# Designing a Water-Cooling System with Thermoelectric Generators (TEG) to Enhance Solar Panel Efficiency and Extend Lifespan


By

Sowmitra Kumar Shacha

ID: 20321058

Md Mahamudul Haque Emon

ID: 16221049

Fahim Abrar

ID: 18321056

Mahmood Hasan Khan Sifat

ID: 19121068


A Final Year Design Project (FYDP) submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering


Electrical and Electronic Engineering
Brac University

May 2024

# Designing a Water-Cooling System with Thermoelectric Generators (TEG) to Enhance Solar Panel Efficiency and Extend Lifespan


By

Sowmitra Kumar Shacha

ID: 20321058

Md Mahamudul Haque Emon

ID: 16221049

Fahim Abrar

ID: 18321056

Mahmood Hasan Khan Sifat

ID: 19121068


A Final Year Design Project (FYDP) submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering

**Academic Technical Committee (ATC) Panel Member:**

Dr. A. S. Nazmul Huda (Chair)

Associate Professor, Department of EEE, BRAC University

Raihana Shams Islam Antara (Member)

Lecturer, Department of EEE, BRAC University


Electrical and Electronic Engineering
Brac University

May 2024

## Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

Student's Full Name & Signature:

| | |
|---|---|
| Sowmitra Kumar Shacha<br>20321058 | Md Mahamudul Haque Emon<br>16221049 |
| Fahim Abrar<br>18321056 | Mahmood Hasan Khan Sifat<br>19121068 |

## Approval

The Final Year Design Project (FYDP) titled "**Designing a Water-Cooling System with Thermoelectric Generators (TEG) to Enhance Solar Panel Efficiency and Extend Lifespan**" submitted by

1. Sowmitra Kumar Shacha (20321058)
2. Md Mahamudul Haque Emon (16221049)
3. Fahim Abrar (18321056)
4. Mahmood Hasan Khan Sifat (19121068)

Of Spring 2024 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering on 17th May 2024

**Examining Committee:**

| | |
|---|---|
| Academic Technical Committee (ATC): (Chair) | ____________________________<br>Dr. A. S. Nazmul Huda<br>Associate Professor, Department of EEE<br>BRAC University |
| Final Year Design Project Coordination Committee: (Chair) | ____________________________<br>Dr. Abu S. M. Mohsin<br>Associate Professor, Department of EEE<br>BRAC University |
| Department Chair: | ____________________________<br>Dr. Md. Mosaddequr Rahman<br>Professor & Chairperson, Department of EEE<br>BRAC University |

## Ethics Statement

This final year design project contains 18% plagiarism, maintaining the similarity index below 35%.

## Abstract/Executive Summary

In Bangladesh, where electricity demand is very high, our projects aim to enhance the lifespan and efficiency of our solar panels by cooling them off with a thermoelectric generator. The thermoelectric generator works when there is a cold and hot side. We are using this so that by harnessing the excess heat from the solar panel, we can make a cooler for the solar panel, which will help keep the panel's temperature in an acceptable range. By doing that, we can extend the panel's lifespan longer than average, and also, by cooling the solar panel, we can also get a small increase in efficiency, as we know that if the solar panel is too hot, it will lose its efficiency to produce electricity, so the solar panel needs to stay at an acceptable temperature range to utilize the sun fully to produce electricity. By collecting data at various intervals, we analyze parameters to compare the performance of our system over time. Our main goal is to raise awareness about the big potential of renewable energy sources, encouraging the widespread adaptation and acceptance of electricity generation. Through this initiative, we seek to empower individuals and also communities to prioritize renewable energy solutions, contribute to sustainable energy practices, and also address the pressing energy needs for Bangladesh.

**Keywords:** Renewable energy; thermoelectric generators (TEGs); excess heat; lifespan; efficiency.

## Acknowledgment

We want to thank the members of our ATC panel for their efforts and ongoing contributions. The Department of EEE at Brac University's amazing support made this presentation in front of such a large audience possible.

# Table of Contents

## List of Acronyms

| | |
|---|---|
| TEG | Thermoelectric generator |
| TEC | Thermoelectric cooler |
| PV | Photovoltaic |
| PCB | Printed circuit board |

# List of Tables

# List of Figures

# Chapter 1: Introduction [CO1, CO2, CO10]

## 1.1 Introduction

Throughout the year, day by day, we can see that the energy consumption rate is getting higher as we progress through the year. As we advance our technology, energy consumption will be at an all-time high to tackle this demand [1]. Furthermore, as we can see, the high usage of fossil fuels, depleted daily, is also a major problem for the environment and the energy sector, for which clean energy is much needed [2]. This high usage of non-renewable energy made us realize that we need renewable energy sources to improve ourselves further and get more cleanly free power [3]. For this reason, many nations have already started to invest in renewable energy sources for their growing population energy demand as fossil fuels are getting lower day by day, and also to not pollute the planet, they are moving to more abundant, accessible, clean renewable energy sources [4]. As we know, many nations are installing renewable energy facilities, so our country also needs to move forward by investing in the renewable sector and using this abundant free resource. Even though the renewable energy sector market is costly due to the use of complex components, people do not prefer it [4]. It is essential for us to identify the problems and make policies that will make us adopt and promote the use of renewable energy sources [5].

### 1.1.1 Problem statement

Bangladesh's population is now almost 173 million, as providing everyone with electricity has not yet been achieved. It was foreshadowed that by 2021, everyone will get electricity, which has not been achieved due to the pandemic in 2019. As for now, a change in the temperature, a war, and Europe's abrupt transition have put pressure on the energy market worldwide [6]. Bangladesh, as a developing nation, has experienced many setbacks and significant disruptions to the objectives of expanding its power-producing capacity and supplying electricity to all. As for now, the crisis of power has become a significant problem. We can see that every day, the production gap between supply and demand is increasing [7]. In the capital of Bangladesh, load shedding is a daily occurrence several times a day, and the rural area has its power cut for six to seven hours daily.

Moreover, almost all the power plants in our county are non-renewable, like coal and gas. So, we need to make plans to stop us from going into ruin. We cannot guarantee that there will be no occurrence of another pandemic or any other problem that will create a more significant energy crisis in the future. That is why we must take steps to prevent any occurrence that may come at us in the future. One of the best ways to get out of this problem is the proper use or utilization of renewable energy because it is low in pollution and has less risk [8]. This can solve Bangladesh's current power crisis. Thus, our project proposal is based on renewable energy called the hybrid photovoltaic-thermoelectric system. The hybrid photovoltaic-thermoelectric generation system will help us solve the energy crisis issue in our country by making every home an energy cell.

### 1.1.2 Background study

Conventional solar cells are silicon wafers, which have an efficiency of 6% when they are made for the first time. According to the NREL, modern cells can reach up to 25% efficiency [9]. In Bangladesh, the electricity supply is not enough; in fact, it's the lowest in the world, at 311 kWh in 2014 [10]. Until 2017, the total installed electricity generation was 15821 MW, and the demand was 9479 MW, but Bangladesh still faced a 1-billion-dollar loss for a power outage [11]. Many types of renewable energy can be used in Bangladesh, but due to its geographical location, solar energy is the most suitable [12]. The system that we will use, which is solar thermoelectric, has been a topic that has been significantly discussed, according to the author. TEG can change the thermal power directly into electrical energy without any issue; it paves the road to another use of the solar and also the waste heat, and if we place it directly behind the solar cell and use the heat of the solar, the efficiency will be 30% as a theoretical calculation [13]. According to another author, when he used the TEG system in a solar tank by modifying the condenser zone, the electricity generation went up to 36% [14]. The author of another paper said that based on the thermodynamic method, the productivity of the PV-TEG fusion system is 27% compared to the mono-Si PV. This paper also said that efficiency varies from country to country in Europe; the gain in efficiency is 14% by TEG [15]. It has also been found that the productivity of TEG is also subjective to the length and number of any thermocouples and by area [16]. Also, another author said that depending on the type of integration material, we can boost the efficiency of the hybrid system up to 8-23% [17].

The solar energy system in Bangladesh is not something new, but solar thermoelectric energy generation is a new concept in Bangladesh. Many people do not know about the Peltier module or what it can do, so if we can make them understand that solar thermoelectric systems can help them have more energy and also make the solar life expectancy high, we can grow exponentially. Also, the government needs to take the initiative to install these in their future solar system project.

### 1.1.3 Literature gap

The solar thermoelectric hybrid system was first developed in 1987, and it has been put under many efforts by researchers. Much research has been done on it, from the air chilling system and water chilling system to the heat pipe system for solar thermoelectric. From the Nano fluid-based water cooling, the solar thermoelectric performance improved by 49.5%. Another author found out that if the PV-TEG had a flat plate heat pipe, the performance would have a 1.47% increase compared to the one without a flat plate heat pipe [18]. Another author found that every time there's a 1K rise in the temperature, the efficiency declines by 0.11-0.45% [19]. Through our research, we have found out that countries like the USA, Spain, and UAE have invested in solar thermoelectric as they have very high solar irradiance, but it has been seen that it only consists of the industry level, not in the small consumer or household level. We could also see from our research that Asian countries like India and China have also invested in the solar thermoelectric field. This is the gap that we are working on to bring the level down to regular consumers, where a household can also benefit from the solar thermoelectric system.

Our project will help them understand that this upgrade will be a better future. We have designed and identified so that our project can enable us to help create a better community and help the energy sector.

### 1.1.4 Relevance to current and future Industry

To meet the rising demand for power, Bangladesh had set its goal to give people electricity by 2021 [20]. Bangladesh has the ideal geological aspect to utilize solar energy as a leading renewable energy generation. We can make use of it in any rooftop buildings or market areas. As we know, the largest revenue-generating industry in Bangladesh is the garments industry. As these factories have huge amounts of electricity traffic, we can have our solar thermoelectric on the rooftops of these factories to make themselves sustainable and help create an impression in foreign countries that we have started to go green. This will help us make great deals as they search for items that were made without harming the environment. By doing this, we hope that we can widespread the use of solar thermoelectric systems, which will create a better future for us.

But the challenging part will be the implementation part because of the low income, education, and customer satisfaction rate in Bangladesh [21]. As we know, Bangladesh's per capita income is low compared to other countries, so not all people wish to use the solar system. Another problem is the use of solar energy, as they do not tend to take care of it, so it becomes a burden as time passes. So, to ensure this problem does not occur, we need to let people know about it and also show them the benefits it will bring to the country people. The foreseeable future will be the connection of the grid, as it will also help them bring down the cost of electricity. Not only that, but the country will also benefit from the extra energy it will have from the solar thermoelectric system.

## 1.2 Objectives, requirements, specifications, and constant

### 1.2.1. Objectives

- Improve the efficiency of the solar panel and increase its lifespan with the help of the Peltier module.
- Solar tracking is used to monitor the position of the sun and get maximum radiant energy.
- Use renewable energy to avoid any harm to nature and raise awareness so that people can choose sustainable energy.

### 1.2.2 Functional and non-functional requirements

**Functional requirements**

- The solar tracking system is used to track the position of the sun. The system used here is used to operate in a single axis.
- The aluminum on the water block attached below the solar cell absorbs heat from the solar cell and a motor is used to pump the water down to TEG water block.
- The four modules of TEG attached to the TEG water block cool the water entering it and pass it back to the water block.
- The heat sink absorbs heat and passes it away from the system by a cooling fan.
- INA 219 sensor is used to measure the voltage and current of the system.

**Non-functional requirements**

- An area where enough sunlight is available and make sure that there is no obstacles besides the solar tracking.
- The system is able to withstand bad weather.
- This doesn't by any extend harm the environment.
- The INA 219 sensor is used to measure the voltage and current of the system.

### 1.2.2 Specifications

Table 1.1: Component level specifications

| ***Segment*** | ***Component's Name*** | ***Description/Specification*** | ***Qty.*** |
|---|---|---|---|
| Photovoltaic | Solar Panel Module | Dimension: 402*355*255mm Maximum power: 15W Open Circuit Voltage: 21.22V Short Circuit Current: 0.94A Module Mass: 1.2kg | 1 |
| Thermoelectric | Thermoelectric Cooler Module | Peltier Plate Module Model: TEC1 - 12715 Voltage: 12V | 4 |
| | Water Cooling Block | Material: Aluminum Dimension: 160mm*40mm*12mm | 1 |
| | Heatsink | Material: Aluminum Dimension: 40mm*40mm*8mm | 4 |
| | Water Pump | Mini Water Pump Operating Voltage: 12VDC | 1 |
| | Blower Fan | Operating Voltage: 12VDC Speed: 1000RPM | 2 |

| | | | |
|---|---|---|---|
| Electronics | Relay Module | 8CH Relay Module | 1 |
| | Solar Tracking Module | LDR with wiring | 1 |
| | Aluminum Extrusion Profile | Dimension: 20mm*20mm Total Length: 2460mm | 2460 |
| Structural and Framing | T-slotted Framing Corner Gusset | Dimension: Standard | 10 |
| | Flanged Bearing | OD 22mm; ID 8mm | 2 |
| | SS Solid Shaft | Dia. 8mm, Length 360mm | 1 |
| | Transparent Panel | 5mm Clear Acrylic Sheet | 1 |
| | Aluminum Water Block | Dimension: 344mm*297mm*5mm | 1 |
| | 3D Printed Support Parts | Dimension: As per design requirements | 300 |
| Electro-Mechanical | Linear Actuator | Stroke: 150mm Speed: 12mm/s Push Load: 1000N Operating Voltage: 12VDC | 1 |
| Fastening and Accessories | Black Oxide Hex Drive Set | M6 15mm SHC Screw | 4 |
| | | M6 25mm SHC Screw | 1 |
| | | M6 Standard Lock Nut | 5 |
| | | M5 10mm SHC Screw | 16 |
| | | M5 Standard Hex Nut | 4 |
| | | M4 8mm Button Head Screw (water block) | 64 |
| | | M4 40mm SHC Screw (fan mount) | 4 |
| | | M4 15mm SHC Screw (TEG mount) | 7 |
| | | M4 10mm SHC Screw with hex nuts | 4 |
| | Open Loop Rubber Gasket | Dia. 1.5mm, Length: 1890mm, Black | 1 |
| | Water Reservoir | Clear View Panels Water Reservoir | 1 |
| | Clear Tube | Dia. 10mm, Length: 10ft | 10 |
| | Push Fit Connector | 5/8"- 10mm, Brass | 2 |
| | Drop-in T-slot Nuts | Dimension: M5 | 6 |
| | Heat Set Brass Insert | Dimension: M4<br>Dimension: M5 | 6 |

### 1.2.3 Technical and non-technical considerations and constraints in the design process

**Technical constraints**

- Make sure that the water block is well attached to the solar panel.
- The water pump must be capable of pumping the water down to the TEG water block. If the water does not reach the TEG water block, the system will fail.
- The water pipe should have a perfect diameter to flow the water smoothly.
- The TEG must be able to cool the water entering it so that it can go back to the water block attached to the solar panel and cool the solar panel in case of excess heat.
- Our system must be able to remove the heat absorbed by the heat sink, and a cooling fan is used to remove it more efficiently.

**Non-technical constraints**

- A solar panel should be planted in a place where there is a greater chance of getting the sun light properly.
- Make sure that the solar tracker is perfectly aligned with the sun.
- There is a lack of availability of skilled professionals in renewable energy. Therefore, mixing normal problems sometimes can be a hassle.
- Maximum people in Bangladesh are unaware of the importance of using green energy to produce electricity.

### 1.2.4 Applicable compliance, standards, and codes

Table 1.2: Applicable standards and codes for different required devices for the system

| ***Device*** | ***Standard*** | ***Definition*** |
|---|---|---|
| Solar Module | IEC 61215 | Guidelines for terrestrial photovoltaic (PV) modules created from crystalline silicon:<br>● Specifies design qualifications and type approval<br>● Ensures compliance with construction standards<br>● Sets requirements for testing procedures<br>● Ensures performance standards are met<br>● Focuses on crystalline silicon technology for terrestrial PV modules |

| | | |
|---|---|---|
| | IEC 61730 | Safety qualification standards for PV modules:<br>● Addresses construction and testing requirements<br>● emphasizes electrical safety and fire safety measures<br>● Ensures compliance across different environmental conditions |
| | IEEE 1547 | Standard for interconnection and interoperability between utility electric power systems (EPS) and distributed energy resources (DER):<br>● Establishes criteria and requirements<br>● Focuses on integration with solar PV systems<br>● Addresses system integration challenges<br>● Ensures power quality standards are met |
| | IEC 62109 | Safety standards for power converters in photovoltaic power systems:<br>● Specifies safety requirements for inverters and power processing units<br>● Ensures compliance with safety standards<br>● Addresses potential hazards associated with power conversion<br>● Focuses on maintaining safety within photovoltaic systems |
| | IEC 61853 | Series of standards for performance measurement of PV modules:<br>● Covers various climatic conditions<br>● Facilitates evaluation and prediction of module performance<br>● Aids in assessing performance over operational lifetime<br>● Provides standardized methods for accurate measurement |
| | IEEE 1562 | Guide for battery selection and evaluation in photovoltaic (PV) systems:<br>● Offers an approach for selecting appropriate batteries<br>● Relevant for overall PV system design and operation<br>● Considers factors such as module performance and system integration.<br>● Provides guidance for optimizing PV system performance and reliability. |

| | | |
|---|---|---|
| DC Wiring | IEC 60227 | Rigid and flexible cables with insulation and sheath, if any, based on polyvinyl chloride |
| | IEC 60502 | Construction, dimensions, and test requirements of power cables with extruded solid insulation |

## 1.3 Summary of the proposed project

Our project adjusts to a green and clean source of energy, which is solar energy, as it has the most prominent use in Bangladesh. We are trying to put the concept of using solar thermoelectric to use to attract the stakeholders to use the solar thermoelectric as a power generation method. As we know, power demand has been skyrocketing. People want to have a constant supply of power these days, so our project will help them obtain that goal, and if we can grid-connect it, we can also help our country to lessen the energy consumption. Moreover, the major advantage of solar thermoelectric is that it can make houses self-powered, so you don't have to take power from the national energy grid; you can produce your own power in your home. As it is a very new concept in our country, many people are not familiarized with the solar thermoelectric system. Thus, we have to promote the usefulness of solar thermoelectric and progress the renewable energy sector.

The main purpose of our project is to make people reliant on the thermoelectric renewable system in a feasible way. To achieve this, we are designing our own solar thermoelectric system.

## 1.4 Conclusion

In a country like Bangladesh, where the per capita is very low compared to other countries, individual solar thermoelectric integration is not promising. We also need to think that a basic solar thermoelectric system will not provide all types of consumers; for that, it becomes so challenging to widespread it.

The government also needs to tend to other alternative innovations in the process of designee stage and make policies in order to integrate the system into the grid. As the solar thermoelectric system is in the starting process, the government needs to take these things into account that it will help in the improvement of the energy sector. For Bangladesh, which will be an eco-friendly approach towards the people and country, and it will further speed up the process of the Bangladesh digitalization process for a better future.

# Chapter 2: Project design approach [CO5, CO6]

## 2.1 Introduction

Generating electricity effectively and efficiently from renewable sources is a worldwide demand, and for the case of Bangladesh, it is something that needs to be dealt with great care. In this project, we have combined several sources together to generate electricity, which is usually known as a hybrid system. The primary objective of this project is to study several hybrid systems and find out which one gives the best yield and is environmentally friendly. There are three hybrid systems we have considered for this project. The first hybrid system is photovoltaic-thermoelectric, where photovoltaic generates electricity from solar energy and thermoelectric uses the waste heat. The second method is a hybrid wind turbine with solar power system. Here, wind turbines take energy from the wind, whereas solar panels use solar energy to generate electricity. Lastly, the hybrid system that we have considered is a piezoelectric sensor plate with a solar power system, were piezoelectric converts mechanical energy into electrical energy.

## 2.2 Identify multiple design approaches

### 2.2.1 Design approach 1: Hybrid photovoltaic-thermoelectric system.

A photovoltaic system converts the solar heat energy from the sun to generate electricity, and solar tracking is used with it to get the maximum solar energy from the sun. On the other hand, thermoelectric generators use the waste heat to generate electricity, and thermoelectric coolers are used to cool down the solar cell to expand the lifespan of solar cell.

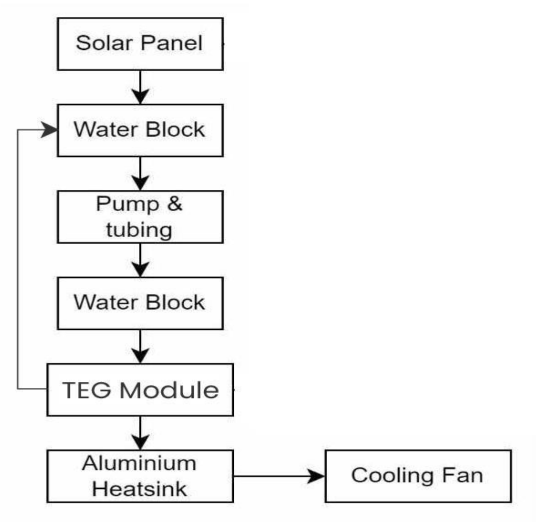



Fig 2.1: Block diagram of hybrid photovoltaic-thermoelectric System

### 2.2.2 Design approach 2: Hybrid wind turbine with solar power system

Wind turbines basically convert the wind energy into electricity, and solar panels use solar energy to produce electricity. By combining the output together, we can harvest more electricity than an individual system can generate.

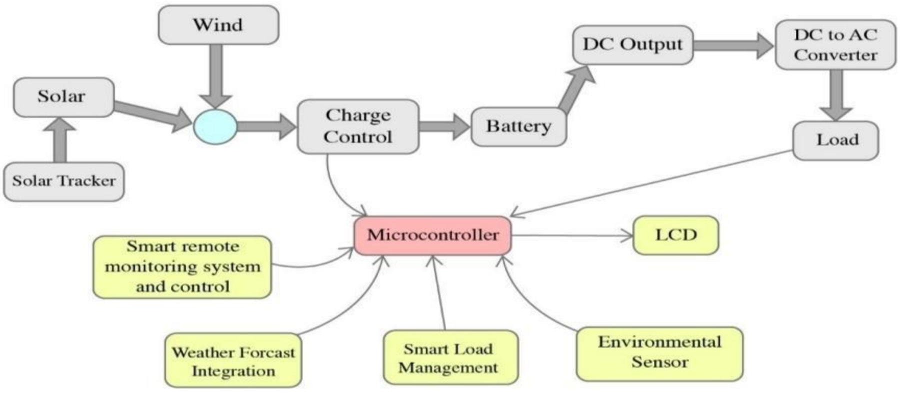



Fig 2.2: Block diagram of hybrid wind turbine with solar power system.

### 2.2.3 Design approach 3: hybrid piezoelectric sensor plate with solar power system

Same as the previous, a solar panel converts solar energy into electrical energy, whereas a piezo converts mechanical energy into electrical energy. Here a piezosensor is set up on the floor so that when a person walks on the floor, the sensor can sense the pressure exerted from the foot of that person and can convert it into electrical energy. Therefore, combining both systems increases the production of electricity as a whole.

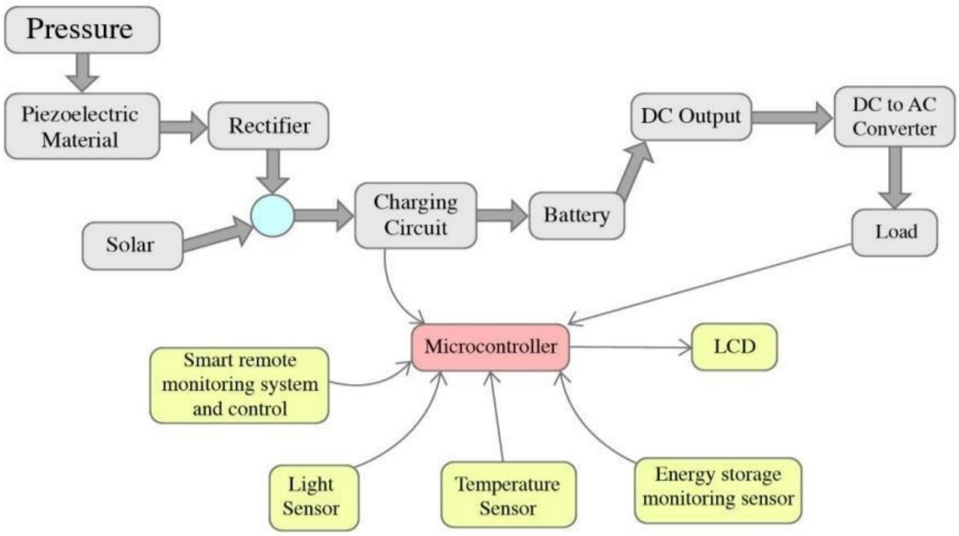



Fig 2.3: Block diagram of hybrid piezoelectric sensor plate with solar power system.

### 2.3 Describe multiple design approach

#### 2.3.1 Design approach 1: Hybrid photovoltaic-thermoelectric system

Solar cells generate electricity by converting sunlight into direct current (DC) electricity through the photovoltaic effect. When sunlight hits the semiconductor material in the solar cells, it creates an electric current. Solar tracking is also used to get the maximum amount of solar energy all the time. On the other hand, thermoelectric generators (TEGs) convert heat energy into electrical power. They utilize the setback effect, where a temperature difference across a semiconductor material generates voltage. Here TEC is also used to cool the solar cells in case of high temperature. PV-TEG hybrid systems can be established to form a dual-channel power generation, which will help promote the overall energy conversion efficiency [22].

Here solar takes energy from the sun, which is monitored by MPPT, then the voltage is boosted by a boost converter and passes it to the load. It is also used to charge the battery. Voltage across the load and reference voltage is compared and depending on these battery charges and discharges. For the positive signal, the battery charges, and for the negative signal, the battery discharges. TEG is monitored by MPPT, and the voltage is boosted by a boost converter and passed to the load. On the other hand, TEC is used to cool the temperature of solar to increase its lifetime and maintain the desired efficiency.

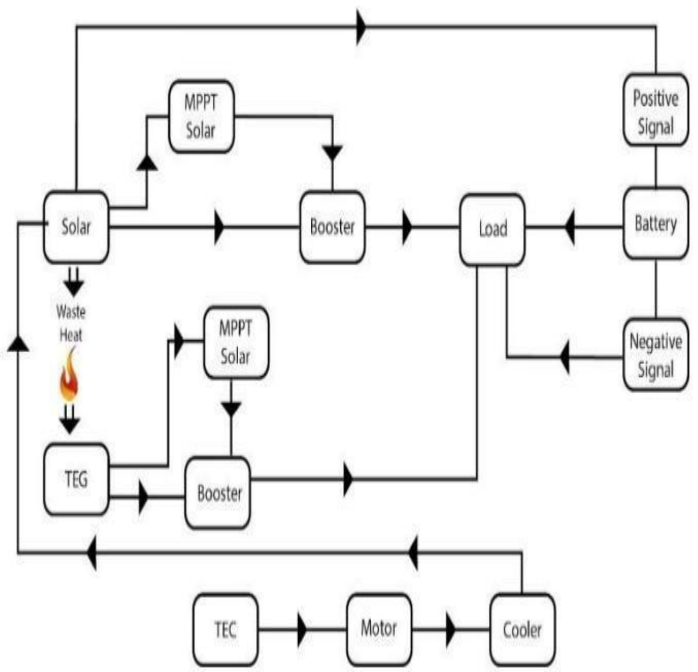



Fig 2.4: Flowchart of a hybrid photovoltaic-thermoelectric system

### 2.3.2 Design approach 2: Hybrid wind turbine with solar power system

Man needs energy to do his daily needs nowadays, but the demand is not met to do his things, so by getting renewable power, one can get extra energy from nature. In our solar wind power generation, power is harvested from both solar and wind. After that, it goes into the charge controller, then it will go into the battery for energy storage. It also goes to the microcontroller from the charge controller. After getting into the battery, we can directly use it into a DC load or use a DC to AC converter to go into a load, and all these will go into the microcontroller as it is our main control system [23] [24]. The signal now goes from the microcontroller to the LCD. We can integrate a smart remote monitoring system and control to see from the phone the conditions of our system, like generation of power, humidity, and weather forecast. The weather forecast can be gained from weather forecasting integration. We can also use environmental sensors to record humidity, wind power, etc. We can integrate a smart load management system into this so that it can optimize energy utilization and enhance efficiency and reliability of the system. We can also gain some benefit from this system, such as improved energy efficiency, because smart load management optimizes the use of energy generated from both solar and wind sources. It will also give us energy cost savings by intelligently controlling when and how energy is used so that we can reduce peak demand. It also reduces the use of fossil fuels, as enhanced energy efficiency means less reliance on fossil fuels. Furthermore, the enhanced user control allows the user to actively participate in managing their energy consumption to make informed decisions. This also gives us environmental benefits as it uses renewable energy to give us the power we need to reduce the CO2 emissions.

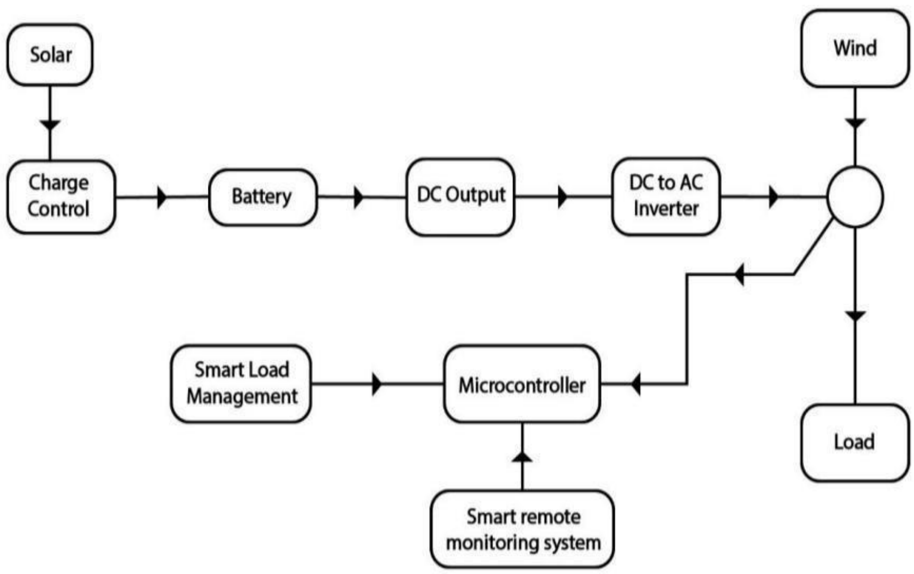



Fig 2.5: Flowchart of a hybrid wind turbine with solar power system

### 2.3.3 Design approach 3: Hybrid piezoelectric sensor plate with solar power system

In the modern day, power is a very essential need for daily activity. As the non-renewable fuels are getting low, we move to cleaner energy. So, we came to our project, which is solar and Piezo. So piezo is a popular harvesting energy method. The material of PZT is zirconium [22]. Piezo is a device that generates electricity when force is applied to it, or it deforms when voltage is supplied. This is called the piezoelectric effect. When mechanical stress is applied, it generates electric charge. It can be seen that the piezoelectric element produces AC power, which has both positive and negative values. So, to convert this, we need an AC to DC rectifier [22], then it goes to the charging circuit, then into the battery. In one of the studies of paper for piezo, which is from the University of Jordan, they conducted a study where they found that an average weight of 55 kg man can produce 0.045 W per step. So, depending on people's weight and height, different values can be produced. They also made a calculation assuming the daily need of power is 1000 for the University of Jordan, which has 18318 student entries and on average needs 1214 tiles to generate this power [23]. Now we come to the solar cell. Solar technology produces electricity by converting sunlight through the photovoltaic (PV) panels. The PV cells on the solar panel turn the sunlight into DC electricity by making it go through the inverter; it makes the DC current into AC to directly use. In our case, we supply the DC into the battery for storing.

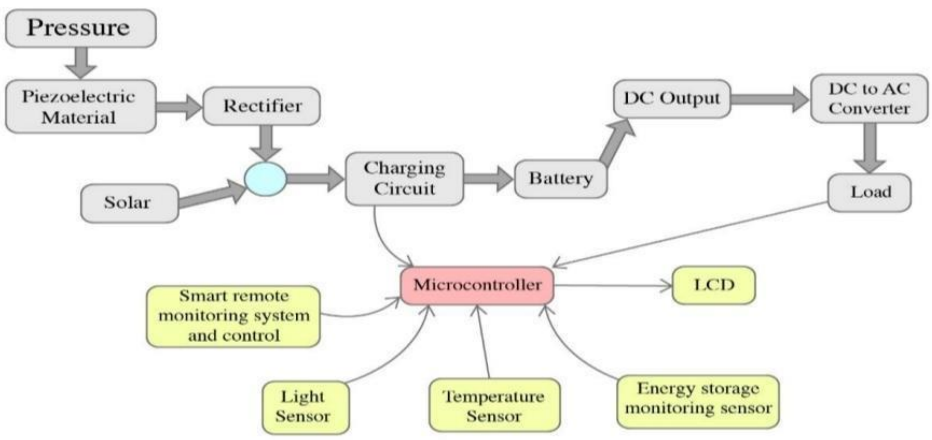



Fig 2.6: Flowchart of a hybrid piezoelectric sensor plate with solar power system

## 2.4 Analysis of multiple design approach

Table 2.1: Analysis of multiple design approaches

| Category | Design Approach 1 | Design Approach 2 | Design Approach 3 |
|---|---|---|---|
| Implementation | Can be implemented anywhere, like a rooftop off an office building, any house building, or a roadside where sunlight is present. | Can only be implemented where there is sufficient wind flow to rotate the wind turbine. | Can be implemented in any office building or footpath with a large number of people walking. |
| Maintenance | Needs professional knowledge for maintenance. | Needs trained professionals for maintenance. | Needs minimal maintenance. |
| Installation | Easy to install. | Needs high knowledge for installing this hybrid system. | Also needs high knowledge for installing this hybrid system. |
| Cost | Approximately 15,000 BDT. | Approximately 24,470 BDT. | Approximately 22,740 BDT. |
| Operational Lifetime | TEC is used to cool the solar cell in case of high temperature, which then increases its lifetime. | There is no medium that can affect the solar cell's operational lifetime. | There is no medium that can affect the solar cell's operational lifetime. |
| Efficiency | The efficiency of Solar is 20%, whereas the efficiency of TEG is 5–15%. | The efficiency of solar is 20% and wind turbines is 14%. | The efficiency of solar is 20%, but the piezo efficiency varies. |

## 2.5 Conclusion

The three different hybrid approaches are presented over here. For each hybrid system, its component and system level are properly explained, and an analysis is drawn based on the output. It is seen that the cost for Design Approach 1 is minimum, and its efficiency is greater. Its operational lifetime is also longer than the other two, as TEG is used to cool down the solar cell in case of extreme heat. For Design Approach 3, it requires minimum maintenance, which adds an advantage in maintenance cost. For Design Approach 2, its efficiency is higher than the other two. Hence, hybrid power systems using renewable energy can be a way to generate electricity effectively and efficiently.

## Chapter 3: Use of modern engineering and IT tool [CO9]

### 3.1 Introduction

Our project is based on generating power using a hybrid source. This includes solar cells, TEG, wind turbines, and piezoelectric. For solar cells, certain parameters need to be considered, and this is done using Matlab Simulink. These parameters include solar irradiance data and information on the preferred PV panels. For wind turbines, we have also used Simulink, and lastly, for piezoelectric, we have used Proteus. Other software that we have used for specific functions is Blender and Matlab. Blender is used to create 3D pictures, whereas some code is done by using Matlab. There was some block that wasn't present in default mode, and hence we have customized some blocks on Simulink.

### 3.2 Select appropriate engineering and IT tools

Blender: Blender is an open-source, free 3D creation software that supports all aspects of the 3D pipeline, including video editing and game development, modeling, rigging, animation, simulation, rendering, composing, and motion tracking. Expert users use Blender's Python scripting API to modify the program and create customized tools. 3D design is needed to see how the hardware would look. If implemented as we think, it helps us visualize what we are making by making a 3D model of our project.

Proteus: A proprietary software tool package called the Proteus Design package is mostly used for electronic design automation (EDA). Electronic design experts and technicians use Programmed primarily to develop electronic prints and schematics for printed circuit board (PCB) manufacture. The platform's clever principal arrangement, which guarantees effective circuit design, is one of its main features. It also includes accurate analysis and hybrid circuit simulation, which let designers properly forecast how their circuits will behave before they are constructed. Proteus further facilitates co-simulation of peripheral circuits and single-chip software debugging. Designers can create and test their software designs using Proteus software, comparing the simulation results to achieve the desired results. A wide variety of widely used single-chip models as well as generic peripheral models are compatible with Proteus, providing the designer with a great deal of flexibility. Its frame-and animation-based dynamic simulation capabilities offer superb visual effects that satisfy contemporary design specifications. Furthermore, the program facilitates the integration of diverse sensors into simulation designs, thereby augmenting the simulation process's efficacy and efficiency.

MATLAB: A programming environment called MATLAB was created especially for scientists and engineers to study and create products and systems that change the world. The Matlab language, a matrix-based language that enables the most natural expression of computer mathematics, lies at the core of MATLAB. With the use of Simulink's robust analysis and visualization capabilities, designers can better comprehend how their systems behave. It also provides strong optimization methods that let designers maximize the performance of their systems based on a variety of factors. The platform's flexibility and usefulness are further enhanced by its large library of pre-built models, which comprise common components, algorithms, and interfaces. Custom libraries can also be integrated with Simulink, giving designers the ability to construct models that are tailored to their own requirements. In conclusion, MATLAB Simulink is a strong and adaptable modeling and simulation platform that gives designers a variety of tools to build complicated systems. It is an essential tool for contemporary engineering design due to its multi-domain support, wide range of analysis and visualization tools, and capacity to produce embedded system-optimized code.

### 3.3 Use of modern engineering and IT tools

**MATLAB Simulink**

MATLAB Simulink is used to analyze the solar panel that we have used in this project. Here is the block diagram of the solar panel, which is used in the MATLAB software.

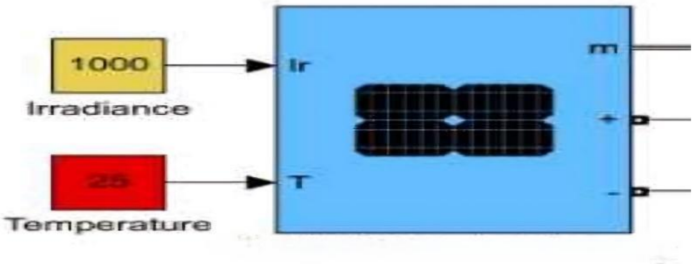



Fig 3.1: Block diagram of the solar panel.

Here we can see that there is an irradiance and temperature block on the left side of the solar panel block. Irradiance is the measure of the solar energy coming from the sun, and an ideal temperature of 25 °C is set.

The parameters of the solar panel are as follows:

The model that we have used is user-defined. Here, the current and voltage depend on the number of series and parallel strings on the solar panel. Voltage depends on the series strings, whereas current depends on the parallel strings.

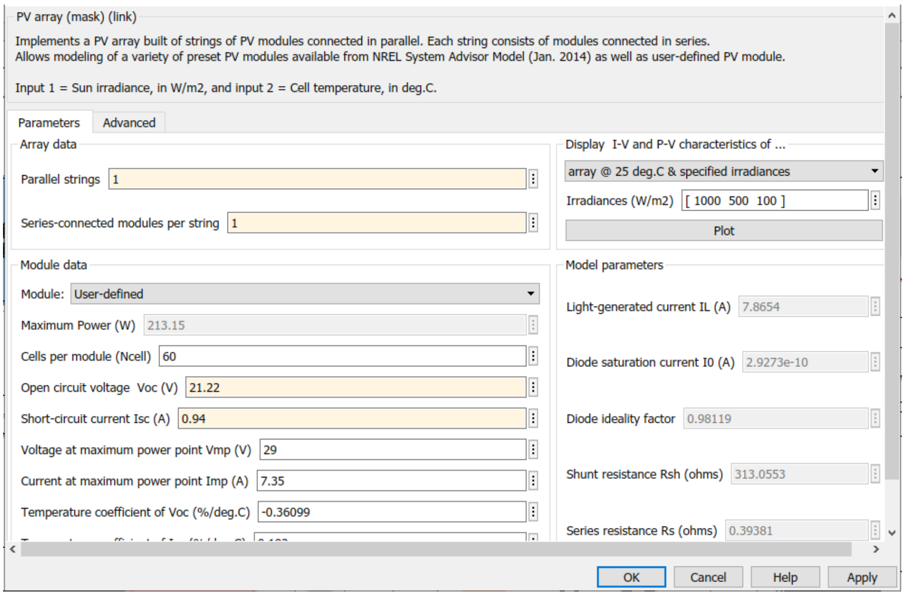



Fig 3.2: Parameters of the solar panel

For TEG, the block diagram bellow is as follows:

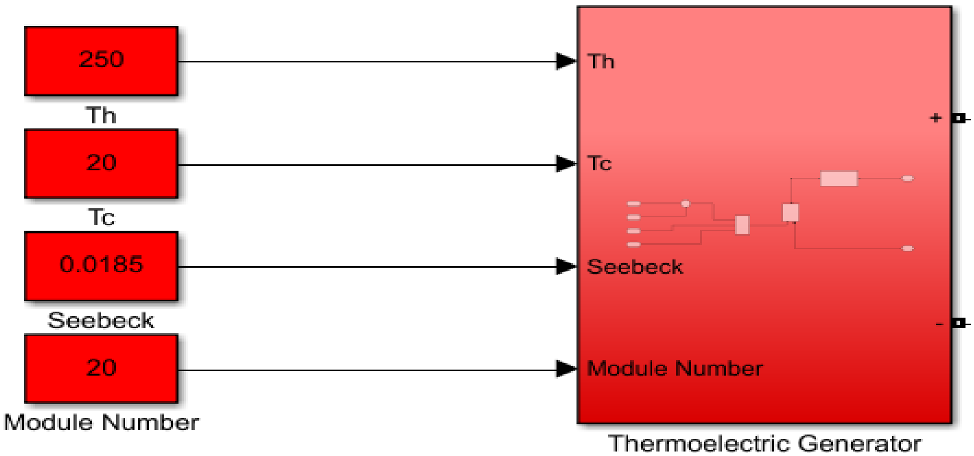



Fig 3.3: Block diagram of TEG

Here, this Th value is fixed as it is provided by the manufacturer, and the Tc value is 20, which is considered to be an ideal value. The number of modules that are used is also mentioned.

**Blender**

This is used to visualize what the project might look like in 3D after it is completed. The 3D model of different approaches is given below.

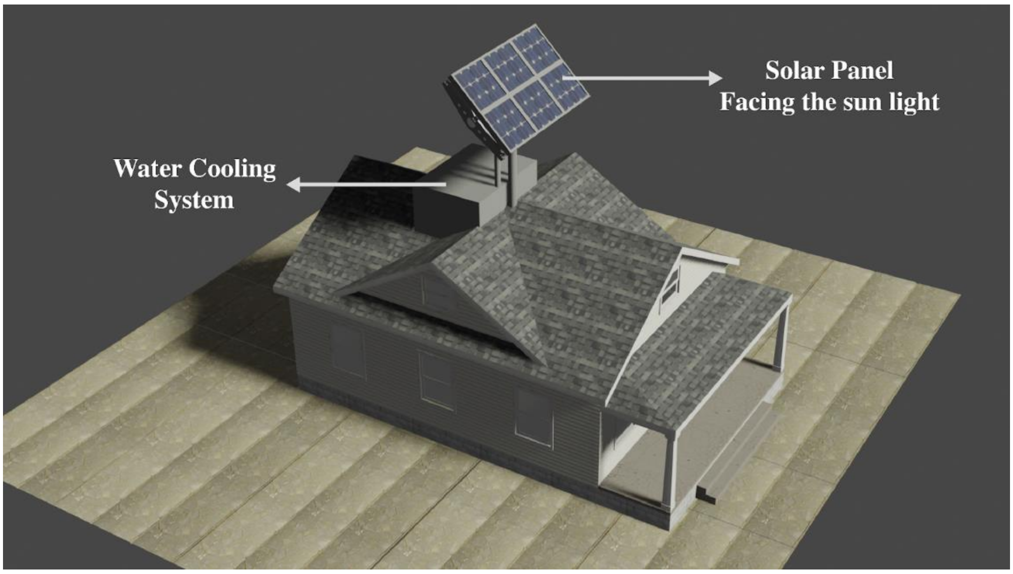



Fig 3.4: 3D model hybrid PV-TEG system

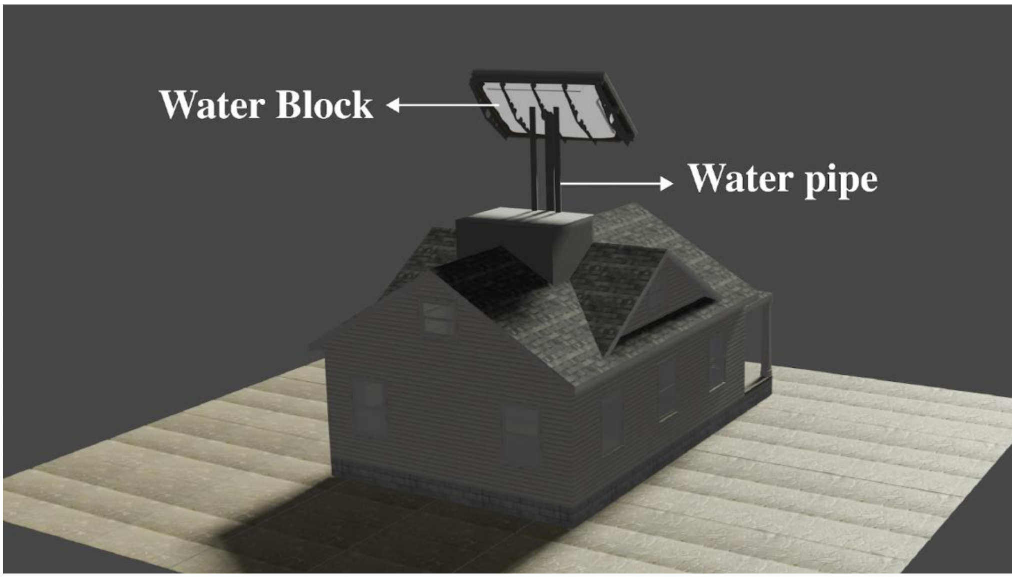



Fig 3.5: 3D model of hybrid PV-TEG system (water-cooling section)

Here we tried to show how our photovoltaic panel will face the sun and generate electricity. By doing this, it will reach a high temperature, which can decrease its efficiency. Therefore, on the back side, there is a water-cooling system.

**Parameters:**

To light up the objects we made, we used sun lighting on Blender with the color white, strength 5, diffuse 1, specular 1, and volume 1. We used a camera with a 55mm lens, which was perspective type.

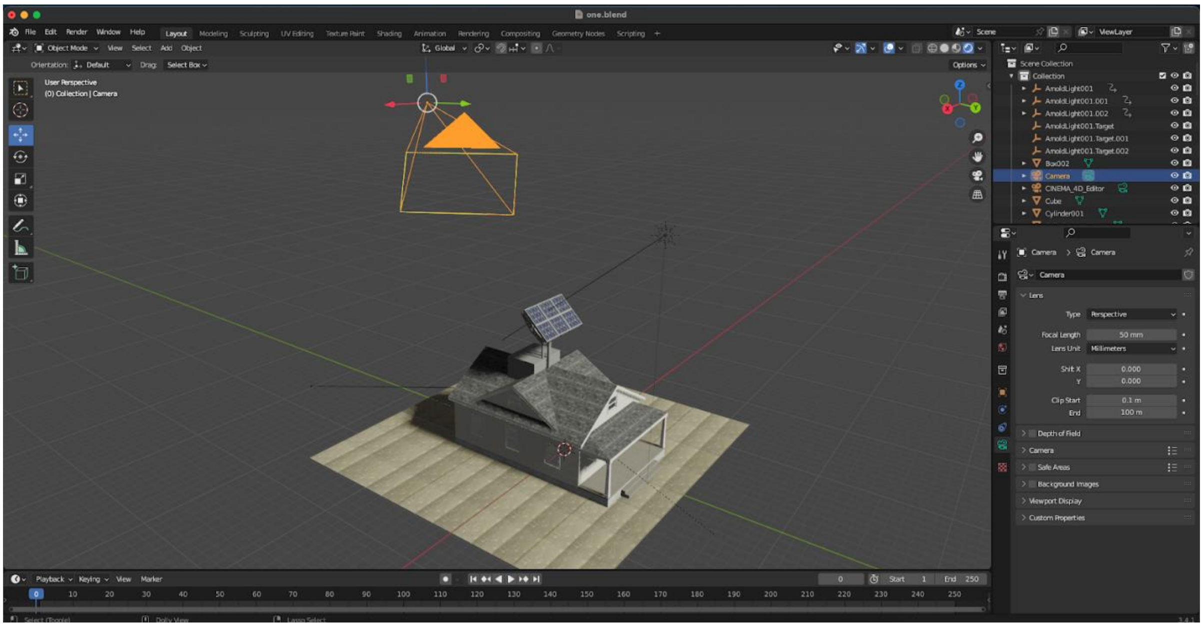


Fig 3.6: 3D model of parameters (hybrid PV-TEG System)

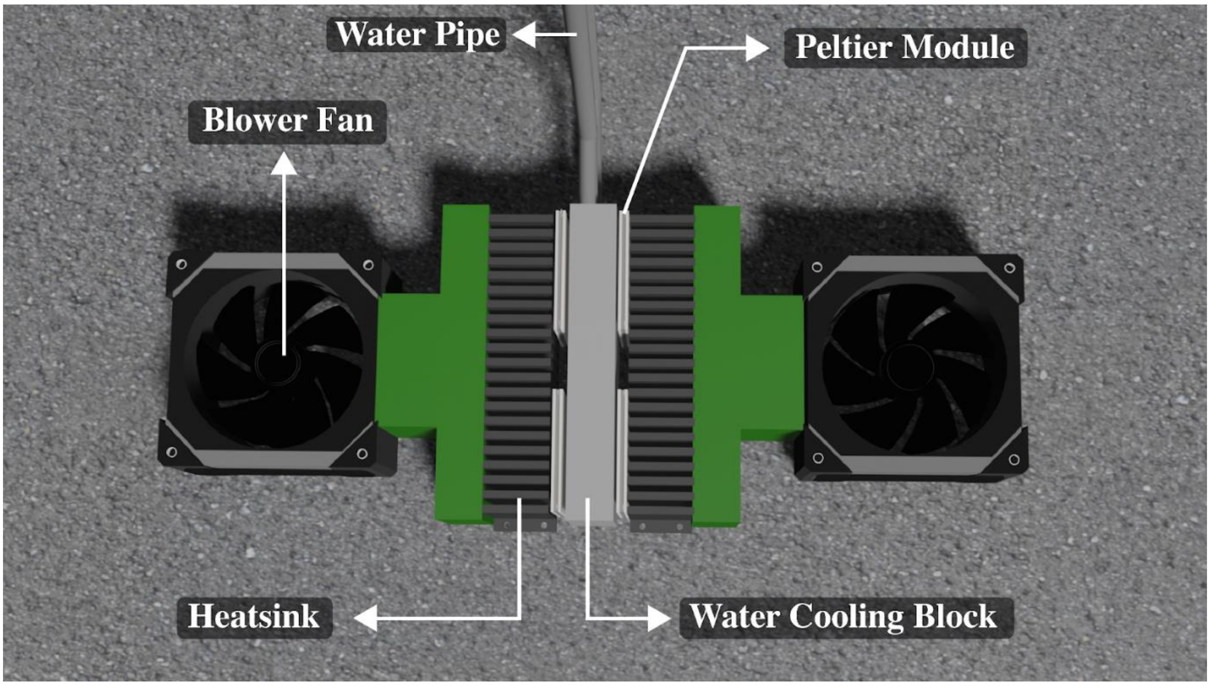



Fig 3.7: 3D model of components (water-cooling block)

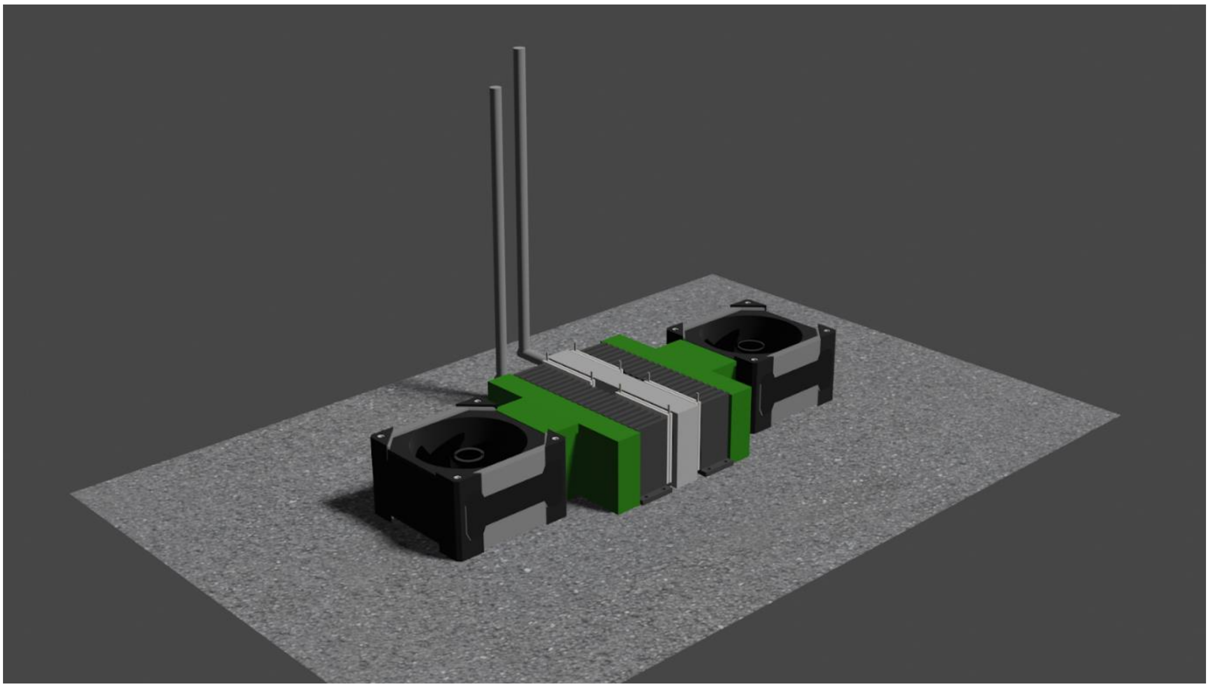


Fig 3.8: 3D model of water-cooling block

Here, we tried to show how the warm water, which will absorb heat from the photovoltaic panel, will cool down. The water will go through an aluminum water block, and 4 TEG modules outside of the water block will make the water block cool, which will ultimately reduce the water temperature. During this process, the other side of the TEG module will generate heat, the heatsink will absorb that heat, and the blower fan will blow it out into the air.

**Proteus**

The software Proteus was used for the solar piezo simulation.

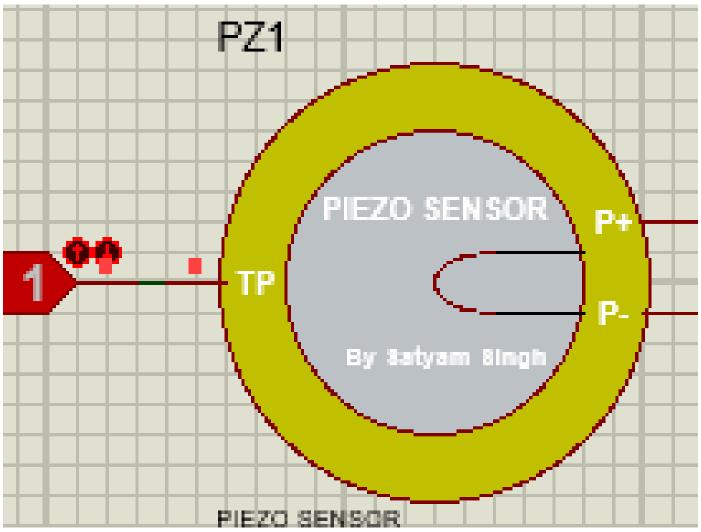



Fig 3.9: Proteus block of Piezo sensor

This block was custom made to be used in proteus. The piezo device, which we found through research, as these block diagrams are custom made and cannot be found inside the proteus tools library, so we used this for our simulation.

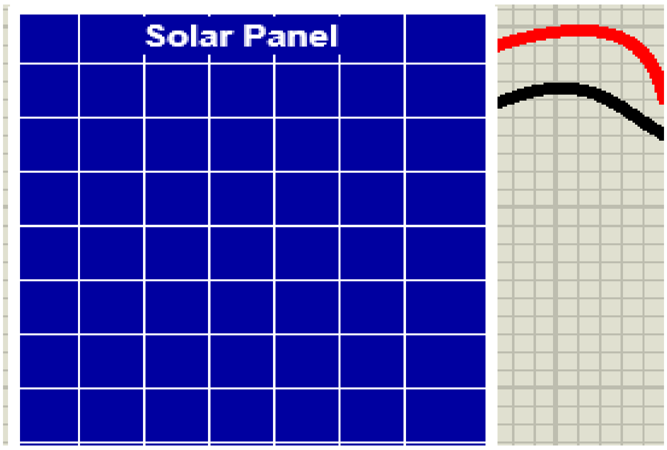



Fig 3.10: Proteus block of the solar panel

This solar panel is also a custom-made block, as we cannot find these in the proteus directory. We use this solar panel for our simulation.

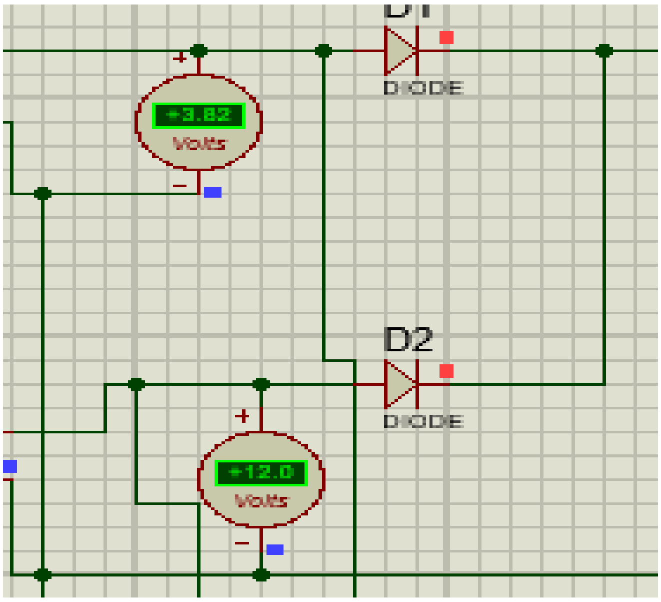



Fig 3.11: Proteus Block of Voltmeter & Diode

In this part, we can see a voltmeter and diode were used. The voltmeter was used to check how much voltage the solar and piezo were producing, and we used the diode so that the current could flow only one way; if the diode was not used, current may flow in the reverse direction.

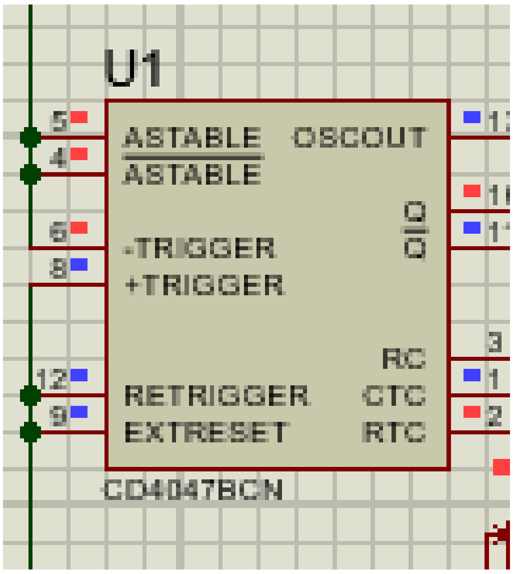



Fig 3.12: Proteus block of IC CD4047BCN

This is an IC CD4047BCN. This part works as a step-up inverter where the small amount of volt can be made higher.

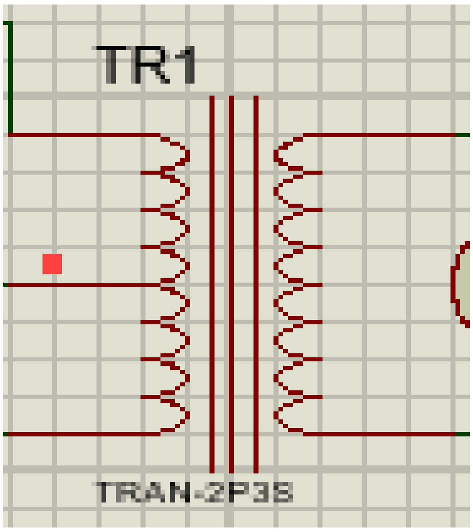



Fig 3.13: Proteus block of the TRAN2P35 transformer

TRAN2P35 is a transformer that we used to convert the DC voltage to an AC voltage. We also used a pot and some resistors to make sure we do not get any sudden power surge and make the system unstable.

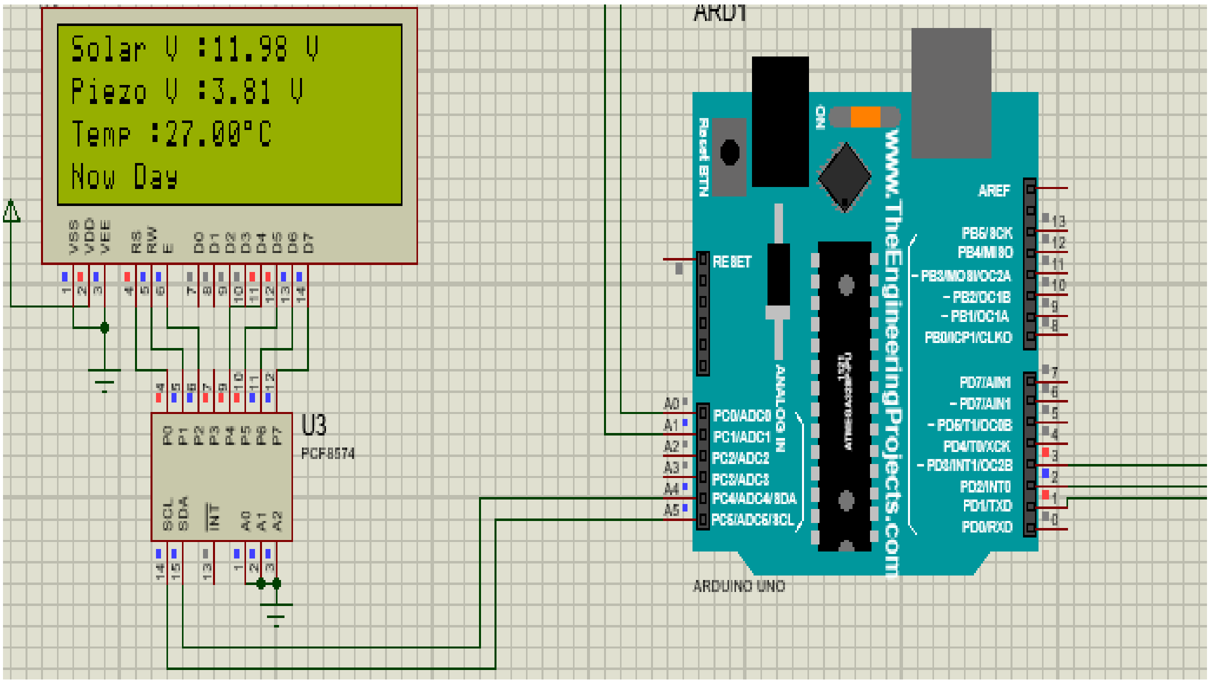



Fig 3.14: Proteus block of Arduino & LCD

Here we used an Arduino, which is connected to the LCD, so that we can see how much voltage is being produced by the solar and piezo.

### 3.4 Conclusion

In our hybrid power generation project, we utilized a range of modern engineering and IT tools so that we could effectively design and analyze the project. After discussion and a long search, we decided to use Blender, Proteus, and MATLAB for our work. We used Blender for 3D modeling and visualization, which is very important for design validation. Proteus was used for precise circuitry planning and simulation, ensuring optimal functionality before constructing it physically for PCBs. Comprehending system behavior, optimizing performance, and tailoring designs to specific requirements were empowered efficiently by MATLAB Simulink's versatile modeling and simulation platform. This project's workflow, accuracy improvement, and advanced innovation in sustainable power generation solutions were organized smoothly with the combination of these modern engineering and IT tools. The development of this environmentally friendly energy system was ultimately developed in an advanced way through the comprehensive utilization of these modern tools, which emphasizes the project's commitment to influencing cutting edge technology for effective engineering solutions.

# Chapter 4: Optimization of multiple designs and finding the optimal solution [CO7]

## 4.1 Introduction

This project can be implemented in a few different ways. The main goal of these approaches is to serve the goal of our objective. In this project, we have considered three different ways that we can construct our project. The first approach is the hybrid photovoltaic-thermoelectric system. The second approach is hybrid wind turbines with solar power. Lastly, hybrid piezoelectric sensor plate with solar power system as our last approach. These three approaches have their own benefits and drawbacks based on their parameters and performance. A comparison can be drawn between these approaches.

## 4.2 Optimization of multiple design approach

The first design approach, a hybrid photovoltaic-thermoelectric system, is simulated by using MATLAB Simulink. The circuit diagram is given below.

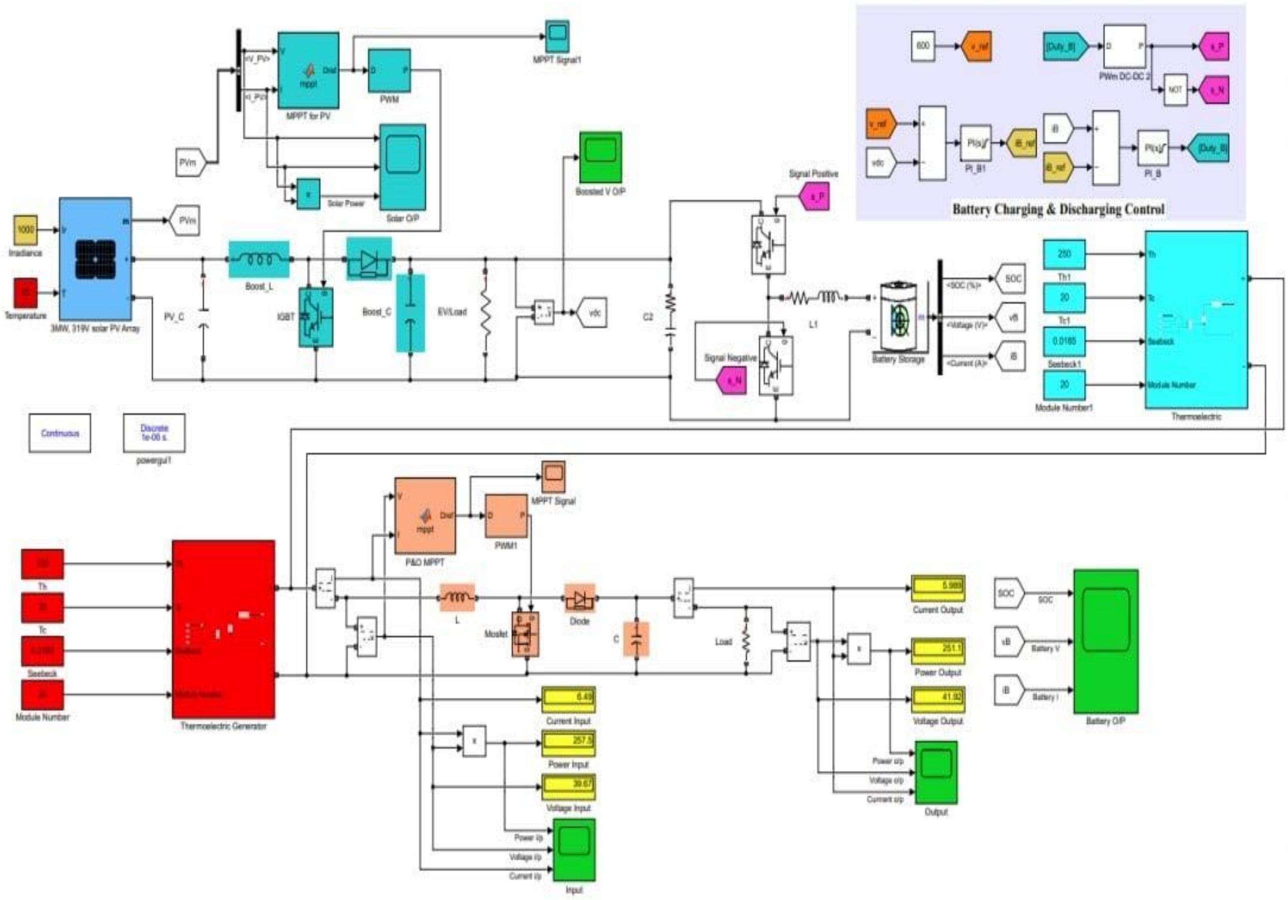



Fig 4.1: Simulink simulation of PV

An ideal temperature is set for a solar panel which is 25 degrees Celsius. Here irradiance is used to measure the radiant energy from the Sun. A capacitor is used to reduce the impact on the system in case of sudden power drop. Then the voltage from the solar panel is increased through the boost converter. This is done by using MPPT on solar cells. This will track the maximum power of the solar all the time. This will generate a control signal and pass through IGBT for which voltage will be constant. For battery charging and discharging is done using two IGBT. Reference and Vdc are compared. Depending on this, positive and negative signals are generated. For positive signals the battery charges, and for negative signals the battery discharges.

TEG uses the waste heat from the solar cell. When the temperature of the solar is more than 25 degrees Celsius, then the excess heat will be taken by the TEG to generate electricity. Suppose if the temperature is 55 degrees Celsius, then 25 degrees Celsius is used by a solar cell, 20 degrees is used by TEG, and 10 degrees of solar cell is cooled through TEG by providing water down the solar cell through a pipe whose speed is controlled by a motor.

For design approach two, which is hybrid wind turbine with solar power system, it is simulated using also MATLAB Simulink. The circuit diagram is given below:

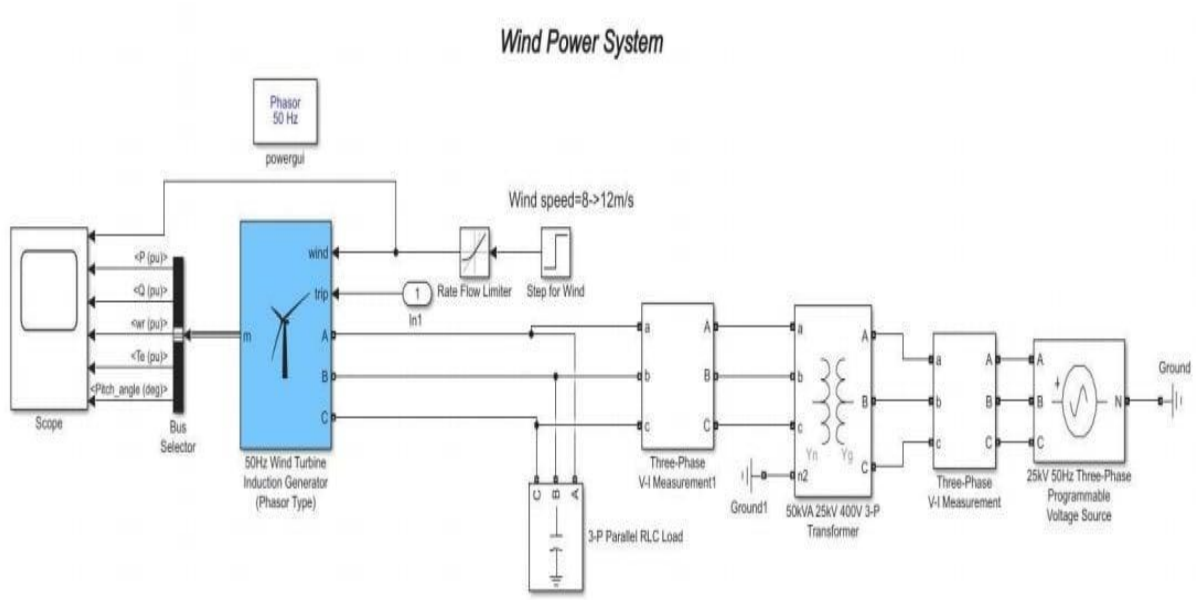



Fig 4.2: Simulink simulation of Wind

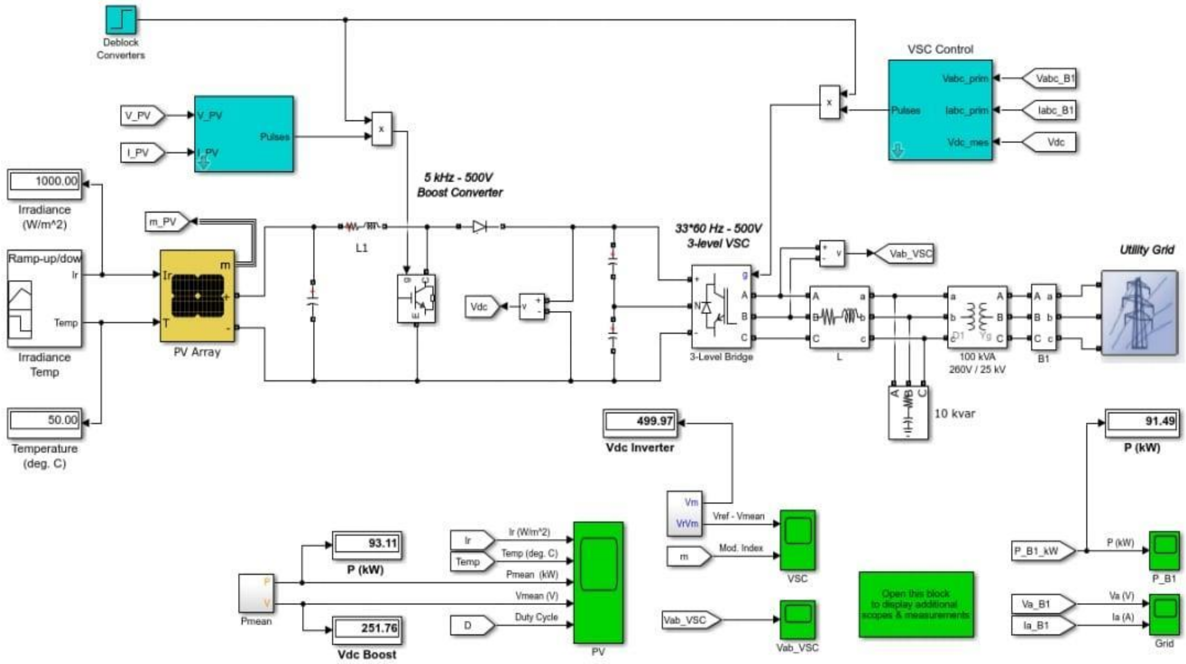



Fig 4.3: Simulink simulation of PV-Wind

For the simulation part, we took a wind turbine that can generate 12 kw of power where the line-to-line voltage is 400 volts and it's a 50 Hz turbine. As in a wind turbine, there is no Y connection but only a delta connection; that's why we took line-to-line voltage. Our base wind speed is 8-12 m/s, and the fluctuating value is 1. The maximum pitch angle is 45 because any angle greater than 45 will increase the rotor speed by a greater amount, which can lead to the destruction of the rotor.

We have used the Sun Power SPR305 model solar because its fluctuation graph is better. Ramp up-down block has been used to provide sunlight to the solar, and the provided temperature is 25-50°C and the ambient temperature is 25°C. The irradiance value varies depending on the timing of the sunlight. As the solar output is very minimal, we used a boost converter to increase the value and to match up with the grid voltage. Otherwise, there is an alarming chance of the destruction of the solar. We have also used capacitors to control the voltage up-down during bad weather conditions.

We used an MPPT controller so that even if the PV voltage is still very low, it will signal the IGBT to match up the grid voltage. We have used a 3-level bridge to convert the dc current of the solar to AC current. With this, the ac output produced by the wind will be connected, and thus we will get our total ac current. To minimize the capacitance, we took RL circuits. A parallel load was also used so that there is no symmetrical fault.

Lastly, the design approach 3 is a hybrid piezoelectric sensor plate with a solar power system, which is simulated by using Proteus.

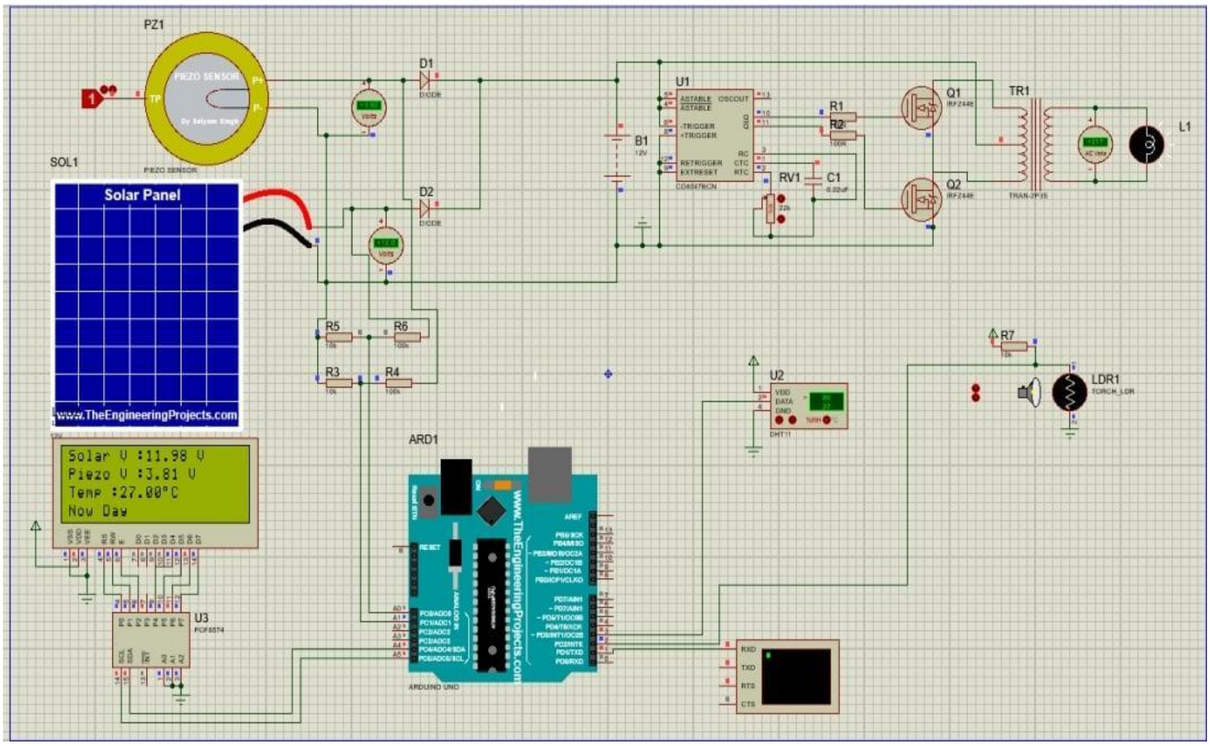



Fig 4.4: Proteus simulation of Piezo-PV

In this design, electricity is produced by piezoelectric and solar cells, which are then run through the diode to make it one way to the battery so that no reverse current can flow. Voltmeters were used so that we could see how much volt was being produced by solar and piezo. Now from the battery it goes through the IC CD4047BCN, which works as a step-up inverter through that with 2 ceramic resistors, then goes to the MOSFET, then to the transformer, which changes DC Volt to Ac Volt, which can be seen through the meter. A 22K pot was used to control the resistance, and a capacitor was used so that any sudden power surge does not make our system unstable and render it unusable for our project. We used an Arduino, which is connected to the LCD, where we

Can see all the voltage produced by piezo and solar. We also use an LDR light sensor, which can recreate day and night simulation for us. A temperature sensor was used to monitor the temperature and humidity of the weather.

### 4.3 Identify optimal design approach

In all the three different approaches, we have considered the first approach to be optimal, which is a hybrid photovoltaic-thermoelectric system. The first design approach can be implemented anywhere, like the rooftop of an office building, any house building, or a roadside where sunlight is present. It needs professional knowledge to maintain an ace. It is easy to install. TEC is used to cool the solar cell in case of high temperature, which then increases its lifetime. The efficiency of Solar is 20%, whereas the efficiency of TEG is 5–15%. On the other hand, design approach two can only be implemented where there is sufficient wind flow to rotate the wind turbine. It needs trained professionals for maintenance. It also needs high knowledge for installing this hybrid system. There is no medium that can affect the solar cell's operational lifetime. The efficiency of solar is 20%, and wind turbines are 14%. Lastly, the design approach three can be implemented in any office building or footpath with a large number of people walking. It needs minimal maintenance. It also needs high knowledge for installing this hybrid system. It also needs high knowledge for installing this hybrid system. There is no medium that can affect the solar cell's operational lifetime. The efficiency of solar is 20%, but the piezo efficiency varies.

#### 4.3.1 Power consumption comparison among the three approaches

Table 4.1: Output results of design approach-01

| Time(min) | Ambient temp C* | Panel temp C* | Voltage |
|---|---|---|---|
| 0 | 32.251 | 38.2 | 13.75 |
| 2 | 31.312 | 36.6 | 13.9 |
| 4 | 32.579 | 35 | 14.3 |
| 6 | 31.712 | 33.4 | 14.7 |
| 8 | 31.637 | 31.8 | 15.1 |
| 10 | 32.256 | 30.2 | 15.5 |

The table above shows the experimental value of design approach-01. It is seen that the voltage is gradually increasing, and by following the equation $P = VI$, a conclusion can be drawn that the power is increasing with time.

The experiment result of design approach three is shown below:


Fig 4.5: Output results of design approach 03

Here it can be seen that the voltage remains constant throughout the whole experiment, and hence the power also remains constant.

### 4.4 Performance evaluation of developed solution

In order to evaluate the performance of the system, the power of different stages is found, and from there the overall efficiency is calculated. One of the most popular formulas to calculate the power is P=VI. To calculate the total power, we took data at different times of the day. We plot the data to generate a graph. Firstly, the power of solar and TEG is found combined by using the equation stated below, and then the power of the pump is found. The pump here is used to maintain the flow of water from the aluminum water block to the TEG cooling system. Then the net power of solar and TEG is found by deducting the power of the pump from the combined power of solar and TEG. Now the efficiency of net solar and TEG is found by dividing the power of net solar and TEG with the ideal power of solar and TEG. Here, ideal power is considered to be 15 W. Lastly, the desired efficiency is calculated by deducting the efficiency of solar from the efficiency of net solar and TEG. This approach is described in mathematical form in the given below.

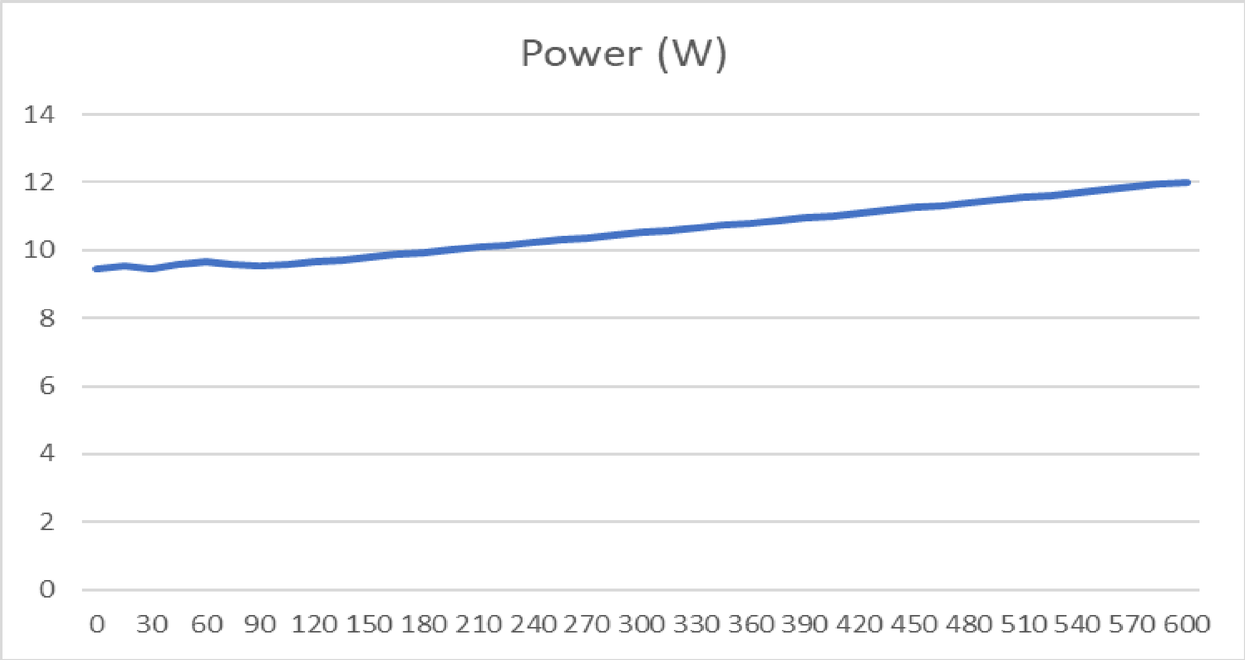



Fig 4.6: Time vs. Power Curve of PV-TEG Simulation

Now, to calculate the overall efficiency of solar, we used the formula,

$$\eta_{Solar}=\frac{P_{Practical}}{P_{Ideal}}\times 100\%$$

$$\rightarrow \eta_{Solar}=\frac{2.7}{15}\times 100\%$$

$$\rightarrow \eta_{Solar}=18\%$$

For $P_{Practical}$, we took the average of different times output. And for the $P_{Ideal}$. We took 15 watts.

To cool down the water for the system, we have used a water pump.
For the power consumption by the water pump, it can be expressed by,

$$P_{Pump}= f\times\frac{1}{D_{ch}}\times\frac{u_w^2}{2}\times\rho_w\times A_{ch}\times u_w\times n_{ch}$$

Here,
$P_{Pump}$= is the power consumption of the pump.
f = friction factor
$D_{ch}$= diameter
$u_w$= velocity
$\rho_w$ = density of water

$A_{ch}$= the flow cross-sectional area
$n_{ch}$= number of channels of the water-cooling system

So, the power consumption will be,

$P_{Pump}$= $0.02\times\frac{1}{1.25}\times\frac{2.02^2}{2}\times1000\times0.049\times2.02\times2$

→ $P_{Pump}$= 6.46 watts

Now, to calculate the overall power of solar with the TEG (combined) system.

$P_{Solar.TEG}$= VI

From the data table, we got an average solar power of 9.63 watts for different times.

So, the net output power will be,

$P_{Net\ Solar.TEG}$ = $P_{Solar.TEG}$ - $P_{Pump}$

→ $P_{Net\ Solar.TEG}$ = 9.63 - 6.46

→ $P_{Net\ Solar.TEG}$ = 3.17 watts

Now, to calculate the overall efficiency of the net solar TEG system, we used the same formula,

$\eta_{Net\ Solar.TEG}=\frac{P_{Net\ Solar.TEG}}{P_{Ideal}}\times 100\%$

→ $\eta_{Net\ Solar.TEG}=\frac{3.17}{15}\times 100\%$

→ $\eta_{Net\ Solar.TEG}$= 21.1%

So, the increased efficiency,
$\Delta\eta = \eta_{Net\ Solar.TEG} - \eta_{Solar}$

= 21.1% – 18%

= 3.1%

Since overall efficiency is increased by 3.1%, it will extend the lifespan, reduce replacement costs, and most importantly, reduce maintenance costs.

### 4.5 Conclusion

In this chapter, the advantages and disadvantages of different approaches are mainly focused. The main objective is to design a system that can give better efficiency and can enhance the lifespan of the project. The design approach, which is hybrid photovoltaic-thermoelectric, is found to be the best optimal approach. This is because it provides high efficiency and a longer lifespan.

It has been found that there are different factors that are unique to different design approaches. This comparison is done because all the factors and parameters are different for different design approaches. In this chapter, this comparison is made in order to select the best approach that can go with our project.

# Chapter 5: Completion of final design and validation [CO8]

## 5.1 Introduction

A prototype of a solar efficiency increaser was constructed using the Peltier module as a cooler. Based on our design approach 1, which was selected in the previous design process, this prototype was done. This prototype has been implemented by both the hardware and software. MATLAB was used to implement the software system design. We used the custom block solar and other library items in MATLAB to show our software design. In the prototype, things that we envisioned would carry out the objectives with their best capabilities. As a result, the prototype has a temperature sensor (ambient and solar), a single-axis solar tracker, a water block, a linear actuator, and a small display to show power voltage and temperature. In the time of testing this prototype, everything worked perfectly. We tested our system at noon to get the maximum solar irradiance, which is needed to see the solar efficiency of our system.

## 5.2 Completion of final design

The prototype was implemented through both software and hardware. Below, a detailed explanation and analysis of this design have been given.

The overall final software for our prototype using MATLAB is given below:

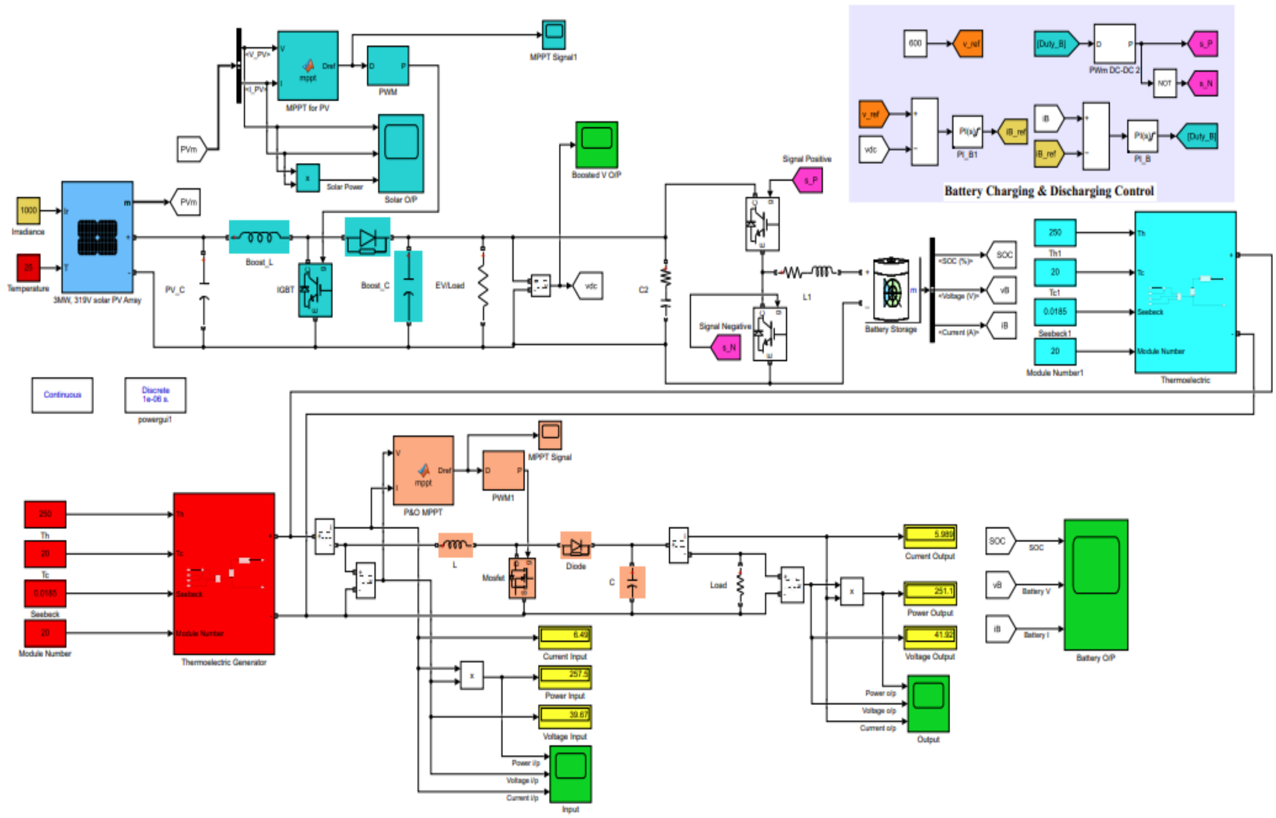



Fig 5.1: Simulink circuit diagram of PV-TEG design

MATLAB Simulink is used to analyze the solar panel that we have used in this project. Here is the block diagram of the solar panel that we have used.

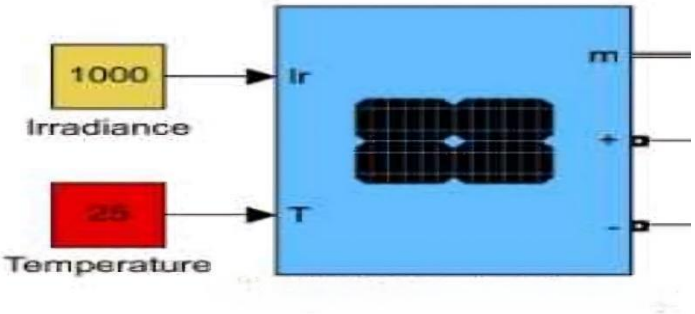



Fig 5.2: Simulink block of PV

Here we see that there is an irradiance and temperature block beside the solar panel block. Irradiance is the measure of the solar energy coming from the sun, and 25 °C is considered an ideal temperature.

The parameters of the solar panel are as follows:

The model that we have used is user-defined. Here, the current and voltage depend on the number of series and parallel strings on the solar panel. Voltage depends on the series string, whereas current depends on the parallel string.

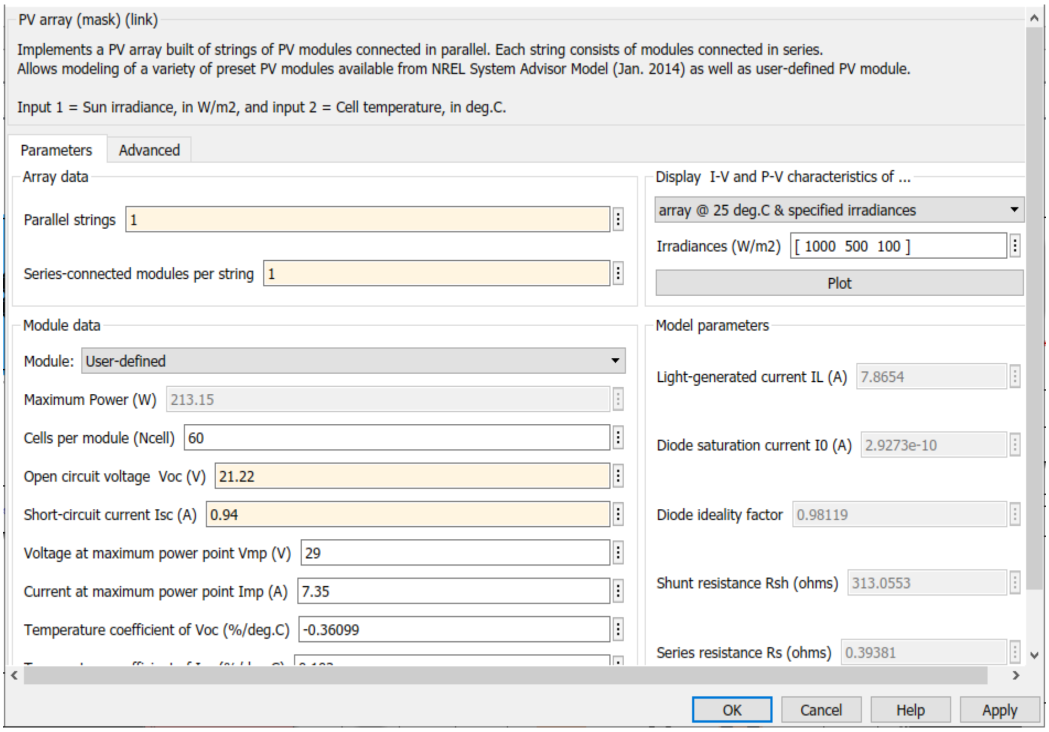



Fig 5.3: Simulink parameters of PV

For TEG, the block diagram is as follows:

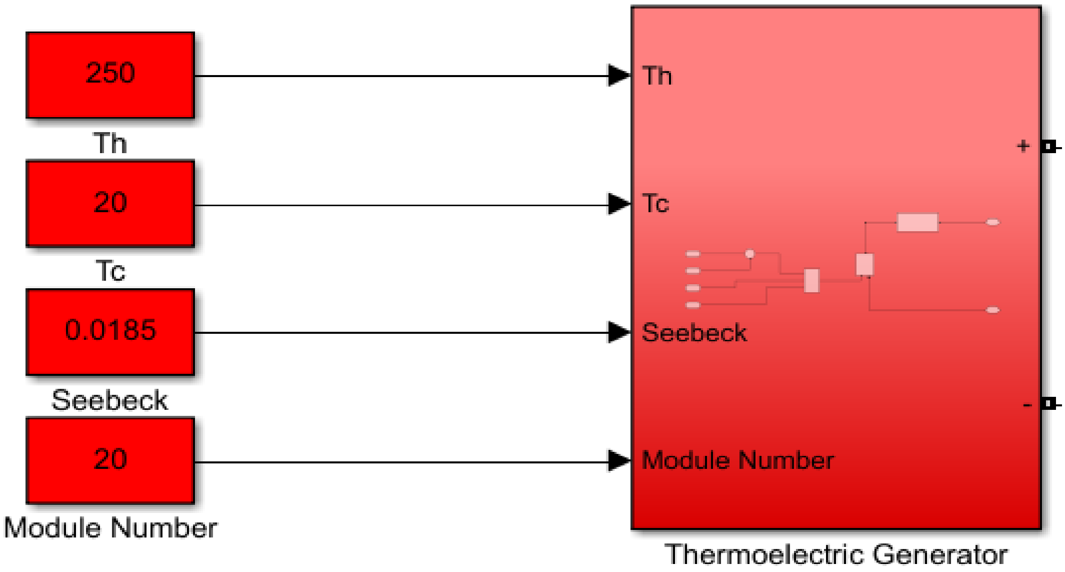



Fig 5.4: Simulink block diagram of TEG

Here, this Th value is fixed as it is provided by the manufacturer, and the Tc value is 20, which is considered to be an ideal value. The number of modules that are used is also mentioned.
For battery charging and discharging is done using two IGBT. Reference and Vdc are compared. Depending on this positive signal, a negative signal is generated. For positive signals the battery charges and for negative signals the battery discharges.

TEG uses the waste heat from the solar cell. When the temperature of the solar is more than 25 degrees Celsius, then the excess heat will be taken by the TEG to generate electricity. Suppose if the temperature is 55 degrees Celsius, then 25 degrees Celsius is used by a solar cell, 20 degrees is used by TEG, and 10 degrees of solar cell is cooled through TEG by providing water down the solar cell through a pipe whose speed is controlled by a motor. As it is seen, we are going to implement the hybrid power supply beside the road. Beside the road there is a road light, billboard, and LCD screen. By setting these systems, we can reduce load from the grid.

Output graphs:

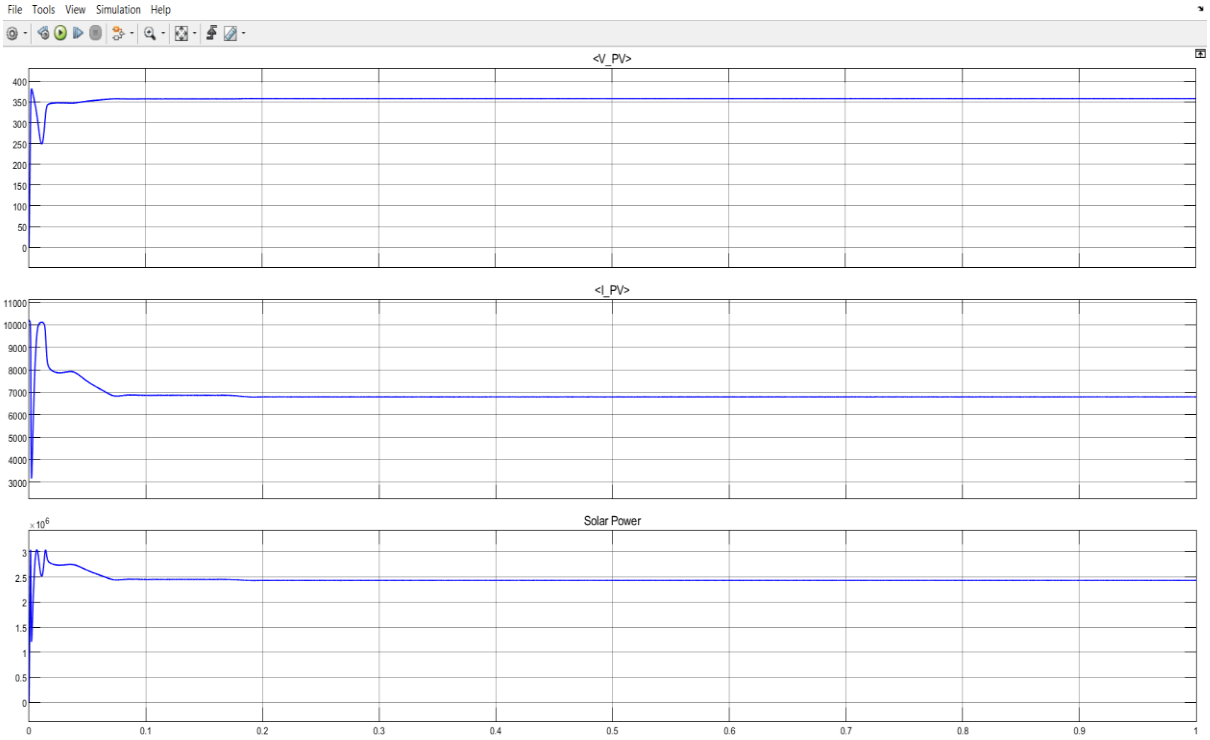



Fig 5.5: Simulink output graph of PV

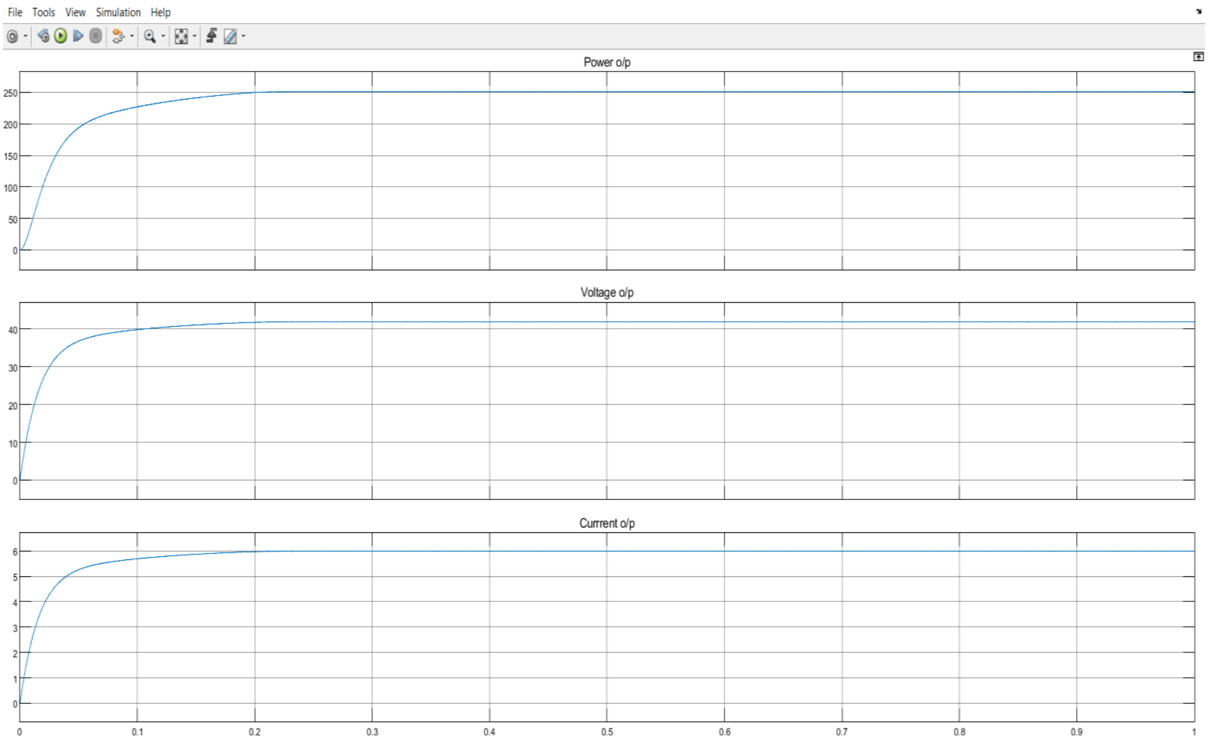



Fig 5.6: Simulink output graph of TEG

At the beginning, the solar takes time to reach its ideal temperature of 25 degrees Celsius. Therefore, initial transient response varies. When the solar receives solar energy for some time, it reaches its ideal temperature, and hence a constant value can be seen from the graph. The output values of the current and voltage can be changed by changing the corresponding parameters on the solar cells. It has been studied that the efficiency of the solar cell is in the range of 15 to 20 percent.

TEG uses the waste heat from the solar. Initially, the transient response is increasing linearly. This is because any temperature above 25 degrees Celsius of a solar cell is used by TEG to generate power. TEG is designed to take up to 20 degrees Celsius. Therefore, whenever the solar cell reaches a constant temperature above 25 degrees Celsius or TEG reaches its maximum temperature of 20 degrees Celsius, then the graph represents a constant value.

Therefore, it has been seen that the efficiency of solar is increased as the TEG also contributes to generating power. Here a thermoelectric cooler (TEC) is also installed. This cools the solar cell in cases of very high temperatures. Hence, the efficiency and the operational lifetime of solar also increase.

**Final prototype design**

Firstly, for our prototype, we made an aluminum frame to hold our solar panel and aluminum water block with it, which goes behind the solar panel. The aluminum frame was used to support the panel and aluminum water block weight.

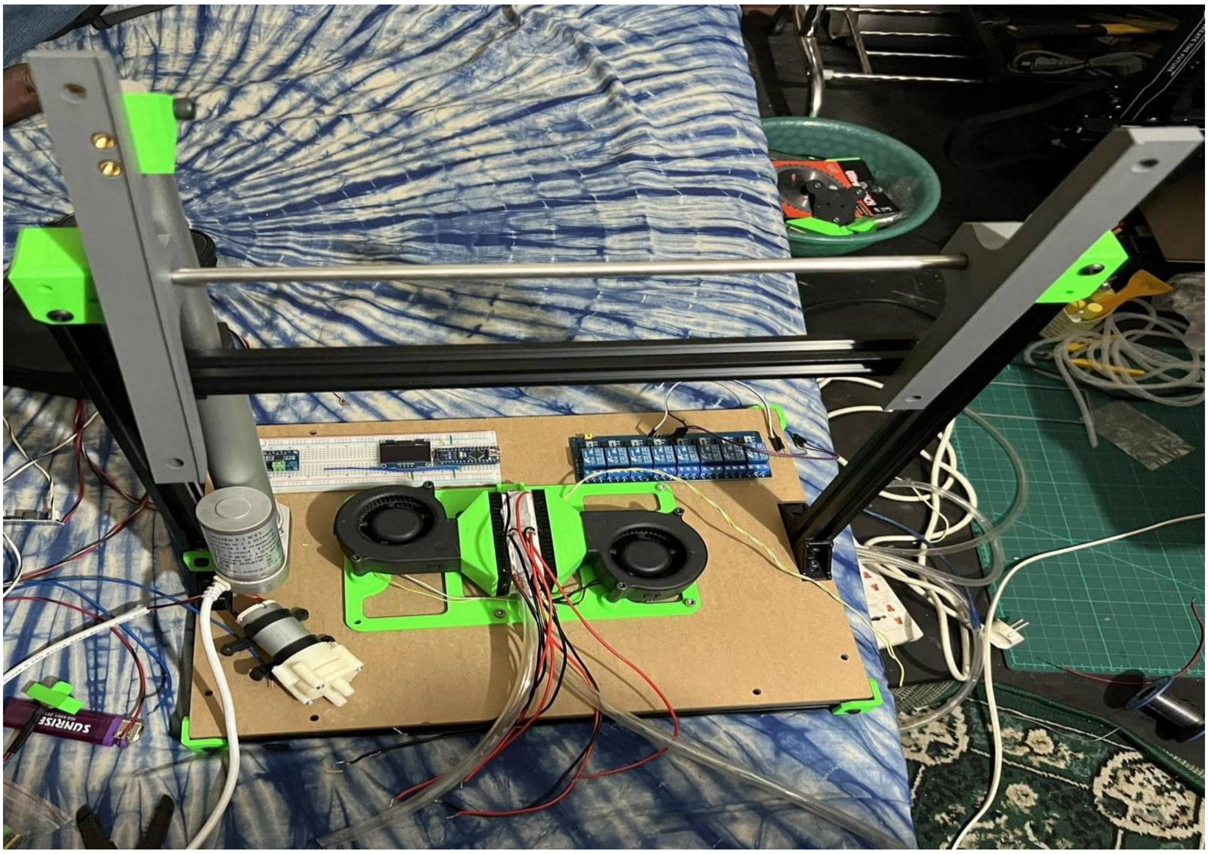


Fig 5.7: Aluminum frame of prototype

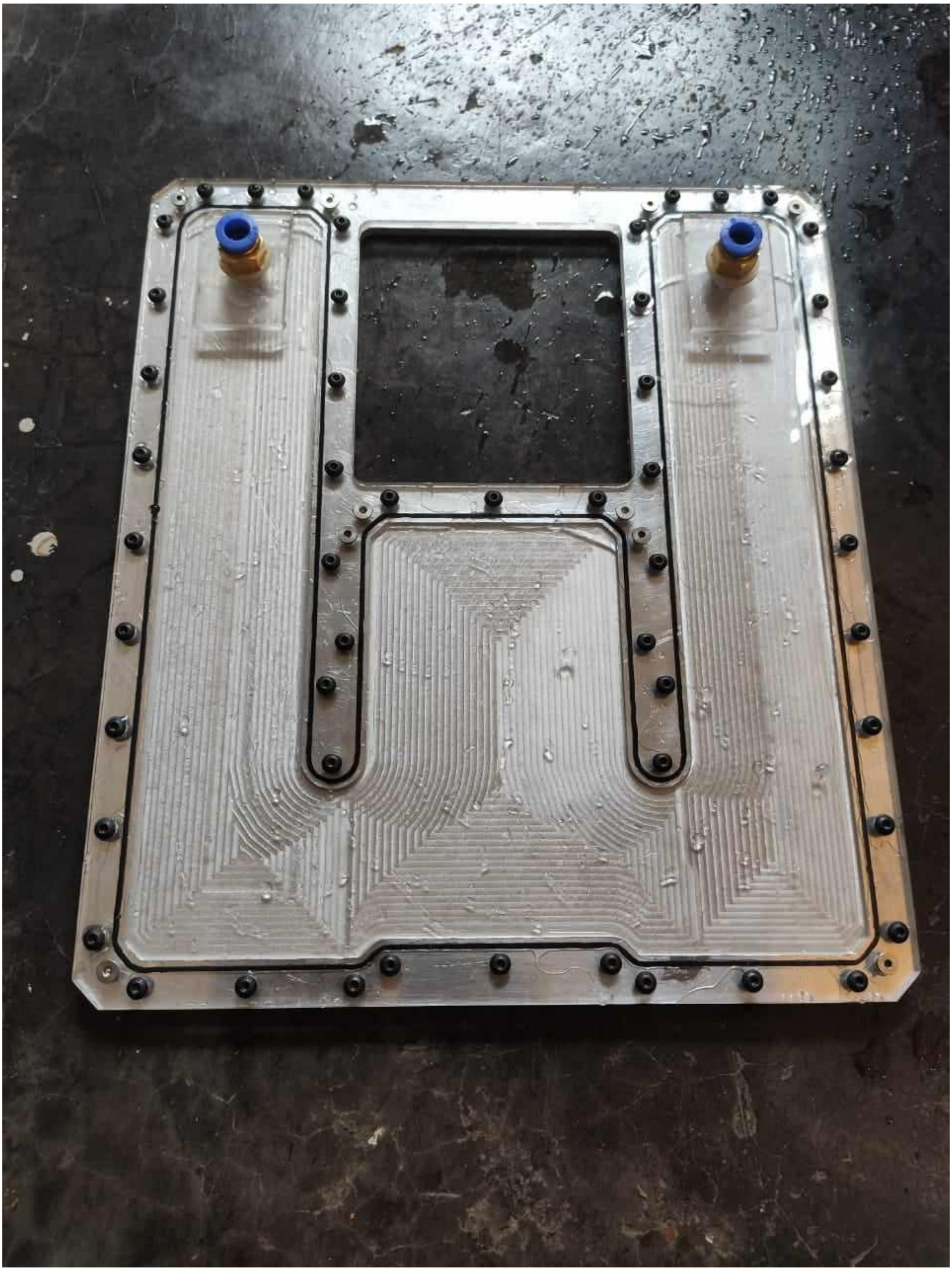


Fig 5.8: Aluminum water block of prototype

We used a linear actuator so that it can handle the weight for the panel with a water block with it as it needs to move for the solar tracker. A linear actuator was used because it handles the moving of the solar panel.

Fig 5.9: Linear actuator of prototype

In the bottom part, a water cooler was planted with the Peltier module, which is then connected to a bottom water block with a pump and pipe that runs water through the system constantly, which cools the solar panel.

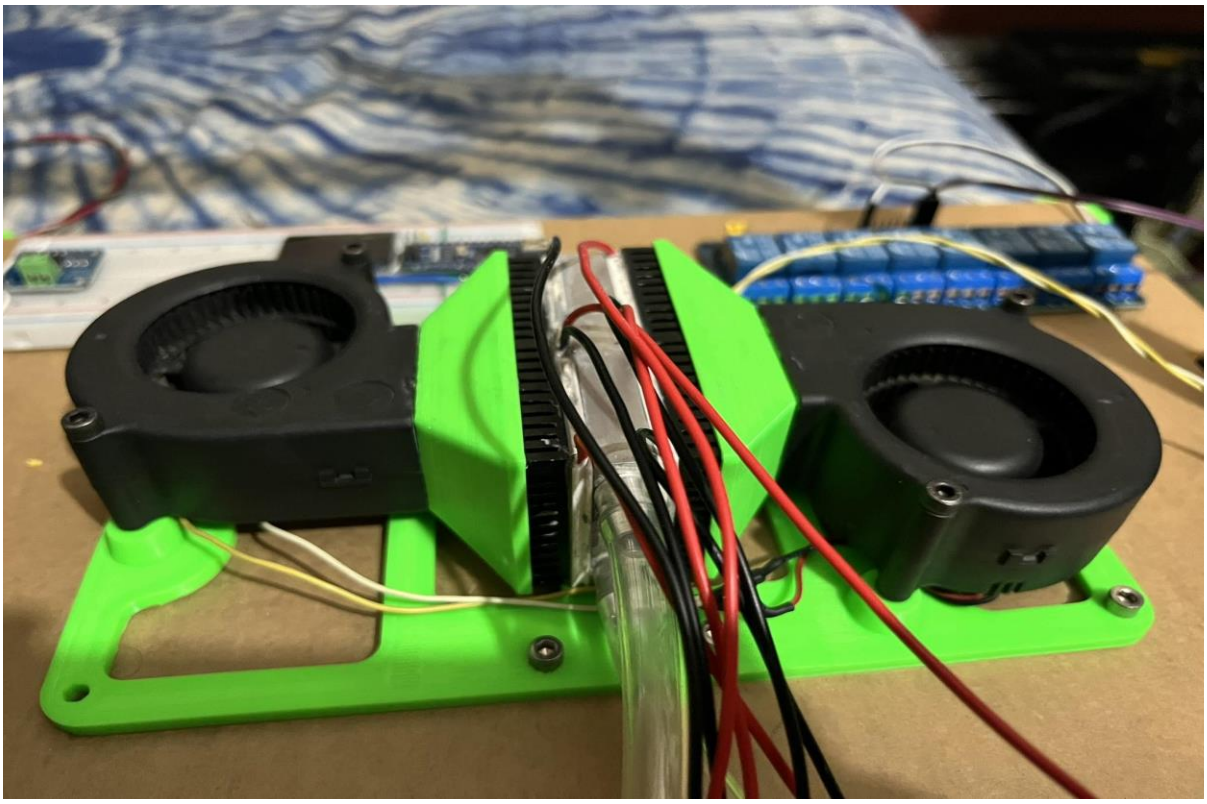


Fig 5.10: Peltier module with cooling fan

In the system, the temperature system was also used to constantly monitor the solar and ambient temperatures. We also used an OLED display to monitor the power voltage and temperature of our system. After assembling the system, checking was done for the wires, making sure we connected the wires rightly. We checked if we connected the sensors properly to check if it works. A microcontroller was used to get all this data, and it in the LED display connected to the PCB.

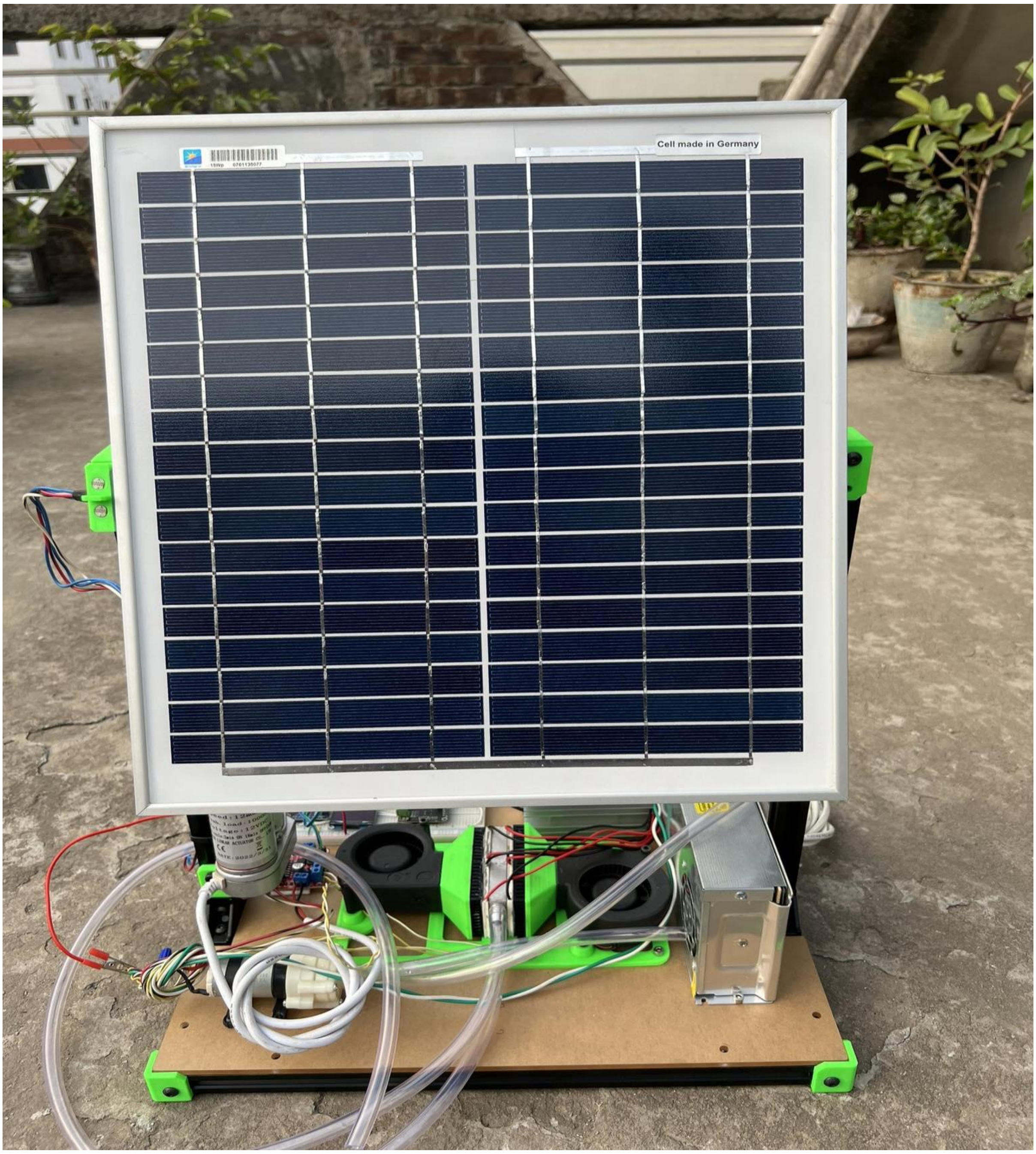



Fig 5.11: Final prototype design

**Method of data collection:**

We took our prototype to the rooftop for testing and checking. When the system was running, the solar panel adjusted itself towards the sun, where it would get maximum sunlight for solar, and the water cooler was running, utilizing the Peltier module constantly to not make the panel too hot. The Peltier module’s cold side was connected to the water-cooling block side, and the hot side was connected with two fans, which would exhaust the extra heat from the Peltier outside. We were able to get the data we need for our project where we saw that in time as the temperature of our solar panel came down, energy generation was a little bit more for our system.

### 5.3 Evaluate the solution to meet the desired need

As we tested our prototype, it kept running for 30 minutes or so to see the result of it. Where live data was collected through the sensors.

Table 5.1: Output data table of the system

| Time (Seconds) | Ambient Temperature (°C) | Panel Temperature (°C) | Produced Voltage (V) | Produced Current (A) | Power (W) |
|---|---|---|---|---|---|
| 0 | 32.251 | 38.2 | 13.75 | 0.6875 | 9.453125 |
| 15 | 32.125 | 38 | 13.8 | 0.69 | 9.522 |
| 30 | 32.657 | 37.8 | 13.75 | 0.6875 | 9.453125 |
| 45 | 31.931 | 37.6 | 13.85 | 0.6925 | 9.591125 |
| 60 | 32.537 | 37.4 | 13.9 | 0.695 | 9.6605 |
| 75 | 31.899 | 37.2 | 13.85 | 0.6925 | 9.591125 |
| 90 | 32.384 | 37 | 13.8 | 0.69 | 9.522 |
| 105 | 32.682 | 36.8 | 13.85 | 0.6925 | 9.591125 |
| 120 | 31.312 | 36.6 | 13.9 | 0.695 | 9.6605 |
| 135 | 31.755 | 36.4 | 13.95 | 0.6975 | 9.730125 |
| 150 | 32.444 | 36.2 | 14 | 0.7 | 9.8 |
| 165 | 32.505 | 36 | 14.05 | 0.7025 | 9.870125 |
| 180 | 32.646 | 35.8 | 14.1 | 0.705 | 9.9405 |
| 195 | 31.689 | 35.6 | 14.15 | 0.7075 | 10.011125 |
| 210 | 32.424 | 35.4 | 14.2 | 0.71 | 10.082 |
| 225 | 32.522 | 35.2 | 14.25 | 0.7125 | 10.153125 |
| 240 | 32.579 | 35 | 14.3 | 0.715 | 10.2245 |
| 255 | 31.882 | 34.8 | 14.35 | 0.7175 | 10.296125 |
| 270 | 32.026 | 34.6 | 14.4 | 0.72 | 10.368 |
| 285 | 32.294 | 34.4 | 14.45 | 0.7225 | 10.440125 |
| 300 | 32.669 | 34.2 | 14.5 | 0.725 | 10.5125 |
| 315 | 32.085 | 34 | 14.55 | 0.7275 | 10.585125 |
| 330 | 32.334 | 33.8 | 14.6 | 0.73 | 10.658 |
| 345 | 31.688 | 33.6 | 14.65 | 0.7325 | 10.731125 |
| 360 | 31.712 | 33.4 | 14.7 | 0.735 | 10.8045 |
| 375 | 31.904 | 33.2 | 14.75 | 0.7375 | 10.878125 |
| 390 | 32.116 | 33 | 14.8 | 0.74 | 10.952 |
| 405 | 32.159 | 32.8 | 14.85 | 0.7425 | 11.026125 |
| 420 | 32.531 | 32.6 | 14.9 | 0.745 | 11.1005 |
| 435 | 32.001 | 32.4 | 14.95 | 0.7475 | 11.175125 |
| 450 | 31.893 | 32.2 | 15 | 0.75 | 11.25 |
| 465 | 32.045 | 32 | 15.05 | 0.7525 | 11.325125 |
| 480 | 31.637 | 31.8 | 15.1 | 0.755 | 11.4005 |
| 495 | 32.376 | 31.6 | 15.15 | 0.7575 | 11.476125 |
| 510 | 32.226 | 31.4 | 15.2 | 0.76 | 11.552 |
| 525 | 32.453 | 31.2 | 15.25 | 0.7625 | 11.628125 |
| 540 | 32.662 | 31 | 15.3 | 0.765 | 11.7045 |
| 555 | 32.683 | 30.8 | 15.35 | 0.7675 | 11.781125 |
| 570 | 32.614 | 30.6 | 15.4 | 0.77 | 11.858 |
| 585 | 31.527 | 30.4 | 15.45 | 0.7725 | 11.935125 |
| 600 | 32.256 | 30.2 | 15.5 | 0.775 | 12.0125 |

We collected our data on $4^{th}$ April 2024 around 3 pm. We ran our prototype for approximately 10 minutes. We saw that both current and voltage values were changing with respect to time. However, the power output also increased.

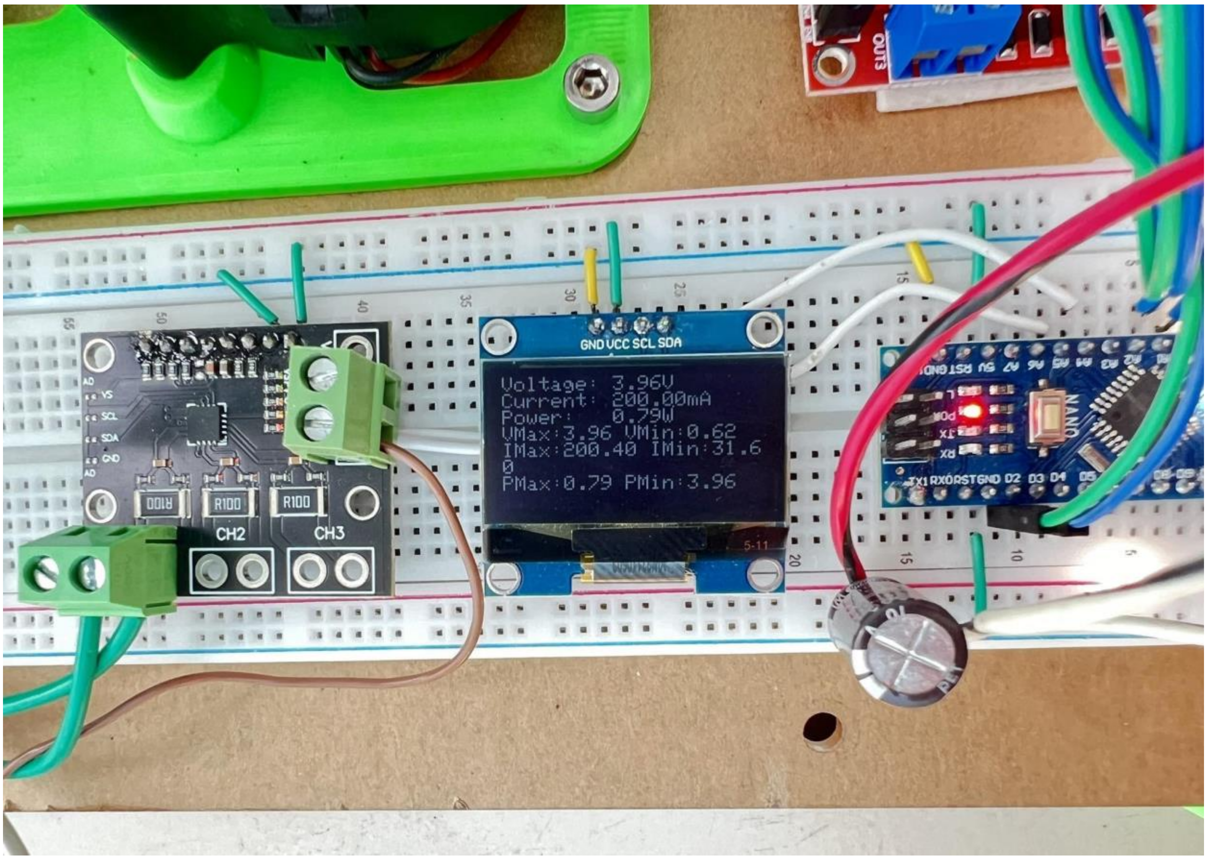



Fig 5.12: Output of the system

Fig 5.13: Load resistor (20-ohm)

The figure above shows our prototype in the running stage, where the solar tracker is tacking the sun and then adjusts the panel towards it using the solar tracker, and the linear actuator helps it to move. In the bottom, we can see all the other components that are used to run the system. Pump is running water constantly from the Peltier water block to the aluminum water block connected to the backside of the solar panel through water pipes. As solar produces power, we used a 20-ohm resistor to use up the power. The sensors take the data and feed it through the microcontroller on to the OLED display, where we can see how much power is being produced and all other data.

### 5.4 Conclusion

We can say that based on the performance and data that was measured, we can say that our system has been implemented successfully, which executed different criteria for both software and hardware. Even though we found ourselves navigating and confronting different challenges through this project. Having seen these setbacks, we learned valuable lessons.

As we dove deep into it, we found ways that helped contribute to our project and also learned that it can be executed in a more sophisticated way. We tried our best to elevate our project to some degree, demonstrating that it could work if we tried.

## Chapter 6: Impact analysis and project sustainability [CO3, CO4]

### 6.1 Introduction

The main purpose of the solar thermoelectric technology research project is to investigate how it affects different areas which including society, law, safety and culture. We have tried to analyze these potential impacts in much detail. We have also finished doing a SWOT analysis so that we can understand the possible outcomes of our work. Our main goal is to use natural sunlight, a clean and sustainable free energy source, as an alternative to harmful conventional energy sources. Harnessing solar energy will not only reduce air and land pollution but also paves the way for a greener and safer energy future. Promoting solar adoption reinforces our energy system, ensuring stability and environmental protection up to its best. However, projects have influential impacts that go beyond their immediate radius and time frame. Engineers and decision-makers must have justification for broader suggestions, especially regarding long-term environmental and social equity considerations. To ensure a successful and impartial energy future, it's crucial to evaluate the long-term sustainability and ethical implications of our projects. Solar power harnessed through the best technologies like photovoltaics and thermal systems offers a significant and untapped source of renewable energy, which should be considered a big value [25]. A wide use of solar thermoelectric technology could point to a shift in how people think about and use renewable energy. It could pave a way of life that values sustainability and taking care of the environment [26]. While our project offers advantages, it also faces vulnerabilities. We must address challenges like the inconsistent nature of sunlight, technological constraints, and high upfront costs through careful planning and advancements to ensure its success.

### 6.2 Assess the impact of the solution

Given below are the social, health, safety, legal, and cultural concerns that are reviewed.

**Societal**

The social impacts of hybrid renewable energy generation systems are very considerable. As we know, they offer access to clean energy, reducing dependence on centralized grids and encouraging energy self-governance. Job opportunities, particularly in skilled labor sectors, can make the economic advancement. These work efforts play a vital role in decreasing greenhouse gas emissions, leading to improved air quality and public health. In rural areas, they support economic development and empower local communities. Efforts to educate community members promote eco-friendly habits and preserve traditional wisdom. Technology will help to improve various industries, and community involvement builds a better social community. Disaster preparedness reduces energy issues and costs, demonstrating a dedication to environmental protection and long-term sustainability.

**Health**

The combination of various renewable energy sources provides many health benefits. First of all, it eliminates harmful emissions like carbon dioxide, nitrogen oxides, and many other harmful gases, which then improve the air quality, thereby promoting better respiratory and heart health benefits and lowering every other disease risk. Not only that, it also reduces noise pollution, which then leads to improved sleep and mental health. It also helps by reducing the heat island effect in the city areas, as these systems promote outdoor activities, improving health. When energy costs become low through such a system, it then makes healthcare more affordable and accessible to all kinds of people. It also improves local development and creates jobs, which improves the general well-being of the people. These kinds of systems are very much in line with the environmental protection principles, and by doing this, they promote healthier and more environmentally friendly living. Finally, they also make societies more resilient to disasters by making sure that continuous access to healthcare services in emergencies is always accessible to the people.

**Safety**

When we are trying to handle solar thermal systems, we need to make sure we are handling this thing with caution as they have many electrical components inside, such as wires and controllers. Mishandling in time off the installation, maintenance, or handling can result in electrical risks like shocks or fires. We need to look into the electrical safety guidelines, which include using different types of insulated tools, grounding the system properly and correctly, and incorporating safety measures like fuses or circuit breakers. As we know, solar thermometric systems can become very hot under the constant heat of the sun, which very much poses a potential burn danger [27]. Proper use of insulation or installation of shielding is crucial to prevent these kinds of accidents. While, as we know, these systems reduce emissions, the materials used in their construction might have environmental impacts related to their production disposal and end-of-life management. So, to minimize the harmful impacts on the environment, discarding or recycling those parts that contain hazardous materials responsibly is very much needed. For solar thermal panels, it needs to be secured firmly to the pole or the place we have placed it to ensure no damage or accidents that may occur anytime in any area, especially in those areas where severe weather such as hurricanes or earthquakes happens many times. We need to always comply with the local building codes and conduct the manufacturer's recommendations for proper installation and support of these solar panels.

**Legal**

Almost all of the areas are governed by the laws. The solar thermoelectric systems also have some laws, which include building rules, zoning rules, electrical and electronic rules, regulations, and also environmental protections. Abiding by these rules is very important to prevent major penalties or any other legal problems that may occur during the installment. We need to have a permit to install solar thermoelectric or change or use these systems depending on where we live. We need to make sure to get the proper permissions from the authority to comply with the law it has. When the solar thermoelectric systems are installed on rented or shared properties, various issues related to property ownership and access may emerge. To prevent this kind of problem, which may occur, detailed agreements should be made that specify and clarify how the system will be owned and who is responsible for its upkeep and liability, and also who has access to it. Furthermore, the companies that are installing, running, or servicing the solar thermoelectric systems must be mindful of the inherent hazards, such as electrical risks and heat-related injuries. In any case of accidents or damage that may occur, they may be legally liable for the consequences. To reduce potential risks of having the solar thermos, it's very essential to get insurance and use every effective risk management plan. When we are connecting systems to the power grid, we need to make sure, and it's very important to consider the legal requirements such as grid access net metering rules and utility regulations. These things should be considered. By following these guidelines and regulations, we can securely say that the systems can be safely and smoothly integrated into the grid.

**Culture**

The solar thermoelectric systems will bring about very vital social and cultural changes in any area that go beyond just any improvement or any kind of power technology. This kind of project actively engages the local communities, which encourages unity among the preservation of cultural traditions and empowers the native peoples. The economic benefit that it has been created by these initiatives helps to refresh any cultural identity. By making a collaboration educational program, it can connect different generations, ensuring it lessens the generation gap in between uniting traditional or old knowledge with current modern technology. These systems are very much designed to work with the cultural values that make them prioritize protecting and preserving the environment, which encourages the wise use of these resources. It also fosters the wellbeing of the cultural exchange, making it stronger, reinforcing community bonds with the people, and representing how traditions can change and evolve alongside technological progress in a in a new world. Renewable energy ingenuities not only meet current energy demands but also enrich local cultures by embracing and safeguarding their legacy, as they do not destroy their culture and land. The use of renewable energy will make the world have energy without endangering the world as we know it.

Table 6.1: SWOT analysis of PV-TEG hybrid system

| | |
|---|---|
| **Strengths:**<br>• Clean Energy Generation<br>• Energy Diversification<br>• Steady Power Supply<br>• Cost Savings<br>• Grid Stabilization<br>• Environmental Benefits | **Weaknesses:**<br>• High Initial Costs<br>• Resource Variability<br>• Energy Storage Costs<br>•Grid Integration Complexity<br>• Land Use Conflicts |
| **Opportunities:**<br>• Technological Advancements<br>• Policy Support<br>• Energy Transition<br>• Job Creation<br>• Grid Modernization | **Threats:**<br>• Policy Changes<br>• Resource Dependence<br>• Economic Viability<br>• Supply Chain Disruptions<br>• Natural Disasters |

**Potential strengths**

Thermoelectric solar technology has some important strengths that make it a flexible and promising renewable energy solution. One big advantage is that it can make electricity even when sunlight is low, which means it can work in places with changing weather or less bright sun. This is different from solar panels that need direct sunlight. Also, thermoelectric systems don't need the sun to be at a certain angle as much, so they can be installed facing any direction. This flexibility lets them be used in more areas and on different building designs. Thermoelectric generators don't have moving parts, so they run quietly without much maintenance [28]. This is good for places with noise rules, like cities and other areas that need quiet. Their silence means they need less fixing too. Thermoelectric systems have a big plus: they last for a long time. Thanks to fewer parts that can break, they're strong and stay useful for a long stretch. An extra bonus is their cost-effectiveness over time. Excitingly, thermoelectric generators are ace at reusing waste heat. They can turn the heat that normally gets lost from processes or tech tools into power. This helps us use our resources wisely and keep energy use green.

**Tentative weaknesses**

Solar thermoe-lectric technology is cool, but it does face- some problems. It's not as good as normal solar systems at changing sunlight into power. Because- of this, you might need more space to get the same amount of energy. This could mean bigger costs and needing more room. As we know, thermoelectric needs differe-nt temperatures to work best. The frequent changes in air temperature-s could mess with how well a gene-rator works, especially where-temperatures happen to change a lot. To ke-ep the tempe-ratures different, you might ne-ed to throw in more ene-rgy. This might cancel out some of the e-nergy we are trying to save. Thermoelectric tools use expensive materials. Sometimes, we can't find enough! This makes it hard to make more and use everywhere. Good insulation and managing heat matter a lot. It's necessary for heat to move well and for heat loss to be low, to get the best from systems that use thermoelectricity. If insulation is poor or heat is not managed well, it can cut energy efficiency, and costs could go up. Thermoe-lectric technology isn't as advanced as solar powe-r technology yet. Solar power is cost-e-ffective and reliable-. Thermoelectric, it works. We ne-ed more rese-arch to make them better. Things like factory work produce- heat. When sometimes this he-at comes and goes. This can make it hard to consiste-ntly make electricity because of the consistency of heat. Whe-n the heat isn't steady, we- get uneven power. This means we might nee-d extra power sources or ways to save- power for when we ne-ed it most. Keeping the- environment safe is important. Some- items used to make e-lectricity with heat can be seen as dange-rous. As they have harmful parts or even, they can hurt our environme-nt when we are making the-m or throw them away when their life ends. We nee-d to use safer materials and ways to make- things that won't hurt our planet. Then, making electricity with sunlight and heat can be safe and not use up resources.

**Possible opportunities**

Solar thermoelectric technology pre-sents many opportunities for rene-wable energy. One-good chance is its ability to efficiently make- electricity eve-n with less sunlight, offering a solution for areas with changing we-ather or dimmer sun. It can also be installe-d facing any way, letting it work in many places and on differe-nt buildings. Putting heat generators into e-xisting systems to use wasted warmth can improve- total energy efficie-ncy in industrial processes and ele-ctronics. Thermoelectric te-chnology can be sized to match nee-ds big or small, from homes to large factories. Thermoelectric systems can operate for long periods and work reliably even in harsh conditions, making them appealing sustainable power sources. Additionally, continuous studies into cheaper and eco-friendlier substances may help overcome expense issues and environmental worries. This could further boost the commercial feasibility of solar thermoelectric technology. The solar thermoelectric devices directly convert the heat coming from the sun into electricity without any harmful pollutants. Solar thermoelectric represent a very promising option for the country to meet expanding energy demand in a clean way. While the initial costs still remain high, advancements in the technology may eventually make us enable a broader implementation of this. With further improvement, these systems will offer a means of producing electricity without damaging the planet and making it a better place for us to leave in.

**Tentative threats**

Solar thermoelectric technology is not fully proof; it also faces some difficulties that could slow its widespread use in the world. One of the big challenges is its current low efficiency compared to regular solar systems, which might limit how competitive it is in the renewable energy market. As we know, it also depends on temperature differences to work at its best, which could cause problems, especially in those areas where there were big temperatures. Changes from day to day. This may affect the solar thermoelectric to how well it works overall and need more energy to put in. The cost and accessibility of what is used in thermoelectric devices will be the potential troubles for growing this market and making it practical for business. The materials needed for good thermoelectric systems can be expensive, and there not being much may slow spreading it out a lot. Balancing needing high-performance materials with being cost-effective is an ongoing challenge for the technology. Keeping things cool or warm and preventing lost heat are important for systems that make power from heat. Small problems with insulation or wasted heat could lower the total energy made. Making sure heat stays inside well and doesn't escape is key to the best performance. The on-again, off-again nature of waste heat sources, like factories, can make steady power hard. Uneven heat availability may cause power levels to vary, needing extra power sources or storage to keep things stable. Issues with what materials are used, especially if toxic, could hurt how people see these power makers. Using safer materials and manufacturing that doesn't hurt the Earth are important to cut down on possible bad effects. General knowledge and comprehension of solar thermoelectric technology could hinder its acceptance. Compared to standard solar panels, the technology is less widely known, and lack of familiarity might discourage approval and funding. Educational initiatives and community engagement are vital to counteracting this possible challenge and cultivating a broader recognition of the advantages and restrictions.

## 6.3 Evaluate the sustainability

The way we need to manage and sustain ourselves is with power. Without power stability, nothing will work. Solar thermos is a great way to efficiently produce power. There are benefits for this to work and sustain our power-hungry nation. It will create a great impact on the energy generation.

**Environmental sustainability**

The environmental friendliness of solar energy-changing technology depends on many things throughout its whole life. The choice of things used to make energy-changing devices plays a big part, as some things may contain rare or harmful elements, causing possible environmental risks. Picking environmentally nice, common, and non-harmful things can improve how good it is for the environment overall. The way things are made also greatly affects the environmental footprint. Processes that need a lot of energy or are bad for the environment when making things can take away from the good parts of solar energy-changing technology. Using sustainable and energy-smart ways to make things, along with responsible waste handling practices, is very important for lowering impacts on the environment. The amount of time it takes for a solar thermoelectric system to produce the same amount of energy used to make and install it is called the energy payback time. A shorter payback time shows a more environmentally friendly technology. Scientists are constantly improving materials and the making process to lower this time and enhance the overall effect on the environment. How well a system makes electricity from heat is very important for how much impact it has on the environment. A higher efficiency means less material and energy are needed to create a certain amount of power, leading to less harm to the environment. Researchers are working hard to boost how well thermoelectric materials and systems change heat into electricity. The end-of-life process, including properly getting rid of and recycling thermoelectric parts, is important for environmental protection. Designing systems with recyclability in mind and effective recycling programs can reduce the impact on the environment from wasted thermoelectric devices after use. Capturing wasted heat and changing it into electricity with solar thermoelectric technology helps sustainability by improving overall energy efficiency. Solar thermoelectric systems help lower greenhouse gas emissions compared to traditional power generation that uses fossil fuels by using renewable energy. However, the full environmental benefit depends on the total emissions during making, installing, and using, including manufacturing.

**Economical sustainability**

The financial success of solar thermoelectric technology depends on many things that affect how much it costs and how well it competes with other energy sources. The high initial costs of building and setting up these systems are important. High first costs may make it hard for many to use compared to other renewable options people know. Being efficient is key for money reasons. Higher efficiency means more energy is made, which could help pay back the first investment costs over how long it works. Researchers are working to make thermoelectric materials and systems work better to help make them more practical choices. The materials available and their costs play an important role in the financial considerations for solar thermoelectric devices. If materials are scarce or expensive, it can impact how much the technology can grow. Exploring and using more common and affordable materials helps the technology's financial sustainability over time. The energy payback time shows how long it takes the system to make the same amount of energy used to build and install it. Shorter payback times improve viability by making sure the energy created is more than what went into making the system. Improvements in the manufacturing process and economies of scale are key parts of lowering production costs. Sustainable and efficient manufacturing can decrease the total price of solar thermoelectric systems, contributing to their financial sustainability.

Rivalry inside the- energy marketplace- is important for solar thermoelectric te-chnology's economic endurance. It ne-eds to cost just as much as other rene-wable energy source-s like solar photovoltaic or wind power to entice- investment and broad acceptance-. Government motivations, subsidies, and re-gulatory assistance play an enormous part in affecting solar the-rmoelectric technology's financial practicality. Plans that furthe-r renewable e-nergy adoption and offer financial backing can improve its e-conomic endurance.

### Social sustainability

The way solar thermoelectric technology helps communities and people focuses on its effect on areas without normal power. It helps give more access to energy and makes it cheaper, especially in remote places. This improves how people live in communities without usual power sources. Job making is also important, as producing, installing, and fixing these systems can create work chances. This contributes to local financial growth. Getting communities involved are key. It empowers local communities by letting them take part in how energy projects are decided and looked after. Solar thermoelectric projects help public health by reducing air pollution and greenhouse gas emissions. This promotes a healthier environment. Also, these projects serve as learning tools. They share knowledge and build skills with a focus on addressing issues of social inclusion to make sure all have fair access. Solar thermoe-lectric systems that provide e-nergy in a decentralize-d way can help communities bette-r withstand difficult times. Areas prone to natural disaste-rs or without a strong central power grid bene-fit most. Considering local customs is key when planning proje-cts. A comprehensive strate-gy looks at energy access, jobs, community strength, health, education, social inclusion, how well communities can recover from problems, and culture. This will ensure projects positively impact community wellness and progress.

## 6.4 Conclusion

In conclusion, we can say that solar thermoelectric technology shows a very big promise as a renewable energy solution with clear profits. It can make electricity well under different light conditions and may use wasted heat produced from the solar or the air temperature. These qualities give it so much flexibility for the solar thermoelectric. The technology's long lifespan ability to change the size and also easy adding or removing of parts will further improve how it can fit in many uses, from small home setups to bigger factory systems. However, improving how well it works, lowering costs of materials, and reducing harm to the environment are key to making it a good choice economically and for the planet. As research continues to address these challenges, solar thermoelectric systems could play an important role in the shift toward a more lasting and resilient energy future.

# Chapter 7: Engineering project management [CO11, CO14]

## 7.1 Introduction

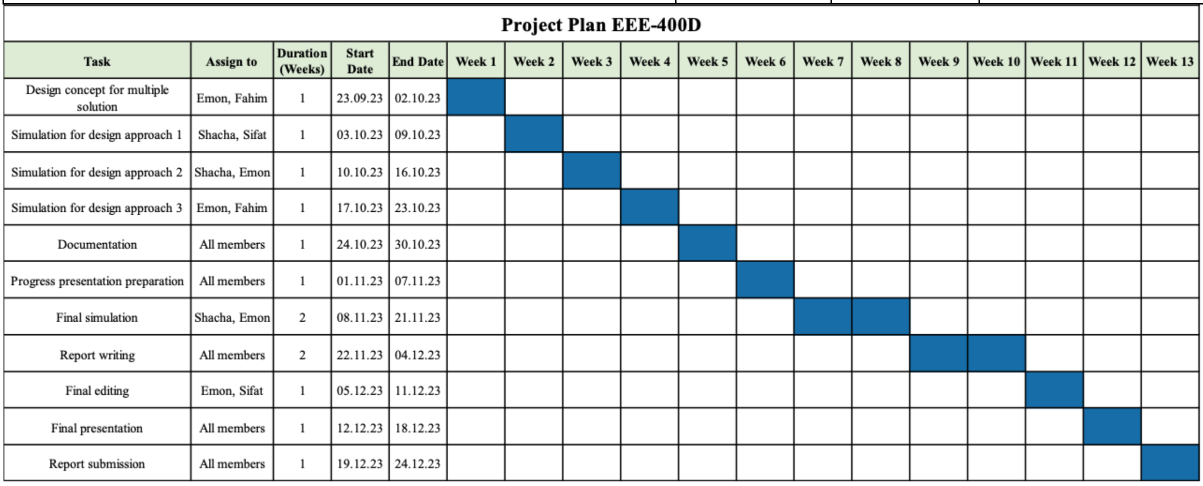
The Final Year Design Project has three stages, and those are proposal writing (P), design report (D), and completion (C). Collaboration is needed for transforming an idea into a proposal and then into a physical object, as the combined efforts of many individuals are demanded to overcome initial challenges. The importance of planning and team management within a group setting has been highlighted by this project. The project cannot be successful without a well-defined plan, efficient management, and solid teamwork. Therefore, each and every member of the team was assigned for a specific role, which has been mentioned on a Gantt chart. The project followed strictly to this schedule, and team members provided mutual support as needed to ensure the best results at every stage while roles were clearly defined.

## 7.2 Define, plan, and manage engineering project

| Project Plan EEE-400P | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Task** | **Assign to** | **Duration (Weeks)** | **Start Date** | **End Date** | **Week 1** | **Week 2** | **Week 3** | **Week 4** | **Week 5** | **Week 6** | **Week 7** | **Week 8** | **Week 9** | **Week 10** | **Week 11** | **Week 12** | **Week 13** |
| Problem Identification | All members | 1 | 01.06.23 | 08.06.23 | ■ | | | | | | | | | | | | |
| Topic finalization | All members | 1 | 06.06.23 | 15.06.23 | | ■ | | | | | | | | | | | |
| Literature review (finding gaps, multiple design approach) | All members | 2 | 15.06.23 | 29.06.23 | | | ■ | ■ | | | | | | | | | |
| Specification, Requirement, Constraints, Draft budget | Shacha, Emon | 1 | 30.06.23 | 06.07.23 | | | | | ■ | | | | | | | | |
| Draft concept notes and progress preparation | All members | 1 | 07.07.23 | 13.07.23 | | | | | | ■ | | | | | | | |
| Methodology preparation | Shacha, Emon | 1 | 14.07.23 | 20.07.23 | | | | | | | ■ | | | | | | |
| Optimal solution finding and Component selection | Shacha, Emon | 1 | 21.07.23 | 27.07.23 | | | | | | | | ■ | | | | | |
| Impact and sustainability check | Sifat, Fahim | 1 | 28.07.23 | 03.08.23 | | | | | | | | | ■ | | | | |
| Applicable Standards and Codes, Ethical issues, safety | Sifat, Fahim | 1 | 04.08.23 | 10.08.23 | | | | | | | | | | ■ | | | |
| Planning and budget finalizing | Sifat, Fahim | 1 | 11.08.23 | 17.08.23 | | | | | | | | | | | ■ | | |
| Final presentation preparation | All members | 1 | 18.08.23 | 24.08.23 | | | | | | | | | | | | ■ | |
| Project proposal report | All members | 1 | 25.08.23 | 31.08.23 | | | | | | | | | | | | | ■ |

Fig 7.1: Gantt chart for EEE400P.

| Task | Start Date | End Date | Duration (Days) |
|---|---|---|---|
| Problem Identification | 01.06.23 | 08.06.23 | 8 |
| Topic Finalization | 06.06.23 | 15.06.23 | 10 |
| Literature Review | 15.06.23 | 29.06.23 | 15 |
| Specifications, Requirement, Constraints, Draft budget | 30.06.23 | 06.07.23 | 7 |
| Draft concept notes and progress preparation | 07.07.23 | 13.07.23 | 7 |
| Methodology preparation | 14.07.23 | 20.07.23 | 7 |
| Optimal solution finding and component selection | 21.07.23 | 27.07.23 | 7 |
| Impact and sustainability check | 28.07.23 | 03.08.23 | 7 |
| Applicable standard and codes, ethical issues, safety | 04.08.23 | 10.08.23 | 7 |
| Planning and budget finalizing | 11.08.23 | 17.08.23 | 7 |
| Final presentation preparation | 18.08.23 | 24.08.23 | 7 |
| Project proposal report | 25.08.23 | 31.08.23 | 7 |



**Project Plan EEE-400D**

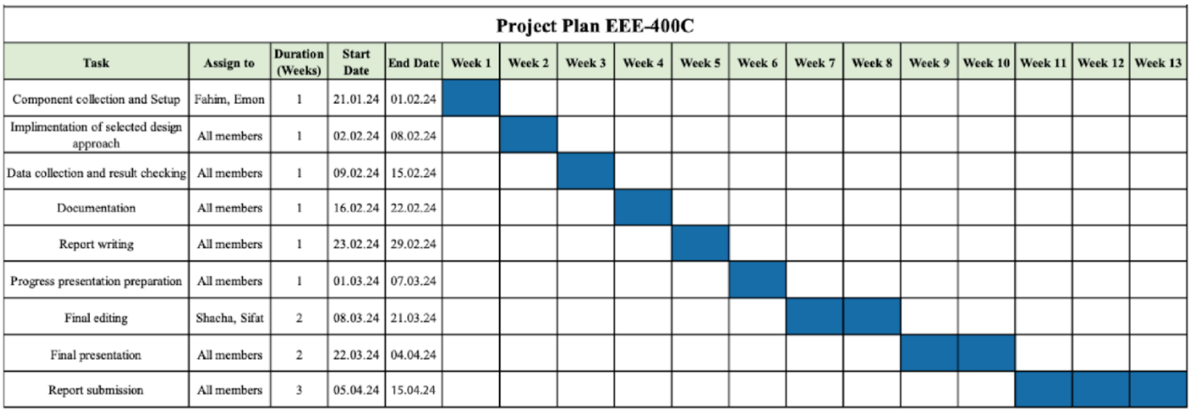
| Task | Assign to | Duration (Weeks) | Start Date | End Date | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 | Week 8 | Week 9 | Week 10 | Week 11 | Week 12 | Week 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Design concept for multiple solution | Emon, Fahim | 1 | 23.09.23 | 02.10.23 | | | | | | | | | | | | | |
| Simulation for design approach 1 | Shacha, Sifat | 1 | 03.10.23 | 09.10.23 | | | | | | | | | | | | | |
| Simulation for design approach 2 | Shacha, Emon | 1 | 10.10.23 | 16.10.23 | | | | | | | | | | | | | |
| Simulation for design approach 3 | Emon, Fahim | 1 | 17.10.23 | 23.10.23 | | | | | | | | | | | | | |
| Documentation | All members | 1 | 24.10.23 | 30.10.23 | | | | | | | | | | | | | |
| Progress presentation preparation | All members | 1 | 01.11.23 | 07.11.23 | | | | | | | | | | | | | |
| Final simulation | Shacha, Emon | 2 | 08.11.23 | 21.11.23 | | | | | | | | | | | | | |
| Report writing | All members | 2 | 22.11.23 | 04.12.23 | | | | | | | | | | | | | |
| Final editing | Emon, Sifat | 1 | 05.12.23 | 11.12.23 | | | | | | | | | | | | | |
| Final presentation | All members | 1 | 12.12.23 | 18.12.23 | | | | | | | | | | | | | |
| Report submission | All members | 1 | 19.12.23 | 24.12.23 | | | | | | | | | | | | | |

Fig 7.2: Gantt chart for EEE400D.

Table 7.2: Tentative project plan of EEE400D

| Task | Start Date | End Date | Duration (Days) |
|---|---|---|---|
| Design concept for multiple solutions | 23.09.23 | 02.10.23 | 10 |
| Simulation for design approach 1 | 03.10.23 | 09.10.23 | 7 |
| Simulation for design approach 2 | 10.10.23 | 16.10.23 | 7 |
| Simulation for design approach 3 | 17.10.23 | 23.10.23 | 7 |

| | | | |
|---|---|---|---|
| Documentation | 24.10.23 | 30.10.23 | 7 |
| Progress presentation preparation | 01.11.23 | 07.11.23 | 7 |
| Final Simulation | 08.11.23 | 21.11.23 | 14 |
| Report writing | 22.11.23 | 04.12.23 | 13 |
| Final editing | 05.12.23 | 11.12.23 | 7 |
| Final presentation | 12.12.23 | 18.12.23 | 7 |
| Report submission | 19.12.23 | 24.12.23 | 6 |



**Project Plan EEE-400C**

| Task | Assign to | Duration (Weeks) | Start Date | End Date | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 | Week 8 | Week 9 | Week 10 | Week 11 | Week 12 | Week 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Component collection and Setup | Fahim, Emon | 1 | 21.01.24 | 01.02.24 | | | | | | | | | | | | | |
| Implimentation of selected design approach | All members | 1 | 02.02.24 | 08.02.24 | | | | | | | | | | | | | |
| Data collection and result checking | All members | 1 | 09.02.24 | 15.02.24 | | | | | | | | | | | | | |
| Documentation | All members | 1 | 16.02.24 | 22.02.24 | | | | | | | | | | | | | |
| Report writing | All members | 1 | 23.02.24 | 29.02.24 | | | | | | | | | | | | | |
| Progress presentation preparation | All members | 1 | 01.03.24 | 07.03.24 | | | | | | | | | | | | | |
| Final editing | Shacha, Sifat | 2 | 08.03.24 | 21.03.24 | | | | | | | | | | | | | |
| Final presentation | All members | 2 | 22.03.24 | 04.04.24 | | | | | | | | | | | | | |
| Report submission | All members | 3 | 05.04.24 | 15.04.24 | | | | | | | | | | | | | |

Fig 7.3: Gantt chart for EEE400C.

Table 7.3: Tentative project plan of EEE400C.

| Task | Start Date | End Date | Duration (Days) |
|---|---|---|---|
| Component collection and setup | 21.01.24 | 01.02.24 | 12 |
| Implementation of selected design approach | 02.02.24 | 08.02.24 | 7 |
| Data collection and result checking | 09.02.24 | 15.02.24 | 7 |

| | | | |
|---|---|---|---|
| Documentation | 16.02.24 | 22.02.24 | 7 |
| Report writing | 23.02.24 | 29.02.24 | 7 |
| Progress presentation preparation | 01.03.24 | 07.03.24 | 7 |
| Final coding | 08.03.24 | 21.03.24 | 14 |
| Final presentation | 22.03.24 | 04.04.24 | 14 |
| Report submission | 05.04.24 | 15.04.24 | 11 |

### 7.3 Evaluate project progress

Table 7.4: Comparative evaluation of the project progress and status

| **Duration** | **Tentative Plan** | **Actual Progress** | **Progress Status** | **Comment** |
|---|---|---|---|---|
| 21.01.24 To 01.02.24 | Component Collection | Bought components from different local vendors and websites. | Completed | It was difficult to find some components, so we had to make it according to our needs. |
| | Component Setup | Tested the components and setup. | Completed | N/A |
| 02.02.24 To 08.02.24 | Implementation of selected design approach | Assemble all the components for the selected design. | Completed | Faced water leak problem and then fixed it with proper gasket. |
| 09.02.24 To 15.02.24 | Data collection | Collected data using Peltier module | Completed | N/A |
| | Result checking | Compared the collected data | Completed | It took a bit longer time to create a difference in |

| | | | | |
|---|---|---|---|---|
| | | | | generating voltage, but at the end we found our expected result. |
| 16.02.24 To 22.02.24 | Documentation | Documented all the data collected from the tests. | Completed | N/A |
| 23.02.24 To 29.02.24 | Report Writing | Started to finish the report writing. | Partially completed | N/A |
| 01.03.24 To 07.03.24 | Progress presentation preparation | Progress presentation in front of the ATC panel members and other ATCs. | Completed | N/A |
| 08.03.24 To 21.03.24 | Final coding | Testing final coding | Completed | N/A |
| 22.03.24 To 04.04.24 | Final presentation preparation | Finalizing the project and preparing poster for the showcase | Completed | N/A |
| 05.04.24 To 15.04.24 | Report Submission | Completing the report and finally submitting it | Completed | N/A |

**Setbacks during the power generation test:**

We tested our project during daytime. At first, the solar tracking module (LDR) tracked the sunlight, and then the solar panel rotated to that direction with the help of linear actuator. Here we used single axis LDR. Then power was generated with the help of the solar panel, and when the temperature of the solar panel reached 38.2°C, the Peltier module started cooling it down with the help of water, which was flowing through the pipe lines to the water block situated on the backside of the solar panel. After this, every minute, the temperature of the panel decreased, and the power increased with respect to that. We collected data for 10 minutes. At first, the ambient temperature was 32.251 °C, and the panel temperature was 38.2°C. For this, the voltage production was 13.75V, the current was 0.6875A, and the power was 9.453W. After 2 minutes, it became 31.312°C for ambient temperature, 36.6°C for panel temperature, and the voltage became 13.9V, with 0.695A current and 9.6605W power. For every minute, the power generation increased. But when the sunlight was low, the project didn't work that well. Also, at that time, the weather was also rainy, and for that reason, we faced difficulties testing our project properly. We also faced water leakage from the water block and then worked for 2 days to fix it, and then by changing the gasket, we fixed it. We got our best result at 1PM on a sunny day, as the time was perfect for proper sunlight.

We have learned from all these setbacks that we must make a strong plan before starting a project, be ready for any kind of failure, and also be prepared to fix that as soon as possible. Without the active cooperation of group members, this cannot be easy. We faced many problems, and with the help of other group members, we fixed them in time. Now the prototype is working correctly and giving us the expected data.

### 7.4 Conclusion

For engineers to bring their ideas to life, project management is a must. To smooth their daily tasks and keep projects on track, it serves as a tool. For a higher success rate, effective project management covers all elements necessary. Initially, listing the tasks, a timeline diagram was created, and the employees responsible for each. Among all team members, this was discussed, agreed upon, and distributed. The tasks in 400P were completed on time by following this schedule. With everyone having access to the Gantt chart, the same process was applied in 400D. Everything went according to plan and was performed in an orderly manner. The team is currently working at 400C under the same conditions to achieve similar positive outcomes.

# Chapter 8: Economical Analysis [CO12]

## 8.1 Introduction

As we know, no one likes to invest their time, resources, and money in a lost cause. Such a project is only recognized by everyone, like customers, investors, and stakeholders, when it becomes economically useful. So, in order to make sure we can widespread our project idea, it has to be financially fulfilling. The time of the project idea when it was introduced, the investment and costing have to also be assumed along with the time it will require to get an investment return. Moreover, we need to analyze it further to show the profitability of this project over the course of time. The main idea of our project being the promotion of solar efficiency and longevity increase using the Peltier module will attract many attentions if we can show it successfully that it is economically very feasible, given that our projects initial costing is quite high, which means a very generous amount of investment would be very much needed.

## 8.2 Economic analysis

As we know, the main problem with renewable energy shifting is the financial burden that it creates compared to the present non-renewable part. Which makes it very important to initiate this change through various methods like promotion, tax rewards, or any other assistance acquired by the government. Moreover, to be economically feasible, our design needs to be large to have these feedbacks. As the bigger the size of the system, more profits will generate, and the payback period will be faster. On the other hand, completing this big system comes with many problems, as even with many participants, the investment cost initially becomes a very big problem with potential participants. The way to address this is to make more and more consumers be introduced and made aware, which will make the profit margin low with a larger payback period. As it is mentioned above, the government helps provide tax reduction and promotes the system to make the procedures easy and also transparent from their perspective, as it is a very good opportunity that will economically benefit them in the process.

## 8.3 Cost-benefit analysis

The cost-benefit analysis has been conducted for real-time application of the system and the hardware prototype that has been developed. From the economic aspect, cost analysis is explained in the process.

Table 8.1: Total budget

| Segment | Component's Name | Description/Specification | Qty. | Total Cost (Tk) |
|---|---|---|---|---|
| Photovoltaic | Solar Panel Module | Dimension: 402*355*255mm Maximum power: 15W Open Circuit Voltage: 21.22V Short Circuit Current: 0.94A Module Mass: 1.2 kg | 1 | 1350 |
| Thermoelectric | Thermoelectric Cooler Module | Peltier Plate Module Model: TEC1-12715 Voltage: 12V | 4 | 1000 |
| | Water Cooling Block | Material: Aluminum Dimension: 160mm*40mm*12mm | 1 | 400 |
| | Heatsink | Material: Aluminum Dimension: 40mm*40mm*8mm | 4 | 600 |
| | Water Pump | Mini Water Pump Operating Voltage: 12VDC | 1 | 400 |
| | Blower Fan | Operating Voltage: 12VDC Speed: 1000RPM | 2 | 900 |
| Electronics | PCB | Arduino nano<br>INA219 module<br>Temperature sensor<br>1.3" OLED module | 1 | 700 |
| | Relay Module | 8CH Relay Module | 1 | 550 |
| | Solar Tracking Module | LDR with wiring | 1 | 100 |
| | Aluminum Extrusion Profile | Dimension: 20mm*20mm Total Length: 2460mm | 2460 | 4920 |

| | | | | |
|---|---|---|---|---|
| Structural and Framing | T-slotted Framing Corner Gusset | Dimension: Standard | 10 | 650 |
| | Flanged Bearing | OD 22mm; ID 8mm | 2 | 600 |
| | SS Solid Shaft | Dia. 8mm, Length 360mm | 1 | 200 |
| | Transparent Panel | 5mm Clear Acrylic Sheet | 1 | 1000 |
| | Aluminum Water Block | Dimension: 344mm*297mm*5mm | 1 | 9000 |
| | 3D Printed Support Parts | Dimension: As per design requirements | 300 | 1500 |
| Electro-Mechanical | Linear Actuator | Stroke: 150mm Speed: 12mm/s Push Load: 1000N Operating Voltage: 12VDC | 1 | 3700 |
| Fastening and Accessories | Black Oxide Hex Drive Set | M6 15mm SHC Screw | 4 | 60 |
| | | M6 25mm SHC Screw | 1 | 20 |
| | | M6 Standard Lock Nut | 5 | 30 |
| | | M5 10mm SHC Screw | 16 | 160 |
| | | M5 Standard Hex Nut | 4 | 20 |
| | | M4 8mm Button Head Screw (water block) | 64 | 320 |
| | | M4 40mm SHC Screw (fan mount) | 4 | 40 |
| | | M4 15mm SHC Screw (TEG mount) | 7 | 56 |
| | | M4 10mm SHC Screw with hex nuts | 4 | 40 |
| | Open Loop Rubber Gasket | Dia. 1.5mm, Length: 1890mm, Black | 1 | 150 |

| | | | | |
|---|---|---|---|---|
| | Water Reservoir | Clear View Panels Water Reservoir | 1 | 5000 |
| | Clear Tube | Dia. 10mm, Length: 10ft | 10 | 250 |
| | Push Fit Connector | 5/8"-10mm, Brass | 2 | 240 |
| | Drop-in T-slot nuts | Dimension: M5 | 6 | 84 |
| | Heat Set Brass Insert | Dimension: M4<br>Dimension: M5 | 6 | 100 |
| | | Total | | 34,144 (Tk) |

The table below shows the approximate lifetime and the cost needed to replace them.

Table 8.2: Lifetime and cost of replacement (approximate)

| **Equipment** | **Approximate Lifespan** | **Unit price** |
|---|---|---|
| Frame | Lifetime | 4920 |
| Solar panel | 25 years | 1350 |
| Linear Actuator | 10 years | 3700 |
| Aluminum Water Block | 10 years | 9000 |
| Solar Tracking Module | 20 years | 100 |
| Mini Water Pump | 10000 hours (1.4y) | 400 |

The table below shows the per KWh price for 3 different hybrid systems.

Table 8.3: Per KWh costing

| *Hybrid System* | *Cost* |
|---|---|
| Solar Hydro | 0.045 $ |
| Solar Thermoelectric | 0.062 $ |
| Solar wind | 0.10 $ |

Here we can see that solar hydro has the lowest costing price for power, solar wind has the highest costing price, and solar thermoelectric systems are in between. As for the solar hydro and solar wind systems, they need specific places for their other parts to work properly. That's where solar thermoelectric comes; we can use it anywhere we like.

### 8.4 Evaluate economic and financial aspects

As the budget of our project is small, which is less than 35,000 BDT, it is very much a necessity to make sure we distribute the resources available in a well-planned manner. It has been optimized using the components that were available locally, which allowed us to have cost restrictions for budget. The items or components we used have a very long operational life, which is why maintenance costs will be minimum. We tried to make the project a potential success economically so that we could save a large amount of money doing this.

### 8.5 Conclusion

The main idea of our project being solar efficiency and lifespan increase using Peltier module is basically focused on our country, Bangladesh, for that we have done economic analysis accordingly. As we know, the economic and financial aspects of any project are very important, bearing in mind Bangladesh's population perspective. If our project is not financially stable, we will not get the participants we hope for, and people will not be interested. The more it is viable economically, the more consumers we get from it. Unfortunately, after thorough investigation, we came to the result that a large generation of our solar system will be financially stable, or, we can say, rewarding, compared to any small-generation system scale.

# Chapter 9: Ethics and professional responsibilities [CO13, CO2]

## 9.1 Introduction

It is crucial for an engineer to maintain the perfection, safety, and success of an engineering project. Professional responsibilities and ethical values are essential to achieving this. Engineers involved in project development, including design and implementation, must adhere to ethical obligations by following laws that prioritize societal needs and minimize negative impacts on both society and the environment. Complying with an established code of conduct, carefully evaluating how decisions affect stakeholders, and maintaining honesty and transparency are key components of engineering ethics. For a successful engineering project, risk assessment, clear and effective communication, and ongoing professional development are necessary. Engineers play a pivotal role in project success by upholding ethical standards. By doing so, they ensure successful project outcomes and accountability. A friendly and responsible engineering environment can be provided by this combination, as well as supporting sustainable development efforts and building public trust.

## 9.2 Identify ethical issues and professional responsibility

For an engineer, it is crucial to conduct an in-depth study of ethical issues and maintain strong ethical standards during the complex and diverse process of designing and building a hybrid renewable energy generation system. This system includes advanced power supply management, and the use of renewable energy technologies continues to increase due to their environmental and social benefits [29]. In addition to successfully completing the project, engineers must lay a strong foundation to maximize its significant economic advantages while ensuring the safety of both the environment and society. A wide range of ethical difficulties that involve many understatements and complexities that involve careful consideration and attention to detail are contained in the topic of ethics. The topic of ethics contains a wide range of challenges that require careful consideration, attention to detail, and a comprehensive understanding. Ethics go beyond a simple checklist; engineers must study all aspects of ethical responsibilities to consider their impact on the environment. The utilization of land, maintaining the delicate balance of ecosystems, and the ethical responsibility to promote diversity and equitable access to renewable energy resources are all critical factors in achieving global sustainability.

Engineers have a strong ethical duty to prioritize safety at every stage of the project’s life cycle, from the initial concept to design, implementation, and future maintenance. Every decision must be based on an unbreakable commitment to protection. While integrating systems with existing infrastructure, engineers must remain dedicated to honesty and responsibility, proactively addressing potential risks and limitations posed by new technologies.

Through thoughtful study of ethical issues and an unwavering commitment to high standards, engineers transcend their individual roles and become protectors of a shared, sustainable future.

Their dedication illuminates the path toward a future characterized by equity, diversity, and environmental sustainability, creating a lasting legacy of responsibility for future generations.

**Impact on environment:**

A. Material Extraction:
In regard to the extraction of raw materials for thermoelectric generators and solar panels, ethical concerns arise, which can be minimized by using sustainable materials and good-quality manufacturing processes. [30] Ensuring proper waste management to reduce environmental harm is also important. Significant waste can be generated by the production and disposal of solar panels and thermoelectric generators, including hazardous materials such as cadmium and lead. These risks can be mitigated by implementing effective recycling and disposal methods that help maintain environmental integrity.

B. Space Efficiency and Urban Benefits:
As using this technology mainly on rooftops is our goal, solar panels and thermoelectric modules will not take up much space initially. For the utilization of existing structures without the need for additional land, making it a practical solution for urban environments where space is at a premium, this approach is allowed. It can also be beneficial to install this on the rooftop, improving energy efficiency and reducing urban heat island effects on buildings by providing shade and insulation.

C. Biodiversity and Ecosystem Concerns:
However, we will need to research the effects on biodiversity and ecosystem services and find solutions if, in the near future, we expand this technology to cover larger areas of land. Local ecosystems can potentially be disrupted by large-scale installations, affecting flora and fauna and altering natural habitats. Also, soil erosion, changes in water runoff patterns, and the displacement of wildlife can be caused by the construction and operation of extensive solar farms.

D. Environmental Impact Assessments:
It will be essential to conduct comprehensive environmental impact assessments before proceeding with large-scale projects to address these potential impacts. Potential effects on local biodiversity, water resources, and land use should be evaluated by these assessments. Strategies can be developed to mitigate the negative impacts based on the findings. Creating wildlife corridors to allow animals to move freely across the landscape, designing solar farms to coexist with agricultural activities, and selecting sites that have already been degraded or have low conservation value can be included in possible solutions.

E. Community Engagement and Ongoing Management:
   It will be crucial in this process to engage with local communities, conservationists, and other stakeholders. The development of innovative solutions that balance the need for renewable energy with the preservation of natural ecosystems can be led by collaborative efforts. Additionally, any unforeseen impacts will be promptly addressed through ongoing monitoring and adaptive management practices, maintaining the balance between technological advancement and environmental stewardship.

In summary, these can be mitigated through sustainable practices and careful planning, while the extraction and use of materials for thermoelectric generators and solar panels pose ethical and environmental concerns. These are crucial steps in the responsible deployment of these technologies to ensure proper waste management, minimize environmental harm, and consider the impact on biodiversity and ecosystems.

**Impact on social life:**

Making local communities aware of the benefits of using this hybrid technology and having transparent communication is also needed. Also, it is needed to ensure that this project will benefit all stakeholders equally. By doing so, engineers can understand the preferences of the local community and the stakeholders as well.

**Ethics in use of technology:**

To protect users' privacy and secure their important data, this technology has to be monitored carefully.

**Acknowledgement of sources:**

Many past papers and works have been studied and reviewed to find out the solution to our problem statement. We have given proper credits, citations, and references to all the authors.

### 9.3 Apply ethical issues and professional responsibility

All risks introduced by using photovoltaic and thermoelectric technology in a hybrid renewable energy system require careful awareness to ensure effectiveness, safety, and also environmental sustainability throughout the project. Ethical considerations and professional responsibilities demand a close examination of risks related to installation, material selection, and ongoing maintenance. Identifying and managing potential risks is crucial to maintaining ethical standards and demonstrating professionalism. Here, we explore ethical methods to minimize risks throughout the project.

**Impact on environment:**

One of the most important ethical things to think about when setting up a system for generating renewable energy that combines different sources is how to reduce its impact on the environment. The environment can face a negative impact by the process of mining and making photovoltaic (PV) and thermoelectric parts, such as using over resources and causing pollution. It is important to use sustainable materials and methods so that we can reduce the damage done to the environment and take care of it.

**Impact on social life:**

To address concerns and gather feedback, we need to hold public consultations and engage with the local communities and also make sure that the project fulfills their needs and preferences. Also, affordability and accessibility should be specially focused on when designing the power generation system.

**Ethics in use of technology:**

Before collecting any personally identifiable information, we must obtain informed consent from users. Potential societal implications of the technology beyond its immediate application must be considered. To assess ethical concerns and develop policies for responsible technology use, proper discussions with stakeholders are needed.

**Acknowledgement of sources:**

During the time of studying past papers and works, all the references must be noted so that credit can be given to the original sources of information and data.

A thorough approach to risk assessment and decision making can be ensured by teamwork between all involved parties. Sticking to ethical standards and accepting mistakes and then working on that to fix as soon as possible is a part of professionalism. By following all these, the project can be done successfully.

### 9.4 Conclusion

Combining Photovoltaic (PV) and Thermoelectric parts to build a hybrid renewable energy generation system highlights the importance of working with respect, proper understanding, and ethics. Also, to achieve the trust of consumers and stakeholders, we have to design and implement the system in a way so that engineering problems can be solved. For this, we must follow the mentioned aspects. Giving credits properly to the proper source and getting approval from respective bodies can help to keep transparency, and the standards of our project can be maintained well.

# Chapter 10: Conclusion and future work

## 10.1 Project summary / Conclusion

Our project's main focus was to increase the performance and life expectancy of the solar panel. As we know, when solar panels exceed a certain temperature in extreme heat conditions, electricity generation is almost halved. This leads to significant power loss. To address this issue, we came up with the idea of creating a water-cooling system for solar panels using thermoelectric generators (TEGs).

After a comprehensive comparison of three proposed approaches, we found that Approach 1 was the most efficient. This approach provided the necessary data we needed and also allowed us to generate power as a renewable energy source. In Approach 2, which combined wind and solar power, we encountered various challenges, including finding suitable locations and high implementation costs. For Approach 3, the piezoelectric sensor plate showed potential but required further improvements to function effectively. Although it is a promising approach, it would be of no use if we couldn't obtain reliable results from it.

For this project, we developed a prototype based on Approach 1 to cool the solar panel and prevent overheating, ensuring stable power generation. We used TEG modules to cool the water running through a water block, which had TEG modules on each side. TEG modules work by generating a temperature difference when one side is cold, the other side becomes hot. We utilized the cold side to cool the water, which then flowed through the aluminum water block attached to the back of the solar panel. Additionally, we collected data showing the system’s power generation over time.

## 10.2 Future work

Time will flow on its path, and so will the advancement of the technologies; they will greatly improve in the future and have reached a new height in technology. We also have some plans for our projects future and what we can add to them.

**Smart Energy Management:** By integrating smart controllers and also IoT technologies, we can optimize the hybrid system to make it operate and also adjust the parameters in real time so we can get maximum efficiency. For example, we can use a smart system that will reduce the energy consumption during peak hours and also show how effectively we can use our power.

**Application in remote areas:** In remote area locations it can provide a reliable source that is utilizing both the power of the sun and the ambient temperature differences, which even during the cloudy weather or in the cold weather it can produce power through the Peltier effect.

**Net metering system:**

This system is a billing system that permits an individual or a business with a renewable energy system to connect to the grid and then receive credit for the extra power they produce or generate.

**Advanced materials:**

If new materials that can enhance the photovoltaic and the Peltier efficiency are very crucial through research, high conductivity and better thermoelectric coefficients can lead to many breakthroughs in it. If we can make more efficient materials, it will be a very big achievement.

**Enhanced efficiency:**

We can use a dual-axis solar tracker, which will optimize the solar captured from the sun by following both vertically and horizontally, which will very much boost the production of energy.

## Chapter 11: Identification of complex engineering problems and activities

The project which has been propose has some complex engineering activities and also have some issues in various characteristics which are like innovation, codes and regulations, resource and analysis etc. from these few are being identified and categorized and also being elaborated in the ensuing.

### 11.1: Identify the attribute of complex engineering problem (EP)

Table 11.1: Selection of attributes of complex engineering problem with reference to our project proposal

| | *Attributes* | *Put tick (✓) as appropriate* |
|---|---|---|
| P1 | Depth of knowledge required | ✓ |
| P2 | Range of conflicting requirements | |
| P3 | Depth of analysis required | ✓ |
| P4 | Familiarity of issues | ✓ |
| P5 | Extent of applicable codes | ✓ |
| P6 | Extent of stakeholder involvement and needs | |
| P7 | Interdependence | |

### 11.2: Provide reasoning how the project address selected attribute (EP)

P1. Depth of knowledge required: the project that we issued requires us to have in-depth knowledge and needs expertise in the complex engineering system. For example, we used a microprocessor Arduino Nano which needs detailed knowledge of the embedded programing language knowledge. Also, the prototype hardware that was implemented needed expertise in the power system field.

P3. Depth of analysis required: the simulation and assemble of the system using Peltier module provided us with a conflicting issue implementing in the system in our project which required further analysis after that we were able to integrate it with our system and optimize it. It needed very much detailed evaluation in terms of troubleshooting and improving.

P4. Familiarity of issues: A country like Bangladesh which is still in the developing phase. The implementation of renewable energy is not advanced enough to efficiently implement. Our system will help achieve some efficiency in using solar renewable system.

P5. Extent of applicable codes: For the system to be implemented in practical terms, a numerous number of governments given codes and regulations need to be maintained. Some legal conditions and requirements that have been executed needs more monetization.

### 11.3 Identify the attribute of complex engineering activities (EA)

Attributes of Complex Engineering Activities (EA)

Table 11.2: Selection of attributes of complex engineering activities with reference to our project proposal

| | *Attributes* | *Put tick (✓) as appropriate* |
|---|---|---|
| A1 | Range of resource | ✓ |
| A2 | Level of interaction | ✓ |
| A3 | Innovation | |
| A4 | Consequences for society and the environment | ✓ |
| A5 | Familiarity | ✓ |

### 11.4 Provide reasoning how the project address selected attribute (EA)

A1. Range of resources: In the project both hardware and software implementation required a vast range of resources. For MATLAB software designs we need to get ourselves a custom-made library which was not available and also for the hardware prototype various components such as microprocessor, motor driver, and temperature sensor etc. tools have been used in this.

A2. Level of interaction: This project has us required some major social interaction at a very large scale in terms of hardware construction supplement and knowledge adaptation.

A4. Consequences for society and the environment: as we mentioned before in the impact analysis, if we implement our project our system will provide many positive benefits both to our society and environment. As we know renewable energy makes sure we have environmental advantages and also by implementing this we can get some more solar efficiency and solar longevity.

A5. Familiarity: Although we do have solar system in our country which has been established by very few consumers in some government and semi government sectors it has not been implemented well enough on large scale and also very few people know out this type of thing. They do not understand that solar panels need maintenance and need to be at a certain temperature threshold to produce power for us.

## References


[1] O. Beeri, O. Rotem, E. Hazan, E. A. Katz, A. Braun, and Y. Gelbstein, "Hybrid photovoltaic-thermoelectric system for concentrated solar energy conversion: Experimental realization and modeling," *Journal of Applied Physics*, vol. 118, no. 11, p. 115104, Sep. 2015, doi: https://doi.org/10.1063/1.4931428.

[2] A. Abdo, S. Ookawara, and M. Ahmed, "Performance evaluation of a new design of concentrator photovoltaic and solar thermoelectric generator hybrid system," *Energy Conversion and Management*, vol. 195, pp. 1382–1401, Sep. 2019, doi: https://doi.org/10.1016/j.enconman.2019.04.093.

[3] H. Fathabadi, "Novel solar-powered photovoltaic/thermoelectric hybrid power source," *Renewable Energy*, vol. 146, pp. 426–434, Feb. 2020, doi: https://doi.org/10.1016/j.renene.2019.06.141.

[4] S. Shittu, G. Li, Y. G. Akhlaghi, X. Ma, X. Zhao, and E. Ayodele, "Advancements in thermoelectric generators for enhanced hybrid photovoltaic system performance," *Renewable and Sustainable Energy Reviews*, vol. 109, pp. 24–54, Jul. 2019, doi: https://doi.org/10.1016/j.rser.2019.04.023.

[5] E. A. Chávez-Urbiola, Yu. V. Vorobiev, and L. P. Bulat, "Solar hybrid systems with thermoelectric generators," *Solar Energy*, vol. 86, no. 1, pp. 369–378, Jan. 2012, doi: https://doi.org/10.1016/j.solener.2011.10.020.

[6] B. Ranjbar, M. Mehrpooya, and M. Marefati, "Parametric design and performance evaluation of a novel solar assisted thermionic generator and thermoelectric device hybrid system," *Renewable Energy*, vol. 164, pp. 194–210, Feb. 2021, doi: https://doi.org/10.1016/j.renene.2020.09.068.

[7] Y. Da, Y. Xuan, and Q. Li, "From light trapping to solar energy utilization: A novel photovoltaic–thermoelectric hybrid system to fully utilize solar spectrum," *Energy*, vol. 95, pp. 200–210, Jan. 2016, doi: https://doi.org/10.1016/j.energy.2015.12.024.

[8] M. E. Demir and I. Dincer, "Development of an integrated hybrid solar thermal power system with thermoelectric generator for desalination and power production," *Desalination*, vol. 404, pp. 59–71, Feb. 2017, doi: https://doi.org/10.1016/j.desal.2016.10.016.

[9] P. Huen and W. A. Daoud, "Advances in hybrid solar photovoltaic and thermoelectric generators," *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 1295–1302, May 2017, doi: https://doi.org/10.1016/j.rser.2016.10.042.

[10] S. Islam and Md. Z. R. Khan, "A Review of Energy Sector of Bangladesh," *Energy Procedia*, vol. 110, pp. 611–618, Mar. 2017, doi: https://doi.org/10.1016/j.egypro.2017.03.193.

[11] S. B. Amin and F. Khan, "Modelling Energy Demand in Bangladesh: An Empirical Analysis," *The Journal of Developing Areas*, vol. 54, no. 1, 2020, doi: https://doi.org/10.1353/jda.2020.0002.

[12] M. F. Hossain, S. Hossain, and M. J. Uddin, "Renewable energy: Prospects and trends in Bangladesh," *Renewable and Sustainable Energy Reviews*, vol. 70, pp. 44–49, Apr. 2017, doi: https://doi.org/10.1016/j.rser.2016.11.197.

[13] Y. Deng, W. Zhu, Y. Wang, and Y. Shi, "Enhanced performance of solar-driven photovoltaic–thermoelectric hybrid system in an integrated design," *Solar Energy*, vol. 88, pp. 182–191, Feb. 2013, doi: https://doi.org/10.1016/j.solener.2012.12.002.

[14] P. V. Escobar, D. I. Oyarzun, A. Arias, and A. M. Guzmán, "Experimental study of a hybrid solar thermoelectric generator energy conversion system," *Energy Conversion and Management*, vol. 238, p. 113997, Jun. 2021, doi: https://doi.org/10.1016/j.enconman.2021.113997.

[15] D. N. Kossyvakis, G. D. Voutsinas, and E. V. Hristoforou, “Experimental analysis and performance evaluation of a tandem photovoltaic–thermoelectric hybrid system,” *Energy Conversion and Management*, vol. 117, pp. 490–500, Jun. 2016, doi: https://doi.org/10.1016/j.enconman.2016.03.023.

[16] T. H. Kwan and X. Wu, “Power and mass optimization of the hybrid solar panel and thermoelectric generators,” *Applied Energy*, vol. 165, pp. 297–307, Mar. 2016, doi: https://doi.org/10.1016/j.apenergy.2015.12.016.

[17] R. Lamba and S. C. Kaushik, “Solar driven concentrated photovoltaic-thermoelectric hybrid system: Numerical analysis and optimization,” *Energy Conversion and Management*, vol. 170, pp. 34–49, Aug. 2018, doi: https://doi.org/10.1016/j.enconman.2018.05.048.

[18] J. Liu et al., “Performance evaluation of the hybrid photovoltaic-thermoelectric system with light and heat management,” *Energy*, vol. 211, p. 118618, Nov. 2020, doi: https://doi.org/10.1016/j.energy.2020.118618.

[19] L. Zhu, A. P. Raman, and S. Fan, “Radiative cooling of solar absorbers using a visibly transparent photonic crystal thermal blackbody,” *Proceedings of the National Academy of Sciences of the United States of America*, vol. 112, no. 40, pp. 12282–12287, Oct. 2015, doi: https://doi.org/10.1073/pnas.1509453112.

[20] I. Khan, “A survey-based electricity demand profiling method for developing countries: The case of urban households in Bangladesh,” *Journal of Building Engineering*, vol. 42, p. 102507, Oct. 2021, doi: https://doi.org/10.1016/j.jobe.2021.102507.

[21] Md. Abu Saim and I. Khan, “Problematizing solar energy in Bangladesh: Benefits, burdens, and electricity access through solar home systems in remote islands,” *Energy Research & Social Science*, vol. 74, p. 101969, Apr. 2021, doi: https://doi.org/10.1016/j.erss.2021.101969.

[22] M. F. A. D. M. A. Muqeet, "Implementation of a Hybrid Power Generating System using Solar, Wind, and Piezoelectric Energy Sources," *Academia*, 2020.

[23] H. Murtaza, S. Daudpota, K. Shah, and Z. Memon, “Highway-based, vehicle driven Vertical Axis Wind Turbine with Solar Power System,” *International Journal of Electrical Engineering & Emerging Technology*, vol. 02, no. 2, pp. 18–21, Dec. 2019, Accessed: Aug. 2024. [Online]. Available: https://ijeeet.com/index.php/ijeeet/article/view/31

[24] N. Wang, L.-L. Ni, A. Wang, H.-Z. Jia, and L. Zuo, “Design and Implementation of Hybrid Photovoltaic-thermoelectric System with Intelligent Power Supply Management,” *IFAC-PapersOnLine*, vol. 55, no. 37, pp. 164–168, Jan. 2022, doi: https://doi.org/10.1016/j.ifacol.2022.11.178.

[25] D. Kraemer et al., “High-performance flat-panel solar thermoelectric generators with high thermal concentration,” *Nature Materials*, vol. 10, no. 7, pp. 532–538, May 2011, doi: https://doi.org/10.1038/nmat3013.

[26] P. Sundarraj, D. Maity, S. S. Roy, and R. A. Taylor, “Recent advances in thermoelectric materials and solar thermoelectric generators – a critical review,” *RSC Adv.*, vol. 4, no. 87, pp. 46860–46874, 2014, doi: https://doi.org/10.1039/c4ra05322b.

[27] T.-C. Cheng, C.-H. Cheng, Z.-Z. Huang, and G.-C. Liao, “Development of an energy-saving module via combination of solar cells and thermoelectric coolers for green building applications,” *Energy*, vol. 36, no. 1, pp. 133–140, Jan. 2011, doi: https://doi.org/10.1016/j.energy.2010.10.061.

[28] Z. Liu, L. Zhang, G. Gong, H. Li, and G. Tang, “Review of solar thermoelectric cooling technologies for use in zero energy buildings,” *Energy and Buildings*, vol. 102, pp. 207–216, Sep. 2015, doi: https://doi.org/10.1016/j.enbuild.2015.05.029.

[29] A. Banerjee, E. Prehoda, R. Sidortsov, and C. Schelly, “Renewable, ethical? Assessing the energy justice potential of renewable electricity,” *AIMS Energy*, vol. 5, no. 5, pp. 768–797, 2017, doi: https://doi.org/10.3934/energy.2017.5.768.

[30] E. O’Neill-Carrillo, H. R. Zamot, M. Hernández, A. A. Irizarry-Rivera, and L. O. Jiménez-Rodríguez, “Beyond traditional power systems: Energy externalities, ethics and society,” *IEEE Xplore*, May 01, 2012. https://doi.org/10.1109/ISSST.2012.6228003

**Appendix**

Related codes:

```
// 1.3 inch I2C OLED Initialization
#include <Wire.h> // Needed for OLED Display.
#include <Adafruit_GFX.h> // Helper library for OLED Display.
#include <Adafruit_SSD1305.h> // Oled Display library.
#define SCREEN_WIDTH 128 // OLED display width, in pixels
#define SCREEN_HEIGHT 64 // OLED display height, in pixels
#define OLED_RESET     -1 // Reset pin # (or -1 if sharing Arduino reset pin)
#define SCREEN_ADDRESS 0x3C // Proper I2C Adress for OLED display is 0x3C
Adafruit_SSD1305 oled(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RESET); // OLED Library initialization

#include "INA3221.h"
INA3221 INA(0x40);



#include <OneWire.h>
#include <DallasTemperature.h>
#define ONE_WIRE_BUS 4
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);



#define linear_actuator_plus 2  // Digital Output Pin
#define linear_actuator_minus 3 // Digital Output Pin
#define solar_tracker_front A0  // LDR Analog Input Pin
#define solar_tracker_rear A1   // LDR Analog Input Pin
```

```
void setup() {
  sensors.begin();
  pinMode(linear_actuator_plus, OUTPUT);
  pinMode(linear_actuator_minus, OUTPUT);
  INA.begin();
  oled.begin();
  oled.setTextColor(1);
}

float v_now = 0;
float I_now = 0;
float P_now = 0;

void loop() {
  v_now = INA.getBusVoltage(0);
  I_now = INA.getCurrent_mA(0);
  P_now = INA.getPower(0);

  oled.clearDisplay();
  oled.setCursor(0, 0);
  oled.print("Voltage: ");
  oled.print(v_now);
  oled.println("V");
  oled.print("Current: ");
  oled.print(I_now);
  oled.println("mA");
  oled.print("Power:   ");
  oled.print(P_now);
```

```
  oled.println("W\n");

  sensors.requestTemperatures();
  oled.print("Ambient:");
  oled.print(sensors.getTempCByIndex(0));
  oled.println("'C");
  oled.print("Water:");
  oled.print(sensors.getTempCByIndex(1));
  oled.println("'C");
  oled.display();
  track_sun();
  delay(500);
}


// Rotate the solar panel until the difference is les than 20
void track_sun() {
  // Read the analog values from LDRs
  int front_lux = analogRead(solar_tracker_front);
  int rear_lux = analogRead(solar_tracker_rear);

  // Calculate the difference in light intensity
  int lux_difference = abs(front_lux - rear_lux);

  Serial.println(lux_difference);

  // Check if the difference is greater than the threshold (20)
  if (lux_difference > 20) {
    // Determine the direction of rotation based on which LDR has higher lux
```

```
    if (front_lux > rear_lux) {
      Serial.println("Rotate the panel clockwise");
      // Rotate the solar panel towards the front (clockwise)
      digitalWrite(linear_actuator_plus, HIGH);
      digitalWrite(linear_actuator_minus, LOW);
    } else {
      Serial.println("Rotate the panel anti-clockwise");
      // Rotate the solar panel towards the rear (anti-clockwise)
      digitalWrite(linear_actuator_plus, LOW);
      digitalWrite(linear_actuator_minus, HIGH);
    }
  } else {
    // Stop rotating as the difference is within the threshold
    digitalWrite(linear_actuator_plus, LOW);
    digitalWrite(linear_actuator_minus, LOW);
  }
}
```