A PROJECT REPORT

ON

" ENERGY MONITORING, USAGE OPTIMIZATION AND CONDITION MONITORING SYSTEM "

Submitted to

SAVITRIBAI PHULE PUNE UNIVERSITY

In Partial Fulfilment of the Requirement for the Award of

BACHELOR'S DEGREE IN INSTRUMENTATION AND CONTROL ENGINEERING

BY

SAHIL AVINASH DESHPANDE	B120244614
PRITAM RAJENDRA PAWAR	B120244647

UNDER THE GUIDANCE OF

Prof. ARUN D. SONAR

DEPARTMENT OF INSTRUMENTATION ENGINEERING

DR. D.Y. PATIL INSTITUTE OF TECHNOLOGY

PIMPRI, PUNE - 411018

2017-2018

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CERTIFICATE

This is certify that the project entitled

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submitted by

SAHIL AVINASH DESHPANDE	**B120244614**
PRITAM RAJENDRA PAWAR	**B120244647**

is a record of bonafide work carried out by them, in the partial fulfilment of the requirement for the award of Degree of Bachelor of Engineering (**Instrumentation and Control Engineering**) at Dr. D.Y. Patil Institute of Technology, Pimpri, Pune under the Savitribai Phule Pune University. This work was completed during year 2017-2018, under our guidance.

Date: / /

Prof. Arun D. Sonar	**Prof. Arun D. Sonar**	**Dr. Suresh N. Mali**
(Guide)	**(HOD)**	**(Principal)**

Date: 01/06/2018

Certificate

This is to certify that the project entitled**, " Energy Monitoring, Usage optimization and Condition Monitoring System ",** carried out by **Mr. Sahil Avinash Deshpande**, student of **Instrumentation Engineering Department** at Dr. D.Y. Patil Institute of Technology, Pimpri-18, is entirely sponsored by **Mr. Makarand Deshmukh** of General Electric.

The project was completed under the guidance of **Mr. Makarand Deshmukh** who is currently working as an Embedded Engineer in **GE oil and gas** for the last 1.5 years. Makarand has earlier worked with **L&T** for 5.5 years in the embedded domain and has substantial experience in concept development, design, testing and validation of embedded products.

The Project titled **" Energy Monitoring, Usage optimization and Condition Monitoring System"** is an electronic embedded system developed to acquire details of electric power consumption along with the necessary steps for monitoring and optimization of the same.

Authorized Signatory

Mr. Makarand Deshmukh

Date: 01/06/2018

Certificate

This is to certify that the project entitled**, " Energy Monitoring, Usage optimization and Condition Monitoring System ",** carried out by **Mr. Pritam Rajendra Pawar**, student of **Instrumentation Engineering Department** at Dr. D.Y. Patil Institute of Technology, Pimpri-18, is entirely sponsored by **Mr. Makarand Deshmukh** of General Electric.

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Mr. Makarand Deshmukh

Acknowledgements

We are profoundly grateful to our project guide, **Prof. Arun D. Sonar** for his expert guidance and continuous encouragement throughout, to see that this project meets its targets, from its commencement to its completion.

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Finally, we must express our sincere heartfelt gratitude to all the staff members of Instrumentation Engineering Department who helped us directly or indirectly during this course of this work.

Sahil Avinash Deshpande
Pritam Rajendra Pawar

ABSTRACT

As the supply and demand of electrical energy is challenged within the context of environmental awareness, the need to monitor and optimize power usage is of utmost importance. Electrical energy plays a critical role in our lives, as it is an enabling product, an intangible necessity used to power our systems. In order to manage our energy and prevent the consequences caused by energy wastage, a need arises to develop tools to accurately measure and optimize energy usage.Currently, energy meters available in the market can measure and indicate the energy consumption of an entire household or a business premises. However, they are expensive and do not offer measurement for individual systems; particularly high power consuming electrical appliances such as Air Conditioners or Refrigerators. Despite these meters being highly precise and accurate, they see a device level limitation of energy and condition monitoring.

The primary objective of the proposed system is to precisely monitor the energy consumed by each individual device present at a premise.The electronic module shall be a replacement for a standard household switchboard and additionally would be able to calculate and locally display the energy consumed by the devices connected to the same. A certain premise may have several switchboards installed, controlling numerous devices in which case, one of the many modules shall be the master module. Data from all the modules along with device identification shall be relayed to the master. The master module in any premise shall be able to communicate along with the PC application software that would be the heart of the system. The application software shall provide an advanced graphical user interface to the user from where, the user shall be able to not only control the many modules, but also view energy consumption of the appliances connected in various formats such as graphical or numerical. It will receive energy consumption data from the electronic modules and over period of time and analyse the data to understand the variations in energy consumption of a particular device. The learning so far acquired by the PC Software shall be used by the same to monitor the condition of a probable failing device, a device that may be under maintenance or a device that is completely un operational. It will also learn the usage of a particular device and generate a projected energy meter bill for the user and by extension, an energy usage plan.

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Chapter 1

Introduction

The conservation of electrical energy is unquestionably of great importance to all of us, since we rely on energy for every task we perform every single day. Energy supplies are limited and, to maintain a good quality of life, we must find ways to use energy wisely. Measuring the energy that is being consumed is the first step toward finding ways to decrease it. In a developing country like India, energy conservation is a major issue. To conserve the energy first we need to measure and monitor the energy consumption, however we often see the lack of technology to do so. Therefore, a need arises to have a system which can literate the public about their energy consumption and provide measures to reduce their energy consumption. As per the fundamentals of Instrumentation and Control Engineering, before we can control or optimize, we first need to measure.
Systems used in our houses currently are inadequate in providing detailed information about the usage of electrical energy and also lack accuracy required to monitor and optimize power consumption. The Electro-Mechanical electricity meters, used currently, have accuracy limits and are prone to tampering. They also lack the ability to measure parameters such as voltage, current or instantaneous power.

The proposed system will precisely measure the power consumed by each individual device and facilitate the user to analyse the power usage. The system will sense and generate data that will be transmitted to the server. Furthermore, data analysis, processing, optimization and generation of statistics will be carried out. The user will be able to interact with the system.
This document gives a detailed report about the technology used to fulfil the objectives mentioned above. An attempt was made to develop this project as a commercial product, hence, this report will also include the steps taken for development of a commercial product right from defining the requirements, using some project management techniques to testing.

Chapter 2

Literature Survey

The advent of smart energy meters has automated the entire process of billing generation system over commercial energy usage which was previously done using electro-mechanical meters. Although western countries practice its usage more, it is still unknown to many developing countries like India. A smart energy meter can be defined as an electronic device that performs seamless monitoring and recording of the energy usage of household appliance by digital means. Different from conventional metering system, where the readings have to be collected by the service providers, smart meters autonomously forward the readings to its service providers for impartial and error-free usage statistics.

2.1 Present Work

The following white papers show current research being carried out related to smart energy metering.

1. **Wireless Power Consumption Monitoring and Analysis System Using Winters Forecasting Method**
   Dominic Joseph R. Enriquez, Marcel Lowell G. Villanueva, Samuel Matthew G. Dumlao, Rosula S.J. Reyes Department of Electronics, Computer, and Communications Engineering Ateneo de Manila University Quezon City, Philippines.
   Aim of this paper is to monitor, analyse and forecast the power consumption of individual rooms or working areas in order to devise ways on how to reduce the overall electric consumption. A Raspberry pi was used as the main microcontroller.

2. **IoT based Smart Home Design using Power and Security Management**

Punit Gupta, Jasmeet Chhabra Department of Electronics and Communication Engineering, Department of Computer Science Engineering, Jaypee University of Information Technology Jaypee University of Information Technology, Himachal Pradesh, India.
The design and implementation of an Ethernet-based Smart Home intelligent system for monitoring the electrical energy consumption based upon the real time tracking of the devices at home an INTEL GALILEO 2ND generation development board.

3. **Power Consumption/Supply Control Using Neural Network for Micro Grids**
Tsunashi Kaneko, Shohei Shimizu, Hiromitsu Ohmori, Keio University.
Design and Implementation of control scheme using neural network for micro grids with isolated operation mode. Normally, the micro grid operates in interconnected mode with the medium voltage network, however when the power go down, the micro grid must have the ability to operate stably autonomously.

4. **Power Reduction for Smart Homes in an Internet of Things Framework**
Abdul Razaque, Peter Oddo, et. al. Department of Electrical and Computer Engineering Cleveland State University, USA
Design and implement a Smart Meter (SM) to reduce and monitor the power consumption of household devices. The Smart Meter uses a sensor-based microcontroller and an actuator that work together to analyze the power consumption of each electronic household device. The Smart Meter is implemented by an Automatic Measuring Threshold Value (AMTV) algorithm to set threshold values for each appliance.

5. **Reducing Power Consumption in Data Center by Predicting Temperature Distribution and Air Conditioner Efficiency with Machine Learning**
Yuya Tarutani , Kazuyuki Hashimoto, et.al. Cybermedia Center, Osaka University, Osaka,Japan. (2016 IEEE International Conference on Cloud Engineering)
Procedure for controlling the operational parameter of air conditioner for reducing power consumption of data centers by using a machine learning technique was demonstrated. The power consumption of the air conditioners by around 30at maximum was successively demonstrated through proactive control based on the prediction method.

2.2 Literature Gap / Scope of Work

1. A system can be developed that can accurately monitor and display the power consumed by each individual electrical appliance.
2. Development of a low cost smart energy metering system, which can be commercial.
3. Development of a simple, user friendly user interface will encourage the user to get more involved and interested about their energy usage
4. A local display that will display the energy usage statistics can be developed.
5. Use of statistical tools for analysing the energy usage of each individual device will let the user know the device health and predict device failures.

2.3 Problem Statement

Electrical energy plays a vital role in our lives as it is an enabling product and an intangible necessity. In order to manage and optimize our power usage there is a need to develop tools to accurately and precisely monitor power consumed by each individual device/ appliance. Monitoring is the first step towards controlling and reducing the usage of electrical energy. Reduction in the usage of power can also be achieved if the statistics of power usage patterns are studied over a period of time and the optimal settings are computed. This project proposes an innovative model that will address the above issues.

Chapter 3

Requirements Specification

3.1 Functionality

Following are the functional requirements of the system :

1. The system should be able to measure line AC voltage.
2. The system should be able to measure AC current drawn by each device connected to the board
3. Calculations required for finding out the power consumed by each device, and the total power calculated should be done by the on board microcontroller.
4. Power supply required for the board must be present on the circuit itself.
5. The system should calculate and store data power reading data for each individual device as well as data for the entire board.
6. Remote access to the devices should be made possible with the circuit.
7. System should provide good accuracy of measurement as it will directly affect the monetary readings of the power consumed.

3.2 Usability

Following are the requirements from the user's point of view :

1. The User Interface on the computer should provide the user with the ability to observe, record, analyse the power reading data for individual device as well as all the devices.
2. A local display on the board itself, should be provided to monitor the power consumption of each device
3. As the circuit works to measure line AC voltage, adequate safety should be provided in the circuit.
4. Provision for remote access of electrical devices connected to the board must be made. The devices should be able to be controlled directly from the location of the board as well as remotely, from a computer.
5. The system should be able to show the power consumption in monetary terms.
6. The system should provide the user with suggestions for optimization their power usage.
7. The system should alert the user in case of a probable device failure. A alert should also be provided when maintenance of any device is needed.
8. All of the power consumption data should be available to the user in various formats which are user friendly.
9. The system should be cost effective.

Chapter 4

Project Planning

4.1 Developing a Product

4.2 The V-Model Approach

This project uses **The V-Model Approach** for system hardware design. Defining and planning the work flow before starting a project is an important part of SLDC(System Development Life Cycle) The systems development life cycle (SDLC), is a term used in systems engineering to describe a process for planning, creating, testing, and deploying an system.

The V-model is an SDLC model where execution of processes happens in a sequential manner in a V-shape. It is also known as **Verification and Validation model.**
The V-Model is an extension of the waterfall model and is based on the association of a testing phase for each corresponding development stage. This means that for every single phase in the development cycle, there is a directly associated testing phase. This is a highly-disciplined model and the next phase starts only after completion of the previous phase. Under the V-Model, the corresponding testing phase of the development phase is planned in parallel. So, there are Verification phases on one side of the V and Validation phases on the other side. The Implementation Phase joins the two sides of the V-Model.
The following illustration depicts the different phases in a V-Model

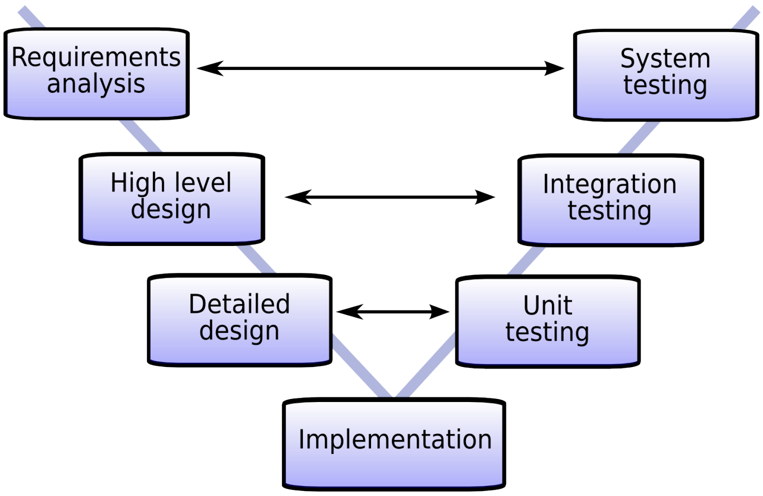


Figure 4.1: The V-Model Approach

4.2.1 Phases of the V-Model

The various phases of the V-model are as follows:

1. A system test plan is created. The test plan focuses on meeting the functionality specified in the requirements gathering.

2. The high-level design (HLD) phase focuses on system architecture and design. It provide overview of solution, platform, system, product and service/process. An integration test plan is created in this phase as well in order to test the pieces of the software systems ability to work together.

3. The low-level design (LLD) phase / Detailed Design Phase is where the actual components are designed. It defines the actual logic for each and every component of the system. Detailed study of every component and its design comes under LLD. Component tests/Unit tests are created in this phase as well.

4. The implementation phase is where the integration of all components takes place. Once this is complete, the path of execution continues up the right side of the V where the test plans developed earlier are now put to use.

The V-Model approach to product design has a advantage Proactive error tracking that is errors are found at early stage.This Avoids the downward flow of the errors.The V-model approach is used for small to medium sized projects where requirements are clearly defined and fixed.

4.3 The Proof of Concept (PoC) Approach

Proof of concept (PoC) is a realization of a certain method or idea in order to demonstrate its feasibility,or a demonstration in principle with the aim of verifying that some concept or theory has practical potential. It is a demonstration, the purpose of which is to verify that certain concepts or theories have the potential for real-world application. PoC is therefore a prototype that is designed to determine feasibility, but does not represent deliverables.

The hardware design of this project has been divided into multiple PoC's. Each component in the System Design chapter was prototyped and tested individually before integrating all the components to form a complete system. Use of the PoC approach gives the technical feasibility of the system before the final implementation/integration. It helps in component selection and detailed study of each individual component used. However, the Requirement Specification becomes a very important document before going for the PoC approach. The requirements must be very clear and fixed before starting the work using the PoC approach.

4.4 Gantt Chart

A Gantt chart is a type of bar chart that illustrates a project schedule.This chart lists the tasks to be performed on the vertical axis, and time intervals on the horizontal axis.The width of the horizontal bars in the graph show the duration of each activity.Gantt charts illustrate the start and finish dates of the terminal elements and summary elements of a project.

4.4.1 Benefits of Gantt Chart

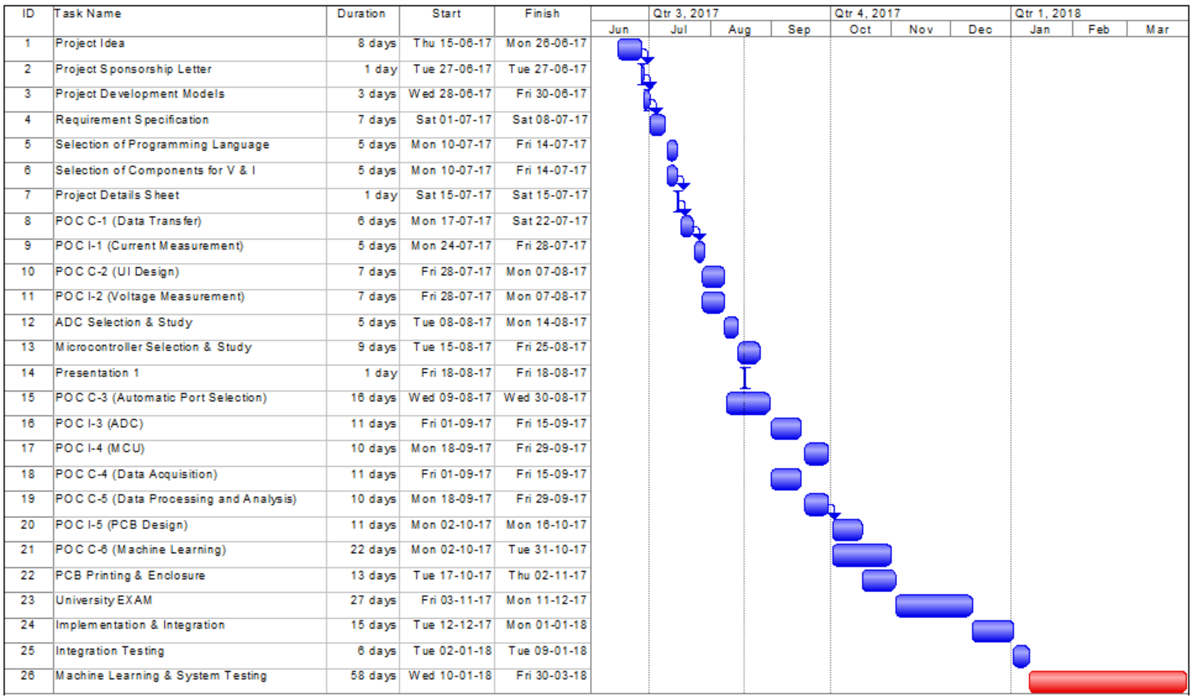
Some benefits of the Gantt Chart include:

1. Clarity - Its ability to boil down multiple tasks and timelines into a single document.
2. Motivation - Use of Gantt Charts sets a deadline, which is a motivating factor for the members.
3. Time Management - An overview of all the tasks to be performed leads to better time management

4. Efficiency - Gives the ability for teams members to leverage each others deadlines for maximum efficiency

5. Accountability - Using Gantt charts allows both the team members to track team progress, highlighting both big wins and major failures.

The following figure shows the Gantt Chart of this project.



ID	Task Name	Duration	Start	Finish
1	Project Idea	8 days	Thu 15-06-17	Mon 26-06-17
2	Project Sponsorship Letter	1 day	Tue 27-06-17	Tue 27-06-17
3	Project Development Models	3 days	Wed 28-06-17	Fri 30-06-17
4	Requirement Specification	7 days	Sat 01-07-17	Sat 08-07-17
5	Selection of Programming Language	5 days	Mon 10-07-17	Fri 14-07-17
6	Selection of Components for V & I	5 days	Mon 10-07-17	Fri 14-07-17
7	Project Details Sheet	1 day	Sat 15-07-17	Sat 15-07-17
8	POC C-1 (Data Transfer)	6 days	Mon 17-07-17	Sat 22-07-17
9	POC I-1 (Current Measurement)	5 days	Mon 24-07-17	Fri 28-07-17
10	POC C-2 (UI Design)	7 days	Fri 28-07-17	Mon 07-08-17
11	POC I-2 (Voltage Measurement)	7 days	Fri 28-07-17	Mon 07-08-17
12	ADC Selection & Study	5 days	Tue 08-08-17	Mon 14-08-17
13	Microcontroller Selection & Study	9 days	Tue 15-08-17	Fri 25-08-17
14	Presentation 1	1 day	Fri 18-08-17	Fri 18-08-17
15	POC C-3 (Automatic Port Selection)	16 days	Wed 09-08-17	Wed 30-08-17
16	POC I-3 (ADC)	11 days	Fri 01-09-17	Fri 15-09-17
17	POC I-4 (MCU)	10 days	Mon 18-09-17	Fri 29-09-17
18	POC C-4 (Data Acquisition)	11 days	Fri 01-09-17	Fri 15-09-17
19	POC C-5 (Data Processing and Analysis)	10 days	Mon 18-09-17	Fri 29-09-17
20	POC I-5 (PCB Design)	11 days	Mon 02-10-17	Mon 16-10-17
21	POC C-6 (Machine Learning)	22 days	Mon 02-10-17	Tue 31-10-17
22	PCB Printing & Enclosure	13 days	Tue 17-10-17	Thu 02-11-17
23	University EXAM	27 days	Fri 03-11-17	Mon 11-12-17
24	Implementation & Integration	15 days	Tue 12-12-17	Mon 01-01-18
25	Integration Testing	6 days	Tue 02-01-18	Tue 09-01-18
26	Machine Learning & System Testing	58 days	Wed 10-01-18	Fri 30-03-18

Figure 4.2: Gantt Chart

Chapter 5

System Design

5.1 Block Diagram

5.1.1 Very High Level Block Diagram

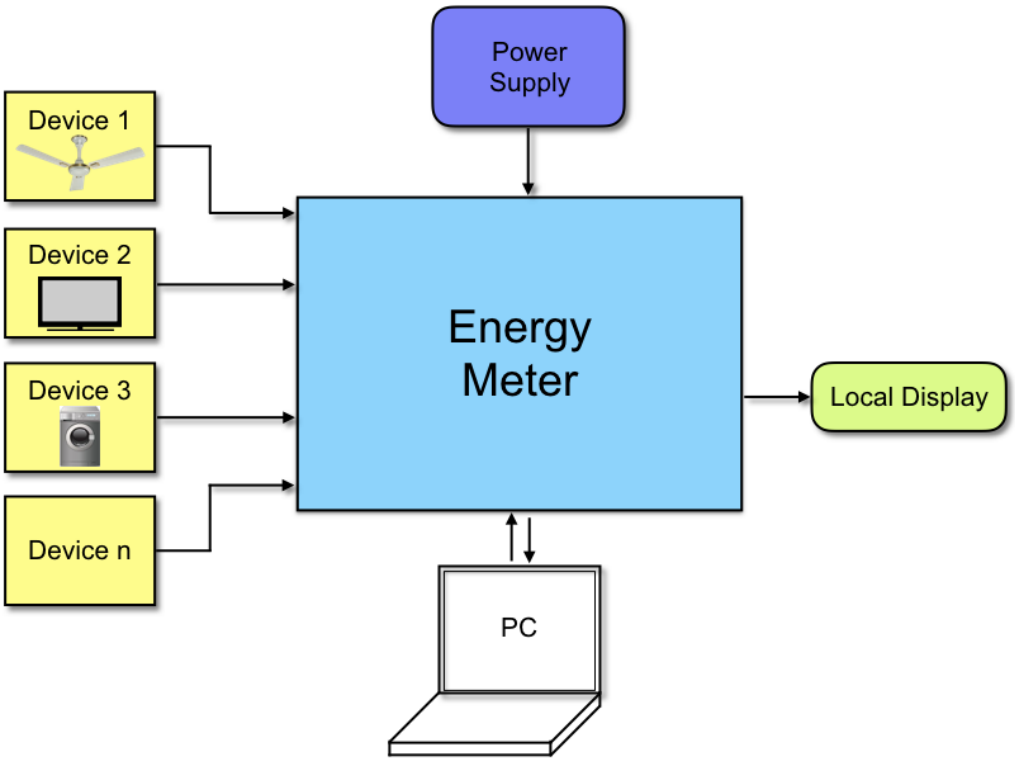


Figure 5.1: Very High Level Block Diagram

5.1.2 High Level Block Diagram

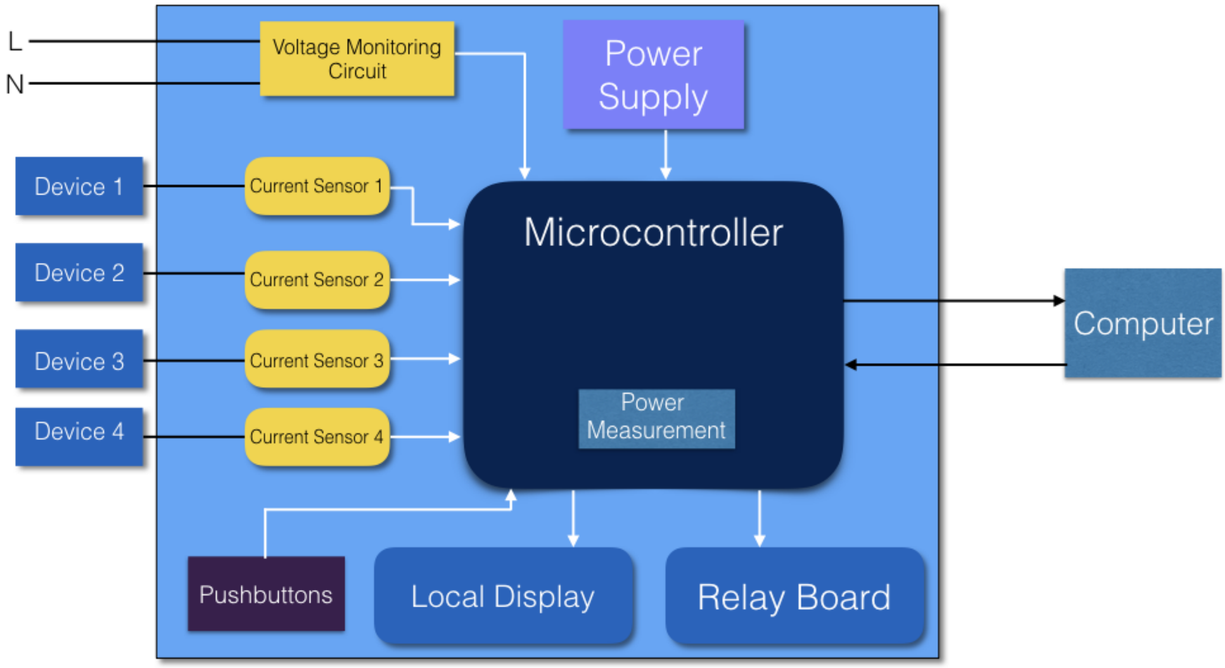


Figure 5.2: High Level Block Diagram

The Above diagram shows the components of the the proposed system. The inputs to the system are the voltage and current sensing circuits along with pushbuttons that control the relays. The Microcontroller does the processing related to the power measurement and also communicates the data with the computer. The outputs from the system are a local display which will show the power consumption statistics to the user and a relay board which will allow the user to control the electrical devices from the board or from the computer user interface.

5.2 Electrical Energy and Power

5.2.1 Electrical Power

Electric power is the rate, per unit time, at which electrical energy is transferred by an electric circuit. The SI unit of power is the watt, one joule per second. The electric power in watts produced by an electric current I consisting of a charge of Q coulombs every t seconds passing through an electric potential (voltage) difference of V is

$$P = VQ/t = VI \tag{5.1}$$

where,

P is Power(Work done per unit time)
Q is electric charge in coulombs
t is time in seconds
I is electric current in amperes
V is electric potential or voltage in volts

The power of an electrical appliance tells us how much electrical energy it transfers in a second .Power, P is measured in watts (W) where:

$$1W = 1J/s(Joule/Second) \tag{5.2}$$

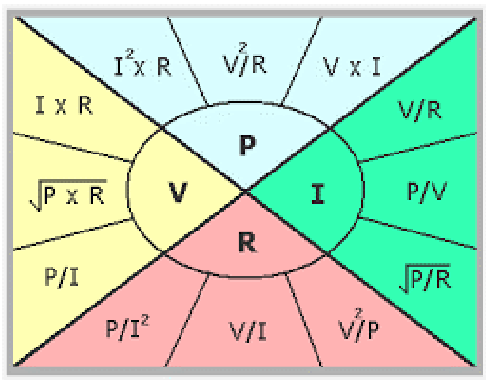


Figure 5.3: Power Equations

$$P = IV = I^2R = V^2/R \tag{5.3}$$

where R is the electrical resistance.

Electrical Energy is the ability of electric current to do work.

We know that Potential Difference V is the Energy Transferred by 1 Coulomb of charge, Q, that moves between two points.

$$V = E/Q \tag{5.4}$$

And, Electrical Current is the rate of charge of flow.

$$Q = It \tag{5.5}$$

Combining the above two equations, we get

$$E = VQ = VIt \tag{5.6}$$

Energy, E is measured in:

1. Joules (J) when the power is in watts and the time, t, is in seconds.
2. Kilowatt hours (kWh) when the power is in kilowatts and the time, t, is in hours.

In a DC circuit, the voltages and currents are generally constant, that is not varying with time as there is no sinusoidal waveform associated with the supply. However in an AC circuit, the instantaneous values of the voltage, current and therefore power are constantly changing being influenced by the supply. So we can not calculate the power in AC circuits in the same manner as we can in DC circuits, but we can still say that power (p) is equal to the voltage (v) times the amperes (i).

Another important point is that AC circuits contain reactance, so there is a power component as a result of the magnetic and/or electric fields created by the components. The result is that unlike a purely resistive component, this power is not only consumed but instead is stored and then returned back to the supply as the sinusoidal waveform goes through one complete periodic cycle.

Thus, the average power absorbed by a circuit is the sum of the power stored and the power returned over one complete cycle. So a circuits average power consumption will be the average of the instantaneous power over one full cycle with the instantaneous power, p defined as the multiplication of the instantaneous voltage, v by the instantaneous current, i. Note that as the sine function is periodic and continuous, the average power given over all time will be exactly the same as the average power given over a single cycle.

5.2.2 Real Power / Active Power (P)

The actual amount of power being dissipated or performs the useful work in the circuit is called as active or true or real power. It is measured in watts. Real Power is given by the formula :

$$P = V_{rms} I_{rms} cos\phi \tag{5.7}$$

where,
P is the real power in **watts (W)**
Vrms is the rms voltage = Vpeak/2 in Volts (V)
Irms is the rms current = Ipeak/2 in Amperes (A)
ϕ is the impedance phase angle = phase difference between voltage and current.

5.2.3 Reactive Power (Q)

A sinusoidally alternating voltage applied to a purely resistive load results in an alternating current that is fully in phase with the voltage. However, in many applications it is common for there to be a reactive component to the system, that is, the system possesses capacitance, inductance, or both. These electrical properties cause the current to change phase with respect to the voltage: capacitance tending the current to lead the voltage in phase, and inductance to lag it.

For sinusoid currents and voltages at the same frequency, reactive power in vars is the product of the RMS voltage and current, or the apparent power, multiplied by the sine of phase angle between the voltage and the current. The reactive power Q (measured in units of volt-amperes reactive or var) is given by:

$$Q = V_{rms} I_{rms} sin\phi \tag{5.8}$$

where,
Q is the reactive power in **volt-ampere-reactive (VAR)**
Vrms is the rms voltage = Vpeak/2 in Volts (V)
Irms is the rms current = Ipeak/2 in Amperes (A)
ϕ is the impedance phase angle = phase difference between voltage and current.

5.2.4 Apparent Power (S)

Apparent power is equal to the product of root-mean-square (RMS) voltage and RMS current. In direct current (DC) circuits, this product is equal to the real power (active power) in watts. Volt-amperes are useful only in the context of alternating current (AC) circuits (sinusoidal voltages and currents of the same frequency).With a purely resistive load, the apparent power is equal to the real power. Where a reactive (capacitive or inductive) component is present in the load, the apparent power is greater than the real power as voltage and current are no longer in phase. In the limiting case of a purely reactive load, current is drawn but no power is dissipated in the load.
Apparent Power (S) is given by :

$$S = V_{rms} I_{rms} \tag{5.9}$$

where,
S is the apparent power in **Volt-amper (VA)**
Vrms is the rms voltage = Vpeak/2 in Volts (V)
Irms is the rms current = Ipeak/2 in Amperes (A)

5.2.5 Relation between Real, Active, and Apparent Powers

The real power P and reactive power Q give together the apparent power S:

$$P^2 + Q^2 = S^2 \tag{5.10}$$

5.2.6 The Power Triangle

Power Triangle is the representation of a right angle triangle showing the relation between active power, reactive power and apparent power. When each component of the current that is the active component (Icosϕ) or the reactive component (Isinϕ) is multiplied by the voltage V, a power triangle is obtained as shown in the figure below :

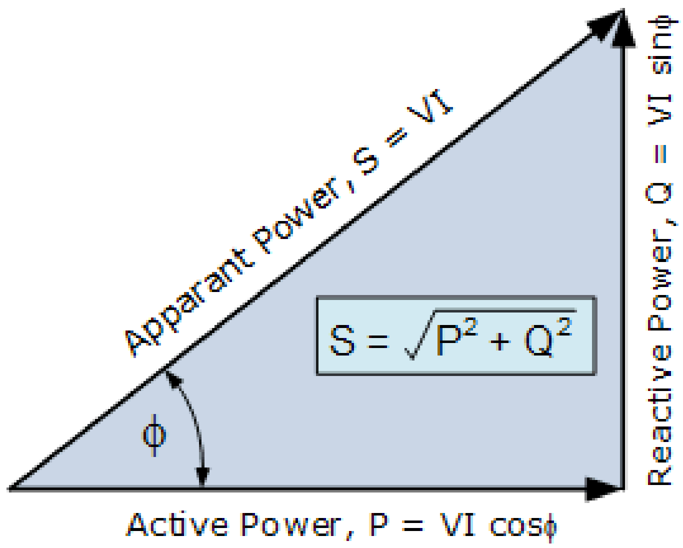


Figure 5.4: The Power Triangle

Real power is placed on the horizontal plane and the reactive power is placed on the vertical plane. The vector addition of these two powers gives apparent power.

5.2.7 Power Factor

In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit, and is a dimensionless number in the closed interval of 1 to 1. A power factor of less than one means that the voltage and current waveforms are not in phase, reducing the instantaneous product of the two waveforms (V I). Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power. A negative power factor occurs when the device (which is normally the load) generates power, which then flows back towards the source, which is normally considered the generator. Power Factor is only related to AC Circuits i.e. There is no Power Factor (p.f) in DC Circuits due to zero frequency.

In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor.

Power Factor may be defined by three definitions :

1. The Cosine of angle between Current and Voltage
   $P = VIcos\phi$

2. The ratio between resistance and Impedance.
   $cos\phi = R/Z$

3. The ratio between Actual Power and Apparent Power
   Power Factor = Real Power / Apparent Power
   $cos\phi = kW/kVA$

The power factor value measures how much the mains efficiency is affected by both phase lag ϕ and harmonic content of the input current.

Linear Loads

In a purely resistive AC circuit, voltage and current waveforms are in step (or in phase), changing polarity at the same instant in each cycle. All the power entering the load is consumed (or dissipated). Where reactive loads are present, such as with capacitors or inductors, energy storage in the loads results in a phase difference between the current and voltage waveforms. During each cycle of the AC voltage, extra energy, in addition to any energy consumed in the load, is temporarily stored in the load in electric or magnetic fields, and then returned to the power grid a fraction of the period later.

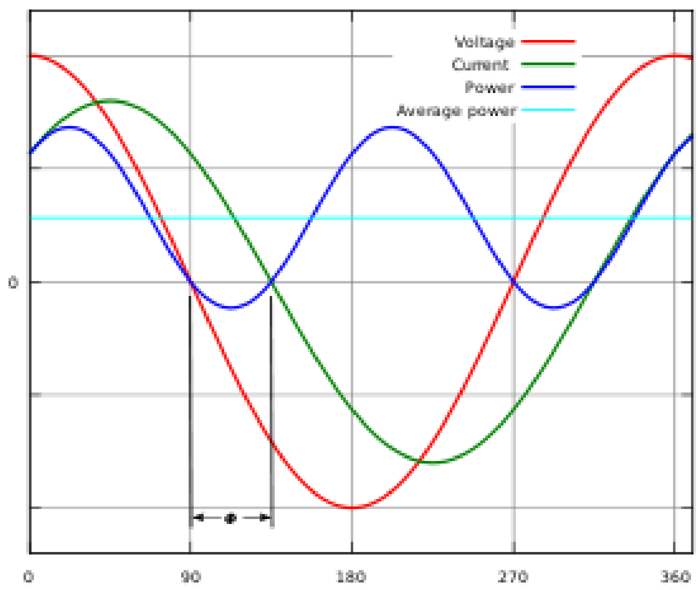


Figure 5.5: Linear Loads

In linear circuits having only sinusoidal currents and voltages of one frequency, the power factor arises only from the difference in phase between the current and voltage.

Non-Linear Loads

Non-linear loads change the shape of the current waveform from a sine wave to some other form. Non-linear loads create harmonic currents in addition to the original (fundamental frequency) AC current. This is of importance in practical power systems that contain non-linear loads such as rectifiers or switched-mode power supplies.

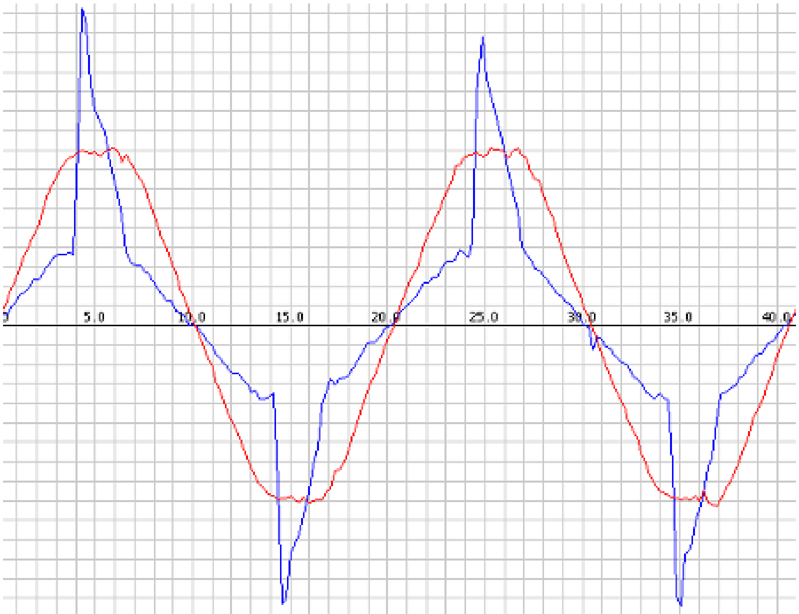


Figure 5.6: Non-Linear Loads

The load current that is drawn has a non-sinusoidal / distorted waveform due to the presence of harmonics.

5.2.8 Measurement of Power

Instantaneous Power

The instantaneous electric power in an AC circuit is given by P=VI where V and I are the instantaneous voltage and current.

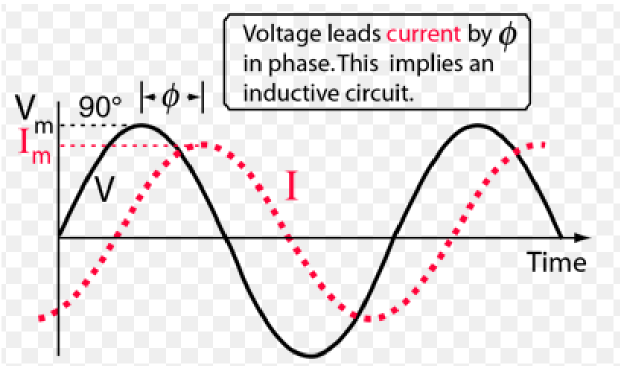


Figure 5.7: Measurement of Instantaneous Power

Since,
$V = V_m sin\omega t$
$I = I_m sin(\omega t - \phi)$
then the instantaneous power at any time t can be expressed as,

$$P_{instantaneous} = V_m I_m sin\omega t sin(\omega t - \phi) \tag{5.11}$$

Average Power

The average power is given by :
$P_{avg} = VIcos\phi$

5.3 Voltage Measurement

An AC mains voltage measurement is needed to calculate real power, apparent power and power factor. In India the mains AC voltage is rated at 230 V AC RMS with a frequency of 50 Hz. This 230V AC RMS is with a tolerance of $\pm10\%$,giving a lower limit of 207 V and an upper limit of 253 V RMS. In order to accurately measure this AC RMS voltage we first need to understand some mathematics behind the Sinusoidal Waveform.

5.3.1 The Sinusoidal AC Waveform

Generators produce electricity from mechanical energy based on the phenomenon called electromagnetic induction.The AC generator produces an alternating sinusoidal voltage, which has some special properties. No other periodic wave (square, triangular, etc.) will pass through a linear network containing energy storage elements, (capacitors and inductors) and leave with the same frequency and shape except for phase and amplitude changes. This is because the derivative and integral of a sinusoidal wave are the same except for phase differences. This is the reason why sinusoidal voltage waveforms are used for AC supply.

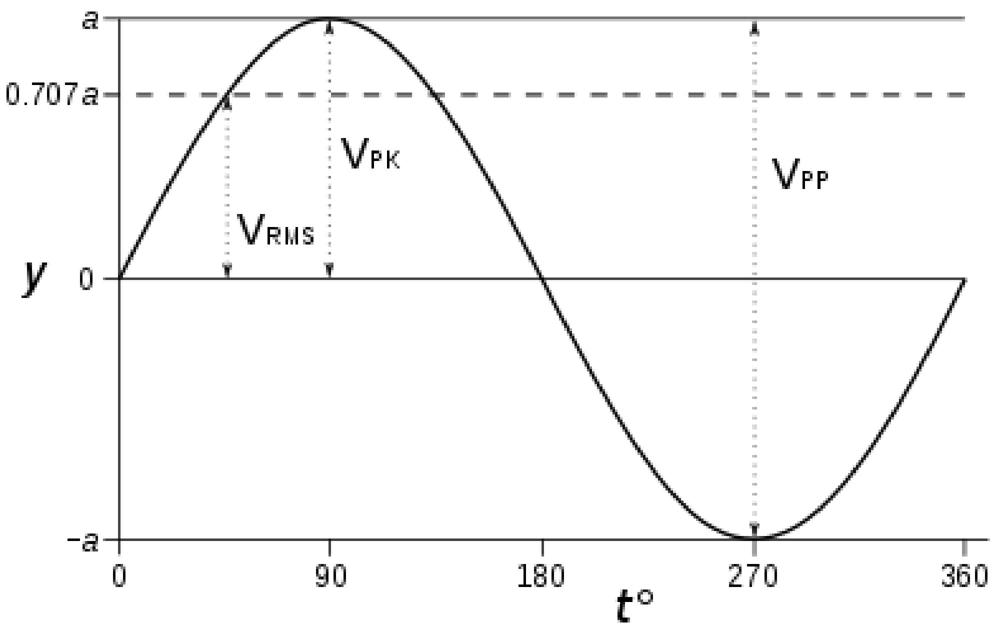


Figure 5.8: Sinusoidal AC Voltage Waveform

Peak Voltage

Peak voltage, VP, is a voltage waveform which is measured from the horizontal axis (at the 0 height reference mark) to the top of the waveform, called the crest of the waveform.

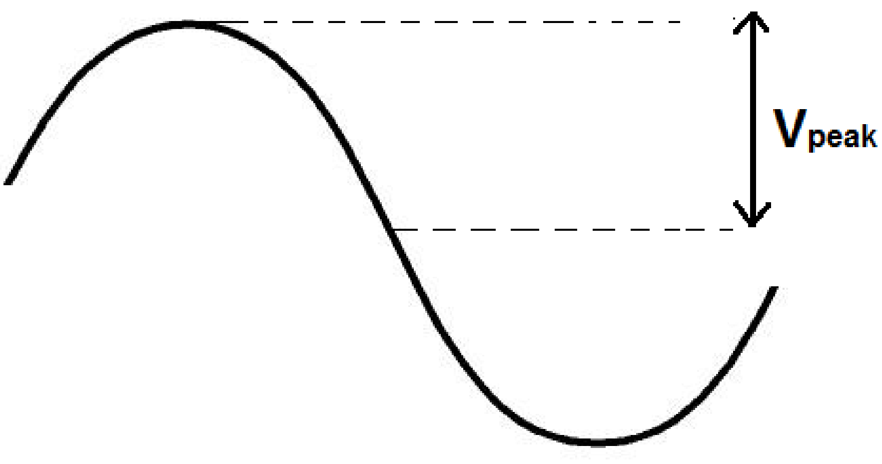


Figure 5.9: Peak Voltage

Peak-to-Peak Voltage

Peak-to-peak voltage, VPP, is a voltage waveform which is measured from the top of the waveform, called the crest, all the way down to the bottom of the waveform, called the trough.

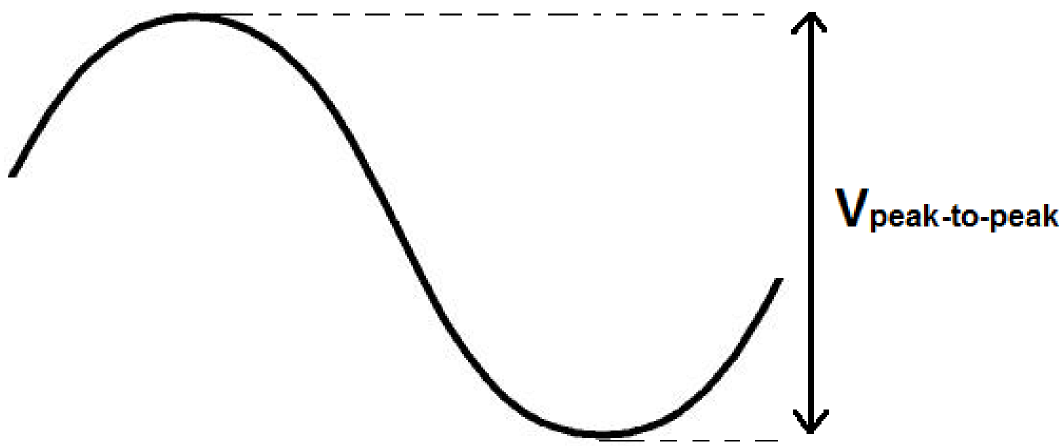


Figure 5.10: Peak-to-Peak Voltage

$$V_{peak-to-peak} = V_{peak} * 2 \tag{5.12}$$

RMS Voltage

Root-mean-square (rms) the most common mathematical method of defining the effective voltage or current of an AC wave. The term RMS, ONLY refers to time-varying sinusoidal voltages, currents or complex waveforms were the magnitude of the waveform changes over time and is not used in DC circuit analysis or calculations were the magnitude is always constant. RMS voltage is a method of denoting a voltage sine waveform (AC waveform) as an equivalent voltage which represents the DC voltage value that will produce the same heating effect, or power dissipation, in circuit, as this AC voltage. In other words, the waveform is an AC waveform, but the RMS value allows this waveform to be specified as if DC, because it is the equivalent DC voltage that delivers the same amount of power to a load in a circuit as the AC signal does over its cycle.

AC and DC waveforms can both represent voltage or current waveforms, but they are in different forms. AC waveforms fluctuate between positive and negative voltage in cycles. DC voltage is just constant one-way voltage that doesn't have cycles. Because of this difference, it's very difficult to compare the two. This is where the RMS value is important. It gives us a standard to compare the amount of power that an AC waveform and a DC waveform can give to a circuit. RMS voltage is the DC equivalent of an AC waveform so that we can compare power dissipation with both the AC power and DC power waveforms. If we have a RMS waveform of an AC signal and it it is the same value as a DC waveform, then we know that both waveforms give off, or dissipates, the same amount of power in a circuit. The reason RMS voltage is also called effective voltage is because it is just as effective as DC voltage in providing power to an element (it's equally effective). Since RMS voltage is the DC equivalent voltage, the RMS voltage is just as effective as its equivalent DC voltage in providing power to an element or load in a circuit.

$$V_{rms} = V_{peak} * (1/\sqrt{2}) = V_{peak} * (0.707) \tag{5.13}$$

$$V_{rms} = V_{peak-to-peak} * (1/2\sqrt{2}) = V_{peak-to-peak} * (0.35355) \tag{5.14}$$

$$V_{rms} = V_{average} * (\pi/2\sqrt{2}) = V_{average} * (1.1107) \tag{5.15}$$

5.3.2 Voltage Divider

The 230V AC RMS is with a tolerance of $\pm 10\%$,giving a lower limit of 207 V and an upper limit of 253 V RMS. From equation (5.13), we can calculate that the maximum Peak Voltage will be $253 * \sqrt{2} = 357.742V$. We need to step down this Peak Voltage to a level of 3.3 V DC, which is the operating voltage for our microcontroller. For this purpose, we have used a simple potential divider which will step down the AC voltage.

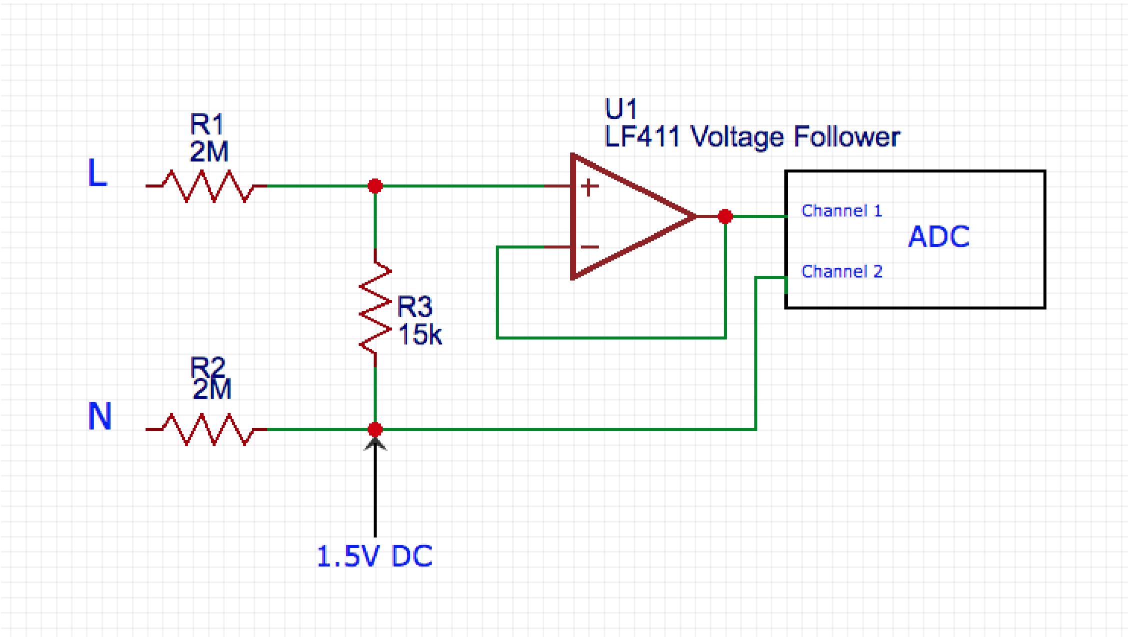


Figure 5.11: Voltage Measurement Circuit

From figure 5.9 we see that, the resistors R1, R2, and R3 form a voltage divider circuit. the gain of this voltage divider can be calculated as follows:

$R1 = R2 = 2M\Omega$
$R3 = 15k\Omega$
$Gain = R2/(R1 + R2 + R3)$
$Gain = 15k/(2M + 2M + 15k)$
$Gain = 15k/4015k$
$Gain = 0.00373599003$

If we multiply this gain by the maximum peak voltage :

$0.00373599003 * 357.742 = 1.336V$

We get a sine wave of 1.336 V peak.
The negative peak of the sine wave , however, is not readable by the microcontroller, and may in fact damage the ADC pin of the microcontroller. So, we add a DC bias voltage of 1.5 V in order to shift this wave.
$1.336 + 1.5 = 2.83V$ maximum
2.83V is well inside the 3.3V operating voltage of the microcontroller ADC. This voltage signal is not given directly to the ADC pin. A unity gain buffer is added before the ADC pin along with a pull down resistor.

5.3.3 LF411 Op-Amp as an unity gain buffer

LF411-N Low Offset, Low Drift JFET Input Operational Amplifier
LF411 is manufactured by Texas Instruments. The LF411 is a low cost, high speed, JFET input operational amplifier with very low input offset voltage and drift. It requires a very low supply current and still maintains a large gain bandwidth product and a fast slew rate.
Features:

1. Internally Trimmed Offset Voltage: $0.5mV$ (Max) operational amplifiers with very low input offset
2. Input Offset Voltage Drift: $7\mu V/^{\circ}C$ (Typ)
3. Low Input Bias Current: 50 pA

4. Low Input Noise Current: $0.01 pA/\sqrt{Hz}$ high voltage JFET input devices provide very low
5. Wide Gain Bandwidth: $3MHz$ (Min)
6. High Slew Rate: $10V/\mu s$ (Min)
7. Low Supply Current: 1.8 mA
8. High Input Impedance: 1012Ω
9. Low Total Harmonic Distortion: 0.02%
10. Low $1/f$ Noise Corner: 50 Hz
11. Fast Settling Time to 0.01%:

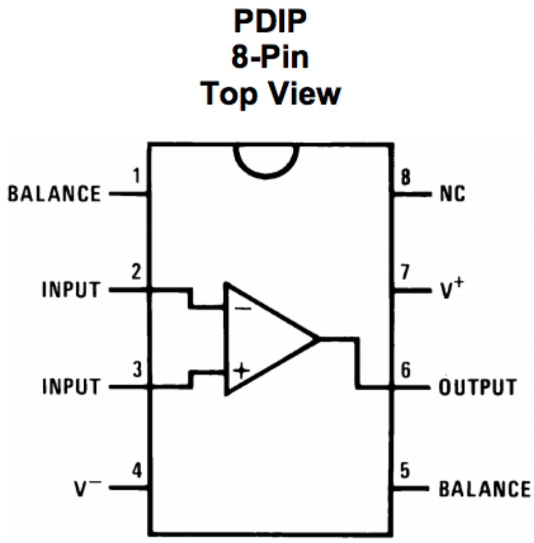


Figure 5.12: LF411 DIP-Package

Voltage Follower/Buffer

A voltage follower (also called a unity-gain amplifier, a buffer amplifier, and an isolation amplifier) is a op-amp circuit which has a voltage gain of 1. This means that the op amp does not provide any amplification to the signal. Voltage followers are generally used to isolate stages from each other. A voltage follower generally has a high input impedance and a low output impedance. This means that whatever circuit is supplying the input signal does not have to provide much current, while the output of the voltage follower can supply significantly more current to the next stage.

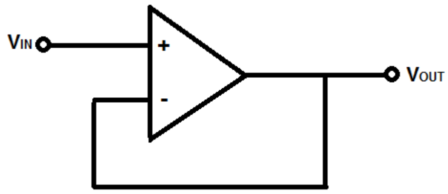


Figure 5.13: Op-Amp as a voltage follower / Buffer

ADC's draw current in large bursts when they sample their input, and this can be disruptive to whatever circuitry might be sourcing the signal. Voltage followers provide isolation between the sourcing circuit, in this case ,the voltage divider and the ADC input pin.This is the reason why the use of voltage followers is important.

5.3.4 TLV431

TLV431 Low-Voltage Adjustable Precision Shunt Regulator

The TLV431 IC, by Texas Instruments is used to provide a DC bias to the stepped down sinusoidal wave after the voltage divider.The TLV431 device is a low-voltage 3-terminal adjustable voltage reference with specified thermal stability over applicable industrial and commercial temperature ranges.

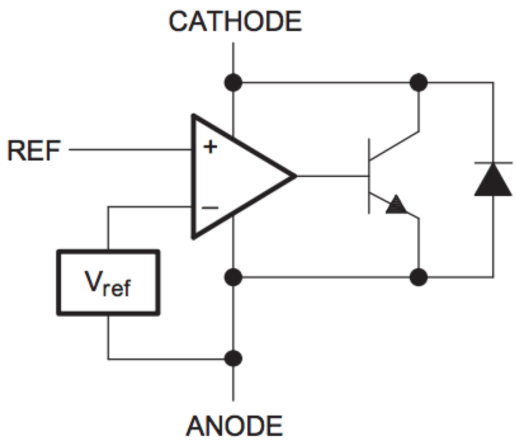


Figure 5.14: TLV431 - Functional Block Diagram

TLV431 consists of an internal reference and amplifier that outputs a sink current base on the difference between the reference pin and the virtual internal pin. The sink current is produced by an internal darlington pair. When operated with enough voltage headroom (greater than $1.24V$) and cathode current (I_{ka}), TLV431 forces the reference pin to $1.24V$. However, the reference pin can not be left floating, as it requires I_{ref} greater than $0.5\mu A$ (see the Functional Block Diagram). This is because the reference pin is driven into an npn, which requires a base current to operate properly. When feedback is applied from the Cathode and Reference pins, TLV431 behaves as a Zener diode, regulating to a constant voltage dependent on current being supplied into the cathode. This is due to the internal amplifier and reference entering the proper operating regions. The same amount of current required in the above feedback situation must be applied to this device in open-loop, servo, or error-amplifying implementations for it to be in the proper linear region giving TLV431 enough gain.

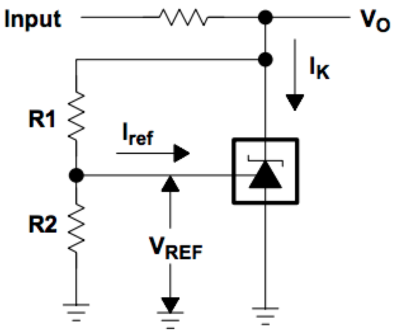


Figure 5.15: Circuit for setting Output Voltage of TLV431

$$V_o = V_{ka} = V_{ref} * (1 + R1/R2) * I_{ref} * R1 \tag{5.16}$$

5.4 Current Measurement

In AC Circuits, the current drawn is only limited by the load. If a heavy load is connected, it draws more current.However, if you connected higher rated load, or shorted the socket, the max current in will be determined by trip point of your circuit breaker. The electricity service providers allocate a fixed amount of load in kW to individual houses, which also determines the maximum amount of current that can be drawn.

5.4.1 Hall Effect

If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor as illustrated. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall Effect.

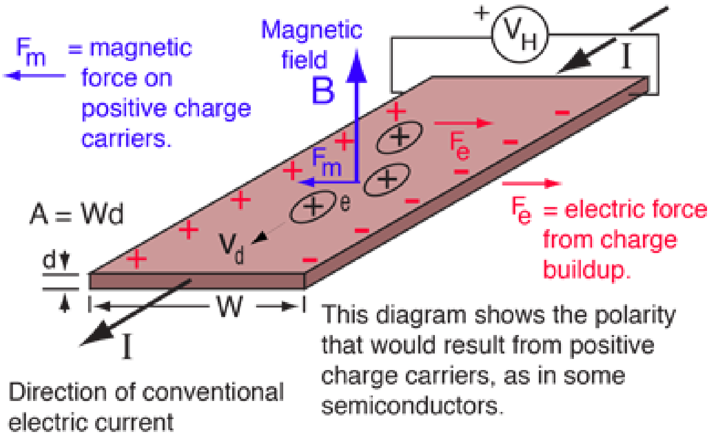


Figure 5.16: Hall Effect

Note that the direction of the current I in the diagram is that of conventional current, so that the motion of electrons is in the opposite direction.

The Hall Voltage is given by:

$$V_H = IB/ned \tag{5.17}$$

where,

I = Current flowing through the conductor.
B = Magnetic field created by the conductor.
n = Density of mobile charges.
e = Electron charge.

Harnessing the Hall Effect

The voltages generated via the Hall effect are small relative to the noise, offsets, and temperature effects that typically influence a circuit.Hall effect sensors are valued for being nonintrusive and for providing electrical isolation between the current path and the measurement circuit. These devices are considered nonintrusive because no significant amount of resistance is inserted into the current path, and thus the circuit being measured behaves almost as if the sensor is not present. An additional benefit is that minimal power is dissipated by the sensor; this is particularly important when measuring large currents. Hall effect sensors can achieve output error as low as 1%. A well-designed resistive current-sense circuit could surpass this, but 1% would generally be adequate in the high-current/high-voltage applications for which Hall effect devices are particularly suitable.

Isolation : One of the dominant benefits of Hall effect sensors is electrical isolation, which in a circuit- or system-design context is often referred to as galvanic isolation. The principle of galvanic isolation is involved whenever a design requires that two circuits communicate in a way that prevents any direct flow of electrical current. A simple example is when a digital signal is passed through an opto-isolator, which converts the voltage pulses to light pulses and thus transmits data optically rather than electrically. One of the primary reasons for implementing galvanic isolation is to prevent problems related to ground loops.

Common Mode Voltage : Another important application for Hall effect sensors is current measurements involving high voltages. In a resistive current-sense circuit, a differential amplifier measures the difference in voltage between one side of a resistor and the other. A problem arises, though, when these voltages are large relative to the ground potential. Hall effect sensors, on the other hand, can convert current to voltage without reference to the measured circuits ground potential. Consequently, as long as the voltages are not large enough to cause physical damage, common-mode voltage does not affect the operation of a Hall effect device.

5.4.2 ACS712 Hall -Effect based Linear Current Sensor

The Allegro ACS712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems.The device consists of a precise, low-offset, linear Hall sensor circuit with a copper conduction path located near the surface of 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 after packaging.

The output of the device has a positive slope when an increasing current flows through the primary copper conduction path (from pins 1 and 2, to pins 3 and 4), which is the path used for current sensing. The internal resistance of this conductive path is 1.2 mΩ typical, providing low power loss. The thickness of the copper

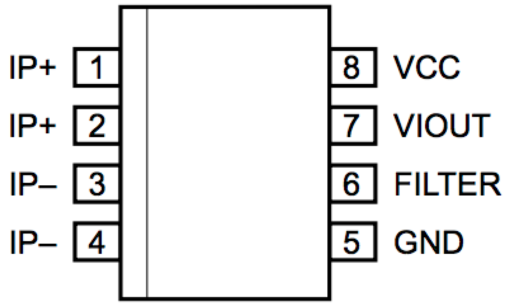


Figure 5.17: ACS712 Pinout

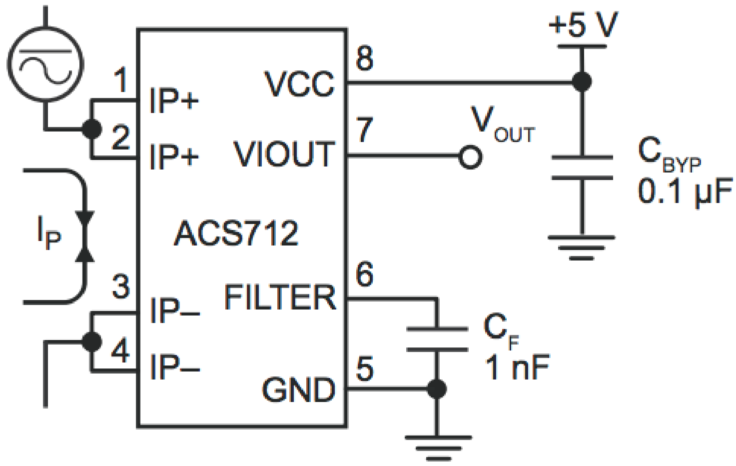


Figure 5.18: ACS712 Typical Application

conductor allows survival of the device at up to 5x overcurrent conditions. The terminals of the conductive path are electrically isolated from the sensor leads.

ACS712 Selection Guide

The ACS712 comes in 3 variants. The table below illustrates the selection guide for the ACS712.

Part Number	Packing*	T_A (°C)	Optimized Range, I_P (A)	Sensitivity, Sens (Typ) (mV/A)
ACS712ELCTR-05B-T	Tape and reel, 3000 pieces/reel	–40 to 85	±5	185
ACS712ELCTR-20A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±20	100
ACS712ELCTR-30A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±30	66

Figure 5.19: ACS712 Selection Guide

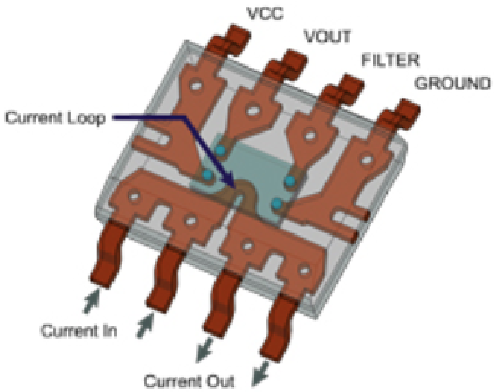


Figure 5.20: ACS712 Construction

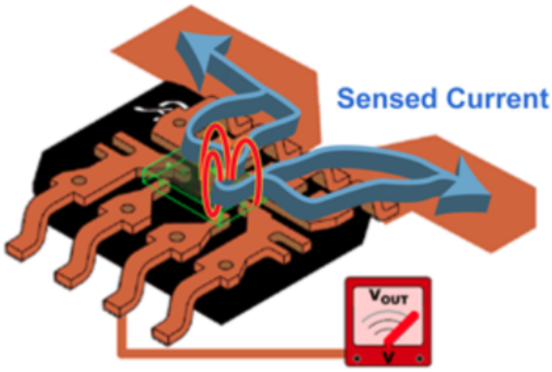


Figure 5.21: ACS712 Working

Working

Current flows in and out of the IC package. It travels in the package through a 3/4 loop inside the package and then back out again. This current flow generates a magnetic field around the loop that is proportional to the magnitude of the current flowing in the conductor. The resistance of this ACS712 IC is only about $1m\Omega$, and therefore the power loss is extremely low, making it highly efficient in sensing currents as high as 50 amps continuous.

An allegro Hall Effect sensor IC is integrated into the package and it sense the magnetic field generated by the current flowing in the conductor. The Hall transducer converts the magnetic field into a voltage. The Hall transducer is placed over the portion of the loop where the magnetic field is strongest. While the hall sensor is in close proximity to the current loop, there is an insulating layer between the two.

At no load, the output of the ACS712 is $V_{cc}/2$.

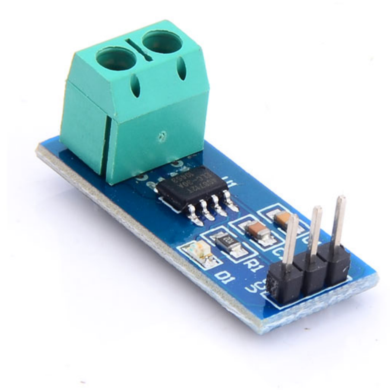


Figure 5.22: ACS712 Breakout Board

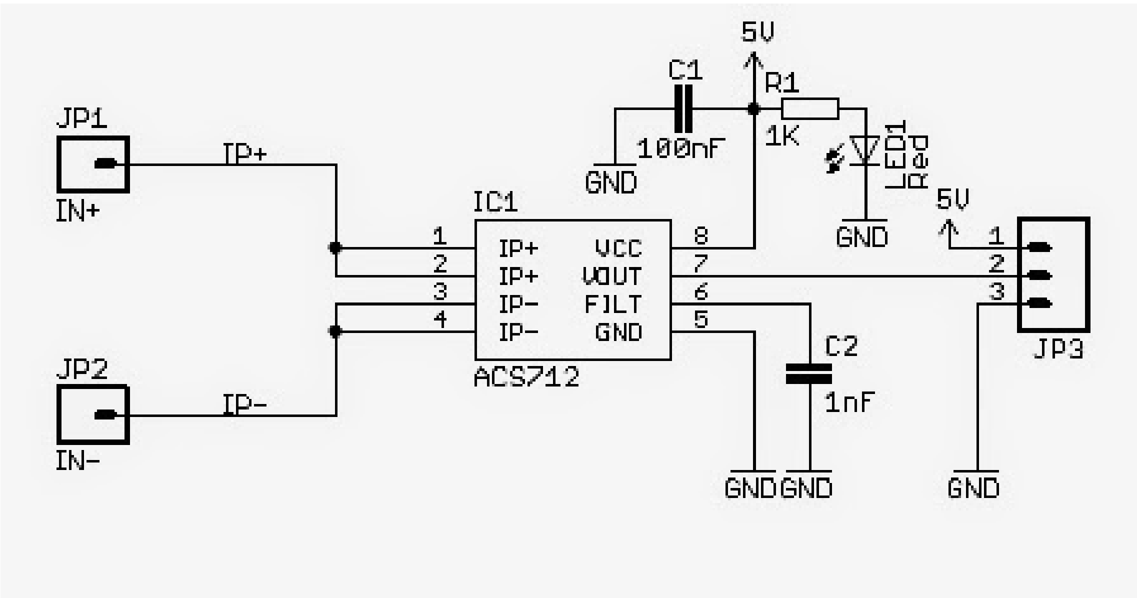


Figure 5.23: ACS712 Breakout Board Schematic

5.4.3 ACS712 Circuit and Connections

ACS712 measures current in two directions. What this means is that, if we sample fast enough and long enough, we are sure to find the peak in one direction and the peak in another direction. With both peaks known, it is a matter of knowing the shape of the waveform to calculate the current. In the case of line or mains power, we know that waveform to be a sinusoidal wave. Knowing that allows us to apply a basic electronic formula to yield a decent result. With an ACS712, current measurements are reported with a voltage output. The figure below shows the schematic for the breakout board.

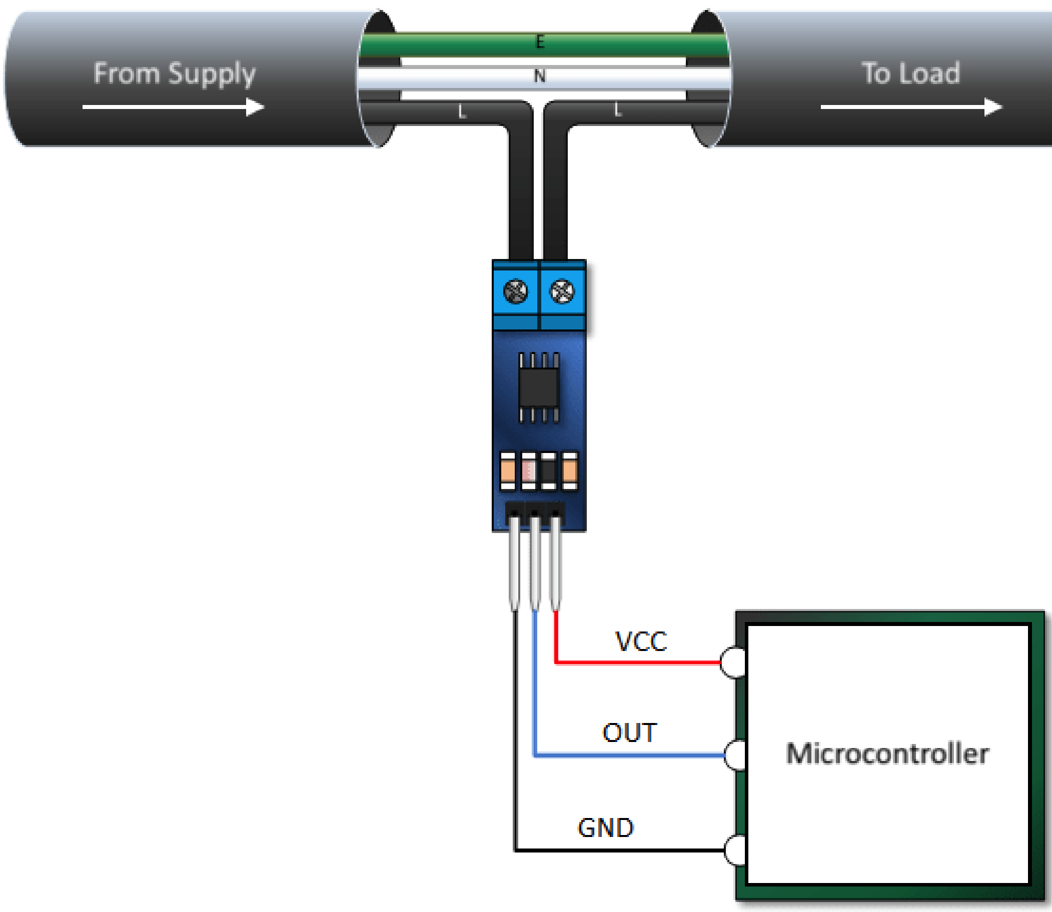


Figure 5.24: ACS712 Connection

Connection

Connect the ACS712 module in the live wire in series with the load. The following figure illustrates connection of ACS712. At zero load, the ACS712 gives a output of $V_{cc}/2$. As the load increases, and the current drawn by the load increases, the ACS712 gives an sine wave output whose magnitude is proportional to the magnitude of current drawn by the load. By finding the peak and peak-to-peak voltage of this sine wave we can calculate the RMS value of the sine wave. Applying the scaling factor, as mentioned in the data sheet, we can find out the value of RMS current drawn by the load.

5.5 Microcontroller

A microcontroller contains one or more CPUs (processor cores) along with memory and programmable input/output peripherals. Microcontrollers are designed for mostly embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips.

5.5.1 Selecting a Microcontroller

Now that we have understood and designed the voltage and current measurement circuits, the next step is choosing the right microcontroller for calculating the power. The following factors were considered while choosing the microcontroller.

1. **Define Hardware Interfaces required :**
   Using the general hardware block diagram, make a list of all the external interfaces that the microcontroller will need to support. There are two general types of interfaces that need to be listed. The first are communication interfaces. These are peripherals such as USB, I2C, SPI, UART, and so on. The second type of interface is digital inputs and outputs, analog to digital inputs, PWMs, etc. These two interface types will dictate the number of pins that will be required by the microcontroller.

2. **Examine and Select the Software Architecture required :**
   The software architecture and requirements can greatly affect the selection of a microcontroller. Determination of RISC, CISC or Harvard Architecture. Number of bits required, amount of processing power required,etc. are all the factors that should be considered.

3. **Identify memory needs :**
   Decide how much RAM is required for the application and how much flash memory is required.

4. **Examine Costs and Power Constraints :**
   While developing embedded applications, such as this project, determining the cost beforehand is very important and a major selection criteria for microcontrollers. Power estimation and constraints also have to defined while choosing a microcontroller.

5. **Investigate Compilers and Programming Tools :**
   Most microcontrollers have a number of choices for compilers, example code and debugging tools. It is important to make sure that all the necessary tools are available for the part. The designer has to be comfortable with the programming language and compiler chosen.

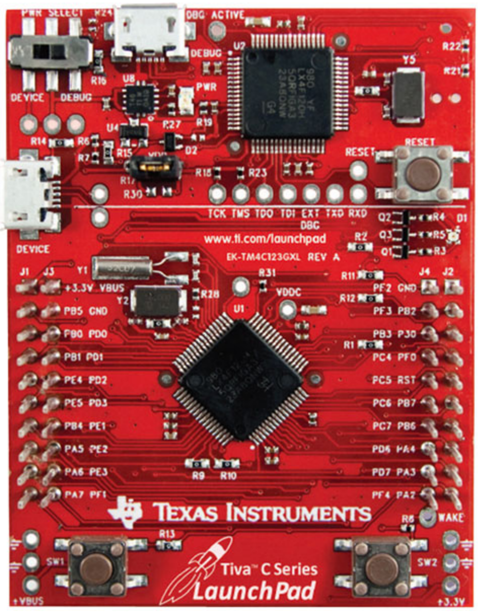


Figure 5.25: Tiva C Series TM4C123G LaunchPad Evaluation Board

5.5.2 The Tiva C Series TM4C123G LaunchPad Evaluation Board

The TM4C123G LaunchPad Evaluation Kit is a low-cost evaluation platform for ARM Cortex-M4F based microcontrollers from Texas Instruments. The design of the TM4C123G LaunchPad highlights the TM4C123GH6PM microcontroller with a USB 2.0 device interface and hibernation module. There are many I/O pins that have multi-personality. This means that they can be easily configured as digital inputs or outputs, analog inputs and outputs or other functions, allowing a great variety of applications, are just the multiple serial ports have the ability to interface with more items such as test cards or other communication modules, etc. The ARM Cortex-M4F Based MCU TM4C123G LaunchPad Evaluation Kit (EK-TM4C123GXL) offers these features:

1. 80MHz 32-bit ARM Cortex-M4-based microcontrollers CPU
2. 256KB Flash, 32KB SRAM, 2KB EEPROM
3. USB 2.0 Host/Device/OTG + PHY
4. Dual 12-bit 2MSPS ADCs, motion control PWMs
5. 8UART,6I2C,4SPI
6. On-board In-Circuit Debug Interface (ICDI)

5.5.3 Tiva C Launchpad ADC

An analog-to-digital converter (ADC) is a peripheral that converts a continuous analog voltage to a discrete digital number. Two identical converter modules are included in Tiva C Launchpad, which share 12 input channels. The TM4C123GH6PM ADC module features 12-bit conversion resolution and supports 12 input channels, plus an internal temperature sensor. Each ADC module contains four programmable sequencers allowing the sampling of multiple analog input sources without controller intervention. Each sample sequencer provides flexible programming with fully configurable input source, trigger events, interrupt generation, and sequencer priority. In addition, the conversion value can optionally be diverted to a digital comparator module. Each ADC module provides eight digital comparators. Each digital comparator evaluates the ADC conversion value against its two user-defined values to determine the operational range of the signal. The Analog-to-Digital Converter (ADC) module uses a Successive Approximation Register (SAR) architecture to deliver a 12-bit, low-power, high-precision conversion value. The successive approximation uses a switched capacitor array to perform the dual functions of sampling and holding the signal as well as providing the 12-bit DAC operation

5.5.4 Code Composer Studio

Code Composer Studio is an integrated development environment (IDE) that supports TI's Microcontroller and Embedded Processors portfolio. Code Composer Studio comprises a suite of tools used to develop and debug embedded applications. It includes an optimizing C/C++ compiler, source code editor, project build environment, debugger, profiler, and many other features. The intuitive IDE provides a single user interface taking you through each step of the application development flow. Familiar tools and interfaces allow users to get started faster than ever before. Code Composer Studio combines the advantages of the Eclipse software framework with advanced embedded debug capabilities from TI resulting in a compelling feature-rich development environment for embedded developers.

System Requirements

A laptop running 32 or 64-bit version of Windows XP, and above or Linux (tested for Ubuntu 14.04) operating system. Laptop should have at least 3GB of free hard drive space and a minimum 1GB of RAM.

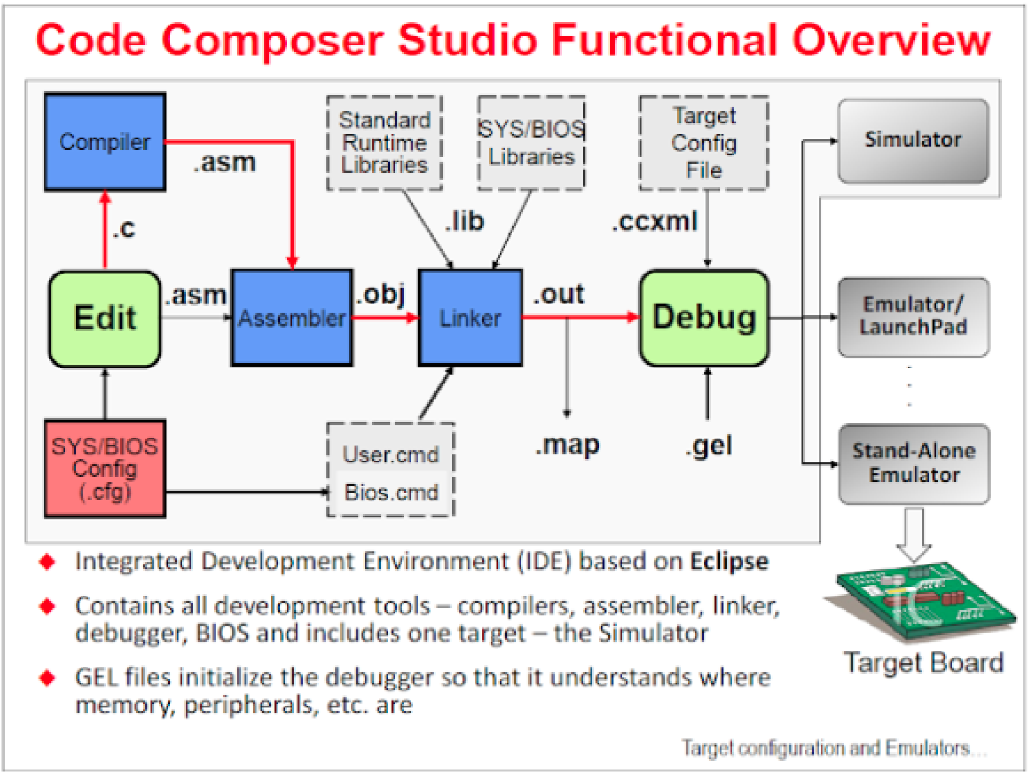


Figure 5.26: Code Composer Studio - Functional Overview

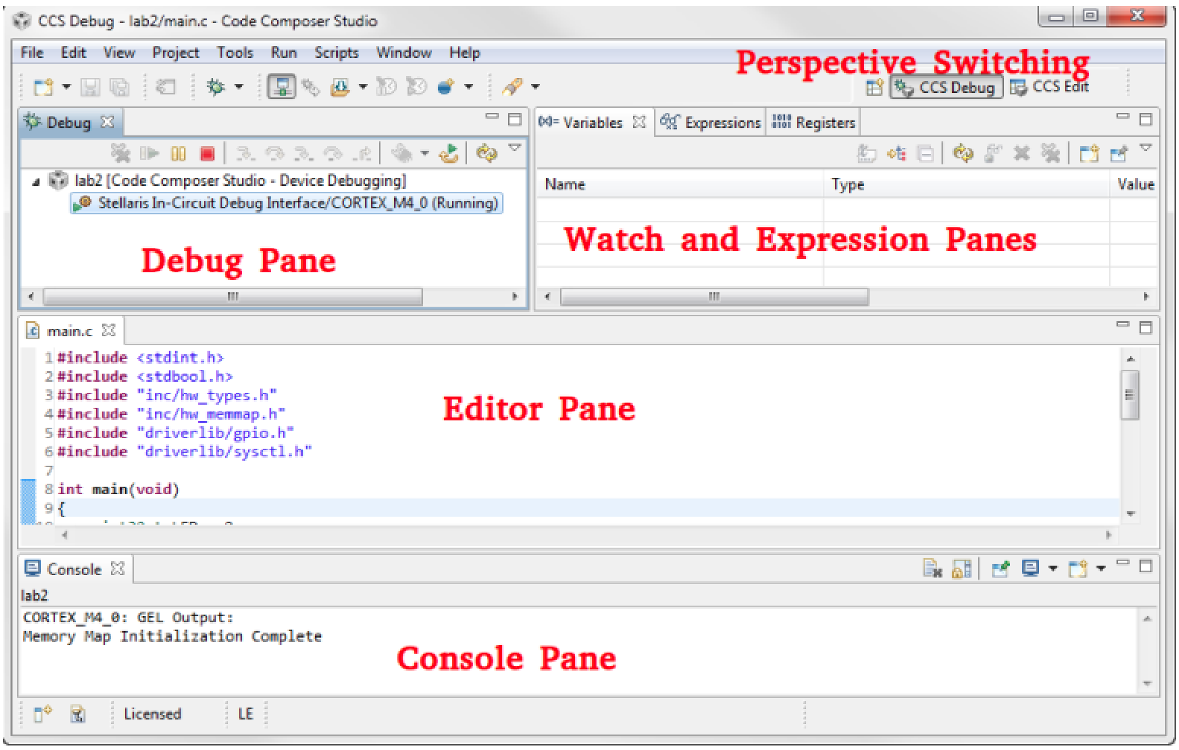


Figure 5.27: Code Composer Studio - UI

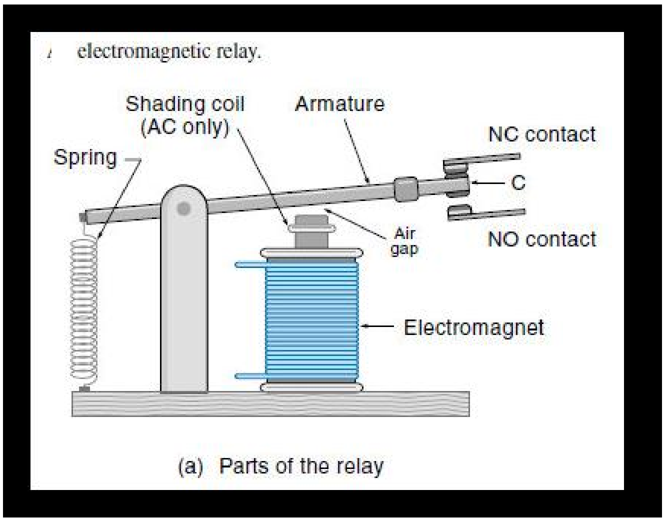


Figure 5.28: Construction of Electromechanical Relay

5.6 Relay Control

The devices connected to the switchboard, whose power we have measured will also have remote access. This can be done by using an electromechanical relay. Electromechanical relays are switches that typically are used to control high power electrical devices. An electromechanical relay, put simply, is a switch. An electrically operated switch to be exact. Relays are electrical parts that are used when a low-power signal is needed in order to control a circuit, or when a number of circuits need to be controlled by one signal. The heart of a relay is an electromagnet. When current flows through the electromagnet, a magnetic field is generated that attracts the armature and the pole is connected from Normally closed to Normally open contact. A spring retains the armature position when no current flows through the electromagnet coil.

The following figure shows an optocoupled relay module.

5.6.1 OptoCoupled Relay Circuit

The optocoupler is a device which contains an LED and a phototransitor in a small package. When power is applied to the LED in the optocoupler, the phototransistor receives the LED light and switches on. This phototransistor is used to drive another NPN transistor which then drives the relay. The driving circuit is completely isolated from the trigger source. In this circuit the relay is powered with the separate circuit / power source. This provides complete optical isolation in the circuit. Diodes D1 and D2 ensure that no current flows back into the source. From

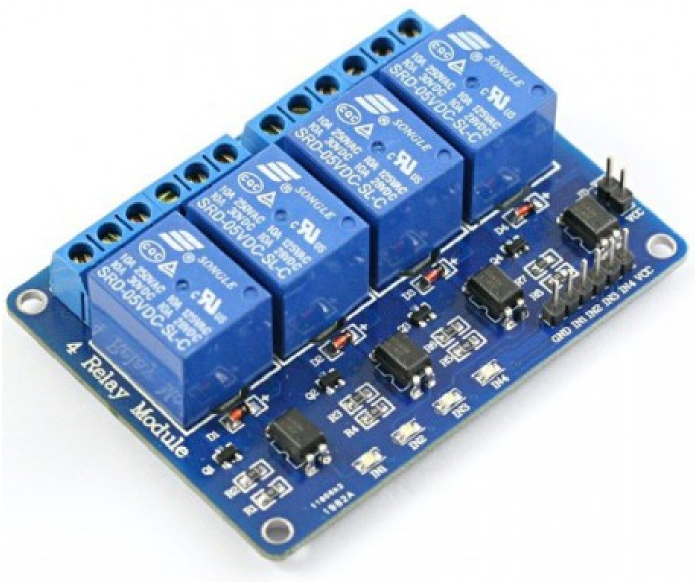


Figure 5.29: Relay Module

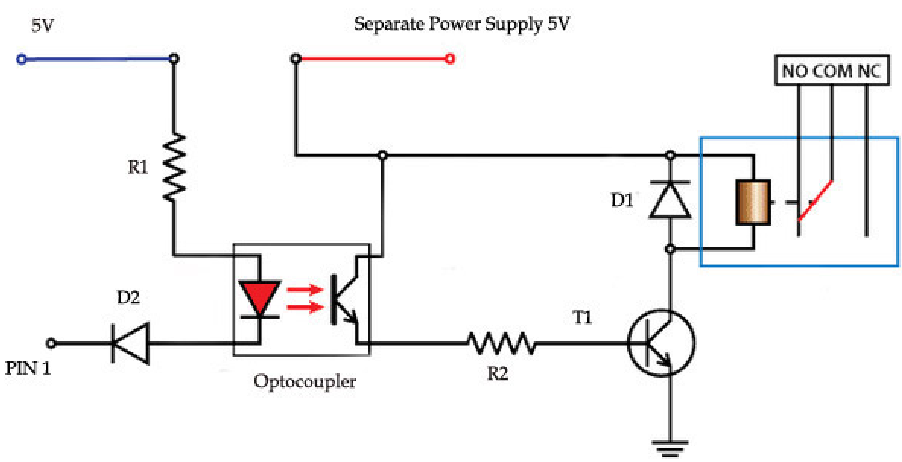


Figure 5.30: Opto Coupled Relay Circuit

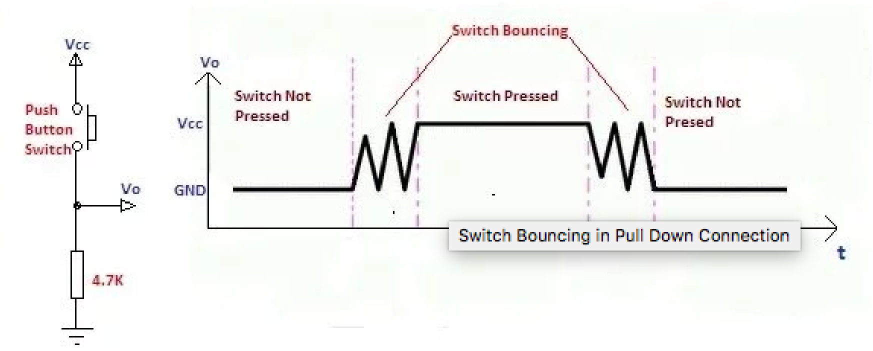


Figure 5.31: Pushbutton Bounce

the above circuit, we can see that the relay will be activated when logic 0 or 0 volts is applied to the input pin, i.e, the circuit is active low. This has to be considered during the programming to control the relay.

5.6.2 Pushbutton

Pushbuttons will be connected to the GPIO pins of the microcontroller. When a pushbutton is pressed, a pulse is registered by the microcontroller. This will then drive the relay coil and switch the electrical device on or off. The pushbutton will be accompanied by a LED on the board to provide acknowledgement that the relay has been turned on.

5.6.3 Pushbutton Bounce

Switch bounce or contact bounce or even called as chatter is a common problem associated with mechanical switches and relays. Switch, relay contacts are made up of spring metals which are forced to contact each other by an actuator. While they collide each other there is a possibility of rebounding for some time before they make a stable contact. In short Switch bounce is a non ideal behavior which generates multiple transitions for a single user input. This effect creates a major problem while we deal with logic circuits. So here we have to remove bounces. And the method to get rid of such bounces is called Switch Debouncing.

R-C Debouncing

The circuit uses two Resistors, Capacitor and a SPST switch.

1. If the switch is open, the voltage across capacitor which is initially zero now charges to Vcc through the $R_{pull-up}$ and $R2$. The output is low (logic 0)

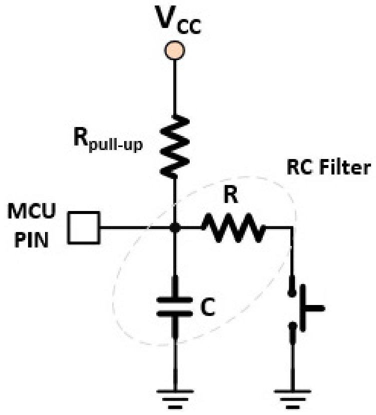


Figure 5.32: R-C Debounce

2. If the switch is closed, the capacitor discharges to zero hence output is high. (logic 1)

The equation for discharging a capacitor is:

$$V_{cap} = Vinitial * e^{(-t/RC)} \tag{5.18}$$

where,
V_{cap} is the voltage across capacitor at time t.
$V_{initial}$ is the voltage initially on the capacitor.
t is the time in seconds.
R and C are the values of Resistor and Capacitor.
We have to select values that ensure the capacitors voltage stays above the threshold value of logic level, till the switch stops bouncing.

5.7 7 Segment LED Display

A seven-segment display (SSD), or seven-segment indicator, is a form of electronic display device for displaying decimal numerals. Generally seven segment displays are available in 10 pin package. Out of 10 pins 8 are LED pins and these are left freely. 2 pins in middle are common pins and these are internally shorted. Depending on either the common pin is cathode or anode seven segment displays can be either named as common cathode or common anode display respectively. Seven segment display works, by glowing the required respective LEDS in the numeral. The display is controlled using pins that are left freely. Forward biasing of

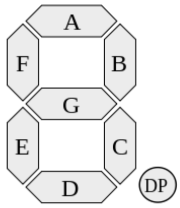


Figure 5.33: The individual segments of a seven-segment display

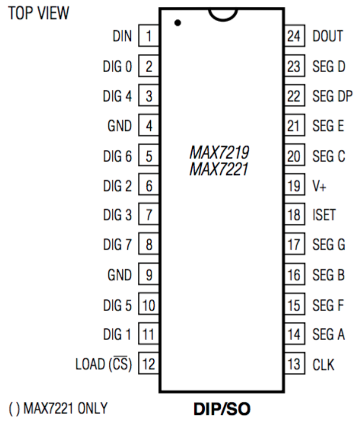


Figure 5.34: MAX7219 Pin Configuration

these pins in a sequence will display the particular numeral or alphabet. Depending on the type of seven segment the segment pins are applied with logic high or logic zero and in the similar way to the common pins also.

5.7.1 MAX7219 - LED Display Driver

The MAX7219 are compact, serial input/output common-cathode display drivers that interface microprocessors (μPs) to 7-segment numeric LED displays of up to 8 digits.Included on-chip are a BCD code-B decoder, multiplex scan circuitry, segment and digit drivers, and an 8x8 static RAM that stores each digit. Only one external resistor is required to set the segment current for all LEDs. The MAX7219 is compatible with SPI Interface. A convenient 4-wire serial interface connects to all common μPs. Individual digits may be addressed and updated without rewriting the entire display. The MAX7219 also allow the user to select codeB decoding or no-decode for each digit.

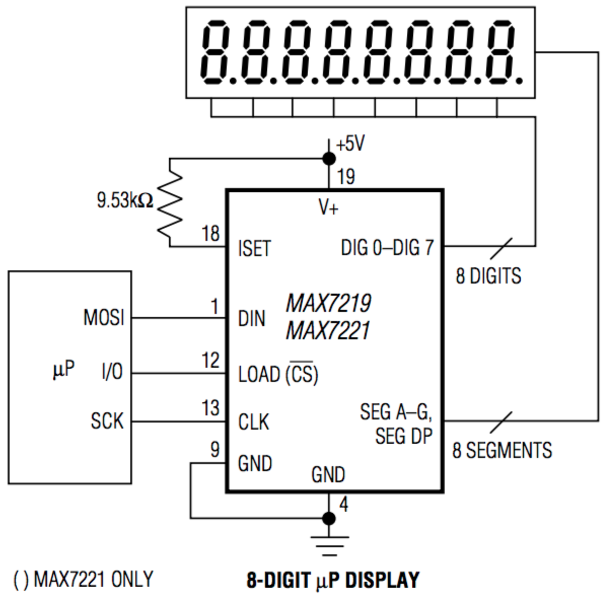


Figure 5.35: MAX7219 Typical Application Circuit

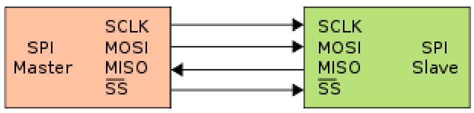


Figure 5.36: SPI Bus

5.7.2 SPI Interface

The Serial Peripheral Interface bus (SPI) is a synchronous serial communication interface specification used for short distance communication, primarily in embedded systems. SPI devices communicate in full duplex mode using a master-slave architecture with a single master. The master device originates the frame for reading and writing. Multiple slave devices are supported through selection with individual slave select (SS) lines.

The SPI bus specifies four logic signals:

1. SCLK: Serial Clock (output from master)

2. MOSI: Master Output Slave Input, or Master Out Slave In (data output from master)

3. MISO: Master Input Slave Output, or Master In Slave Out (data output from slave)

4. SS: Slave Select (often active low, output from master)

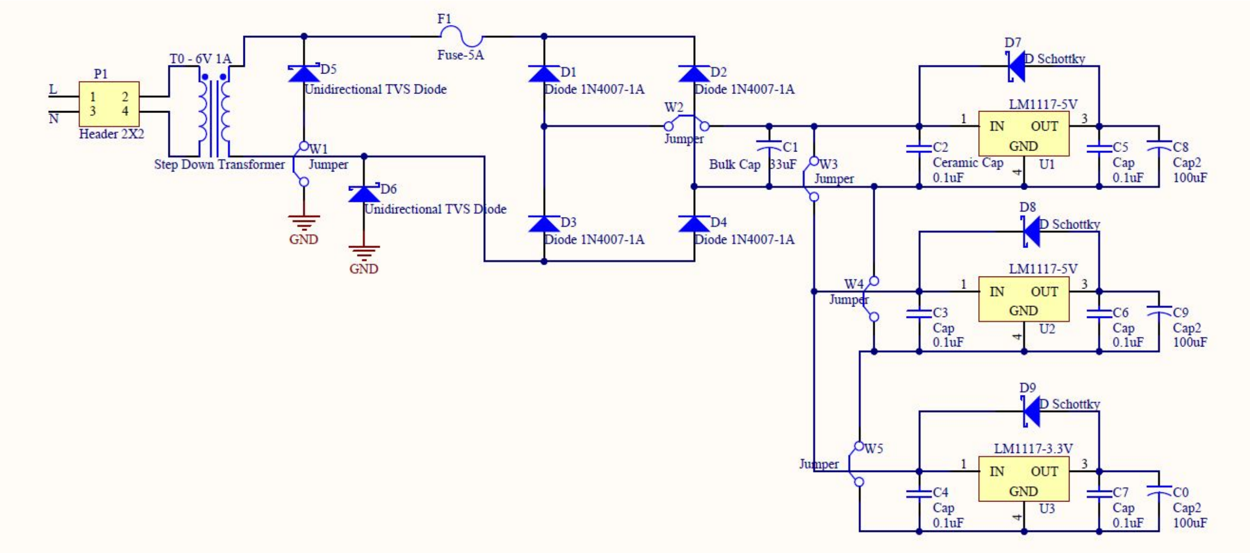


Figure 5.37: Power Supply Design

5.8 Power Supply Design

The follwing figure shows the Power Supply Design for the circuit. A 6V 1amp Transformer steps down the 230V AC to 6 V AC. 4 1N4007 form a Bridge - Rectifier that converts this AC to DC. Transient Voltage Suppression Diodes and a Fuse protect the circuit from any damage due to overcurrent. Next, a linear voltage regulator IC LM1117 is used to get regulated voltage of 3.3V and 5V DC. Various capacitors used in the circuit filter out the AC components in the DC voltage. A Schottky Diode is used as a flyback to protect the LM1117 IC.

The transformer provides 1 ampere of current which is then divided into 3 regulated supplies, 2 of which provide 5V regulated DC and 1 which provides 3.3V AC. The 5V outputs are used for drive the Relay coils and provide supplies to IC's used in the circuit such as TLV431, LF411, MAX7219, etc.
The 3.3V output is used to drive the Tiva board and some LED's. The Power Supply Circuit provides enough current to run all of these IC's. Details about the bridge rectifier working and LM1117 are discussed in the following sections.

5.8.1 Full Bridge Rectifier

A single-phase bridge rectifier consists of four diodes and this configuration is connected across the load. For understanding the bridge rectifiers working principle, we have to consider the below circuit for demonstration purpose.

During the Positive half cycle of the input AC waveform diodes D1 and D2 are

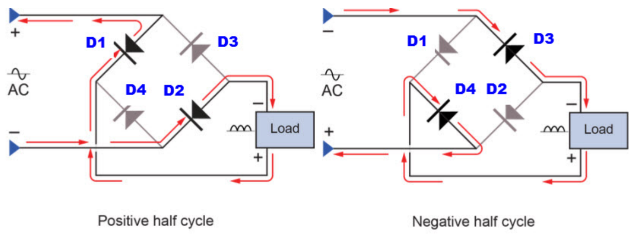


Figure 5.38: Working of a Bridge Rectifer

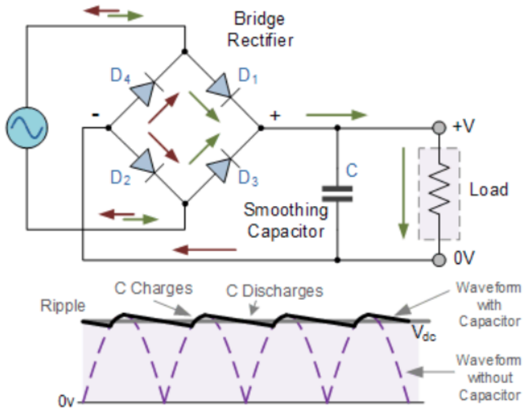


Figure 5.39: Full Bridge Rectifer with a Smoothing Capacitor

forward biased and D3 and D4 are reverse biased. When the voltage, more than the threshold level of the diodes D1 and D2, starts conducting the load current starts flowing through it, as shown as red lines path in the diagram below. During the negative half cycle of the input AC waveform, the diodes D3 and D4 are forward biased, and D1 and D2 are reverse biased. Load current starts flowing through the D3 and D4 diodes when these diodes starts conducting as shown in the figure. We can observe that in both the cases, the load current direction is same, i.e., up to down as shown in the figure so unidirectional, which means DC current. Thus, by the usage of a bridge rectifier, the input AC current is converted into a DC current. The output at the load with this bridge wave rectifier is pulsating in nature, but for producing a pure DC requires additional filter like capacitor.

5.8.2 LM1117 Linear Voltage Regulator

The LM1117 is a low dropout voltage regulator with a dropout of 1.2 V at 800 mA of load current. The LM1117 offers current limiting and thermal shutdown. Its circuit includes a Zener trimmed bandgap reference to assure output voltage accuracy to within 1 The LM1117 adjustable version develops a 1.25V reference voltage, VREF, between the output and the adjust terminal. As shown in the figure, this voltage is applied across resistor R1 to generate a constant current I1. The

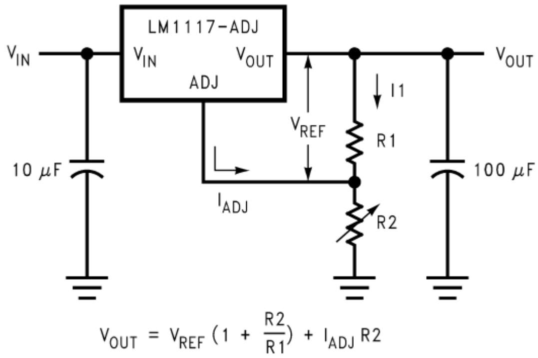


Figure 5.40: LM1117 Adjustable Voltage Regulator Application Circuit

current I_{ADJ} from the adjust terminal could introduce error to the output. But since it is very small ($60\mu A$) compared with the I1 and very constant with line and load changes, the error can be ignored. The constant current I1 then flows through the output set resistor R2 and sets the output voltage to the desired level. The LM1117 is a versatile and high performance linear regulator with a wide temperature range and tight line/load regulation operation. An output capacitor is required to further improve transient response and stability. For the adjustable option, the ADJ pin can also be bypassed to achieve very high ripple-rejection ratios. The LM1117 is versatile in its applications

Protection Diodes

Under normal operation, the LM1117 regulators do not need any protection diode. With the adjustable device, the internal resistance between the adjust and output terminals limits the current. No diode is needed to divert the current around the regulator even with capacitor on the adjust terminal. The adjust pin can take a transient signal of 25V with respect to the output voltage without damaging the device. When a output capacitor is connected to a regulator and the input is shorted to ground, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and rate of decrease of VIN. In the LM1117 regulators, the internal diode between the output and input pins can withstand microsecond surge currents of 10A to 20A. With an extremely large output capacitor (1000 F), and with input instantaneously shorted to ground, the regulator could be damaged. In this case, an external diode is recommended between the output and input pins to protect the regulator, as shown in figure :

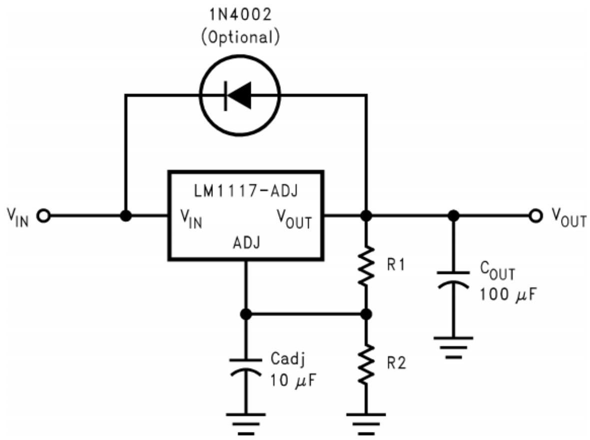


Figure 5.41: Regulator with Protection Diode

5.9 Safety Measures

This section deals with the extra safety measures taken in the circuit. As this project is dealing with AC mains voltage, the following measures are critical.

5.9.1 Fuse

In electronics and electrical engineering, a fuse is an electrical safety device that operates to provide overcurrent protection of an electrical circuit. Its essential component is a metal wire or strip that melts when too much current flows through it, thereby interrupting the current. It is a sacrificial device; once a fuse has operated it is an open circuit, and it must be replaced or rewired, depending on type.

Characteristic Parameters

1. **Rated current I_N**
   A maximum current that the fuse can continuously conduct without interrupting the circuit

2. **Speed**
   The speed at which a fuse blows depends on how much current flows through it and the material of which the fuse is made. The operating time is not a fixed interval, but decreases as the current increases.

3. **The I^2t value**
   The I2t rating is related to the amount of energy let through by the fuse element when it clears the electrical fault. This term is normally used in short circuit

conditions and the values are used to perform co-ordination studies in electrical networks.

4. **Rated voltage**
   The voltage rating of the fuse must be equal to or, greater than, what would become the open-circuit voltage.

5.9.2 TVS Diode

A transient-voltage-suppression (TVS) diode, also transil or thyrector, is an electronic component used to protect electronics from voltage spikes induced on connected wires. The device operates by shunting excess current when the induced voltage exceeds the avalanche breakdown potential. It is a clamping device, suppressing all overvoltages above its breakdown voltage. It automatically resets when the overvoltage goes away, but absorbs much more of the transient energy internally than a similarly rated crowbar device. A transient-voltage-suppression diode may be either unidirectional or bidirectional. A unidirectional device operates as a rectifier in the forward direction like any other avalanche diode, but is made and tested to handle very large peak currents.
A TVS diode is used in the power supply circuit.

5.9.3 Decoupling capacitors

A decoupling capacitor is a capacitor used to decouple one part of an electrical network (circuit) from another. Noise caused by other circuit elements is shunted through the capacitor, reducing the effect it has on the rest of the circuit. An alternative name is bypass capacitor as it is used to bypass the power supply or other high impedance component of a circuit.
A bypass capacitor is often used to decouple a subcircuit from AC signals or voltage spikes on a power supply or other line. A bypass capacitor can shunt energy from those signals, or transients, past the subcircuit to be decoupled, right to the return path. For a power supply line, a bypass capacitor from the supply voltage line to the power supply return (neutral) would be used. A decoupling capacitor is used before grounding any component in the circuit.

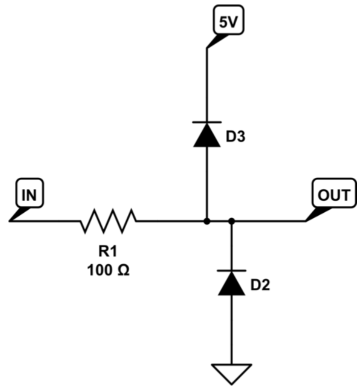


Figure 5.42: Clamping Diodes

5.9.4 Clamping Diodes

Input Clamping is often done with 2 diodes, one goes to V_{cc} and one goes to the ground. If the analog voltage is higher than Vcc (5V) plus the conduction voltage of the diode, the upper diode will conduct and the voltage at the input pin is clamped to Vcc+Conduction Voltage of the diode. On the other hand, if the analog voltage is lower than 0V minus the conduction voltage of the diode, the lower diode will conduct, and the voltage at the input pin is clamped to the conduction voltage of the diode. The resistor will limit the current through the conducting diode. The circuit protects against overvoltage and ESD. This input clamping is done before the voltage measurement circuit output is given to the ADC.

Chapter 6

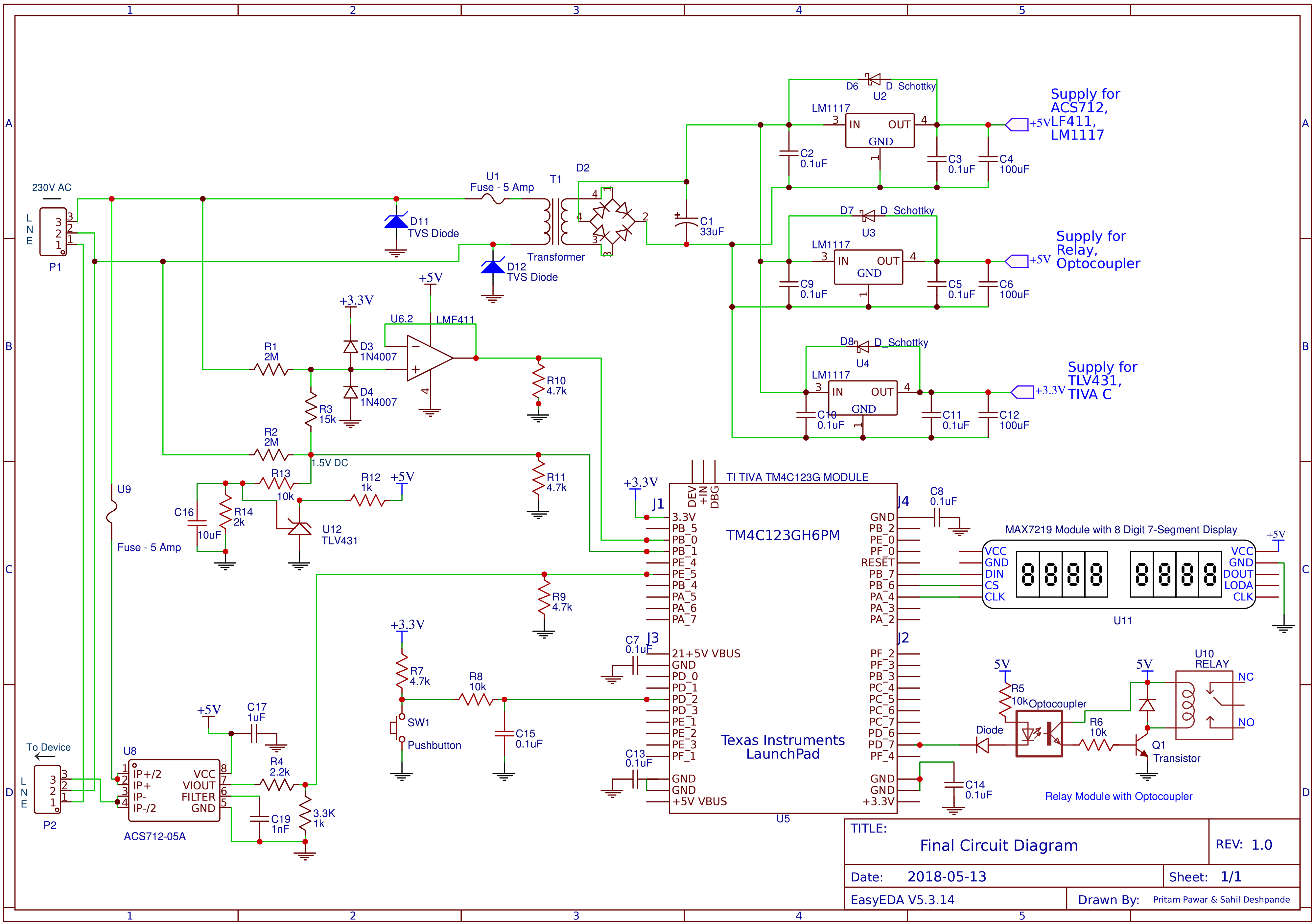
Implementation

6.1 Integration

This chapter deals with the steps required for integration of all the subsystems mentioned in the system design chapter. Starting with all the blocks mentioned in the high level block diagram,firstly the voltage sensing circuit consisting of a voltage divider and a DC bias voltage of 1.5 V, along with an opamp buffer was designed and constructed. Secondly, the ACS712 Current sensing module along with the required signal conditioning circuit was set up. These two circuits are the inputs to the circuits and the analogue input channels of the microcontroller. A switch with a debounce circuit as mentioned in the system design chapter acts as the digital input to the microcontroller. On the Power Supply side, A 6V 1 ampere Transformer steps down the 230 V AC RMS to 6 V AC RMS. The further circuit, consisting of the bridge rectifier and the voltage regulators supply regulated and stable DC voltage to the complete circuit. The two outputs of the circuit, the optocoupled relay to control the devices connected to line voltage and the 7 segment display which displays the power consumed by the device are connected to the microcontroller. The 7 segment display with its driver IC MAX7219 uses SPI interface to connect to the microcontroller.

Circuit components such as decoupling capacitors, pull up and pull down resistors, fuses, etc. are mentioned in the system design chapter. All the components and the subsystems of the circuit and integrated to form a complete circuit diagram as shown in the next section of this chapter.

6.2 Final Circuit Diagram



Supply for ACS712, LF411, LM1117
Supply for Relay, Optocoupler
Supply for TLV431, TIVA C
230V AC
L N E
P1
U1 Fuse - 5 Amp
T1 Transformer
D2
C1 33uF
D11 TVS Diode
D12 TVS Diode
D6 D_Schottky
U2 LM1117
D7 D_Schottky
U3 LM1117
D8 D_Schottky
U4 LM1117
C2 0.1uF
C3 0.1uF
C4 100uF
C5 0.1uF
C6 100uF
C9 0.1uF
C10 0.1uF
C11 0.1uF
C12 100uF
U6.2 LMF411
R1 2M
R2 2M
R3 15k
D3 1N4007
D4 1N4007
R10 4.7k
R11 4.7k
1.5V DC
R13 10k
R12 1k
R14 2k
C16 10uF
U12 TLV431
U9 Fuse - 5 Amp
TI TIVA TM4C123G MODULE
TM4C123GH6PM
Texas Instruments LaunchPad
U5
J1 J2 J3 J4
C8 0.1uF
C7 0.1uF
C13 0.1uF
C14 0.1uF
MAX7219 Module with 8 Digit 7-Segment Display
U11
R9 4.7k
R7 4.7k
R8 10k
SW1 Pushbutton
C15 0.1uF
U8 ACS712-05A
C17 1uF
R4 2.2k
C19 1nF
3.3K 1k
To Device
P2
R5 10k
Optocoupler
Diode
R6 10k
Q1 Transistor
U10 RELAY
NC NO
Relay Module with Optocoupler
TITLE: Final Circuit Diagram
REV: 1.0
Date: 2018-05-13
Sheet: 1/1
EasyEDA V5.3.14
Drawn By: Pritam Pawar & Sahil Deshpande

6.3 Snapshots of the project

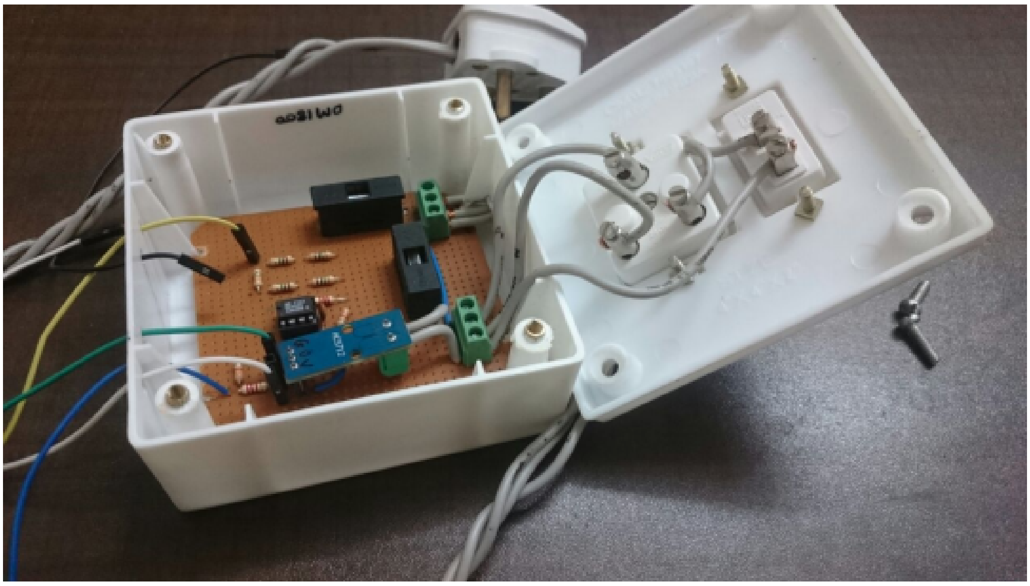


Figure 6.1: Circuit

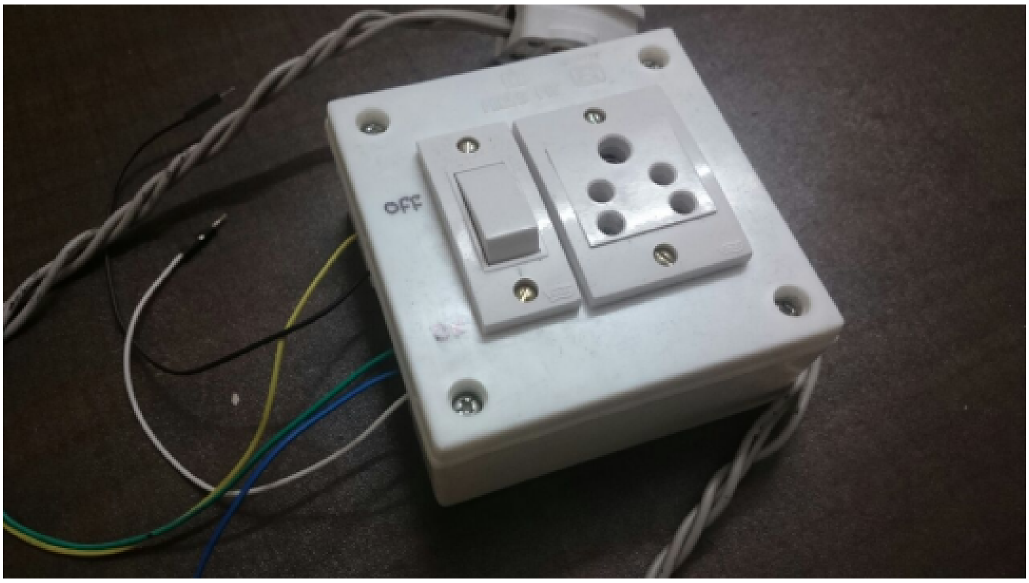


Figure 6.2: Model for single power outlet

Chapter 7

System Testing

7.1 Type of Testing Used

1. **Unit Testing :** Unit testing involves the design of test cases that validate that the internal program logic is functioning properly, and that program inputs produce valid outputs. All decision branches and internal code flow should be validated. It is the testing of individual software units of the application .it is done after the completion of an individual unit before integration. This is a structural testing, that relies on knowledge of its construction and is invasive. Unit tests perform basic tests at component level and test a specific business process, application, and/or system configuration. Unit tests ensure that each unique path of a business process performs accurately to the documented specifications and contains clearly defined inputs and expected results.

2. **Integration Testing :** Integration tests are designed to test integrated software components to determine if they actually run as one program. Testing is event driven and is more concerned with the basic outcome of screens or fields. Integration tests demonstrate that although the components were individually satisfaction, as shown by successfully unit testing, the combination of components is correct and consistent. Integration testing is specifically aimed at exposing the problems that arise from the combination of components.

3. **Functional Test :** Functional tests provide systematic demonstrations that functions tested are available as specified by the business and technical requirements, system documentation, and user manuals.Functional testing is centered on the following items :

   a. Valid Input : identified classes of valid input must be accepted.

   b. Invalid Input : identified classes of invalid input must be rejected

c. Functions : identified functions must be exercised.

d. Output : identified classes of application outputs must be exercised.

e. Systems/Procedures: interfacing systems or procedures must be invoked.

Organization and preparation of functional tests is focused on requirements, key functions, or special test cases. In addition, systematic coverage pertaining to identify Business process flows; data fields, predefined processes, and successive processes must be considered for testing. Before functional testing is complete, additional tests are identified and the effective value of current tests is determined.

4. **System Test :** System testing ensures that the entire integrated software system meets requirements. It tests a configuration to ensure known and predictable results. An example of system testing is the configuration oriented system integration test. System testing is based on process descriptions and flows, emphasizing pre-driven process links and integration points.

5. **White Box Testing :** White Box Testing is a testing in which in which the software tester has knowledge of the inner workings, structure and language of the software, or at least its purpose. It is purpose. It is used to test areas that cannot be reached from a black box level.

6. **Black Box Testing :** Black Box Testing is testing the software without any knowledge of the inner workings, structure or language of the module being tested. Black box tests, as most other kinds of tests, must be written from a definitive source document, such as specification or requirements document, such as specification or requirements document. It is a testing in which the software under test is treated, as a black box .you cannot see into it. The test provides inputs and responds to outputs without considering how the software works.

7.2 Test Cases and Test Results

7.2.1 ACS712 Current Sensor Testing

Test ID	Input (mV)	Expected Value (A)	Actual Value (A)	% Error
T01	185 mV	1.0 A	1.0 A	0 %
T02	92.5 mV	0.5 A	0.49 A	2 %
T03	370 mV	2 A	2.1 A	5 %
T04	370 mV	2 A	2.1 A	5 %
T05	370 mV	2 A	2.1 A	5 %

Table 7.1: ACS712 Current Sensor Testing

7.2.2 Voltage Measurement Circuit Testing

Test ID	Input to ADC (V)	Expected RMS Voltage (V)	Actual RMS Voltage (V)	% Error
T11	2.8 V	246.79 V	247.00 V	0 %
T12	3.0 V	284.75 V	285.00 V	2 %
T13	2.6 V	208.82 V	208.00 V	5 %
T14	2.7 V	227.80 V	228.00 V	5 %
T15	2.9 V	265.77 V	266.00 V	5 %

Table 7.2: Voltage Measurement Circuit Testing

7.2.3 Power Reading Testing

Test ID	Calculated Power (W)	Actual Power (W)	% Error
T21	246.79 W	247.00	0
T22	142.37 W	139.65	2
T23	417.64 W	436.80	5
T24	341.7 W	364.80	5
T25	465.09 W	478.80	5

Table 7.3: Power Reading Testing

Chapter 8

Conclusion and Future Scope

8.1 Conclusion

A system which monitors energy usage of household electrical appliances, analyses the data and suggests optimization techniques along with alerting the user about the health of the electrical devices was designed and manufactured.

The proposed system will significantly reduce energy consumption manifolds, by precisely monitoring the power consumption and optimizing energy usage. The system will assist in early detection of the failure in electrical devices. The proposed product is a energy monitoring and optimizing device that can be easily employed in the current household structures. It should be able to precisely find the faulty device and designed such as to help and guide the consumer for better automation experience.

The system was able to measure the power consumed by the electrical devices. The final circuit that was designed is cost effective.

Once the data about the power consumption is acquired and processed by the system, a Machine Learning algorithm is applied to the data sets. This algorithm learns the trends of power consumption and predicts possible failure of the devices in the future. This failure also alerts the user if there is need for maintenance of the devices. The Machine Learning and data analysing part of this project is done with the partnership of students from the Computer Engineering Department at Dr. D.Y. Patil Institute of Technology, Pimpri, Pune.

8.2 Future Scope

The following features can be added to the existing system :

- A temperature sensor can be incorporated in the circuit to measure the room temperature and display it on the local display.
- A proximity sensor can be used in conjunction with the 7 segment display. The display will turn on only when the user is in proximity of the board, otherwise it will stay off. This will help to reduce the power consumption of the board.
- A PIR motion detector can detect the presence of users in the room. In the absence of any person in the room, the system would turn off the electrical appliances in the room so as to reduce power consumption.
- An Android application that can display the various power usage statistics can be developed.
- Multiple such boards can be daisy chained together using wireless communication technologies such as Zigbee or WiFi.
- This system can be integrated with home automation systems to monitor power usage of the devices connected while also providing remote access to these devices.
- In case of a power failure, the system can be still be running and processing data by using an on board battery and running the microcontroller in low power mode.
- The system can use Variable Frequency Drives to drive fans and airconditioners.
- Power usage statistics collected over a larger time will help the algorithm to correctly predict device failure in the future.

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