OVER CURRENT PROTECTION RELAY USING PIC MICRO CONTROLLER

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JUDUL: **OVER CURRENT PROTECTION RELAY USING PIC MICROCONTROLLER**

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This report is submitted as partial fulfillment of the requirement for the award of the Bachelor Degree of Electrical Engineering (Power System)

Faculty of Electrical & Electronics Engineering
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DECLARATION

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Specially dedicated to my beloved family and those people who
have guided and inspired me throughout my journey of education

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ABSTRACT

Power system protection is the most important requirement before the power system is put into operation. Electrical energy have caused dangers both human and machines. Protection system is mostly controlled by the protection relay. It is the brain of the protection system that monitors input from it sensor as current transformer signals the circuit breaker to open high voltage/current circuits. Over current protection is widely applied at all voltage levels to protect lines, transformer, generators, and motors. Power system protection can be implemented at various stages and various types of protection devices. Industrial operation requires continuous stable power for its operation. The over current relay will serve the purpose on the other hand to protect the system. This project will attempt to design and fabricate over current protection relay using PIC micro controller. The PIC micro controller will cause the circuit breaker to trip when the current from load current reaches the setting value in the PIC micro controller. In order to design it, first the load current need to measure in order to monitor it using current sensor including testing the fault (over current) and when such condition arise, it will isolate in the shortest time possible without harming the any other electrical devices. It will also including in developing the algorithm for instantaneous over current relay and IDMT (Inverse Definite Minimum Time) relay for the circuit breaker to trip. In this project, PIC microcontroller will be used to control and operate the tripping coil in circuit breaker.

ABSTRAK

Perlindungan sistem kuasa adalah keperluan yang paling penting sebelum ia dimasukkan ke dalam operasi. Tenaga elektrik telah menyebabkan bahaya kedua-dua manusia dan mesin-mesin. Sistem perlindungan adalah kebanyakannya dikuasai oleh geganti perlindungan. Ia adalah otak sistem perlindungan yang merasa daripada penderia sebagai isyarat-isyarat pengubah arus pemutus litar untuk membuka voltan tinggi / litar-litar semasa. Sistem perlindungan digunakan dengan meluas untuk melindungi baris-baris, penukar, generator-generator, dan motor-motor. Perlindungan sistem kuasa boleh dilaksanakan pada pelbagai peringkat dan pelbagai perlindungan peranti. Operasi perusahaan memerlukan kuasa stabil yang berterusan untuk operasinya. Geganti semasa akan berkhidmat untuk tujuan itu dan pada masa yang sama untuk melindungi sistem itu. Projek ini akan cuba mereka bentuk sistem geganti perlindungan menggunakan mikro pengawal PIC. Mikro pengawal PIC akan menyebabkan pemutus litar putus apabila arus elektrik melebihi nilai yang ditetapkan dalam mikro pengawal PIC. Untuk mereka bentuknya, pertama sekali arus elektrik mesti diukur pada masa yang sama untuk memerhatinya menggunakan penderia termasuk menguji kesalahan (arus elektrik lebih) dan bila keadaan itu wujud, ia akan memutuskan litar elektrik dalam masa terpantas tanpa membahayakan alat-alat elektrik yang lain. Ia juga termasuk dalam memajukan algoritma untuk geganti serta-merta dan Masa Minimum Yang Songsang (IDMT) untuk memutuskan litar elektrik. Dalam projek ini, mikro pengawal PIC akan digunakan untuk mengawal dan beroperasi lingkaran dalam pemutus litar elektrik.

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LIST OF ABBREVIATIONS

DC	-	Direct Current
AC	-	Alternate Current
CT	-	Current Transformer
TMS	-	Time Multiplier Setting
VCB	-	Vacuum Circuit Breaker
ACB	-	Air Circuit Breaker
MCCB	-	Moulded Case Circuit Breaker
PCB	-	Printed Circuit Board
GUI	-	Graphical User Interface
PIC	-	Programmable Intelligent Computer
IDMT	-	Inverse Definite Minimum Time
LCD	-	Liquid Crystal Display

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CHAPTER 1

INTRODUCTION

1.1 Background

Electrical Power System protection is required for protection of both user and the system equipment itself from fault, hence electrical power system is not allowed to operate without any protection devices installed. Power System fault is defined as undesirable condition that occurs in the power system. These undesirable conditions such as short circuit, current leakage, ground short, over current and over voltage.

With the increasing loads, voltages and short-circuit duty in distribution system, over current protection has become more important today. The ability of protection system is demanded not only for economic reason but also consumers just expect 'reliable' service. In a Power System Protection, the system engineer would need to a device that can monitor current, voltage, frequency and in some case over power in the system. Thus a device called Protective Relay is created to serve the purpose. The protective relay is most often relay coupled with Circuit Breaker such that it can isolate the abnormal condition in the system. In the interest of reliable and effective protection, some designers of power distribution/power controllers select relay as opposed to electro-magnetic circuit breakers as a method of circuit protection.

1.2 Overview of Over Current Relay Project

An "Over Current Relay" is a type of protective relay which operates when the load current exceeds a preset value. In a typical application the over current relay is used for over current protection, connected to a current transformer and calibrated to operate at or above a specific current level.

This project will attempt to design and fabricate over current protection relay using PIC micro controller. The PIC micro controller will cause the circuit breaker to trip when the current from load current reaches the setting value in the PIC micro controller.

In order to design it, first the load current need to measure in order to monitor it using current sensor including testing the fault (over current) and when such condition arise, it will isolate in the shortest time possible without harming the any other electrical devices. It will also including in developing the algorithm for instantaneous over current relay and IDMT (Inverse Definite Minimum Time) relay for the circuit breaker to trip. In this project, PIC microcontroller will be used to control and operate the tripping coil in circuit breaker.

1.3 Objective

The objectives of this project are;

I. To design and fabricate over current protection relay using PIC micro controller which can operate on the permissible conditions by setting the over current value.

II. To test unwanted conditions (over current) and when such conditions arise to isolate the fault condition in the shortest time possible.

III. To investigate IDMT curve characteristic.

1.4 Scope of Project

The scopes of the project are;

i. To measure and analyze load current from current sensor.
   - The load current (energizing current) will be measured by using current sensor and converted from analog voltage to digital using PIC16F877A. Then the load current will display on the LCD.

ii. Trip circuit breaker using PIC microcontroller.
   - The over current value is set in the PIC and when faults (over current) occur, PIC will energize the circuit breaker tripping coil which will cause the circuit breaker to trip.

iii. Develop algorithm for instantaneous over current relay and IDMT relay.
   - The over current setting may be given by definite time or inverse definite minimum time (IDMT) characteristic. There are four curves for over current complying with the IEC 255 and are named ‘Normal Inverse’, ‘Very Inverse’, ‘Extremely Inverse’ and ‘Long Time Inverse’. This project is to develop the ‘Long time Inverse’ characteristic of IDMT.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Introduction

This chapter will discuss the study about significant parts of protection system such as the important of protection system, protection devices, types of protection system and protection relay. It also includes the PIC Microcontroller which is ‘the brain’ for this over current protection relay.

2.2 What Is Over Current

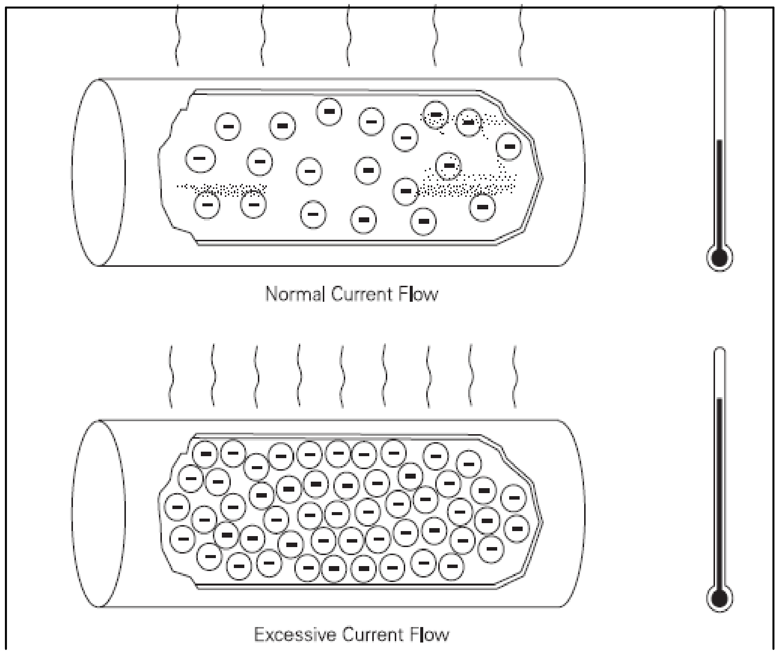


Figure 2.1: Over Current Flow

The National Electrical Code defines over current as any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault. Current flow in a conductor always generates heat. The greater the current flow, the hotter the conductor. Excess heat is damaging to electrical components. For that reason, conductors have a rated continuous current carrying capacity or ampacity. Over current protection devices are used to protect conductors from excessive current flow. These protective devices are designed to keep the flow of current in a circuit at a safe level to prevent the circuit conductors from overheating [4].

2.3 Why Protection System Is Important

Fault impose hazard to both user and the system itself and when it comes to user, life is the concern and when it concern the system it is merely to provide stable electrical power system on top of that prevent damage to the expensive equipment used. In summary, the needs of power protection are [1]:

Table 2.1: Power System Protection Area

User/Personnel Safety	Prevent injury and accident.
Equipment	Safe guard the equipment from over current, over voltage and frequency drift that can cause damage
General Safety	Prevent secondary accident that result from power system fault such as fire
Power Supply Stability	Ensure that continuous and stable electrical power supplied by the system/grid
Operation Cost	Ensure that the system is operating at optimal efficiency and reduce equipment maintenance and replacement cost

Shock Phenomenon is almost similar to electrocution. High voltage above 500V can cause human skin rupture. The effect of this is the decrease of human body resistance. In certain condition, the resistance may drop down to about 500Ω. At 500V from Ohms law,

$I=V/R$ therefore,

$I=500/500 = 1A$

Typically 16mA is considered hazardous to human. The following table shows the effect of current on human at 60Hz, AC. [2]

Table 2.2: Effect of Live Current on Human

Current	Effect on Human
1 mA	Barely perceptible
16 mA	Maximum current an average man can grasp and "let go"
20 mA	Paralysis of respiratory muscles
100 mA	Ventricular fibrillation threshold
2 Amps	Cardiac standstill and internal organ damage
15/20 Amps	Common fuse or breaker opens circuit

2.4 Power System Protection Devices

The idea of power protection system is to isolate the fault in the shortest time possible. Once fault occurs, the isolation part takes place by opening or disconnecting the circuit at the fault section. Almost all protection devices will act automatically when fault occurs but that doesn’t mean it will protect the electrical equipments. Relay is the most common device that can actually serve the problems. Relay is a device which disconnects the circuit when there is input (to relay). Relay can be dividing into three major types;

- **Instantaneous (Instant reaction)**

  Instantaneous over current protection is considered the simplest protection scheme. It is widely used because of its quick reaction time.

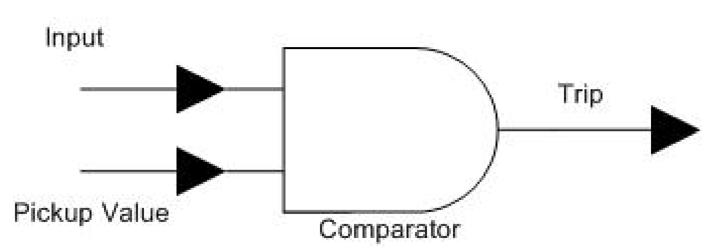


Figure 2.2: Logic diagram of instantaneous over current scheme

The relay pick up value is commonly set to a value anywhere between 125-135% of the maximum load current and 90% of the minimum fault current. These values help to minimize unnecessary responses from the relay. The Following formula is used to calculate the pick up value [5]:

$$1.2\times \text{Max load current} \leq \text{Pick up value} \leq 0.9\times \text{Min fault current} \quad [5]$$

- **Time Delay (Tripping will only occurs after certain settable time)**

  There are two settings that must be applied to all time-delay over current relays: 1) the pickup value and 2) the time delay. Time relays over current are designed to produce high operation at high current slow operation at low current; hence, an inverse time characteristic. Relays from different manufactures may have different inverse time characteristics. In order to use these inverse time characteristics, you must first calculate the following:

  "Multiples of pickup values" = fault current / pick up value [5]

- **Numerical Relay (Static relay uses microprocessor and operate based on numerical method calculation)**

  Numerical relay is a special type of digital relay that actually uses the capability of the modern microprocessor to actually calculate the fault value and perform analysis such as Fourier Analysis on the fault data before even making decision to trip the system or not. Numerical Relay also usually has the capability to record the faults value for analysis. Most often these relays are also equipped with communication port that allow maintainer to download information form the relay after the fault has occurs or just for system health analysis purposes [2].

		
Microprocessor Base Relay	Time Delay Relay	Numerical Relay

Figure 2.3: Types of protection relay

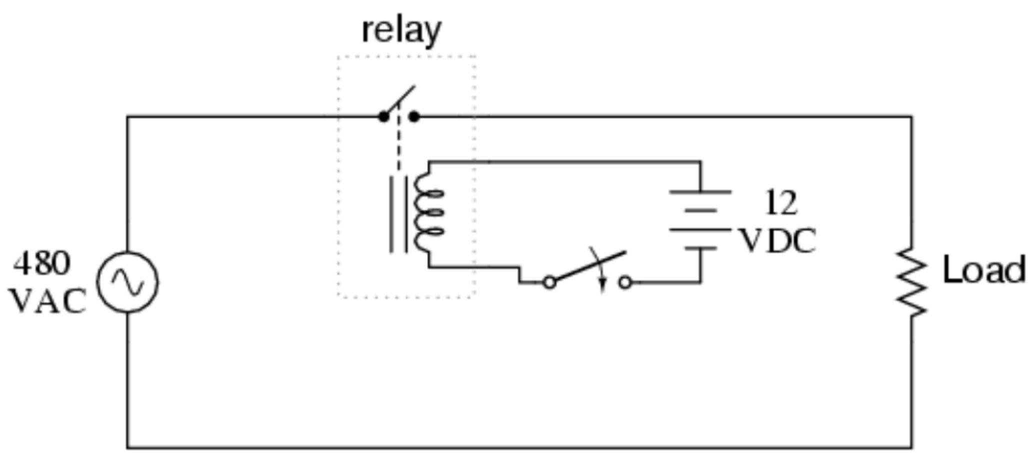


Figure 2.4: Basic principle operation of a relay

Figure 2.3 shows the basic principle of a relay and how it would be used in electrical circuit. The high voltage is connected to the load via the relay such that automatic disconnection of the load can happen in the case of fault occurrences.

Relay is a passive device that can only be ON or OFF state by default. As such it does not actually know if when it should start to operate and when it should not. Active device that can actually "see" or sense the fault is required to instruct the relay on what to do. These devices are then connected to the relay input to make a mini protection scheme that can actually monitor faults and take necessary action.

To be able to do a good job, the protection scheme should be able to eliminate the fault condition on the smallest portion of the circuit in the shortest time possible. [2]

2.5 Types of Protection System

Power protection system can be implemented into two ways which are 'non-unit schemes' and 'unit schemes'.

2.5.1 Non-Unit Protection

The Non-Unit protection scheme work on the system and it might overlap with another protection device in the systems. The use of this mode of protection is usually to isolate the whole circuit when a fault occurs. [2]

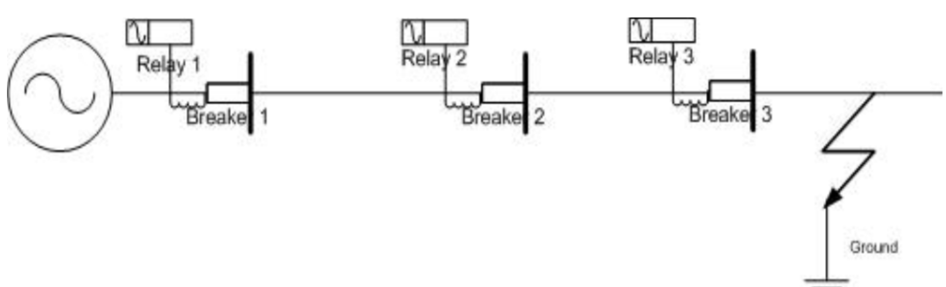


Figure 2.5: One line diagram typical non-unit protection

There are three protection relays installed in this system for the protection. If instantaneous relay is use, fault occurring at 3 will cause the whole system to trip because relay 1 and 2 also can see the fault. If IDMT (Inverse Definite Minimum Time) is use, the relay will isolate in the smallest section which in 3. Note that relay at 2 will trigger after several settable times and take over (isolate) the fault if relay at 3 fail to isolate the fault. The advantage of this system is it has the backup capability and it guarantee that the fault will be removed by at least one of the protection relay.

2.5.2 Unit Protection

The main purpose of the unit protection scheme is to protect a defined or discrete zone of location that is usually the zone bounded by the 2CT used for differential current measurement. Relay used in Unit Protection scheme are usually Differential Protection relay [2]. The protection system should be designed to satisfy the following requirements:

1) Under normal conditions the breakers are not tripped
2) Under fault conditions only the breaker closest to the fault will trip
3) If the closest breaker fails to operate, then the next breaker closest to the fault will trip [5].

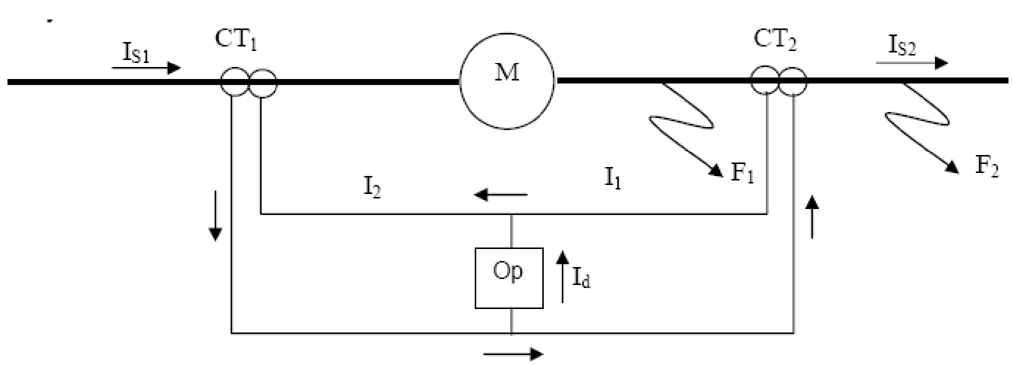


Figure 2.6: Differential fault current measurement

The figure above shows the operation of a unit protection. The two CT is used to measure the incoming and outgoing current into the protected load M. Under normal operating condition, I_{S1} will be equal to I_{S2}, therefore, $I_1 = I_2$, thus result in I_d=0. However, when $I_1 \neq I_2$ (Fault at F1), then Id will have the value of I_1-I_2. The current is then detected by the relay that will then cause trip in the system. For this protection scheme, if the fault occurs at F2, the protection system will not be able to detect the fault because it is happening outside the protection zone of the system.

Figure 2.7: Type SPAJ 140C Over current and Earth Fault Relay

2.5.3 Inverse Time Over current Protection

In a system for which the fault current is practically determined by the fault location, without being substantially affected by changes in the power source impedance, it is advantageous to use inverse definite minimum time (IDMT) over current protection. This protection provides reasonably fast tripping, even at a terminal close to the power source where the most severe faults can occur [8].

The inverse time over current protection elements have the IDMT characteristics defined by equation;

$$t = TMS \times \left\{ \left[\frac{k}{\left(\frac{I}{Is} \right)^{a} - 1} \right] + c \right\}$$

Where:

t = operating time for constant current I (seconds),

I = energizing current (amps),

Is = over current setting (amps),

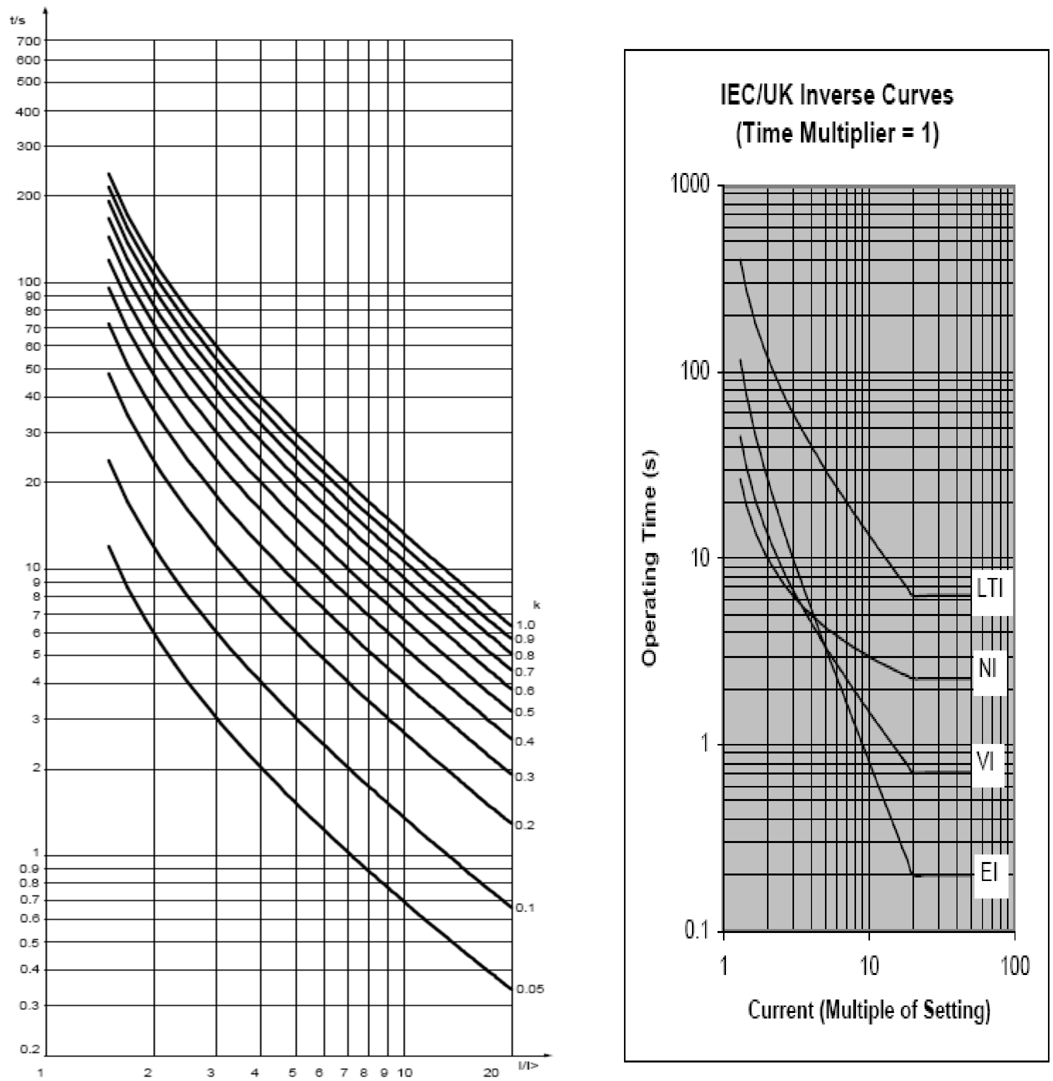
TMS = time multiplier setting,

k, a, c = constants defining curve.

Four curve types are available as defined in Table 2.3. They are illustrated in Figure below.

Table 2.3: Specification of IDMT Curves

Curve Description	**k**	**a**	**c**
IEC Normal Inverse (NI)	0.14	0.02	0
IEC Very Inverse (VI)	13.5	1	0
IEC Extremely Inverse (EI)	80	2	0
IEC/UK Long Time Inverse (LTI)	120	1	0



(a) (b)

Figure 2.8: Figure (a) shows that the ‘Long Time Inverse’ characteristic and (b) is types of IDMT Characteristic

2.6 'The Brain'

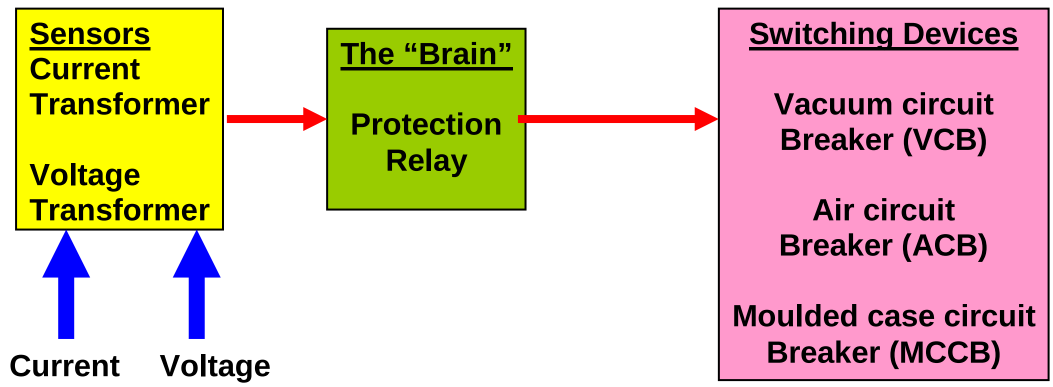


Figure 2.9: Building block of protection system

The block diagram above shows the protection system flow. Protection system is mainly controlled by the protection relay which is the brain of the protection system. Current transformer/voltage transformer will drop voltage/current in secondary windings. If there are over current/over load, the protection relay will open the circuit (cut-off) and cause the switching devices to trip. Protection relay play an important role in this system to cause the circuit breaker to trip and it can be implemented at various stages and various types of protection devices. Most of all, the protection relay only act as the brain of the protection and actual switching work are done by the circuit breakers and isolators.

2.7 PIC Micro Controller

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640 originally developed by General Instrument's Microelectronics Division. The name PIC initially referred to

"Programmable Interface Controller", but shortly thereafter was renamed "Programmable Intelligent Computer".

PICs are popular with developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability [7].

PIC microcontrollers are frequently used in automatically controlled products and devices, such as automobile engine control systems, remote controls, office machines, appliances, power tools, and toys. By reducing the size, cost, and power consumption compared to a design using a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to electronically control many more electrical and mechanical devices [6].

To summarize, a microcontroller contains (in one chip) two or more of the following elements in order of importance [8]:

i. Includes Powerful Microchip PIC16F877 Microcontroller with 8kb Internal Flash program memory
ii. Operating Speed at 10MHz
iii. Direct In-Circuit Programming for Easy Program Updates
iv. Up to 28 I/O points with easy to connect standard headers
v. Internal EEPROM
vi. 8 Channel 10-bit A/D Converter
vii. One 16-bit Timer with Two 8-bit Timers
viii. Serial port
ix. Reset Button

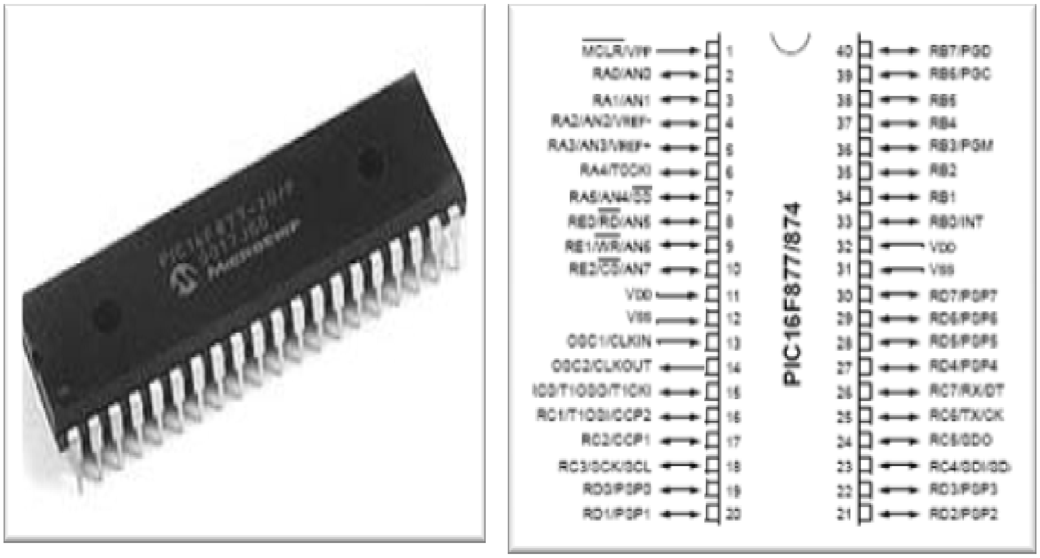


Figure 2.10: PIC 16F877A and it’s Schematic

2.8 Summarization

Power system protection is a very important element in electrical field and it is required to protect equipments as well as human. This chapter is likely to approach the review about important part in the electrical protection system which is over current protection relay. Over current protection relay which utilize with microprocessor and is based on the most advanced digital technology, is now widely used to protect lines, generators, transmission and motors. To develop this project, the knowledge about the controller which is ‘the brain’ for this system is very important. This project will use PIC micro controller as the processor. Though, the result of this project should have the basic operation and principles of over current relay.

CHAPTER 3

METHODOLOGY AND DESIGN

3.1 Introduction

This chapter explains how to design the over current relay including hardware and software implementation. This chapter also will cover about designing the basic PIC circuit, keypad and LCD, current sensor circuit, interfacing PIC to circuit breaker and PIC programming.

Before looking the details of designing this project, it is best to start with brief review of the system design. Figure 3.1 shows the complete system design of over current relay.

3.2 System Design

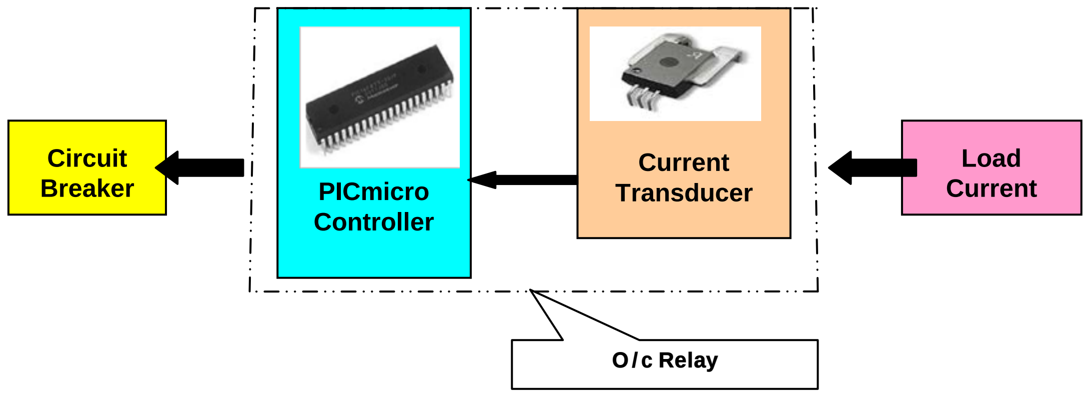


Figure 3.1: Block diagram of the system

The whole idea of this project is to isolate the faulty conditions from the load current by controlling the circuit breaker tripping coil using PIC micro controller. When there are over current at the bus bar (load current), current transformer will supply the reduced current to current sensor.

Current sensor will be used to measure the load current and will convert this current to certain voltage level as an input to microcontroller. Microcontroller will process and compare this voltage with desired voltage setting and will operate the tripping coil in circuit breaker if input voltage reaches the setting value.

3.3 Main Components

3.3.1 Current Transformer

Current Transformers (CT's) are instrument transformers that are used to supply a reduced value of current from bus bar or cables to meters, protective relays, sensors, and other instruments. CT's provide isolation from the high current primary, permit grounding of the secondary for safety, and step-down the magnitude of the measured current to a value that can be safely handled by the instruments.

CT ratios are expressed as a ratio of the rated primary current to the rated secondary current. For example, a 300:5 CT will produce 5 amps of secondary current when 300 amps flow through the primary. As the primary current changes the secondary current will vary accordingly. With 150 amps through the 300 amp rated primary, the secondary current will be 2.5 amps (150: 300 = 2.5: 5).

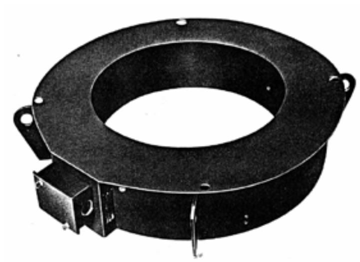


Figure 3.2: Current transformer

3.3.2 Current Sensor

Current sensor is a device, usually electrical, electronic, electro-mechanical, electromagnetic, photonic, or photovoltaic that converts one type of energy (current) or physical attribute to another (voltage) for various purposes including measurement or information transfer. In this project, current sensor will be used to induce current from current transformer to certain voltage level as an input to PIC micro controller.

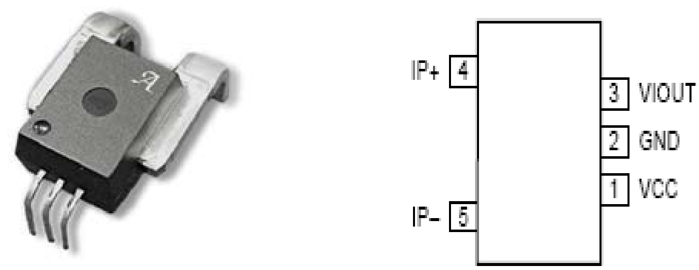


Figure 3.3: Current sensor types ACS754LCB-050-PFF.

Figure 3.3 show that the current sensor used in this project which is to measure the load current from current transformer. The Allegro ACS75x family of current sensors provides economical and precise solutions for current sensing in industrial, automotive, commercial, and communications systems. The device package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, power supplies, and over current fault protection.

The device consists of a precision, low-offset linear Hall sensor circuit with a copper conduction path located near the die. Applied current flowing through this copper conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy at the factory.

This current sensor will measure the maximum current 50A from load current as its primary nominal current (Ipn). The output voltage, Vout (1mA=40mV) which is connected to the PIC micro controller as an analog.

Features and benefits:

▪ Monolithic Hall IC for high reliability
▪ Single +5 V supply
▪ 3 kVRMS isolation voltage between terminals 4/5 and pins 1/2/3 for up to 1 minute
▪ 35 kHz bandwidth
▪ Automotive temperature range
▪ End-of-line factory-trimmed for gain and offset
▪ Ultra-low power loss: 100 μΩ internal conductor resistance
▪ Ratiometric output from supply voltage
▪ Extremely stable output offset voltage
▪ Small package size, with easy mounting capability
▪ Output proportional to AC and DC currents

3.3.3 Circuit Breaker

A circuit breaker as a device designed to open and close a circuit by no automatic means, and to open the circuit automatically on a predetermined over current without damage to itself when properly applied within its rating. In addition, circuit breakers provide automatic over current protection of a circuit. Every circuit breaker has a specific ampere, voltage, and fault current interruption rating. The ampere rating defines the maximum current a circuit breaker can carry without tripping and normally residential circuit breakers are available with ratings from 10-

125 amps. The short circuit current should be of the order of around 200 A or higher for normal 10 A or 16 A ratings outlet to guarantee that the normal wire protecting fuse or breaker will quickly disconnect the supply in case of short circuit. The ratings of the circuit breaker depend on networks installed. The larger network the larger ratings.

Figure 3.4: Allen-Bradley circuit breaker with shunt trip coil

When supplying a branch circuit with more than one live conductor, each live conductor must be protected by a breaker pole. These may either contain two or three tripping mechanisms within one case, or for small breakers, may externally tie the poles together via their operating handles. Two pole common trip breakers are common on 120/240 volt systems where 240 volt loads (including major appliances or further distribution boards) span the two live wires. Three pole common trip breakers are typically used to supply three phase power to large motors or further distribution boards.

3.4 Hardware Implementation

This section will discuss about components that have been used in this project included basic PIC circuit, 5V supply, keypad & LCD, PIC interfacing with circuit breaker and current sensor circuit.

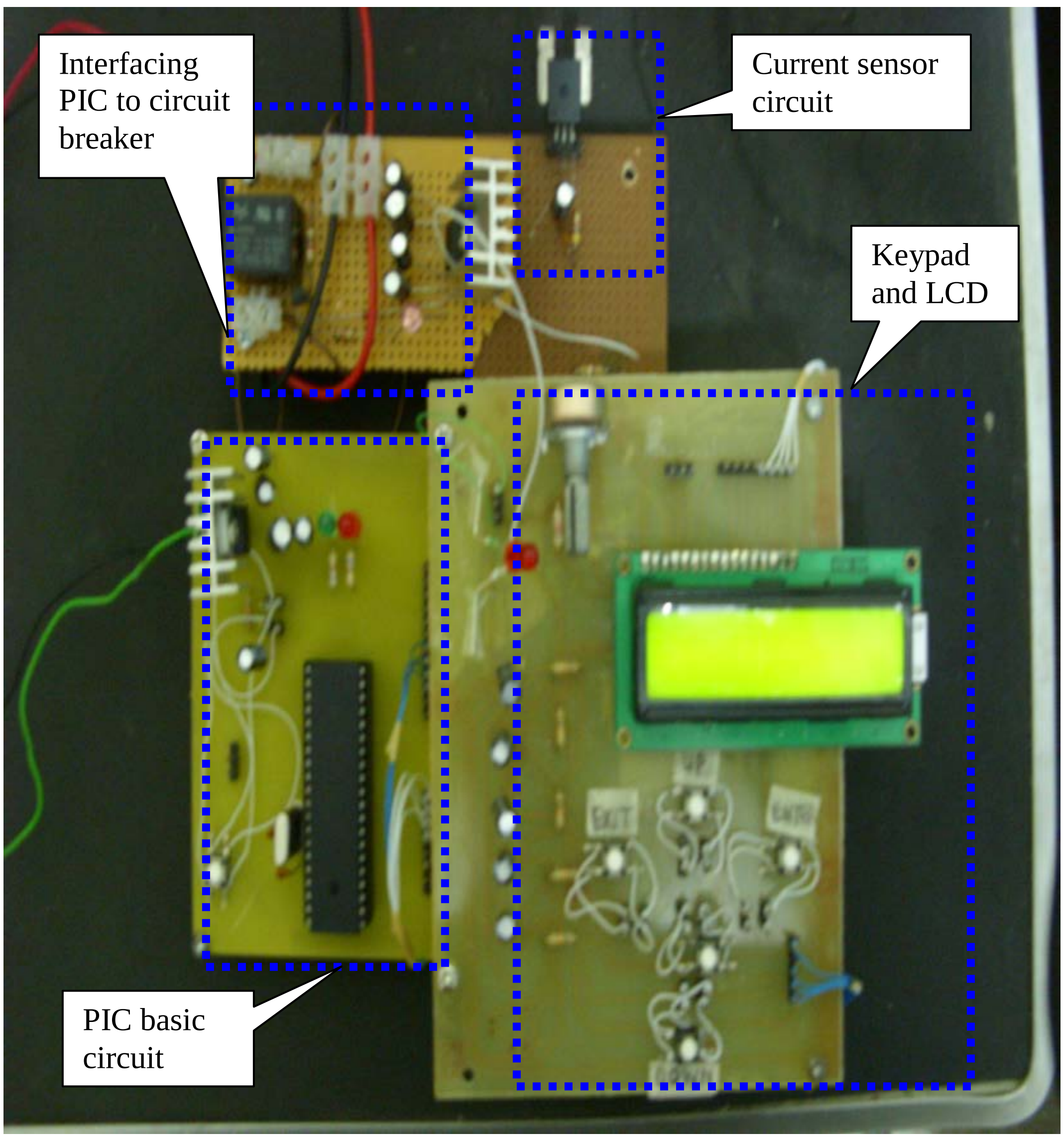


Figure 3.5: Full picture of hardware

3.4.1 Basic PIC Circuit

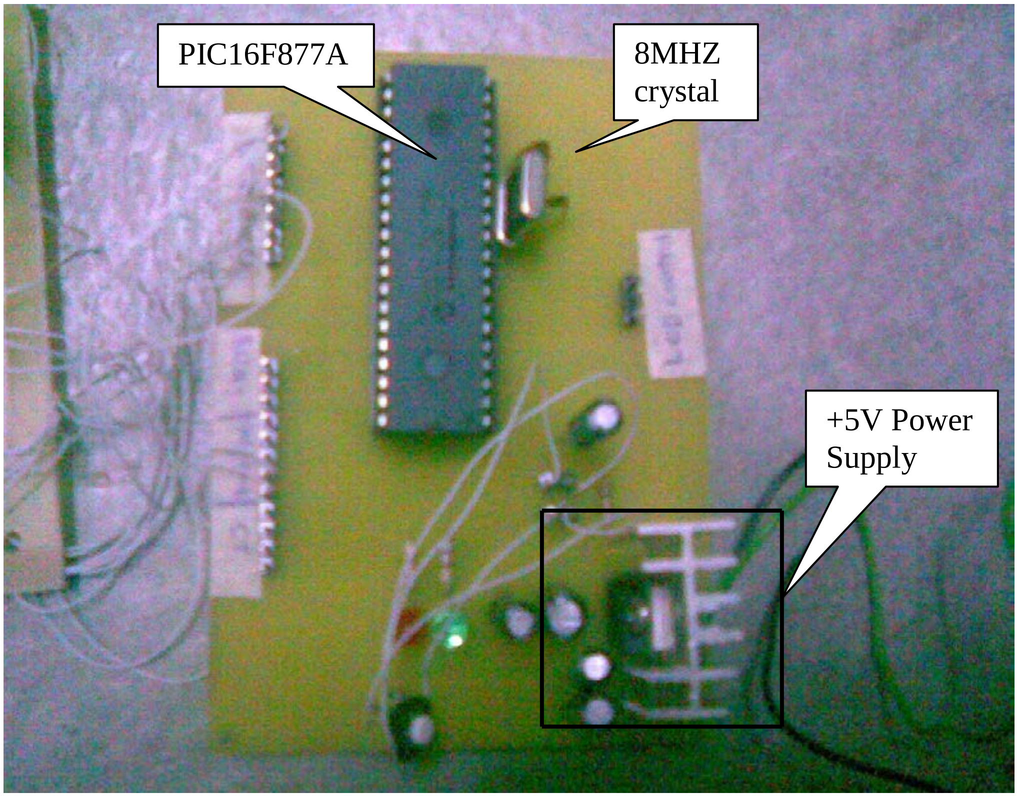


Figure 3.6: Basic PIC Circuit

Figure 3.6 and figure 3.7 show that basic PIC circuit implemented using PCB which is the main circuit (brain). The PIC Controller Board uses a 40-PIN PIC 16F877A as a controller. In this design, port A (portA.3) is used as an analog input from current sensor. For port B (portB.2 – portB.5), the pin is used as an input from keypad (push button switch). The LCD is used 4 bit for transferring data and at LCD, pin number 11 to 14 (DB4 – DB7) is use for receiving data from PIC-Microcontroller which is from port D. Besides that, at port E, only pin 2 and pin 3 were use which is Enable (E) and Register Select (RS) from LCD pin while portB.1 is for the output to circuit breaker.

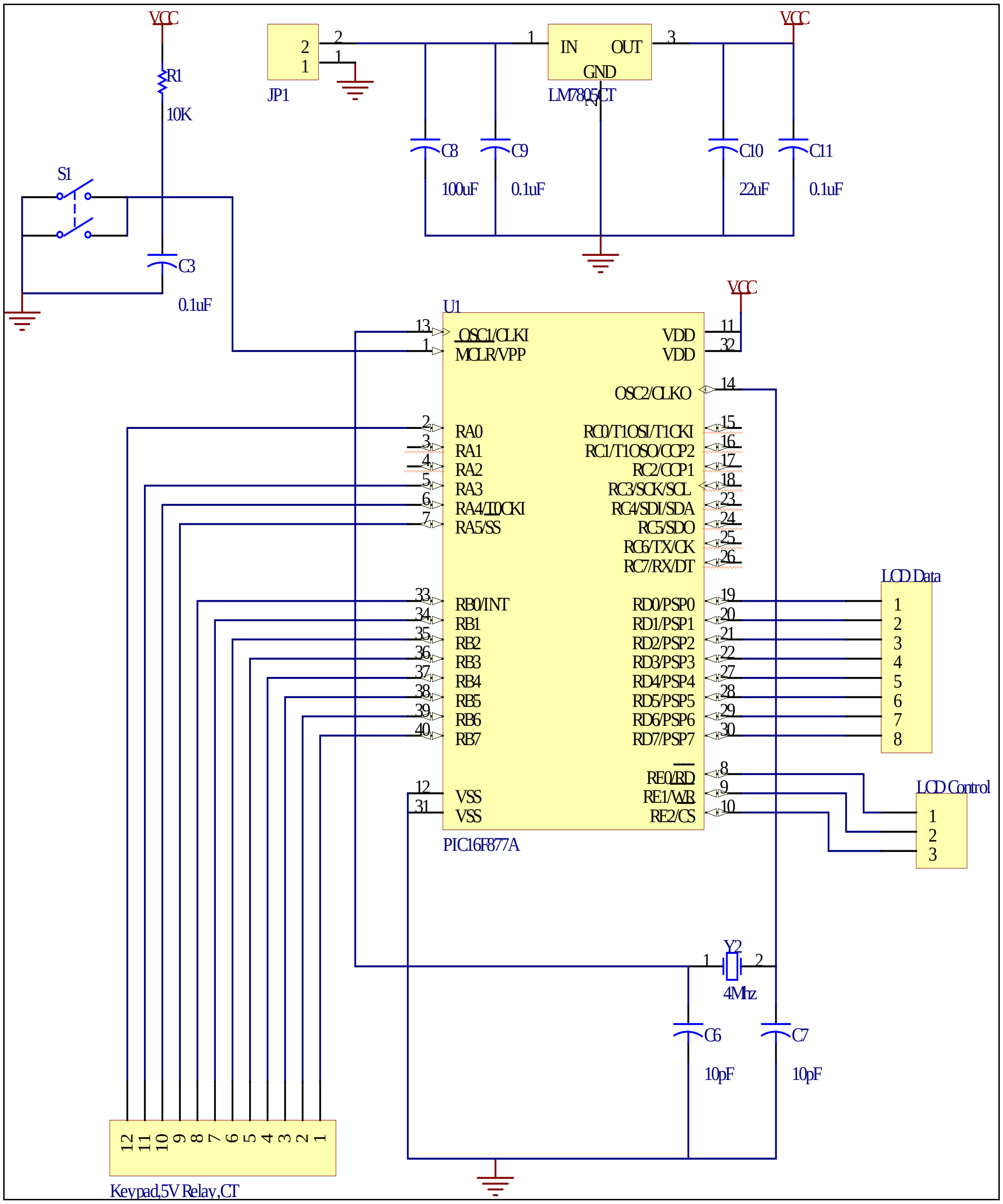


Figure 3.7: PIC basic circuit developing

Table 3.1: Pin connected to PIC16F877A over current relay system

Pin Name	**Pin No.**	**Description**	**Application**
VDD	11,32	Positive supply (+5V)	Power supply to PIC
VSS	12,31	Ground references	Ground references
MCLR	1	Input	For reset button
OSC1,OSC2	13,14	For oscillator	Connected to 4MHz crystal with 10pF capacitor
RA3/AN3	5	Analog input	Analog input from current sensor
RB2-RB5	35-38	Push button switch	Keypad input
RB0	33	Output to 5V relay	To trip circuit breaker
RD4-RD7	27-30	Output	Connected to LCD data (DB0-DB7)
RE1-RE2	9,10	Output	Connected to LCD pin for R/S and Enable.

3.4.2 +5V Power Supply

Most digital logic circuits and processors need a +5 volt power supply. To use these parts we need to build a regulated +5 volt source. Voltage regulator can limit the voltage to PIC and to prevent damage to PIC. Usually we start with an unregulated power supply ranging from 9 volts to 24 volts DC. To make a +5 volt power supply, we use a LM7805 voltage regulator IC (Integrated Circuit). The IC is shown below.

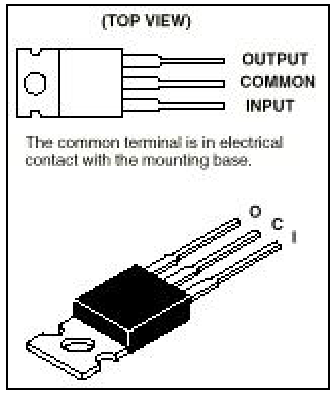


Figure 3.8: Voltage Regulator

Sometimes the input supply line may be noisy. To help smooth out this noise and get a better 5 volt output, capacitors is usually added to the circuit.

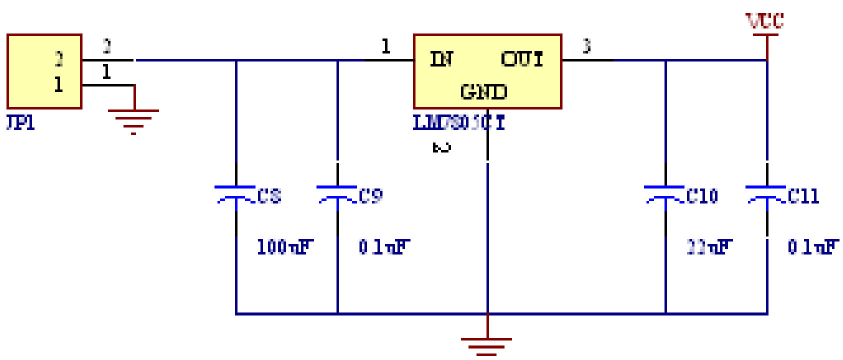


Figure 3.9: Schematic circuit of +5V power supply

3.4.3 Keypad and LCD

Keypad and LCD is implemented in one PCB. LCD is used to display load current and keypad is used to insert setting current. LCD that has been used is 2x16 JHD162A type while push button (normally open) is used for keypad.

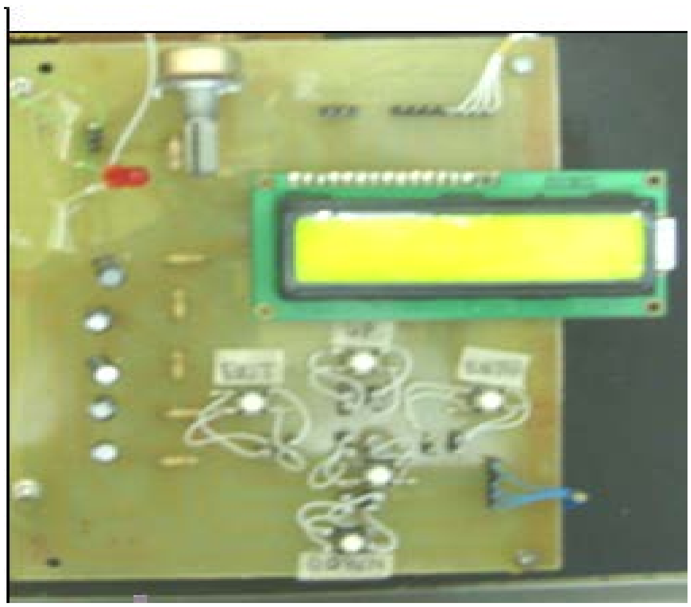


Figure 3.10: Keypad and LCD

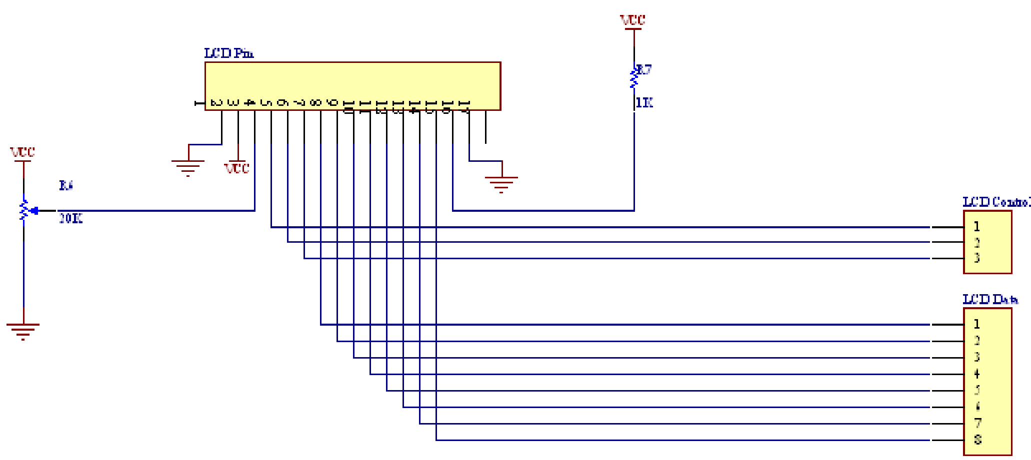


Figure 3.11: Pin connection of LCD

Table 3.2: LCD pin configurations

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
VSS	VCC	VEE	RS	R/W	E	DB0	DB1	DB2	DB3	DB4	DB5	DB6	DB7	LED+	LED-

Figure 3.11 shows the connections for using an LCD with the PIC16F877 experiments. This circuit diagram shows how to connect LCD to the PIC16F877. The setting value is set at the keypad as shown in figure 3.12 and it will display the value at LCD. The LCD helps in the debugging process if something doesn't work quite right the first time, and is used to display the results when everything goes according to plan.

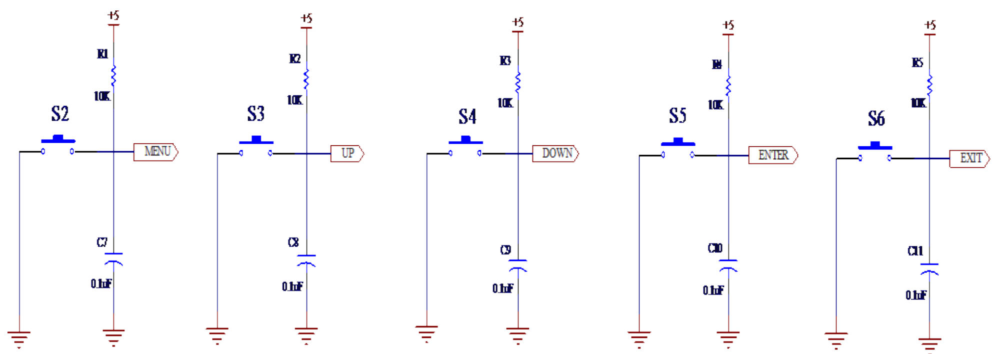


Figure 3.12: Keypad (push button) circuit

3.4.4 Interfacing PIC16F877A to Circuit Breaker

The voltage output from the PIC micro controller is normally 5V. We can't connect the PIC micro controller directly to the circuit breaker without using external devices. In order to serve the purpose, a relay with 5V tripping coil and 240VAC contact will be used to interface the PIC micro controller to circuit breaker.

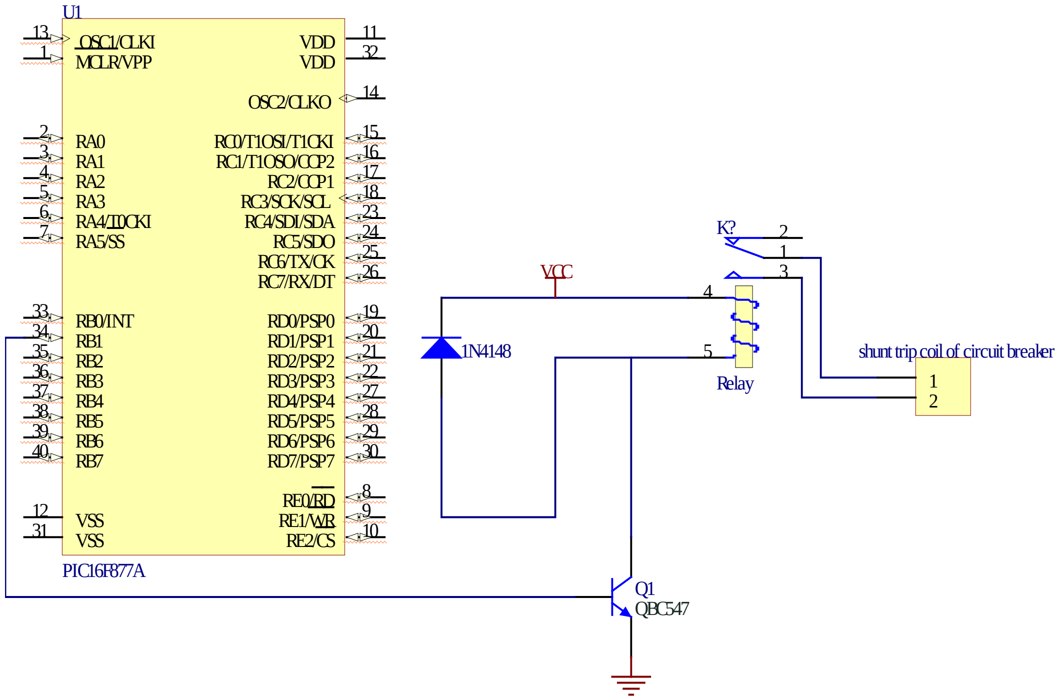


Figure 3.13: Interfacing PIC to circuit breaker

Relays are devices which allow low power circuits to switch a relatively high Current/Voltage ON/OFF. For a relay to operate a suitable pull-in & holding current should be passed through its coil. Generally relay coils are designed to operate from a particular voltage often its 5V or 12V. The function of relay driver circuit is to provide the necessary current (typically 25 to 70ma) to energize the relay coil**.**

Figure 3.13 shows the basic relay driver circuit. As you can see an NPN transistor BC547 is being used to control the relay. The transistor is driven into saturation (turned ON) when a LOGIC 1 (output voltage) is written on the port pin at PIC 16F877A thus turning ON the relay. The relay is turned OFF by writing LOGIC 0 on the port pin. A diode (1N4007/1N4148) is connected across the relay coil; this is done so as to protect the transistor from damage.

3.4.5 Current Sensor Circuit

Current transducer is a type of current sensor which induces current to voltage. In this project, the Allegro ACS754-050 current sensor is used to induce the input current from it to a voltage to PIC micro controller. The current sensor has 5 pin which are pin 4 and 5 for the input. Pin 1 and 2 for the supply voltage which is +5V and -5V while pin 3 is the output voltage.

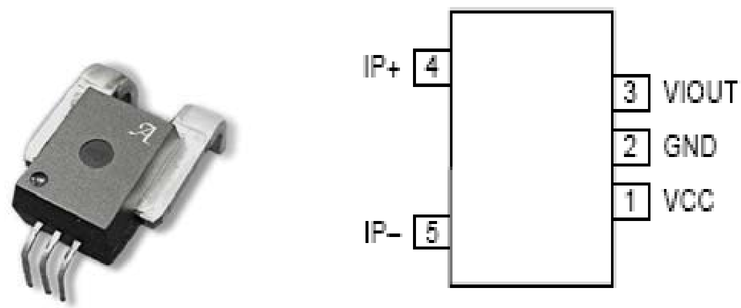


Figure 3.14: Current sensor pin-out diagram

Table 3.3: Current sensor terminal list

Number	**Name**	**Description**
1	VCC	Device power supply pin
2	GND	Signal ground pin
3	VOUT	Analog output signal pin
4	IP+	Terminal for current being sensed
5	IP-	Terminal for current being sensed

The output of the device has a positive slope (>VCC / 2) when an increasing current flows through the primary copper conduction path (from terminal 4 to terminal 5), which is the path used for current sensing. The thickness of the copper conductor allows survival of the device at up to 5 times over current conditions. The terminals of the conductive path are electrically isolated from the sensor leads (pins 1 through 3). This allows the ACS754 family of sensors to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques. The current sensor has the sensitivity of 40mV/A.

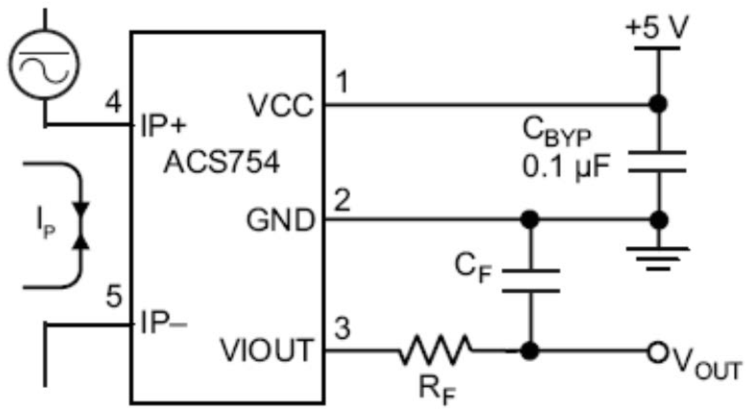


Figure 3.15: Typical application of ACS754-050

In order to reduce noise, 10nF capacitor and 10KΩ resistor is added as shown at figure 3.15. The output pin which is Vout is connected to portA.3 at PIC micro controller as an analog input.

3.5 Software Implementation

This section will discuss about software which has been implemented in this project which are DXP Protel (2004) for designing the circuit and PicBasic Pro Compilers (Micro Code Studio) for the programming.

3.5.1 DXP Protel (2004)

All hardware is implemented using Printed Circuit Board (PCB). All the circuit is draw using Altium DXP which is electronics design software which provides a complete and diverse set of capabilities for electronic product development.

Altium allows to better communicate the breadth of technologies integrated on its DXP platform – board-level system design and verification, FPGA-level system design and verification, embedded software development, CAM engineering, and design data, document and library management. Protel 2004's schematic editor provides full support for designs that contain repeated blocks of circuitry. Figure below shows that the software that have been used in this project to design for designing the circuit.

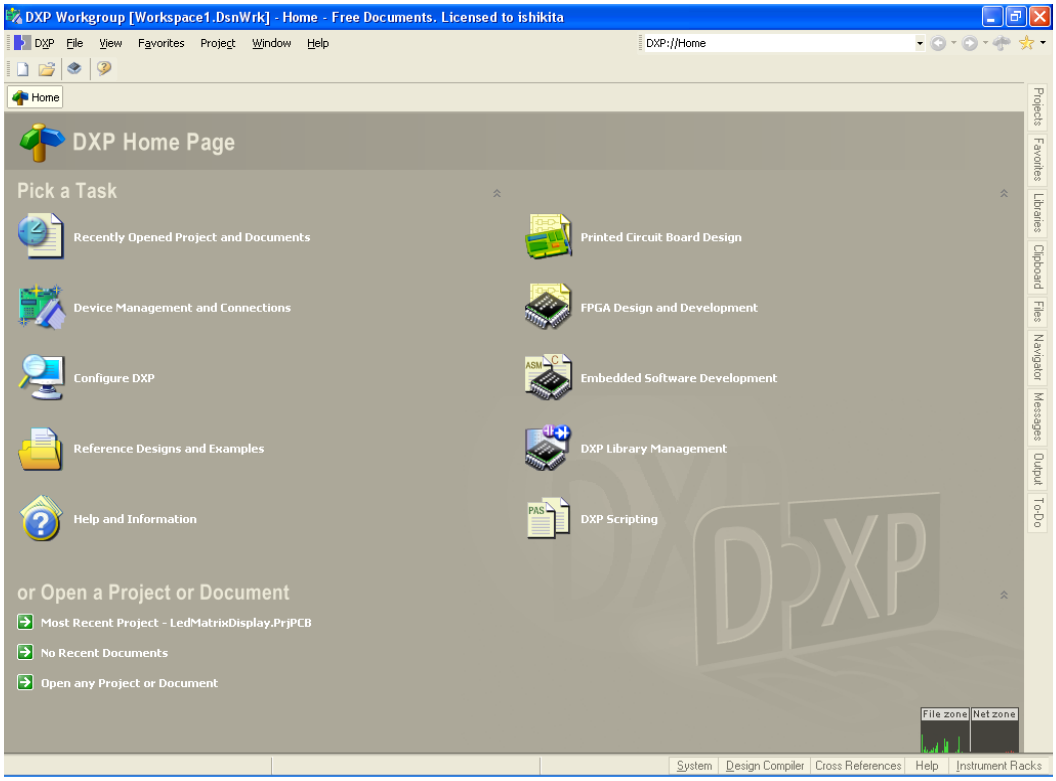


Figure 3.16: DXP Protel home page

The size of the board and the track should be setting as the same as the required by the components that will be soldered on the board. Figure 6 showed the board setting exactly the same specification with strip board.

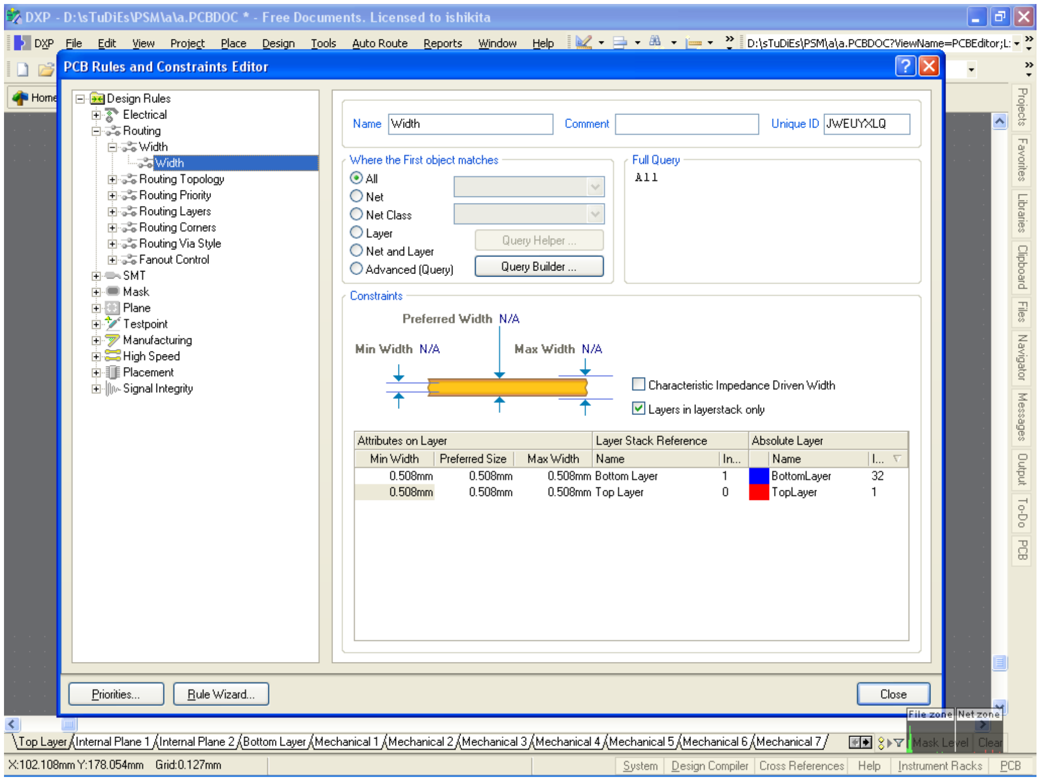


Figure 3.17: Track size setting

The board layout will be designed with the toolbars that has been provided by the software. The complete PCB layout for basic PIC circuit and LCD board is shown in figure below.

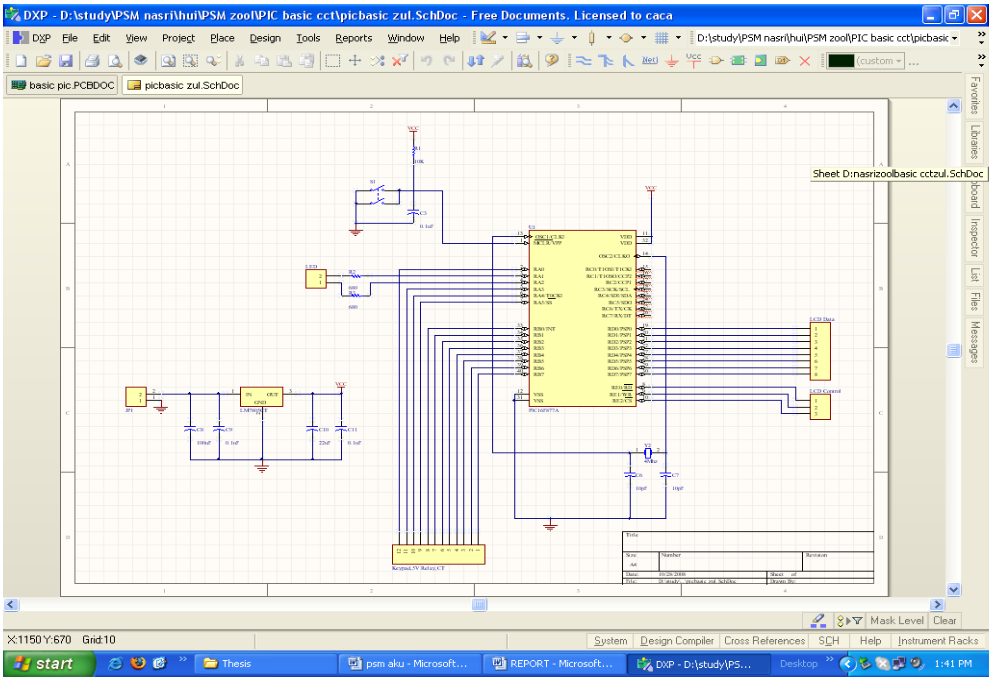


Figure 3.18: Basic PIC circuit

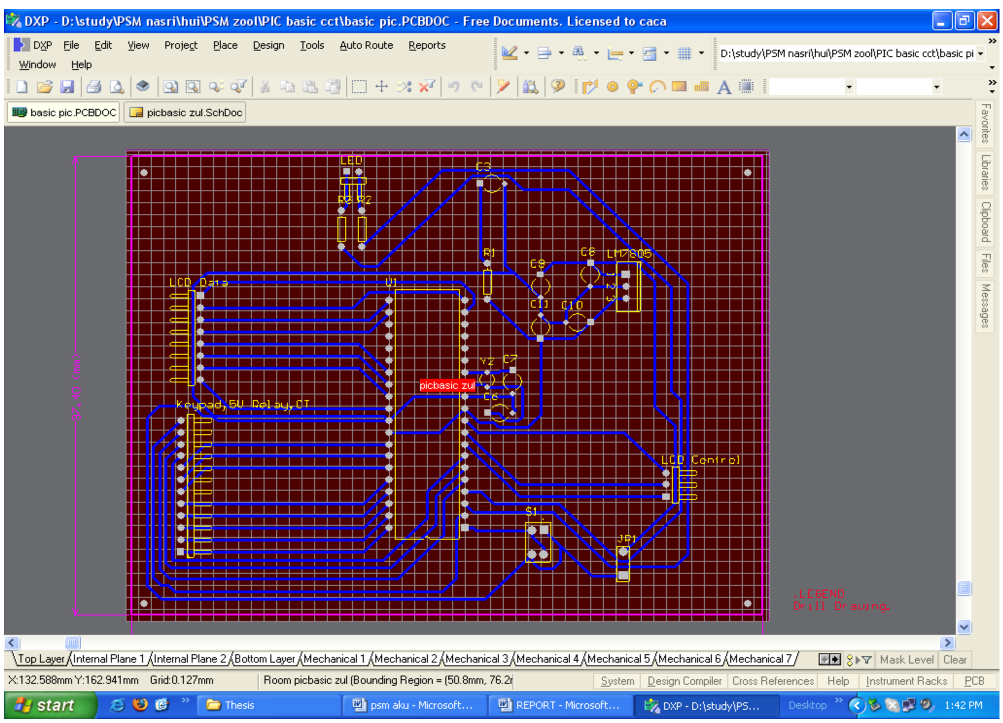


Figure 3.19: Basic PIC circuit (PCB layout)

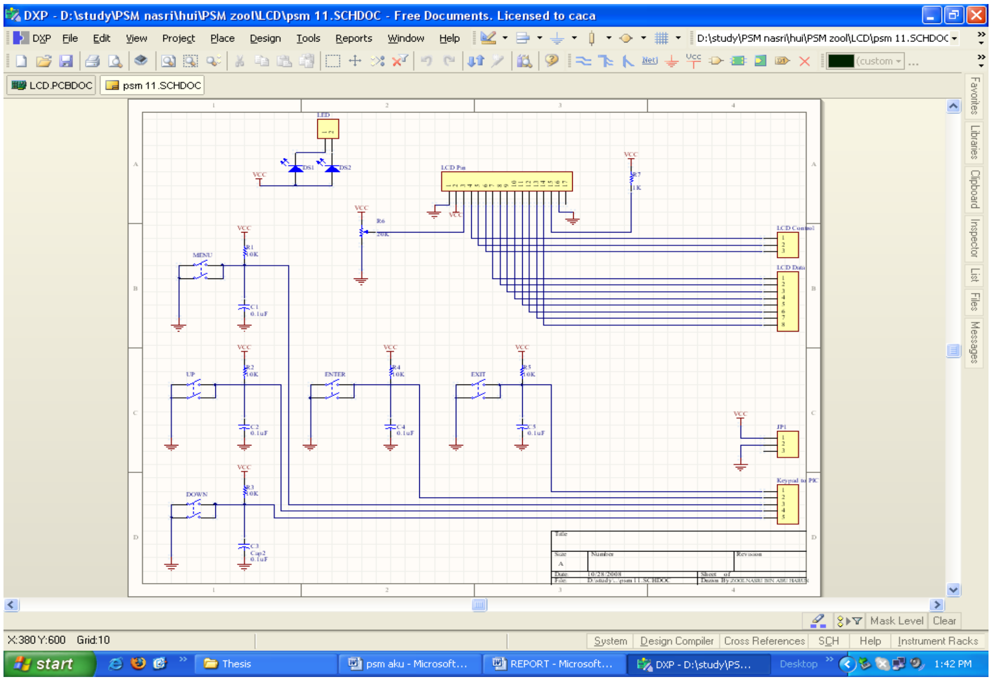


Figure 3.20: LCD circuit

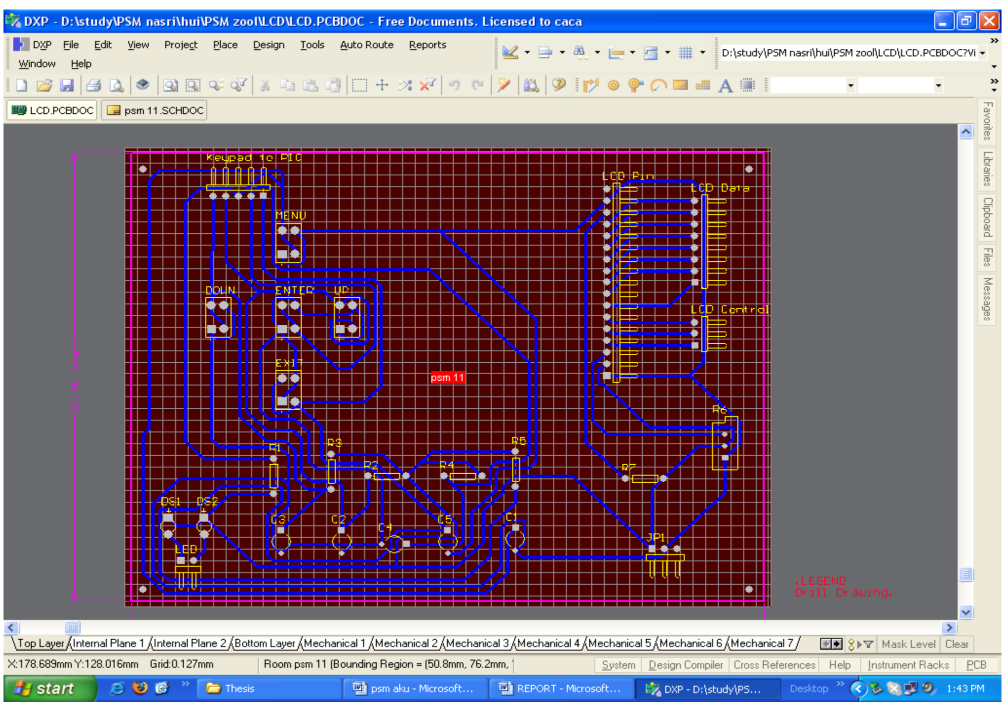


Figure 3.21: LCD circuit (PCB layout)

3.5.2 Programming the PIC16F877A

Micro Code Studio is a powerful, visual Integrated Development Environment (IDE) with In Circuit Debugging (ICD) capability designed specifically for microEngineering Labs PICBasic PRO compiler. The code explorer allows you to automatically jump to include files, defines, constants, variables, aliases and modifiers, symbols and labels that are contained within your source code. It's easy to set up your compiler, assembler and programmer options or you can let Micro Code Studio do it for you with its built in auto search feature. Compilation and assembler errors can easily be identified and corrected using the error results window.

For designing the Over current Protection Relay it is required a lot of technical skills and knowledge about the command that will be use while written the program in PicBasic Pro Compilers (Micro Code Studio). The flash memory technology of the PIC 16F877A microcontroller permits the microcontroller to be programmed, erase and programmed again repeatedly and it saves us more time to construct ideal program.

Figure 3.18 is the flowchart of the programming which is the flow of program running in PIC-Microcontroller. As usually, they will be the starting of the program. Here, the user have to insert 3 setting value which is I> (IDMT setting current), I>> (instantaneous setting current) and TMS (time multiple setting). Then the LCD will display the energizing current, Is. At this time the PIC micro controller will first start compare the energizing current with, Is with I>> setting. If Is is bigger than I>>, the circuit breaker will instantly trip. If no, then Is will compare with I> setting and if Is is bigger than I>, it will delay for seconds base on IDMT (Inverse Definite Minimum Time) curves before the circuit breaker trip. If no, Is will again compare with I>> setting. The IDMT curve that has been implemented in the programming is ‘Long Time Inverse’ curve as shown in figure 3.18.

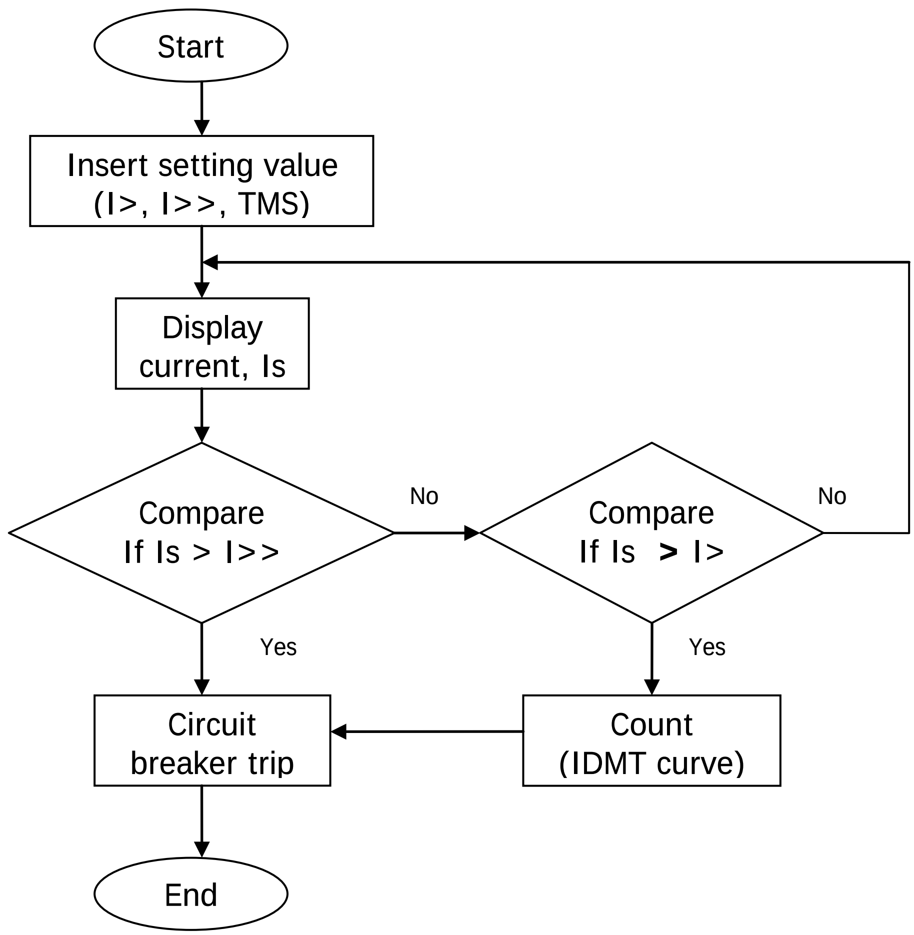


Figure 3.22: Flowchart of Over current Protection Relay

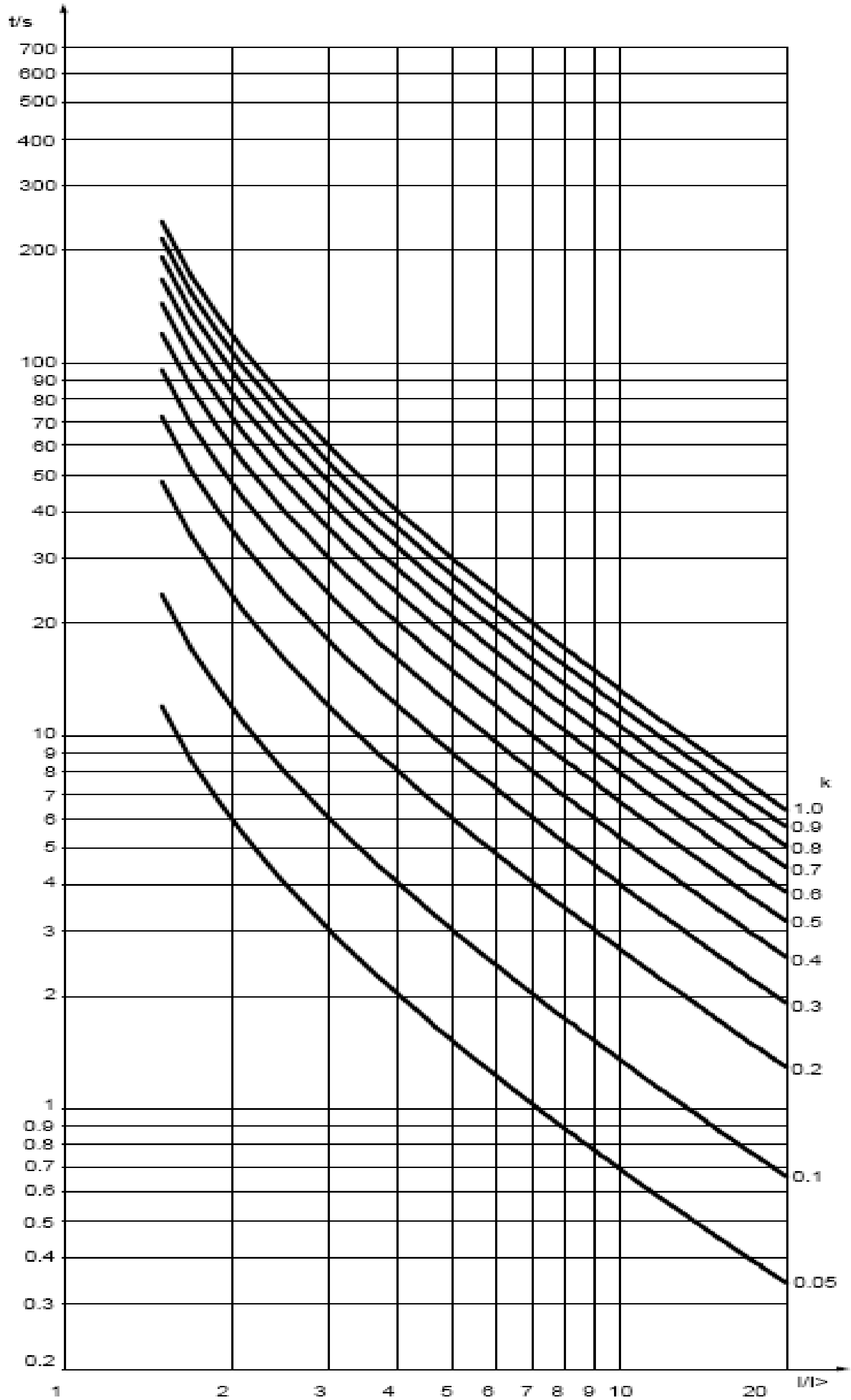


Figure 3.23: IEC/UK Long-time inverse-time curves

3.6 Summarization

Circuit breaker is the main output of this project which is to isolate the faulty condition (fault current) while LCD will monitor the energizing current and display the fault current. All the circuit in this project will be controlled by PIC micro controller which acts as the processor in this project. The PIC micro controller will do the task and operate depend to the current that being sensed. Keypad (push button) is also another input which plays an important role in setting value and to interface with LCD. It is very important to implement the hardware stage by stage so that it will be easy to troubleshoot if there's a problem. The most important thing is to make sure that the PIC micro controller can constantly operate and functioning so that it will keep all circuits runs.

CHAPTER 4

RESULTS & DISCUSSION

4.1 Introduction

In this chapter, the function of circuit and operating of Over Current Protection Relay system will be discussed according to the flow of program and the result that obtained from this project. The analysis is divided into 4 parts:

i. Power supply output voltages
ii. Current sensor output voltages and analysis
iii. Over current relay operation
iv. Operating of shunt trip coil

4.2 Power Supply Output Voltages

The analysis of supply voltage is important to ensure the voltage is not exceeding the required value. Electronic component such as PIC just need 5V to operate. If the component is supplied more than that, the component will be hot and in some cases it can blow. So it is important to analyze the input voltage to all components to ensure it get the required supply voltages.

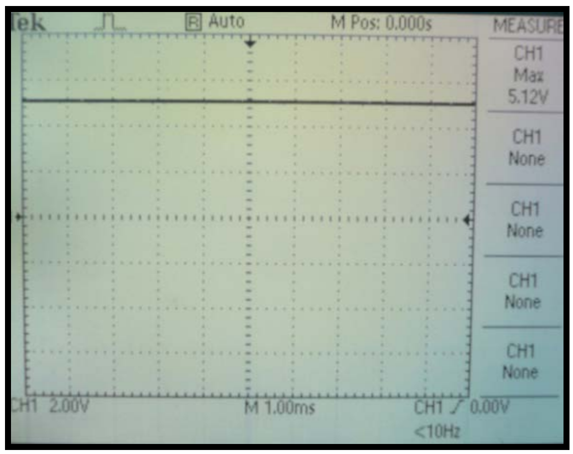


Figure 4.1: Power supply output voltage

Figure 4.1 is the outputs of power supply. This supply came from LM 7805 voltage regulator, enters the PIC. All the circuits in this project required 5V power supply including LCD, current sensor and 5V relay. From the figure we can see that the output is 5.12V which match the supply voltages that PIC and other components needed. It is very smooth and the voltage is near to the desired value.

4.3 Current Sensor Output Voltages and Analysis

Current sensor is the input of this project and plays an important role in order to monitor the current. The current sensor type ACS754LCB-050 manufacturer by Allegro Microsystems provides economical and precise solutions for current sensing in this project. This part will discuss about output voltages from current sensor and its flow to get the precise value to display it on the LCD.

4.3.1 Filtering the Output Noise

The minimum current that can be resolute by the current sensors is limited by the noise present in the output of the sensors which is Vout. In general, resolution may be improved by the addition of external filters on the sensor output. Even though, beyond certain levels, such filtering limits the bandwidth and response time of the sensor. Figure 4.2 shows that reading using oscilloscopes of output voltages from current sensor with no external filters.

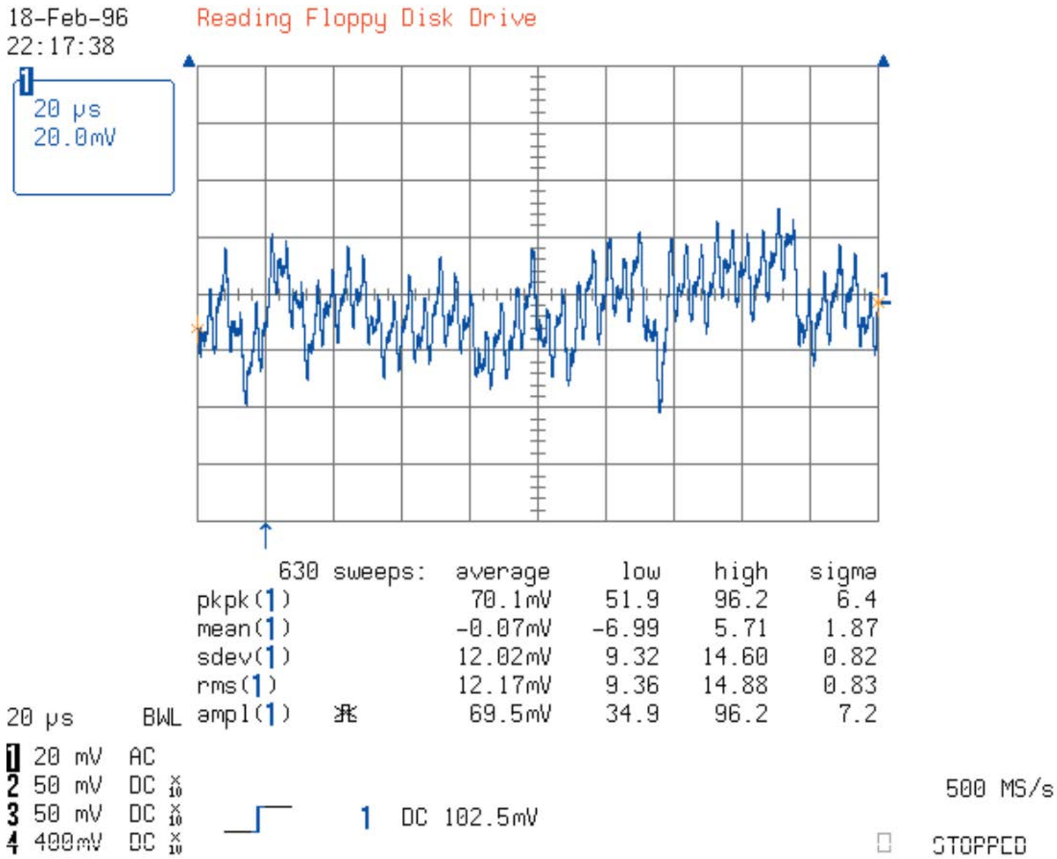


Figure 4.2: Reading of Vout at zero current with no external filters

From the oscilloscope, we can see that the peak-peak output voltage is 70.1mV at zero current. Refer to the datasheet; the output noise with no external filters is typically 65mV, plus with electrical offset voltage, ±10mV, it should be 75mV. The oscilloscope reading is approximately 75mV, same as the datasheet. The output noise voltage is quiet large if there is no external filters are added. In order to eliminate it, a filter combination, implemented by a passive R-C network is added with value 10KΩ resistor and 10nF capacitor. By adding external filter will result in only a minimal reduction in sensor response time and bandwidth. Figure below shows that the reading of zero current with external filter added. The reading shows that the peak-peak noise is decrease 39.2mV and it shows that the R-C element filters does work to reduce the noise.

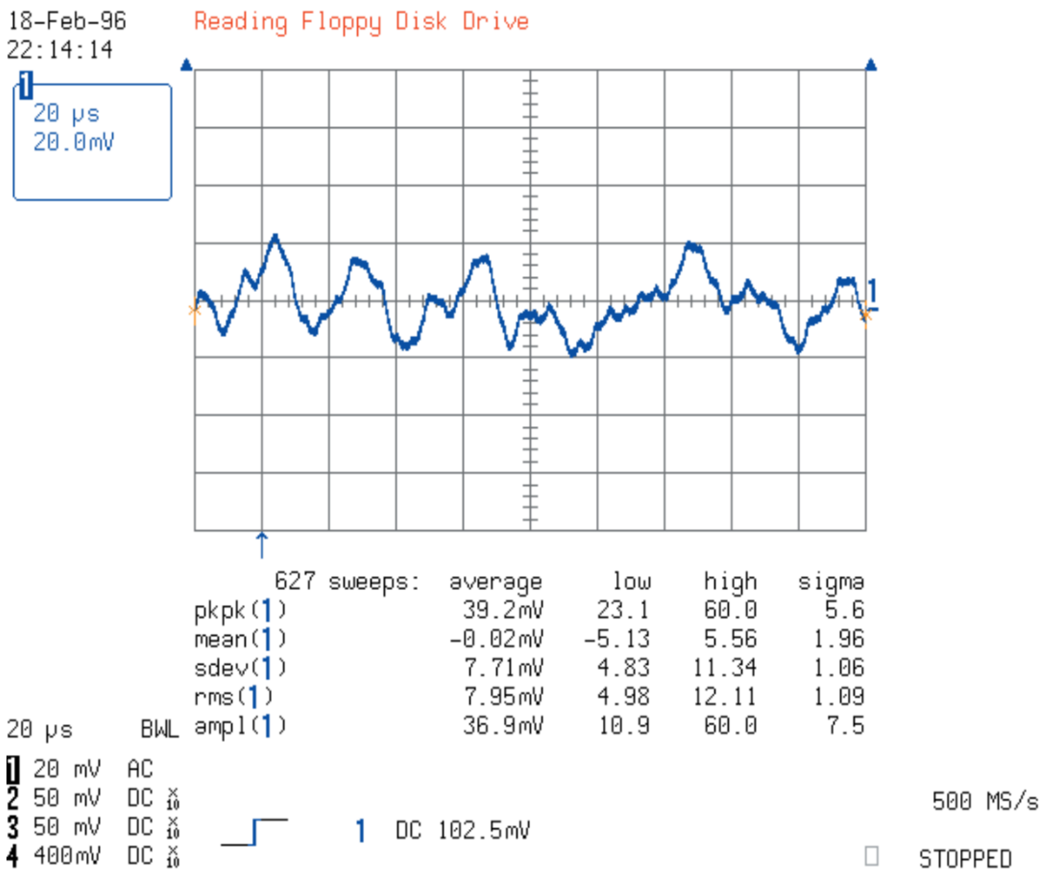


Figure 4.3: Reading of Vout at zero current with external filters

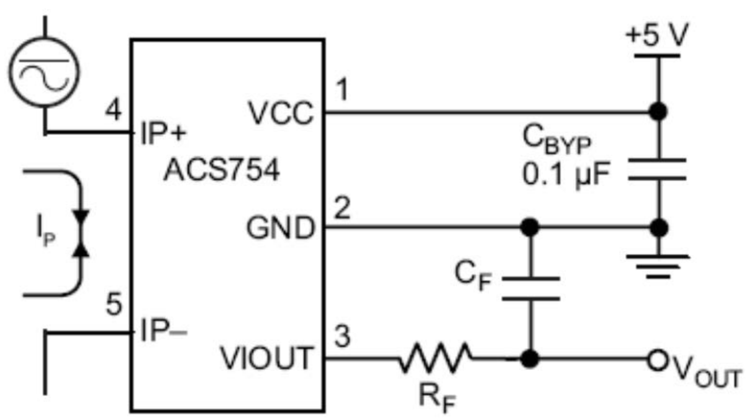


Figure 4.4: External R-C filter

4.3.2 Current Sensor Output Results

The output voltage from current sensor is an analog voltage. The PIC16F877A has an internal analog to digital converter which can convert the analog input to digital. The output pin of current sensor is connected to portA.3 of PIC. Then output of the PIC is connected to LCD in order to display the load current. Figure below shows that the reading on oscilloscopes from the current sensor.

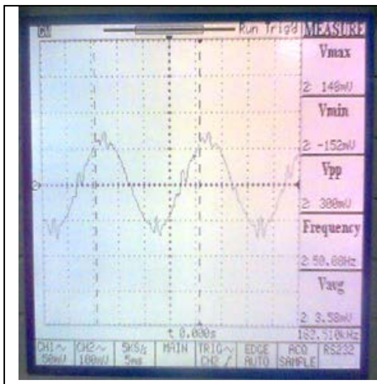
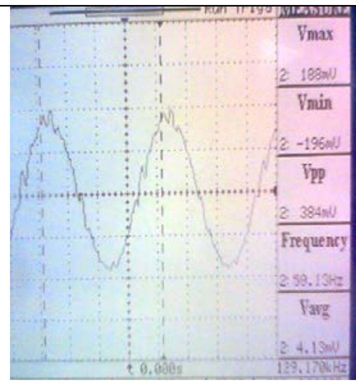
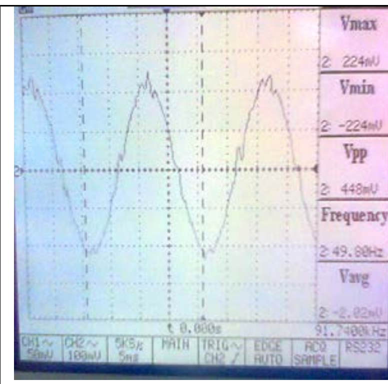
		
Reading on 2A	Reading on 3A	Reading on 4A

Figure 4.5: Reading of output pin from current sensor

Figure 4.5 shows the output voltage from current sensor is an alternating voltage with 50Hz frequency.

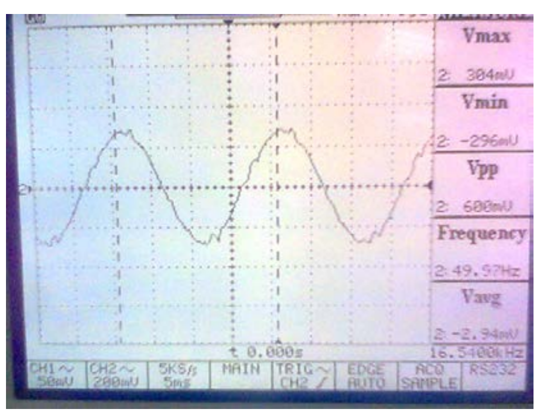


Figure 4.6: Output voltage from current sensor

Since the input voltage to PIC from the current sensor is an alternating voltage, the result that will display on LCD also an alternating voltage. To get the maximum value from the alternating voltage, the input voltage is sampled to 5 values in programming the PIC. The sampling data then is compared using IF…THEN to get the maximum value and stored as the input voltage. The sensitivity of the current sensor is 40mV/A. 1A increasing in load current will result in 40mV increasing from the output pin. Figure 4.6 shows that the load current display on the LCD is approximately as displayed on the ammeter.

Figure 4.7: Result of load current

4.4 Over Current Relay Operation

This part will discuss about the operation of over current relay and the result obtained from LCD which is the main output besides of circuit breaker. The LCD also is one of the scope and very important to this project. The result can be illustrated according to the figure below which is step by step for operating this over current relay.

Figure 4.8: LCD show the start-up of the project

Figure 4.9: LCD display the setting value

Figure 4.7 shows that the LCD is in beginning state of the system which is according to the program flow. Then, after a while, the LCD shows the instruction of inserting the setting value of I> (IDMT setting current), I>> (instantaneous setting current) and TMS (time multiplier setting). The setting value is inserted as shown in figure 4.9. The I> is set for 2A, I>> is set for 9A and TMS is set for 0.1.

Figure 4.10: Insert the setting value

Figure 4.11: LCD display the load current

After inserting the setting value, ENTER button is pushed and the LCD will display the load current, I as shown in figure 4.10. This is the initial state this of over current relay. At this state, the PIC will compare the load current, I with the setting value of I> and I>>. There will be two conditions which are; the load current exceed in the range of I> to I>> setting and the load current exceed the I>> setting. If the load current remained in normal condition which is below I> setting, the LCD will only display the load current.

Figure 4.11 shows that the load current exceeded within the range of I> and I>> setting. These indicate that there are over current in the load.

Figure 4.12: LCD display the load current exceeds the I> setting

The LCD shows that the load current, I is 8A and the I> setting is 2A. Base on the ‘Long Time Inverse’ curve, I/I> equals to 4 and the TMS setting is 0.1, the time delay before the circuit breaker operate is 4 seconds same as the curve below and LED will blink for 4 seconds.

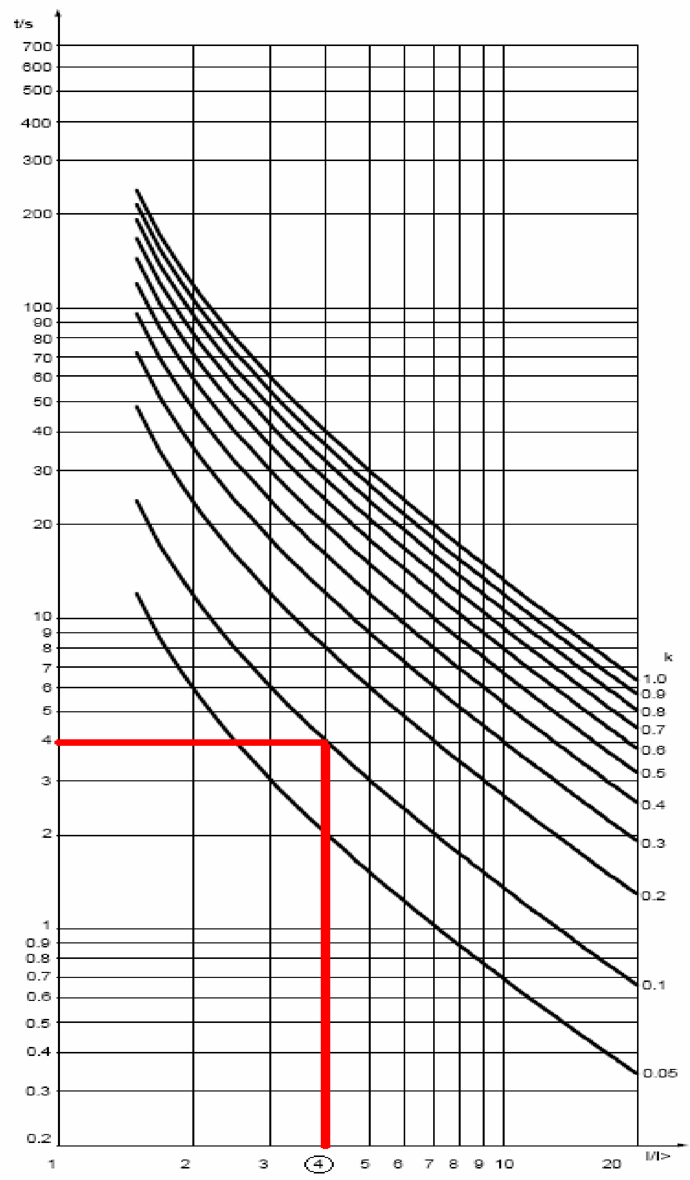


Figure 4.13: IEC/UK ‘Long Time Inverse’ curves

If the load current, I exceed the I>> setting, the circuit breaker will instantaneously trip without delay. These indicate that there are fault current in the load. Figure 4.13 shows the result of fault current.

Figure 4.14: LCD shows the fault current

4.5 Operating the Shunt Trip Coil

The shunt trip coils allows a circuit breaker to be tripped remotely by applying a voltage to the wire leads. The unit consists of an intermittent solenoid with a tripping plunger and a cutoff switch, and is mounted so that when the solenoid is energized, the trip lever presses against the trip bar and trips the circuit breaker.

The over current relay operate as a normally open circuit connected to the shunt trip coil of the input of circuit breaker. Activating the over current relay causes a 240 VAC signal to energize the shunt trip coil of the breaker. Figure below shows that diagram of over current relay connected in series with the circuit breaker.

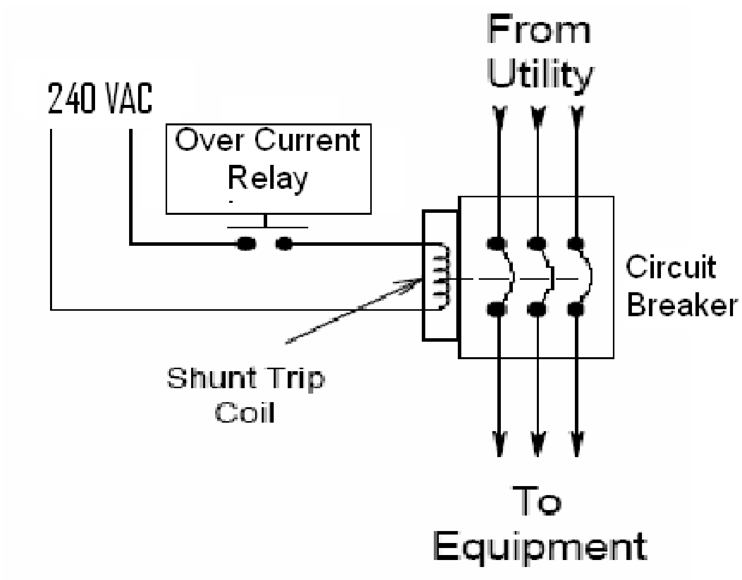


Figure 4.15: Diagram of shunt trip coil operation

When the over current relay activated, the circuit latches in a closed position and triggers the shunt trip coil of the input circuit breaker causing the breaker to shut down. It acts like a switch to trigger the shunt trip coil. Once trigger, the internal relay in over current relay is automatically reset to its normal position.

4.6 Summarization

The results of this project depend when it operate same as the basic operation of over current protection relay which is to isolate the faulty conditions. This chapter has described about the result obtained stage by stage, start with power supply output voltage, output current sensor and the operating of over current relay. In this project, the circuit breaker will operate when the current exceed the setting value and it depends on instantaneous trip or IDMT trip.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Introduction

This chapter discuss about the conclusion and future recommendation. This project has two major parts which is hardware description and software implementation. Both topics were very related and important to each other and can be applied to perform the system more effective in the future.

5.2 Conclusion

The function of Over Current Protection Relay is to monitor the unwanted condition (fault current) and isolate it in the shortest time possible. In this project, the Over Current Protection Relay Using PIC micro Controller has been developed to isolate the fault current and it can operate on the permissible conditions by controlling the setting current.

This project has successfully developed which has the basic operation and principles of over current protection relay in the market but it lack of performances, efficiency and reliability. It is because this project has been implemented using PIC micro controller and other cheap components compare to real over current relay which use microprocessor and is based on the most advanced digital technology.

5.3 Recommendation

For future works, some recommendations have been listed based on the problems faces in order to improve the performances of the system.

i. Hardware Improvement

The keypad and LCD should be more innovative such as touch screen LCD and keypad with numbers because it gives more option on the applications. It will be easier for user to key in data and monitoring the current. A touch screen LCD should be added in order to make it user's friendly.

ii. GUI (Graphical User Interface)

GUI using VB (Visual Basic) or other software should be added so that user can easily monitor using computer. It is highly recommended so that the over current relay will be more efficient.

iii. Combine With Earth Fault Relay

The over current relay system can be combine with earth fault relay in order to be more effective in the protection system. Besides sensing the over current, the system can monitor and isolate the earth fault current.

5.4 Cost and Commercialization

This part will describe the parts and overall cost of fabricating the Over Current Protection Relay Using PIC micro Controller. This part also will explain the commercialization of project.

5.4.1 Project Costing

Table 5.1: The cost of components

Devices	Qty	Model	Unit	Manufacturer	Unit Cost (RM)	Extended Cost (RM)
Capacitor	12		0.1uF		RM 0.15	RM 1.80
Capacitor	2		15pF		RM 0.15	RM 0.30
Capacitor	3		100uF		RM 0.15	RM 0.45
Capacitor	3		22uF		RM 0.15	RM 0.45
Capacitor	1		10nF		RM 0.15	RM 0.15
Crystal	1		4MHz		RM 2.00	RM 2.00
Current Transducer	1	ACS754 LCB-050-PFF	50A Rating	Allegro Microsystem	RM 34.36	RM 34.36

Diode	1	1N414S			RM 0.50	RM 0.50
LCD	1	2X16 JHD16A			RM 15.00	RM 15.00
PIC	1	16F877A		Microchip	RM 26.00	RM 26.00
Potentiometer	1		20KΩ		RM 3.00	RM 3.00
Relay	1		5V-240V AC		RM 5.00	RM 5.00
Resistor	8		10KΩ		RM 0.10	RM 0.80
Resistor	2		4.7KΩ		RM 0.10	RM 0.20
Transistor NPN	1	QBC547			RM 0.50	RM 0.50
Voltage Regulator	1	LM 7805CT			RM 1.00	RM 1.00
Push Button Switch	5				RM 1.00	RM 1.00
					Total	**RM 92.51**

5.4.2 Commercialization

From the project costing, the overall cost to fabricate this Over current Protection Relay Using PIC micro Controller is about RM 92.51. This cost somewhat low because the components used were a basic components that can easily get in the market. This project can be upgraded as mentioned in future developments but the price may be increase a little bit but it still affordable compare to the real over current relay in the market which cost thousands.

This Over Current Relay can be commercialized in the three phase motor protection or small motors due to the maximum ampere (50 Amps) that this system can tolerate. If we want to apply it in the power system protection such as in distribution or feeder, the current sensor maximum ampere (input to over current relay) can be upgraded to the maximum 200Amps. The application on IDMT curves can also be improved with an additional of ‘Normal Inverse’ curves, ‘Very Inverse’ curve and ‘Extremely Inverse’ curve which it can be added by changing the programming in the PIC.

There are several boards in this project that using strips board like interfacing PIC to circuit breaker and current sensor circuit. So that the size of the over current relay designed in this project is quite large but the size can be reduced by using Printed Circuit Board (PCB) instead of using strip board. It will be an advantage when the designed circuit is small but have same capability with original circuit.

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[7] *PIC16F87X Data Sheet (PDF)*
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APPENDIX A

PIC16F87X

28/40-Pin 8-Bit CMOS FLASH Microcontrollers

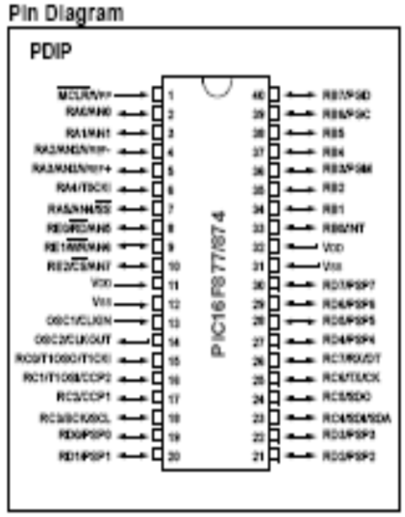
Devices Included in this Data Sheet:

- PIC16F873
- PIC16F874
- PIC16F876
- PIC16F877

Microcontroller Core Features:

- High performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM)
  Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low power, high speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial, Industrial and Extended temperature ranges
- Low-power consumption:
  - < 0.6 mA typical @ 3V, 4 MHz
  - 20 µA typical @ 3V, 32 kHz
  - < 1 µA typical standby current

Pin Diagram



Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during SLEEP via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I^{2}C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

Key Features PICmicro™ Mid-Range Reference Manual (DS33023)	PIC16F873	PIC16F874	PIC16F876	PIC16F877
Operating Frequency	DC - 20 MHz	DC - 20 MHz	DC - 20 MHz	DC - 20 MHz
RESETS (and Delays)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)
FLASH Program Memory (14-bit words)	4K	4K	8K	8K
Data Memory (bytes)	192	192	368	368
EEPROM Data Memory	128	128	256	256
Interrupts	13	14	13	14
I/O Ports	Ports A,B,C	Ports A,B,C,D,E	Ports A,B,C	Ports A,B,C,D,E
Timers	3	3	3	3
Capture/Compare/PWM Modules	2	2	2	2
Serial Communications	MSSP, USART	MSSP, USART	MSSP, USART	MSSP, USART
Parallel Communications	—	PSP	—	PSP
10-bit Analog-to-Digital Module	5 input channels	8 input channels	5 input channels	8 input channels
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions

1.0 DEVICE OVERVIEW

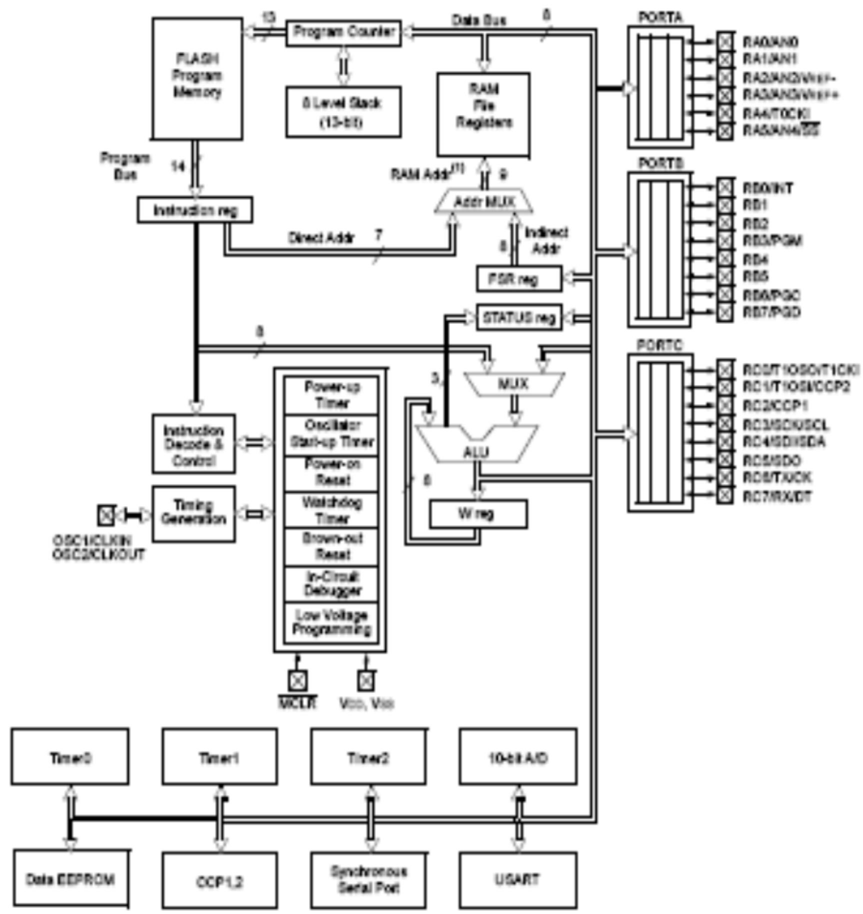
This document contains device specific information. Additional information may be found in the PICmicro™ Mid-Range Reference Manual (DS33023), which may be obtained from your local Microchip Sales Representative or downloaded from the Microchip website. The Reference Manual should be considered a complementary document to this data sheet, and is highly recommended reading for a better understanding of the device architecture and operation of the peripheral modules.

There are four devices (PIC16F873, PIC16F874, PIC16F876 and PIC16F877) covered by this data sheet. The PIC16F876/873 devices come in 28-pin packages and the PIC16F877/874 devices come in 40-pin packages. The Parallel Slave Port is not implemented on the 28-pin devices.

The following device block diagrams are sorted by pin number; 28-pin for Figure 1-1 and 40-pin for Figure 1-2. The 28-pin and 40-pin pinouts are listed in Table 1-1 and Table 1-2, respectively.

FIGURE 1-1: PIC16F873 AND PIC16F876 BLOCK DIAGRAM

Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	13	14	30	I	ST/CMOS[4]	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	14	15	31	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
$\overline{MCLR}$/VPP	1	2	18	I/P	ST	Master Clear (Reset) input or programming voltage input. This pin is an active low RESET to the device.
						PORTA is a bi-directional I/O port.
RA0/AN0	2	3	19	I/O	TTL	RA0 can also be analog input0.
RA1/AN1	3	4	20	I/O	TTL	RA1 can also be analog input1.
RA2/AN2/VREF-	4	5	21	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage.
RA3/AN3/VREF+	5	6	22	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage.
RA4/T0CKI	6	7	23	I/O	ST	RA4 can also be the clock input to the Timer0 timer/counter. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	8	24	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	I/O	TTL/ST[1]	RB0 can also be the external interrupt pin.
RB1	34	37	9	I/O	TTL	
RB2	35	38	10	I/O	TTL	
RB3/PGM	36	39	11	I/O	TTL	RB3 can also be the low voltage programming input.
RB4	37	41	14	I/O	TTL	Interrupt-on-change pin.
RB5	38	42	15	I/O	TTL	Interrupt-on-change pin.
RB6/PGC	39	43	16	I/O	TTL/ST[2]	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	40	44	17	I/O	TTL/ST[2]	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming data.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as an external interrupt.
2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.
3: This buffer is a Schmitt Trigger input when configured as general purpose I/O and a TTL input when used in the Parallel Slave Port mode (for interfacing to a microprocessor bus).
4: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION (CONTINUED)

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	I/O/P Type	Buffer Type	Description
						PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	15	16	32	I/O	ST	RC0 can also be the Timer1 oscillator output or a Timer1 clock input.
RC1/T1OSI/CCP2	16	18	35	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	17	19	36	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	18	20	37	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I^2C modes.
RC4/SDI/SDA	23	25	42	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).
RC5/SDO	24	26	43	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	25	27	44	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	26	29	1	I/O	ST	RC7 can also be the USART Asynchronous Receive or Synchronous Data.
						PORTD is a bi-directional I/O port or parallel slave port when interfacing to a microprocessor bus.
RD0/PSP0	19	21	38	I/O	ST/TTL(3)	
RD1/PSP1	20	22	39	I/O	ST/TTL(3)	
RD2/PSP2	21	23	40	I/O	ST/TTL(3)	
RD3/PSP3	22	24	41	I/O	ST/TTL(3)	
RD4/PSP4	27	30	2	I/O	ST/TTL(3)	
RD5/PSP5	28	31	3	I/O	ST/TTL(3)	
RD6/PSP6	29	32	4	I/O	ST/TTL(3)	
RD7/PSP7	30	33	5	I/O	ST/TTL(3)	
						PORTE is a bi-directional I/O port.
RE0/$\overline{RD}$/AN5	8	9	25	I/O	ST/TTL(3)	RE0 can also be read control for the parallel slave port, or analog input5.
RE1/$\overline{WR}$/AN6	9	10	26	I/O	ST/TTL(3)	RE1 can also be write control for the parallel slave port, or analog input6.
RE2/$\overline{CS}$/AN7	10	11	27	I/O	ST/TTL(3)	RE2 can also be select control for the parallel slave port, or analog input7.
VSS	12,31	13,34	6,29	P	—	Ground reference for logic and I/O pins.
VDD	11,32	12,35	7,28	P	—	Positive supply for logic and I/O pins.
NC	—	1,17,28, 40	12,13, 33,34		—	These pins are not internally connected. These pins should be left unconnected.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as an external interrupt.
2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.
3: This buffer is a Schmitt Trigger input when configured as general purpose I/O and a TTL input when used in the Parallel Slave Port mode (for interfacing to a microprocessor bus).
4: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

3.0 I/O PORTS

Some pins for these I/O ports are multiplexed with an alternate function for the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin.

Additional information on I/O ports may be found in the PICmicro™ Mid-Range Reference Manual, (DS33023).

3.1 PORTA and the TRISA Register

PORTA is a 6-bit wide, bi-directional port. The corresponding data direction register is TRISA. Setting a TRISA bit (= 1) will make the corresponding PORTA pin an input (i.e., put the corresponding output driver in a Hi-Impedance mode). Clearing a TRISA bit (= 0) will make the corresponding PORTA pin an output (i.e., put the contents of the output latch on the selected pin).

Reading the PORTA register reads the status of the pins, whereas writing to it will write to the port latch. All write operations are read-modify-write operations. Therefore, a write to a port implies that the port pins are read, the value is modified and then written to the port data latch.

Pin RA4 is multiplexed with the Timer0 module clock input to become the RA4/T0CKI pin. The RA4/T0CKI pin is a Schmitt Trigger input and an open drain output. All other PORTA pins have TTL input levels and full CMOS output drivers.

Other PORTA pins are multiplexed with analog inputs and analog VREF input. The operation of each pin is selected by clearing/setting the control bits in the ADCON1 register (A/D Control Register1).

Note:	On a Power-on Reset, these pins are configured as analog inputs and read as '0'.

The TRISA register controls the direction of the RA pins, even when they are being used as analog inputs. The user must ensure the bits in the TRISA register are maintained set when using them as analog inputs.

EXAMPLE 3-1: INITIALIZING PORTA

```
BCF     STATUS, RP0   ;
BCF     STATUS, RP1   ; Bank0
CLRF    PORTA         ; Initialize PORTA by
                      ; clearing output
                      ; data latches
BSF     STATUS, RP0   ; Select Bank 1
MOVLW   0x06          ; Configure all pins
MOVWF   ADCON1        ; as digital inputs
MOVLW   0xCF          ; Value used to
                      ; initialize data
                      ; direction
MOVWF   TRISA         ; Set RA<3:0> as inputs
                      ; RA<5:4> as outputs
                      ; TRISA<7:6>are always
                      ; read as '0'.
```

FIGURE 3-1: BLOCK DIAGRAM OF RA3:RA0 AND RA5 PINS

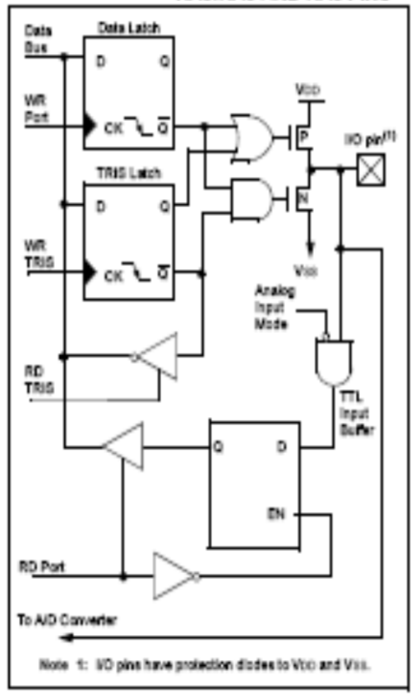


FIGURE 3-2: BLOCK DIAGRAM OF RA4/T0CKI PIN

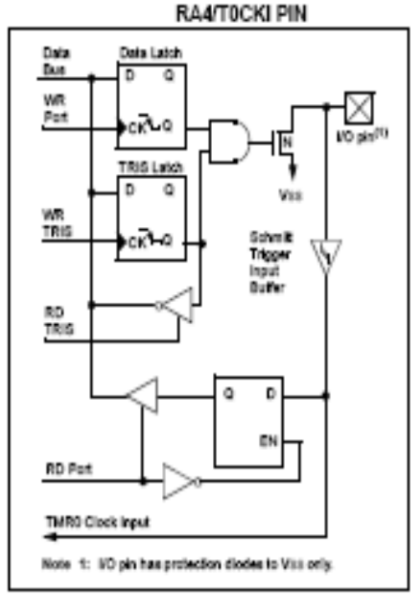


TABLE 3-1: PORTA FUNCTIONS

Name	Bit#	Buffer	Function
RA0/AN0	bit0	TTL	Input/output or analog input.
RA1/AN1	bit1	TTL	Input/output or analog input.
RA2/AN2	bit2	TTL	Input/output or analog input.
RA3/AN3/VREF	bit3	TTL	Input/output or analog input or VREF.
RA4/T0CKI	bit4	ST	Input/output or external clock input for Timer0. Output is open drain type.
RA5/$\overline{SS}$/AN4	bit5	TTL	Input/output or slave select input for synchronous serial port or analog input.

Legend: TTL = TTL input, ST = Schmitt Trigger input

TABLE 3-2: SUMMARY OF REGISTERS ASSOCIATED WITH PORTA

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other RESETS
05h	PORTA	—	—	RA5	RA4	RA3	RA2	RA1	RA0	--0x 0000	--0u 0000
85h	TRISA	—	—	PORTA Data Direction Register						--11 1111	--11 1111
9Fh	ADCON1	ADFM	—	—	—	PCFG3	PCFG2	PCFG1	PCFG0	--0- 0000	--0- 0000

Legend: x = unknown, u = unchanged, - = unimplemented locations read as '0'.
Shaded cells are not used by PORTA.

Note: When using the SSP module in SPI Slave mode and $\overline{SS}$ enabled, the A/D converter must be set to one of the following modes, where PCFG3:PCFG0 = 0100, 0101, 011x, 1101, 1110, 1111.

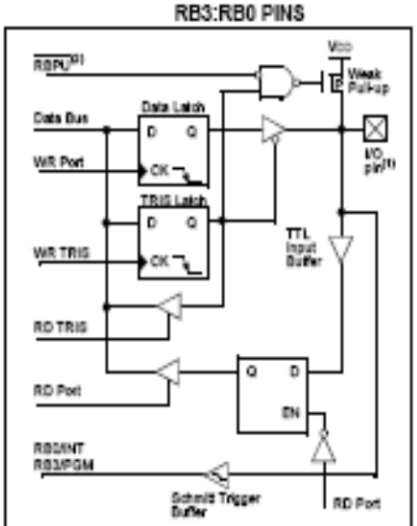
3.2 PORTB and the TRISB Register

PORTB is an 8-bit wide, bi-directional port. The corresponding data direction register is TRISB. Setting a TRISB bit (= 1) will make the corresponding PORTB pin an input (i.e., put the corresponding output driver in a Hi-Impedance mode). Clearing a TRISB bit (= 0) will make the corresponding PORTB pin an output (i.e., put the contents of the output latch on the selected pin).

Three pins of PORTB are multiplexed with the Low Voltage Programming function: RB3/PGM, RB6/PGC and RB7/PGD. The alternate functions of these pins are described in the Special Features Section.

Each of the PORTB pins has a weak internal pull-up. A single control bit can turn on all the pull-ups. This is performed by clearing bit RBPU (OPTION_REG<7>). The weak pull-up is automatically turned off when the port pin is configured as an output. The pull-ups are disabled on a Power-on Reset.

FIGURE 3-3: BLOCK DIAGRAM OF RB3:RB0 PINS



Note 1: I/O pins have diode protection to VDD and VSS.

2: To enable weak pull-ups, set the appropriate TRIS bit(s) and clear the RBPU bit (OPTION_REG<7>).

Four of the PORTB pins, RB7:RB4, have an interrupt-on-change feature. Only pins configured as inputs can cause this interrupt to occur (i.e., any RB7:RB4 pin configured as an output is excluded from the interrupt-on-change comparison). The input pins (of RB7:RB4) are compared with the old value latched on the last read of PORTB. The "mismatch" outputs of RB7:RB4 are OR'ed together to generate the RB Port Change Interrupt with flag bit RBIF (INTCON<0>).

This interrupt can wake the device from SLEEP. The user, in the Interrupt Service Routine, can clear the interrupt in the following manner:

a) Any read or write of PORTB. This will end the mismatch condition.
b) Clear flag bit RBIF.

A mismatch condition will continue to set flag bit RBIF. Reading PORTB will end the mismatch condition and allow flag bit RBIF to be cleared.

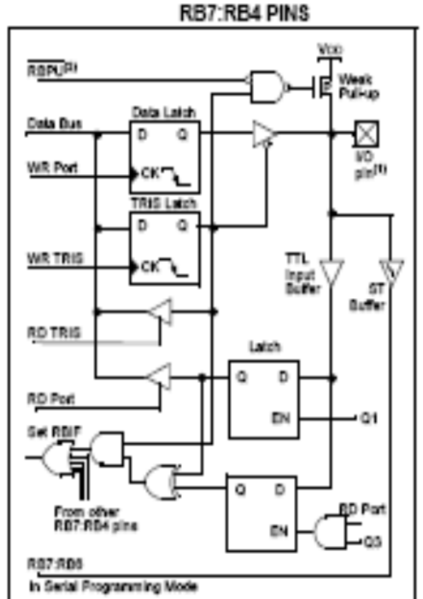
The interrupt-on-change feature is recommended for wake-up on key depression operation and operations where PORTB is only used for the interrupt-on-change feature. Polling of PORTB is not recommended while using the interrupt-on-change feature.

This interrupt-on-mismatch feature, together with software configureable pull-ups on these four pins, allow easy interface to a keypad and make it possible for wake-up on key depression. Refer to the Embedded Control Handbook, *"Implementing Wake-up on Key Strokes"* (AN552).

RB0/INT is an external interrupt input pin and is configured using the INTEDG bit (OPTION_REG<6>).

RB0/INT is discussed in detail in Section 12.10.1.

FIGURE 3-4: BLOCK DIAGRAM OF RB7:RB4 PINS



Note 1: I/O pins have diode protection to VDD and VSS.

2: To enable weak pull-ups, set the appropriate TRIS bit(s) and clear the RBPU bit (OPTION_REG<7>).

TABLE 3-3: PORTB FUNCTIONS

Name	Bit#	Buffer	Function
RB0/INT	bit0	TTL/ST[1]	Input/output pin or external interrupt input. Internal software programmable weak pull-up.
RB1	bit1	TTL	Input/output pin. Internal software programmable weak pull-up.
RB2	bit2	TTL	Input/output pin. Internal software programmable weak pull-up.
RB3/PGM[3]	bit3	TTL	Input/output pin or programming pin in LVP mode. Internal software programmable weak pull-up.
RB4	bit4	TTL	Input/output pin (with interrupt-on-change). Internal software programmable weak pull-up.
RB5	bit5	TTL	Input/output pin (with interrupt-on-change). Internal software programmable weak pull-up.
RB6/PGC	bit6	TTL/ST[2]	Input/output pin (with interrupt-on-change) or In-Circuit Debugger pin. Internal software programmable weak pull-up. Serial programming clock.
RB7/PGD	bit7	TTL/ST[2]	Input/output pin (with interrupt-on-change) or In-Circuit Debugger pin. Internal software programmable weak pull-up. Serial programming data.

Legend: TTL = TTL input, ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.

2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.

3: Low Voltage ICSP Programming (LVP) is enabled by default, which disables the RB3 I/O function. LVP must be disabled to enable RB3 as an I/O pin and allow maximum compatibility to the other 28-pin and 40-pin mid-range devices.

TABLE 3-4: SUMMARY OF REGISTERS ASSOCIATED WITH PORTB

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other RESETS
06h, 106h	PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0	xxxx xxxx	uuuu uuuu
86h, 186h	TRISB	PORTB Data Direction Register								1111 1111	1111 1111
81h, 181h	OPTION_REG	RBPU	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0	1111 1111	1111 1111

Legend: x = unknown, u = unchanged. Shaded cells are not used by PORTB.

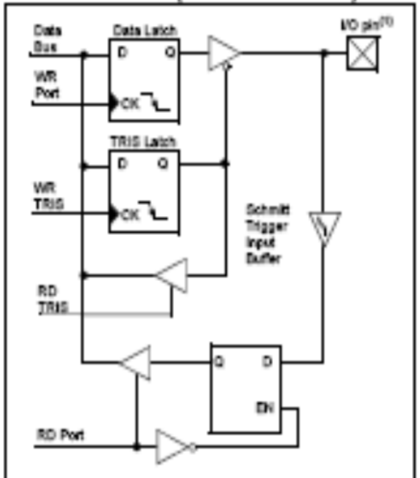
3.4 PORTD and TRISD Registers

PORTD and TRISD are not implemented on the PIC16F873 or PIC16F876.

PORTD is an 8-bit port with Schmitt Trigger input buffers. Each pin is individually configureable as an input or output.

PORTD can be configured as an 8-bit wide microprocessor port (parallel slave port) by setting control bit PSPMODE (TRISE<4>). In this mode, the input buffers are TTL.

FIGURE 3-7: PORTD BLOCK DIAGRAM (IN I/O PORT MODE)



Note 1: I/O pins have protection diodes to VDD and VSS.

TABLE 3-7: PORTD FUNCTIONS

Name	Bit#	Buffer Type	Function
RD0/PSP0	bit0	ST/TTL(1)	Input/output port pin or parallel slave port bit0.
RD1/PSP1	bit1	ST/TTL(1)	Input/output port pin or parallel slave port bit1.
RD2/PSP2	bit2	ST/TTL(1)	Input/output port pin or parallel slave port bit2.
RD3/PSP3	bit3	ST/TTL(1)	Input/output port pin or parallel slave port bit3.
RD4/PSP4	bit4	ST/TTL(1)	Input/output port pin or parallel slave port bit4.
RD5/PSP5	bit5	ST/TTL(1)	Input/output port pin or parallel slave port bit5.
RD6/PSP6	bit6	ST/TTL(1)	Input/output port pin or parallel slave port bit6.
RD7/PSP7	bit7	ST/TTL(1)	Input/output port pin or parallel slave port bit7.

Legend: ST = Schmitt Trigger input, TTL = TTL input
Note 1: Input buffers are Schmitt Triggers when in I/O mode and TTL buffers when in Parallel Slave Port mode.

TABLE 3-8: SUMMARY OF REGISTERS ASSOCIATED WITH PORTD

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other RESETS
08h	PORTD	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD0	xxxx xxxx	uuuu uuuu
88h	TRISD	PORTD Data Direction Register								1111 1111	1111 1111
89h	TRISE	IBF	OBF	IBOV	PSPMODE	—	PORTE Data Direction Bits			0000 -111	0000 -111

Legend: x = unknown, u = unchanged, - = unimplemented, read as '0'. Shaded cells are not used by PORTD.

3.5 PORTE and TRISE Register

PORTE and TRISE are not implemented on the PIC16F873 or PIC16F876.

PORTE has three pins (RE0/$\overline{RD}$/AN5, RE1/$\overline{WR}$/AN6, and RE2/$\overline{CS}$/AN7) which are individually configureable as inputs or outputs. These pins have Schmitt Trigger input buffers.

The PORTE pins become the I/O control inputs for the microprocessor port when bit PSPMODE (TRISE<4>) is set. In this mode, the user must make certain that the TRISE<2:0> bits are set, and that the pins are configured as digital inputs. Also ensure that ADCON1 is configured for digital I/O. In this mode, the input buffers are TTL.

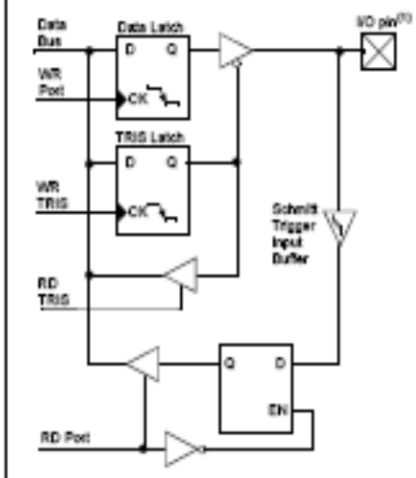
Register 3-1 shows the TRISE register, which also controls the parallel slave port operation.

PORTE pins are multiplexed with analog inputs. When selected for analog input, these pins will read as '0's.

TRISE controls the direction of the RE pins, even when they are being used as analog inputs. The user must make sure to keep the pins configured as inputs when using them as analog inputs.

Note:	On a Power-on Reset, these pins are configured as analog inputs, and read as '0'.

FIGURE 3-8: PORTE BLOCK DIAGRAM (IN I/O PORT MODE)



Note 1: I/O pins have protection diodes to VDD and VSS.

TABLE 3-9: PORTE FUNCTIONS

Name	Bit#	Buffer Type	Function
RE0/$\overline{RD}$/AN5	bit0	ST/TTL(1)	I/O port pin or read control input in Parallel Slave Port mode or analog input: $\overline{RD}$ 1 = Idle 0 = Read operation. Contents of PORTD register are output to PORTD I/O pins (if chip selected)
RE1/$\overline{WR}$/AN6	bit1	ST/TTL(1)	I/O port pin or write control input in Parallel Slave Port mode or analog input: $\overline{WR}$ 1 = Idle 0 = Write operation. Value of PORTD I/O pins is latched into PORTD register (if chip selected)
RE2/$\overline{CS}$/AN7	bit2	ST/TTL(1)	I/O port pin or chip select control input in Parallel Slave Port mode or analog input: $\overline{CS}$ 1 = Device is not selected 0 = Device is selected

Legend: ST = Schmitt Trigger input, TTL = TTL input
Note 1: Input buffers are Schmitt Triggers when in I/O mode and TTL buffers when in Parallel Slave Port mode.

TABLE 3-10: SUMMARY OF REGISTERS ASSOCIATED WITH PORTE

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other RESETS
09h	PORTE	—	—	—	—	—	RE2	RE1	RE0	---- -xxx	---- -uuu
89h	TRISE	IBF	OBF	IBOV	PSPMODE	—	PORTE Data Direction Bits			0000 -111	0000 -111
9Fh	ADCON1	ADFM	—	—	—	PCFG3	PCFG2	PCFG1	PCFG0	--0- 0000	--0- 0000

Legend: x = unknown, u = unchanged, - = unimplemented, read as '0'. Shaded cells are not used by PORTE.

REGISTER 3-1: TRISE REGISTER (ADDRESS 89h)

R-0	R-0	R/W-0	R/W-0	U-0	R/W-1	R/W-1	R/W-1
IBF	OBF	IBOV	PSPMODE	—	Bit2	Bit1	Bit0
bit 7							bit 0

Parallel Slave Port Status/Control Bits:

bit 7 **IBF**: Input Buffer Full Status bit
1 = A word has been received and is waiting to be read by the CPU
0 = No word has been received

bit 6 **OBF**: Output Buffer Full Status bit
1 = The output buffer still holds a previously written word
0 = The output buffer has been read

bit 5 **IBOV**: Input Buffer Overflow Detect bit (in Microprocessor mode)
1 = A write occurred when a previously input word has not been read (must be cleared in software)
0 = No overflow occurred

bit 4 **PSPMODE**: Parallel Slave Port Mode Select bit
1 = PORTD functions in Parallel Slave Port mode
0 = PORTD functions in general purpose I/O mode

bit 3 **Unimplemented:** Read as '0'

PORTE Data Direction Bits:

bit 2 **Bit2**: Direction Control bit for pin RE2/$\overline{CS}$/AN7
1 = Input
0 = Output

bit 1 **Bit1**: Direction Control bit for pin RE1/$\overline{WR}$/AN6
1 = Input
0 = Output

bit 0 **Bit0**: Direction Control bit for pin RE0/$\overline{RD}$/AN5
1 = Input
0 = Output

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

11.0 ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

The Analog-to-Digital (A/D) Converter module has five inputs for the 28-pin devices and eight for the other devices.

The analog input charges a sample and hold capacitor. The output of the sample and hold capacitor is the input into the converter. The converter then generates a digital result of this analog level via successive approximation. The A/D conversion of the analog input signal results in a corresponding 10-bit digital number. The A/D module has high and low voltage reference input that is software selectable to some combination of V_{DD}, V_{SS}, RA2, or RA3.

The A/D converter has a unique feature of being able to operate while the device is in SLEEP mode. To operate in SLEEP, the A/D clock must be derived from the A/D's internal RC oscillator.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register0 (ADCON0)
- A/D Control Register1 (ADCON1)

The ADCON0 register, shown in Register 11-1, controls the operation of the A/D module. The ADCON1 register, shown in Register 11-2, configures the functions of the port pins. The port pins can be configured as analog inputs (RA3 can also be the voltage reference), or as digital I/O.

Additional information on using the A/D module can be found in the PICmicro™ Mid-Range MCU Family Reference Manual (DS33023).

REGISTER 11-1: ADCON0 REGISTER (ADDRESS: 1Fh)

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{DONE}$	—	ADON
bit 7							bit 0

bit 7-6 **ADCS1:ADCS0:** A/D Conversion Clock Select bits
00 = Fosc/2
01 = Fosc/8
10 = Fosc/32
11 = FRC (clock derived from the internal A/D module RC oscillator)

bit 5-3 **CHS2:CHS0:** Analog Channel Select bits
000 = channel 0, (RA0/AN0)
001 = channel 1, (RA1/AN1)
010 = channel 2, (RA2/AN2)
011 = channel 3, (RA3/AN3)
100 = channel 4, (RA5/AN4)
101 = channel 5, (RE0/AN5)(1)
110 = channel 6, (RE1/AN6)(1)
111 = channel 7, (RE2/AN7)(1)

bit 2 **GO/$\overline{DONE}$:** A/D Conversion Status bit
If ADON = 1:
1 = A/D conversion in progress (setting this bit starts the A/D conversion)
0 = A/D conversion not in progress (this bit is automatically cleared by hardware when the A/D conversion is complete)

bit 1 **Unimplemented:** Read as '0'

bit 0 **ADON:** A/D On bit
1 = A/D converter module is operating
0 = A/D converter module is shut-off and consumes no operating current

Note 1: These channels are not available on PIC16F873/876 devices.

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

REGISTER 11-2: ADCON1 REGISTER (ADDRESS 9Fh)

U-0	U-0	R/W-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	—	—	—	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

bit 7 **ADFM:** A/D Result Format Select bit
1 = Right justified. 6 Most Significant bits of ADRESH are read as '0'.
0 = Left justified. 6 Least Significant bits of ADRESL are read as '0'.

bit 6-4 **Unimplemented:** Read as '0'

bit 3-0 **PCFG3:PCFG0:** A/D Port Configuration Control bits:

PCFG3: PCFG0	AN7[1] RE2	AN6[1] RE1	AN5[1] RE0	AN4 RA5	AN3 RA3	AN2 RA2	AN1 RA1	AN0 RA0	V_{REF+}	V_{REF-}	CHAN/ Refs[2]
0000	A	A	A	A	A	A	A	A	V_{DD}	V_{SS}	8/0
0001	A	A	A	A	V_{REF+}	A	A	A	RA3	V_{SS}	7/1
0010	D	D	D	A	A	A	A	A	V_{DD}	V_{SS}	5/0
0011	D	D	D	A	V_{REF+}	A	A	A	RA3	V_{SS}	4/1
0100	D	D	D	D	A	D	A	A	V_{DD}	V_{SS}	3/0
0101	D	D	D	D	V_{REF+}	D	A	A	RA3	V_{SS}	2/1
011x	D	D	D	D	D	D	D	D	V_{DD}	V_{SS}	0/0
1000	A	A	A	A	V_{REF+}	V_{REF-}	A	A	RA3	RA2	6/2
1001	D	D	A	A	A	A	A	A	V_{DD}	V_{SS}	6/0
1010	D	D	A	A	V_{REF+}	A	A	A	RA3	V_{SS}	5/1
1011	D	D	A	A	V_{REF+}	V_{REF-}	A	A	RA3	RA2	4/2
1100	D	D	D	A	V_{REF+}	V_{REF-}	A	A	RA3	RA2	3/2
1101	D	D	D	D	V_{REF+}	V_{REF-}	A	A	RA3	RA2	2/2
1110	D	D	D	D	D	D	D	A	V_{DD}	V_{SS}	1/0
1111	D	D	D	D	V_{REF+}	V_{REF-}	D	A	RA3	RA2	1/2

A = Analog input D = Digital I/O

Note 1: These channels are not available on PIC16F873/876 devices.
2: This column indicates the number of analog channels available as A/D inputs and the number of analog channels used as voltage reference inputs.

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

The ADRESH:ADRESL registers contain the 10-bit result of the A/D conversion. When the A/D conversion is complete, the result is loaded into this A/D result register pair, the GO/$\overline{DONE}$ bit (ADCON0<2>) is cleared and the A/D interrupt flag bit ADIF is set. The block diagram of the A/D module is shown in Figure 11-1.

After the A/D module has been configured as desired, the selected channel must be acquired before the conversion is started. The analog input channels must have their corresponding TRIS bits selected as inputs.

To determine sample time, see Section 11.1. After this acquisition time has elapsed, the A/D conversion can be started.

11.2 Selecting the A/D Conversion Clock

The A/D conversion time per bit is defined as T_{AD}. The A/D conversion requires a minimum $12T_{AD}$ per 10-bit conversion. The source of the A/D conversion clock is software selected. The four possible options for T_{AD} are:

- $2T_{OSC}$
- $8T_{OSC}$
- $32T_{OSC}$
- Internal A/D module RC oscillator (2-6 µs)

For correct A/D conversions, the A/D conversion clock (T_{AD}) must be selected to ensure a minimum T_{AD} time of 1.6 µs.

Table 11-1 shows the resultant T_{AD} times derived from the device operating frequencies and the A/D clock source selected.

TABLE 11-1: T_{AD} vs. MAXIMUM DEVICE OPERATING FREQUENCIES (STANDARD DEVICES (C))

AD Clock Source (T_{AD})		Maximum Device Frequency
Operation	**ADCS1:ADCS0**	**Max.**
$2T_{OSC}$	00	1.25 MHz
$8T_{OSC}$	01	5 MHz
$32T_{OSC}$	10	20 MHz
RC[1, 2, 3]	11	(Note 1)

Note 1: The RC source has a typical T_{AD} time of 4 µs, but can vary between 2-6 µs.

2: When the device frequencies are greater than 1 MHz, the RC A/D conversion clock source is only recommended for SLEEP operation.

3: For extended voltage devices (LC), please refer to the Electrical Characteristics (Sections 15.1 and 15.2).

11.3 Configuring Analog Port Pins

The ADCON1 and TRIS registers control the operation of the A/D port pins. The port pins that are desired as analog inputs must have their corresponding TRIS bits set (input). If the TRIS bit is cleared (output), the digital output level (V_{OH} or V_{OL}) will be converted.

The A/D operation is independent of the state of the CHS2:CHS0 bits and the TRIS bits.

Note 1: When reading the port register, any pin configured as an analog input channel will read as cleared (a low level). Pins configured as digital inputs will convert an analog input. Analog levels on a digitally configured input will not affect the conversion accuracy.

2: Analog levels on any pin that is defined as a digital input (including the AN7:AN0 pins), may cause the input buffer to consume current that is out of the device specifications.

APPENDIX B

ACS754xCB-050

Fully Integrated, Hall Effect-Based Linear Current Sensor with High Voltage Isolation and a Low-Resistance Current Conductor

Features and Benefits

- Monolithic Hall IC for high reliability
- Single +5 V supply
- 3 kV_{RMS} isolation voltage between terminals 4/5 and pins 1/2/3 for up to 1 minute
- 35 kHz bandwidth
- Automotive temperature range
- End-of-line factory-trimmed for gain and offset
- Ultra-low power loss: 100 μΩ internal conductor resistance
- Ratiometric output from supply voltage
- Extremely stable output offset voltage
- Small package size, with easy mounting capability
- Output proportional to AC and DC currents

Package: 5 pin module (leadform PFF)

Description

The Allegro ACS75x family of current sensors provides economical and precise solutions for current sensing in industrial, automotive, commercial, and communications systems. The device package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, power supplies, and overcurrent fault protection.

The device consists of a precision, low-offset linear Hall sensor circuit with a copper conduction path located near the die. Applied current flowing through this copper conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy at the factory.

The output of the device has a positive slope (>V_{CC} / 2) when an increasing current flows through the primary copper conduction path (from terminal 4 to terminal 5), which is the path used for current sensing. The internal resistance of this conductive path is typically 100 μΩ, providing low power loss. The thickness of the copper conductor allows survival of the device at up to

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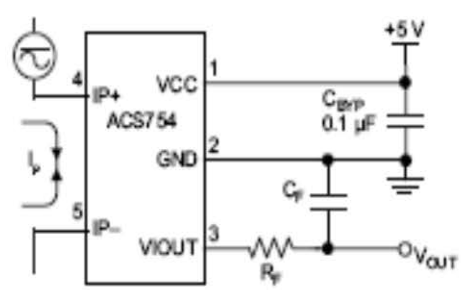
Typical Application



Application 1. The ACS754 outputs an analog signal, V_{OUT}, that varies linearly with the uni- or bi-directional AC or DC primary sensed current, I_P, within the range specified. C_F is recommended for noise management, with values that depend on the application.

Description (continued)

5× overcurrent conditions. The terminals of the conductive path are electrically isolated from the sensor leads (pins 1 through 3). This allows the ACS75x family of sensors to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques.

The device is fully calibrated prior to shipment from the factory. The ACS75x family is lead (Pb) free. All pins are coated with 100% matte tin, and there is no lead inside the package. The heavy gauge leadframe is made of oxygen-free copper.

Selection Guide

Part Number	T_{OP} (°C)	Primary Sensed Current, I_P (A)	Sensitivity Sens (Typ.) (mV/A)	Package		Packing[1]
				Terminals	Signal Pins	
ACS754LCB-050-PFF	–40 to 150	±50	40	Formed	Formed	Bulk, 170 pieces/bag
ACS754SCB-050-PFF[2]	–20 to 85	±50	40	Formed	Formed	

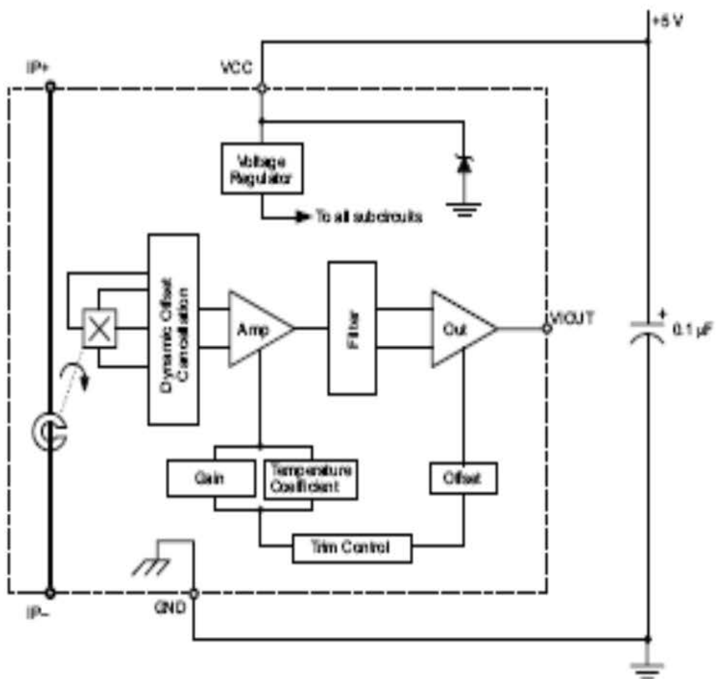
[1]Contact Allegro for additional packing options.
[2]Variant is in production but has been determined to be NOT FOR NEW DESIGN. This classification indicates that sale of the variant is currently restricted to existing customer applications. The variant should not be purchased for new design applications because obsolescence in the near future is probable. Samples are no longer available. Status change: April 28, 2008.

Absolute Maximum Ratings

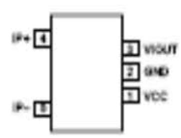
Characteristic	Symbol	Notes	Rating	Units
Supply Voltage	V_{CC}		16	V
Reverse Supply Voltage	V_{RCC}		–16	V
Output Voltage	V_{IOUT}		16	V
Reverse Output Voltage	V_{RIOUT}		–0.1	V
Maximum Basic Isolation Voltage	V_{ISO}		353 VAC, 500 VDC, or V_{pk}	V
Maximum Rated Input Current	I_{IN}		200	A
Output Current Source	$I_{OUT(Source)}$		3	mA
Output Current Sink	$I_{OUT(Sink)}$		10	mA
Nominal Operating Ambient Temperature	T_A	Range L	–40 to 150	°C
		Range S	–20 to 85	°C
Maximum Junction	$T_J(max)$		165	°C
Storage Temperature	T_{stg}		–65 to 170	°C

TÜV America Certificate Number: U8V 04 11 54214 001	Fire and Electric Shock EN60950-1:2001

Functional Block Diagram



Pin-out Diagram



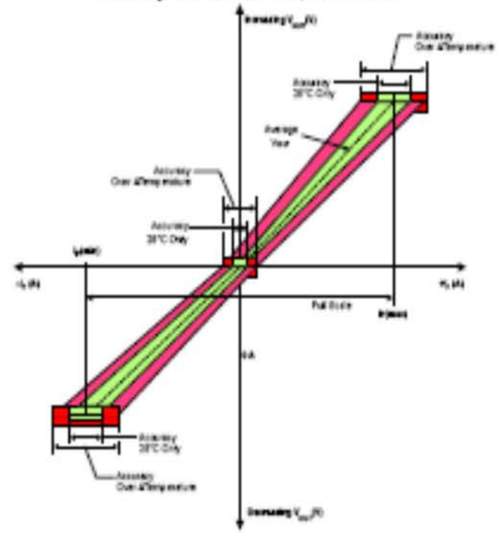
Terminal List Table

Number	Name	Description
1	VCC	Device power supply pin
2	GND	Signal ground pin
3	VIOUT	Analog output signal pin
4	IP+	Terminal for current being sensed
5	IP–	Terminal for current being sensed

ELECTRICAL CHARACTERISTICS, over operating ambient temperature range unless otherwise stated

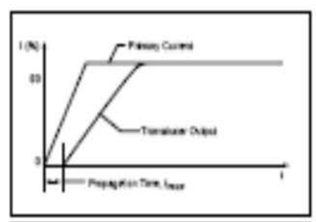
Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Primary Sensed Current	I_P		–50	–	50	A
Supply Voltage	V_{CC}		4.5	5.0	5.5	V
Supply Current	I_{CC}	V_{CC} = 5.0 V, output open	6.5	8	10	mA
Output Resistance	R_{OUT}	I_{OUT} = 1.2 mA	–	1	2	Ω
Output Capacitance Load	C_{LOAD}	VOUT to GND	–	–	10	nF
Output Resistive Load	R_{LOAD}	VOUT to GND	4.7	–	–	kΩ
Primary Conductor Resistance	$R_{PRIMARY}$	I_P = ±100A; T_A = 25°C	–	100	–	µΩ
		Pins 1-3 and 4-5; 60 Hz, 1 minute	3.0	–	–	kV
PERFORMANCE CHARACTERISTICS, -20°C to +85°C, V_{CC} = 5 V unless otherwise specified						
Propagation time	t_{PROP}	I_P = ±50 A, T_A = 25°C	–	4	–	µs
Response time	$t_{RESPONSE}$	I_P = ±50 A, T_A = 25°C	–	12	–	µs
Rise time	t_r	I_P = ±50 A, T_A = 25°C	–	11	–	µs
Frequency Bandwidth	f	–3 dB , T_A = 25°C	–	35	–	kHz
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	–	40	–	mV/A
		Over full range of I_P	37.8	–	42.0	mV/A
Noise	V_{NOISE}	Peak-to-peak, T_A = 25°C, no external filter	–	65	–	mV
Linearity	E_{LIN}	Over full range of I_P	–	–	±1.5	%
Symmetry	E_{SYM}	Over full range of I_P	98	100	102	%
Zero Current Output Voltage	$V_{OUT(Q)}$	I = 0 A, T_A = 25°C	–	V_{CC}/2	–	V
Electrical Offset Voltage (Magnetic error not included)	V_{OE}	I = 0 A, T_A = 25°C	–10	–	10	mV
		I = 0 A	–20	–	20	mV
Magnetic Offset Error	I_{ERROM}	I = 0 A, after excursion of 100 A	–	±0.1	±0.40	A
Total Output Error (Including all offsets)	E_{TOT}	Over full range of I_P, T_A = 25°C	–	±1.0	–	%
		Over full range of I_P	–	–	±5.0	%
PERFORMANCE CHARACTERISTICS, -40°C to +150°C, V_{CC} = 5 V unless otherwise specified						
Propagation time	t_{PROP}	I_P = ±50 A, T_A = 25°C	–	4	–	µs
Response time	$t_{RESPONSE}$	I_P = ±50 A, T_A = 25°C	–	12	–	µs
Rise time	t_r	I_P = ±50 A, T_A = 25°C	–	11	–	µs
Frequency Bandwidth	f	–3 dB , T_A = 25°C	–	35	–	kHz
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	–	40	–	mV/A
		Over full range of I_P	36.0	–	42.8	mV/A
Noise	V_{NOISE}	Peak-to-peak, T_A = 25°C, no external filter	–	65	–	mV
Linearity	E_{LIN}	Over full range of I_P	–	–	±1.8	%
Symmetry	E_{SYM}	Over full range of I_P	98	100	102	%
Zero Current Output Voltage	$V_{OUT(Q)}$	I = 0 A, T_A = 25°C	–	V_{CC}/2	–	V
Electrical Offset Voltage (Magnetic error not included)	V_{OE}	I = 0 A, T_A = 25°C	–10	–	10	mV
		I = 0 A	–35	–	35	mV
Magnetic Offset Error	I_{ERROM}	I = 0 A, after excursion of 100 A	–	±0.1	±0.40	A
Total Output Error (Including all offsets)	E_{TOT}	Over full range of I_P, T_A = 25°C	–	±1.0	–	%
		Over full range of I_P	–	–	±9.9	%

Output Voltage versus Sensed Current
Accuracy at 0 A and at Full-Scale Current

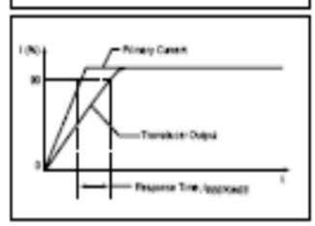


Definitions of Dynamic Response Characteristics

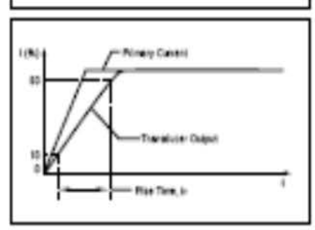
Propagation delay (t_{PROP}). The time required for the sensor output to reflect a change in the primary current signal. Propagation delay is attributed to inductive loading within the linear IC package, as well as in the inductive loop formed by the primary conductor geometry. Propagation delay can be considered as a fixed time offset and may be compensated.



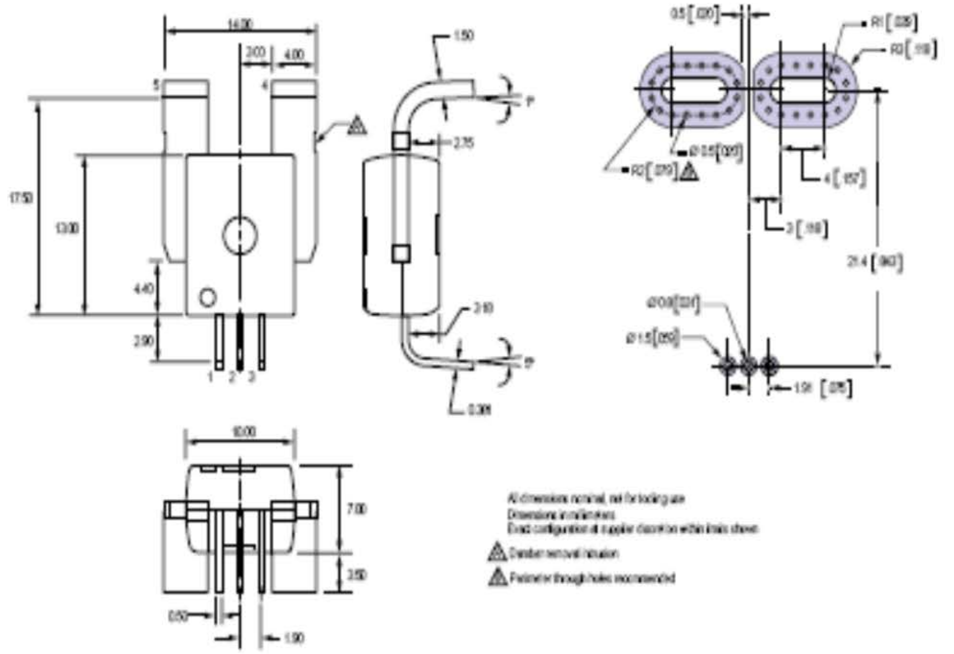
Response time ($t_{RESPONSE}$). The time interval between a) when the primary current signal reaches 90% of its final value, and b) when the sensor reaches 90% of its output corresponding to the applied current.



Rise time (t_r). The time interval between a) when the sensor reaches 10% of its full scale value, and b) when it reaches 90% of its full scale value. The rise time to a step response is used to derive the bandwidth of the current sensor, in which $f(-3\text{ dB}) = 0.35/t_r$. Both t_r and $t_{RESPONSE}$ are detrimentally affected by eddy current losses observed in the conductive IC ground plane.



Package CB, 5-pin module, leadform PFF



Creepage distance, current terminals to sensor pins: 7.25 mm
Clearance distance, current terminals to sensor pins: 7.25 mm
Package mass: 4.63 g typical

Package Branding

Two alternative patterns are used

ACS754 *RCBPPP* *YYWWA*	ACS	Allegro Current Sensor
	754	Device family number
	R	Operating ambient temperature range code
	CB	Package type designator
	PPP	Primary sensed current
	YY	Date code: Calendar year (last two digits)
	WW	Date code: Calendar week
	A	Date code: Shift code

ACS754 *RCBPPP* *L...L* *YYWW*	ACS	Allegro Current Sensor
	754	Device family number
	R	Operating ambient temperature range code
	CB	Package type designator
	PPP	Primary sensed current
	L...L	Lot code
	YY	Date code: Calendar year (last two digits)
	WW	Date code: Calendar week

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APPENDIX C

JHD162A SERIES

■CHARACTERISTICS: DISPLAY CONTENT: 16 CHAR x 2ROW

CHAR. DOTS: 5 x 8

DRIVING MODE: 1/16D

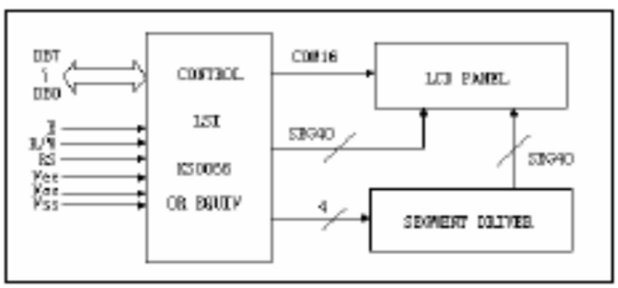
AVAILABLE TYPES:

TN, STN(YELLOW GREEN、GREY、B/W)
REFLECTIVE, WITH EL OR LED BACKLIGHT
EL/100VAC, 400HZ
LED/4.2VDC

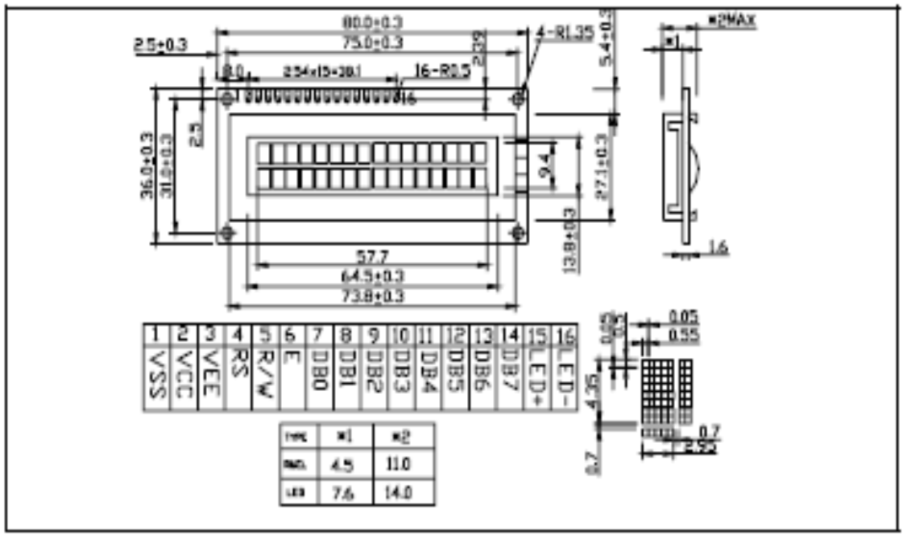
■PARAMETER (V_{DD}=5.0V±10%, V_{SS}=0V, T_a=25℃)

Parameter	Symbol	Testing Criteria	Standard Values			Unit
			Min.	Typ.	Max	
Supply voltage	V_{DD}-V_{SS}	-	4.5	5.0	5.5	V
Input high voltage	V_{IH}	-	2.2	-	V_{DD}	V
Input low voltage	V_{IL}	-	-0.3	-	0.6	V
Output high voltage	V_{OH}	$-I_{OH}$=02mA	2.4	-	-	V
Output low voltage	V_{OL}	I_{OL}=1.2mA	-	-	0.4	V
Operating voltage	I_{DD}	V_{DD}=5.0V	-	1.5	3.0	mA

■APPLICATION CIRCUIT



■DIMENSIONS/DISPLAY CONTENT



PIN CONFIGURATION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
VSS	Vcc	VEE	RS	R/W	E	DB0	DB1	DB2	DB3	DB4	DB5	DB6	DB7	LED+	LED-

AC Characteristics Read Mode Timing Diagram

Table 12. AC Characteristics (V_{DD} = 4.5V ~ 5.5V, Ta = -30 ~ +85°C)

Mode	Characteristic	Symbol	Min.	Typ.	Max.	Unit
Write Mode (Refer to Fig-6)	E Cycle Time	tc	500	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	20	
	E Pulse Width (High, Low)	tw	230	-	-	
	R/W and RS Setup Time	tsu1	40	-	-	
	R/W and RS Hold Time	t_{H1}	10	-	-	
	Data Setup Time	tsu2	80	-	-	
	Data Hold Time	t_{H2}	10	-	-	
Read Mode (Refer to Fig-7)	E Cycle Time	tc	500	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	20	
	E Pulse Width (High, Low)	tw	230	-	-	
	R/W and RS Setup Time	tsu	40	-	-	
	R/W and RS Hold Time	t_H	10	-	-	
	Data Output Delay Time	t_D	-	-	120	
	Data Hold Time	t_{DH}	5	-	-	

Table 13. AC Characteristics (V_{DD} =2.7V ~ 4.5V, Ta = -30 ~ +85°C)

Mode	Characteristic	Symbol	Min.	Typ.	Max.	Unit
Write Mode (Refer to Fig-6)	E Cycle Time	tc	1000	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	25	
	E Pulse Width (High, Low)	tw	450	-	-	
	R/W and RS Setup Time	tsu1	60	-	-	
	R/W and RS Hold Time	t_{H1}	20	-	-	
	Data Setup Time	tsu2	195	-	-	
	Data Hold Time	t_{H2}	10	-	-	
Read Mode (Refer to Fig-7)	E Cycle Time	tc	1000	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	25	
	E Pulse Width (High, Low)	tw	450	-	-	
	R/W and RS Setup Time	tsu	60	-	-	
	R/W and RS Hold Time	t_H	20	-	-	
	Data Output Delay Time	t_D	-	-	360	
	Data Hold Time	t_{DH}	5	-	-	

APPENDIX D

```
'**********************************************************
*
'*  Name    : Over current Relay Using PIC16F877A
'*  Author  : ZOOLNASRI BIN ABU HARUN
'*  Notice  : Copyright (c) 2008 [select VIEW...EDITOR OPTIONS]
'*          : All Rights Reserved
'*  Date    : 15/10/2008
'*  Version : 1.0
'*  Notes   : IEC/UK Long-time inverse-time curves
'**********************************************************
*
define osc 4

'---------LCD stuff------------------------
DEFINE LCD_DREG       PORTD
DEFINE LCD_DBIT       4
DEFINE LCD_RSREG      PORTE
DEFINE LCD_RSBIT      1
DEFINE LCD_EREG       PORTE
DEFINE LCD_EBIT       2
DEFINE LCD_BITS       4
DEFINE LCD_LINES      2
DEFINE LCD_COMMANDUS  2000
DEFINE LCD_DATAUS     10

' Define ADCIN parameters
Define  ADC_BITS        8       ' Set number of bits in result
Define  ADC_CLOCK       3       ' Set clock source (3=rc)
Define  ADC_SAMPLEUS    50      ' Set sampling time in uS

adcon1 = %00000100
ADCON0 = %11011101
trisd = 0                'set port D output
trisb = %00111100
trise = 0                'set port E output

'-----------Current sensor stuff-------------
t var byte
```

```
t0 var byte
t1 var byte
t2 var byte
t3 var byte
t4 var byte
t5 var byte
volts1 var word
volts2 var word
volts3 var word
volts4 var word
volts5 var word
conv1 con 19
conv2 con 60

'----------------number------------------------
tambah var byte
asal var byte
kira var byte
asal = 0
kira = 0
tambah1 var byte
asal1 var byte
kira1 var byte
asal1 = 0
kira1 = 0
tambah2 var byte
asal2 var byte
kira2 var byte
asal2 = 0
kira2 = 0

'-----------IDMT algorithm---------------------
second var word
second1 var byte
second2 var word
second3 var word
second5 var word
second5 = 0
TMS var word
tm var word
```

```
nisbah var word

'-----------Keypad & output---------------------
down var portb.2
up var portb.4
exit var portb.3
enter var portb.5
CB var portb.0
led var portb.1
low CB
low led

pause 500

main:
    low led
    low CB
    pause 100
    lcdout $fe,1

    lcdout $fe,$80+3, "ZOOLNASRI"
    lcdout $fe,$c0+3, "EE 04020"

    pause 3000
    lcdout $fe,1

    lcdout $fe,$80+3, "O/C RELAY"
    lcdout $fe,$c0, "USING PIC16F877A"
    pause 3000
    gosub set

goto main

set:                            'I> setting (IDMT)
    low led
    low CB
    tambah = kira + asal

    pause 100
    lcdout $fe,1
```

```
    lcdout $fe,$80, "I>=" ,dec2 tambah, " A," , "I>>=",dec2 tambah2,"
A"
    lcdout $fe,$c0+4, "TMS=0.", dec1 tambah1

    if down = 0 then loop
    if up = 0 then loop1
    if enter = 0 then set2
goto set

loop:
   kira = 1
   asal = tambah
goto set

loop1:
   kira = -1
   asal = tambah
goto set

set2:                     'I>> setting (instantaneous)
    tambah2 = kira2 + asal2

    pause 100
    lcdout $fe,1
    lcdout $fe,$80, "I>=" ,dec2 tambah, " A," , "I>>=",dec2 tambah2,"
A"
    lcdout $fe,$c0+4, "TMS=0.", dec1 tambah1

    if down = 0 then loop2
    if up = 0 then loop3
    if enter = 0 then set1
    if exit = 0 then set
goto set2

loop2:
   kira2 = 1
   asal2 = tambah2
goto set2

loop3:
```

```
   kira2 = -1
   asal2 = tambah2
goto set2


set1:                          'TMS setting
    tambah1 = kira1 + asal1

    pause 100
    lcdout $fe,1
    lcdout $fe,$80, "I>=" ,dec2 tambah, " A," , "I>>=",dec2 tambah2,"
A"
    lcdout $fe,$c0+4, "TMS=0.", dec1 tambah1

    if down = 0 then loop4
    if enter = 0 then menu1
    if exit = 0 then set2

goto set1

loop4:
   kira1 = 1
   asal1 = tambah1
   if asal1 = 9 then loop21
goto set1

loop21:
   asal1 = 0
   kira1 = 0
   tambah1 = 0
goto set1

menu1:
    second5 = 0

    low led
    low CB
    adcin 3,t1                  'ADCIN, get 5 sample and store as variable
    pause 15
    adcin 3,t2
```

```
pause 15
adcin 3,t3
pause 15
adcin 3,t4
pause 15
adcin 3,t5
pause 15

if t1>t2 then              'compare the highest
  IF T1>T3 THEN
    IF T1>T4 THEN
      IF T1>T5 THEN
        t = T1
      ELSE 'T5>T1
        t = T5
      ENDIF
    ELSE 'T4>T1
       IF T4>T5 THEN
         t = T4
       ELSE 'T5>T4
         t = T5
       ENDIF
    ENDIF
  ELSE  'T3>T1
    IF T3 > T4 THEN
      IF T3>T5 THEN
        t = T3
      ELSE 'T5>T3
        t = T5
      ENDIF
    ELSE  'T4>T3
      IF T4>T5 THEN
         t = T4
      ELSE 'T5>T4
         t = T5
      ENDIF
    ENDIF
  ENDIF
ELSE 'T2>T1
  IF T2>T3 THEN
```

```
      IF T2>T4 THEN
        IF T2>T5 THEN
          t = T2
        ELSE 'T5>T2
          t = T5
        ENDIF
      ELSE 'T4>T2
         IF T4>T5 THEN
           t = T4
         ELSE 'T5>T4
           t = T5
         ENDIF
      ENDIF
    ELSE  'T3>T2
      IF T3 > T4 THEN
        IF T3>T5 THEN
          t = T3
        ELSE 'T5>T3
          t = T5
        ENDIF
      ELSE  'T4>T3
        IF T4>T5 THEN
           t = T4
        ELSE 'T5>T4
           t = T5
        ENDIF
      ENDIF
    ENDIF
  ENDIF

  if t<129 then
     volts3=0
'
     pause 100
     lcdout $fe,1
     lcdout $fe,$80+3, "I=000.00 A"
     if exit = 0 then set

     else
```

```
        t0 = t-128
        volts1 = t0*conv1
        volts2 = t0*conv2
        volts2 = volts2/100
        volts1 = (volts1 + volts2) - 10     'offset voltage
        volts3 = volts1/40
        volts4 = volts1//40

        pause 100
        lcdout $fe,1
        lcdout $fe,$80+3, "I=" ,dec3 volts3, "." , dec2 volts4, " A"

    if volts3 > tambah2 then trip1       'compare setting current
    if volts3 > tambah then IDMT          'with energizing current
    if exit = 0 then set

    endif

goto menu1

IDMT:                           'IDMT calculation

    nisbah = volts1 / (4*tambah)
    tm = nisbah - 10
    TMS = (12000 / tm)*tambah1
    second2 = TMS*10
    second1 = second2/1000
    second = second2//1000

    pause 100
    lcdout $fe,1
    lcdout $fe,$80+2, "If=" ,dec3 volts3, "." , dec2 volts4, " A"
    lcdout $fe,$c0+2, "t(s)=", dec2 second1, ".", dec3 second

    gosub delay
goto IDMT

delay:                          'delay in seconds before trip
    second3 = 575 + second5
```

```
high led
pause 300
low led
pause 200

adcin 3,t1                    'ADCIN
pause 15
adcin 3,t2
pause 15
adcin 3,t3
pause 15
adcin 3,t4
pause 15
adcin 3,t5
pause 15

if t1>t2 then
  IF T1>T3 THEN
    IF T1>T4 THEN
      IF T1>T5 THEN
        t = T1
      ELSE 'T5>T1
        t = T5
      ENDIF
    ELSE 'T4>T1
       IF T4>T5 THEN
         t = T4
       ELSE 'T5>T4
         t = T5
       ENDIF
    ENDIF
  ELSE  'T3>T1
    IF T3 > T4 THEN
      IF T3>T5 THEN
        t = T3
      ELSE 'T5>T3
        t = T5
      ENDIF
    ELSE  'T4>T3
      IF T4>T5 THEN
```

```
          t = T4
        ELSE 'T5>T4
          t = T5
        ENDIF
      ENDIF
    ENDIF
  ELSE 'T2>T1
    IF T2>T3 THEN
      IF T2>T4 THEN
        IF T2>T5 THEN
          t = T2
        ELSE 'T5>T2
          t = T5
        ENDIF
      ELSE 'T4>T2
         IF T4>T5 THEN
          t = T4
         ELSE 'T5>T4
          t = T5
         ENDIF
      ENDIF
    ELSE  'T3>T2
      IF T3 > T4 THEN
        IF T3>T5 THEN
          t = T3
        ELSE 'T5>T3
          t = T5
        ENDIF
      ELSE  'T4>T3
        IF T4>T5 THEN
          t = T4
        ELSE 'T5>T4
          t = T5
        ENDIF
      ENDIF
    ENDIF
  ENDIF

  t0 = t-127
  volts1 = t0*conv1
```

```
    volts2 = t0*conv2
    volts2 = volts2/100
    volts1 = (volts1 + volts2)
    volts5 = volts1/40
    volts4 = volts1//40

    gosub saat
goto delay

saat:
    second5 = second3
    if second5 >= second2 then trip
    if volts5 > tambah2 then trip2
    if volts5 < tambah then menu1

goto delay

trip:                   'circuit breaker trip
    high CB
    pause 300

    gosub tamat
goto trip

tamat:
    low CB
    high led

    if enter = 0 then menu1
    if exit = 0 then set
goto tamat

trip1:                  'circuit breaker trip
    high CB
    pause 200

    pause 100
    lcdout $fe,1
    lcdout $fe,$80+2, "If=" ,dec3 volts3, "." , dec2 volts4, " A"
```

```
    gosub tamat1
goto trip1

tamat1:
    low CB
    high led

    if enter = 0 then menu1
    if exit = 0 then set
goto tamat1

trip2:                          'circuit breaker trip
    high CB
    pause 200

    pause 100
    lcdout $fe,1
    lcdout $fe,$80+2, "If=" ,dec3 volts5, "." , dec2 volts4, " A"

    gosub tamat2
goto trip2

tamat2:
    low CB
    high led

    if enter = 0 then menu1
    if exit = 0 then set
goto tamat2

end
```