HYBRID PIEZOELECTRIC-SOLAR BASED ENERGY HARVESTING CARPET

A Final Year Project Report

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In Partial Fulfillment

Of the Requirements for the Degree of

Bachelors of Mechanical Engineering

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ABSTRACT

Hybrid Photovoltaic and Piezoelectric Energy Harvesting is an attractive method for clean energy production in areas with power shortage. The basic objective of the project is to prepare a small-scale standalone integrated energy harvesting system. A Hybrid system based on the integration of Photovoltaic and Piezoelectric Energy is to be developed. Solar Cell and Piezoelectric Transducers meet all energy requirements of the system. A mathematical module was developed for both the system in separate form and in integrated form as well in order to predict the effectiveness of the system under different working parameters. The model for piezoelectric was solved using MATLAB® software numerically. The verification of model was done by means of parametric analysis. The results of mathematical model were verified though simulations by using COMSOL® software and the optimum working conditions for the system were identified. COMSOL® utilized the Finite element method (FEM) to solve the computational model. In addition, the modelling of solar collector is done to evaluate the production of electric signal after the process of heating from Sun. This also became the basis of MATLAB® code, which demanded evaluation of versatile coefficients for various reasons. COMSOL Analysis for the stress analysis of Piezoelectric tells us the electricity production. A small-scale working prototype is to be developed to validate the theoretical results. It is finally concluded that the integrated energy harvesting model is a feasible and efficient way of harvesting energy.

ORIGINALITY REPORT

We hereby declare that no portion of the work of this project or report is a work of plagiarism and the workings and findings have been originally produced. The project has been done under the supervision and guidance of Dr. Waqas Hassan Tanveer and Hafiz M. Abd-ur-Rehman and has not been a support project of any similar work serving towards a similar degree's requirement from any institute. Any reference used in the project has been clearly cited and we take sheer responsibility if found otherwise.

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ABBREVIATIONS

PV	Photovoltaic
Pb-Acid	Lead Acid
PZT	Lead Zirconate Titanate

NOMENCLATURE

e	Coupling matrix
C_E	Elasticity matrix
ε_S	Permittivity matrix
I_{op}	Open circuit current
I_{sc}	Short Circuit Current

CHAPTER 1: INTRODUCTION

Motivation

We live in a world of industrial globalization where the advent of twenty first century came with an era of industrial revolution. This revolution was accompanied with an increase in power requirement, which required boosted net fuel consumption. The revolution that has proven to be fruitful for humanity brought along its baggage. The increase in fuel consumption resulted in increase in its environmental effects and the rate of global warming, air pollution has been ever increasing. This has been the cause of increasing health problem so in order to solve these problems, the progressive economies have started exploring green energy resources and the world has been shifting its fuel requirement to renewable energy resources. Renewable energy, which is often termed as 'Green Energy', provides with a clean source of energy to fulfill our requirements. Various surveys have proved that global capacity of Green Energy has increased twice since 2008, which in Year 2008 was 18.5% of total world energy capacity, and it is estimated that it could reach 30% by 2022. According to International Renewable Energy Agency (IRENA), the renewable capacity has increased twice in past 10 years. In fact, European Union Council is planning to rely 34% of its power requirements on renewable energy by 2030, which is huge advancement in Green Energy Harvesting. The switch to renewable has many advantages, which not only involves economic benefits but also the environmental fruits. Some of many advantages of this switch includes:

- Less Global Warming
- Improved Public Health
- Increase in Jobs
- Stable energy prices
- Reliability
- Resilience
- Increase in Energy Efficiency
- Decrease in Climate Change

Green Energy can be harvested from many resources. It can be harvested from Solar Energy, Wind Power, Hydroelectric Energy, Biomass, Hydrogen and Fuel Cells, Geothermal Energy, Energy from tides of ocean and Vibrational Energy. These are some of the ways of harvesting renewable energy.

Solar Energy is one of the easiest and most economical way of harvesting energy and it has a lot of potential in this field. Solar Energy is probably the cleanest way of harvesting energy. Every developed country is shifting towards solar energy. It is estimated that United States had over 50 gigawatts of installed photovoltaic capacity in last couple of year. Similarly, Germany has the third largest Photovoltaic installed capacity recorded until 2016.Our neighbouring country India is producing almost 22 megawatts of electricity through solar energy.

Another area of Energy harvesting involves the conversion of vibrational energy into electrical energy that is producing electricity from piezoelectric. This is relatively a new area of energy production and is more directed toward research. Experimental setups have been installed on roads in Israel and Netherlands to harvest this energy into electrical energy and it opened new area of research. The use of piezoelectric in energy harvesting has same advantages of solar power generation.

So as a result of the above facts and claims, it is extremely enticing to have a cost-effective setup of integrated setup of hybrid photovoltaic and piezoelectric harvesting setup to be installed in Pakistan. Pakistan has a lot of potential in this area and the power requirement of the country can be partially shifted towards this kind of setups Small hybrid power generations can be setup in different cities of the countries that can work as standalone power generation units. Pakistan is a country whose average summer temperature is relatively appropriate Photovoltaic power generation and number of vehicles running on roads in the country is huge. Hence, the integrated Photovoltaic and Piezoelectric Energy harvesting units can be installed on roads as to produce electricity.

Photovoltaic Power Generation

Photovoltaic Energy involves the use of available solar cells. The sunlight falls on solar cells exciting the electrons present in cells and resulting in their excitation. The excitation is due to increase in energy of electrons. This excitation results in flow of electrons, which in turn result flow of current. The current produced by PV Cells is Direct in nature and there is no change in polarity. The performance of these cells is highly dependent on available amount of sunlight.

Piezoelectric Power Generation

Piezoelectric Power Generation is relatively a new concept of electricity production. It involves the use of piezoelectric transducers, which are available in variety according to budget requirements etc. The vibrations produced in Piezoelectric are the primary sources of electricity. The vibrations produced by application of stress on piezoelectric transducers results in the production of electricity. The current produced by Piezoelectric if Alternating in Nature. The performance of this setup is very much dependent on the stresses being applied on Piezoelectric

Integrated PV and Piezoelectric

The working principle of integrate PC and Piezoelectric Model of power generation is indeed the integration of otherwise two standalone systems. The two power generating units produce electricity separately and then the electric signal produced by these two models are integrated into a single power-producing unit. This unified electric signal can then be used for powering appliances.

Problem Statement

To introduce an efficient economic power generation setup involving following key points

- Incorporation of PV cells into Piezoelectric energy harvesting systems for enhanced energy collection
- Integrating the two forms of energy
- pulsating output of piezoelectric transducer
- stream of photovoltaic current
- Development of an energy efficient system with less Payback Period

Deliverables/Objectives of Project

Following are the main objectives of the project:

- Comprehensive study on integration of two energy collection units normally used independently
- Analysis of Piezoelectric using software
- Analysis of Photovoltaic Cells using software
- Mathematical modelling of system
- Development of an optimum prototype that harvest energy by both means

Advantages

Following are the advantages of using thus system:

- It is an easy renewable energy harvesting setup using two most readily available sources of renewable energy

- It is cost effective as it results in reduction of electricity bills when used for powering houses
- Its maintenance cost is relatively low
- Beneficial for environment as it provides a relatively clean form of energy
- The setup can be installed anywhere depending on the availability of sunlight
- Since it consists of two standalone setups thus one system can work as backup for other in case of some kind of problem
- Opens up a new potential area of research
- More suitable for country like Pakistan where there is power shortage

Project Plan

The tasks required for the project are divided into following subtasks as below:

- Design Selection
- Component Procurement
- Testing with Components
- Fabrication
- Work Presentation

Gantt Chart

Following is the Gantt Chart for project:

Figure 1: Gantt Chart

Project Plan

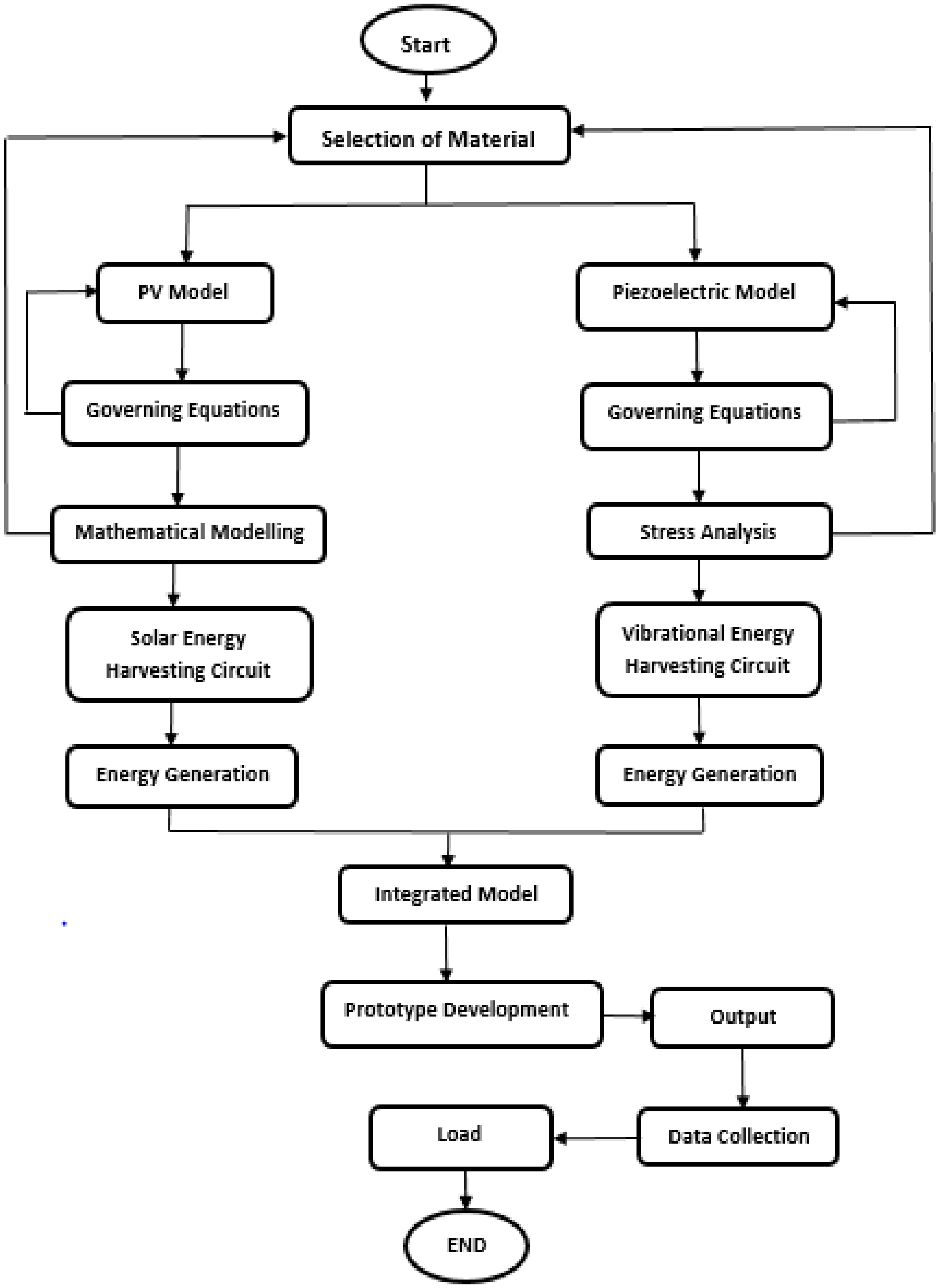


Figure 2: Project Plan

CHAPTER 2: LITERATURE REVIEW

Solar Energy Harvesting

Solar energy is a free, inexhaustible source of energy which has a great potential to meet energy requirements of world and power satellites. The breakthrough to use solar power for heating purposes was the 1st major discovery in this field. And using solar cells for production of electricity from solar energy was the 2nd discovery. In 1839, a French Physicist Edmund Becquerel realized that sun's energy could produce a "Photovoltaic Effect". In the 1880s, Selenium Photovoltaic (PV) cells were developed that could convert light into electricity with efficiency of around 1-2%, but the concept wasn't yet comprehended by scientists. It was not until Albert Einstein proposed an explanation for "Photoelectric Effect" in the early 1990s, for which he was awarded nobble prize.

Why Use Solar Energy

The solar energy is available in excess and it is being wasted but it has a great potential which could be exploited easily for the betterment of globe and to preserve environment. Conventionally used fossil fuels for power generation have several disadvantages. Firstly, we only have limited source of fossil fuel which are being depleted very quickly. Secondly, they are highly hazardous for environment. For instance, smoke produced as a result of burning of coal and oil is a huge source of air pollution and CO_2 emission which in turn causes global warming disturbing natural life cycle. Thirdly, most of power in Pakistan is being generated from oil which is usually imported making it an expensive source of energy generation. So solar cells, though currently an expensive source of energy, are great source of energy generation. Additionally, in country like Pakistan where we have energy crises, the additional amount of energy available in form of sunlight could be exploited alongside other hydro projects. [1]

In our case we would be using solar energy to power same appliances such as Chargers or Street light. There have been a lot of research on energy harvesting for using it for small appliances and instruments. And nowadays it has become really necessary to exploit solar energy. If houses and offices generate some amount of energy it would lower power demand from commercial supply grid. [2]

Photo Voltaic Cells

Photo Voltaic cells are used to generate electricity directly from sunlight. The incident light causes a flow of positive charges (Holes) and Negative Charges (Electrons) in PN

Semiconductor which generates electricity which could be used to power street lights, house, parking stands or could be added to grid for commercial use. The incident light contains photons of different energies and we need to use a material of respective energy band to obtain maximum output, according to that silicon is one of the best materials that could be used for maximum output

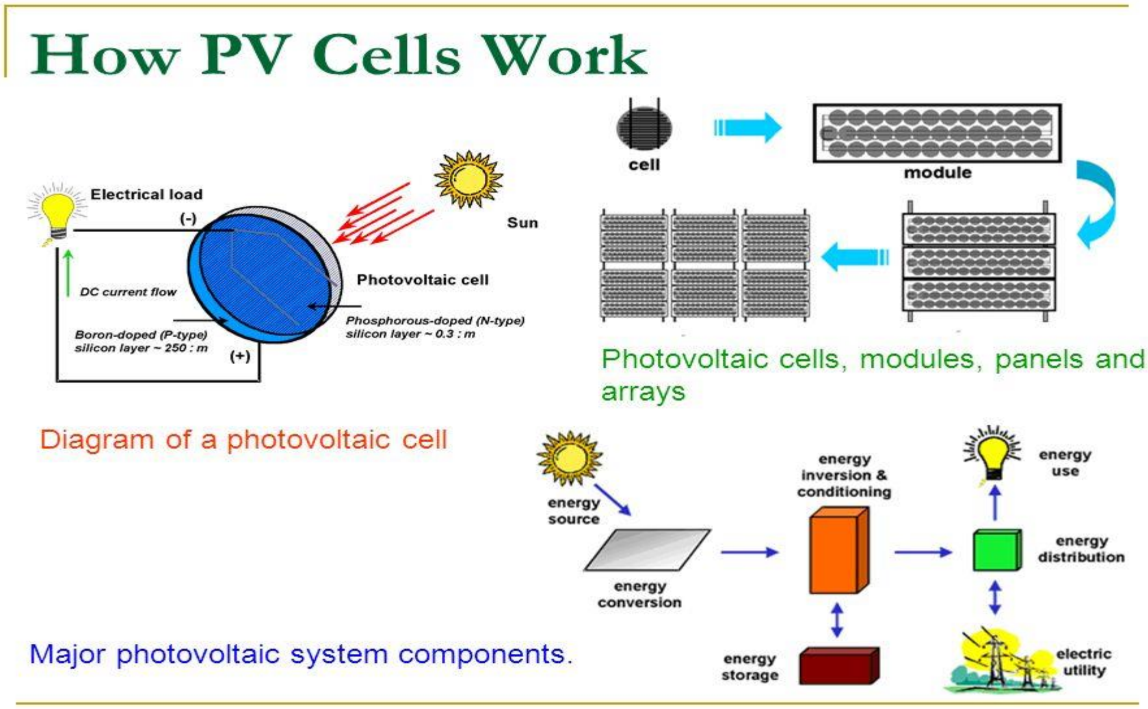


Figure 3: Working of PV Cells

The output the solar PV systems could be maximized either by mechanically tracking the sun and setting the orientation of the panel in such a direction so as to maximize the received solar irradiance or by tracking the maximum power point under changing conditions of insolation and temperature.

Performance of PV Cells

The overall performance of solar cell depends on Irradiance and Temperature. The power received from the sun changes on day to day basis and from morning to evening which affects output generated by PV cells. Not only this, both irradiance and temperature affect efficiency of solar cell. [1]

The temperature also plays crucial role in the performance of photovoltaic conversion process. Both the efficiency and the power output of a PV module depends linearly on the temperature, decreasing with increase in *T*. Similarly, irradiance is the other factor contributing towards the performance of PV Cells. The usual trend is output increase when irradiance increases and it decreases when irradiance falls.

Silicon Based PV Cells

Crystalline silicon photovoltaic (PV) cells have the highest share in the market currently, they constitute almost 90% of the total solar cells produced annually. They are also expected to play a greater role in future as the world moves towards green energy. The peak efficiency being obtained from crystalline Silicon PV Cells is around 25-27%. However, the efficiency of industrial cells is far low, nearly 15-18% due to change in standard conditions and factor such as lamination. These efficiencies could be further improved but at the greater financial cost putting more burden on pocket of consumer. PV Cells with higher efficiency have various advantages in performance but as stated earlier they are not suitable for low cost production owing to complexity in their structures and their manufacturing takes much more time.

The technologies related to monocrystalline and polycrystalline PV cells are compared and discussed with regard to the corresponding material technologies, like silicon ingot and wafer production. We can achieve High energy conversion rates and lower processing costs at same time but for that we need to use advanced production method and technologies. And the various researches show that use of these technologies can lead to efficiency of more than 25%.

The PV cell is basically a semiconductor or a PN junction with the properties of semiconductor material. Several studies show that the various technologies used in initial stages for production of solar cells were related to silicon semiconductor devices. The advancements made in production methods helped us in increasing efficiency of solar cells over 20%. And the mass production helped in bringing sown the cost of semiconductor devices based on silicon. Other production technologies such as silver-paste screen printing and firing for are hence needed to further bring down the cost and increase the production volume of silicon-based PV solar cells. Further to achieve the cost of electricity from as close to power plants as possible or even lower material and production expenditures are as important as efficiency of solar cells. And it is currently one of the most important issue to achieve lower production cost and higher efficiency. Minimizing the cost of production of expensive pure crystalline silicon substrates could be targeted to reduce the cost of silicon solar cell modules. [3]

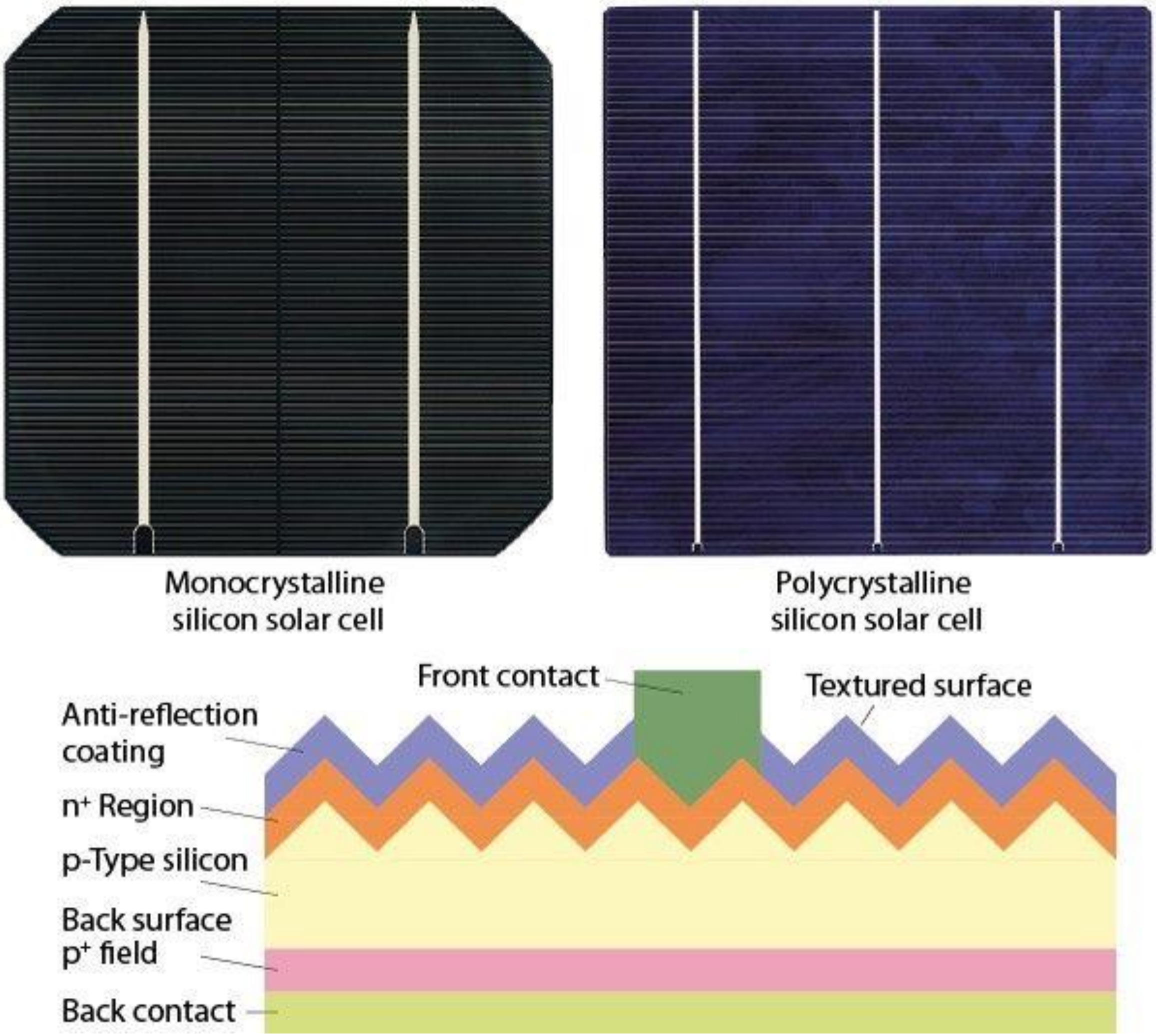


Figure 4: Polycrystalline vs Monocrystalline Solar Cell

Generations of PV Cells

Photovoltaic cells have been divided into three categories depending upon the technologies. The 1st generation is wafer based solar panels such as polycrystalline and monocrystalline Solar cells. The 2nd generation contains thin film based solar cells such as amorphous solar cells and cadmium telluride (CdTe). And the 3rd generation contains nanotech based solar cells such as perovskites. The efficiency of 1st generation solar cells is around 25% when tested in lab conditions and for the module based, it is 23%. The efficiency of 2nd generation solar cells is around 18% in lab conditions and is around 14% for module. The efficiency of 3rd generation solar cells is much greater than these two generations, nearly greater than 30%.

Advantages of Photovoltaic Power

The Photovoltaic solar power has several advantages that makes it one of the most promising technologies for future of the world. Considering environmental aspects, solar energy is non-polluting. Since it has only stationary parts involved in apparatus, there are no chances of breakdown. It requires very little maintenance and almost no supervision, and has a life of 15 to 30 years with very low running costs and smaller payback period. The small or large systems could be built to power hinterlands. Solar Cells could easily be distributed to distant areas. In comparison to coal, gas or nuclear power solar energy should be preferred since it is a clean renewable source of energy. Solar Power also has advantage over Hydropower and wind power as both of them requires moving parts in form turbines. [4]

Payback Period

As discussed earlier, the conversion efficiency of solar cells depend upon irradiance and temperature. So, the performance of Solar panels is quite dependent upon the area in which they are to be used. However, Solar panels usually pay for itself in 3 to 5 years depending upon the area of usage. After that it would be like having a free energy until the end of panel’s working life.

The Energy Payback Period of solar cell module basically varies from 1 to 5 years from lowest time to highest, for the following modules ranked in the following order: Cadmium Telluride (CdTe), Copper Indium galliumdiselenide, 2^{nd} generation amorphous silicon , polycrystalline silicon and monocrystalline silicon. [5]

Piezoelectric Energy Generation

The word piezo is a Greek word meaning “To Press” so piezoelectricity is basically electricity generation from force or pressure. The Piezoelectric Effect was first discovered by Curie Brothers, Pierre and Marques Currie in 1880. So the basic principle states that applied force would generate output voltage in certain materials or applied voltage would result in deformation of those materials. This effect is put into to use for several uses in current epoch.

History of Piezoelectricity

The discovery of Piezoelectric Effect was made by Currie Brothers as stated earlier. But the converse effect was discovered by Lippmann through fundamental laws of Thermodynamics. The 1st mentionable application of piezoelectric occurred during the 1st World War. This was ultrasonic submarine detector being credited to Paul Langevin. Except SONAR Transducers, the piezoelectric materials were used for several purposes between two world wars. Besides that, piezoelectric materials were used in applications such as microphones, accelerometers, ultrasonic transducers etc. The significant research has been made on piezoelectric materials and in their properties in developed countries over the last few decades. The new piezoelectric devices could be designed by tailoring a material to exhibit desired properties.[6]

Working of Piezoelectric

Below a certain temperature, each crystal of piezoelectric material has tetragonal structure and corresponding dipole moment. These dipoles form local regions of alignment known as "Domains". When electric field is applied along such materials these localized poles get aligned in specific direction and remnant polarization occurs as a result of which gets permanent elongation and permanent deformation which is usually in very small amount. [7]

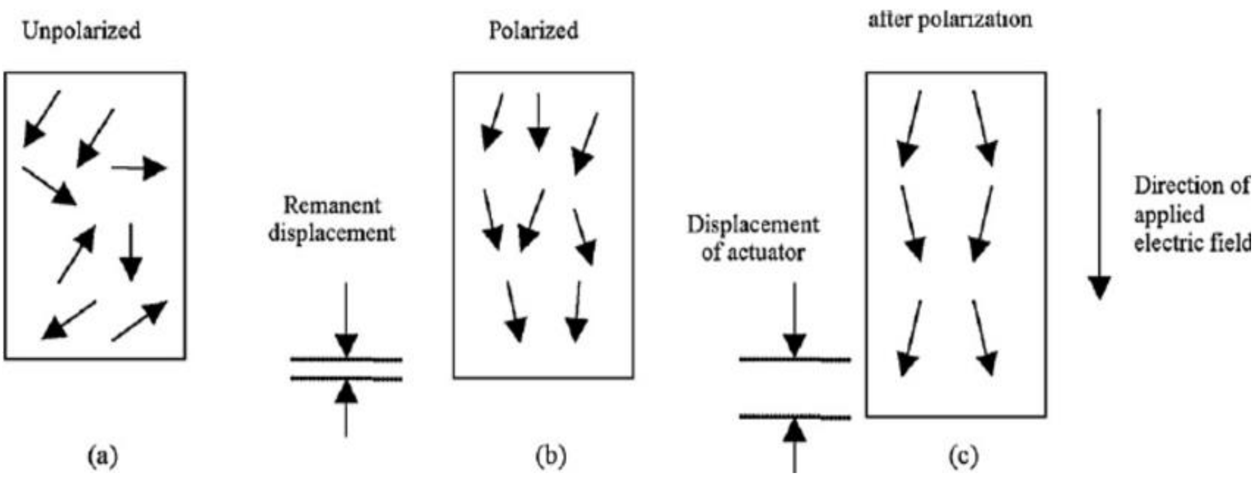


Figure 5: Polarization of Poles in Piezoelectric

Piezoelectric Effect

We would look into electromechanical properties of piezoelectric materials in this section. Whenever a poled piezoelectric ceramic is mechanically strained it becomes electrically polarized producing an electric charge on the surface of the material, this is known as **"Direct**

Polarization Effect" as shown in figure4. And this is the property that we would be using in our experiments.

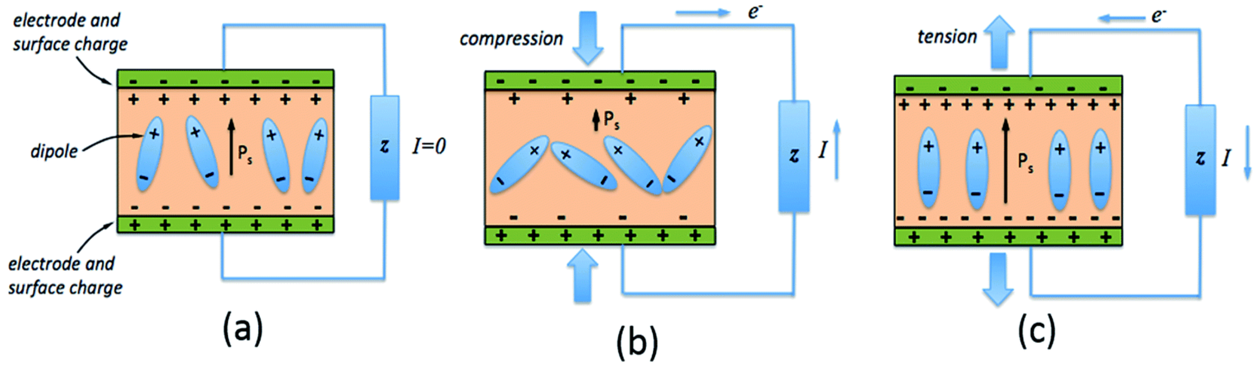


Figure 6: Direct Piezoelectric Effect

The other phenomenon known as **"Converse Piezoelectric Effect"** occurs when an electric field is applied to the piezoelectric crystal and material gets deformed.

Material Used

We conducted studies on several materials that could be used for piezoelectricity. The potential materials that could be used involve Perovskites, ZnO based piezoelectric nanostructures and PZT4, PZT8 and Barium Titanate. Multifunctional ZnO semiconductor is potential candidate for electronics. The semiconducting and piezoelectric properties of environment friendly ZnO are really remarkable and could be put to use, but we had a one issue with this material and that is its relative cost as compare to PZT4. That's why we have not used Zinc Oxide Nanostructures. [8]

Piezoelectric effect is exhibited by variety of the materials that possess a non-symmetric crystal structure e.g. quartz and tourmaline. The artificially produced piezoelectric crystals include Rochelle salt, ammonium dihydrogen-phosphate and lithium sulphate. The piezoelectric cermaics also exhibit this property. The piezoelectric ceramics are polycrystalline crystals in contrast to the naturally occurring piezoelectric crystals. The most commonly produced piezoelectric ceramics are lead zirconate titanate (PZT), barium titanate and lead titanate. Polycrystalline ceramic materials have several advantages, they are easy to fabricate and their modeling into several shapes and sizes is easy process. In contrast, single crystals must be cut along certain specific directions known as crystallographic, limiting the possible geometric shapes, but they offer superior piezoelectric properties. [9]

Lead Zirconate Titanate (PZT) is one of most commonly used piezoelectric material for power generation and that is the material that we opted for our project. We had a choice between PZT4 and PZT8 but we decided to go for PZT4 due to its availability and reasonable cost. PZT is being used in shoe technology and several other purposes. While perovskite was other choice but since it is still in research bases and available to very limited extent and too at higher price so it was not a smart choice. So out of all these options PZT4 was a clear winner. To sum up, from literature review and simulation results we were able to conclude that outputs of commonly used piezoelectric materials (PZT4, PZT8 and $BaTiO_3$) fall in the same category. The other factors that differentiate them are their costs, durability and ease of procurement that's why decided to use PZT4 for our project [10]

The Integrated Model

The final part of our project involves integration of two individual technologies viz. solar energy from sun and energy generated as a result of pressure using piezo-electrics. We have discussed both standalone technologies in detail in aforementioned portion. Now we will be going one step ahead and discussing why integration of these technologies could be of great value and how we are going to achieve our desired objective. In the last portion we will discuss how to store the generated energy and how to control two different outputs and how to combine them in form of one.

Why Use Integrated Model

Well, both standalone methods have their disadvantages or better to quote limitations. As we know harvesting energy from solar cells greatly depends upon amount of radiation incident on PV Cells and temperature and we know the factor of irradiances changes from area to area. For instance, it is possible certain portions of Pakistan receive far more solar energy than other parts annually as shown in figure5. Secondly, the day to day conditions are very dynamic. It is possible sky is clear one day and the power generation is optimum but other day it's cloudy and we can't get enough of energy from PV cells. So the performance of solar cell is quite contingent to weather conditions regardless of efficiency of system. Thirdly, during night, there is no sun out so power generated. [11]

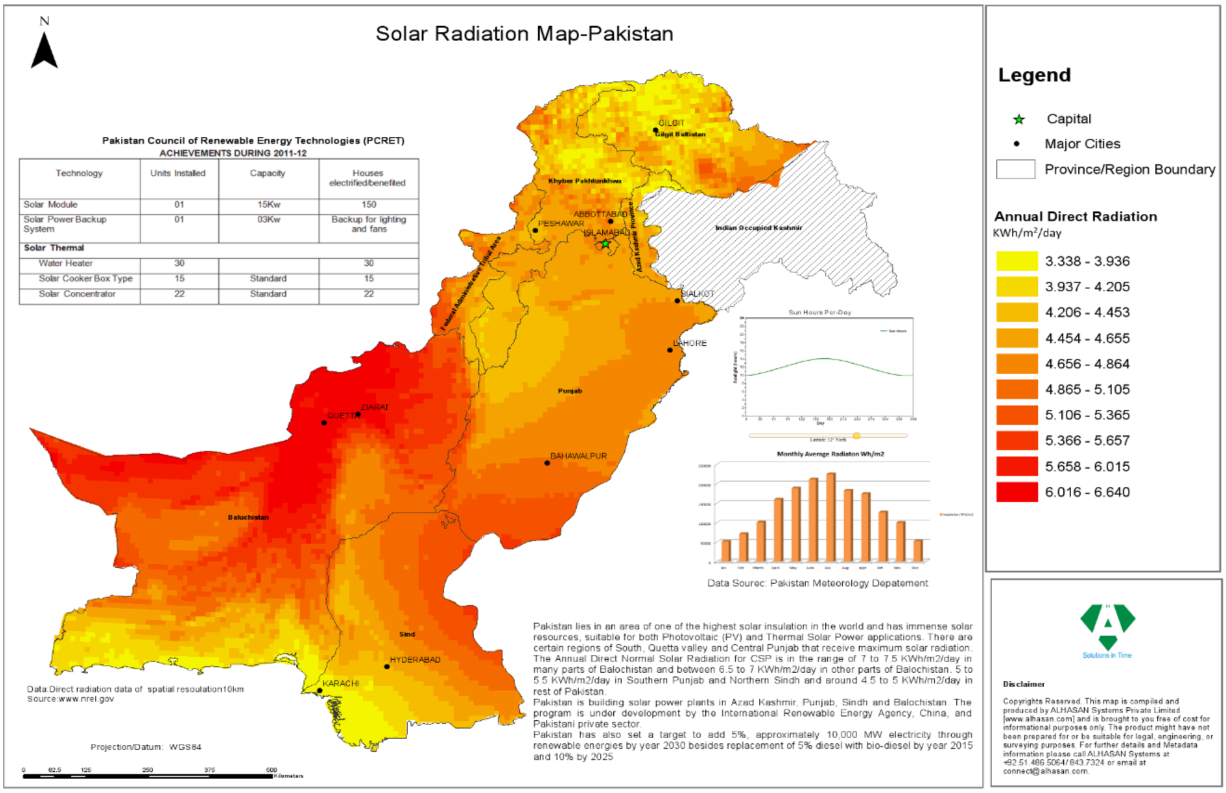


Figure 7: Solar Map of Pakistan

Now coming to the piezoelectric part, as in our use the generation of power from piezoelectric is heavily dependent on traffic flow. Thus, it could be producing its maximum value at one time when traffic flow is heavy and at other time it could be generating no power at all creating a huge gap. Secondly piezoelectric in our case is our producing very minute amount of power so it requires a lot of time to reach a specific value of charge before it could be used to power some appliance such as street light. Owing to these two factors using piezoelectric alone could be costly.

This gives us a potential area to target, that is, integrating these two standalone technologies. Now solar cell would be producing power throughout the day surely dependent upon irradiance and alongside piezoelectric would also generate a small fraction of current that could be stored in battery through properly designed electronic circuit using relay and microcontroller. So, whenever sun is out we are getting output from our PV Cell arrangement and whenever we are having flow of traffic we would be getting output from both of these technologies.

How to Achieve Integration

The integration of these two technologies require a system consisting of microcontroller, Relay, LED Display and energy storage element as shown in Figure6. The circuitry is designed in such a way that output from both sources get stored in rechargeable battery which supplies energy to the appliance to be run. The microcontroller controls output from both of these sources and supplies to Battery and display it on LED.

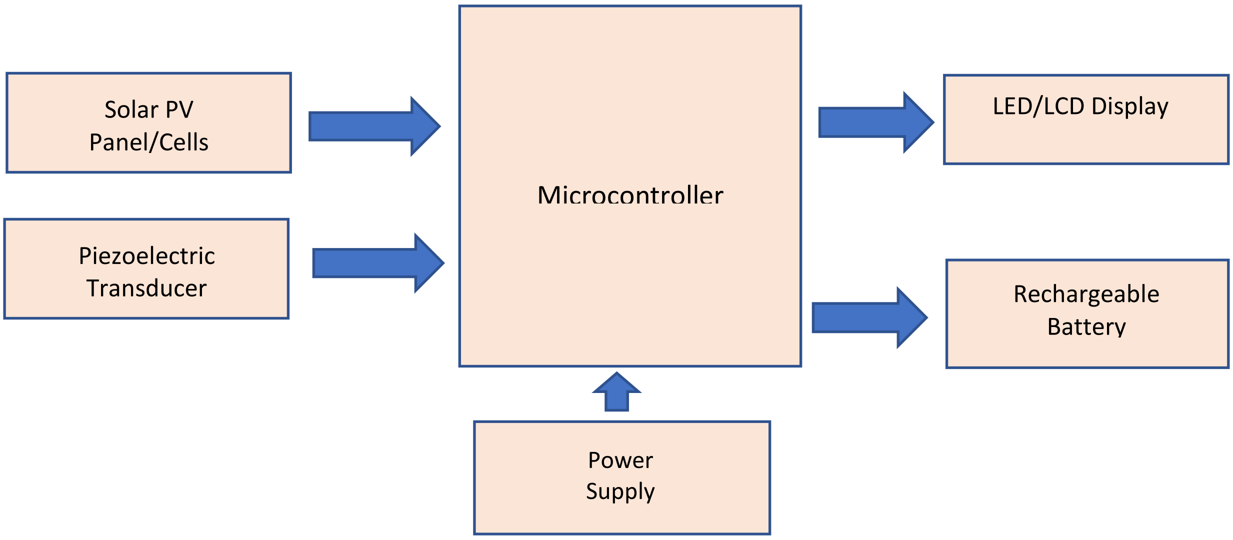


Figure 8: Conceptual Design of Integrated Model

The microcontroller adjusts the timing of in such a way that output from PV cell or array is transferred to battery directly but in case of piezoelectric transducer it is first stored in capacitor and once it reaches specific value, the circuit of PV cells gets open and charge flow from that circuit stops and the output generated from Piezoelectric is transmitted into battery. One thing should be kept in mind piezoelectric transducer produces output in the form of peak which is delivered to battery only when certain amount of output has been achieved. [12]

Energy Storage Element

Energy is to be stored in Lead Acid Battery. A Lead Acid battery was chosen over a lithium battery due to multiple factors. Firstly, it is much cheaper. Secondly, it is much safer and environment friendly. Furthermore, it operates perfectly in high and low temperature conditions.

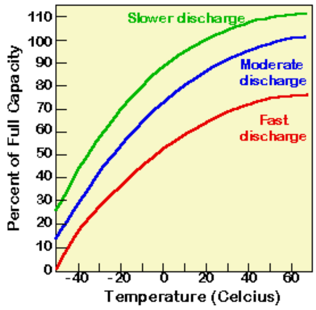


Figure 9: Relation between battery Discharge Rate, Temperature and Capacity

The capacity of battery degrades due to sulfation and shedding of active material over the period of time. The factors on which degradation of battery capacity strongly depends include following parameters:

1. the regime of charging and discharging experienced by battery
2. the Degree of Discharge (DOD) of the battery throughout its life
3. the exposure of battery to prolonged periods of low value of discharge
4. Another factor that plays important role is the average temperature of the battery over its lifetime [13]

CHAPTER 3: METHODOLOGY

Schematic Diagram

The schematic of a standalone system to capture the mechanical piezoelectric energy is conceptualized as below, that is to be integrated with another standalone circuitry of piezoelectric-energy generating circuit.

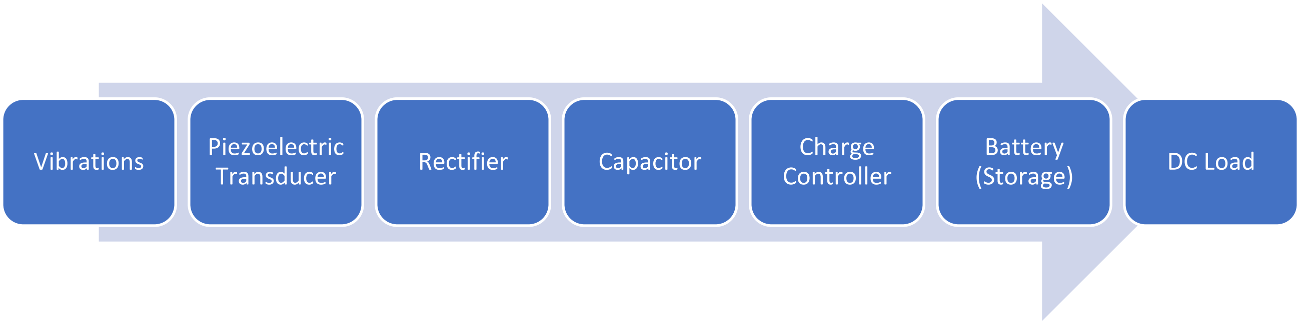


Figure 10: Standalone Piezoelectric System

Similarly, a standalone system to capture the solar photovoltaic energy from the solar irradiance, we have a system that is as follows:

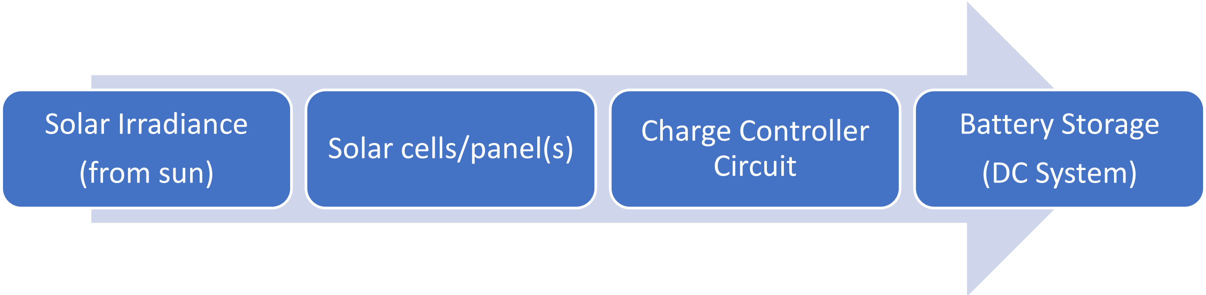


Figure 11: Standalone PV System

Now, we show the combined schematic exemplifying the aforementioned conceptualized model is shown below.

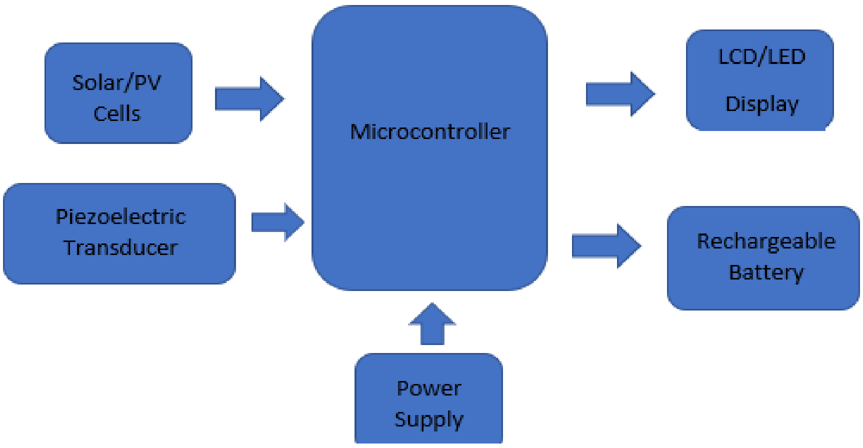


Figure 12: Integrated Model Conceptualized

The main working components are piezoelectric transducers and solar PV cells/panel(s) since they are crucial in the integration of a harvested photovoltaic energy with piezoelectric energy that is being captured through different means.

As shown in the literature review, the hybrid i.e. the main concern is capturing the generated integrated energy which is consisting of two parts i.e. one from the pulsating output of Piezoelectric transducer triggered by the load or any kind of movement on the piezoelectric carpet, and the continuous energy that is being taken up from the solar cells or panel(s) (during daytime only). The output of the piezoelectric takes time to reach a certain level and thus rendering it traffic-dependent.

The energy collection systems have been designed as described in the following lines:

The energy was stored in the sealed lead acid battery after the integration is done. The PV cells do it in a continuous manner (similar case in almost all of the solar charging systems) and the piezoelectric transducers store this energy initially in a capacitor for a short period of time and then as the output is reached a threshold of 14-15 volts (above than the 12V required), the photovoltaic energy that is continuously being supplied to battery from the solar irradiance is interrupted/stopped for a brief moment of time, equal to the time constant of the capacitor used. The capacitor rating or the size determines the amount of energy portion/part out of whole energy that is collected, bigger capacitors contribute bigger energy portion leading to equity-based systems but somehow, the photovoltaic system contributes more and remains overwhelmingly dominating over the piezoelectric because of the excessive and continuous energy input.

The supervision of this energy collection system is done by an Atmel-Atmega Arduino microcontroller. The microcontroller code was made in a way that some sensors after taking values for voltage and current controlled the inputs of microcontroller to display the values of energy collected.

Hence, this prototype after collecting and storing the integrated output (in a Lead Acid Battery), displays it on an LCD the amount of energy received.

Photovoltaic Energy Collection System

Consider the diagram in which a solar energy collecting circuit has been shown.

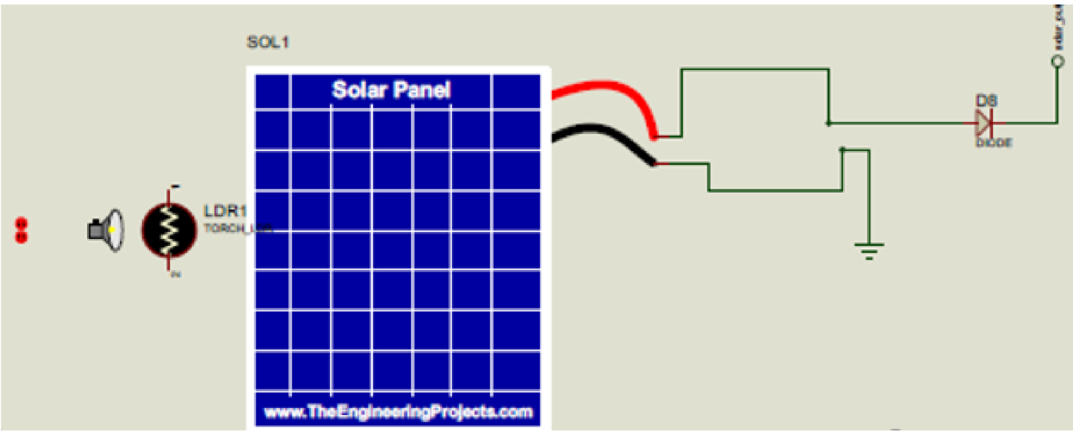


Figure 13: PV Energy Collection Circuit

The incident photovoltaic energy at the solar panel (as shown in the figure below) is flowed through a relay to a voltage regulator or a battery charger. The relay remains connected or on in normal conditions to complete the circuit for charge flow to the battery from the solar panel. It also provides spontaneously a bias voltage for the working and initiation of energy collection and working of the microcontroller. The diode placed after the solar panel inhibits the reverse flow of the current. The relay coil is activated through the signal amplifier which itself is given actuation by microcontroller signal.

Piezoelectric Energy Collection System

Consider the diagram in which a solar energy collecting circuit has been shown.

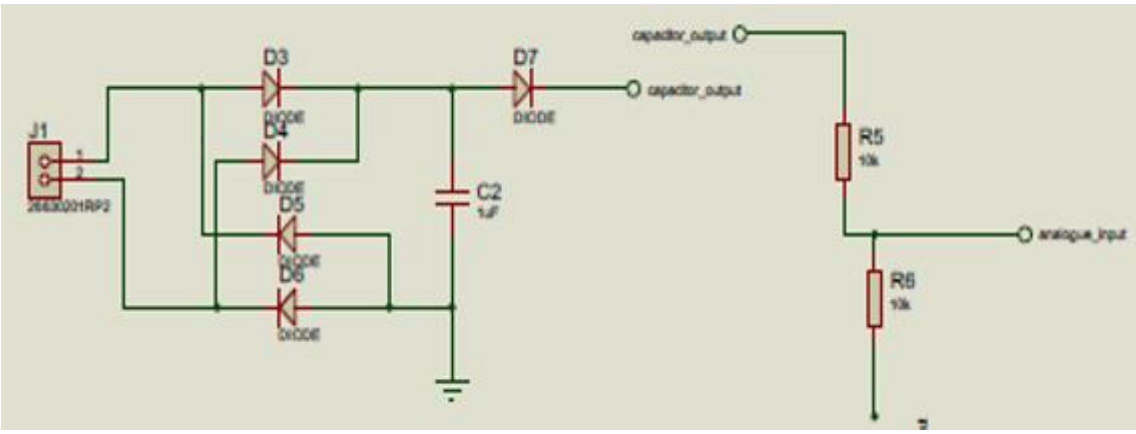


Figure 14: Piezoelectric Energy Collection Circuit

As we know, the piezoelectric transducers consisting of crystal element which shows sensitivity to the applied load or any changing conditions of load, movement etc. depending upon the type of the sensor or transducer. The crystals on being loaded produce weal alternating voltages in response to the vibrations induced by the loading conditions.

In our design, the piezoelectric cells provide electrical energy to the circuit (as done in the Proteus Design Suite) at the 'PIEZO' terminal. After full-wave rectification of the voltage received at the said terminal, the energy is stored in a capacitor (instead of it being directly supplied to the battery). The result is that, as this system of piezoelectric is traffic dependent making an always-varying loading conditions, (possibly including voltages as high as 12V which is the value of battery voltage), the peak voltages are clipped off or filtered. These filtered voltages are then stored temporarily and when they achieve a certain level of voltage (here 14-15 volts) after building upon a voltage, (and signal is enables from microcontroller using voltage sensor) and capacitor is discharged to the battery ultimately.

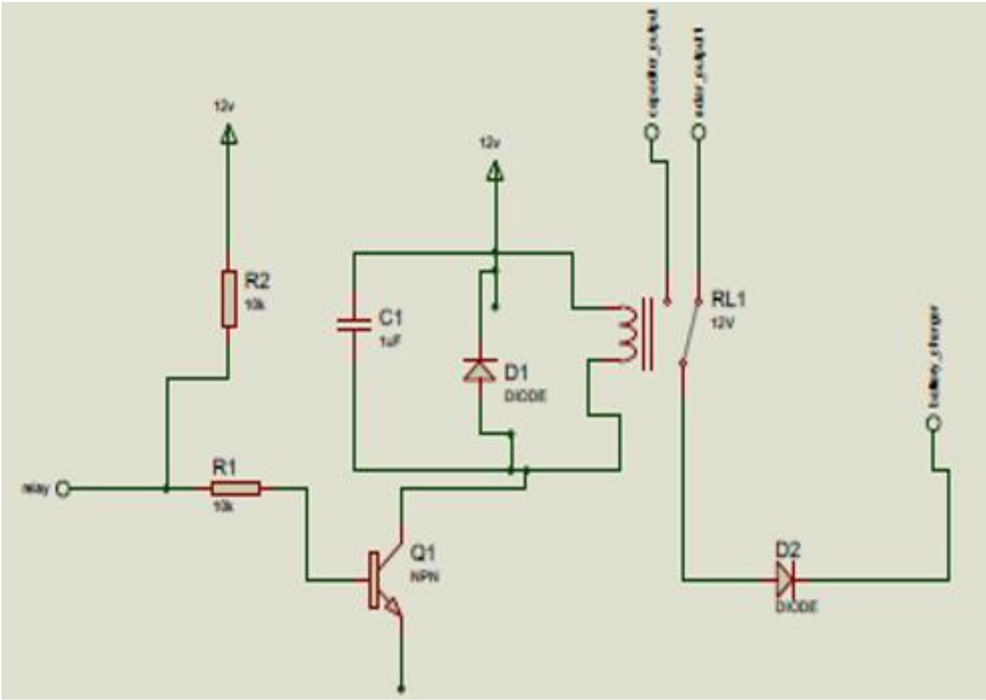


Figure 15: Pulse charge Controller

There is also a pulse charge controller circuit which functions i.e. shown in figure, that should capacitor reach fifteen Volts, the Atmega microcontroller after reading the voltage from sensor puts the relay switch on to take the output from capacitor. The capacitor discharge takes less than three seconds, bringing the 'relay' to point where the connection with solar output is resumed again until piezoelectric-capacitor generates 12V again as one-time constant is passed (i.e. ~63% of total output).

Mathematical Modeling

Mathematical Modeling for Piezoelectric Elements:

The figure shows the directions of forces on the crystal of piezoelectric. As we know from literature review, the physical constants are independent of directions, these physical constants are related to forces and their directions of application. The subscript has two letters referring to the stress and strain for the crystal under elastic loading. Shearing forces are in direction 4, 5, 6; however, 1,2, 3 represent the three coordinate axial directions.

Then, some important variables and constants that were crucial in study of piezoelectric modeling are explained as follows:

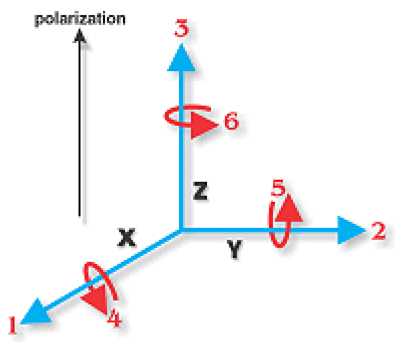


Figure 16: Directions and Axial Forces

1. The piezoelectric charge constant (d) is defined as the generated polarization divided by stress applied mechanically on to a piezoelectric crystal (in other words, strain taken per unit of electric field). So that, the d_{33} means that strain is induced per unit electric field and both taken in direction 3 (explained above in diagram)
2. The piezoelectric voltage constant (g) can be taken as strain experienced by crystal element divided by applied electric displacement. Similarly, g_{33} means strain is induced per unit electric displacement both in direction 3.
3. The dielectric constant or permittivity (ε) is explained as the displacement per unit field. Also, $\boldsymbol{\varepsilon^T_{11}}$ means for permittivity for displacement and field (both in direction 1) at constantly applied stress on the crystal.
4. The electromechanical coupling factor (k) indicates how effective the piezoelectric is able to do the conversion between electrical and mechanical energies. K_{33} means that both field and longitudinal vibrations induced both in direction 3.

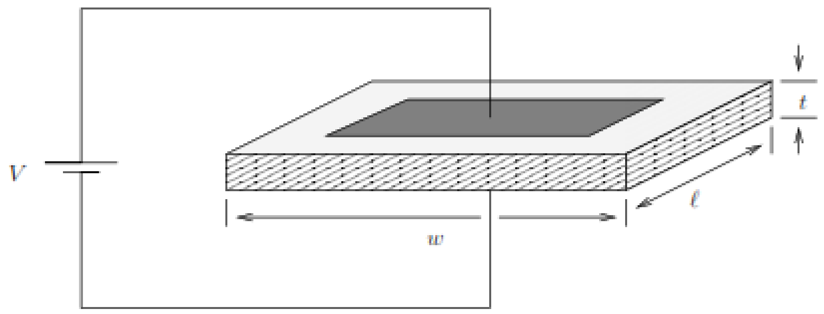


Figure 17: Charge deposition in a piezoelectric transducer

The piezoelectric materials have the property of polarization under the loading conditions. At the micro level, there are domains and atoms having charges when seen into the crystal elements of the piezoelectric under load. The loads imbalance the zero dipole moments present in the crystal materials and on whole some polarization is achieved owing t the domains reorganization and nonzero dipole moments (electric polarization). This very concept, is given name of Piezoelectric Effect. And there is an important connection between the electric polarization and the applied stresses (loading conditions). This relation can be described better in two ways:

1. Stress Charge form
2. Strain Charge form

The difference occurs as different material properties are required for either of the two forms during analysis. For example, consider the **Stress-Charge Form**

$$\boldsymbol{T} = \boldsymbol{C_E S} - \boldsymbol{e^T E} \, ;$$

$$\boldsymbol{D} = \boldsymbol{eS} + \varepsilon_{\boldsymbol{S}}\boldsymbol{E}$$

Where the variables or constants used have been described in appendix A.

Similarly, the Von Mises stresses were checked for these buzzer-type piezoelectric elements. The results are fine as no problem is seen anywhere near our values of constant loads used on these buzzer type piezoelectric elements.

Mathematical Modeling for Solar PV cells:

The equations used for the mathematical modeling of solar PV Cells are described as follows. The complete Simulink models simulated in MATLAB environment have been discussed in the 'Results' section.

Voltage Current Characteristic Equations:

$$I_{PH} = [I_{SC} + K_i(T - 298)].\frac{G}{1000}$$

Saturation Current

$$I_0 = I_{rs}(\frac{T}{T_n})^3 exp[\frac{q.E_{g0}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)]$$

Reverse Saturation Current

$$I_{rs} = \frac{I_{sc}}{[exp\left(^{q.V_{OC}}/_{N_S knT}\right) - 1]}$$

Current Through Shunt

$$I_{Sh} = \frac{V.^{N_P}/_{N_S} + I.R_s}{R_{sh}}$$

Output Current

$$I = N_P.I_{Ph} - N_P.I_0\left[exp\left(\frac{^V/_{N_S} + I.^{R_s}/_{N_P}}{n.V_t}\right) - 1\right] - I_{Sh}$$

Diode Terminal Voltage

$$V_t = \frac{k.T}{q}$$

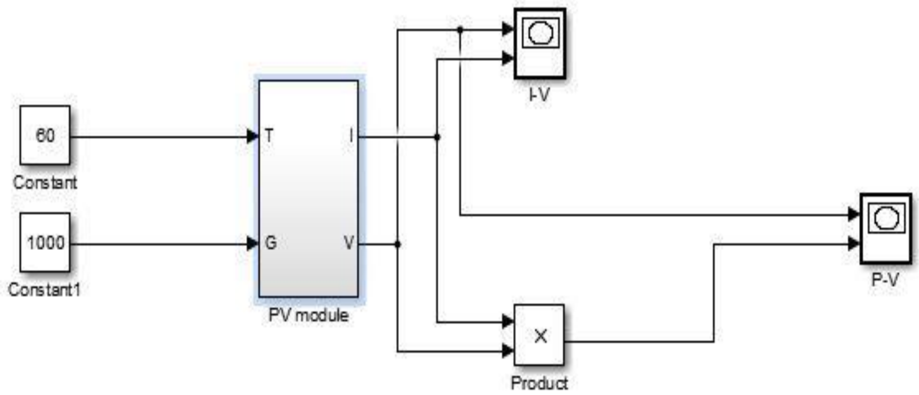


Figure 18: Integrated Circuit of Project in Simulink

The current-Voltage (I-V) and Power-Voltage (P-V) curves were obtained in the Simulink (MATLAB) at three different constant temperatures and a trend was followed. As the multiplicative product of current and voltage equates the power i.e.

P (power in watts) = V (voltage in volts) x I (current in amperes)

The maximum current is given by the solar cell in the absence of resistive elements or resistances in circuit between its two opposite terminals. This is also referred to when there is short circuiting and this is called short circuit current (I_{sc}). Similarly, when the resistance is infinite or no current is found, this is called open circuit voltage (V_{op}).

The typical I-V and P-V curves obtained have been presented in the 'Results' section for 12-volt Module with maximum values of power at the knee(s) of such graphs have been presented therein.

Finite Element Modeling in COMSOL (computational Studies)

In this subsection, we present the Finite Element Method (FEM) in COMSOL Multiphysics package in which mesh was made (of fine type) and analyzed. COMSOL incorporates the boundary and initial conditions. By using the FEM method, the equations that are built-in COMSOL based on the principles of numerical methods. The results and the conclusions obtained are of concern whenever the conditions are plugged in taking their relationships in consideration. The domain is divided into finite control elements. Same case is applied here in which mesh is generated of standard level to segregate the system into many control elements on the basis of to what extent we want accuracy in results and reduce numerical lapse in results. After this, complex Partial differential equation, which are otherwise pretty difficult to solve manually are being converted into Algebraic equations within COMSOL and thus have generated the numerous results which are accumulated in the next section.

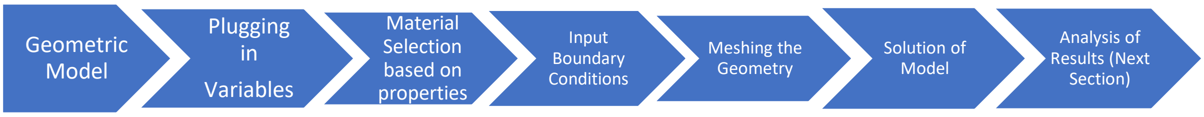


Figure 19: Timeline of Mathematical Modeling

In the COMSOL Modeling, we had employed some *assumptions* in using a material i.e.

We considered 'Ground at Base' while simulating the piezoelectric sensors. Besides, a fixed constraint was assumed at the base. There was a floating potential at the top surface in this analysis. The piezoelectric material (in this case: Lead Zirconate Titanate PZT-4) was taken as round in shape and form, when seen its crystal or element encapsulate inside it. In all the calculations and the analyses of all types, there was a constant, evenly distributed boundary load applied on top surface equaled 700N.

Step-1 Geometric Model/mesh: We selected the "Physics Controlled-Fine Mesh generated by COMSOL (Unstructured Fine CVs)"

Step-2 List of all constants and variables used in the COMSOL analysis have been described already above in the piezoelectric Modeling

Step-3 Physical Models: The physical models used in this analysis and the properties of the material used are as following, using the COMSOL library.

Simulations were performed on three different piezoelectric materials to compare their electric potential outputs.

- PZT-4
- PZT-8
- $BaTiO_3$

The results of the simulations have been discussed in the results' section.

We changed the diameter and thickness while keeping the loading conditions constant i.e. 700 newtons. The results have been presented in tabular form above in the "Results and Discussion" section. The finalized values used in the analysis were as follows:

Diameter=25mm;

Thickness=0.45mm;

Density = 7500 Kg/m^3;

The **elasticity matrix** so formed was:

{ordering (xx, yy, zz, yz, xz, xy)} = {1.38999e+011[Pa], 7.78366e+010[Pa], 1.38999e+011[Pa], 7.42836e+010[Pa], 7.42836e+010[Pa], 1.15412e+011[Pa], 0[Pa], 0[Pa], 0[Pa], 2.5641e+010[Pa], 0[Pa], 0[Pa], 0[Pa], 0[Pa], 2.5641e+010[Pa], 0[Pa], 0[Pa], 0[Pa], 0[Pa], 0[Pa], 3.0581e+010[Pa]} Pa

[*Note:* Pa *stands for Pascal in the aforementioned matrix.*]

The **Coupling Matrix** is given as

{0[C/m^2], 0[C/m^2], -5.20279[C/m^2], 0[C/m^2], 0[C/m^2], -5.20279[C/m^2], 0[C/m^2], 0[C/m^2], 15.0804[C/m^2], 0[C/m^2], 12.7179[C/m^2], 0[C/m^2], 12.7179[C/m^2], 0[C/m^2], 0[C/m^2], 0[C/m^2], 0[C/m^2], 0[C/m^2]} Cm2

Finally, the **relative permittivity** was

{762.5, 762.5, 663.2}

[Note: Above mentioned properties have been taken from the COMSOL material library.]

Step-4 Mesh the geometry: The following mesh has been made in the COMSOL (fine type).

Figure 20: Mesh Generated in COMSOL

Step-5 Solve the Model: Compute the model by clicking on “compute”. The basic gist of the things happening is the PDEs converted into set of algebraic differential equations which are solved simultaneously using boundary conditions.

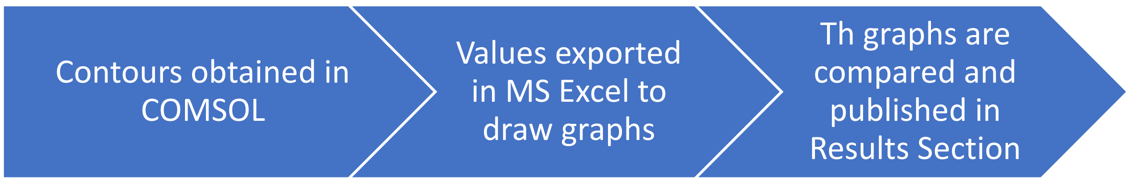


Figure 21: Solution of the Model

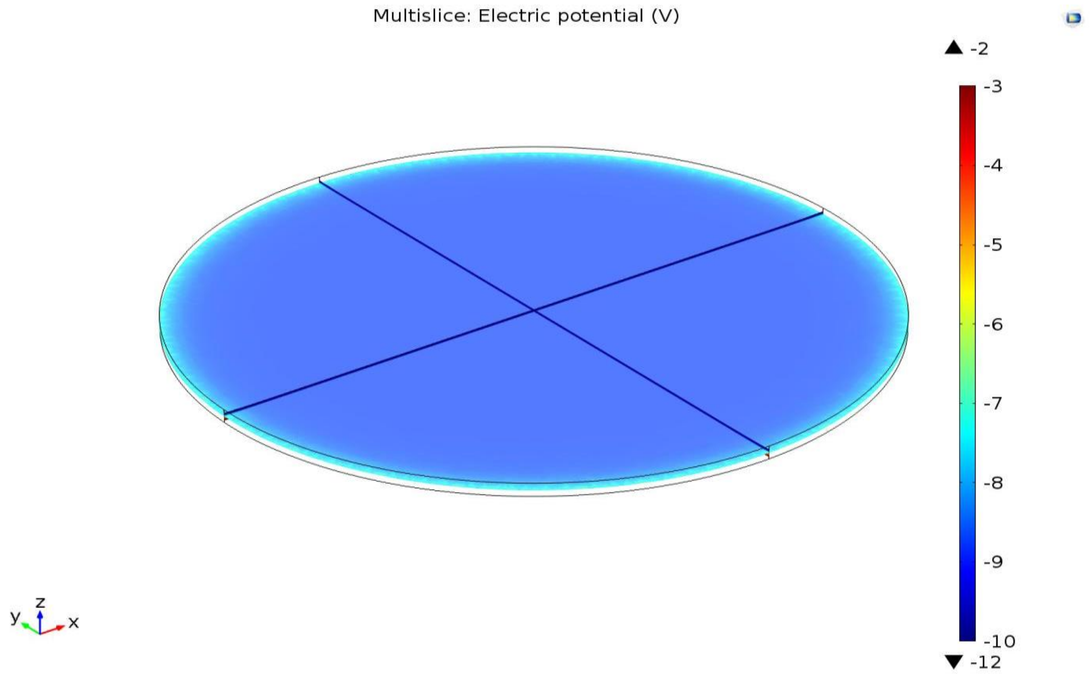
CHAPTER 4: RESULTS AND DISCUSSION

Material Selection

Simulation was performed on three different piezoelectric materials to compare their electric potential outputs.

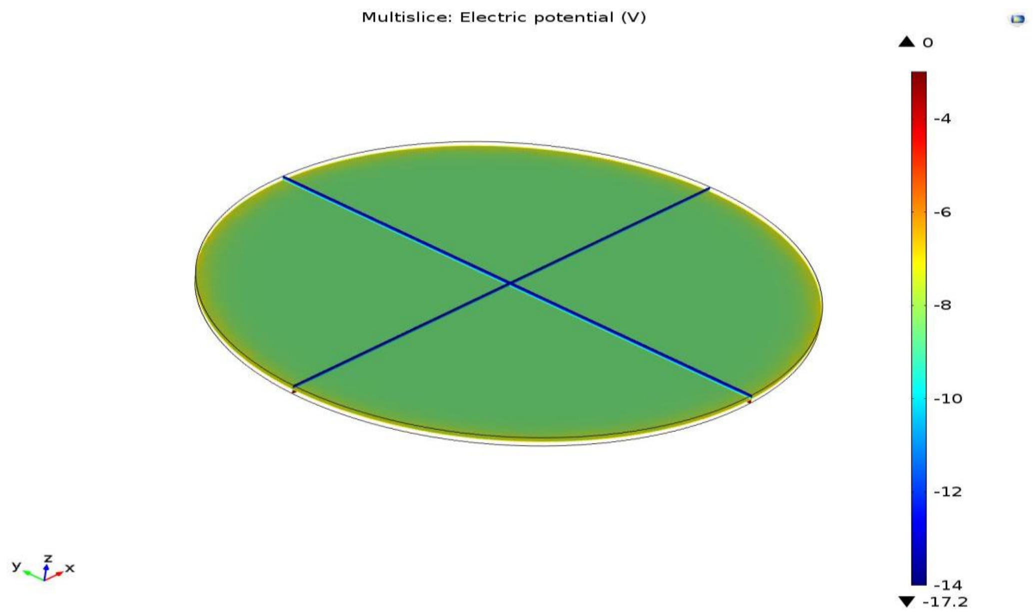
- PZT4
- PZT8
- $BaTiO_3$

PZT4



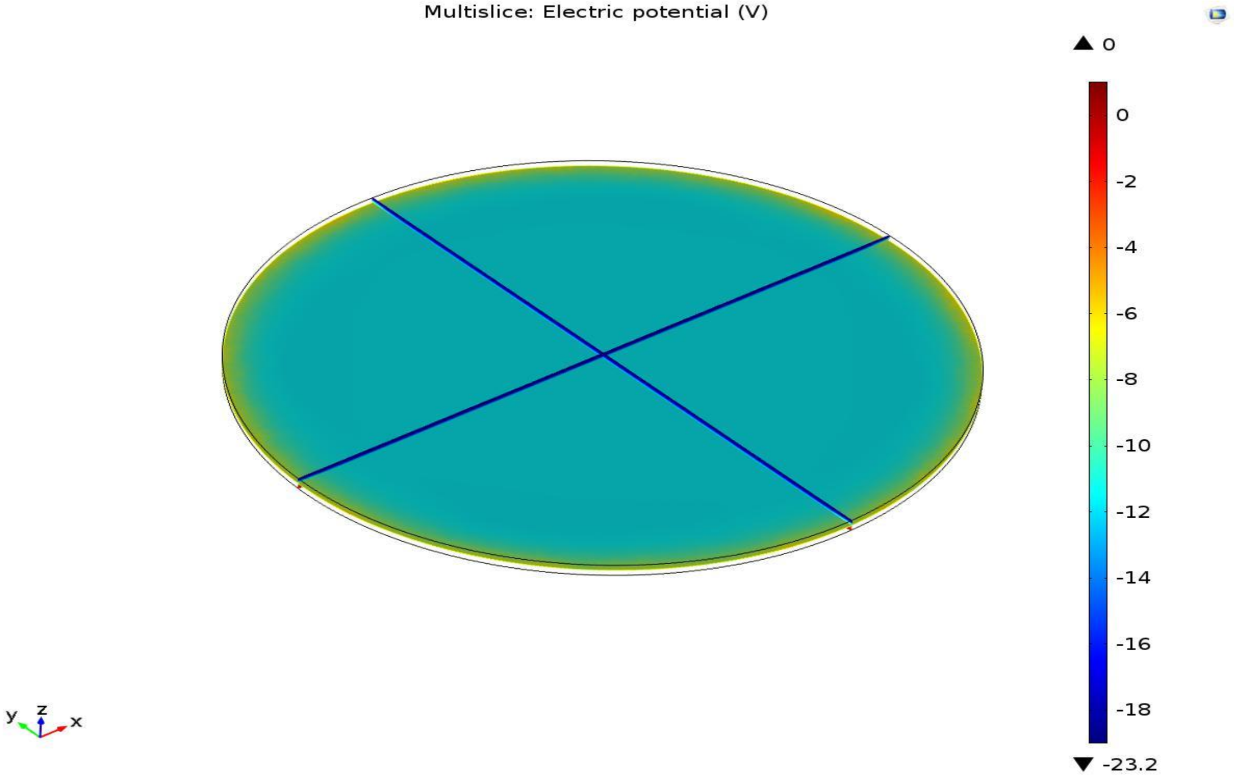
(Diameter: 20mm, Thickness: 0.45mm, Boundary Load: 700N)

PZT8



(Diameter: 20mm, Thickness: 0.45mm, Boundary Load: 700N)

$BaTiO_3$



(Diameter: 20mm, Thickness: 0.45mm, Boundary Load: 700N)

Material	**Electric Potential Output (V)**
PZT4	7.5-8.5
PZT 8	8
$BaTiO_3$	8-10

Discussion on Piezoelectric

From literature review and simulation results, we were able to conclude that outputs of commonly used piezoelectric materials (PZT4, PZT8 and $BaTiO_3$) fall in the same range. The other factors that differentiate them are their costs, durability and ease of procurement. We decided to prefer PZT4 for our project.

Results of simulation in COMSOL

Piezoelectric simulation in COMSOL was performed to obtain results for following quantities.

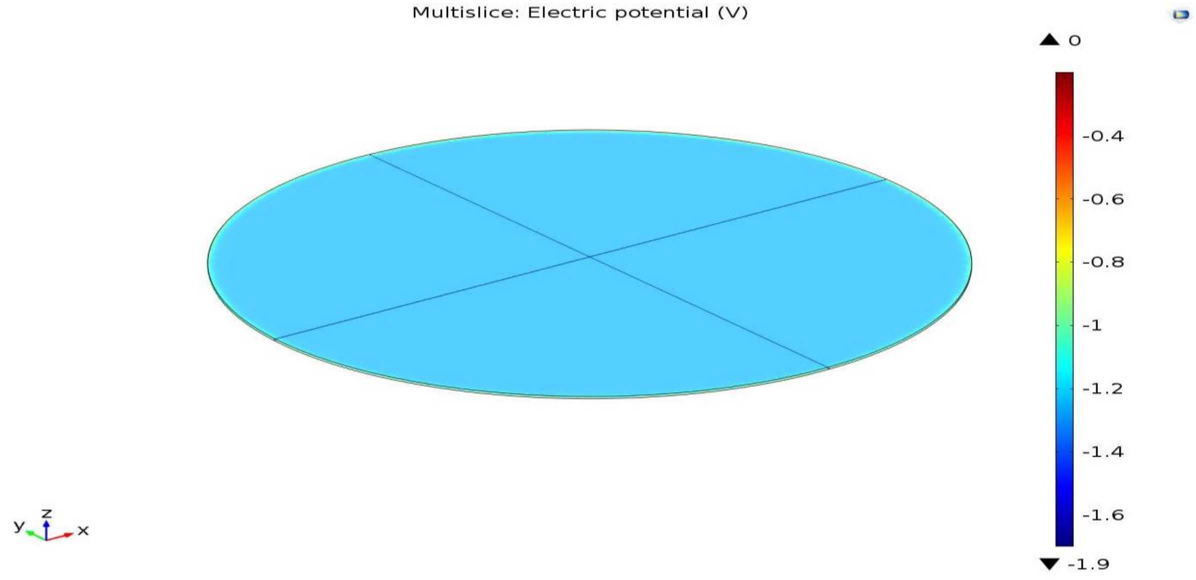
- Electric Potential

- Stresses developed
- Eigen frequency
- Total surface displacement

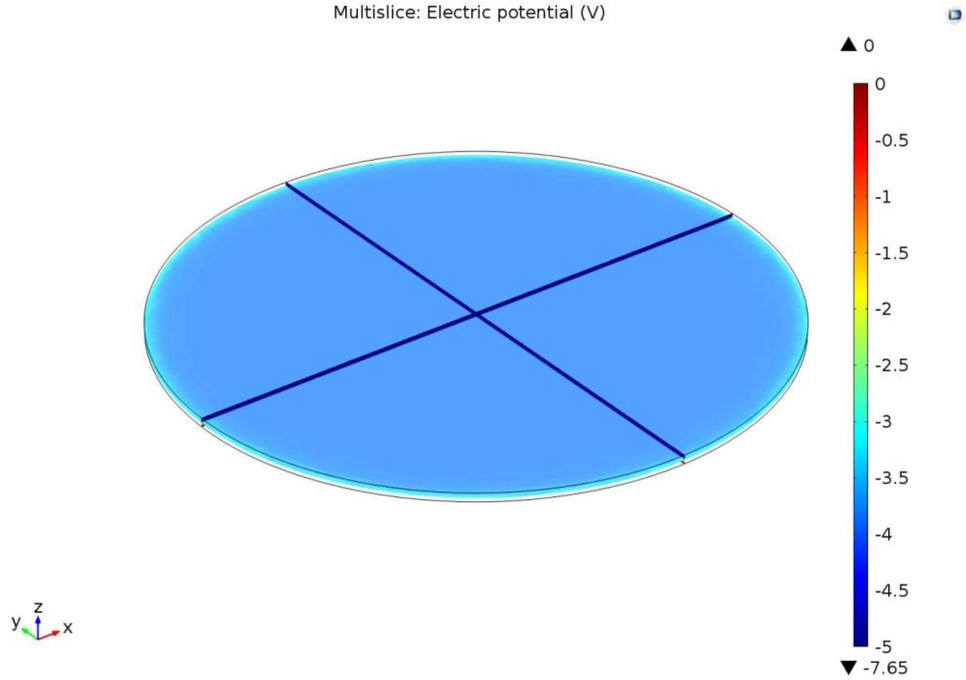
Electric Potential Variation:

Iterations with fixed diameter and varying thickness were performed. Results were obtained for variation in electric potential.

Diameter: 30mm Thickness: 0.15mm Boundary load: 700N



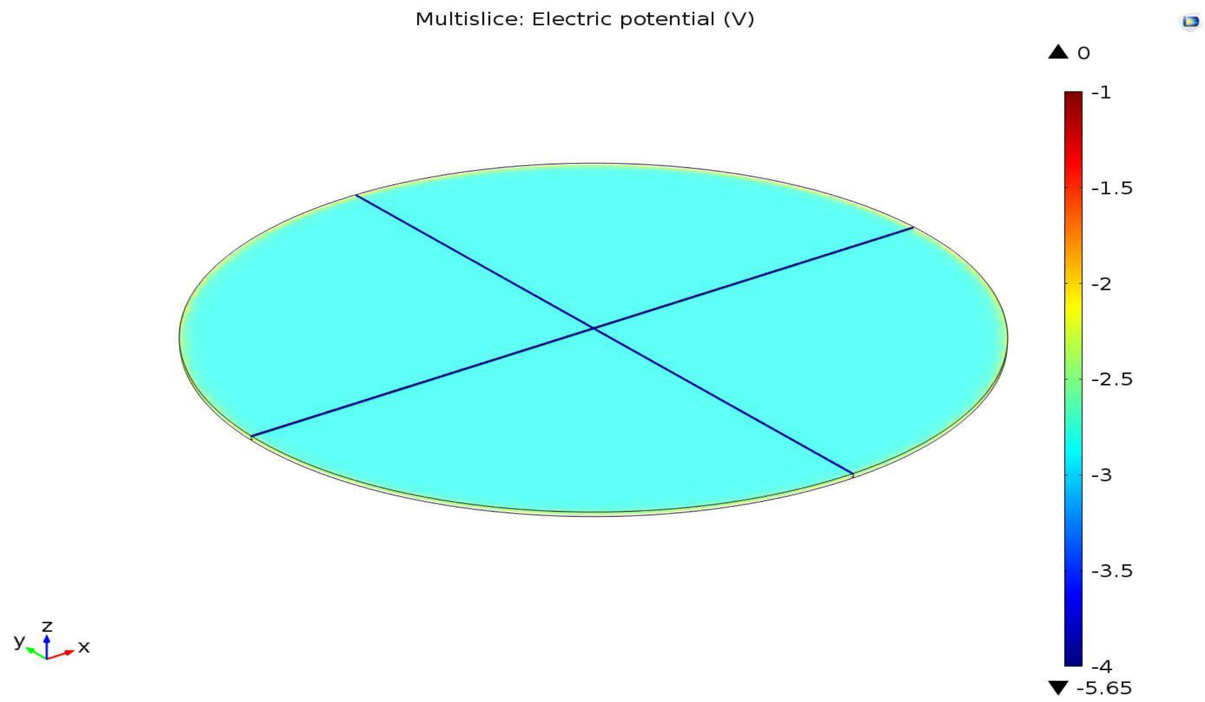
Diameter: 30mm Thickness: 0.45mm Boundary load: 700N



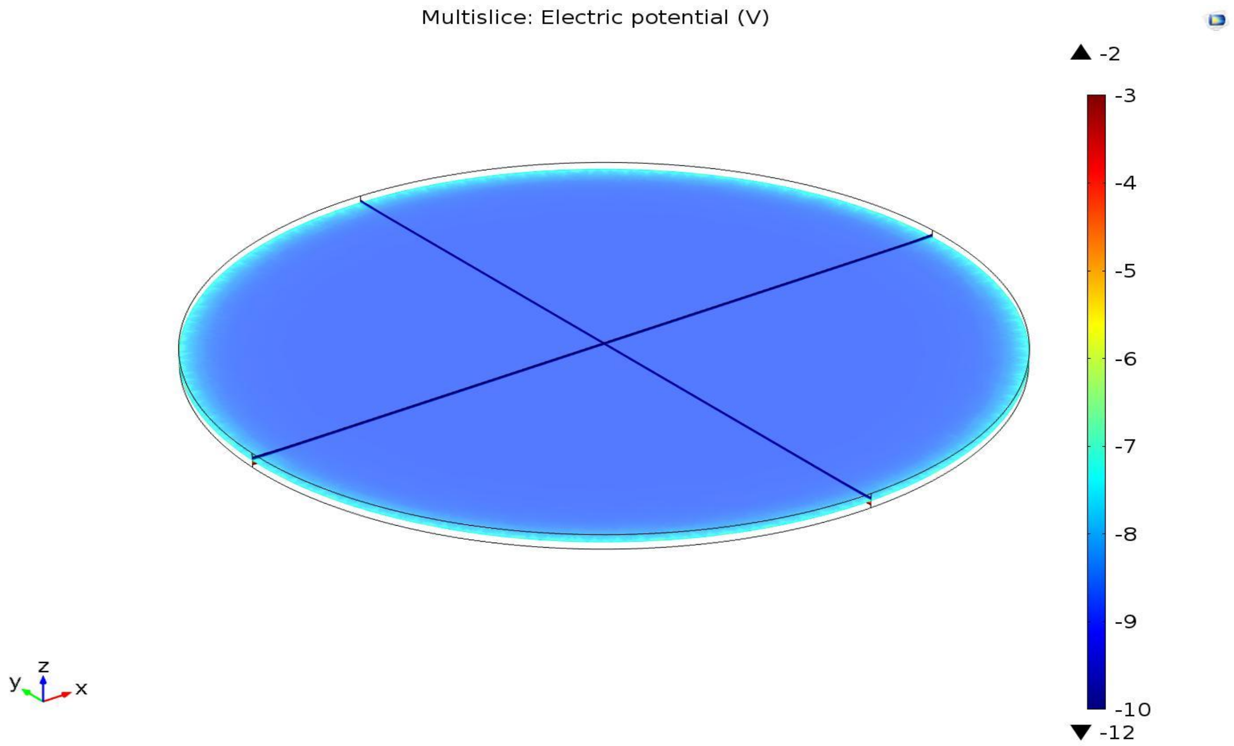
Diameter (mm)	Thickness (mm)	Electric Potential (V)
30	0.15	1.1-1.3
30	0.25	1.8-2.1
30	0.35	2.5-3
30	0.45	3.1-3.6

Similar iterations were performed at a fixed diameter of 20 mm and varying thickness from 0.15 mm to 0.45 mm.

Diameter: 20mm **Thickness: 0.15mm** **Boundary load: 700N**



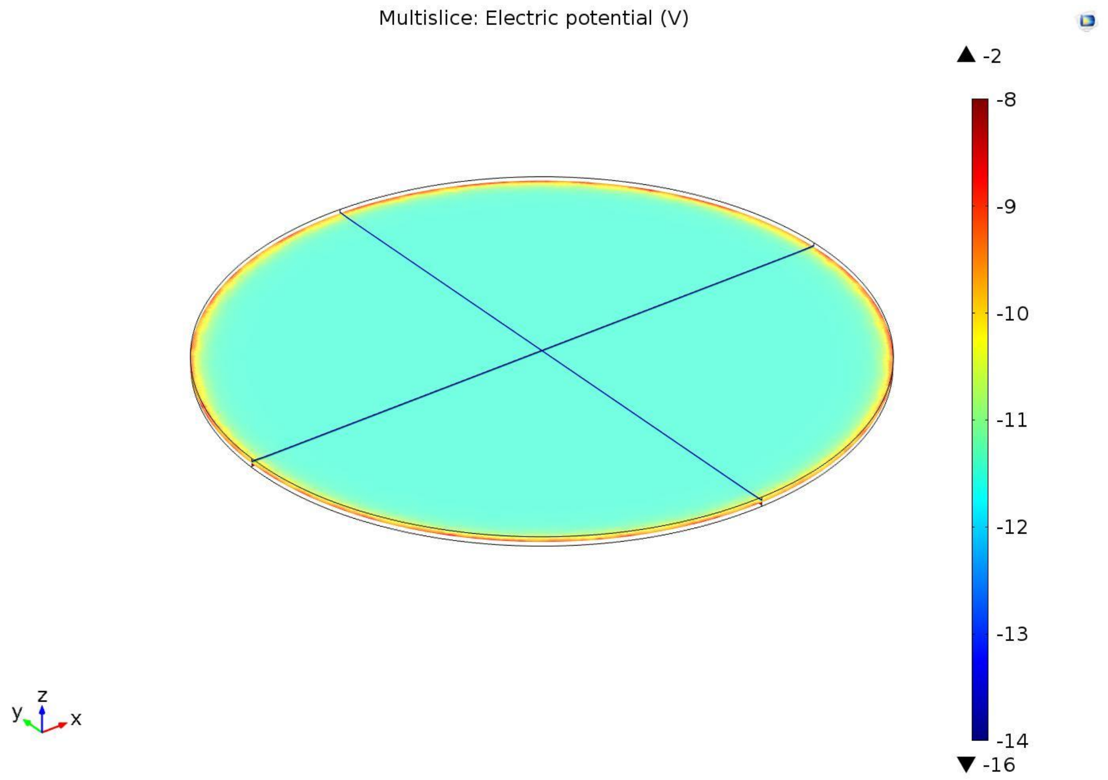
Diameter: 20mm **Thickness: 0.45mm** **Boundary load: 700N**



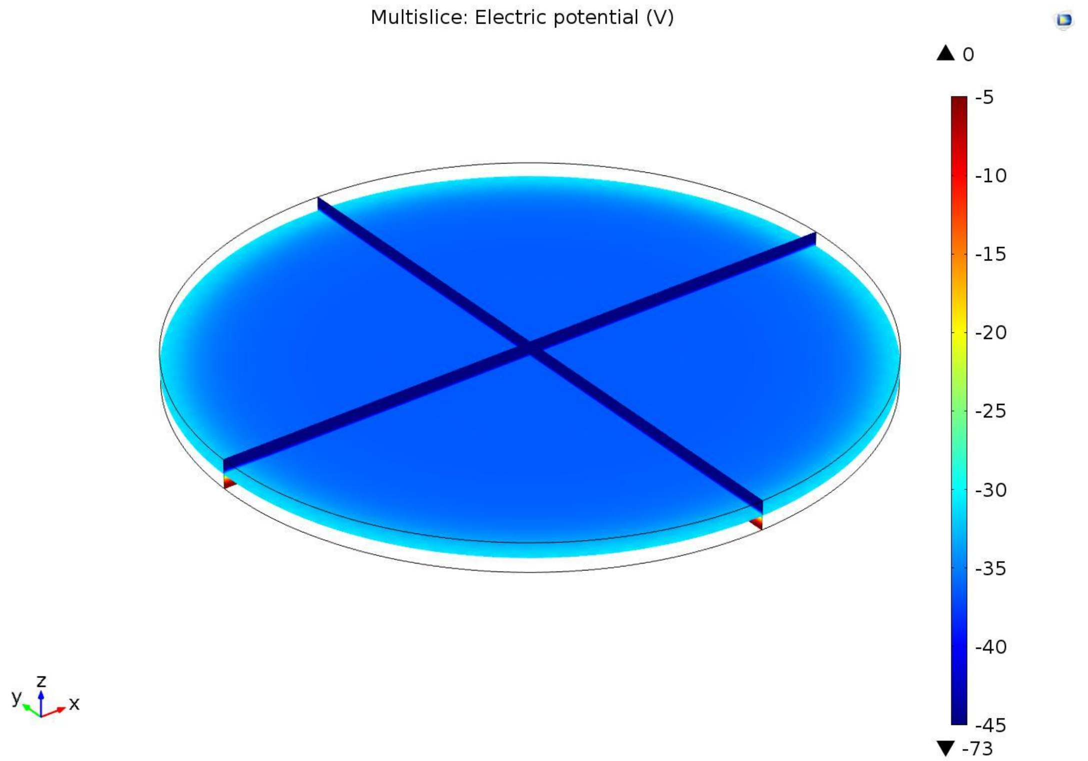
Diameter (mm)	Thickness (mm)	Electric Potential (V)
20	0.15	2.5-3
20	0.25	4.2-4.7
20	0.35	6-8
20	0.45	7.5-9

Similar iterations were performed at a fixed diameter of 10 mm and varying thickness from 0.15 mm to 0.45 mm.

Diameter: 10mm Thickness: 0.15mm Boundary load: 700N

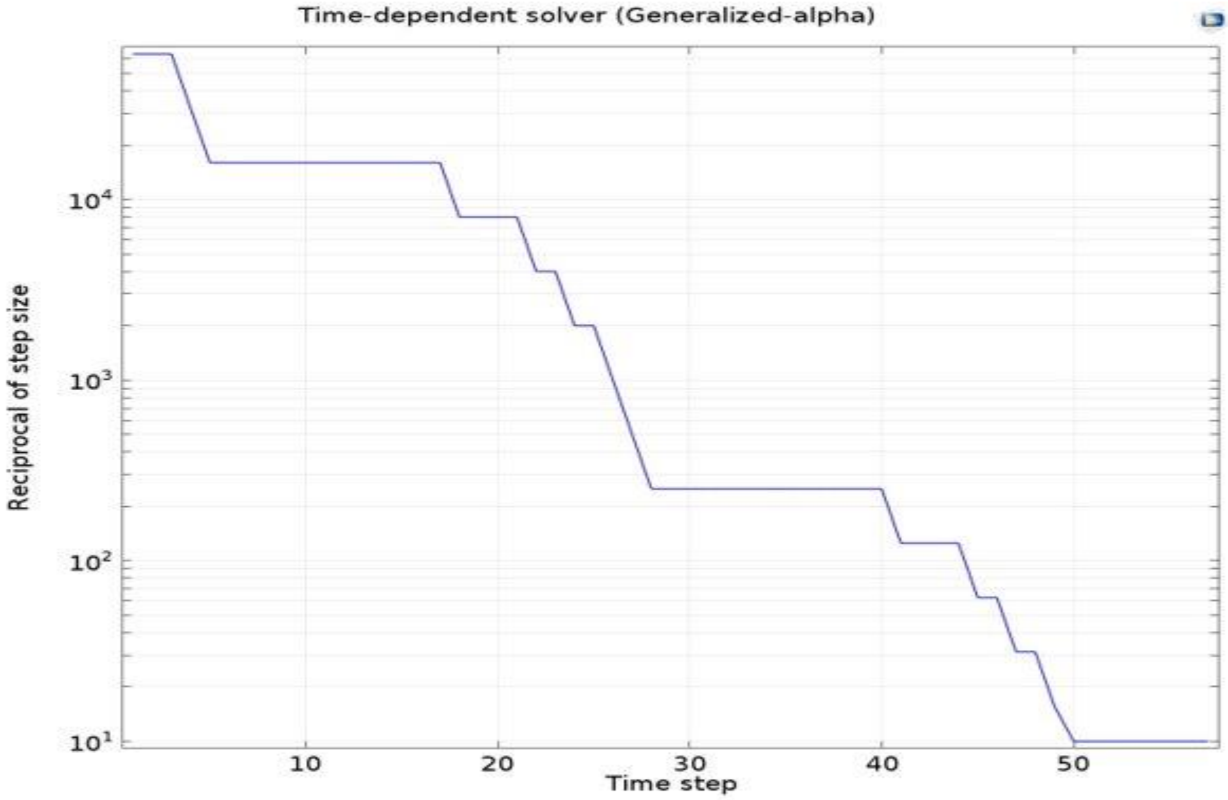


Diameter: 10mm Thickness: 0.45mm Boundary load: 700N



Diameter (mm)	Thickness (mm)	Electric Potential (V)
10	0.15	10-12
10	0.25	16-18
10	0.35	22-27
10	0.45	32-36

Convergence Plot



Convergence plot is a representation of solution convergence. The time dependent solver is computing the solution system of equations at each time step via a set of iterative techniques based upon Newton's method. These iterative techniques evaluate a function, as well as its derivative, at every time step. The derivative is also known as the Jacobian and is relatively expensive to compute. Therefore, the software will try to minimize the re-evaluation of the Jacobian, by default. If the solver has difficulty converging, it will instead reduce the requested time step size and try to compute the solution. Software will modify the given time step to reach the solution. Initial time step used was 0.01 seconds.

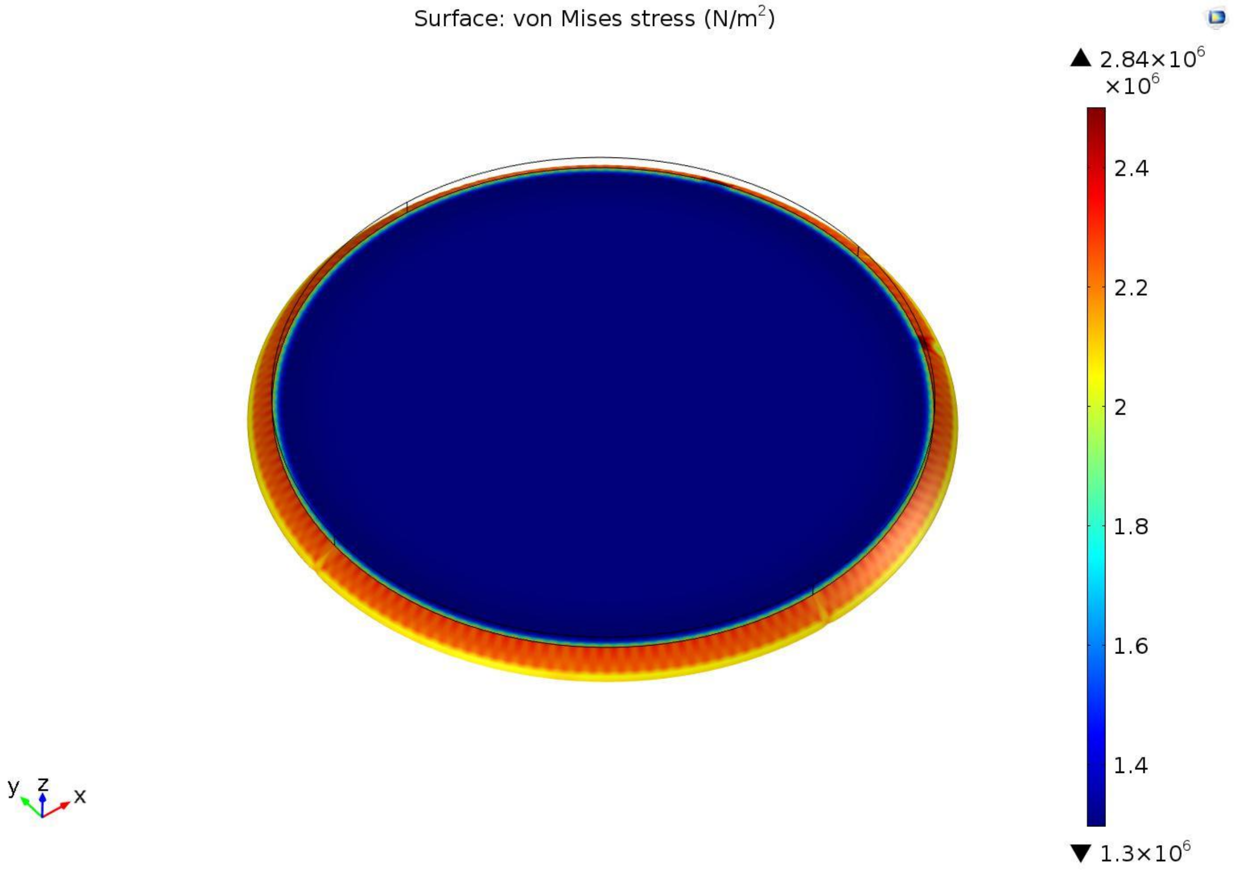
Interpretation of Results:

- With increase in thickness of piezoelectric element at constant diameter and boundary load, electric potential output increases.
- With increase in diameter of piezoelectric element at constant thickness and boundary load, electric potential output decreases.
- With increase in boundary load at constant thickness and diameter, electric potential output increases.

From results, we were able to conclude that with increase of thickness to diameter ratio, electric potential output of piezoelectric element increases.

Stresses Developed (Von Mises Stress):

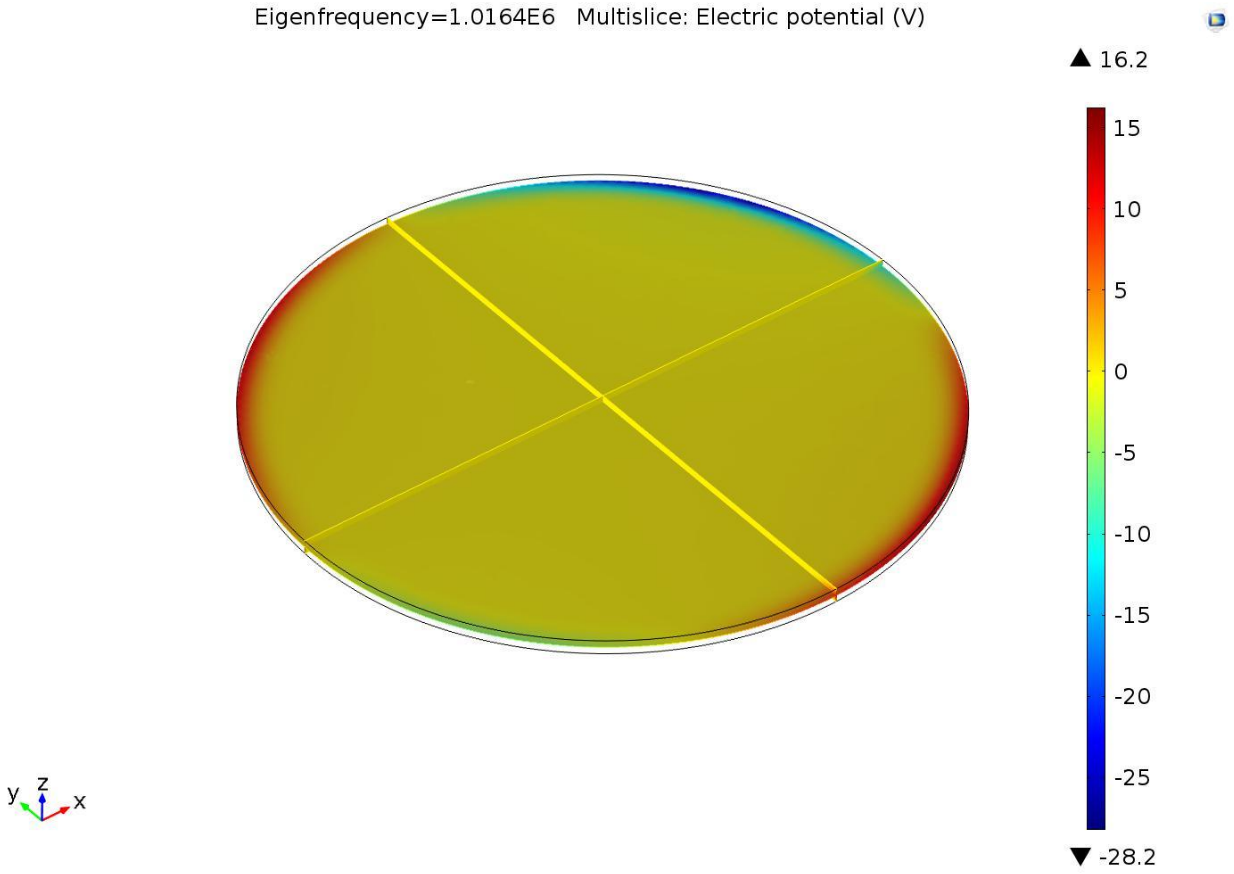
Results were obtained for stresses developed in piezoelectric element as a result of application of force on them. Evenly distributed force of 1000N was applied and results were generated using COMSOL.

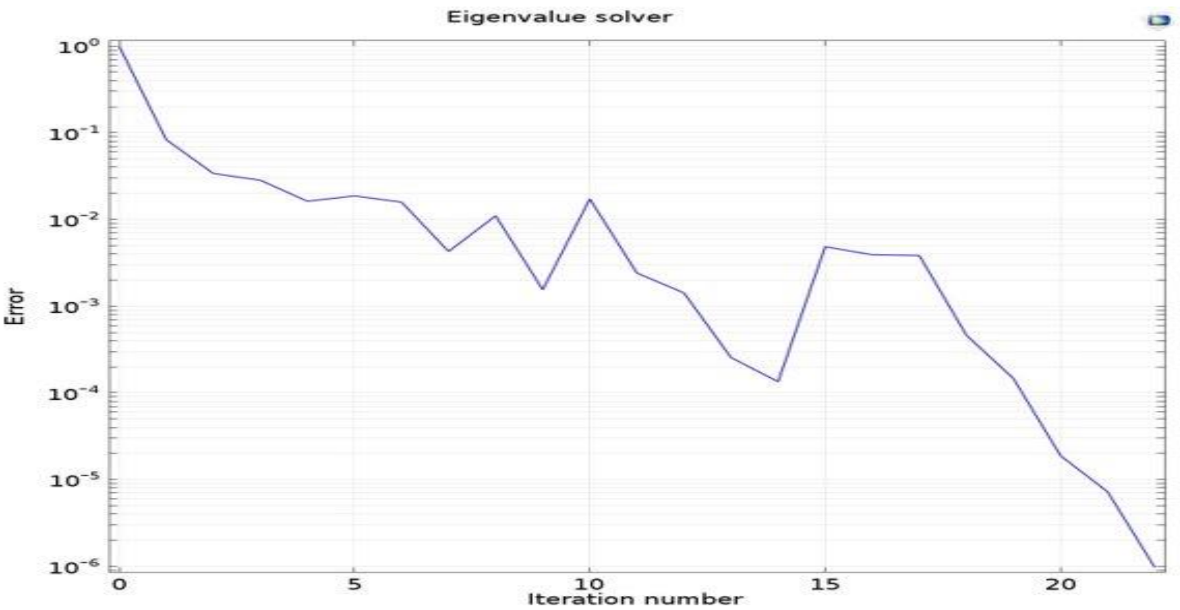


Results indicated that maximum stress developed was in the range of 2.84 MPa. The average ultimate tensile stress of lead zirconate titanate is much higher and lies in the range of 270 MPa. (from Wiley Library)

Eigen Frequency

Eigen frequency was determined using Eigen frequency studies in COMSOL.

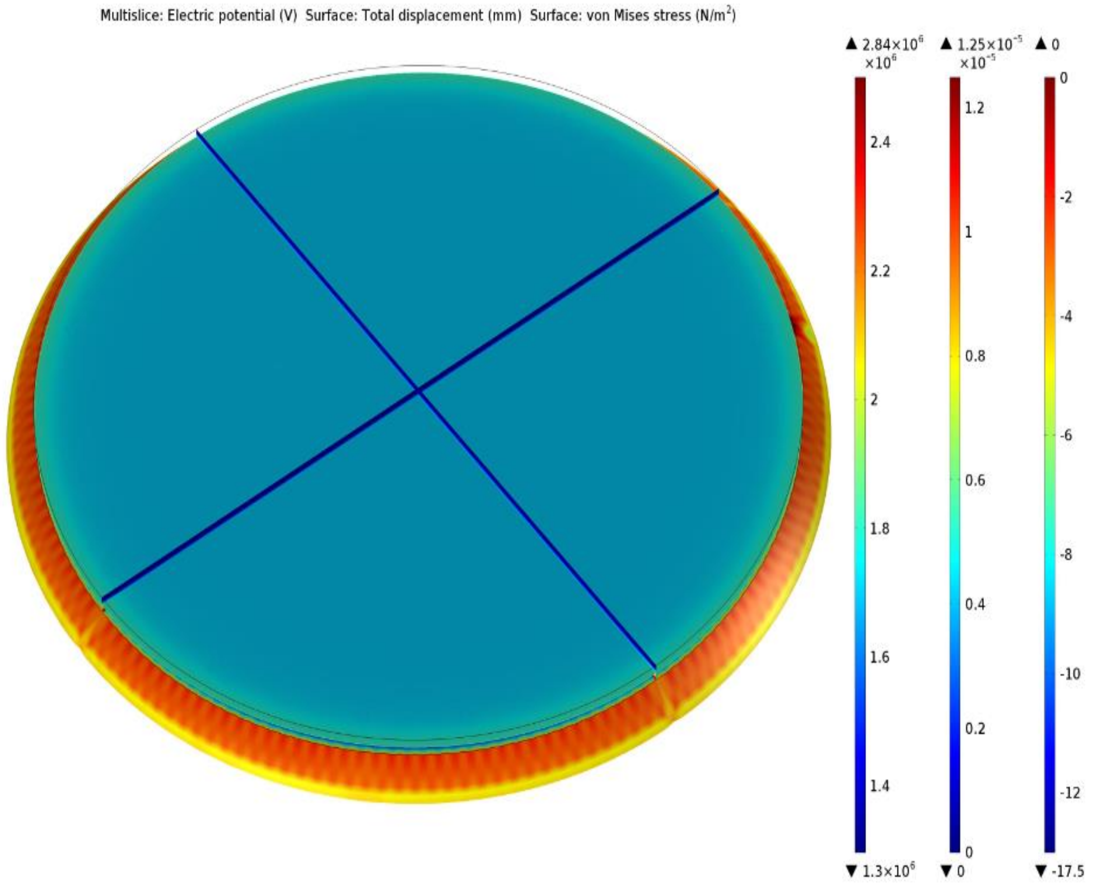




Eigen frequency solution was reached with default relative tolerance for error.

Total Surface Displacement

Surface displacement induced as a result of applied force was estimated using COMSOL simulation.



Solar Panel Simulation

Solar Panel simulation and optimization was performed using SIMULINK (MATLAB). Results were obtained for Power-Voltage (PV) and Current-Voltage (IV) curves at different operating temperatures.

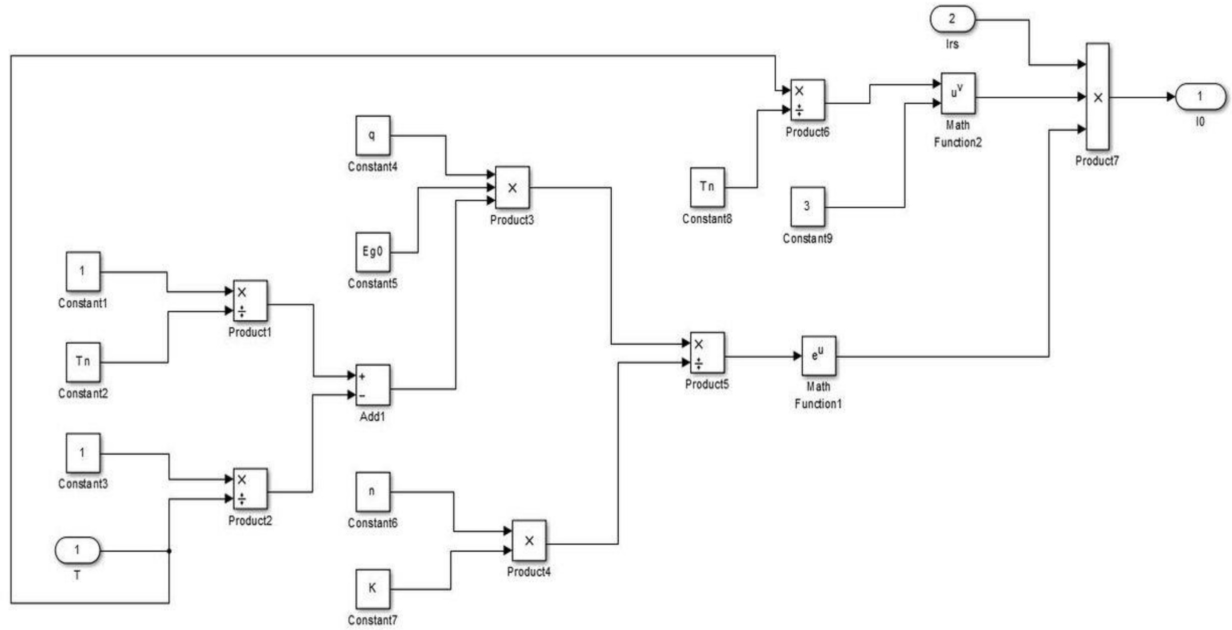
Equations and Simulink Models

Voltage Current Characteristic Equations

$$\boldsymbol{I_{PH} = [I_{SC} + K_i(T - 298)].\frac{G}{1000}}$$

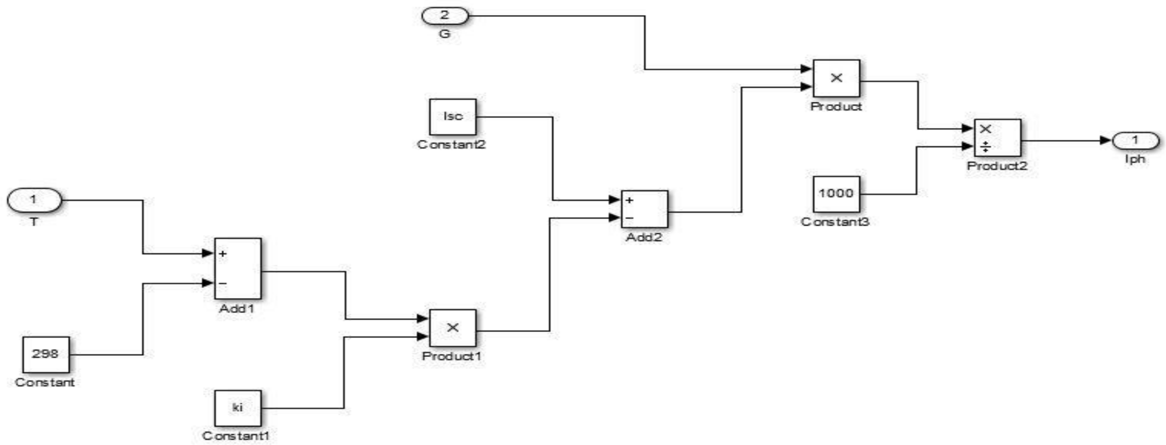
Saturation Current

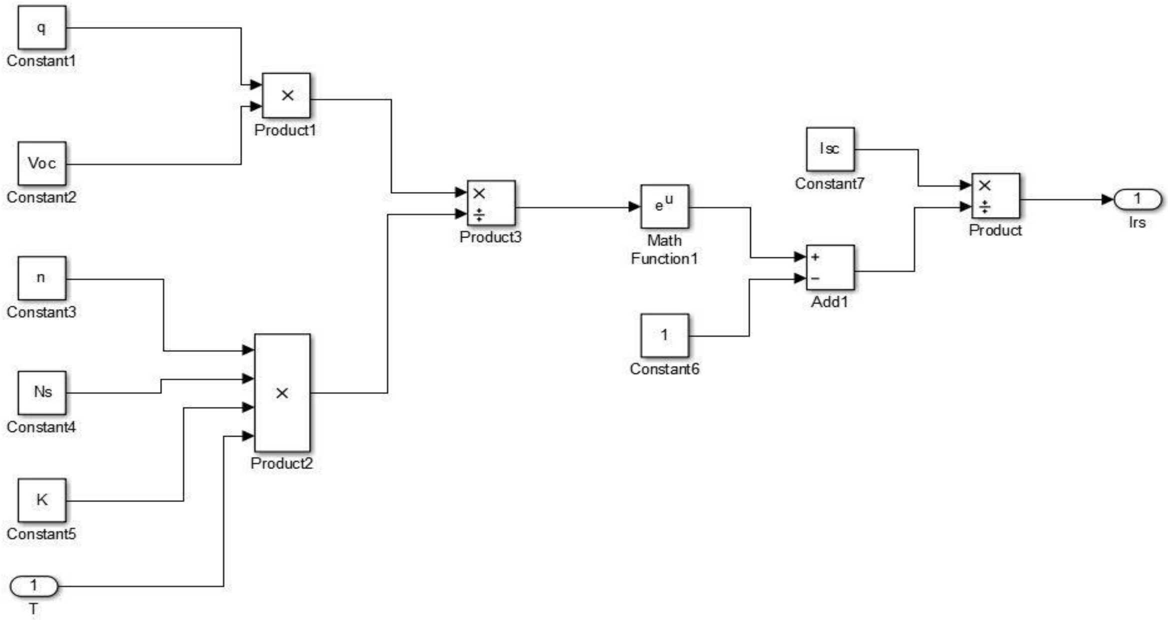
$$\boldsymbol{I_0 = I_{rs}(\frac{T}{T_n})^3 exp[\frac{q.E_{g0}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)]}$$



Reverse Saturation Current

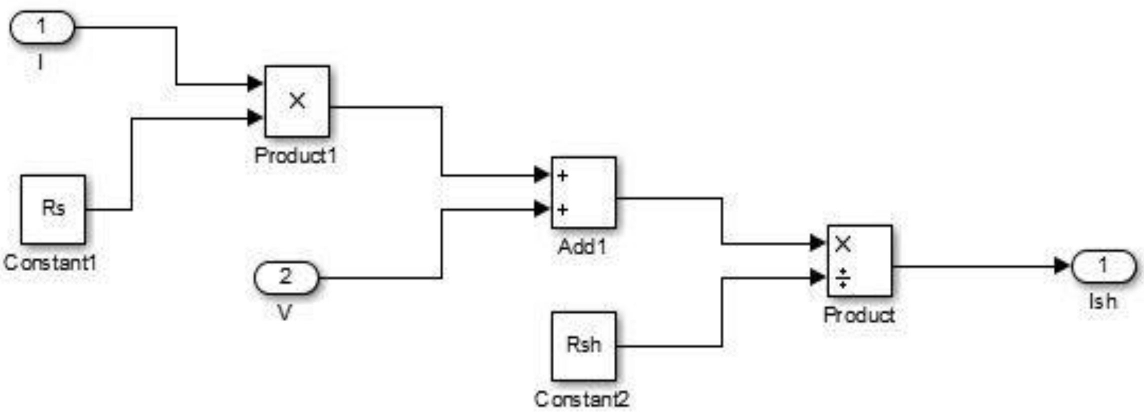
$$\boldsymbol{I_{rs} = \frac{I_{sc}}{[exp\left(q.V_{oc}/_{N_S knT}\right) - 1]}}$$





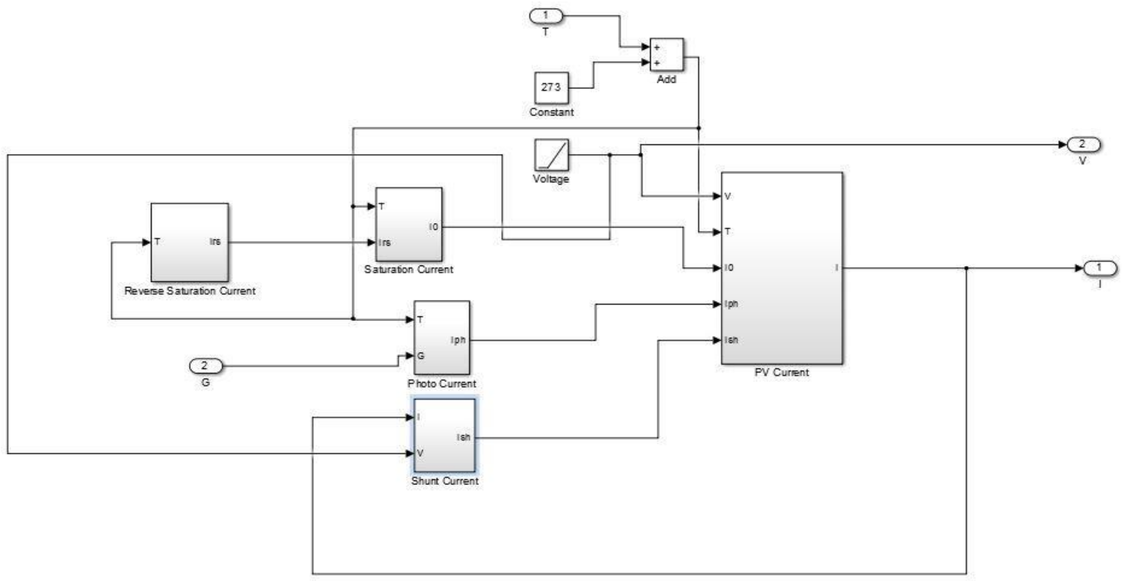
Current through Shunt

$$I_{Sh} = \frac{V.{}^{N_P}/_{N_S} + I.R_s}{R_{sh}}$$

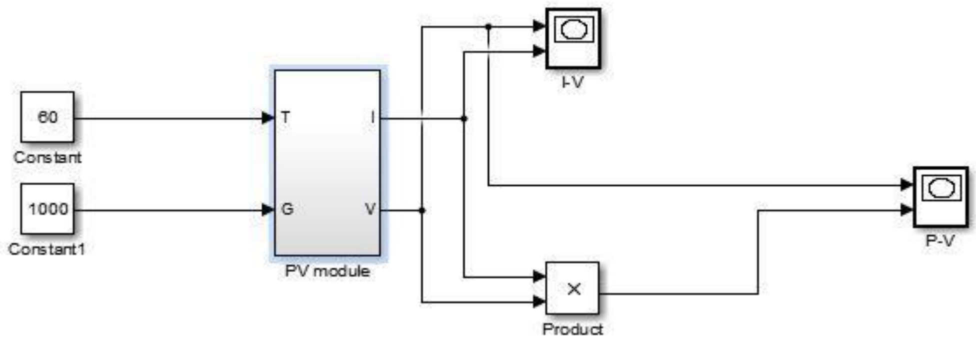


Output Current

$$I = N_P.I_{Ph} - N_P.I_0\left[exp\left(\frac{V/_{N_S} + I.{}^{R_s}/_{N_P}}{n.V_t}\right) - 1\right] - I_{Sh}$$



Simulink Model with all combined Subsystems

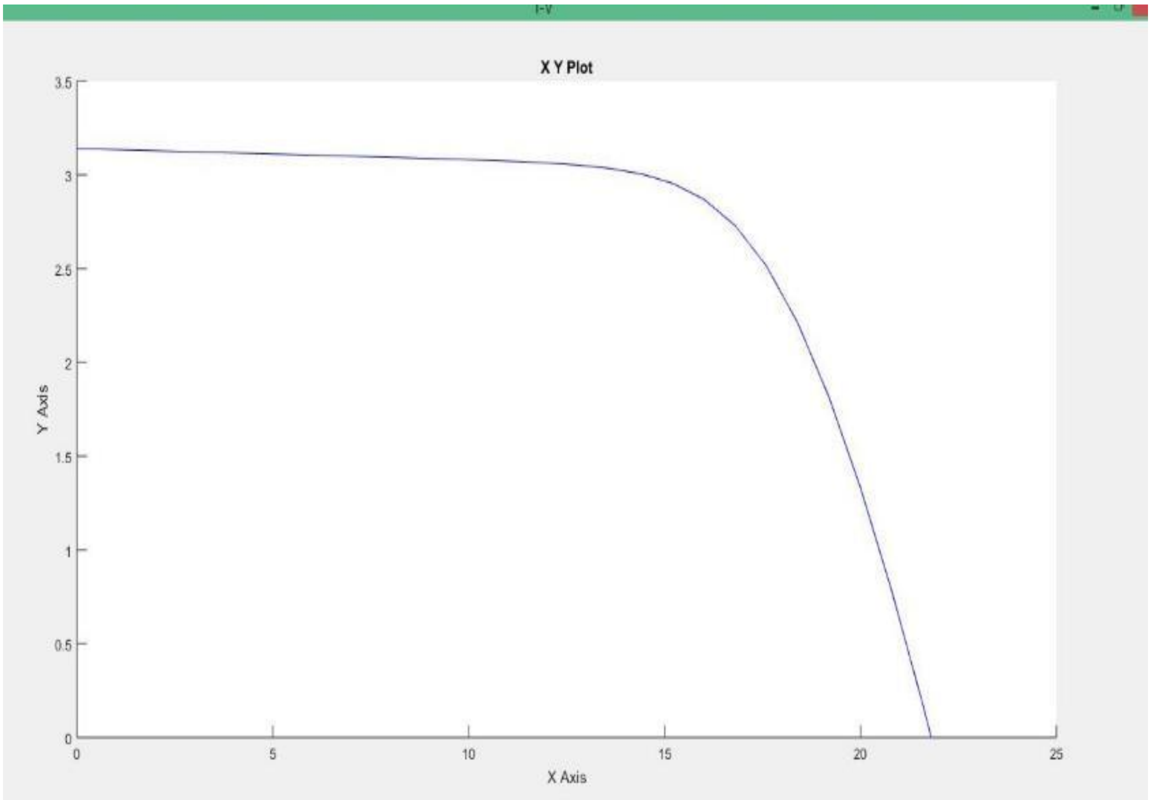


I-V Curves

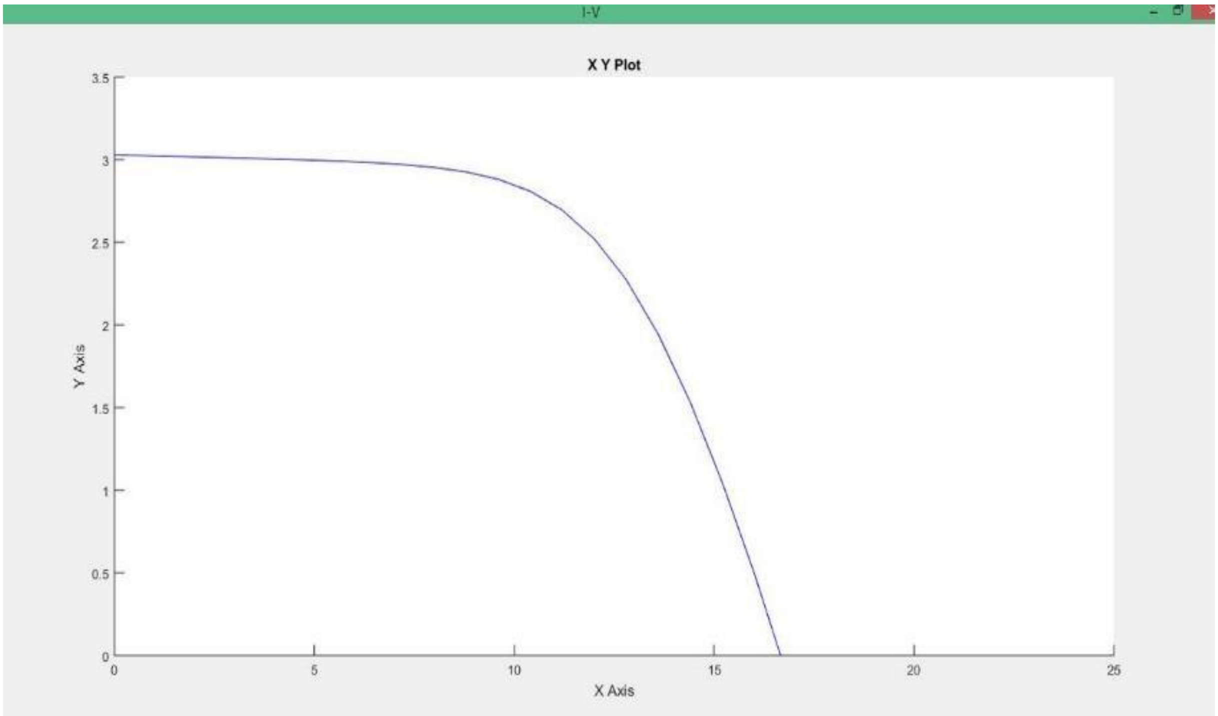
Temp. = **298K**

x-axis = **V**

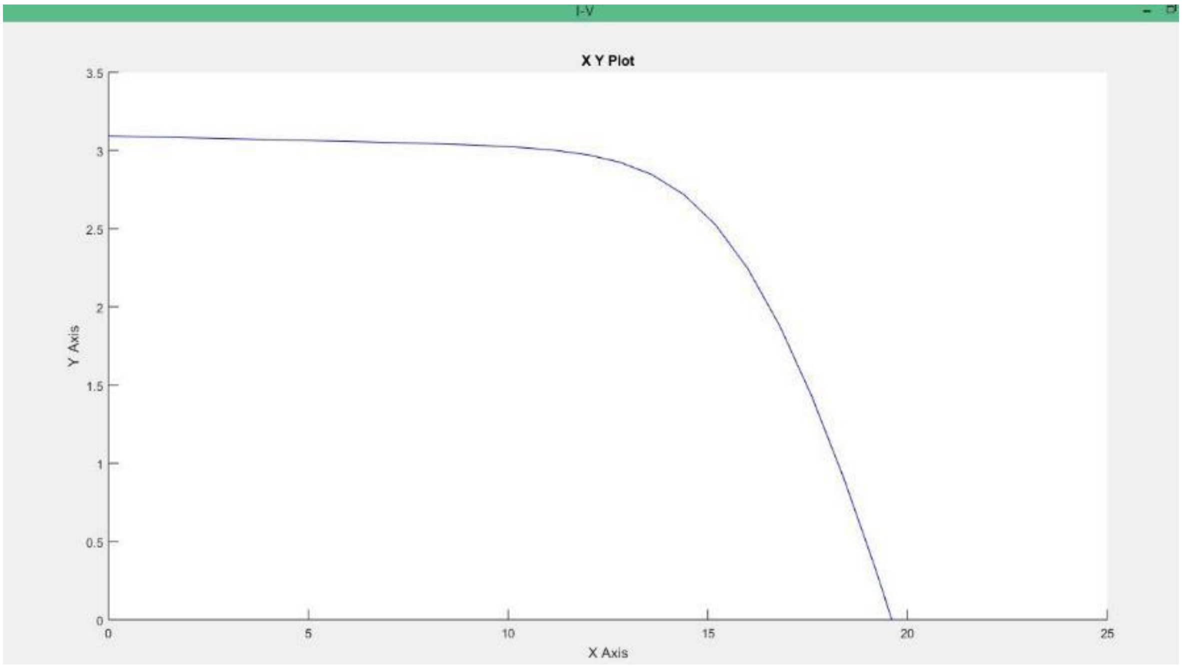
y-axis = **I**



Temp. = **313K**
x-axis = **V**
y-axis = **I**

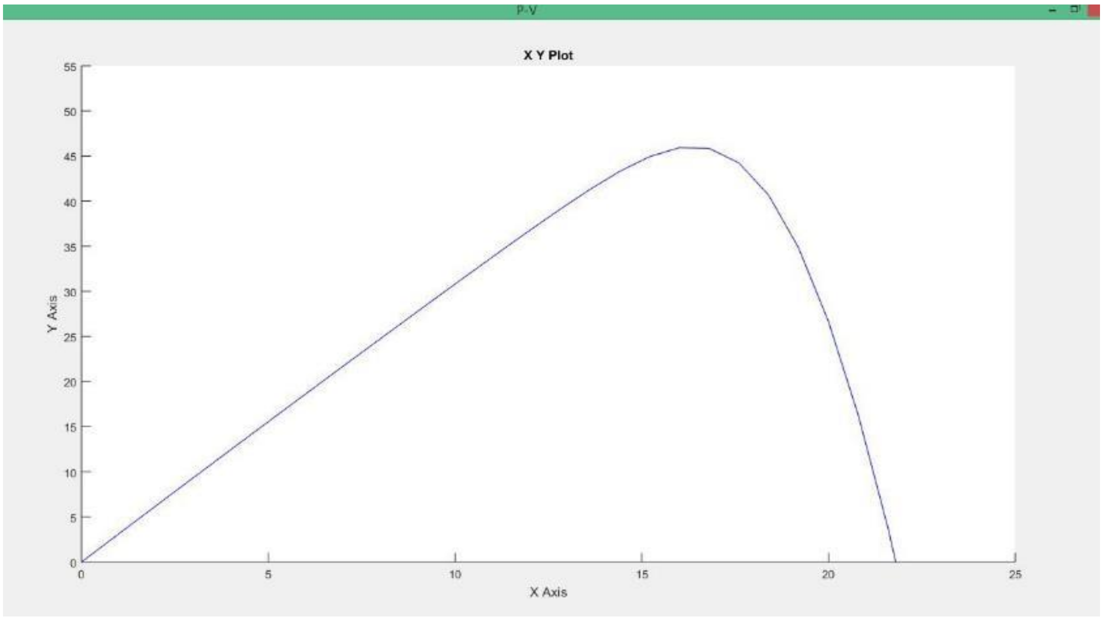


Temp. = **333K**
x-axis=**V**
y-axis = **I**

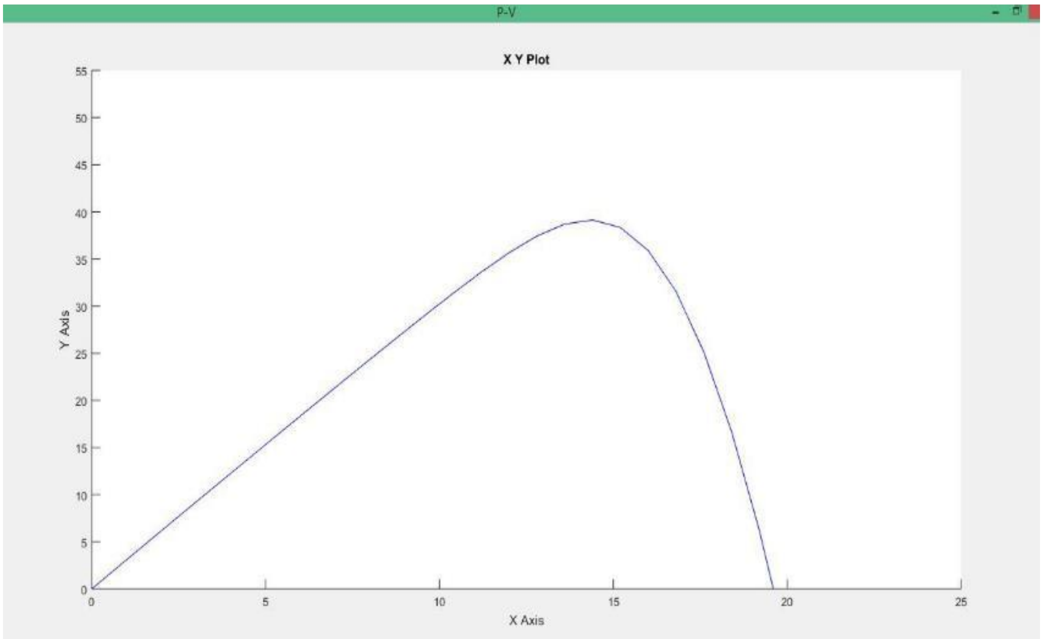


P-V Curves

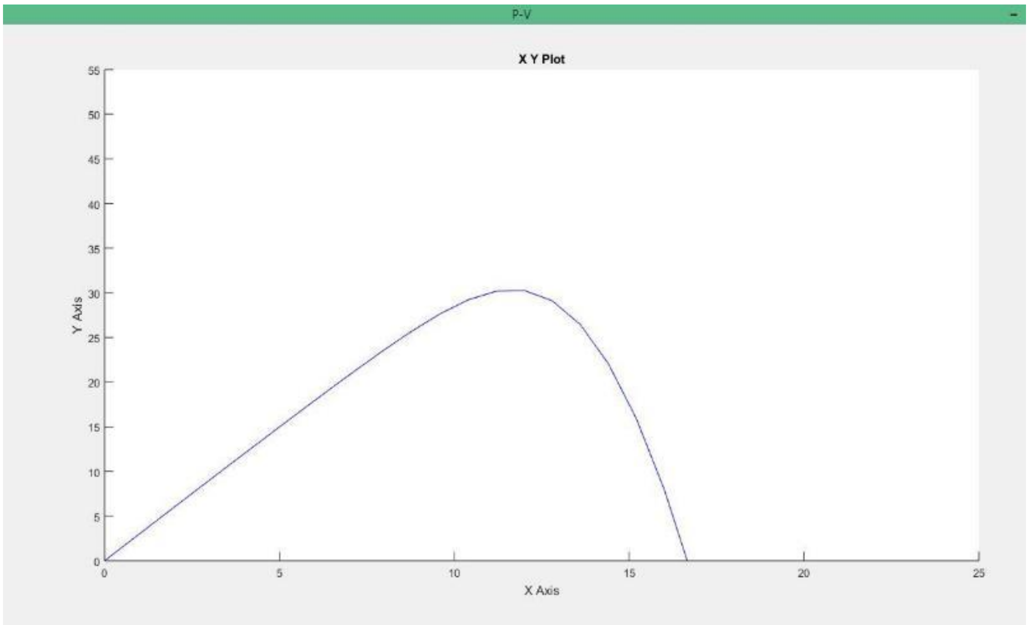
Temp. = **298K**
x-axis = **V**
y-axis = **P**



Temp. = **313K**
x-axis=**V**
y-axis = **P**



Temp. = **333K**
x-axis=**V**
y-axis = **P**

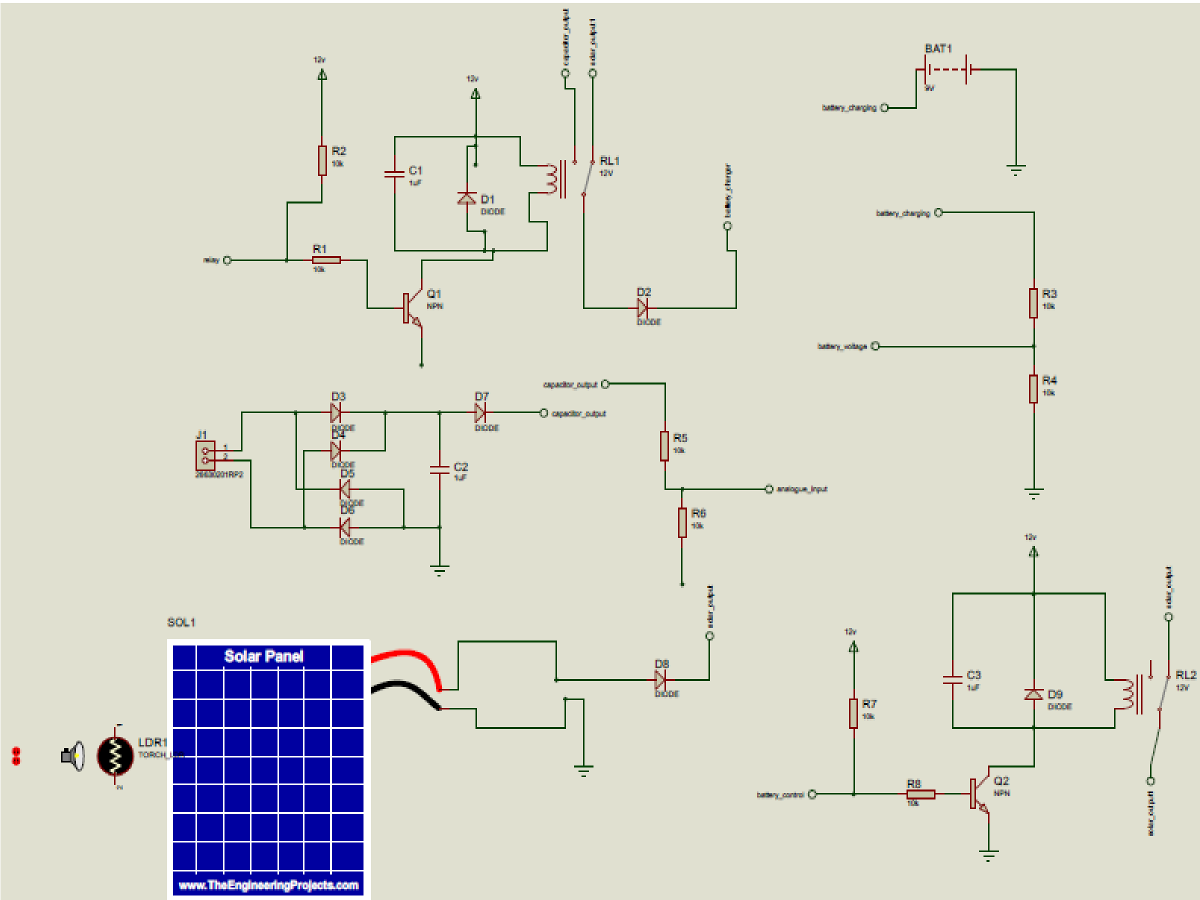


Discussion on PV Cells

Solar cells are sensitive to temperature. With the increase of temperature, voltage is decreased and current is increased slightly. Power output of solar cell decreases with the temperature. The best performance of solar panels is expected in sunny day with a low temperature.

Circuit Diagram Validation

Circuit diagram was validated using Proteus Design Suite.



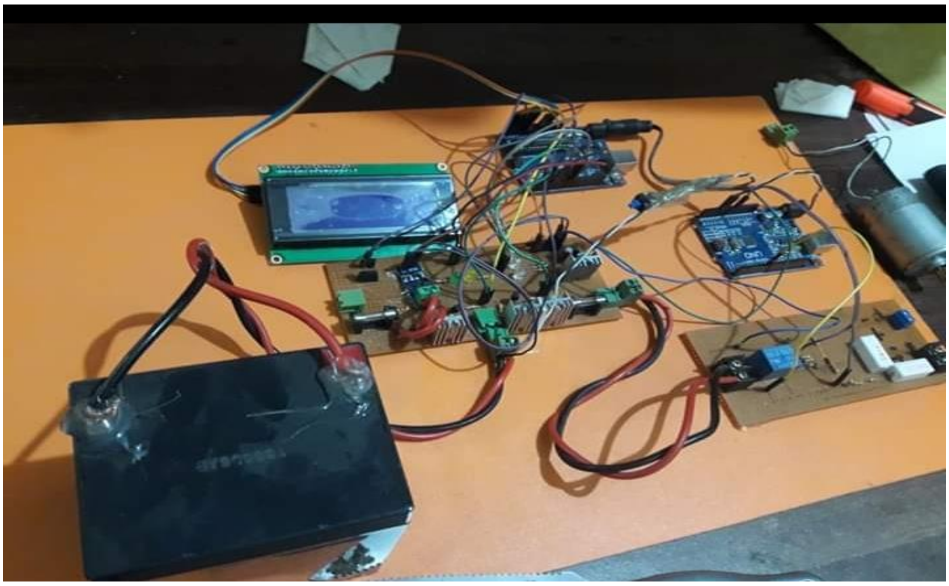
The power was 8.0 Watthour and the voltage of 12V was observed at stall conditions with current of 0.8Amperes.

The components used in the project were:

- Arduino Uno (DIP)
- Arduino Uno (SMD)
- DC Motor
- 20 X 4 LCD
- I2C Module

- Fuse + Holder
- IRF 9540 (Power MOSFET)
- MBR 2045 (Schottky Barrier Diode)-Power Diode
- 2N2222
- ACS 12 5Amp
- 7805 Voltage Regulator
- LEDs
- Battery 12V
- LM 34
- Relay 5V
- Resistors 5W
- Terminal 2 pin
- Heat Sink
- Piezoelectric Transducers (X 6)
- Capacitors
- IN 4007
- Springs
- Solar Panel (40W)
- Wires
- Nuts and Bolts for Wooden Platform

The finalized model and its underlying characteristic working models are shown in the following pages: First picture is depicting the charge controller circuit of the project which is concerned about collection of energy from both means; solar and piezo ends.



Similarly, the block diagrams of the whole circuit and the charge controller have been described in detail as follows:

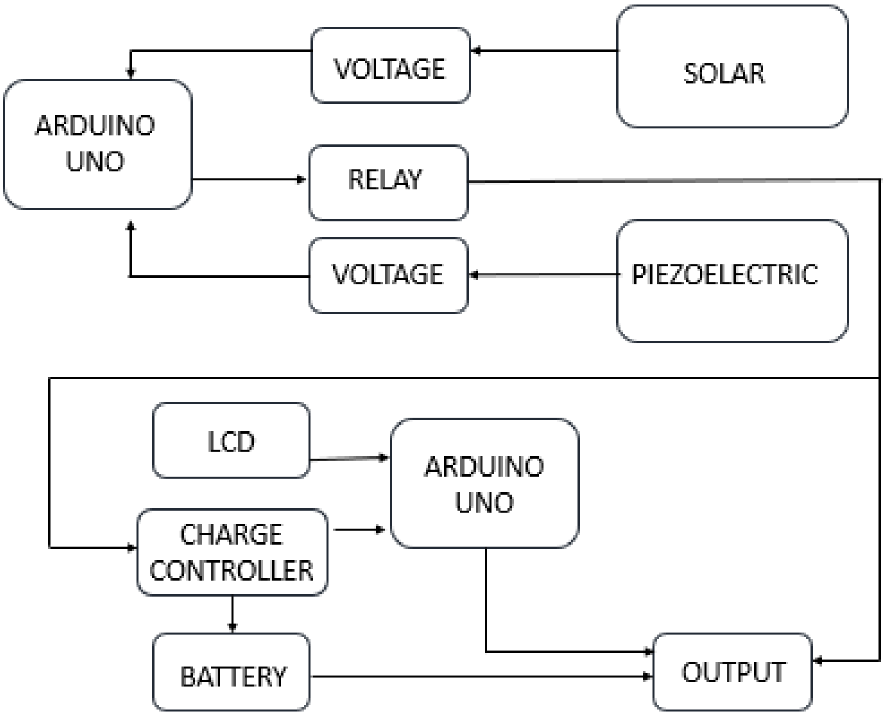


Figure: Working System Block Diagram

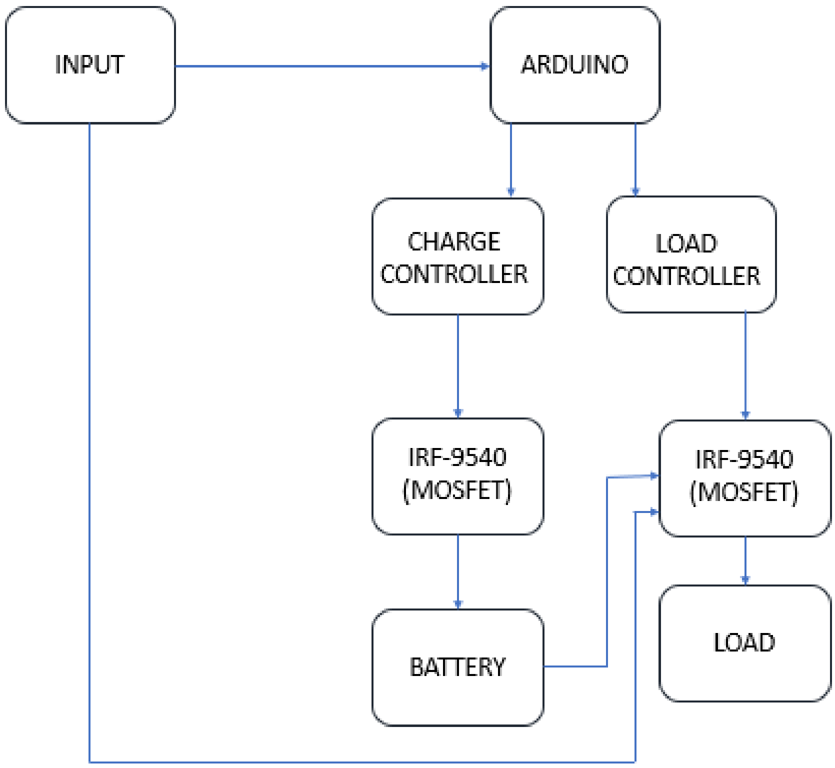


Figure: Charge Controller Circuit in Working Condition (as demonstrated)

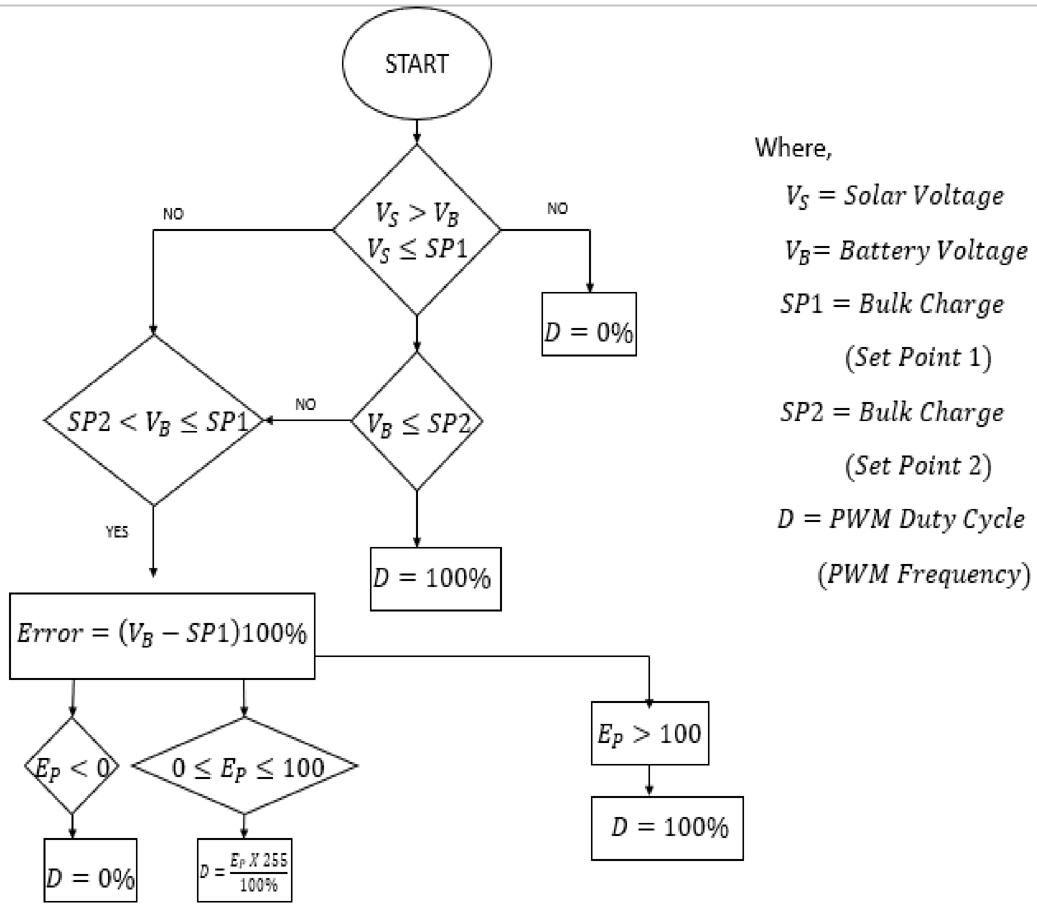


Figure: Working Algorithm in Charge Controller Circuit

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

A theoretical study of Piezoelectric Module integrated with Photovoltaic Solar Panel was presented. The parameter 'g' influences the behavior of the system was studied theoretically and the results were compared with the literature. The analytical study was done by developing a mathematical model for the governing equations of Piezoelectric and PV Solar Cell. The mathematical model was solved using an iterative scheme with the help of MATLAB® software. These results were verified with a finite element analysis of the membrane module using COMSOL®. The performance trends obtained were compared with the literature. Based on the results, we drew the following conclusions:

- The electric signal generated by Piezoelectric is fluctuating and depends on the amount of stresses induced on piezoelectric surface. The output of the piezoelectric is dependent on the repetitiveness of the stress being applied
- The electric signal from Solar Cell is constant in nature. Its output is dependent on the amount of sunlight available for Photovoltaic Panels. The quality of Solar Panel also plays and important role in quality of electric signal.
- Increasing the quality of Solar Panel results in increased output but the cost of the system increases accordingly.
- Increasing the material of Piezoelectric will affect its output and the cost of system will change accordingly. The choice of selection of material depends upon the availability of resources.
- The integration of two standalone systems is a crucial part of the project. The integrated output of system very much depends upon two systems.
- The two systems woks as a backup for each other in case of system failure. If one system shuts down in case of power failure, the other can produce output on its own.

Recommendations

Hybrid Green Energy Harvesting Carpets provides a clean solution to alternate energy production. It uses renewable resources to produce electricity. It is a onetime investment with relatively low maintenance cost. Since the resources required for the system are readily available, the installation to be done is relatively easier. For future work, following points are recommended:

- There is a need to promote and facilitate research in this field as it is relatively a new field of energy harnessing.

- The power producing capacity of the system is entirely dependent on investment available for system installations.
- Currently these systems are being used in couple of countries as separate energy production unit and there is a dire need to integrate the two-standalone systems.
- To make this technology more feasible and readily accessible for public use, the government investment and subsidies are required.

Our world is currently suffering from energy crisis and shortage of water. In the face of these circumstances, these hybridized energy production units driven by renewable energy resources like solar power and mechanical vibrations are sustainable alternatives to these energy and water crisis. Solar energy resources are present in abundance and it will decrease the harmful effects of traditional energy consumption on the environment. Moreover, harnessing the vibrational energy is relatively a new concept but it can be implemented successfully on road bumps as well. With further research and proper development of Piezoelectric and solar technologies, Integrated Solar Cell and Piezoelectric could become a valid course of action for solving future energy crisis.

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APPENDIX A-VARIABLES USED IN PIEZOELECTRIC EQUATIONS

T = Stress

S = Strain

E = Electric Field

D = Electric Displacement

e = Coupling matrix

C_E = Elasticity matrix

ε_S = Permittivity matrix

APPENDIX B-ARDUINO CODE UTILIZED FOR SOLAR ENRGY COLLECTION

```
const int solarvpin=A0;

const int pezovpin=A1;

double adconevolt=0.0048828125;

int solaradc;

int pezoadc;

float ratio=2.4;

double tsolarv=0.0;

double tpezov=0.0;

float svoltage=0.0;

float pvoltage=0.0;

const int relaypin=7;

void setup() {

Serial.begin(9600);

pinMode(solarvpin,INPUT);

pinMode(pezovpin,INPUT);

pinMode(relaypin,OUTPUT);

}


void loop() {

solaradc=analogRead(solarvpin);

pezoadc=analogRead(pezovpin);

tsolarv=solaradc*adconevolt;
```

```
tpezov=pezoadc*adconevolt;
svoltage=(ratio*tsolarv)-0.5;
pvoltage=(ratio*tpezov)-1;
Serial.println(pvoltage);
if(pvoltage <=10)
{
digitalWrite(relaypin,HIGH);
}
else
digitalWrite(relaypin,LOW);
}
```

APPENDIX C-ARDUINO CODE FOR COMPLETE CIRCUIT

```
#include <Wire.h>

#include <LiquidCrystal_I2C.h>

#define SOL_ADC A0     // Solar panel side voltage divider is connected to pin A0

#define BAT_ADC A1    // Battery side voltage divider is connected to pin A1

#define CURRENT_ADC A2  // ACS 712 current sensor is connected to pin A2

#define TEMP_ADC A3   // LM 35 Temperature is connected to pin A3

#define AVG_NUM 10    // number of iterations of the adc routine to average the adc readings

#define BAT_MIN 10  // minimum battery voltage for 12V system

#define BAT_MAX 15.0  // maximum battery voltage for 12V system

#define BULK_CH_SP 14.4 // bulk charge set point for sealed lead acid battery // flooded type set it to 14.6V

#define FLOAT_CH_SP 13.6  //float charge set point for lead acid battery

#define LVD 10         //Low voltage disconnect setting for a 12V system

#define PWM_PIN 3        // pin-3 is used to control the charging MOSFET //the default frequency is 490.20Hz

#define LOAD_PIN 2       // pin-2 is used to control the load

#define BAT_RED_LED 5

#define BAT_GREEN_LED 6

#define BAT_BLUE_LED 7

#define LOAD_RED_LED 8

#define LOAD_GREEN_LED 9

byte solar[8] = {0b11111,0b10101,0b11111,0b10101,0b11111,0b10101,0b11111,0b00000};///solar icon

byte battery[8] = {0b01110,0b11011,0b10001,0b10001,0b10001,0b10001,0b10001,0b11111}; //icon for battery

byte energy[8] = {0b00010,0b00100,0b01000,0b11111,0b00010,0b00100,0b01000,0b00000}; // icon for current
```

```
byte temp[8] =
{0b00100,0b01010,0b01010,0b01110,0b01110,0b11111,0b11111,0b01110};//icon for
termometer

byte charge[8] =
{0b01010,0b11111,0b10001,0b10001,0b10001,0b01110,0b00100,0b00100,};// icon for
battery charge

byte
not_charge[8]={0b00000,0b10001,0b01010,0b00100,0b01010,0b10001,0b00000,0b00000};

///////////////////////DECLARATION OF ALL GLOBAL VARIABLES//////////////////////

float solar_volt=0;

float bat_volt=0;

float load_current=0;

int temperature=0;

int temp_change=0;

float system_volt=0;

float bulk_charge_sp=0;

float float_charge_sp=0;

float charge_status=0;

float error=0;

float Ep=0;

int duty =0;

float lvd;

float msec=0;

float last_msec=0;

float elasped_msec=0;

float elasped_time=0;

float ampSecs = 0;

float ampHours=0;

float watts=0;

float wattSecs = 0;

float wattHours=0;

////////////////////////////////////////////////////////////////////////////////
```

```
LiquidCrystal_I2C lcd(0x27,20,4);  // Set the LCD I2C address
/////////////////////////
int ADC_OUTPUT;
double onevolt=0.0048828125;
double volt=0.0;
double mvolt;
float  tempF;
float  tempC;
/////////////////////////////
int sensitivity = 100; // use 100 for 20A Module and 66 for 30A Module
int offsetvoltage = 2500;
double Voltage = 0;
double ecurrent = 0;// Current measuring
double oneadc=4.8828125;
/////////////////////////////
void setup()
{
Serial.begin(9600);
pinMode(BAT_RED_LED,OUTPUT);
pinMode(BAT_GREEN_LED,OUTPUT);
pinMode(BAT_BLUE_LED,OUTPUT);
pinMode(LOAD_RED_LED ,OUTPUT);
pinMode(LOAD_GREEN_LED,OUTPUT);
pinMode(PWM_PIN,OUTPUT);
pinMode(LOAD_PIN,OUTPUT);
digitalWrite(PWM_PIN,LOW);  // default value of pwm duty cycle
digitalWrite(LOAD_PIN,LOW);  // default load state is OFF
lcd.begin();   //
lcd.backlight();
lcd.createChar(1,solar);
```

```
lcd.createChar(2, battery);
lcd.createChar(3, energy);
lcd.createChar(5,temp);
lcd.createChar(6,charge);
lcd.createChar(7,not_charge);
lcd.clear();
}
void loop()
{
 read_data();
 system_voltage();
 setpoint();
 charge_cycle();
 power();
 load_control();
 led_indication();
 lcd_display();
 }
 int read_adc(int adc_parameter)
{

  int sum = 0;
  int sample ;
  for (int i=0; i<AVG_NUM; i++)
  {                                  // loop through reading raw adc values AVG_NUM number of
times
    sample = analogRead(adc_parameter);    // read the input pin
    sum += sample;                        // store sum for averaging
    delayMicroseconds(50);              // pauses for 50 microseconds
  }
```

```
  return(sum / AVG_NUM);               // divide sum by AVG_NUM to get average and return
it

}

void read_data(void)

 {

   //5V = ADC value 1024 => 1 ADC value = (5/1024)Volt= 0.0048828Volt

   // Vout=Vin*R2/(R1+R2) => Vin = Vout*(R1+R2)/R2   R1=100 and R2=20

    solar_volt = read_adc(SOL_ADC)*0.00488*(120/20);

    bat_volt   = read_adc(BAT_ADC)*0.00488*(120/20);

    Voltage = (read_adc(CURRENT_ADC)*oneadc); // Gets you mV

    load_current = ((Voltage - offsetvoltage) / sensitivity);

    ADC_OUTPUT = analogRead(A3);

    volt=ADC_OUTPUT*onevolt;

    mvolt=volt*1000;

   tempF=mvolt/10;

   tempC=(tempF-32)*5/9;

   temperature = tempC;

}

void power(void)

{

msec = millis();

elasped_msec = msec - last_msec; //Calculate how long has past since last call of this
function

elasped_time = elasped_msec / 1000.0; // 1sec=1000 msec

watts = load_current * bat_volt; //Watts now

ampSecs = (load_current*elasped_time); //AmpSecs since last measurement

wattSecs = ampSecs * bat_volt; //WattSecs since last measurement

ampHours = ampHours + ampSecs/3600; // 1 hour=3600sec //Total ampHours since program
started

wattHours = wattHours + wattSecs/3600; // 1 hour=3600sec //Total wattHours since program
started
```

```
last_msec = msec; //Store 'now' for next time
}
void system_voltage(void)
{
  if ((bat_volt >BAT_MIN) && (bat_volt < BAT_MAX))
  {
     system_volt = 12;
  }
  else if ((bat_volt > BAT_MIN/2 ) && (bat_volt < BAT_MAX/2))
  {
    system_volt=6;
  }
}
void setpoint(void)
{
  temp_change =(temperature)-25.0; // 25deg cel is taken as standard room temperature
 // temperature compensation = -5mv/degC/Cell
  if(system_volt ==12)
  {
     bulk_charge_sp = BULK_CH_SP-(0.030*temp_change) ;
     float_charge_sp=FLOAT_CH_SP-(0.030*temp_change) ;
     lvd =LVD;
     Serial.println(lvd);


  }


  else if(system_volt ==6)
  {
     bulk_charge_sp = (BULK_CH_SP/2)-(0.015*temp_change) ;
     float_charge_sp= (FLOAT_CH_SP/2)-(0.015*temp_change) ;
```

```
    lvd=LVD/2;
  }
}
void charge_cycle(void)
{
  if (solar_volt > bat_volt && bat_volt <= (bulk_charge_sp+0.3))
  {


   if (bat_volt <= float_charge_sp) // charging start
  {
    charge_status = 1; // indicate the charger is in BULK mode
    duty= 252.45;
    analogWrite(PWM_PIN,duty); // 99 % duty cycle // rapid charging



  }
  else if (bat_volt >float_charge_sp && bat_volt <= bulk_charge_sp)
  {
     charge_status = 2; // indicate the charger is in FLOAT mode
     error  = (bulk_charge_sp - bat_volt);      // duty cycle reduced when the battery voltage
approaches the charge set point
     Ep= error *100 ; //Ep= error* Kp // Assume  Kp=100

     if(Ep < 0)
      {
       Ep=0;
       }
     else if(Ep>100)
       {
```

```
      Ep=100;
     }
   else if(Ep>0 && Ep <=100) // regulating
    {
      duty = (Ep*255)/100;
    }
    analogWrite(PWM_PIN,duty);
  }
 }
  else
  {
  charge_status=0;  // indicate the charger is OFF
  duty=0;
  analogWrite(PWM_PIN,duty);
  }
}
void load_control()
{
 digitalWrite(LOAD_PIN, HIGH); // load is ON
}
void led_indication(void)
{
 battery_led();          //Battery status led indication
 source_led();             //Load led indication
}
void battery_led(void)
{

  if( (bat_volt > system_volt) && ( bat_volt <bulk_charge_sp))
 {
```

```
      leds_off_all();
      digitalWrite(BAT_GREEN_LED,LOW);  // battery voltage is healthy
  }
  else if(bat_volt >= bulk_charge_sp)
  {
      leds_off_all();
      digitalWrite(BAT_BLUE_LED,LOW);  //battery is fully charged
  }
   else if(bat_volt < system_volt)
  {
      leds_off_all();
      digitalWrite(BAT_RED_LED,LOW);  // battery voltage low
  }
}
void source_led()
  {
    if(solar_volt >=5)
    {
      digitalWrite(LOAD_GREEN_LED,HIGH);
    }
    else
    {
      digitalWrite(LOAD_RED_LED,HIGH);
    }
   }
void leds_off_all(void)
{


  digitalWrite(BAT_RED_LED,HIGH);
  digitalWrite(BAT_GREEN_LED,HIGH);
```

```
  digitalWrite(BAT_BLUE_LED,HIGH);
  digitalWrite(LOAD_RED_LED, LOW);
  digitalWrite(LOAD_GREEN_LED, LOW);
}
void lcd_display()
{
 lcd.setCursor(0, 0);
 lcd.write(1);
 lcd.setCursor(2, 0);
 lcd.print(solar_volt);
 lcd.print("V");
 lcd.setCursor(14, 0);
 lcd.write(5);
 lcd.setCursor(16, 0);
 lcd.print(temperature);
 lcd.write(0b11011111);
 lcd.print("C");
 lcd.setCursor(0,1);
 lcd.write(2);
 lcd.setCursor(2, 1);
 lcd.print(bat_volt);
 lcd.print("V");
 lcd.setCursor(14, 1);
 lcd.write(2);
 if((charge_status==1) | (charge_status== 2))
 {
 lcd.write(6);
 }
 else
 {
```

```
 lcd.write(7);
 }
 lcd.setCursor(0,2);
 lcd.write(3);
 lcd.setCursor(2,2);
 lcd.print(load_current);
 lcd.print("A");
 lcd.setCursor(10,2);
 lcd.print("P ");
 lcd.print(watts);
 lcd.print("W");
 lcd.setCursor(0,3);
 lcd.print("Energy:");
 lcd.print(wattHours);
 lcd.print("WH");
}
```
