
256 Bytes
Data
EEPROM
EEADR
8
2
Analog-To-Digital Converter
Analog Comparators
and Reference
VREF
AN0
AN1
AN2
AN3
AN4
AN5
AN6
AN7
C1IN-
C1IN+
C1OUT
C2IN-
C2IN+
C2OUT

APENDIX C: ASSEMBLY LANGUAGE

```
;****************************************
; Written by OCHIENG ALLAN OMONDI          *
; University of Nairobi                   *
; Electrical and Information department   *
;Reg No: F17/1365/2010
;Date: 2nd march, 2015
;For PIC16f690
;clock frequency: 4MHz
;****************************************
;TOPIC: A MICROCONTROLLER BASED TRANSFORMER PROTECTION
        List p = 16f690
        Include "P16F690.INC"
        __config _INTRC_OSC_NOCLKOUT & _WDT_OFF & _CP_ON &_MCLRE_OFF&_BOR_ON
;________________
;REGISTER DECLARATIONS
;________________
        CBLOCK 0x20
COUNTER         ;counter register
OUTPUTH         ;for storing  ADC values
OUTPUTL         ;for storing ADC values
Count           ;counter register
count1          ;counter register
counta          ;counter register
PDel0           ;for creating delay
PDel1           ;creating delay
DelayH          ;for creating delay
DelayL          ;for creating delay
Countb          ;count register
THOUSANDS       ;for storing thousands digit value
HUNDREDS        ;for storing hundreds value
TENS            ;for storing tens digit value
ONES            ;for storing ones digit value
FIRST_DEC       ;for storing first decimal  value
SEC_DEC         ;for storing second decimal value
THIRD_DEC       ;for storing third decimal value
        ENDC
;-----------------------------------------------------
        ORG 0H      ;first instruction at address 0
        GOTO START
        errorlevel -302

;____________________________________________
; LCD subprogram
;____________________________________________
LCDINIT
BCF STATUS,RP0      ;Ensure operation in bank 0
```

```
CALL Delay20   ;Time for LCD to power on

MOVLW b'00111000' ;start initialization 8 bit

CALL    Delay50 ;delay after LCD goes on

CALL     LCDcom          ;call LCD instructions

MOVLW 0Ch ;Display ON,cursor & blink OFF

CALL    LCDcom

MOVLW          0X02      ;takes cursor home

CALL    LCDcom

MOVLW 0x01               ;clear LCD display

CALL LCDcom

MOVLW b'00000110'       ;Increment display

CALL LCDcom


;--------------------------------------------------------

;FIRST ROW DISPLAY

;--------------------------------------------------------

ROW1

        CLRF    COUNTER

        clrf     count     ;set counter register to zero

        movlw   b'10000000'

        movwf   COUNTER

LINE1

        MOVF   COUNTER,W ; move to 1st row &
column

        call     LCDcom

        incf     COUNTER, f

        movf     COUNTER,W

        SUBLW    8FH  ;check characters

        BTFSC   STATUS,C  ;is there carry?

        GOTO    Message  ;NO? write

        GOTO    next  ;otherwise go to next

    Message

        Movf    count, w  ; move counter value into W
        CALL    Text      ;get character from text table

        CALL    CHAR_DISP

        XORLW 0x00      ;is it a zero?

        BTFSC   STATUS, Z  ;skip if zero bit clear

        GOTO    next ;otherwise go to next subroutine

        INCF     count, f  ;increment counter

        GOTO    LINE1    ;then go to line 1

next

        CLRF    COUNTER ;clear counter register

        movlw   0xCA    ;where next line begins

        movwf   COUNTER

        call       FIRST_LINE    ;write on second line

        MOVLW            " "

        CALL    CHAR_DISP

        MOVLW            "A"

        CALL CHAR_DISP

        MOVLW            "M"

        CALL CHAR_DISP

        MOVLW            "P"

        CALL CHAR_DISP

        MOVLW            "S"
```

```
                CALL    CHAR_DISP

                RETURN
;=======================================================================
;MAKING COMPARISON TO DETERMINE IF TO TRIGGER RELAY/BUZZER/LEDs
;-------------------------------------------------
COMPARE2
WARNING
        MOVF OUTPUTH,W
        SUBLW 40H ;compare register value to 40H
        BTFSC STATUS, C ;skip next if carry bit clear
        GOTO    NORMAL
        GOTO WARNING2
        RETURN
WARNING2
        MOVF    OUTPUTL,W
        SUBLW 0X00

        BTFSS   STATUS,C
        CALL    RED_BLINK ;buzzer and fan
        return
COMPARE
FAULT
        MOVF OUTPUTH,W
        SUBLW 80h
        BTFSS STATUS,C
        ;GOTO   NORMAL
        GOTO FAULT_ALERT
        RETURN
FAULT_ALERT
        MOVF    OUTPUTL,W
        SUBLW 00h

        BTFSS   STATUS,
        CALL    ALERT_CONTROL; buzzer/fan ON
        return
ALERT_CONTROL
        BCF PORTB, 4
        CALL        Delay255
        CALL        Delay255
        BSF PORTB,7   ;switches on buzzer
        BSF PORTB, 6 ;switches ON RELAY
        CALL        RED_BLINK0
        CALL        disp; display during fault
        return
disp
        CALL        DANGER
        CALL        Delay255   ;callDelay255
        MOVWF       0x01
        CALL        LCDcom   ;clear LCD
        CALL Delay255
        CALL ROW1
```

```
        CALL Delay255
    return
RED_BLINK0
    BCF     PORTB, 4
    BSF     PORTA, 5 ;red lights
    return
RED_BLINK
    BCF     PORTB, 4
    BSF     PORTA, 5
    CALL Delay50 ;Hold RED flash for 255msec
    BCF     PORTA, 5
    CALL Delay50
    return
;--------------------------------------------------------
; SUBROUTINE TO MAKE GREEN LED blink when
the current is within normal/rated value
;--------------------------------------------------------
NORMAL
    CLRF    PORTB
    CLRF    PORTA
    BSF     PORTB, 4
    CALL    Delay255
    BCF     PORTB, 4
    call    Delay255
    BCF     PORTB,7
    ;switch off buzzer
    BCF     PORTB, 6
    ;switches off Relay
```

```
    RETURN
DANGER
    CLRF    COUNTER
    CLRF    count                   ;set
counter register to zero
    MOVLW       b'10000000'
    MOVWF       COUNTER

LINE12
    MOVF    COUNTER,W ;1st row, 1ST column
    CALL    LCDcom
    INCF    COUNTER, f
    MOVF    COUNTER,W
    SUBLW       90H
    BTFSC   STATUS,C
    GOTO    Message2
    CALL Delay255
    CALL    Delay255
    CALL Delay255
    CALL    Delay255
        RETURN
Message2
    MOVF    count, w ;put counter value in W
    CALL    Text2 ;get character from text table
    CALL    CHAR_DISP
    XORLW0x00 ;is it a zero?
    BTFSS   STATUS, Z
    INCF    count, f
```

```
                    GOTO    LINE12
Text2
                     ADDWF           PCL, F
                     DT "OVERCURENT FAULT"

                     RETURN



;========================================
=============================
;WRITING THE CHARACTER TO LCD
;---------------------------
CHAR_DISP
          MOVWF            PORTC
          BSF       PORTB,5;set both RS and E
          BSF       PORTA,1            ;set E
          CALL    Delay5
          BSF                   PORTB,5 ;set RS
          BCF                   PORTA,1 ;clear E
          CALL    Delay5
          RETURN
;========================================
=============================
FIRST_LINE
          MOVF   COUNTER,W      ;move to 1st row,
first column
          call       LCDcom
          return
```

```
;========================================
=============================
;GIVING INSTRUCTIONS TO LCD
;---------------------------
LCDcom
     movwf         PORTC
     bcf  PORTB, 5    ; (4) Write instruction to display
          call         Delay5
     bsf  PORTA,1     ; (5) enable
     call Clock
     bcf  PORTA,1     ; (5)
     CALL          Clock
          CLRF     DelayL
          movlw    08h ; about 6mS delay @ 4MHz
          movwf    DelayH
DELOOP
          NOP    ;small delay
          NOP
          NOP
          DECFSZDelayH,f
          GOTO    DELOOP
     return
;=================================
;RELAY, BUZZER AND LED WARNING
;================================
```

```
;=======================================
=======================

;DELAYS at 4MHz

;---------------------------

Delay255      movlw   0xff    ;delay 255 mS
              goto    d0
Delay100      movlw   d'100'  ;delay 100mS
              goto    d0
Delay50       movlw   d'50'   ;delay 50mS
              goto    d0
Delay20       movlw   d'20'   ;delay 20mS
              goto    d0
Delay5        movlw   0x05 ;delay 5.000ms
d0            movwf   count1
d1            movlw   0xC7    ;delay 1mS
              movwf   counta
              movlw   0x01
              movwf   countb
Delay_0
              decfsz  counta, f
              goto    $+2
              decfsz  countb, f
              goto    Delay_0

              decfsz  count1  ,f
              goto    d1
              return
```

```
; -----------------------------

; CLOCKING DELAY - 64uS @ 4MHz

; -----------------------------

Clock   movlw 40h
        movwf DelayL
STEP    decfsz DelayL,f
    GOTO      STEP
     return

;=======================================
======

;TEXT TO DISPLAY

;=======================================
======

Text
                ADDWFPCL, f
                DT "CURRENT IN AMPS:"
                RETURN

;<><><><><><><><><><><><><><>

;MAIN PROGRAM                  <>

;<><><><><><><><>><>><><>

START
                ;clear all the ports
        BCF STATUS,RP0 ;select register bank 0
        BCF STATUS,RP1
        CLRF PORTA  ;clear all the ports
        CLRF PORTB
        CLRF PORTC
```

```
        BSF STATUS,5    ;select register bank 1

        MOVLW B'00000001'       ;setup port A (
RA0=input,RA1-2=Output )

        MOVWF TRISA

        MOVLW .0        ;setup port b

        MOVWF TRISB

        CLRF TRISC      ;PortC is output

        MOVLW  b'01101000'      ;internal oscillator

        MOVWF           OSCCON

        BCF STATUS,RP0


                CALL LCDINIT

CURRENT         call CURRENT_DISPLAY

                CALL COMPARE2

                CALL COMPARE

                goto CURRENT


;________________________________

;ADC CONVERSION

;________________________________

ADC_conv

        BSF STATUS,RP0                  ;Bank 1

        MOVLW b'01010000'
        ;ADC clock at 4MHz/16(Tad=4.0us)

        MOVWF ADCON1                    ;

        BSF TRISA,0             ;Set RA0 to input

        BCF STATUS,RP0                  ;Bank 2

        BSF STATUS,RP1                  ;

        BSF ANSEL,0     ;Set RA0 to analogue

        BCF STATUS,RP0          ;Bank 0

        BCF STATUS,RP1

        MOVLW 0x01  ;Vdd Vref (bit 6), AN0 (0000
of bit 5-2), On (bit 0)

        MOVWF ADCON0 ;also LEFT JUSTIFY

        CALL Clock      ;sampling time

        BCF STATUS,RP1          ;BANK 0

        BCF STATUS,RP0

        BSF ADCON0,GO  ;Start conversion

        BTFSC ADCON0,GO  ;Is conversion done?

        GOTO $-1        ;No, test again

        ;STORING THE RESULTS

        MOVF ADRESH,W ;Read upper 8 bits

        MOVWF OUTPUTH

        BANKSEL   ADRESL

        MOVF ADRESL,W  ;Read lower 2 bits

        BCF STATUS,RP1   ;BANK 0

        BCF STATUS,RP0

        MOVWF OUTPUTL

        BCF STATUS,RP0     ;Bank 0

        return

;BCD CONVERSION


;------------------------------------------------------

;DISPLAY THE CURRENT LEVEL

;------------------------------------------------------
```

```
CURRENT_DISPLAY
	CALL ADC_conv ;Get the value from the conversion
CONVERT
	CLRF	THOUSANDS
	CLRF	HUNDREDS
	CLRF	TENS
	CLRF	ONES
	CLRF	FIRST_DEC
	CLRF	SEC_DEC
	CLRF	THIRD_DEC
;WEGHT OF BIT9 = 15.015
BIT9
	BTFSS	OUTPUTH, 7
	GOTO	BIT8
	MOVLW		.1
	ADDWF	TENS, F
	MOVLW		.5
	ADDWF	ONES, F
	MOVLW		.1
	ADDWF	SEC_DEC, F
	MOVLW		.5
	ADDWF	THIRD_DEC, F

;WEIGHT FOR BIT8 = 7.507
BIT8
	BTFSS	OUTPUTH,6
	GOTO	BIT7
	MOVLW		.7
	ADDWF	ONES, F
	MOVLW		.5
	ADDWF	FIRST_DEC,F
	MOVLW		.7
	ADDWF	THIRD_DEC, F

;WEIGHT FOR BIT7 = 3.754
BIT7
	BTFSS	OUTPUTH,5
	GOTO	BIT6
	MOVLW		.3
	ADDWF	ONES, F
	MOVLW		.7
	ADDWF	FIRST_DEC,F
	MOVLW		.5
	ADDWF	SEC_DEC,F
	MOVLW		.4
	ADDWF	THIRD_DEC, F

;WEIGHT FOR BIT6 = 1.877
BIT6
	BTFSS	OUTPUTH,4
	GOTO	BIT5
	MOVLW		.1
	ADDWF	ONES,F
```

```
        MOVLW       .8
        ADDWFFIRST_DEC, F
        MOVLW       .7
        ADDWFSEC_DEC, F
        MOVLW       .7
        ADDWFTHIRD_DEC, F

;WEIGHT FOR BIT5 = 0.938
BIT5
        BTFSS   OUTPUTH,3
        GOTO    BIT4
        MOVLW       .9
        ADDWFFIRST_DEC,F
        MOVLW       .3
        ADDWFSEC_DEC, F
        MOVLW       .8
        ADDWFTHIRD_DEC, F

;WEIGHT FOR BIT4 = 0.469
BIT4
        BTFSS   OUTPUTH,2
        GOTO    BIT3
        MOVLW       .4
        ADDWFFIRST_DEC, F
        MOVLW       .6
        ADDWFSEC_DEC, F
        MOVLW       .9
        ADDWFTHIRD_DEC, F

;WEIGHT FOR BIT3 = 0.235
BIT3
        BTFSS   OUTPUTH,1
        GOTO    BIT2
        MOVLW       .2
        ADDWFFIRST_DEC, F
        MOVLW       .3
        ADDWFSEC_DEC, F
        MOVLW       .5
        ADDWFTHIRD_DEC, F

;WEIGHT FOR BIT2 = 0.117
BIT2
        BTFSS   OUTPUTH,0
        GOTO    BIT1
        MOVLW       .1
        ADDWFFIRST_DEC, F
        MOVLW       .1
        ADDWFSEC_DEC, F
        MOVLW       .7
        ADDWFTHIRD_DEC,     F

;WEIGHT FOR BIT1 = 0.059
BIT1
        BTFSS   OUTPUTL,7
```

```
	GOTO	BIT0
	MOVLW		.5
	ADDWF	SEC_DEC,F
	MOVLW		.9
	ADDWF	THIRD_DEC,F

;WEIGHT FOR BIT0 = 0.029
BIT0
	BTFSS	OUTPUTL,6
	GOTO	MODIFY
	MOVLW		.2
	ADDWF	SEC_DEC,F
	MOVLW		.9
	ADDWF	THIRD_DEC,F

;MODIFY EACH REGISTER FOR DISPLAY
MODIFY
	MOVLW		.10
;Adjusting third decimal place
	INCF	SEC_DEC, F
	SUBWF	THIRD_DEC, F
	BTFSC	STATUS, C
	GOTO	$-3
;At this point it has gone beyond zero thus SEC-DEC has extra value
	DECF	SEC_DEC, F
	ADDWF	THIRD_DEC, F

	MOVLW		.10
;Adjusting second decimal place
	INCF	FIRST_DEC, F
	SUBWF	SEC_DEC, F
	BTFSC	STATUS, C
	GOTO	$-3
;At this point it has gone beyond zero thus FIRST-DEC has extra value
	DECF	FIRST_DEC, F
	ADDWF	SEC_DEC, F

	MOVLW		.10
;Adjusting FIRST decimal place
	INCF	ONES, F
	SUBWF	FIRST_DEC, F
	BTFSC	STATUS, C
	GOTO	$-3
;At this point it has gone beyond zero thus ONES has extra value
	DECF	ONES, F
	ADDWF	FIRST_DEC, F

	MOVLW		.10
;Adjusting ONES place
	INCF	TENS, F
	SUBWF	ONES, F
	BTFSC	STATUS, C
```

```
	GOTO	$-3
;At this point it has gone beyond zero thus TENS has extra value
	DECF	TENS, F
	ADDWF	ONES, F

	MOVLW		.10
;Adjusting TENS place
	INCF	HUNDREDS, F
	SUBWF	TENS, F
	BTFSC	STATUS, C
	GOTO	$-3
;At this point it has gone beyond zero thus HUNDREDS has extra value
	DECF	HUNDREDS, F
	ADDWF	TENS, F


;COVERTING THEM TO ASCII and DISPLAYING THE VALUES
	MOVLW		0x30
	ADDWF	ONES,F
	ADDWF	FIRST_DEC,F
VALUE
	MOVLW		0XC3
	CALL	LCDcom
	MOVF	HUNDREDS,W
	BTFSC	STATUS, Z		; if not zero
	GOTO	BLANK
	GOTO	WRITE1
BLANK
	MOVLW " "
; otherwise put in a space
	CALL CHAR_DISP
	GOTO	STEP2

WRITE1
	MOVF	HUNDREDS,W
	ADDLW	30H
	CALL CHAR_DISP
STEP2
	MOVLW		0XC4
	CALL	LCDcom
	MOVF	TENS,W
	BTFSC	STATUS, Z		; if not zero
	GOTO	BLANK2
	GOTO	WRITE2

BLANK2
	MOVF	HUNDREDS,W
	BTFSC	STATUS, Z		; if not zero
	GOTO	SPC
	GOTO	WRITE2
SPC
	MOVLW		" "
; otherwise put in a space
	CALL	CHAR_DISP
```

```
        GOTO    STEP3
WRITE2
        MOVF    TENS,W
        ADDLW30H
        CALL CHAR_DISP
STEP3
        MOVLW           0XC5
        CALL    LCDcom
        MOVF    ONES,W
        CALL CHAR_DISP
        MOVLW           0XC6
        CALL    LCDcom
        MOVLW "."
        CALL CHAR_DISP
        MOVLW           0XC7
        CALL    LCDcom
        MOVF    FIRST_DEC,W
        CALL CHAR_DISP

        MOVLW           0XC8
        CALL    LCDcom
        MOVF    SEC_DEC,W
        BTFSC   STATUS, Z       ; if not zero
        GOTO    BLANK3
        GOTO    WRITE3
BLANK3
        MOVF    THIRD_DEC,W
        BTFSC   STATUS, Z       ; if not zero
        GOTO    SPC1
        GOTO    WRITE3
SPC1
        MOVLW           " "
        ; otherwise put in a space
        CALL    CHAR_DISP
        GOTO    STEP4
WRITE3
        MOVLW           0XC8
        CALL    LCDcom
        MOVF    SEC_DEC,W
        ADDLW30H
        CALL CHAR_DISP

STEP4
        MOVLW           0XC9
        CALL    LCDcom
        MOVF    THIRD_DEC,W
        BTFSC STATUS, Z         ; if not zero
        GOTO    BLANK4
        GOTO    WRITE4

BLANK4
        MOVLW " "
        ; otherwise put in a space
        CALL CHAR_DISP
        GOTO    FINISH
```

```
WRITE4
        MOVLW   0XC9
        CALL    LCDcom
        MOVF    THIRD_DEC,W
        ADDLW   30H
        CALL CHAR_DISP
FINISH
        RETURN
        END                 ;End of program
```

APENDIX D: Bill of Materials

Components	Quantity	Cost(Ksh)
PIC16F690	1	450
16x2 LCD	1	800
Relay	1	100
transistors	2	50
resistors	5	25
Buzzer	1	50
LEDs	2	20
PCB	1	1200
Diodes	2	20
Current sensor	1	700
potentiometer	1	30
TOTAL COST		3425

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