DESIGN AND CONSTRUCTION OF AN ELECTRONIC THERMOSTATIC CONTROL FOR HEATING SYSTEMS

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BY

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BEING A THESIS SUBMITTED TO THE
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NOVEMBER, 2007

DECLARATION

I, Jibril A. Sefiyat, hereby declare that this project was wholly and solely conducted by me under the supervision and guidance of my supervisor, Mr. Abraham Usman.
Information obtained from published and unpublished works of others have been acknowledged accordingly.

Jibril A. Sefiyat

(Student)

(Signature & Date)

CERTIFICATION

I hereby declare that this work titled "ELECTRONIC THERMOSTATIC CONTROL FOR HEATING SYSTEMS" was done by me in partial fulfillment of the requirement for the award of the degree of B.Eng in Electrical and Computer Engineering of the Department of Electrical and Computer Engineering of the Federal University of Technology, Minna.

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DEDICATION

This project is dedicated to my beloved mother HAJIYA GOGO LANTANA for her relentless efforts and love in seeing me through this programme and all other endeavours in my life.

And

To the memory of my late grand mother, Hajiya Aminat Idris (Nna)

ACKNOWLEDGEMENT

First and foremost, I thank the Almighty Allah who, in His infinite mercies has been making my desirable goals possible for me to be achieved despite all odds.

A research of this nature would not have been possible and eventually successful without the helpful ideas and suggestions of my supervisor, Mr. Abraham Usman, his relentless guidance and encouragement has made this endeavor very challenging and interesting. I am also grateful to my humble and intelligent Head of Department, Engr. Abdullahi and the very distinguished lecturers of Electrical and Computer Engineering Department.

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My special appreciation goes to Shehu AbdulRahman for his special love and constant contributions to my achievements.

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Finally, but not the least, my special thanks go His Royal Highness, The Etsu Patigi, Alhaji Ibrahim Chatta Umar for his contributions towards my education.

ABSRACT

In order to obtain a good temperature monitoring and regulating device, there is the need to design a device with a better level of accuracy, sensitivity and effectiveness. This work is the design and construction of an electronic thermostatic control for heating systems. The design uses an electronic control circuit involving an integrated circuit chip (LM35), an NPN transisitor, a comparator IC, and electro-mechanical devices. The LM35 senses temperature changes, compares it with an already pre-set temperature and switches the relay accordingly via a transistor switching unit. The temperature sensor (LM35) provides the device with better accuracy, higher precision, greater sensitivity that is needed for a good temperature monitoring device.

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CHAPTER ONE

1.1 GENERAL INTRODUCTION

In the world today, most heating systems, whether direct or indirect, are governed by some form of thermostatic control designed to maintain a desired temperature set by a thermostat which regulates the input of heat. In the early days, control is often by water temperature, the adjustment being made according to outside weather. Alternatively; control may be by room temperature.

Thermostatic control has the objective of economizing heat as far as possible while avoiding under heating or over heating. Internal heat gain and solar gain may often contribute significantly to the total daily heat requirement of any heating environment; and if superimposed on the normal designed output of a heating system can lead to uncomfortably high internal temperatures. A quick responsive system is therefore desirable. To achieve this, the turn ON and turn OFF type of thermostatic control is considered in this project.

The turn ON and OFF type of thermostatic control is an electronic equipment to trigger automatically when the temperature inside a house, oven, incubators or any heating environment exceeds the required temperature.

The thermostatic control for heating system is designed around a linear-precision integrated circuit temperature sensor, the LM35 from National Semiconductor. The temperature sensor keeps monitoring the temperature of the heating element and generate at its output terminal, an electrical voltage that is proportional to the measured temperature in degree Celsius. The generated electrical voltage from the transducer (LM35) has a factor of 10mV per degree Celsius.

The temperature-voltage relationship has a high level of precision due to the calibration of the sensor to the standard Celsius temperature during process of manufacturing the integrated circuit symbol.

The output of the transducer is used to control a relay through a comparator circuit (LM393) which compares the output voltage of the sensor with a desired reference voltage. The reference voltage is set to the desired value through a potentiometer connected to one of the input terminals of the comparator.

1.2 PROJECT OBJECTIVES

The project is carried out with the aim of meeting the following objectives;

- ◊ To design and construct an electronic thermostatic control for heating systems
- ◊ To improve the accuracy of temperature measurement and control through the use of the precision integrated circuit temperature sensor
- ◊ To produce a more reliable and cost effective means of monitoring and controlling the temperature of heating systems.

1.3 MOTIVATIONS

The need to reduce overheating of our immediate environment constitutes the main factor that prompt the selection of the topic.

CHAPTER TWO

2.0 LITERATURE REVIEW

The thermostat is a device used in the controlling and regulating temperature in an environment, system e.t.c. such that the temperature of the environment or system is 1maintained near a desired temperature set point. Actually, temperature regulation is done by the thermostat by controlling the flow of heat energy into the system or out of the system. The thermostat switches either heating devices or cooling devices.

The construction of thermostat can be carried out in various ways and various sensors may be used in order for the measurement of temperature is achieved. The sensor's output then controls the heating as well as the cooling apparatus.

The thermostat was actually invented in 1885 by Albert Butz LJ [1] and it was the first known example of process control methodology. According to Butz in 1893, it was proposed that several common sensors existed which include;

- Bi – metal mechanical sensors
- Expanding wax pellets
- Electronic Thermistors
- Electrical Thermocouple.

The above sensors had the ability to control either cooling or heating apparatus using either of the following methods listed below;

- Direct mechanical control
- Electrical signals

◊ Pneumatic signals.

In 1896, when Butz proposed the different sensors associated with the thermostat, issues about the principles of the Bi – metal was a subject of interest. Later in 1912 when Bernard Kurt experimented on the Bi- metal sensor, he had this to say.

2.0.1 BI-METAL

An automobile passenger compartment's heating system has a thermostatically controlled value to regulate the water flow and temperature of an adjustable level. In older vehicles the thermostat controls the application of engine vacuum to actuators that control water valves and flappers to direct the flow of air. In modern vehicles, the vacuum actuators may be operated by small solenoids under the control of a central computer. He also said that the on a steam or hot water radiator system, the thermostat may be an entirely mechanical device incorporating a bimetallic strip. Generally, this is an automatic valve which regulates the flow based on the temperature. For the most part, their use in North America is now rare, as modern under flood radiator systems use electric valves, as do some older retrofitted systems. They are still widely employed on central heating radiators throughout Europe, however mechanical thermostats are used to regulate dampers in rooftop turbine vents, reducing building heat loss in cool or cold periods

2.0.2 MILLIVOLT THEMOSTAT

As for a millivolt thermostat, the power of thermostat is actually provided by a thermocouple, heated by a pilot light. This heat provides little power such that the systems must use a low power valve in controlling the gas. Well, this type of device is usually considered generally as old fashioned device because pilot light wastes so much of gas just in the same way a dripping faucet usually wastes very huge amount of water over a long period. Surprisingly they are stick to be found in many gas water heaters.

Existing milligram heating systems can be made far more economical by turning off the gas supply during non-heating season and re-lighting the pilot when the heating season approaches. during the winter month, most of the small amount of heat generate by the pilot flame will probably radiate through the flue and into the house, meaning that the gas is wasted (during a time when the system isn't actively heating) but the pilot-warmed flue continues to add to the total thermal energy in the house.

2.0.3 LINE VOLTAGE THERMOSTART

Some programmable thermostats are available to control the line. Voltage system base-board heater will especially benefit from a programmable thermostat which capable of continuous Control (as are at least some honey well models0 effectively controlling the heater like a lamp dimmer, and gradually increasing and decreasing heating to ensure an extremely constant room temperature (continuous control rather than relaying on the average effect of hysteris 0 systems which include a fan 9 electric furnace wall heaters e.t.c) must typically use on/off control.

Line voltage thermostat are most commonly used for electric space heater such as base board heater or direct wired electric furnace. If a line voltage thermostat is used, systemic power (in united state , 120 or 240 volts) is directly switched by the thermostat with switching current often exceeding 40A, using a low voltage thermostat on a line voltage circuits will result at least in the failure of the thermostat and possibly fire

Line voltage thermostat are sometimes used in other application such as the of fan cool (fan powered from line voltage blowing through a cooled of tubing which is either heated or cooled by a longer system) unit in large system using centralized boiler and checkers

2.0.4 COMBINATION HEATING AND COOLING REGULATION.

As regarding what is to be controlled a forced-air air conditioning thermostat generally has an external switch for heat off/cool and another on/auto to turn the blower fan on constantly or only when heating and cooling running .four wires come to the central-located thermostat from the main heating/cooling unit (usually located in a closed, basement, or occasionally attic) one wire supply 24V ac power connection to the thermostat whilst the other three supply control signal from the thermostat , one for heat , one for cooling and one to turn on the blower fan .the power is supply by the transformer , and when the thermostat makes contact between power and another wire , a relay back at the heating /cooling unit the corresponding functions of the unit.

2.0.5 HOUSEHOLD THERMOSTAT LOCATION

The thermostat should be located away from the rooms cooling or heating vent or device, yet exposed to general airflow from the room(s) to be regulated. An open hall way may most appropriate for a single zone system, where living rooms and bedrooms are operated as a single zone. If the hallway may be closed by doors from the regulated space then there should be left open when the system is in use. If the thermostat is too close to the source controlled then the system will tend to "Short cycle" and numerous start and stops can be annoying and in some case shortened equipment life. a multiple zoned system can save considerable energy by regulating individuals space, allowing unused rooms to vary in temperature turning off the heating and cooling. [1]

2.10 COMPONENT THEORY

2.1.1 TRANSISTORS

Transistors are active components used basically as amplifiers and switches. The two main types of transistors are. The bipolar transistors whose operation depends on the flow of both minority and majority carriers, and the unipolar field effect transistors (called FETs) in which current is due to majority carriers only (either electrons or holes). The transistor as a switch operates in a class A mode. In this mode of bias the circuit is designed such that current flows without any signal present [2]. The value of bias current either increased or decreased about its mean value by input signals (if operated as an amplifier), or ON and OFF by the input signal if operated as a switch fig.2.0 shows the transistor as a switch.

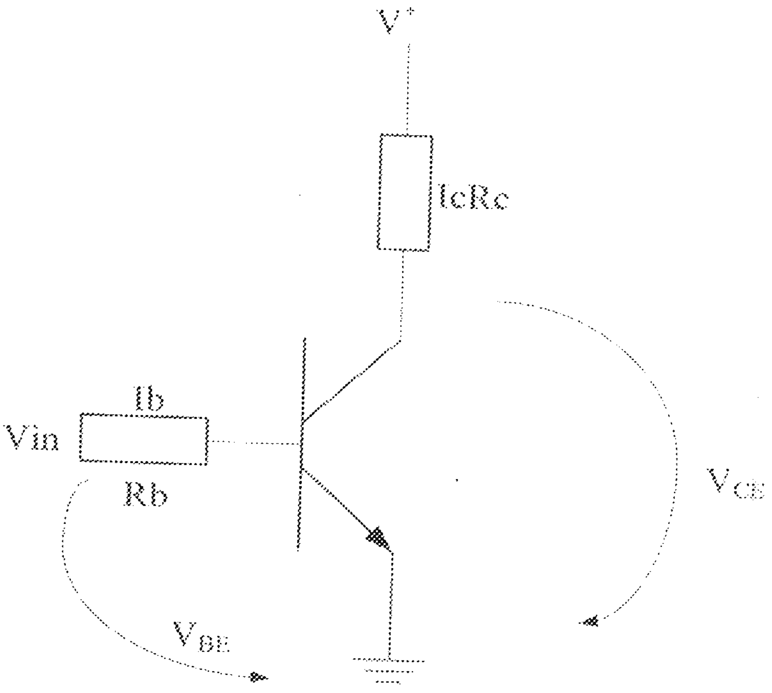


Fig. 2.0: Ttransistor as a switch

For the transistor configuration, since the transistor is biased to saturation

$V_{CE} = 0$, when the transistor is ON,

This implies that,

$V_{+} = I_cR_c + V_{CE}$ ....(2.5)

$V_{in} = I_bR_b + V_{BE}$ ....(2.6)

$\frac{I_c}{I_b} = h_{fe}$ ....(2.7)

$R_b = \frac{V_{in} - V_{BE}}{I_b}$ ....(2.8)

Where

I_c = collector current

I_b = base current

V_{IN} = input voltage

V^+ = Supply voltage

V_{CE} = collector emitter voltage

h_{fe} = current gain

V_{BE} = Base emitter voltage.

2.1.2 COMPARATOR (LM 393)

General Description

The LM393 series consists of two independent precision voltage comparators with an offset voltage specification as low as 2.0 mV max for two comparators that were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. These comparators also have a unique characteristic in that the input common-mode voltage range includes ground. even though operated from a single power supply voltage. The manufacturers data sheet from National Semiconductors website specified the following features.

Features

Wide supply (Voltage range: 2.0V to 36V, Single or dual supplies: ±1.0V to ±18V), Very low supply current drain (0.4 mA) independent of supply voltage, Input common-mode voltage range includes ground. Differential input voltage range equal to the power supply voltage

Applications

Application areas include limit comparators, simple analog to digital converters; pulse, square wave and time delay generators; wide range V_{CO}; MOS clock timers; multivibrators and high voltage digital logic gates [3]

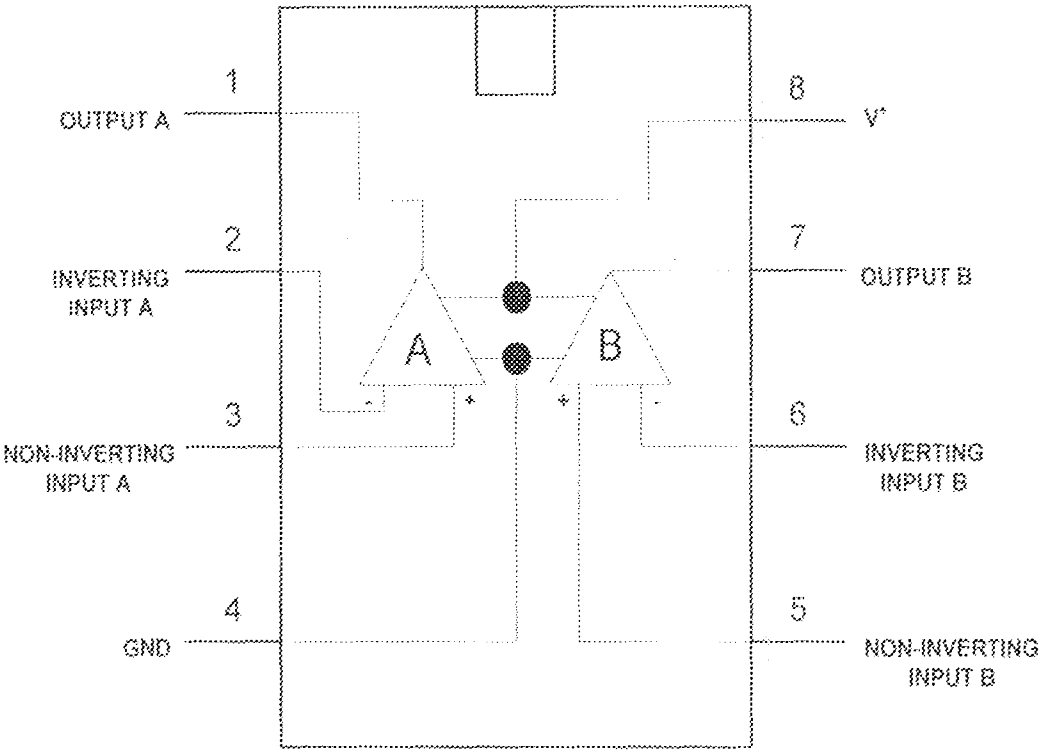


Fig.2.1: Pin layout of LM393

2.1.3 RELAY

A relay is an electrically operated switch. Current flowing through the coil of the relay creates a magnetic field, which attracts a lever and changes the switch contacts. The coil current can be on or off so relays have two switch positions and they are double throw (changeover) switches.

Relays allow one circuit to switch a second circuit, which can be completely separate from the first. For example a low voltage battery circuit can use a relay to switch a 230V

AC mains circuit. There is no electrical connection inside the relay between the two circuits; the link is magnetic and mechanical.

The coil of a relay passes a relatively large current; typically 30mA for a 12V relay, but it can be as much as 100mA for relays designed to operate from lower voltages. Most ICs (chips) cannot provide this current and a transistor is usually used to amplify the small IC current to the larger value required for the relay coil. The maximum output current for the popular 555 timers IC is 200mA so these devices can supply relay coils directly without amplification.

Relays are usually SPDT or DPDT but they can have many more sets of switch contacts, for example relays with 4 sets of changeover contacts are readily available. Most relays are designed for PCB mounting but you can solder wires directly to the pins providing you take care to avoid melting the plastic case of the relay.

The supplier's catalogue should show you the relay's connections. The coil will be obvious and it may be connected either way round. Relay coils produce brief high voltage 'spikes' when they are switched off and this can destroy transistors and ICs in the circuit. To prevent damage you must connect a protective diode across the relay coil.

The animated picture shows a working relay with its coil and switch contacts. You can see a lever on the left being attracted by magnetism when the coil is switched on. This lever moves the switch contacts. There is one set of contacts (SPDT) in the foreground and another behind them, making the relay DPDT.

The relay's switch connections are usually labeled COM, NC and NO:

- COM = Common, always connect to this: it is the moving part of the switch.
- NC = Normally Closed, COM is connected to this when the relay coil is off.
- NO = Normally Open, COM is connected to this when the relay coil is on.
- Connect to COM and NO if you want the switched circuit to be on when the relay coil is on.
- Connect to COM and NC if you want the switched circuit to be on when the relay coil is off.

A relay is a switch operated by an electromagnet; it is useful if we want a small current in one circuit to control another circuit containing a device such as lamp or electric motor which requires a large current, or if we wish several different switch contacts to be operated simultaneously. In this project, a relay was used to control the switching effect of the bulbs used. Fig 2.2a shows the symbol of a relay. The current needed to operate a relay is called the pull-in current and the dropout current is the current in the coil when relay just stops working

If the coil resistance of a relay R and its operating voltage is V, then the pull-in current

I = V/R [3]

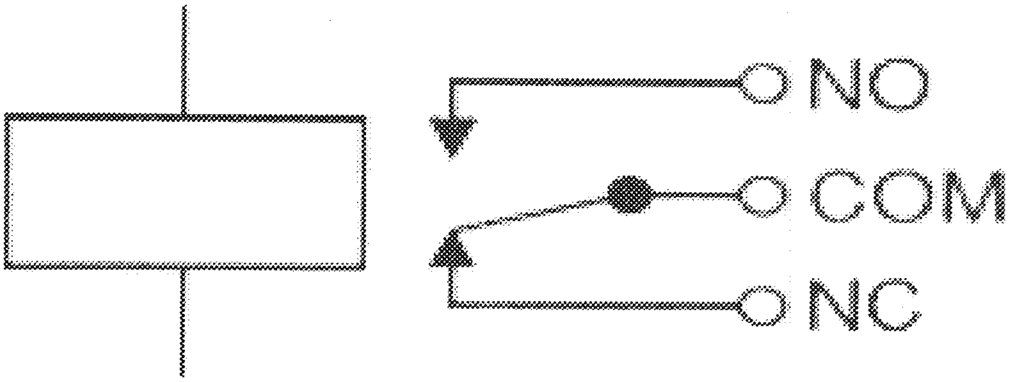


Fig 2.2a: Circuit symbol of a relay

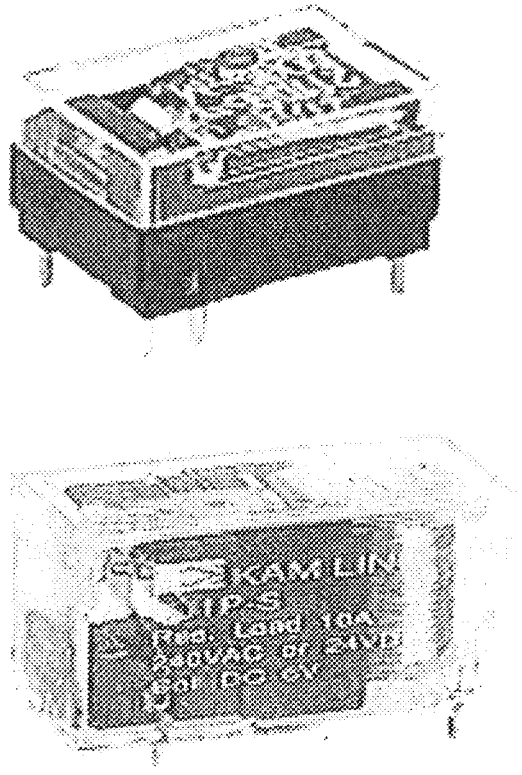


Fig 2.2 b and c: Showing Relays pictures

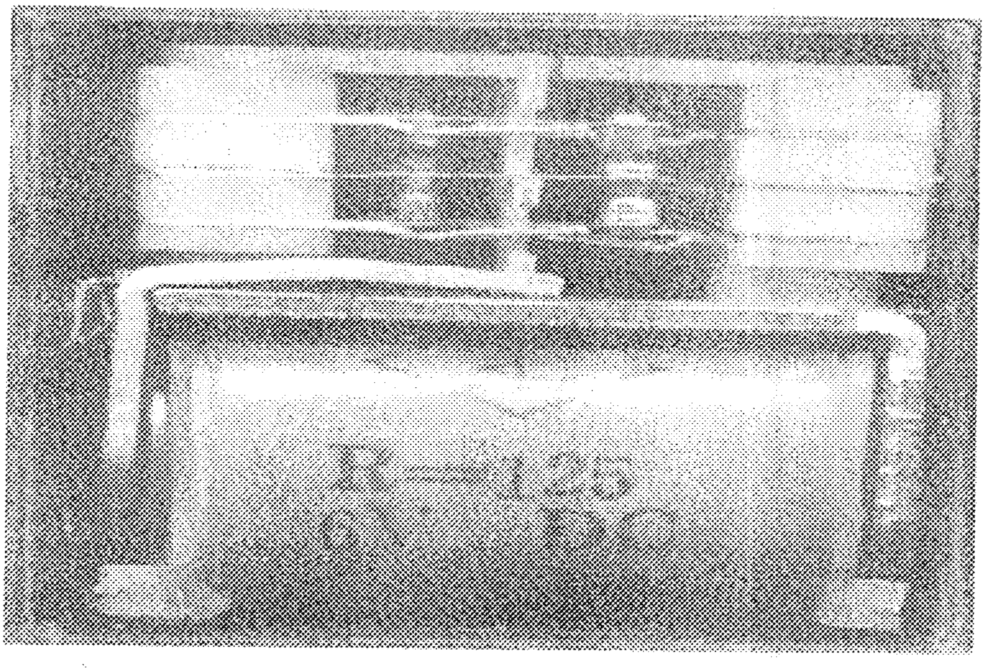


Fig 2.2d: Relay showing coil and switch contacts

2.1.4 PROTECTION DIODES FOR RELAYS

Transistors and ICs (chips) must be protected from the brief high voltage 'spike' produced when the relay coil is switched off. The diagram shows how a signal diode (e.g. 1N4148) is connected across the relay coil to provide this protection. Note that the diode is connected 'backwards' so that it will normally not conduct. Conduction only occurs when the relay coil is switched off, at this moment current tries to continue flowing through the coil and it is harmlessly diverted through the diode. Without the diode no current could flow and the coil would produce a damaging high voltage 'spike' in its attempt to keep the current flowing.

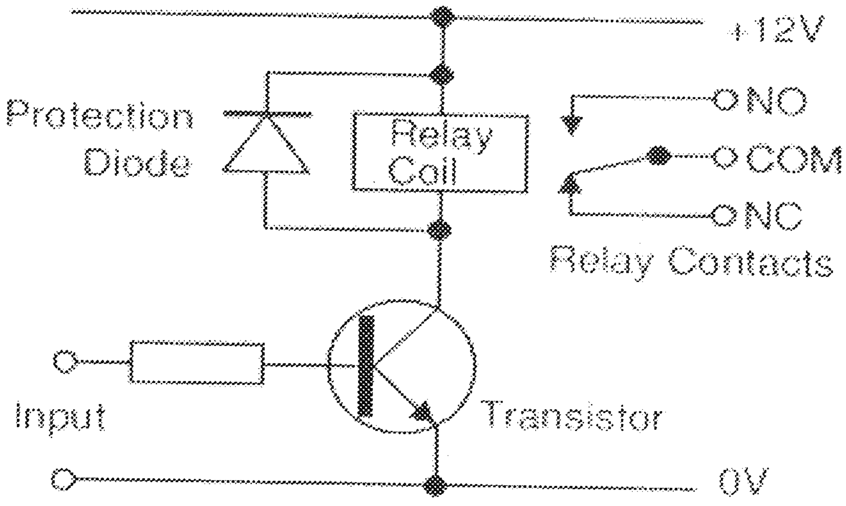


Fig 2.3: Relay connected in a protective mode

2.1.5 LM35 PRECISION CENTIGRADE TEMPERATURE SENSORS

General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±1⁄4°C at room temperature and ±3⁄4°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range, while the LM35C is rated for a −40° to +110°C range (−10° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package. The manufacturer's data sheet from National Semiconductors website specified the following features of the LM35 temperature sensor.

Features

- Calibrated directly in ° Celsius (Centigrade)

- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guarantee able (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 μA current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only ±1/4°C typical
- Low impedance output, 0.1 W,for 1 mA load [3]

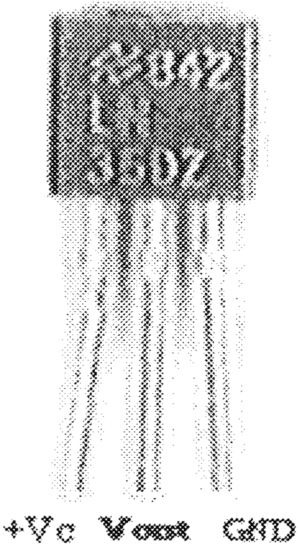


Fig 2.4: Front view of an LM35 temperature sensor

CHAPTER THREE

SYSTEM DESIGN AND ANALYSIS

3.0 BLOCK DIAGRAM

A block diagram is a symbolic representation of the functional or logical relationships between the component (or subsystems) of a system. Block diagrams are usually employed in electronic designs to illustrate the functional or logical relationships of the various units. The block diagram for the system under consideration is as shown below:

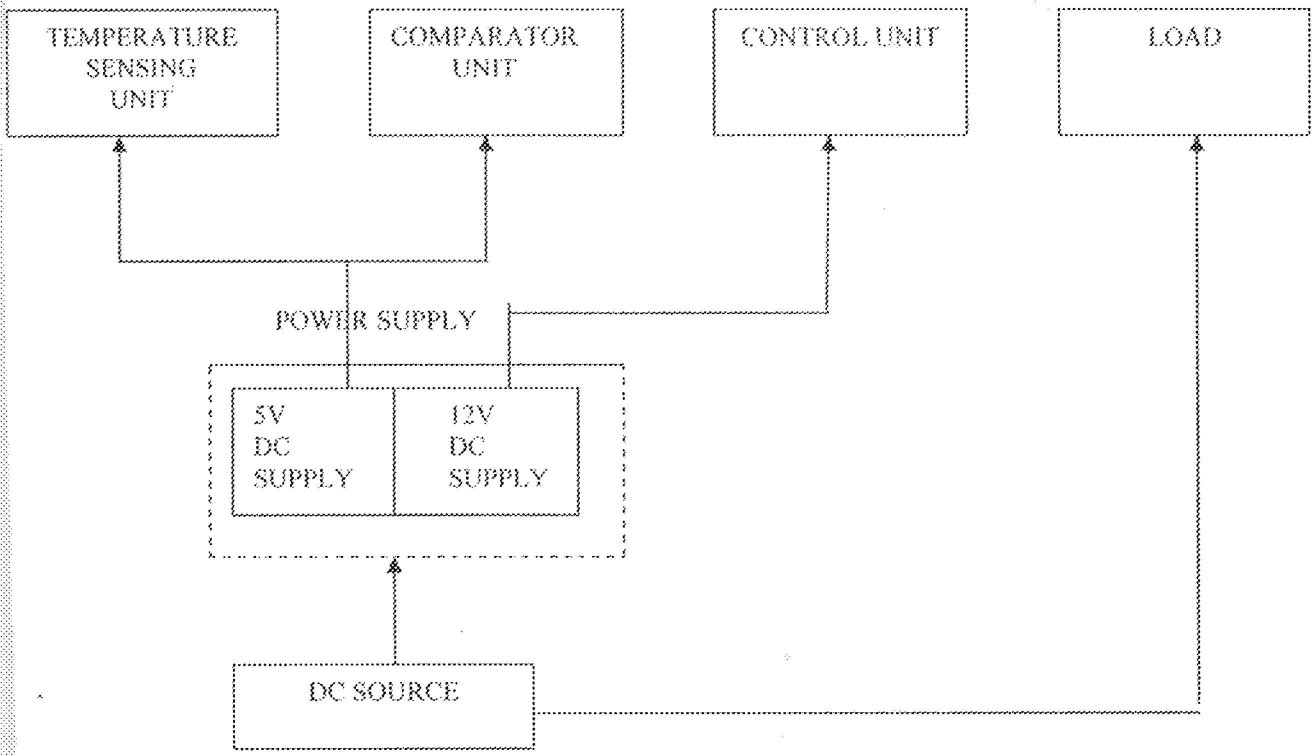


Figure 3.0: Functional Block diagram of the electronic thermostatic control for heating systems.

The system consists of four basic units:

- Temperature sensing unit
- Power supply unit
- Comparator unit
- Control unit

3.1 THE POWER SUPPLY UNIT

Electronic systems generally require regulated DC supply for their normal operation. The project under construction is not an exception since the most economical and readily available power supply is the 240V, 50Hz AC supply, a number of processes need to be carried out on this supply to transform it to the required regulated DC supply.

The following stages are generally involved in the conversion of alternating voltages (AC) to DC voltages:

- Stepping down the AC supply using a step-down transformer of suitable rating
- Rectification of the stepped-down voltage
- Filtering of the rectified voltage to remove ripples (fluctuations)
- Regulation of the filtered voltage to obtain the desired value(s)

The block diagram below gives a summary of how regulated DC voltage is obtained from an AC supply.

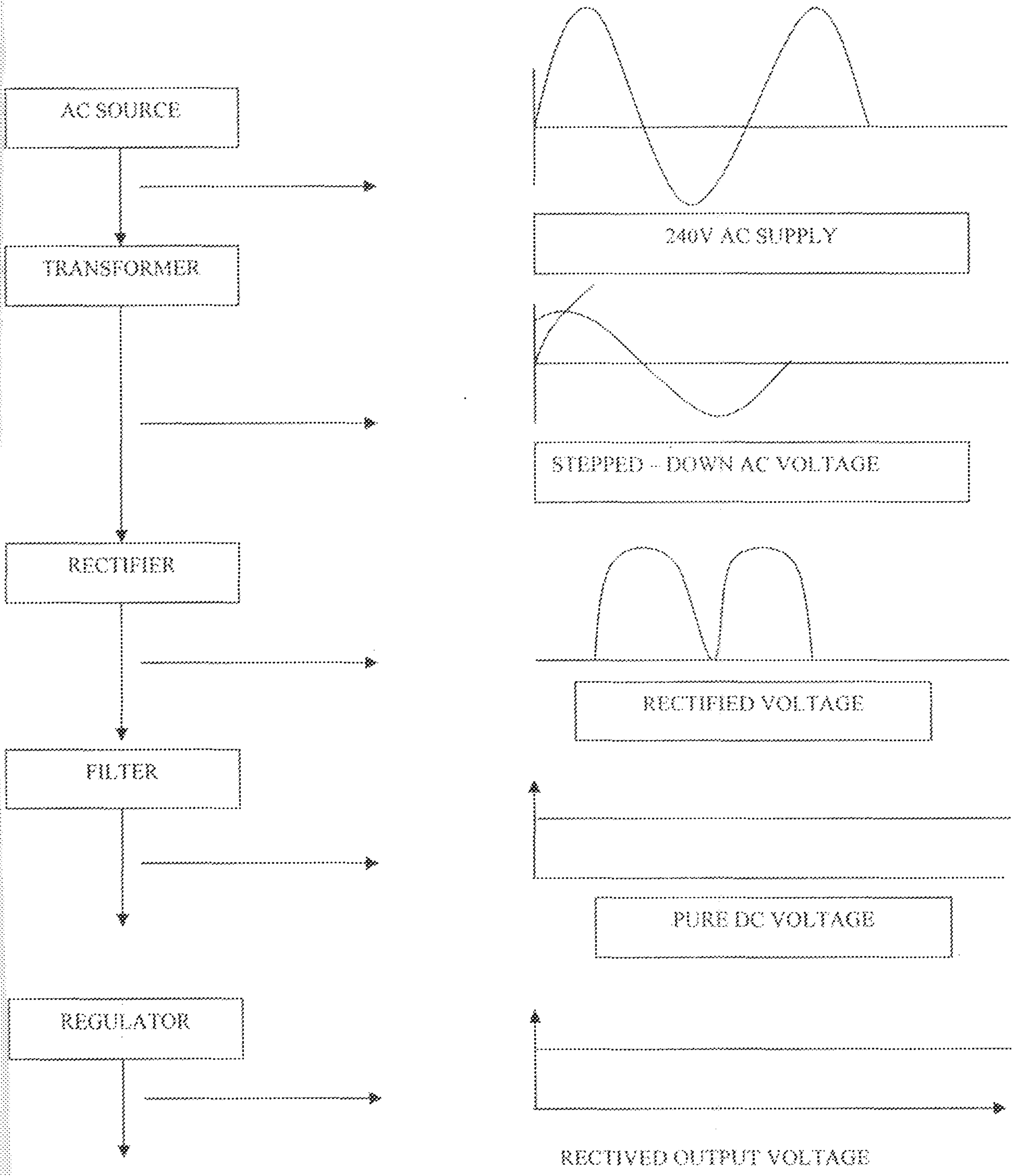


Fig. 3.1: Block Diagram of Power Supply Unit

The power supply unit for this project features a 240/18V transformer, four rectifier diodes (IN4001) connected as a bridge rectifier, flitter capacitor and two fixed voltage regulator: the 7812 and 7805 connected to produce 12V and 5V respectively as shown in the circuit diagram below:

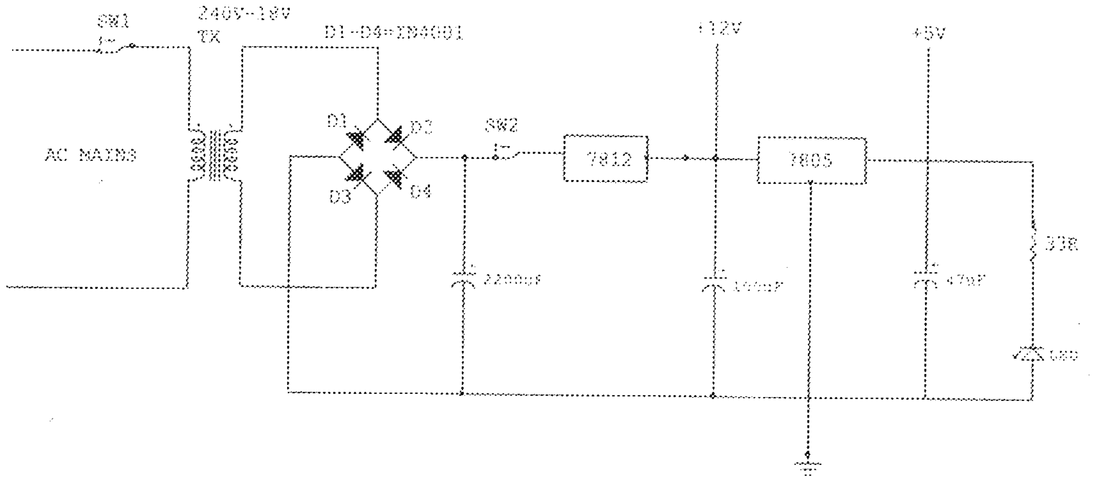


Fig 3.2: Circuit Diagram of the Power Supply Unit.

3.1.1 THE TRANSFORMER

A transformer is an electromagnetic device which is capable of converting AC voltage at one level to AC voltage at another level (either higher or lower). It transfers electrical energy from one circuit to another through an induced magnetic field[4].

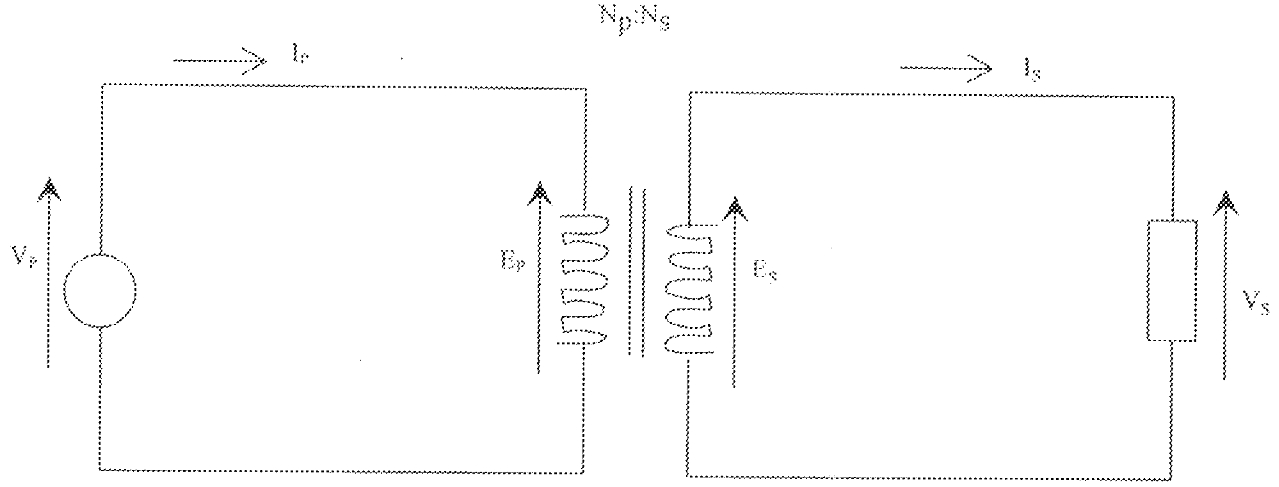


Fig. 3.3: Transformer as a Circuit Element.

If the secondary coil (winding) is connected to a load that allows current to flow, electrical power is transmitted from the primary circuit to the secondary circuit. Assuming there are no losses, all the incoming power is transmitted from the primary circuit to the secondary circuit.

Therefore,

$P_i = I_p V_p = P_o = I_s V_s$ ------------ (3.1)

Equation 3.1 gives the ideal transformer equation

$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$ --------------(3.2)

Where:

V_s = rms value of secondary voltage

V_p = rms value of primary voltage

N_s = Number of turns in secondary winding

N_p = Number of turns in primary winding

I_s = Current flowing in the secondary circuit

I_p = Current flowing in the primary circuit

The transformer used in this design is a 240/18V step-down transformer. The peak value of the output voltage from the transformer is given by the equation.

$V_m = \sqrt{2} V_s$ --------------- (3.3)

Where:

V_m = Peak value of output voltage

V_s = rms value of secondary voltage

$V_s = 18V$

Therefore,

$V_m = \sqrt{2} \times 18$

$V_s = 25.46V$

3.1.2 THE BRIDGE RECTIFIER

A bridge rectifier is a special type of full-wave rectifier comprising of four P-N junction diodes arranged in such a manner that two of the diodes conducts in alternating half-cycle of the input waveform[5].

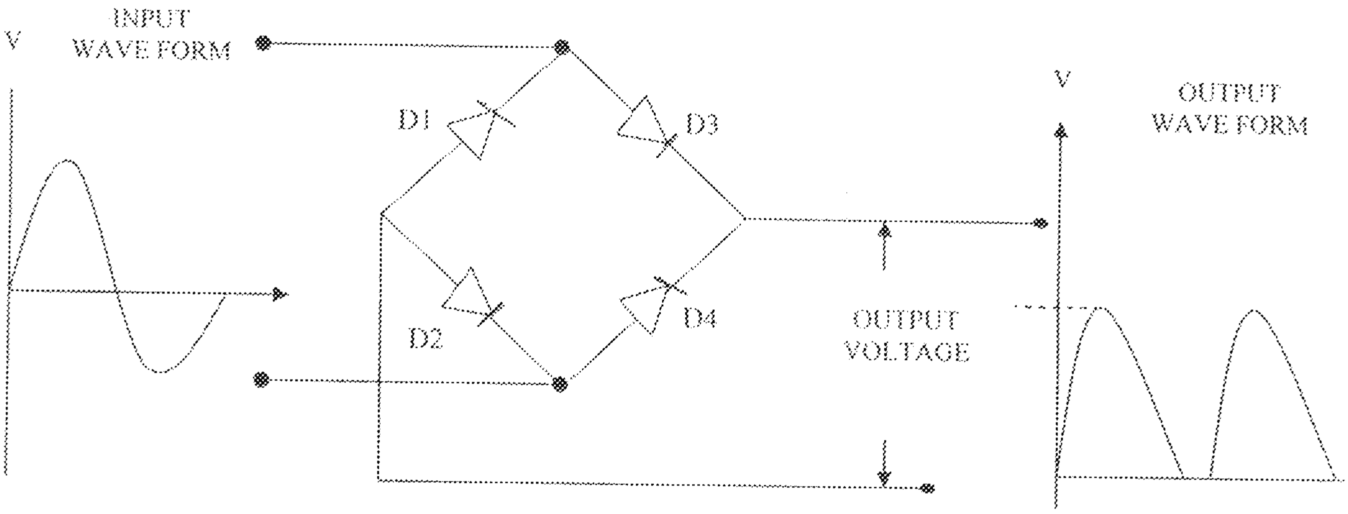
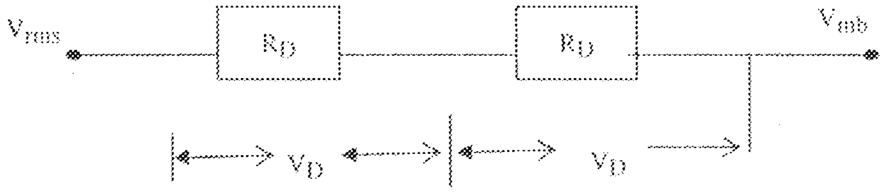


Fig 3.4: The Bridge Rectifier Circuit

The peak DC voltage output of the rectifier is obtained thus:



R_D denotes the forward resistance of each of the two diodes conducting in a particular half-cycle.

Therefore:

$V_{MB} = \sqrt{2}V_{rms} - 2V_D$ ……………… (3.4)

Where:

V_{MB} = peak DC value of the rectified voltage

V_{rms} = rms of the input voltage to the rectifier

V_D = diode forward voltage drop = 0.7V

Therefore:

$V_{MB} = \sqrt{2} \times 18 - 2 \times 0.7$

$= 25.46 - 1.4$

$V_{MB} = 24.06$

$V_{MB} \approx 24V$

The peak value of the rectified DC voltage from the rectifier is 24V.

3.1.3 THE FILTER CAPACITOR

Rectifier circuits usually produce a direct voltage as output. This direct voltage, however, contains an alternating voltage component called ripples. It is always necessary to keep the ripples as small as possible. This can be achieved through the use of smoothing circuits (called filters). The simplest smoothening circuit consists of a capacitor connected across the output rectifier.

The filtering of the rectified voltage is achieved in this design through the use of a 2200µF, 35V capacitor. The voltage rating of the capacitor is selected to be approximately twice the expected output voltage of the rectifier, so that the device is protected from the effect of high voltage supply.

3.1.4 THE VOLTAGE REGULATORS

Voltage regulators are devices used to prevent output voltage change with load current and line voltage thereby producing a relatively stable output voltage [6]. The two voltage regulators used in this project are the 7805 and 7812 fixed regulators and are discussed below:

3.1.4.1 The 12 – Volt Fixed Regulator (7812)

The integrated circuit is a positive voltage regulator with three terminals and is designed to produce a fixed output. It produces an output of +12V from an input which may range from about +7V to about +35V.

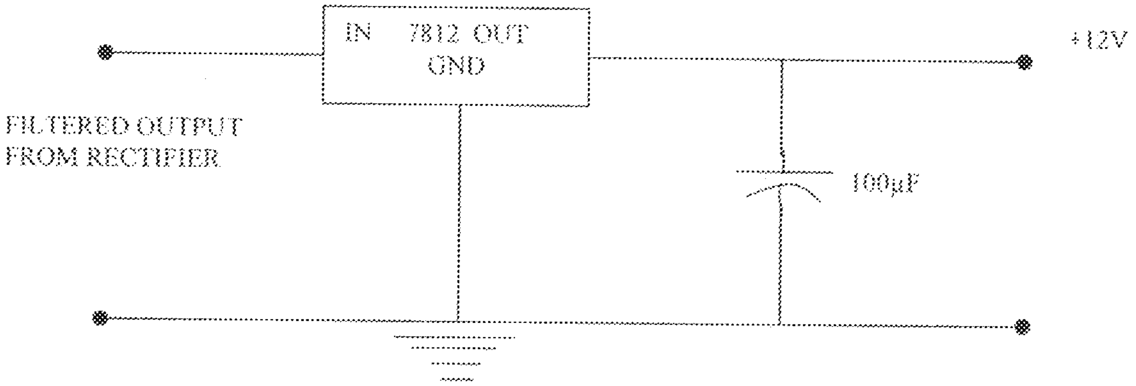


Fig 3.5: Connection Diagram for the 7812

The regulator takes the filtered output from the rectifier as input. The output of the 7812 is held at a steady value of +12V for as long as the input voltage is greater than or equal to 7V, below which the voltage falls out of regulation.

The 12V DC voltage is further stabilized by a 100µF capacitor connected across the output terminal.

3.1.4.2 The 5-Volt Fixed Regulator (7805)

This is used in the circuit to produce a stable 5V DC voltage. It takes the regulated 12V output from the 7812 as input. A 47µF capacitor is connected across the regulator to remove high frequency noise.

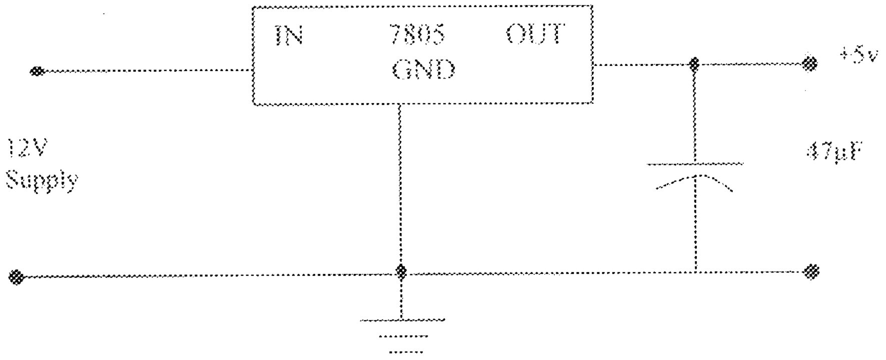


Fig 3.6: Connection Diagram for the 7805.

The 12V supply from the 7812 is connected to the switching circuit due to the requirement of the 12V relay. The 7805 supplies the other parts of the circuit with 5V.

3.1.5 THE POWER INDICATOR CIRCUIT

The power indicator comprises of a light emitting diodes (LED) connected across the 5V supply to indicate when power (voltage/current) is present in the circuit. The light emitting diode is affected by the switching ON and OFF of the power switch. It glows when the switch is ON indicating the presence of power in the circuit.

The LED is connected to the supply through a resistor that limits the current to the diode to a safe value as shown below:

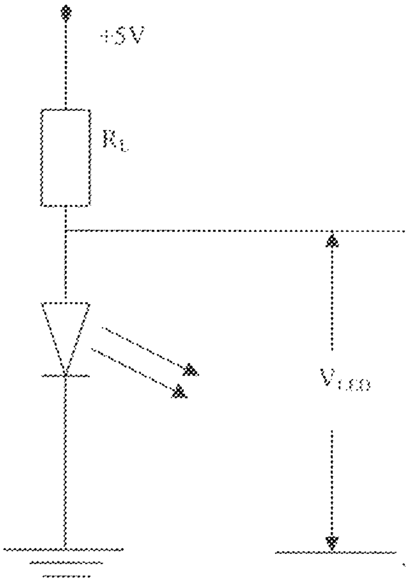


Fig 3.7: The Power Indicator Circuit

The resistance value of the limiting resistor is obtained as:

$$R_L = \frac{V - V_{LED}}{I_{LED}} \quad \text{..........................} (3.5)$$

Where:

R_L = limiting resistance value

V = supply voltage = 5V

V_{LED} = voltage drop expected across the LED

I_{LED} = current through the LED

With,

$I_{LED} = 2mA$, $V_{LED} = 2.7V$

Therefore:

$$R_L = \frac{5 - 2.7}{2 \times 10^{-3}} = 1150\Omega$$

$R_L = 1.15K\Omega$

A standard value of 1k was used in the design.

3.2 THE TEMPERATURE MONITORING UNIT

The temperature monitoring unit comprises of an LM35 temperature sensor wired to provide temperature monitoring as well as heat signal feedback for the device.

The sensor is a three terminal device. The three terminals are: input voltage (supply), output voltage and the ground (GND) terminals.

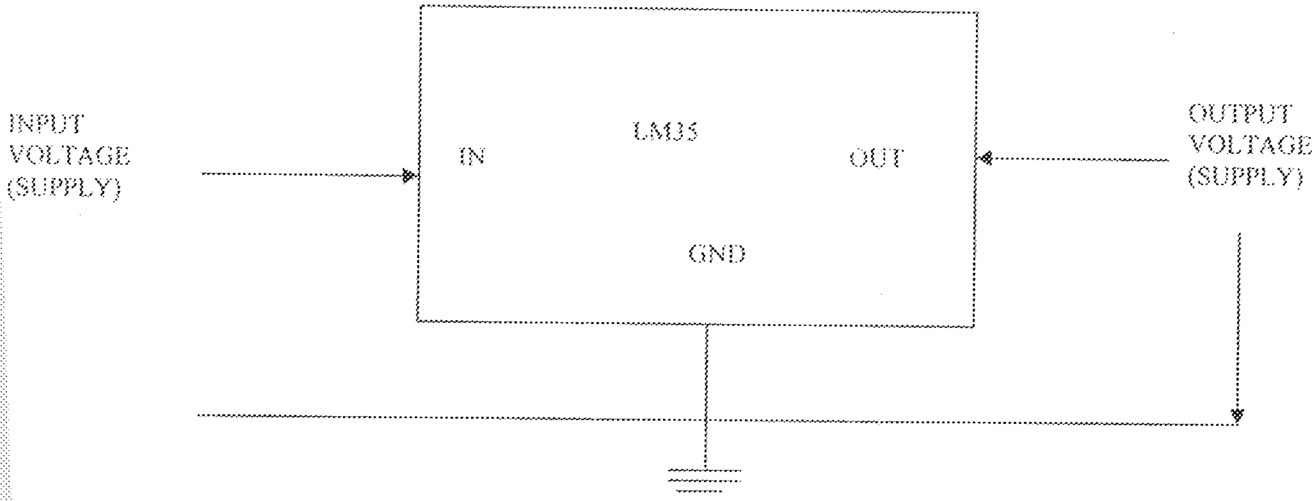


Fig 3.8: Connection Diagram for the LM35

The temperature sensor has a temperature – voltage relationship of 1° C equivalent to 10mV. It operates over a temperature range of 0 – 100°C.

To achieve the desired purpose of this design, the temperature sensor is supplied with +5V and output covers a range of 0 – 1000mV (0.1V) in accordance with the temperature voltage relationship of 1°C equivalent to 10mV. The output terminal of the temperature sensor is connected to a comparator circuit (LM393). It allows the comparator to respond to the referenced temperature.

3.3 THE COMPARATOR UNIT

The comparator unit is used to establish the desired reference output voltages. The unit is wired around a quad comparator integrated circuit (LM393) which is designed for adjusted switching application. The comparator circuit has two input terminals: the inverting input ($V_{in}(-)$) and non-inverting input ($V_{in}(+)$), two power supply terminals and a single output terminal. The output terminal can be in any of two states; logic 0 and logic 1 depending on the relationship between the voltages at the two input terminals.

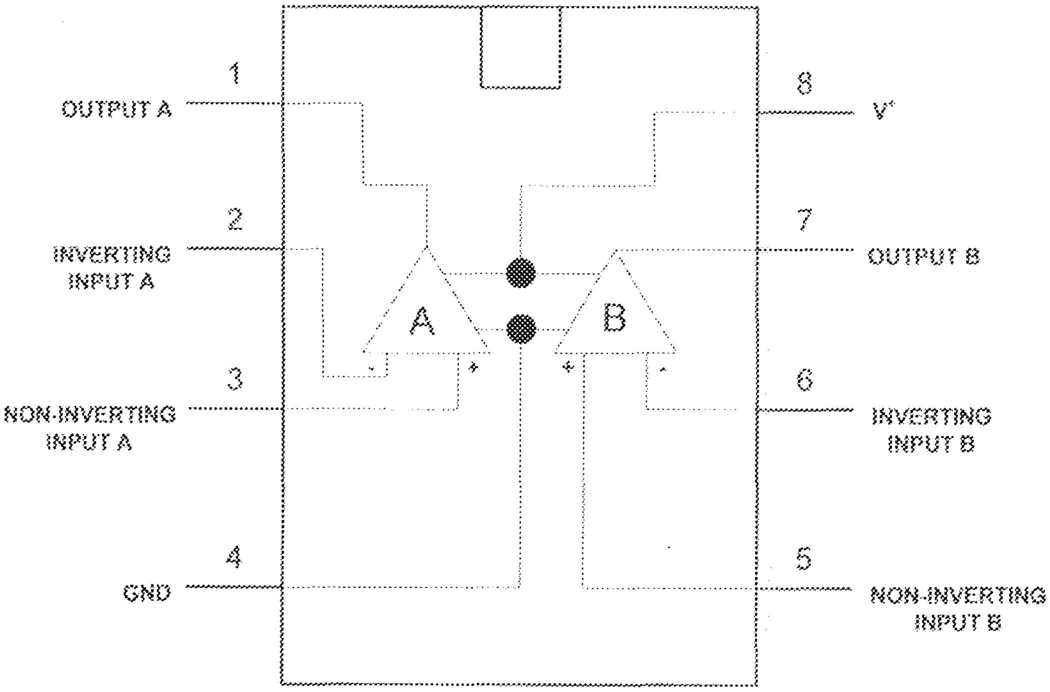


Fig 3.9: The Pin Layout of the LM393

The comparator circuit can typically accepted relatively large input and has provision for selecting the desired reference voltage levels. The output of the comparator work digitally in response to the state of the input conditions. Whenever the non-inverting input V_{in} (+) is greater than the inverting input V_{in} (-), the output is at a logic state of 1, but when the inverting input V_{in} (-) is greater than or equal to the non-inverting input, V_{in} (+), the output is always in a logic state of 0.

3.3.1 Operation of the Comparator Unit

LM339 comparator is incorporated into the circuit to monitor and respond to the output state of the input (LM35). The device functions like a switching tool by adjusting one of its inputs with a particular stable voltage. Since the 5 V regulator supplies voltage to the comparator circuit, extra voltage stabilization circuit such as the one involving zener diode is not involved in the comparator's circuit. The stability of the power supply is sufficient for the aimed operation.

A single LM393 integrated circuit possesses four unit comparators. Only one of the four inbuilt comparators is in use, the others are not connected in the circuit.

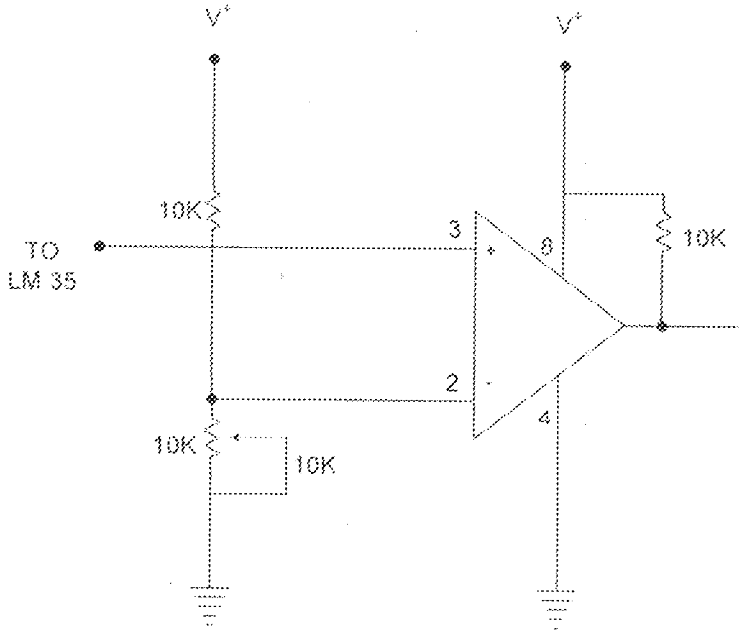


Fig 3.10: The Comparator Circuit

The comparator circuit involves four main components; three resistors and a single comparator unit. A 10kΩ (variable resistor, R_v) is used for adjusting or varying the voltage at the inverting input (V_{in}, (-)) of the comparator. The 10kΩ resistor allows the connection of the output transistor to any choice supply voltage. The actual value of the resistor is not critical, since the transistor is operated in saturation mode: values between few hundreds and few thousand ohms are typical.

The main purpose of the referencing technique is to allow different responses for certain inputs. These inputs (output of the temperature sensor) are applied at the non-inverting side of the comparator (V_{in} (+)). Initial conditions often involve that the voltage at the non-inverting input (V_{in}, (+)) be lower than the inverting input side. As a result of this, the output is in logic state 0. As earlier stated in this chapter, the temperature sensor involves a temperature-voltage relationship of 1°C – 10mV. With this relationship, the voltage at the input of the comparator corresponds linearly to sensor's temperature. For example, a temperature of 35°C corresponds to 350mV with respect to the comparator.

Assuming the inverting input (V_{in} (-)) of the comparator is adjusted to say 500mV (corresponds to 50°C) and the temperature of the temperature sensor is saying around 30°C (corresponding to 300mV). The comparator will give an output of logic state 0 but as the temperature surrounding the temperature sensor increases, its corresponding output voltage also increases. When it gets to a point whereby the temperature of this sensor produces a voltage, which is about going beyond 500mV (corresponding to 50°C). At this point, the output of the comparator changes from state 0 to 1. Therefore, the comparator electronically detects a particular temperature change at the temperature sensor through the set voltage of the inverting input (V_{in} (-)). In fact, the voltage at the inverting input (V_{in} (-)) of the comparator is corresponding to the cutoff temperature for regulation.

3.3.2 The Comparator's Voltage Referencing Circuit

The reference voltage to the inverting input terminal of the comparator is determined by a voltage divider network comprising of two resistors: a fixed resistor R_c and a variable resistor R_v as shown below:

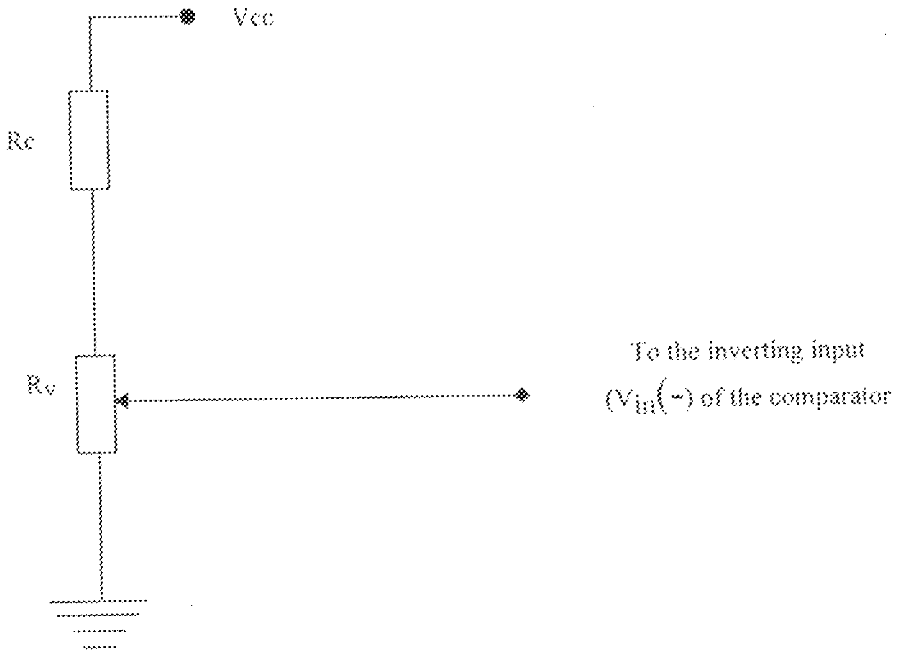


Fig 3.11: The Comparator's Voltage Referencing Circuit

The variable resistor, R_v, is significant for the temperature sensors voltage-temperature referencing. The temperature range of the sensor is 0 – 100°C.

Therefore,

Minimum voltage drop across $R_v = 0 \times 10mV$

$= 0$ (for 0°C)

and

Maximum voltage drop across $R_v = 100 \times 10mV$

$= 1000mV$ (for a temperature of 100°C)

Thus when the variable resistor is adjusted, a particular reference voltage can be selected within the 0 – 1V range. The selected voltage corresponds to a temperature value.

Applying voltage dividers rule to the network of figures 3.10

Voltage drop across R_c is given by

$$V_c = \frac{R_x}{R_c + R_v} \times V_{cc} \text{ ---------------- } (3.6)$$

And the voltage drop across R_v is

$$V_v = \frac{R_v}{R_c + R_v} \times V_{cc} \text{ ---------------- } (3.7)$$

Where

V_{cc} = Supply voltage

The current flowing through the circuit is given by

$$I = \frac{V_v}{R_v}$$

$$I = \frac{V_{cc}}{R_c + R_v} \qquad \text{----------------------------- } (3.8)$$

Substituting V_{cc} = 5V into 3.5, 3.6 and 3.7, we have

$$V_c = \frac{5R_c}{R_c + R_v},$$

$$V_v = \frac{5R_v}{R_c + R_v}; \quad \text{and}$$

$$I = \frac{5}{R_c + R_v} \qquad \text{-------------------------------- } (3.9)$$

A 10Ω variable resistor was used for R_v

Therefore;

$$V_v = \frac{5R_v}{R_c + R_v}$$

$$I_v = \frac{5 \times 10}{R_c + R_v}$$

$R_c + R_v = 50$
$R_c + \quad = 50$

Therefore

$R_c = 40K\Omega$

The current in the circuit is now calculated from equation 3.8

$$I = \frac{5}{10 \times 10^3 + 40 \times 10^3} = \frac{5}{50 \times 10^3}$$

$I = 0.1mA$

3.4 THE CONTROL UNIT

The control unit comprises of a 12V relay, a transistor (2N222A) and a switch, wired in such a manner that the digital output of the comparator is used for switching application.

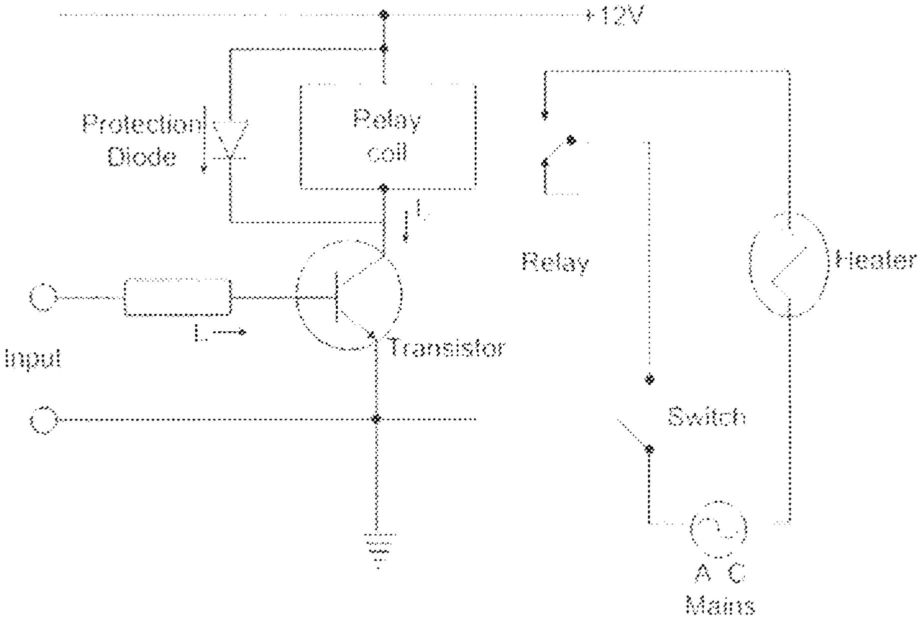


Fig 3.12: The Control Unit

A high logic state output from the comparator is used for switching off power supply to a heating element which directly determines the temperature of the sensor (LM35). A low logic state output from the comparator allows power supply to the heater, which results in increase in temperature of the sensor. The transistor is base biased by a resistor to ensure perfect switching of the transistor between cut-off and saturation.

The temperature sensor feeds back the state of the heater into the comparator. The heater's ON/OFF switching is performed through a relay as a switch. The relay responds to the control signal from the comparator through the transistor. The NPN transistor is configured in the common-emitter configuration and is used for the switching of the 10A/12V relay. The power supply to the control circuit is from a 12V regulator (7812). The collector of the switching transistor is loaded with the resistance of the protection diode D_1 and the resistance of the relay coil R_c.

The relay has three switching terminals A, B and C. Normally, terminal C is connected to A. Whenever a 12V power supply is set across the inductive part of relay, contact C leaves A for B. The initial output state of the relay is restored back when power is cut off from the inductive part.

The switching of the relay is done through the magnetic effect of the coil. When electricity is supplied to the coil, a magnetic field is created around the coil in accordance with the Lenz's law of electromagnetic induction. A back emf is attributed to the induced magnetic field. The switching ON and OFF change in the relays coil sets this back emf which is potentially strong enough to damage the switching transistor. To prevent this damage, a reverse biased diode is placed between the collector of transistor and the supply (V_{cc}). This diode protects the transistor from back emf that might be generated since the relay coil presents an inductive load.

3.4.1 Design Calculations

The value of the base biasing resistor for the transistor is obtained as follows:

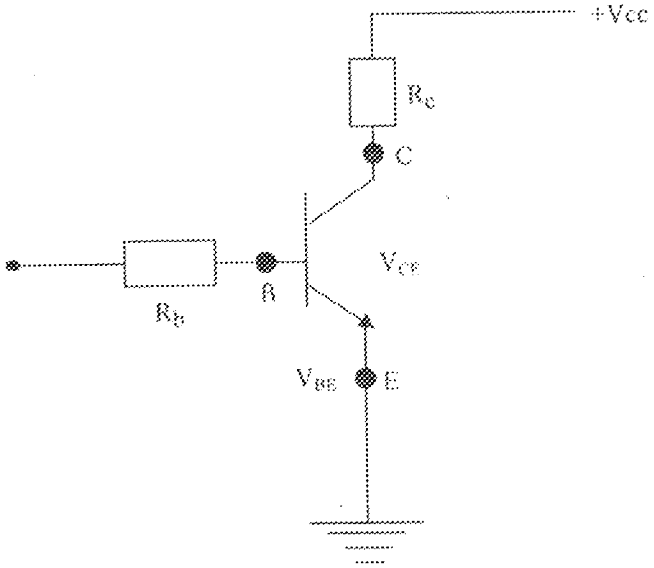


Fig. 3.13: The Switching Transistor

The collector resistor R_c is equal to the resistance of the relay's coil, which is 400Ω for the relay used in this design.

$R_c = 400\Omega$

In saturation mode of the transistor [7], the 12V supply appears across the collector resistance.

From ohm's law:

$V = IR$

Therefore

$I_C = V/R_c = 12/400$

$I_C = 0.03A$

For a transistor, the relationship between the base current I_b and collector current I_c is:

$I_C = \beta Ib$ ---------------------------------- (3.10)

Where

$\beta = h_{FE}$ = the transistor gain.

For the transistor used in this design, the gain is typically 100.

Therefore:

$\beta = h_{FE} = 100$

$I_B = I_C/\beta = 0.03/100 = 0.0003A$

$I_B = 0.3mA$.

5V is expected to switch the transistor through the base.

Therefore:

$$R_b = \frac{V_{cc} - V_{BE}}{I_c} \quad \text{------------------------------} \ (3.11)$$

Where:

$V_{cc} = 5V$

V_{BE} = base emitter voltage = 0.7V

Substituting into equation (3.11)

$$R_b = \frac{5 - 0.7}{0.0003} = 14333.3\Omega$$

$R_b \approx 14.333K\Omega$

A standard value of 10 KΩ was used in the design.

3.4.2 Switching of the Load through the Control Circuit

The output state initially involves the contact of terminal A with C. This results into the flow of AC supply through the heating load whenever the primary switch is closed. The comparator's output is logically 0 for this particular condition. That is, the transistor is cut-off.

When the comparator produces a logical 1 output or relatively high voltage, the transistor is moved into saturation and the relay is energized resulting to the movement of contact C from A to B. The heater's circuit is opened, no more current flows for heating purpose. Heating starts when the base of the transistor is returned back to logic 0 through the comparator.

Summarily, the temperature of the LM35 sensor, indirectly switches ON and OFF the heater through the comparator and relay circuit. When a regulating voltage or temperature is preset at the comparator, heater is ON and OFF in order to keep the temperature around the preset value. Therefore heater and temperature sensor are closely put together.

CHAPTER FOUR

CONSTRUCTION AND TESTING

4.0 CONSTRUCTION

The construction of this project is in 2 stages, the soldering of the components and the coupling of the entire project to the casing.

The power supply stage was first soldered, and then the sensor and comparator stage and all the other stages were soldered. The circuit was soldered in a number of patterns that is, stage by stage. Each stage was tested using the multimeter to make sure it's working properly before the next stage is done. This helps to detect mistakes and faults easily.

The soldering of the circuit was done on a 10cm by 24cm Vero-board. The second stage of the project construction is the casing of the soldered circuit. This project was cased in a transparent plastic glass, this makes the project look attractive, and it helps in marketing the project because the circuit has to be attractive before someone would want to know what it does. The casing has special perforation and vent to ensure the system is not overheating, and this will aid the life span of the circuit.

4.1 TESTING

The testing pin of the digital multimeter was placed on pin 2 of the comparator IC and the temperature equivalent, as related to voltage, was set to 35^0C (350mV) by adjusting the variable resistor. The testing pin was later placed on pin 3 of the same comparator IC and the millimeter's reading was observed. A hot soldering iron was brought close to the temperature sensor (LM35) and the temperature reading was observed, as it increased, on the digital multimeter. Immediately the LM35 sensed a 36^0C temperature, the switching unit of the device was triggered. This switching unit is expected to trigger OFF any heater (load) connected to the device immediately the temperature of the load exceeds that of the device's referenced temperature.

4.2 PRECAUTIONS

1. Integrated circuit socket was used to protect the integrated circuit comparator. This also serves to facilitate easy removal and replacement in case of damage.
2. The soldering iron was always properly heated before use.
3. Components were not overheated.
4. Extra care was exercised during soldering, surplus lead were removed.
5. Correct polarities identification of the components were ensured.
6. Finally, the entire components used were clearly mounted with correct polarity.

4.3 RESULTS

The triggering OFF of the load (heater) connected to the electronic thermostatic control at exactly 36^0C, a centigrade degree higher than the referenced temperature input, helps in the monitoring and regulation of the heater's (load) temperature. It also shows that the device's high precision, accuracy, and high sensitivity. This is the needed advantage that makes electronic thermostatic control better than its mechanical counterparts that use bimetallic strip and thermal sensors.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0 CONCLUSION

The design and construction of this project has not been an easy task in any way, it demands precision and hence a functioning electronic thermostatic control, which has been successfully carried out as described. The detection of heat which depends solely upon the temperature of the sensor device (LM35). The sensor is placed in the heating environment and the detection is through photoelectric effect through a switching unit which is indicated with LED as indicator.

The main aim of this project which is to produce an electronic thermostatic control for heating systems that could accept an input signal from a sensor and then gives an output to indicate that the condition at the input has been fulfilled. With this regard, it can be said that the desired output at the switching unit due to temperature variation at the transducer was satisfactorily obtained. Thus, the aim of the project was achieved.

5.1 RECOMMENDATIONS

To bring this work towards a better temperature control, a more sensitive and reliable temperature transducer should be used.

Sophisticated signal processing techniques using analog to digital converter is recommended in order to display the actual temperature at which the environment is been heated.

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