

A design of Feasible Solar Net Metering System in perspective of Bangladesh

By

Sumaiya Tarique Labiba

19121032

Tanjina Sultana

19121038

Iftekhar Ahmed

19121044

Ankita Kundu

19121048

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

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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is our own original work while completing a 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. We have acknowledged all main sources of help.

Student's Full Name & Signature:

Sumaiya Taqriue Labiba
19121032

Tanjina Sultana
19121038

Iftekhar Ahmed
19121044

Ankita Kundu
19121048

Approval

The Final Year Design Project (FYDP) titled “A Design of Feasible Solar Net Metering System in perspective of Bangladesh” submitted by

1. Sumaiya Taqriue Labiba (19121032)
2. Tanjina Sultana (19121038)
3. Iftekhar Ahmed (19121044)
4. Ankita Kundu (19121048)

Summer 2022 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering on 1st September 2022.

Examining Committee:

Academic Technical
Committee (ATC):
(Chair)

Dr. A.S. Nazmul Huda
Assistant Professor, Department of EEE
BRAC University

Final Year Design Project
Coordination Committee:
(Chair)

Dr. Abu S. M. Mohsin
Associate Professor, Department of EEE
BRAC University

Department Chair:

Dr. Md. Mosaddequr Rahman
Chairperson, Department of EEE
BRAC University

Ethics Statement

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Abstract/Executive Summary

With the increase in demand of energy and the scarcity of non-renewable resources; it has encouraged the modern world to find alternative ways of energy production and distribution as means of a solution. The approach of solar net metering is one of the most beneficial ways for countries possessing higher potential for solar energy, especially Bangladesh. Solar net metering has been introduced in few of the countries worldwide due to the system producing green energy alongside providing financial benefits to the consumers. With net metering, the consumers obtain credits on their electricity bill with respect to the "net" amount of energy used each month which is the difference between the amount of energy the solar generation system produces and the amount of energy consumed by houses during the billing period. The excess electricity formed by the solar system is sent back to the grid. There are different ways to implement solar net metering, it includes community net metering, aggregate net metering and virtual net metering, each containing different beneficiaries for particular consumer categories.

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List of Acronyms

CNM	Community net metering
ANM	Aggregate net metering
VNM	Virtual net metering
PV	Photovoltaic

Glossary

- Aggregate Net Metering:** Aggregated Net Energy Metering is a type of net metering that permits a customer to collaborates electrical meters for the purpose of net energy metering.
- Community Net Metering:** Community Net Metering is a type of net metering where a community including a bunch of households have a single onsite generation of solar electricity using multiple meters households offset power to every houses and excess energy is sent to grid for which consumers enjoy credits on their electricity billings.
- Net Metering:** It is a type of billing mechanism where the consumers who utilize renewable energy sources to produce their own electricity are credited for the surplus amount of electricity they produce and send to the grid.
- Virtual Net Metering:** Virtual net metering is a type of net metering from an offsite solar generation system all the electricity is net metered and sold to the grid and the investor enjoys the monetary benefits from it.

Chapter 1

Introduction [CO1, CO2, CO3, CO10]

1.1 Introduction

When we look around, we notice the growth rate of energy consumption increasing strongly throughout the years, all over the world. The demand for energy is increasing thus society as a whole faces a big challenge to keep pace with this growing need, making a transition in the global energy sector a necessity [1]. Furthermore, with the exhaustion of fossil fuels and serious environmental apprehension associated with their usage, the transition on the road to clean and sustainable energy technologies has become inevitable [2]. This concern regarding the deficiency of non-renewable energy sources in the near future has prompted many to shift to renewable energy sources. A nation's industrial and economic growth is heavily reliant on the sustainability and reliability of its electric power supply [3]. Thus, many countries have already started installing facilities that use renewable energy sources for power generation [4], so why should Bangladesh stay behind? To make Bangladesh a part of such a global transition, our project designs to make use of the most abundant renewable energy source through different types of net metering. Moreover, renewable energy markets are not easily formed due to cost disadvantages and so it's important to identify and adopt policies that will promote the use of renewable energy sources [5]. As a result, supporting mechanisms, such as feed-in tariffs, renewable portfolio standards, and tax policies, are employed by governments, and its continuation is required to develop renewable energy generation along with implementing energy use efficiency for saving energy [4].

1.1.1 Problem Statement

Bangladesh has a current population of almost 170 million, providing electricity to all is a scenario yet to achieve. But it was anticipated to be achieved by the year 2021 if not for the pandemic that surfaced in the year 2019. Now a pandemic, a war, Europe's abrupt transition, historically low global inventories, and uncertain temperatures have all contributed to putting pressure on energy markets throughout the world [6]. Bangladesh, being a developing country has fallen into greater disadvantages and the goals of increasing power generation facilities and providing electricity to all has been disrupted greatly. Currently, the power crisis has become one of the major problems in Bangladesh. Day by day the gap between demand and production is increasing [7]. In Dhaka, load shedding is occurring several times a day, while officials are cutting the power supply for up to five to six hours a day in rural areas [8]. Moreover, most of the power plants in our country are non-renewable energy based, for example: coal and gas, that will be phased out in future creating a greater chaos. So planning and initialization has to begin already to prevent the future from being in ruins. Furthermore, there is no guarantee that variables like another pandemic or war will not occur again causing an even bigger energy crisis in future. Therefore, we have to start taking initiative in order to prevent any mishap or crisis.

The best way out of this problem could be proper utilization of renewable energy for solving the power crisis in Bangladesh because it causes low pollution and has lesser risk associated with it. If quality electric energy at an acceptable price is not secured quickly, a domino effect of energy shortages would undermine the country's overall economic management [6]. Thus, our proposed project idea is based on renewable energy, called the solar net metering system. As this is a new concept and very few works are accomplished utilizing the solar net metering system in Bangladesh, initiative should be taken to develop skilled manpower required for the power sector considering solar net metering scheme. Solar net metering is a utility billing mechanism that offers a credit to the customers who are making excess electricity with their solar panel systems and sending it back to the grid. This idea of solar net metering is a beneficial use of solar energy that will attract potential participants and at the same time increase power generation facilities lessening the issue of power crisis. Most essentially, the people must recognize the situation's uniqueness and recognize that it is a global catastrophe rather than a national one and take actions accordingly and our project idea fits right to it.

1.1.2 Background Study

Bangladesh is an overpopulated country with per capita power generation and consumption of roughly 426 kWh and 375 kWh, respectively [9]. The government has plans to increase power generation in order to ensure access to electricity for all the citizens in the country. The goal is to provide affordable, reliable, sustainable, and modern energy for all by 2030. According to the Renewable Energy Policy of Bangladesh, a target has been set to generate 10% of the total electricity, i.e. 2000 MWh from renewable sources by the year 2020 [9]. But due to various reasons, the goal could not be fulfilled [9]. The different sources of renewable energy that can be utilized in Bangladesh are solar photovoltaic, wind energy, hydro, biogas, biomass, etc. Due to the geographical location of Bangladesh, solar energy has proven to be the most suitable renewable energy source. A total of 270 MW of electricity has been produced so far by utilizing solar energy, the majority of which has come from the Solar Home Systems (SHS) installed as standalone systems in remote off-grid areas [10]. Meanwhile, the number of SHS installations has crossed 5 million [10]. But since more than 3 acres of land is required to produce 1 MW of electricity from solar energy, it has been difficult to arrange vast stretches of land to build large-scale solar power plants [10]. Nevertheless, in order to lean towards environment-friendly renewable sources, solar being the most obvious choice for Bangladesh, measures are being taken to introduce net metering systems. Until now over 50 countries including our neighboring countries such as India and Sri Lanka have successfully adopted net metering schemes and Bangladesh is believed to be not far behind [11].

Net metering is a policy that allows electricity consumers with their own generation capacity to be financially compensated for the energy they produce [12]. Some consumers generate their own electricity using solar panels or photovoltaic systems. After energy usage, the excess energy is exported back to the grid, and the consumers get credited for it. Moreover, one of the major advantages of net metering includes balancing energy demand. The solar panels produce electricity from the solar energy and transmit it to the consumers who use as much energy as they need and the extra energy is sent back to the grid. The transferred

energy is kept track of by the net meter and electricity billing occurs subsequently based on the net amount of electricity imported or exported.

1.1.3 Literature Gap

The United States of America was the first country to implement the net metering system, which synced renewable forms of energy mainly solar or wind energy with the grid [13]. This scheme was developed for renewable energy consumers who were keen on using all of their produced electric power at various times in accordance with their needs. Minnesota was the first state to approve a net metering license and since the main goal of such a system was to feed excess energy to utility networks at the prices regulated by concerned distribution corporations, several other states enacted the net-metering system license after Minnesota [14]. Forty two states in the USA have embraced and put into practice net metering as of right now.

Numerous southeast Asian nations are attempting to balance long-term aspirations for renewable energy with the significant economic expansion that has occurred in recent years. Several nations have tried to enhance the proportion of renewable energy in their national networks as a result of this upgrade. Recently, there has been an increased focus on promoting renewable energy sources on a modest scale in both business and residential locations [15]. Among these target nations, Malaysia, Singapore, Thailand and Indonesia have established frameworks for the installation of rooftop PV systems by their residential customers. But throughout our research we have seen that there is a lack of focus on incorporating all kinds of income levels in such a transition. Especially, in the asian countries where a significant portion of the population is lower to middle income families, it is important to find suitable ways for these income levels to be a part of the change. This is the gap we tried to explore and solve through our project. We identified, designed and fine tuned existing net metering schemes to enable masses to join this movement in a transparent and financially feasible manner.

1.1.4 Relevance to current and future Industry

Bangladesh has set goals and is determined to adopt renewable energy resources in order to meet the rising power demand and for its growing economy until and beyond 2021. One of the main types of renewable energy that Bangladesh has higher prospects of utilizing is solar energy. Thus most effort is given to the PV rooftop market. The most generative industry in Bangladesh is the garments industry and as it is already accustomed to rooftop PV for self-consumption it complements the comparatively high tariffs for the industrial sector in Bangladesh and promotes a more sustainable image to its foreign customers [16]. In Bangladesh, a lot of experience is seen in PV off-grid systems. On the other hand, among the grid-connected PV systems, only a small number were actually working fine. This resulted in a widespread loss of confidence in grid-connected solar that hindered the rooftop PV market in Bangladesh [16]. To re-establish this trust and to test a new incentive for adopting rooftop PV, Bangladesh started implementing a net-metering policy [16].

This introduction of a new phenomenon was a hope that it would ensure widespread use of PV rooftop applications in other market segments. However, this comes with challenges: In

theory, net-metering is not “custom made” for the industrial sector but is rather meant to be adopted by the residential sector, since it usually applies to distributed generation and low overall demand as well as high electricity costs [16]. For Bangladesh’s industrial sector to adapt, net metering is going to be very challenging. The lack of sufficient financial schemes, cross-subsidization of tariffs, quality of components, and insufficient capacity regarding installation and maintenance are currently slowing the market down [16]. After a lot of study regarding net metering policies, it is believed that the stakeholders aim for the rooftop PV to be actually connected to the grid so that the consumers can enjoy the benefits of the net metering system. If this newly introduced net metering scheme is implemented in the correct manner in Bangladesh it will allow the consumers to save electricity by using solar energy directly and feeding excess solar electricity into the grid. Simultaneously, help Bangladesh achieve its goal of maximizing the usage of renewable energy.

Under the Power System Master Plan 2016, Bangladesh aims to add 2 GW of renewable energy projects to achieve an installed capacity of 2,470 MW by 2021 and 3,864 MW by 2041 [16]. This could be made possible using the creative approach of the Net Metering scheme booming the current power industry. However, Bangladesh has to overcome a lot of hindrances on all levels of regulation and implementation in order to make it happen. Bangladesh is not new to solar energy as it already has extensive experience in the area of off-grid solutions, solar home systems, and self-consumption for industrial customers [16]. So looking forward it won't be far away when net metering will be extensively implemented in Bangladesh. Furthermore, with upcoming changes such as switching to smart meters and the grid in the power industry, the transition to renewable energy via methods like solar net metering will become easier, more feasible and popular among the population of Bangladesh.

1.2 Objectives, Requirements, Specification, and constant

The rising concern about the deficiency of non-renewable energy in near future has escalated the usage of renewable energy sources, the most abundant being solar energy. Bangladesh being a developing country cannot promptly switch to solar energy generation without any supportive mechanism, especially the middle to lower income population of Bangladesh. So, in order to make the switching to solar energy generation happen from non-renewable energy generation, we will be using a net metering mechanism. The benefits of net metering are that it balances energy demand and provides financial welfare on electricity billing.

1.2.1. Objectives

The fundamental objectives of the net metering system are listed below:

- To accelerate the reliance on renewable energy resources thus preserving the natural and especially non-renewable energy sources
- To reduce the electricity billing of consumers
- To increase the number of candidates for the net metering scheme by providing a way for both small scale and large-scale investors

1.2.2 Functional and Non-functional Requirements

Functional Requirements

- PV panels must generate enough surplus electricity - The installed PV system must be capable of generating enough electricity that even after the consumption of the community sufficient electricity is exported to the grid making the return on investment of this project a viable one. Any government subsidies will further improve the financial feasibility of the whole system. Thus the choice of the size of the solar generation system taking the community load profile into account is a vital step in our project.
- All the necessary parameter readings needed to determine the individual and community energy production and consumption at all times needs to be stored in a server.
- Multiple meters must keep track - For every member of the community a separate meter must be used to calculate the billing based on their own electricity usage and initial investment to acquire a percentage of the total solar array thus making the system fair for all the participants.
- Push switches to protect the AC meter enclosed in a box from any sort of vandalism.

Non-functional Requirements

- Easier maintenance - Major maintenance of the solar PV system includes cleaning the solar PV panels, checking connections of wires from PV panel to inverters and to the load and performance of the system [17]. In case the consumer is educated and has the capacity to understand the connections of the systems, routine maintenance requirements can be performed like wire checking, connection checking, switches etc. Operational manual for the solar PV system and documentation of the installation provided by the installer can be consulted for necessary maintenance.
- Security - Electrical mishap can cause excess flow of current burning components and if not handled in time can lead to flammable accidents. In order to prevent accidents components like circuit breaker, and lightning arrester are used. Also, a routine check is done by professionals to keep updates on the successive functionality of the system.
- Eco Conscious - Avoidance of off-grid or hybrid inverter systems dictates no usage of battery in our net metering project. Batteries typically made of lithium-ion require frequent changes and their disposal is a huge environmental issue. Thus, to make our system environmentally friendly we went for a completely on-grid system.

1.2.2 Specifications

- Initial energy requirement of households should be served by solar energy produced using the solar panel. Subsequently, if the energy requirement of the households is beyond the threshold, the energy grid supplies the rest.
- The individual and community energy production consumption and transfer records should be stored in the server for further analysis.
- Bidirectionality of the meter to measure the import and export of electricity
- The meters used in the households should be protected against any sort of tampering.

TABLE 1.1 Component level specifications of our designed prototype

Subsystem	Component	Model/Type	Comment
Solar	PV Panel	Poly-crystalline Panel	Generic 12V Solar Panel
	Solar Controller	PWM Adjustable Model	Generic PWM Solar Charge Controller
	Inverter	500 Watt	Typical 12V DC to 220 AC Inverter
	Battery	12Volts 7.5Amp	Generic DC Battery
DC Monitoring and Distribution	Voltage Sensor	Potential Divider Variant	Typical DC Voltage Sensor
	Current Sensor	ACS712	Typical DC Current Sensor
	Micro Controller	Arduino UNO	Typical Microcontroller
	Wifi Module	Esp 8266	General Microcontroller used as an Wifi Module
	Relay	Mechanical Variant	Typical Two Channel Low Level Trigger Relay
	Display (with I2C)	LCD (16 × 2)	Common 16 × 2 LCD Display
Solar Meter For Households	AC Meter	PZEM 004T	Unique Multi-function AC Power Meter
	Wifi Module	Esp 8266	General Microcontroller used as an Wifi Module
	Buzzer	-	Standard Monotone Buzzer
	Switch	-	Typical Push Switch
Grid Representation	Meter	HI-7	Static Kilowatt-Hour Meter
	Inverter	1000 W	Typical 12V DC to 220 AC Inverter
	Battery	12Volts 7.5Amp	Generic DC Battery
	Bulb	-	Generic Light Bulb
Miscellaneous	Wires	-	Typical Connecting Wires
	Board	-	Common Wooden Board
	Buck Converter	LM2596	Typical DC to DC Power Converter
	Plug	2 PIN	Generic 2 PIN Plug
	Light Bulb Holder	-	Generic Light Bulb Holder
	Light Bulb	5 Watt Bulbs	Generic Light Bulb

1.2.3 Technical and Non-technical consideration and constraint in design process

Technical Constraints

- To ensure efficient supply of surplus solar power to the grid, the grid tied inverter must be capable to not only keep the voltage slightly higher than the grid voltage at all times but also match the phase of the grid.
- The grid tied inverter must have the quality to ensure unity power factor so as to avoid any penalty charges resulting from it.
- Segments of the grid receiving a good amount of power from renewable sources such as solar would result in the rise of voltage levels especially during peak production intervals; thus it is paramount that our system has the capability to deliver reactive power to the grid if and when necessary to prevent the aforementioned problem.
- Our system must be able to quickly disconnect itself from the grid when the national grid seems to be down; so as to prevent the harming of any potential workers fixing the national grid.

Non-technical constraints

- Consumer type - In Bangladesh, not all consumers are eligible to use net metering due to the guidelines set by the Bangladesh Energy Regulatory Commission.
- Capacity restriction - Output AC capacity of the renewable energy converter must not exceed a maximum of 70% with respect to the consumer's sanctioned load but also be less than 3 MW according to Bangladesh's net metering guidelines.
- Location constraint - Solar panel installation requires ideal sites, which have more potential for solar energy harvesting. In terms of optimal radiation from the sun, reduced shading can be an ideal location to install solar panels. But these sites are hard to find and harder to come to an agreement to install the solar panel.
- Installation cost - Solar panel requires a lot of manpower and budget to be installed.

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 61215-1:2019	Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 1-1: Special Requirements for Testing of Crystalline Silicon
	IEC 61215-2:2019	Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures
	IEC 61730-1:2019	Photovoltaic (PV) Module Safety Qualification - Part 1: Requirements for Construction
	IEC 61730-2:2019	Photovoltaic (PV) Module Safety Qualification - Part 2: Requirements for Testing
	BDS IEC 61215	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval

	BDS IEC 61730-1:2019	Photovoltaic (PV) module safety qualification part 1: Requirements for Construction
	BDS IEC 61730-2:2019	Photovoltaic (PV) module safety qualification part 2: Requirements for Testing
Grid Tied Inverter	IEC 61727:2020	Photovoltaic (PV) Systems – Characteristics of the Utility Interface
	IEC 62116:2020	Utility-interconnected Photovoltaic Inverters – Test Procedure of Islanding Prevention Measures
	IEC 62109 (Part-1): 2016	Safety of power converters for use in photovoltaic power systems – Part 1: General requirements
	IEC 62109 (Part-2): 2016	Safety of Power Converters for Use in Photovoltaic Power Systems Part 2: Particular Requirements for Inverters
	BDS IEC 62109-1	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements
	BDS IEC 62109-2	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters
	BDS IEC 61727:2020	Photovoltaic (PV) systems - Characteristics of the utility interface
	BDS IEC 62116:2020	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention
Net Meter	IEC 62052-11	Electricity metering equipment - General requirements, tests and test conditions - Part 11: Metering equipment
	IEC 62053-21	Electricity metering equipment - Particular requirements - Part 21: Static meters for AC active energy
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
Circuit Breakers	C37.04	IEEE Standard for Ratings and Requirements for AC High- Voltage Circuit Breakers with Rated Maximum Voltage Above 1000V
	IEEE C37.10.1	IEEE Guide for the Selection of Monitoring for Circuit Breakers
Lightning Arrester	IS:3070- 1993	Specification for surge arrester for alternating current systems. Metal-Oxide lightning Arresters without gaps
	IEC – 60099-4	Surge Arrestors

Net metering is still quite a new concept in Bangladesh and thus the current set of policy and guidelines set in 2018 requires fine tuning for this method to be widely implemented. Some of the most obvious and reasonable standards states that only electricity produced from renewable energy sources are eligible for net metering and the prosumer must not only be a current customer of a utility that is responsible for the supply of electricity in the area [6] but

also have a net metering agreement with that specific utility before the setup of any metering system. Currently only three phase consumers are eligible for the net metering system but hopefully in the future single-phase consumers will also be made eligible increasing the potential users of the metering system. It is also important to note that the prosumer must consume the electricity at the point of renewable energy electricity generation, and only export the excess amount to the grid [6]. Such a policy exempts us from trying to implement a Virtual Net Metering system where all the electricity would be exported and the profits would be distributed according to a pre-allocated share.

Moreover, there are quantifiable limitations on the size of installed renewable energy systems. The output AC capacity of the renewable energy converter can be a maximum of 70% with respect to the consumer's sanctioned load. Furthermore, the maximum output AC capacity of the installed renewable energy system for net energy metering cannot be more than 3 MW [6]. When it comes to the billing systems there are predefined codes as well. The concerned distribution utility shall prepare and send the electricity bill to the consumer for each billing period; if at the end of the month the prosumer is a net importer, they must pay for the net unit of electricity imported but if the prosumer is a net exporter the net amount of electricity exported will be carried over to the next billing period. Finally, if at the end of the settlement period (fiscal year) the prosumer remains as a net exporter of electricity then the utility shall pay for the net exported amount of electricity to the prosumer at different rates (tariff) for the utility set by BERC (Bangladesh Energy Regulatory Commission).

1.3 Summary of the proposed project

Our project adapts a green form of energy that is solar energy as it has the most chance of prosperity in Bangladesh. We incorporate the fresh concept of net metering to attract the stakeholders towards using solar energy for power generation. Net metering is an electricity billing mechanism. Some consumers generate their own electricity using solar panels or photovoltaic systems. After energy usage, the excess energy is exported back to the grid, and the consumers get credited for it. Moreover, one of the major advantages of net metering includes balancing energy demand. As net metering is quite a new concept in Bangladesh, not many are familiar with this mechanism and its fruitfulness. Thus, we have to promote this idea of net metering to increase the transition to renewable energy sources for electricity production.

One of the major purposes of our project is to accelerate reliance on renewable energy through a feasible way of net metering scheme. To achieve this we are not only going to inspect all the available ways of net metering but also design some of our own net metering scheme in a bid to find out the most economically feasible one and optimize it considering the perspective of Bangladesh.

1.4 Conclusion

In a developing country like Bangladesh, where the per capita consumption is very low compared to other countries, individual net metering is not feasible. It is also to be noted, a basic net metering policy is not able to serve all types of consumers, therefore making a widespread, sustainable and financially stable net metering is a challenge. Computing the

load requirements and production rate based on the consumer classifications, and then calculating the payback period can make the system sustainable.

The government needs to keep other innovative alternatives in consideration during the designing stage of policy in order to make the grid integrated solar panels on a realistic basis a success. Because the net metering policy is still in its starting stage, taking into account these aspects would lead to the development of a complete policy that can cater to the diversified consumer base. Net metering is a more dominant approach towards an eco-friendly Bangladesh as it reduces electricity billing creating more incentive for people to become prosumers making their own electricity from renewable energy systems. It further speeds up the process of Digitization of Bangladesh boosting the transition to smart meter and smart grid; also creating job opportunities for future generations.

Chapter 2

Project Design Approach [CO5, CO6]

2.1 Introduction

The worldwide energy crisis is a vital issue that needs to be looked into with great importance. The researchers after analyzing a lot of studies have concluded that the optimum solution to help limit the energy crisis problem is by utilizing the different forms of renewable energies. In the perspective of Bangladesh, the best renewable energy to utilize is solar energy. But solar energy establishments could be costly to arrange. Thus people will only be inclined to promote solar energy when they see a benefit in it. The best way to make it happen is by introducing a net metering scheme. The net metering system allows the consumers to save electricity by using solar energy directly and feeding excess solar electricity into the grid for which their electricity bill is adjusted as their power consumption is deducted from the amount of power delivered to the grid.

There are different approaches to net metering. The four main approaches are single net metering, community net metering, aggregate net metering, and virtual net metering. Among all these approaches, virtual net metering is said to be illegal in Bangladesh as per the net metering policies in Bangladesh. But rest of the approaches can turn out to be extremely beneficial if it is set right. Looking at the current solar landscape in our country, we see that it is mandatory for every new construction of building in Dhaka city including government buildings to have a solar rooftop system. Unfortunately, due to space and usage constriction, many are unable to produce sufficient units of electricity even during peak sunlight hours to import any electricity back to the grid. This makes net metering infeasible in congested cities like Dhaka. There are promising signs though quite a few consumers and companies with a location a bit away from the dense city have set up individual net metering systems. So far approximately 1465 renowned companies have implemented the strategy of net metering such as NESCO, BPDB, BREB etc. [2]. For companies like these, the benefits come in two folds as they are able to invest the high initial costs and achieve economies of scale resulting in a feasible return on investment in a manageable time frame. Additionally, they can advertise themselves as being an environmentally aware company through this. On the other hand, individual consumers involved in such a metering system must themselves bear the high initial costs and maintenance, greatly reducing the potential users of net metering. In order to encourage net metering, our project aims to introduce a net metering system much more financially feasible opening it up to a wider potential consumer base.

2.2 Identify multiple design approach

Upon various criteria we have recorded three distinctive design approaches of Net Metering System such as the distribution system at the consumer's end, site placement opportunities, pre-allocation of tax benefits etc. The issued approaches are identified herewith:

- I. **Community Net Metering** - It focuses on multiple consumers who come to an agreement of using multiple meter systems for multiple households offsetting power

among the consumers of the community. The following figure describes the way community net metering mechanism works. The single onsite solar panel installed produces electricity from solar energy and supplies it to the households of the community. Excess energy that is not utilized by the community is sent to the grid. This track is kept by the net meters that are set up in every household. Thus consumers enjoy the credits on electricity units which is observed in their electricity billings and such an image is depicted in the figure below.

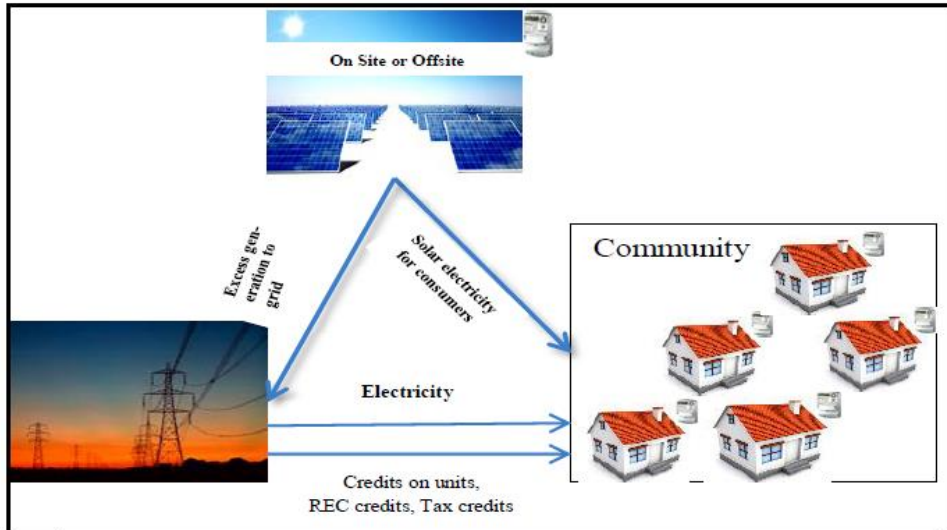


Fig. 2.1 Community net metering system [18]

II. Aggregate Net Metering - It tends to have a single consumer with a single generation system and uses multiple meters underneath the same roof to offset power from multiple meters. Eventually, accumulating all the benefits under a single consumer. In the figure below, we can see that a single onsite generation of solar panels supplies electricity to a huge premise. The surplus electricity is sent to the grid and this track is kept by multiple net meters under the same premise, for which credits on electricity is achieved by the participant. This flow is clearly displayed in the following figure.

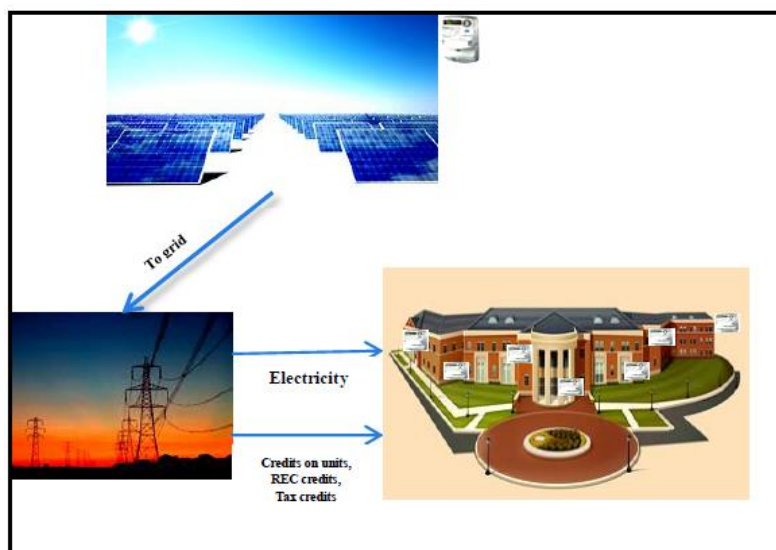


Fig. 2.2 Aggregate net metering system [18]

III. Virtual Net Metering - It has a collective generation system though the generation facility placement is done offsite and the tax benefits are shared among all the consumers involved. In the figure beneath we can see that the solar panel is set offsite and supplies electricity produced from it to offsite households. The electricity that is sent to the grid results in credits that are obtained by the offsite consumers. This track of net electricity consumption is kept by the net meter. This scenario is clearly displayed below.

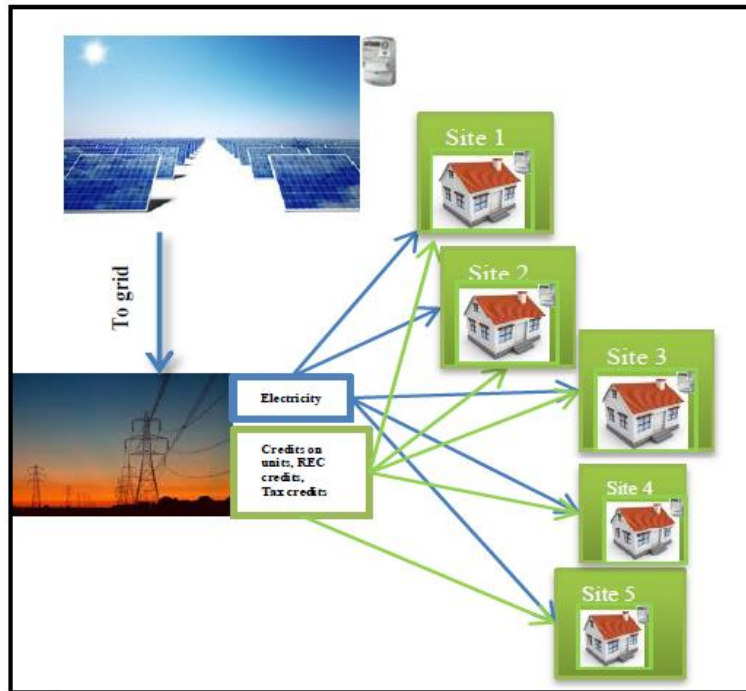


Fig. 2.3 Virtual net metering system [18]

2.3 Describe multiple design approach

An elaborated overview of the Community Net Metering system, Aggregate Net Metering System and Virtual Net Metering System is demonstrated below:

I. Community Net Metering

Community net metering system is claimed as an alternate development of the net metering system proposing a whole community of users to be treated as a single consumer. In this issued design, one collective generation facility is developed rather than customers owning individual solar panels. It further allows a feedback system connected throughout the community where excess energy can be offset among the consumers themselves. Furthermore, a surplus of the generated renewable energy is sent back to the grid and the consumers can have access to this policy onsite or offsite. Consumers can possess multiple meters with different tariff rates. For the billing procedure, the net consumption units of all the consumers combined are computed.

To disclose the advantages, this system offers to achieve economies of scale. The cost and labor of installation of panels, operating and maintenance of individual generation sites, ordering applications, etc. can be avoided as this system proposes only one collective generation site. Furthermore, smaller consumers with insufficient spaces to install individual

solar panels can benefit equally from this project thus encouraging a larger audience to invest in renewable energy. The benefit of installing a generation panel in an optimal location can be realized in terms of absorbing sufficient heat and radiation from the sun avoiding the shading to produce energy. In figure 1, the community net metering system has been depicted as containing a community of multiple users with a single onsite or offsite generation site [18].

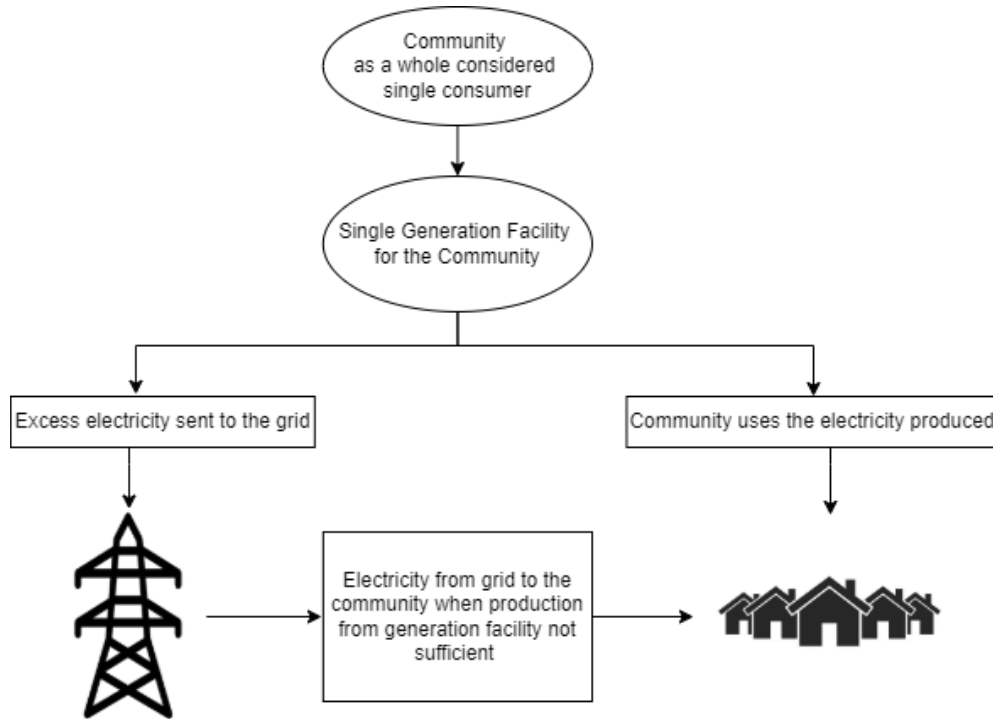


Fig. 2.4 Flowchart of community net metering system

II. Aggregate Net Metering

Aggregate net metering system allows individual consumers to own a single generation site possessing multiple meters per load requirement thus the system tends to offset power among its meters of the same single consumer. The system size is calculated upon aggregating the loads from the corresponding multiple meters. Eliminating the necessity of having different solar panels for each meter, the design also extends to recognizing consumers with different tariff rates to avail of the benefits from a common plant. The advantages provided by this system include achieving economies of scale compared to traditional net metering models as the installation cost for individual panels can be avoided. Additionally, maintenance and operation hassles are reduced as well. The tax benefits and Renewable Energy Certificates (REC) would be accrued to a single customer and the model would also act as a hedge against rising prices [18]. Moreover, this system increased savings for a consumer by providing efficiency in load management and offsetting power between the meters. Despite the aforementioned advantages, the aggregate net metering system requires remodeling of allotted credits and applied tariffs for the consumer. It further raises the issue of determining the eligible sector or property of the consumer. In figure 2, an outline of an aggregate net metering system has been demonstrated containing a single consumer with multiple meters generating power from a single solar generation facility [18].

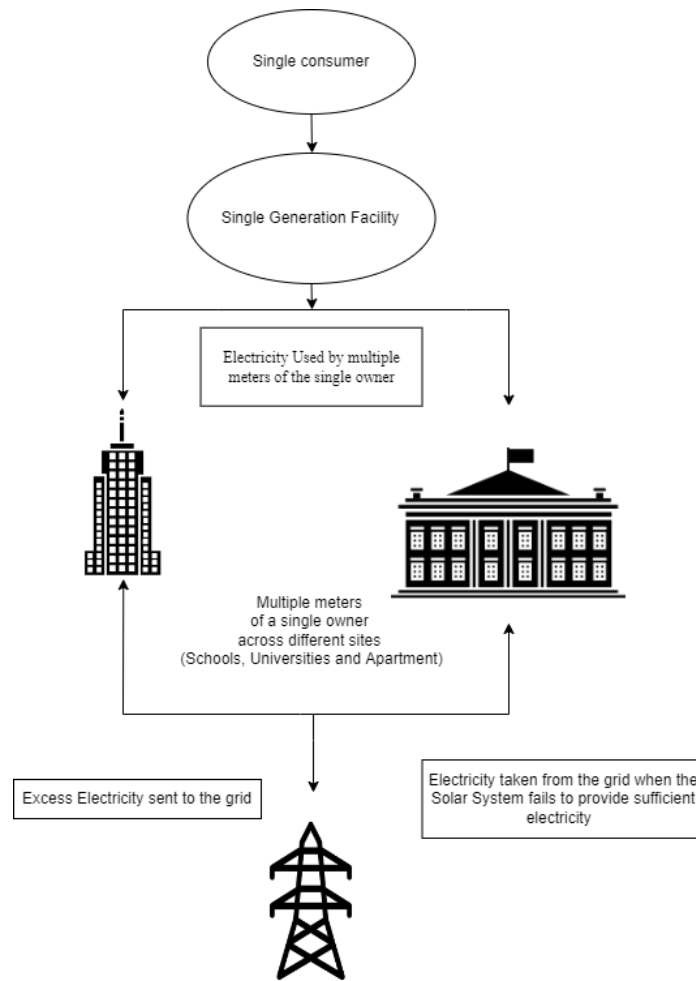


Fig. 2.5 Flowchart of aggregate net metering system

III. Virtual Net Metering

In this type of metering system, the customers can be located anywhere and still buy a certain percentage of equity from a renewable generation facility and benefit from the facilities of net metering policy [18]. The electricity produced is directly exported back to the grid, and units generated are distributed among the beneficiary accounts through some pre-arranged allocation agreement [18]. Such a metering system will be heavily boosted by introducing a smart grid. The amount of electricity produced through this method of net metering is credited at a pre-decided rate per unit, to the monthly bill of the consumer, which offsets only imported units from the grid. These units cannot be used to offset minimum monthly charges on bills and other service charges [18]. It has some common benefits to the aforementioned net metering systems like the strategic location of solar panels to achieve optimal energy from the sun. One unique advantage such a system brings is the opportunity of financial funding like crowdfunding or third-party ownership. Virtual net metering creates opportunities for bigger projects with the one-time investment needed to integrate the system with the grid and as only a single generating facility is set up with multiple bidirectional meters, separate wiring and inverters can be avoided reducing the cost of setting and operating a metering system of such type. Figure 3 is attached below for reference including a single-generation facility exporting the produced solar power to the grid and the consumers availing the power directly from the grid [18].

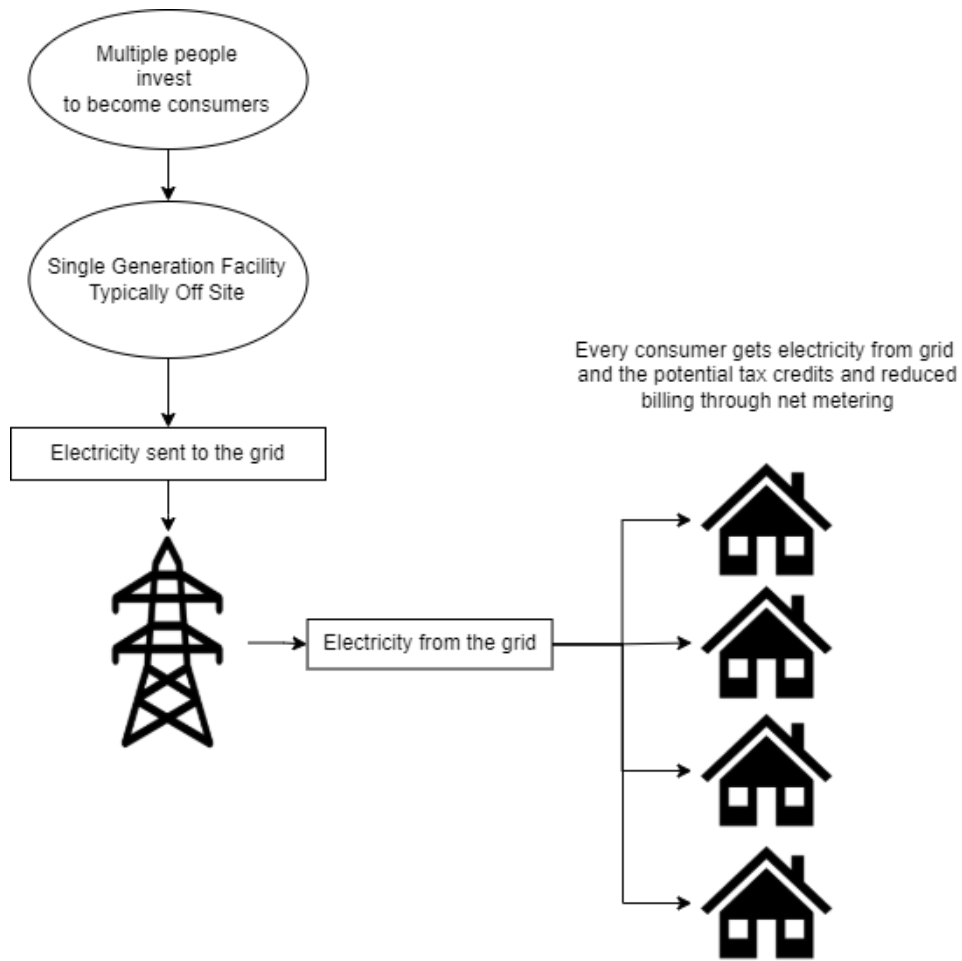


Fig. 2.6 Flowchart of virtual net metering system

2.4 Analysis of multiple design approach

The issued multiple design approaches for net metering systems have been further analyzed depending upon numerous categories including placement requirements, feedback systems, economic efficiency in particular according to different consumer classifications that are represented thoroughly in the proceeding:

TABLE 2.1 Comparative analysis on multiple design approaches of the system

Issued criteria	Community net metering	Aggregate net metering	Virtual net metering
Allocated generation facility	Single generation facility for a community	Individual generation facility per consumer	Single generation facility for a number of consumers
Power offset and feedback system	Power offsets among the multiple consumers of the community	Power offsets among multiple meters of a single consumer	All power generated is exported to grid and revenue and tax benefits shared based on pre allocated share
Economic significance	Economies of scale achieved via planting	Economies of scale achieved through large	Economies of scale achieved via large scale

	collective generation panels, reducing installation costs etc.	scale generation plant	investment to produce big generation facility
Site placement of generation facility	The generation plants can be onsite or within the communal proximity	Requires onsite placement	Only off-site placement is applicable
Appropriate customers	Suitable for rural and communal areas	Suitable for consumers with larger load requirements and multiple meters	Suitable for consumers with an eye for greener future or looking for tax benefits but does not have sufficient space to set up solar array (especially people living in urban areas)
Policy in Bangladesh	Stated legal according to the present net-metering policy	Stated legal in current policy	Currently proclaimed illegal in Bangladesh

Taking the corresponding issues to account, the Community net metering system can be stated as the optimal design considering its feasibility with respect to the majority of the population of our country. The consumers actively participate in power production forming a collective generation facility themselves. The design eliminates the hassle of installing and operating individual solar panels and thus lowers the appliance costs. Availability of optimal location for panel placement is further ensured in this system recalling the fact that there is only a single generation facility required for the whole community. Moreover, smaller consumers who do not have sufficient area to install panels can be served as well through this type of net metering. It further provides financial feasibility via achieving economies of scale. The feedback system is responsible for sending extra electricity back to the grid and offsetting the electrical energy consumed thus reducing monthly electricity bills. Taking the aforementioned advantages to account, community net metering systems can weigh up to be the optimal design in this regard.

2.5 Conclusion

Addressing the urgent global nonrenewable energy shortage predicament and making use of all forms of renewable energy sources in response to this situation is a smart move. In the case of Bangladesh, implementing a net metering program is not only beneficial for employing solar energy, which is abundant here, but also motivates the people to support it. The various approaches to net metering include single net metering, community net metering, aggregate net metering, and virtual net metering. In a community net metering system, a group of users would be treated as a single consumer under a community net metering scheme. Instead of customers owning individual solar panels, one collective generation facility is established under this approach. Secondly, in an aggregate net metering system, individual consumers are able to own a single generation site with multiple meters on it. System has a tendency to balance power among the meters of the same user. The strategy

would operate as a shield against price increases and would accrue tax benefits and Renewable Energy Certificates to a single client. Lastly, in a virtual net metering system, customers can be located everywhere and still purchase a specific share of equity from a renewable power facility. The quantity of electricity generated using this kind of net metering is credited to the consumer's monthly bill at a predetermined rate per unit. But as far as the policy in Bangladesh is concerned, the virtual net metering system is still illegal, and therefore can not be implemented, but the other approaches show promise. Comparison between all of them decides that community net metering system gets the upper hand as it can be implemented in most areas of Bangladesh, reduces appliance cost and monthly electricity bills and achieves economies of scale thus ensuring financial feasibility.

Chapter 3

Use of Modern Engineering and IT Tool [CO9]

3.1 Introduction

Our project is a solar energy-based project so the first and most important tool needed to design our system is a software that is able to provide us with the solar irradiance data and information on the preferable PV panels and inverters. There are many software programs in the market, some are better than others. Following the list of our system needs we narrowed down which software works best for our situation. The two softwares that gave us our desirable outcomes were: PVsyst and Helioscope. Then it was our turn to display the net metering functionalities of our system. After a lot of researching and going through the softwares available we decided to use code in MATLAB and customize blocks in Simulink to represent the net metering part of our project. Furthermore, while designing the prototype of the project Arduino became an integral part of the toolset as all the necessary codings for all types of microcontrollers like Arduino UNO, ESP-8266 were done using it.

3.2 Select appropriate engineering and IT tools

PVsyst

According to its official website, PVsyst is a PC software that deals with the study, sizing and data analysis of complete PV systems. It is widely used for the analysis of stand-alone, grid-connected, pumping and DC-grid PV systems [19]. For our project, we have used PVsyst for obtaining the following results for further analysis:

- Data on monthly solar irradiance
- Per kWh energy cost analysis in USD at different locations in Bangladesh

Helioscope

Helioscope, developed by Folsom Labs is a leading software platform for designing and selling high-performance PV systems. It greatly simplifies the process of engineering and designing solar projects by integrating easy layout tools with bankable performance modeling [19]. We have used this software, particularly for the analysis of shading loss for comparison between different types of solar net metering systems. This software uses satellite imaging to help us design our solar panels in any location that we want. We input our favorable parameters to design the solar panels in our desired location. After which when we run the simulation, we obtain a report containing the analysis on shading loss which is the key element of comparison between the different types of solar net metering systems.

MATLAB Simulink

We have designed our multiple design approaches in order to test the feasibility of these designs using MATLAB Simulink. We have generated custom blocks to implement various portions of the design such as generation system, distribution system and net metering etc. Every design has a few fundamental blocks which are discussed in the next section.

Arduino

It is an open-source platform that concentrates on the creation of various hardware and software products. It is made up of a microcontroller and an Integrated Development Environment (IDE) for programming the microcontroller. These programs were created using C/C++. The programmable microcontroller in Arduino is compatible with a variety of sensors, motor drivers, integrated circuits, modules, and other system technologies, making it a flexible platform. For our project we have used Arduino UNO which is a board for a microcontroller that uses the ATmega328P. It contains 6 analog inputs, a 16 MHz ceramic resonator, 14 digital input/output pins (six of which may be used as PWM outputs), a USB port, a power connector, an ICSP header, and a reset button. It comes with everything needed to support the microcontroller; to get started, just plug in a USB cable, an AC-to-DC converter, or a battery.

3.3 Use of modern engineering and IT tools

In our project we have used multiple modern engineering and IT tools; a few snippets of that usage are demonstrated below.

PVsyst

Through PVsyst software, we have primarily stimulated and examined the economic feasibility and cost analysis based on different locations of Bangladesh. We have performed this analysis as solar irradiance data can differ based on distinct location which could affect the overall economic viability of this project.

For analyzing the cost of energy varying in different locations, we have implemented two different designs using PVsyst. The location has been chosen to be Tangail and Cox's Bazar as the monthly average solar irradiance amount varies by a significant amount in these two districts. Moreover, we have differentiated the size of the solar PV generation plant as well to analyze and verify the effects even further. The simulation results are demonstrated and inspected below as such:

Energy cost analysis at different locations

Location: Tangail

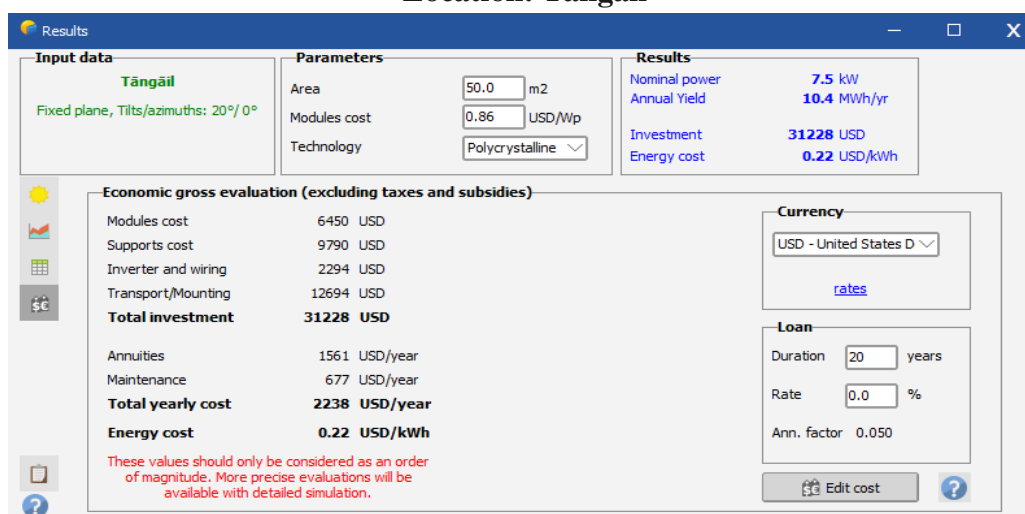


Fig. 3.1 Area limit of 50 m²

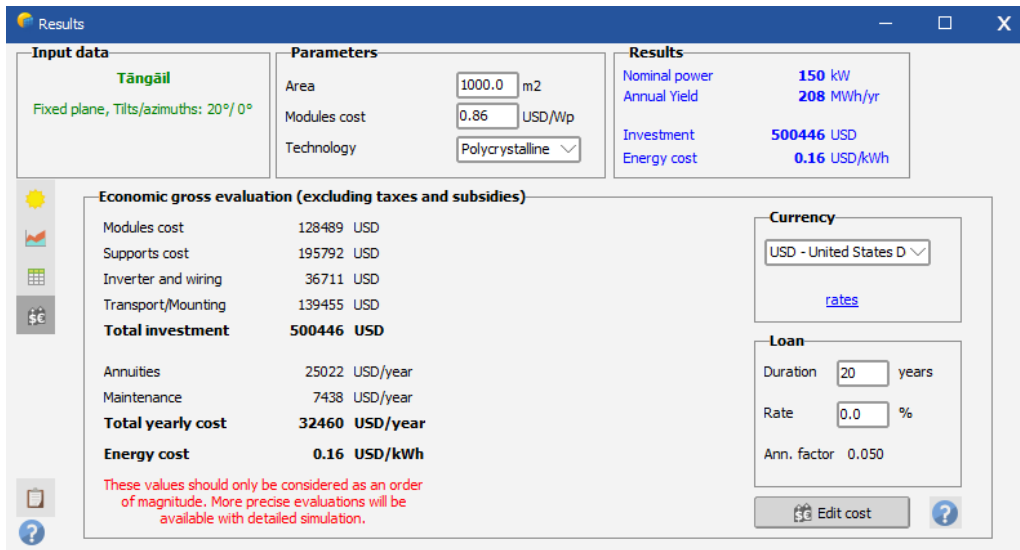


Fig. 3.2 Area limit of 1000 m²

The immediate above pictures showcase the simulation results for user defined parameters set for the solar panels in PVsyst. We selected the location to be Tangail and kept all the parameters that being the module cost and technology same. Except we chose two different areas for our solar panel installation, 50 m² and 1000 m² and observed the energy cost in each case. It can be seen that the energy cost for a larger area is lesser, though the amount of investment in this case is more. Therefore, the results reluctantly propose the idea of a community working together to implement solar net metering. Then the investment will be distributed among the community, along with the government incentive which will somewhat reduce the high budget investment burden. Furthermore, if a community is involved then a larger area for solar panel installation can be managed with ease decreasing the energy cost unlike the case of a smaller area. Thus, it will be a doable project with many benefits.

Location: Cox's Bazar

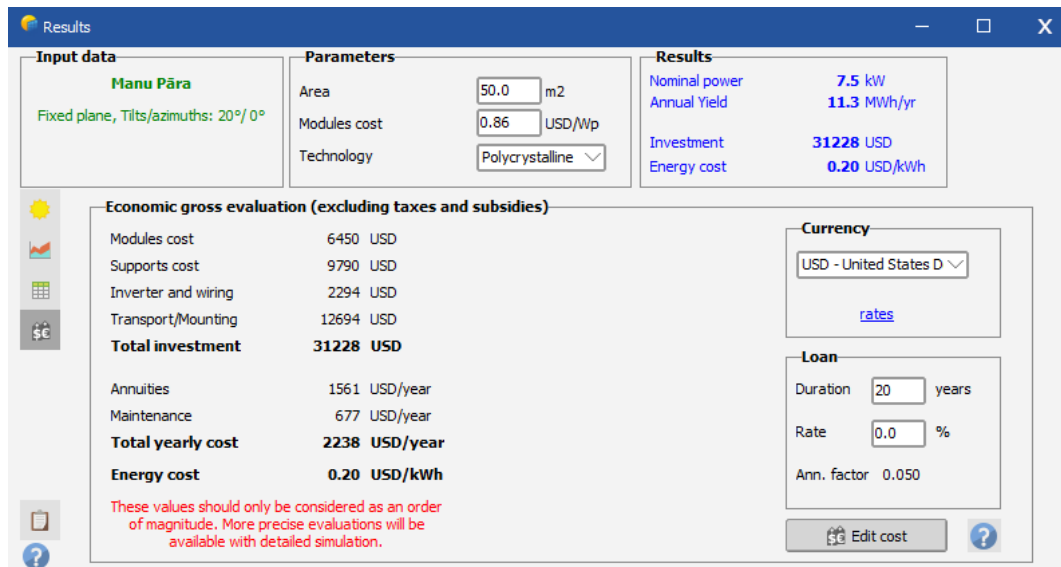


Fig. 3.3 Area limit of 50 m²

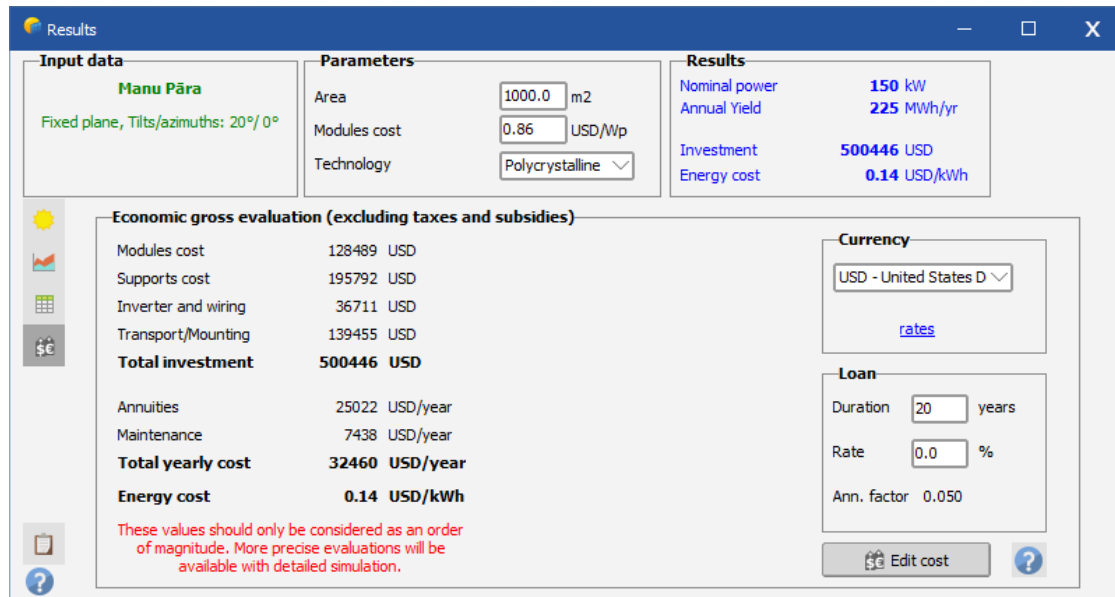


Fig. 3.4 Area limit of 1000 m²

TABLE 3.1 Data on USD/kWh value for two different locations in Bangladesh

Available Area Location	50 m ² (Individual)	1000 m ² (Community, Virtual)
Tangail	0.22 USD/kWh	0.16 USD/kWh
Cox's Bazar	0.20 USD/kWh	0.14 USD/kWh

Then again we repeated the whole process but this time we changed the location to Cox's Bazar. Now, what we noticed is that the energy cost of Cox's Bazar is slightly less even though the investment with respect to the area limit is constant. Thus portraying virtual net metering to be a better option where the location of solar panels with respect to the meters setting is not restricted unlike community net metering. Unfortunately, according to the policies of Bangladesh, virtual net metering is proclaimed to be illegal.

PVsyst solar irradiance data analysis at different locations:

	Global horizontal irradiation
	W/m ²
January	163.8
February	194.5
March	221.5
April	245.1
May	226.5
June	187.6
July	137.9
August	192.9
September	182.6
October	181.7
November	181.7
December	163.7
Year	189.8

	Global horizontal irradiation
	W/m ²
January	140.7
February	168.9
March	209.3
April	214.2
May	218.3
June	185.4
July	166.0
August	194.8
September	173.1
October	160.6
November	153.6
December	133.1
Year	176.5

Fig. 3.5 Solar irradiance data of Cox's Bazar

Fig. 3.6 Solar irradiance data of Tangail

The solar irradiance data is also obtained from PVsyst after setting the required parameters and running the simulation. Here the area limit selected for both the locations were 10 and all other parameters were also kept constant. Solar irradiance is basically the solar power per unit area. From the above solar irradiance data we can predict that the location of Cox's Bazar will be a better spot to install the solar panels, regardless of where the net meters will be set. But this type of design is only possible in case of virtual net metering. For community net metering, the solar panels and the net meters have to be within the proximity of that community in order to be under that community's utility distributor.

Helioscope

In Community and Aggregate net metering systems, the PV generation facilities should be near the load site which limits the benefits of choosing optimized location. Therefore, analyzing shading loss is quite crucial in implementing this project. In order to study the effect of shading losses, two different designs have been generated and simulated in Helioscope keeping all the conditions such as location, plant size, weather the same and only differentiating the shading effects. In Helioscope, the designs have been generated with a graphical approach selecting the atmospheric conditions of Tangail. For the PV model, Canadian Solar CS6U-345M has been used with a total of 2400 modules which is sufficient to generate 828.0kW. Additionally for the inverter, Sunny Tripower 24000TL-US models have been used with a quantity of 28 (673.7kW). The shading effect is formulated by the

graphical representation of trees and nearby buildings and the modules are designed to stand with a 15° tilt. Here, real time data of monthly average solar irradiation and weather conditions (Dataset: TMY 10km Grid, meteonorm) of the corresponding geographical location have been simulated to generate the report.

Analyzing shading losses: Tangail

The graphical representations of two similar generated designs with and without shading losses selecting the location of Tangail are demonstrated:



Fig. 3.7 Design layout of solar PV system without and with shading effects. The green circles represent nearby trees overshadowing the system.

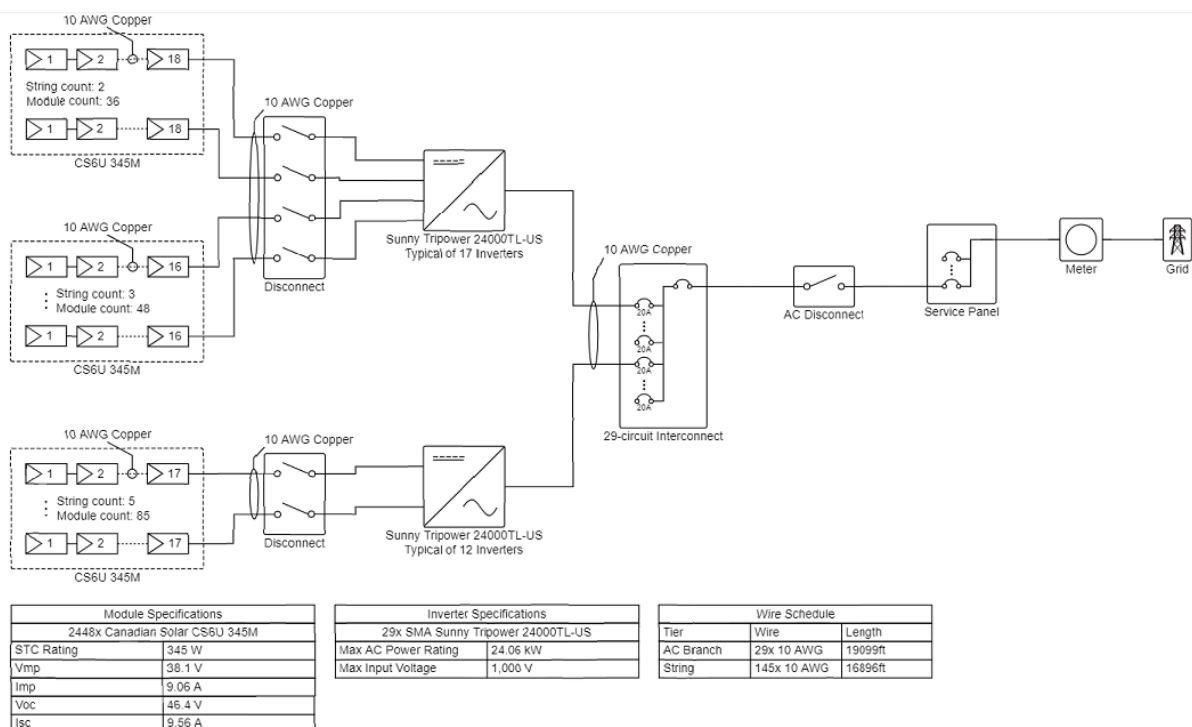


Fig. 3.8 Single line diagram of the PV system designed

Without considering the shading losses

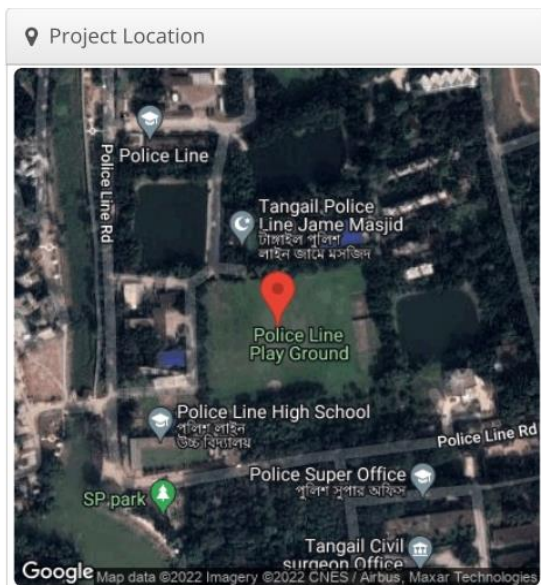


Fig. 3.9 Location of the implemented system

Module DC Nameplate	828.0 kW
Inverter AC Nameplate	673.7 kW Load Ratio: 1.23
Annual Production	1.272 GWh
Performance Ratio	79.9%
kWh/kWp	1,536.2
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)

Fig. 3.10 Location of the implemented system

Components		
Component	Name	Count
Inverters	Sunny Tripower 24000TL-US (SMA)	28 (673.7 kW)
Strings	10 AWG (Copper)	140 (5,387.9 m)
Module	Canadian Solar, CS6U 345M (345W)	2,400 (828.0 kW)

Fig. 3.11 Component details

Field Segments									
Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	15°	176.12651°	1.4 m	4x1	600	2,400	828.0 kW

Fig. 3.12 Component details

Considering the shading losses



Fig. 3.13 Location of implemented system

Module DC Nameplate	527.2 kW
Inverter AC Nameplate	433.1 kW Load Ratio: 1.22
Annual Production	803.9 MWh
Performance Ratio	79.3%
kWh/kWp	1,525.1
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)

Fig. 3.14 Annual production (with shading loss)

Components		
Component	Name	Count
Inverters	Sunny Tripower 24000TL-US (SMA)	18 (433.1 kW)
Strings	10 AWG (Copper)	90 (3,171.3 m)
Module	Canadian Solar, CS6U 345M (345W)	1,528 (527.2 kW)

Fig. 3.15 Component details

Field Segments									
Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	15°	176.12651°	2.4 m	4x1	382	1,528	527.2 kW

Fig. 3.16 Details of panel system

According to the simulated report of the designs, we can see that there is a significant difference in the annual production rates differentiating the shading effects. The PV module system, which is sufficient to generate 828.0kW of power, generated only 527.2kW after being overshadowed by the elements near the site. Furthermore, the amount of converted energy came down to 433.1kW from 673.7kW due to the shading effect. Annually, the system in Tangail generates approximately 1.272GWh energy without considering any

shading losses; however it produces only 803.9MWh with shading losses. Therefore, over 400MWh of energy is wasted due to placement constraints.

MATLAB Simulink

The issued multiple net metering systems have been further formulated in MATLAB Simulink and with corresponding code providing the required data. The detailed explanation of the designs formulation are discussed as such:

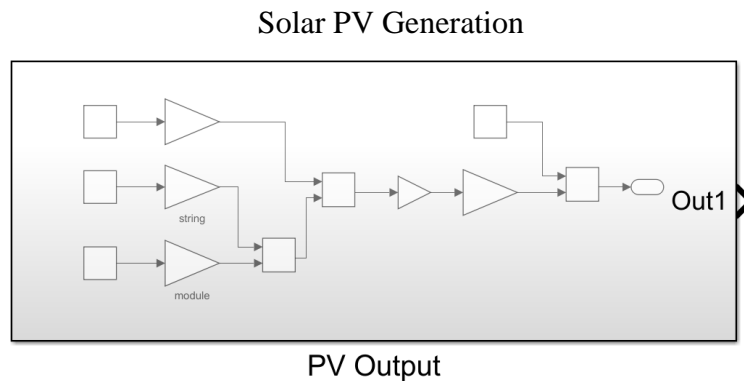


Fig. 3.17 Custom block of solar PV generation

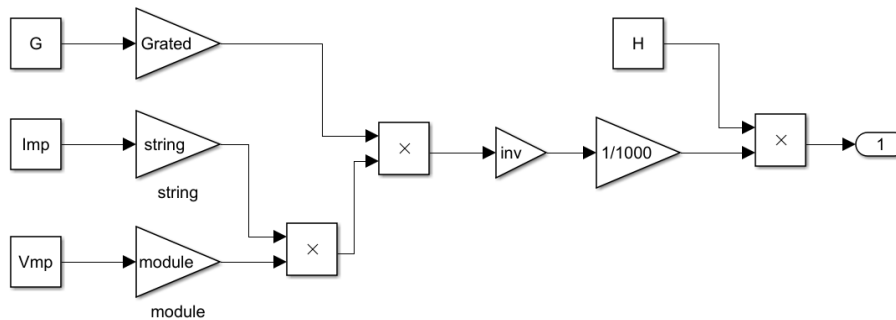


Fig. 3.18 Child-sheet of the custom block for solar PV generation

The above custom block was modeled following equation (1) where the power generated by the array is shown by PV_{Array} while I_{MP} and V_{MP} is the individual PV module maximum power current and individual PV module maximum power voltage respectively. Furthermore, N_{Module} represents the number of modules connected in series, N_{String} is the number of strings and $G(t)$ states the value of solar irradiance in W/m^2 [20]. Inverter efficiency is also taken into account through equation (2) where n_{inv} stands for inverter efficiency.

$$PV_{Array}(t) = (I_{MP} \times N_{String}) \times (V_{MP} \times N_{Module}) \times G(t) - \text{Equation (1)}$$

$$PV_{Out}(t) = PV_{Array}(t) \times n_{inv} - \text{Equation (2)}$$

It can easily be seen that these aforementioned equations are implemented through the custom blocks which results in PV solar output in Watt-hours. Thus it is divided by 1000 to convert into kilowatt-hours. Throughout our project we have struggled to get real time solar irradiance values thus we had to work with monthly average irradiance values obtained from PVsystem. To accommodate this change we had to multiply the kilowatt-hours value with the

total amount of hours in that month; this is achieved through an array H which consists of the number of hours in each month from January to December consecutively.

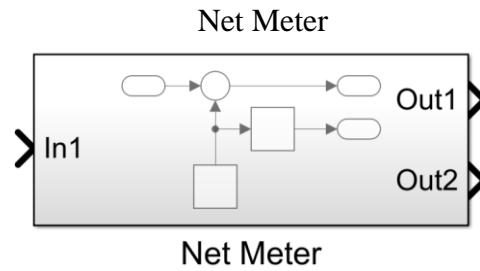


Fig. 3.19 Custom block of net meter

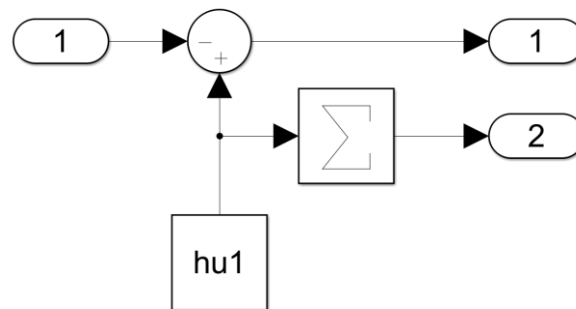


Fig. 3.20 Child-sheet of the custom block for net meter

The custom block for Net Meter is very straightforward as it only subtracts the solar PV generated energy from the monthly load profile. The output is now the monthly energy in kWh taken from the grid. If the value is positive it means net energy is taken from the grid in that specific month while if it is negative it represents the net energy supplied to the grid in that month. The monthly load profile is inserted through the help of an array (hu1 for the above case) and through the sum of elements we can calculate the annual energy consumption of a particular household or apartment.

Arduino

Some important and commonly used sequences of codes are highlighted below along with their explanation to better represent the use of Arduino in order to complete our prototype.

```
String readString;
const char* host = "script.google.com";
const int httpsPort = 443;
WiFiClientSecure client;
String GAS_ID = "AKfycbyiiA44tVD-wwi6DXWbVBqgYGBcmoUv6xry5J8Qdoq3Y32zT-4";
```

```
char* esp_ssid = "HOUSE - 1";
char* esp_pass = "1234567890";
```

Code Snippet 1 (From ESP-8266 of a Household):

In the above code snippet, we have defined the script's host address and a specific port to connect to the server. A "WiFiClientSecure" class's object is defined in this section to establish a connection to the server. Using the "GAS_ID" variable we defined the API key for the project's google sheets. Finally, we defined the microcontroller's access point credentials in case of unavailability of a previously saved wifi hotspot.

```
WiFiManager wifiManager;
wifiManager.setAPCallback(configModeCallback);
if (!wifiManager.autoConnect(esp_ssid, esp_pass)) {
  Serial.println("failed to connect and hit timeout");
  ESP.restart();
  delay(1000);
}
Serial.println("connected...yeey :)");
digitalWrite(D4, LOW);
client.setInsecure();
```

Code Snippet 2 (From ESP-8266 of a Household):

Here (in code snippet two) using an instance variable of class "WiFiManager" we completed all the tasks of connecting to the wifi network. Using ".setAPCallback()" function we defined the function to call in case of failure to connect to a saved network. Then using an if block we checked the wifi connection status. If the connection is successful we skip the if block, otherwise the block is executed and the microcontroller is restarted to connect to the network again or to declare itself as an access point to configure the wifi credentials. Finally, the "setInsecure()" function allows the microcontroller to connect to the host without any problem; this is important as sometimes the server blocks connection from microcontrollers.

```
void measure() {
  Vx = vCal * pzem.voltage(); // voltage(apply calibration correction)
  Ax = iCal * pzem.current(); // current(apply calibration correction)
  VAx = Vx * Ax; // calculate apparent power
  Wx = vCal * iCal * pzem.power(); //effective power (Calibration corrected Value)
  Pfx = pzem.pf(); // power factor
  kWhx = vCal * iCal * pzem.energy(); // sum of energy (Calibration corrected Value)
  Hzx = pzem.frequency(); // line frequency
}
```

Code Snippet 3 (From ESP-8266 of a Household):

In this segment of code presented above, we used a function named "measure()", which measures the AC voltage, current, apparent power, effective power, power factor, energy and frequency of the system. During our prototyping phase, we found a small deviation of the measured value by the sensor with respect to the actual value. Thus a small calibrating factor is introduced. For example, "vCal", and "iCal"; these calibrating factors are taken into calculation while extracting the value from the sensor. The sensor simply puts out the values when requested using the built-in functions like ".voltage()", ".current()", ".power()", ".pf()",

".energy()", ".frequency()" and all these values are put into the global variables so that it can be accessed easily.

```
void measure() { // read values from PZEM-004T v3
  adc_value = analogRead(ANALOG_IN_PIN);
  adc_voltage = (adc_value * ref_voltage) / 1024.0;
  in_voltage = adc_voltage / (R2 / (R1 + R2)) ;

  if (in_voltage < 2.50) {
    in_voltage = 0;
  }
}
```

Code Snippet 4 (From Arduino Uno of the General AC Meter):

In code snippet 4, using the "measure()" function we measured the DC data of the system. The sensors used in this case all of them give analog output. So, using the microcontroller's built-in ADC we read those values. Furthermore, we can see that using a built-in function "analogRead()" we read the value of the voltage sensor. But this is the value of the ADC, which is 10 bits. Thus, to represent its real voltage, this discrete ADC value is converted to the actual voltage coming to the analog pin by multiplying the ref_voltage and finally dividing it by 1024 (2^{10}). One thing we had to keep in mind is that the voltage sensor we are using follows the voltage divider model. As microcontroller pins are at max 5V tolerant, so to measure a DC voltage range of 0V to 25V threshold, the aforementioned model was necessary to use. The analog pin will get the voltage divider's output, but this is not the real DC voltage, so using the voltage divider's resistor values we back-calculated the actual DC input voltage and stored it in the global variable.

3.4 Conclusion

Our solar energy centric project required softwares that could provide solar irradiance data and PV panel and inverter information. After much consideration, PVsyst and Helioscope were chosen. PVsyst provided us with monthly solar irradiance data and per kWh energy cost analysis results for various locations of Bangladesh. For our project, we chose two locations: Cox's Bazar and Tangail, as they have a significant variation in their average monthly solar irradiance amount. After getting their data, the result shows that Cox's Bazar has a less energy cost compared to Tangail even though investment relative to area limit is constant. Solar irradiance data of Cox's Bazar was also more. Furthermore, Helioscope was particularly used for shading loss analysis to compare between the types of solar net metering systems. After inputting the parameters for solar panels in our desired locations and simulating, Helioscope used satellite imaging to give a report of the shading loss analysis. Results show that for the case of Tangail, solar panel placement restrains wastes as much as around 400MWh of energy. Lastly, multiple net metering designs were represented and their feasibility was tested using MATLAB codes and customized Simulink blocks. Also, Arduino was an important part of the prototype design and all codings necessary for microcontrollers were done using it.

Chapter 4

Optimization of Multiple Design and Finding the Optimal Solution [CO5, CO6, CO7]

4.1 Introduction

The project idea that is to be implemented, initially the base being the project proposal is structured. After the proposal is set and the destination is determined there are different ways to reach the destination. But which way can turn out to be the most optimum one is a question that can only be answered once all the ways are explored with full optimization. Thus, all the multiple design approaches for the project are analyzed. Similarly, in our project to determine the best way among all the approaches of net metering was only selected after software simulation for all the designs were accomplished. The results obtained from different designs were analyzed and compared thoroughly in order to deduce the optimal design for our project. After doing an adequate amount of research we selected simulation softwares: PVsyst, Helioscope and MATLAB, MATLAB Simulink, for designing our multiple approaches, in order to determine the optimum design amongst all the optimized multiple designs for our project.

4.2 Optimization of multiple design approach

The net metering scheme is a new concept that consists of mainly four different design approaches in order to be implemented. We had to do our fair share of research to find out which softwares would help us obtain the best simulation result that would showcase the clear comparison among all the approaches. As a result of our research, we utilized softwares like PVsyst, Helioscope and MATLAB Simulink in order to determine which will provide the best outcome for the net metering system in the perspective of Bangladesh.

Throughout our implementation of all different design types, we focused on optimizing all the multiple designs to have some required optimized features. These features included DC and AC monitoring, Web Bill representation, safety system and Load Analysis to determine the correct solar generation system.

DC and AC Monitoring:

As we know, the solar generation system produces DC power which we are continuously monitoring, sending to servers in a bid to compare it with expected production to find out if the system is malfunctioning during long periods of underperformance. On the other hand, AC monitoring is vital not only at household level (wherever applicable) but also at the general production level to find out each consumer's amount of production and consumption. This is very important for the calculation of electricity bills.

Web Bill Representation:

Any approach having multiple owners is bound to have contractual and payment issues; thus to push this problem further from the consumers we have planned for automated electricity

bills to be generated at the end of every month. The method of billing and its calculation is going to be very transparent with real time access to a server displaying all the required parametric values.

Safety System:

Safety in this modern times is of paramount importance; both physical and virtual safety. We have planned to ensure both in our project. Physical safety includes prevention of tampering of individual meters through push buttons, while virtual safety includes privacy of data ensuring only certain accounts (of consumers) can access the server.

Load Analysis:

Analysis of loads while determining the solar generation system is extremely important, it could be the deciding factor of whether the project is going to be profitable or not. Attached below is a detailed discussion of how we did our load analysis while performing software simulation through MATLAB.

For the calculation of the load profile, the monthly average electricity consumption rate (kWh/month) for different types of houses has been surveyed [21]. The electricity consumption of a house is determined by a variety of factors, including the number and type of electrical appliances, as well as the number of people living in the house. We have chosen five such houses for our project that best suits the average household in a typical locality in our country.

TABLE 4.1 Households monthly electricity consumption and their corresponding typical appliances [21]

Household	Family Members	Number of Refrigerators	Number of Iron Machine	Electricity Consumption (kWh/month)
1	5	1	0	210
2	4	2	0	320
3	1	1	0	145
4	4	1	1	280
5	3	1	1	194

For the third month of the year we used the data from the table immediately above as during this month the electricity consumption remains very close to the yearly average as shown by the graph attached below. Electricity consumption is lesser in the earlier months of the year compared to the medial months, thus we predicted values accordingly. It is also seen that electricity consumption is at its highest during the month of August and at the end of the year consumption begins to diminish which we have represented in our load profile data. All our assumptions were made using the help of the figure below where the graphical representation of energy consumption for a year was provided by means of definite inspection.

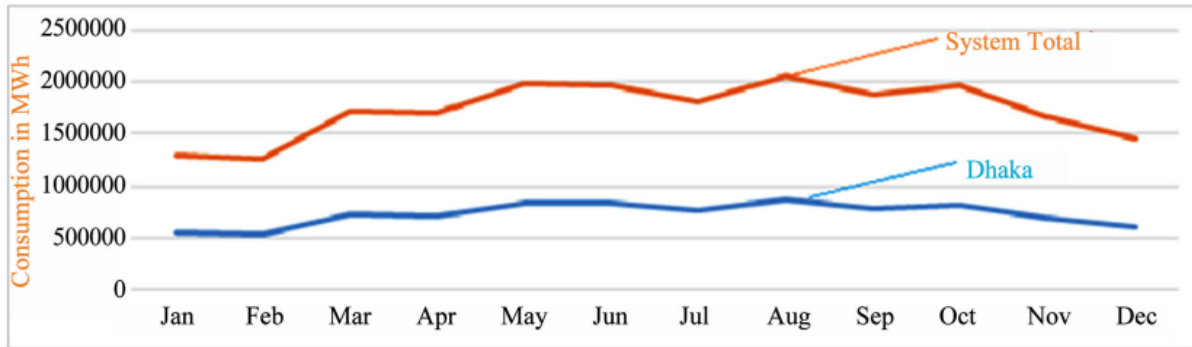


Fig. 4.1 Monthly energy consumption of the year 2016 [22]

Using the monthly energy consumption trend of the year 2016, we predicted the household electricity consumption for all of the months of the year from the average monthly electricity consumption value and acquired data for the load profile of our system.

TABLE 4.2 Electricity consumption rate throughout the year of our five households

Month	Monthly average electricity consumption rate (kWh/month)				
	Household 1	Household 2	Household 3	Household 4	Household 5
January	190	280	130	242	170
February	198	284	128	240	168
March	210	320	145	280	194
April	212	318	148	284	192
May	220	330	154	292	208
June	224	338	158	298	212
July	218	335	150	290	205
August	230	350	162	310	218
September	212	328	158	300	204
October	218	332	160	308	208
November	202	295	138	254	198
December	195	282	132	246	174

4.3 Identify optimal design approach

Analysis: MATLAB Simulink

The issued multiple net metering systems have been further formulated in MATLAB Simulink and with corresponding code providing the required data. The detailed explanation of the designs formulation are discussed below:

I. Community Net Metering system

In the MATLAB design of the community net metering system, the custom solar PV output block which results in the total energy generated (kWh) represents the solar PV generation site. The monthly and yearly total generated amount is shown in the output blocks. The extracted energy from the generation panel is further distributed among five different

households according to their preallocated share through a distribution block. Sequentially, the net metering block representing each of the households takes the PV generated energy as input, subtracts the consumed amount depending on each of their provided load profiles and accumulates the surplus energy as outputs. The output power is basically the surplus amount of energy supplied or taken from the grid. The negative output values stand for the amount supplied to the utility grid and positive values stand for the amount extracted from the grid. The surplus amounts for each of the households are represented in the output blocks in the far-right for each month. The annual surplus energy supplied or extracted from the utility grid summing the monthly outputs and the yearly consumed amounts for the houses are further revealed and demonstrated.

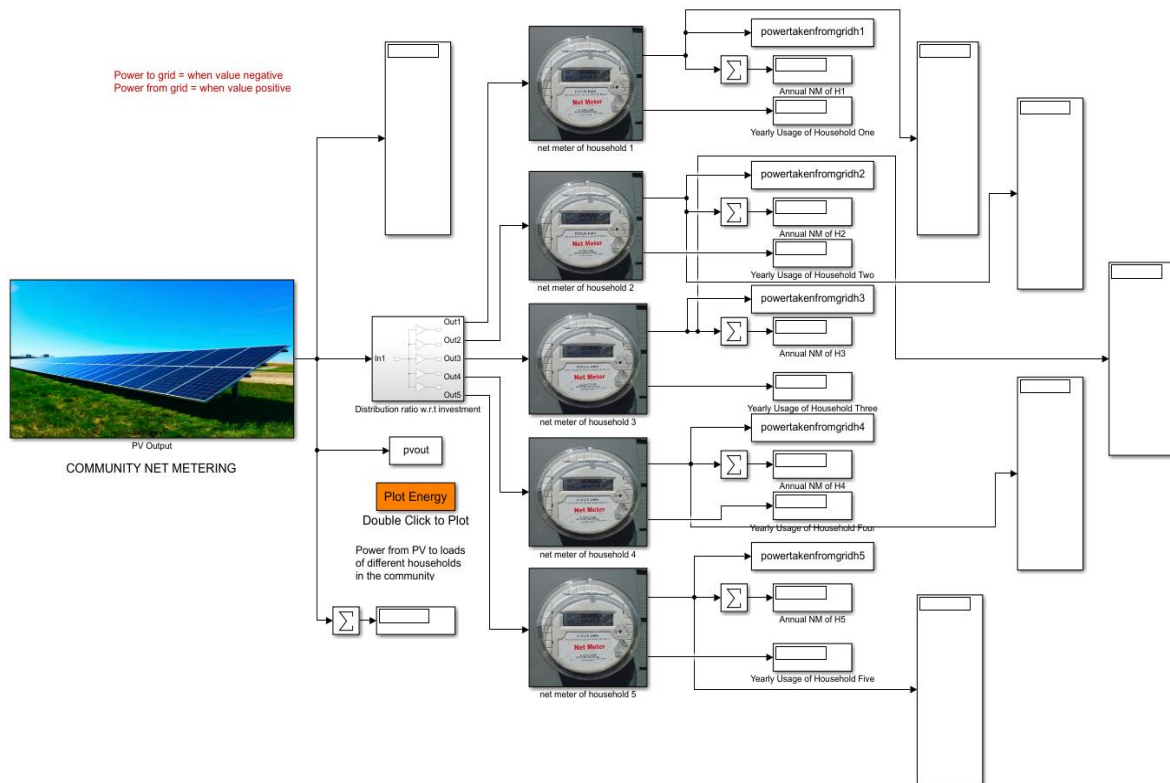


Fig. 4.2 Community net metering software implementation

Programmed code for community net metering system:

```

clc;
clear all;
close all;

%Defining the parameters
Imp = 9.06;
Vmp = 38.1;
G = [140.7 168.9 209.3 214.2 218.3 185.4 166.0 194.8 173.1 160.6 153.6 133.1];
Grated = 1/1000;
string = 5;
module = 10;
inv = 0.95;
H = [744 672 744 720 744 720 744 744 720 744 720 744];
hs1 = 0.15;
hs2 = 0.25;

```



```

hs3 = 0.20;
hs4 = 0.25;
hs5 = 0.15;
hu1 = [190 198 210 212 220 224 218 230 212 218 202 195];
hu2 = [280 284 320 318 330 338 335 350 328 332 295 282];
hu3 = [130 128 145 148 154 158 150 162 158 160 138 132];
hu4 = [242 240 280 284 292 298 290 310 300 308 254 246];
hu5 = [170 168 194 192 208 212 205 218 204 208 198 174];

```

The corresponding parameters defined herewith are required in the custom solar PV generation block which has been extracted from the data sheet of solar PV and inverter components. For the system design, a total of 5 strings and 10 modules have been implemented to meet the required amount of power. It includes Monthly Average solar irradiance data “G”, inverter efficiency “inv”, total number of hours in a month as design has been simulated on monthly rates etc. The variable “hs” represents an array of the preallocated percentages of shares fixed for each of the five households and the array “hu” demonstrates the monthly average energy consumption rate for the houses for each of the month. The consumption data has been extracted from the estimated load profile. An additional function has been generated to plot the energy vs. month curve for the purpose of further analysis.

II. Aggregate Net Metering system:

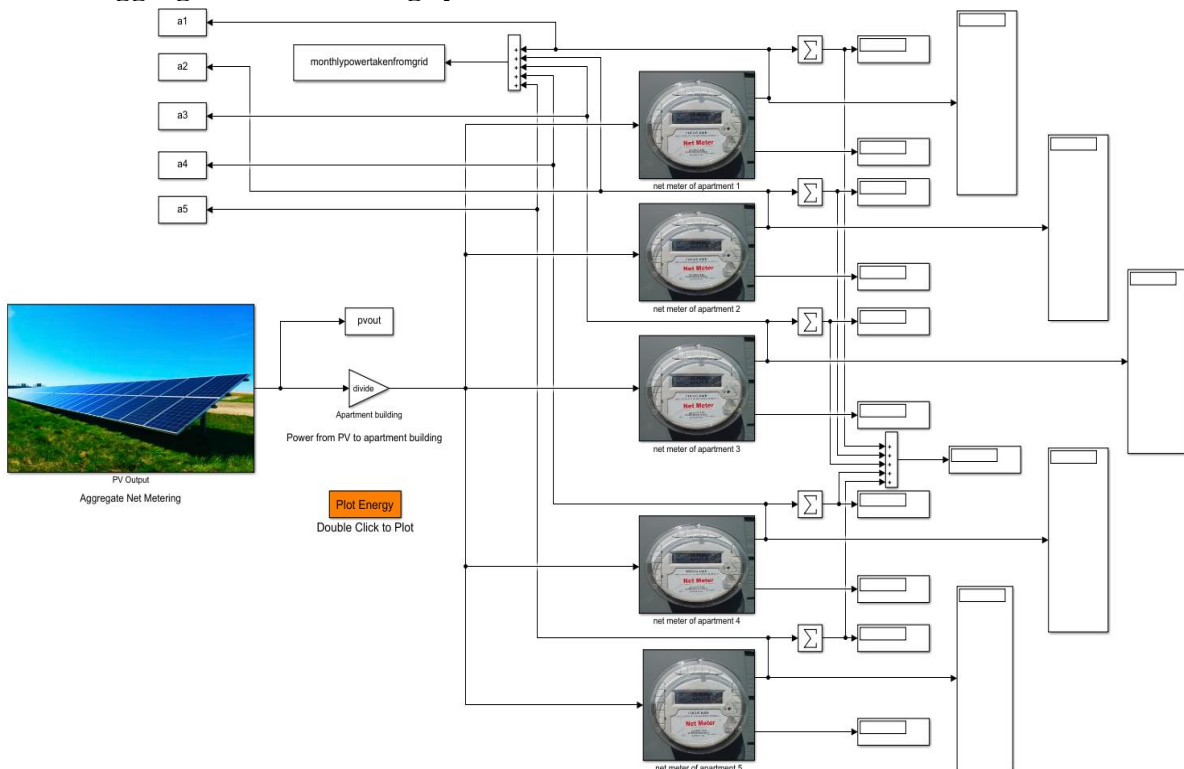


Fig. 4.3 Aggregate net metering system

In the aggregate net metering system design, it is assumed that a single owner distributes the PV generated energy among his multiple consumption ends such as apartments according to their preallocated share. In this case the energy is distributed equally among five different apartments using a gain block. The five net metering blocks take a certain proportion of the generated amount, subtracts the consumed energy by the apartments and calculates the

surplus energy as outputs. The surplus energy represents the amount of energy supplied to or extracted from the utility grid shown in the output blocks. Here, The annual surplus rates are accumulated as well summing the monthly rates for each of the apartments.

Programmed code for Aggregate net metering system:

```

clc;
clear all;
close all;

%Defining the parameters
Imp = 9.06;
Vmp = 38.1;
G = [140.7 168.9 209.3 214.2 218.3 185.4 166.0 194.8 173.1 160.6 153.6 133.1];
Grated = 1/1000;
string = 5;
module = 10;
inv = 0.95;
H = [744 672 744 720 744 720 744 744 720 744 720 744];

divide = 0.2;
hu1 = [190 198 210 212 220 224 218 230 212 218 202 195];
hu2 = [280 284 320 318 330 338 335 350 328 332 295 282];
hu3 = [130 128 145 148 154 158 150 162 158 160 138 132];
hu4 = [242 240 280 284 292 298 290 310 300 308 254 246];
hu5 = [170 168 194 192 208 212 205 218 204 208 198 174];

```

The programmed code for the aggregate net metering system is quite similar to the one applied for community net metering. Although in this system the preallocated share for each apartment has been declared to be equal thus equally distributing the generated power among themselves cumulating 20% share for each apartment which is declared with the variable “divide”.

III. Virtual Net Metering system:

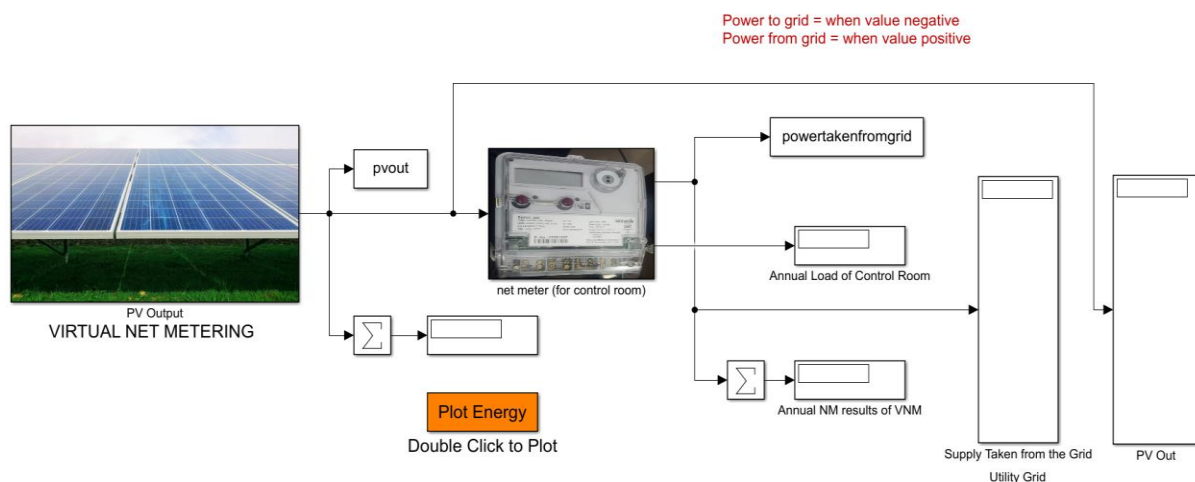


Fig. 4.4 Virtual net metering system software implementation

As aforementioned, in the virtual net metering system, all the generated power from the solar PV system is directly supplied to the utility grid through a control facility. In the MATLAB

design, the solar PV generation block is followed by a control block representing the control room or facility. The control facility has a certain amount of consumption rate due to losses which, in this case, is assumed to be around 24kWh. Therefore, the control facility takes all the generated power from the solar site, subtracts the self-consumption amount and supplies the rest directly to the utility grid. Here, the total generated energy has been demonstrated via the output block and further plotted in graphs. The generated power for each month and energy supplied to the utility grid has been demonstrated and compared in the output blocks on the right. The energy vs. month curve is further plotted in this case.

Programmed code for Virtual net metering system:

```

clc;
clear all;
close all;

%Defining the parameters
Imp = 9.06;
Vmp = 38.1;
G = [163.8 194.5 221.5 245.1 226.5 187.6 137.9 192.9 182.6 181.7 181.7 163.7];
Grated = 1/1000;
string = 10;
module = 5;
inv = 0.95;
H = [744 672 744 720 744 720 744 744 720 744 720 744];

cr = [2 2 2 2 2 2 2 2 2 2 2 2];

```

As aforementioned, the parameters for all three designs have been defined to be similar. The array “cr” represents the amount of energy consumed by the control facility which is recorded due to internal losses. In this particular case, we have assumed that it consumes 2 kWh for each month which sums up to a total of 24kWh annually. This amount is applied to the control room block depicted in Simulink design.

4.4 Performance evaluation of developed solution

In order to select the optimal design, the issued net metering design prototypes formulated in Simulink have been analyzed by plotting energy vs. month graphs and obtaining data from output blocks. The feasibility of designs have been further compared according to various characteristics including advantages and corresponding policies.

The simulation plots and resulted data of MATLAB Simulink implementation of Community, Aggregate and Virtual net metering systems and the selection of the optimal design upon evaluating different aspects are demonstrated as such:

I. Community Net metering system: Matlab simulation

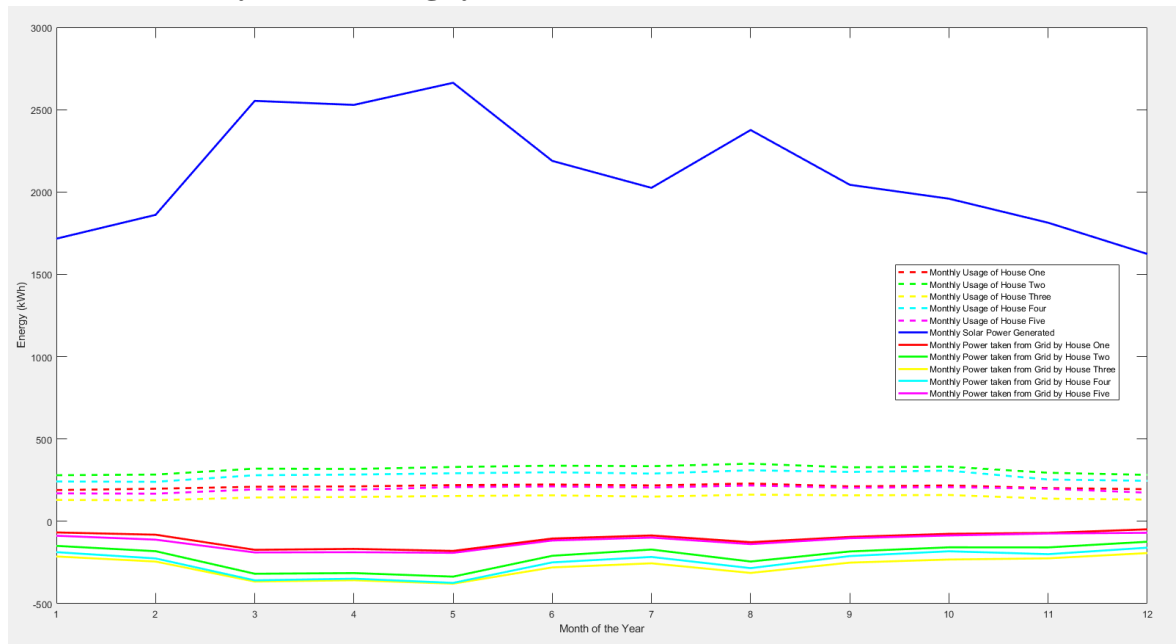


Fig. 4.5 Energy vs month plots for community net metering system

Upon simulating the MATLAB designs of community net metering we have generated the energy vs. month curve plotting the monthly energy consumption rate of each of the households, monthly generated power extracted from the solar PV site and the monthly power supplied to the grid by each of the houses. It is quite noticeable that the monthly energy consumption rate of the household follows almost a constant pattern, differentiating from that range of 100-400 kWh as per the provided load profile. The curve of the solar PV generated amount, on the other hand, fluctuates depending on the average weather conditions and temperature for each month. In the mid-year, the most amount of energy is generated compared to the start and the end of the year, the pattern of which is firmly followed by the amount supplied to or extracted from the utility grid.

TABLE 4.3 Community net metering simulation data sheet and feasibility verification

Month	Household	Allocated maximum transmitted energy from PV (kWh)	Consumed energy of households (kWh)	Surplus energy sold to grid (kWh)
January	1	257.4	190	67.4
	2	429	280	149
	3	343.2	130	213.2
	4	429	242	187
	5	257.4	170	87.4
February	1	279.15	198	81.15
	2	465.25	284	181.25
	3	372.2	128	244.2
	4	465.25	240	225.25
	5	279.15	168	111.15
March	1	382.95	210	172.95
	2	638.25	320	318.25

	3	510.6	145	365.6
	4	638.25	280	358.25
	5	382.95	194	188.95
April	1	379.35	212	167.35
	2	632.25	318	314.25
	3	505.8	148	357.8
	4	632.25	284	348.25
	5	379.35	192	187.35
May	1	399.45	220	179.45
	2	665.75	330	335.75
	3	532.6	154	378.6
	4	665.75	292	373.75
	5	399.45	208	191.45
June	1	328.35	224	104.35
	2	547.25	338	209.25
	3	437.8	158	279.8
	4	547.25	298	249.25
	5	328.35	212	116.35
July	1	303.75	218	85.75
	2	506.25	335	171.25
	3	405	150	255
	4	506.25	290	216.25
	5	303.75	205	98.75
August	1	356.4	230	126.4
	2	594	350	244
	3	475.2	162	313.2
	4	594	310	284
	5	356.4	218	138.4
September	1	306.6	212	94.6
	2	511	328	183
	3	408.8	158	250.8
	4	511	300	211
	5	306.6	204	102.6
October	1	293.85	218	75.85
	2	489.75	332	157.75
	3	391.8	160	231.8
	4	489.75	308	181.75
	5	293.85	208	85.85
November	1	271.95	202	69.95
	2	453.25	295	158.25

	3	362.6	138	224.6
	4	453.25	254	199.25
	5	271.95	198	73.95
December	1	243.6	195	48.6
	2	406	282	124
	3	324.8	132	192.8
	4	406	246	160
	5	243.6	174	69.6
		Total 25,352	Total 13,779	Total 11,573

The data sheet demonstrated above reflects the simulated output of the design. The “Allocated maximum transmitted energy from PV (kWh)” shows the Maximum amount of energy consumable by each household depending on their predefined share. Sequentially, “Consumed energy of households” shows the amount of energy that has been consumed by the houses reflecting the load profile. “Surplus energy sold to grid” represents the surplus amount of energy supplied to or extracted from the grid.

As we can see, the total amount of energy supplied from the PV output is 25.352 MW. The total energy consumed by the households is 13.779 MW. The total surplus energy supplied to the utility grid is 11.573MW at the end of the year. Therefore the consumers will gain altogether 11.573MW worth of profit after implementing the community net metering system in a year.

II. Aggregate Net metering system: Matlab simulation

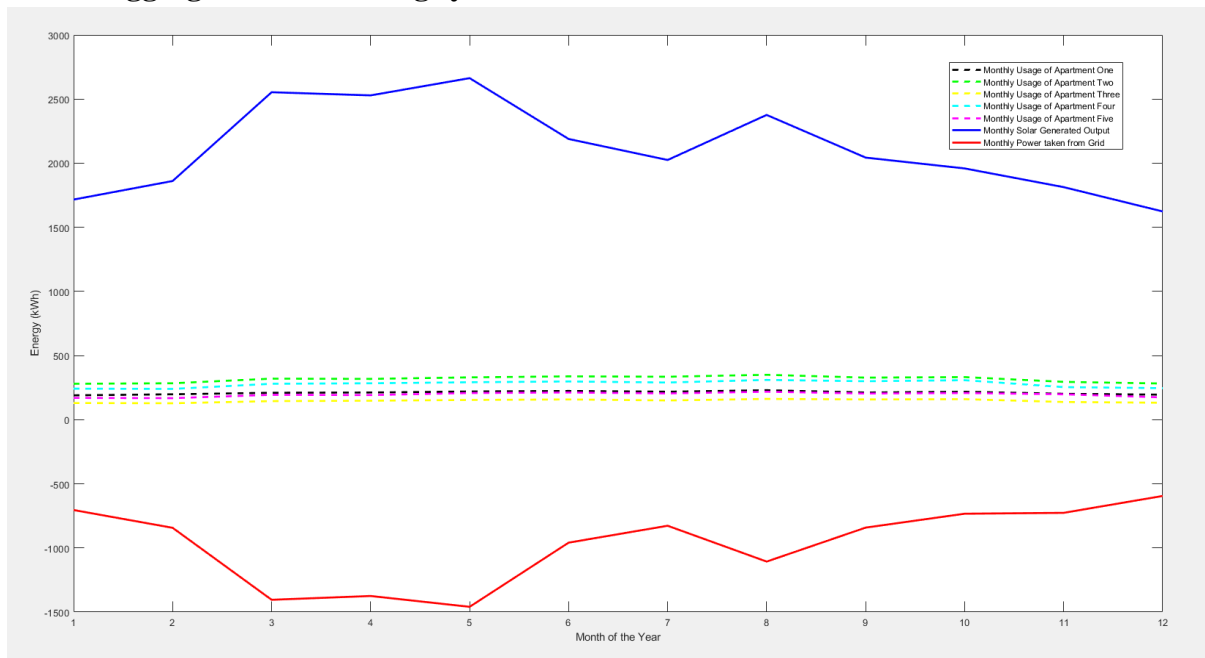


Fig. 4.6 Energy vs month plots for aggregate net metering system

After running the simulation of aggregate net metering we obtained the energy vs. month curve, plotting the monthly energy consumption rate of each of the five apartments, monthly generated power extracted from the solar PV site and the monthly power supplied to the grid

by each of the apartments. It is quite prominent from the graph that the monthly energy consumption rate of the apartment follows almost a constant pattern around 400 kWh with regards to the load profile. On the other hand, the curve of solar PV generation has quite some fluctuations. We can further observe that in the mid-year, the most amount of energy is generated compared to the start and the end of the year, the pattern of which is firmly followed by the amount supplied to or extracted from the utility grid.

TABLE 4.4 Aggregate net metering simulation data sheet and feasibility verification

Month	Household	Allocated maximum transmitted energy from PV (kWh)	Consumed energy of households (kWh)	Surplus energy sold to grid (kWh)
January	1	343.2	190	153.2
	2	343.2	280	63.2
	3	343.2	130	213.2
	4	343.2	242	101.2
	5	343.2	170	173.2
February	1	372.2	198	174.2
	2	372.2	284	88.2
	3	372.2	128	244.2
	4	372.2	240	132.2
	5	372.2	168	204.2
March	1	510.6	210	300.6
	2	510.6	320	190.6
	3	510.6	145	365.6
	4	510.6	280	230.6
	5	510.6	194	316.6
April	1	505.8	212	293.8
	2	505.8	318	187.8
	3	505.8	148	357.8
	4	505.8	284	221.8
	5	505.8	192	313.8
May	1	532.6	220	312.6
	2	532.6	330	202.6
	3	532.6	154	378.6
	4	532.6	292	240.6
	5	532.6	208	324.6
June	1	437.8	224	213.8
	2	437.8	338	99.8
	3	437.8	158	279.8
	4	437.8	298	139.8
	5	437.8	212	225.8

July	1	405	218	187
	2	405	335	70
	3	405	150	255
	4	405	290	115
	5	405	205	200
August	1	475.2	230	245.2
	2	475.2	350	125.2
	3	475.2	162	313.2
	4	475.2	310	165.2
	5	475.2	218	257.2
September	1	408.8	212	196.8
	2	408.8	328	80.8
	3	408.8	158	250.8
	4	408.8	300	108.8
	5	408.8	204	204.8
October	1	391.8	218	173.8
	2	391.8	332	59.8
	3	391.8	160	231.8
	4	391.8	308	83.8
	5	391.8	208	183.8
November	1	362.6	202	160.6
	2	362.6	295	67.6
	3	362.6	138	224.6
	4	362.6	254	108.6
	5	362.6	198	164.6
December	1	324.8	195	129.8
	2	324.8	282	42.8
	3	324.8	132	192.8
	4	324.8	246	78.8
	5	324.8	174	150.8
		Total 25,352	Total 13,779	Total 11,573

As the parameters of the generation site and load profile at the consumer's end have remained similar, the annual produced energy from PV out is 25.352 MW and the amount consumed by the apartment is 13.779 MW, similar to community net metering. Here, the surplus amount sent to or extracted from the utility grid is 11.573 MW. Therefore the single owner will gain a total of 11.573 MW worth of profit in a year from his five apartments after implementing the aggregate net metering system as well. Thus the effective impact of the aggregate net metering system has been further verified.

III. Virtual Net metering system: Matlab simulation

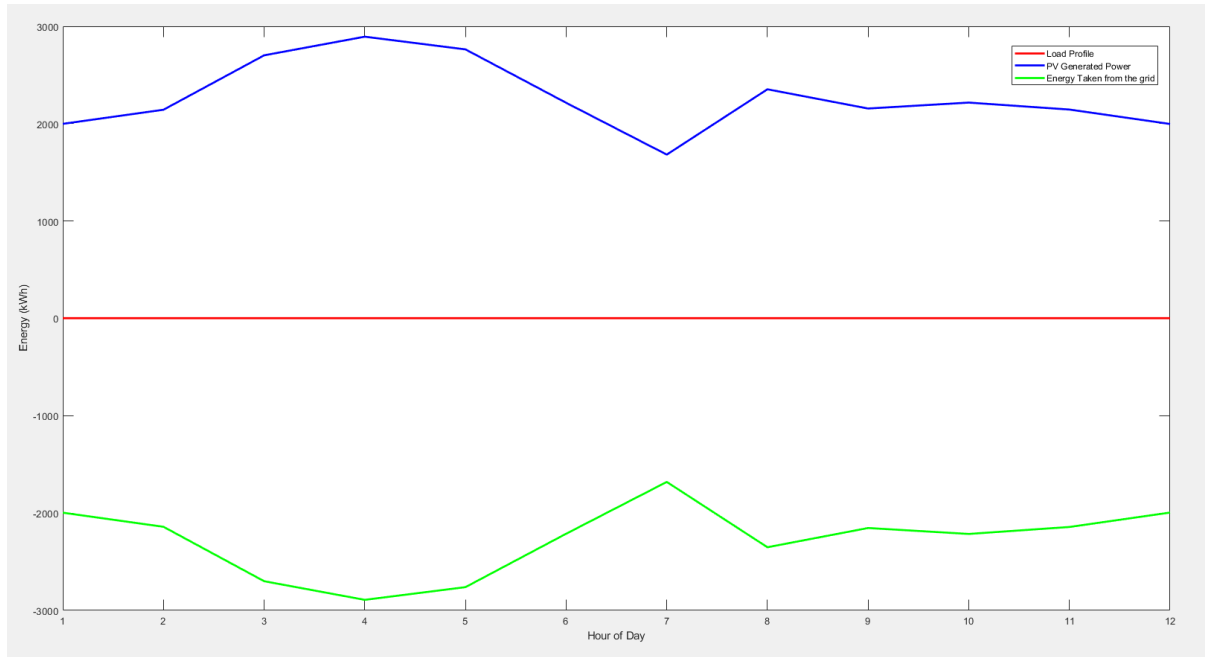


Fig. 4.7 Energy vs month plots for virtual net metering system

When the simulation of virtual net metering is conducted we once again obtain the energy vs. month curve plotting the monthly energy consumption rate of the control room maintaining the surplus supply of generation to the grid and monthly generated power extracted from the solar PV site. It is quite visible that the monthly energy consumption rate of the control room is constant and very minimal as per the given load profile. Whereas the curve of the solar power generated from the PV fluctuates depending on the variable like average weather conditions and temperature for each month. It is quite obvious from the pattern of the graph that in the mid-year, the most amount of energy is generated in comparison to the start and the end of the year, firmly followed by the amount supplied to or extracted from the utility grid.

TABLE 4.5 Virtual net metering system simulation datasheet and feasibility verification.

Month	Maximum generated energy from PV (kWh)	Consumed energy by the control facility (kWh)	Energy sold to grid (kWh)
January	1998	2	1996
February	2143	2	2141
March	2702	2	2700
April	2893	2	2891
May	2763	2	2761
June	2215	2	2213
July	1682	2	1680
August	2353	2	2351
September	2156	2	2154
October	2217	2	2215

November	2145	2	2143
December	1997	2	1995
	Total 27,264	Total 24	Total 27,240

In the case of the virtual net metering system, the solar PV generation site has been installed in a different location thus the total energy produced varies from that of community and aggregate net metering. The solar PV generation plant generates a total of 27.264 MW energy. As aforementioned, this system supplied the entire production directly to the utility grid through a control facility. The control facility or room consumes a certain amount of energy depending on the appliances present in the control room. In the simulated design, we have assumed that the consumed amount to be 2kWh per month, thus annual 24kWh of energy. Subtracting this consumption, the total amount of energy supplied to the grid is approximately 27.240 MW. Therefore, the consumer gains an enormous profit worth of 27.240 MW energy.

TABLE 4.6 Data on power generation and power transfer for the multiple design approaches

Issued Characteristics	Community net metering	Aggregate net metering	Virtual net metering
Annual solar PV generation (Simulink design)	25.352 MW	25.352 MW	27.264 MW
Annual net energy transferred to the grid (Simulink design)	11.573 MW	11.573 MW	27.240 MW

The above table depicts the yearly solar power that is produced when the three different design approaches are modeled in Simulink. Also the annual net energy that can be transferred to the grid. The most beneficial result is obtained using the virtual net metering approach. But many countries like Bangladesh have yet given the flexibility to the policies regarding net metering making this approach hard to implement. The next best approach that is also abided by the policies and is the most favorable design approach is community net metering. Thus this is our optimum design to boost the solar energy sector of our country Bangladesh.

4.5 Conclusion

Our project is designed in such a way that we emphasize on the new concept of net metering that is incorporated with an easily utilizable renewable energy form called solar energy. The main motive behind our idea included conserving natural energy resources and increasing the dependency on renewable energy resources to meet up with the ever-increasing energy demands. Simultaneously, keeping a track of energy flow of households to reduce the electricity bill of consumers in the future.

Through our research work we got to learn that there are multiple ways of implementing a net metering system, community net metering being one of them. In community net metering, the whole community is treated as a single customer and sets up a single generating site. The aggregate load demand consumed by all the participants is critical in determining the size of the generating facility. A number of consumers will come together to form a single facility, hence the hassles of filing application, operation and maintenance of the plant would be reduced. Smaller consumers can be served more effectively. The customers who do not have place for installation of solar panels can be benefited most by such policy, thereby reducing inequities. Another method of net metering is aggregate net metering, where the single consumer with a single generation system offsets power from multiple meters accumulating all the benefits under a single consumer. In this type of metering a single investor tends to use multiple meters in multiple locations all under the investor and enjoys the benefits of it.

The final net metering method that we came across is named virtual net metering. In this type of net metering a collective generation is placed off-site placement and the benefits are enjoyed thoroughly by the collective investors. The benefit of virtual net metering is maximum as almost all of the generated solar energy is sold to the grid. In order to display our net metering features and benefits we selected the software tools PVsyst, Helioscope and MATLAB simulink. The PVsyst software provided us with monthly irradiation data and also helped in making analysis of per kWh energy cost in USD at different locations in Bangladesh. Moreover, we used Helioscope to do the design of the solar panel in the desired location. This software uses satellite imaging for this. The simulation reports of our design provide shading loss analysis for different design approaches as well for further comparison. Finally we used MATLAB and MATLAB simulink software to obtain the solar PV generation values and net energy transfer to and from the utility grid via coded custom build blocks. The designs provide us with energy vs time (months) graphs for analysis and comparison among all the multiple design approaches for the purpose of further analysis.

Chapter 5

Completion of Final Design and Validation [CO8]

5.1 Introduction

Upon further comparative analysis of the issued design approaches, the optimized design of the Community Net metering system has been implemented via both software and hardware prototype. The software design of the system has been implemented in MATLAB using custom blocks for generation and net metering distribution systems executing five households at the load end on a monthly basis. The surplus energy produced after consumption via the households is exhibited in the output blocks representing the amount of energy sent to the grid. On the contrary, the hardware prototype system is executed for two household systems, and the data is measured upon a standby or instant measurement system. Particular ratings including voltage, current, power, power factor, and even frequency have been computed on a real time basis and the data is accessed and directed to an online server using wifi-module. The system has been tested manually upon connecting different quantities of load power usage implemented via light bulbs. A detailed overview of the design formulation and evaluation is demonstrated in the proceedings.

5.2 Completion of final design

The project has been implemented through both software and hardware prototype. A detailed explanation and analysis of the design is depicted below in the proceedings:

Final Software Design

After overall optimization and observation, the final software formulation of the community net metering system implemented via MATLAB is depicted below:

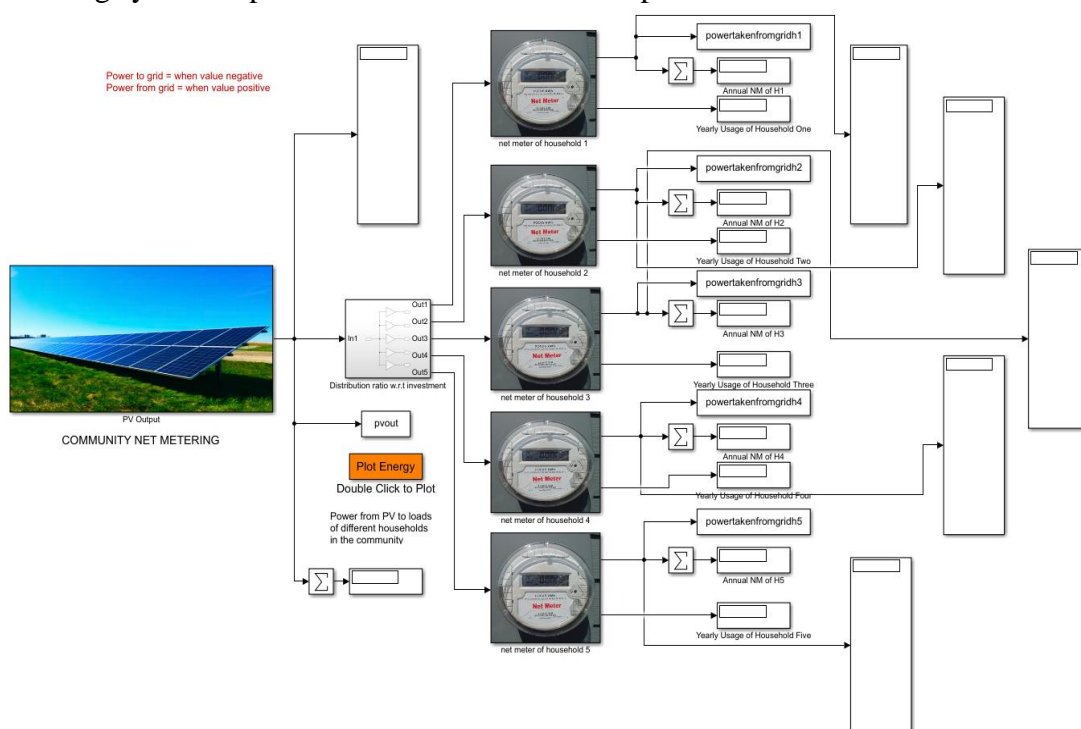


Fig. 5.1 Software implementation of community net metering system

The customized solar PV output block, which yields the total energy generated (kWh), represents the solar PV generating system in the MATLAB design. The output blocks display the total amount earned on a monthly and annual basis. Through a distribution block, the energy collected from the generating panel is then dispersed to five separate houses in accordance with their pre-allocated share. The net metering block for each home sequentially receives the PV-generated power as input, deducts the required amount based on each load profile specified, and accumulates the excess energy as outputs. The extra energy that is delivered from the grid block is essentially the output energy. The utility grid's supply is represented by the negative output numbers, while extraction from the grid is represented by the positive output values. The output blocks show the excess amounts for each of the households for each month. Additionally, the annual excess energy that is delivered to or withdrawn from the utility grid is illustrated by adding the monthly outputs and the annual quantities used by the households.

Final Prototype Design

The hardware prototype design implementation has been categorized into five distinctive systems according to their corresponding purpose including Generation system, Grid system, Load systems or households, Data monitoring and storage system, Power flow distribution system. A detailed overview of each of the systems are described in the proceedings below for reference:

I. Solar Generation System

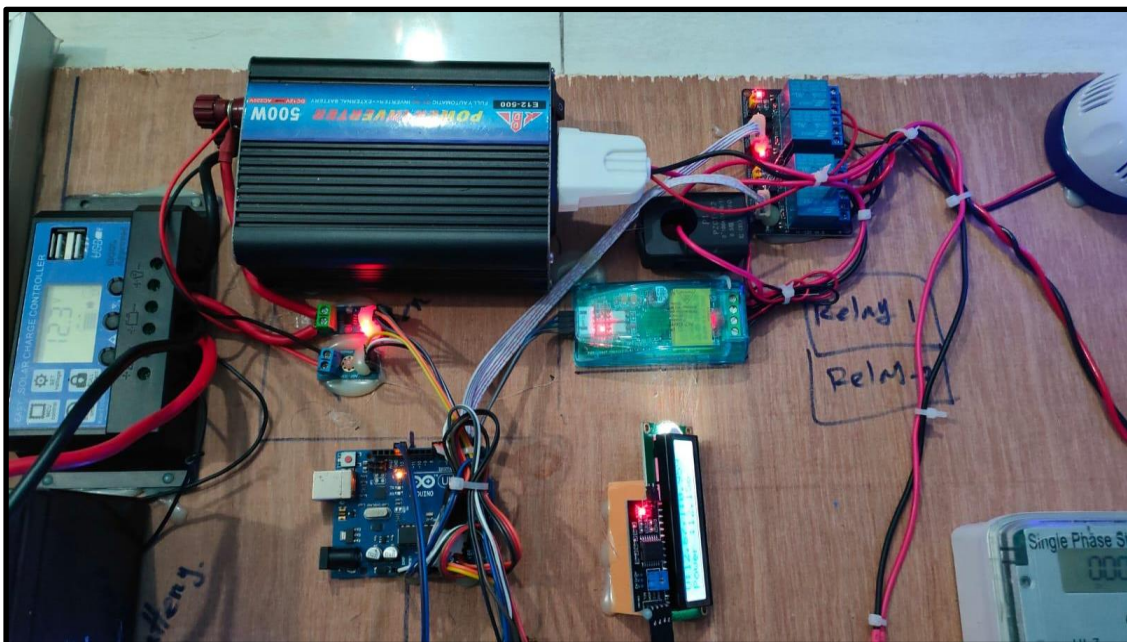


Fig. 5.2 Solar generation system

While formulating our prototype design, the solar PV generation system has been implemented via solar PV arrays to produce energy. An alternate 12V lithium-ion battery has been further connected for the prototype to continue providing stored power even in distinct weather or indoor conditions. Sequentially, an adjustable solar controller of the PWM (Pulse Width Modulation) variant has been attached to the generation panel. The solar charge

controller controls the current flow from the solar generation panel to the battery refraining from overcharging the battery or stabilizing the power flow within an appropriate amount. Furthermore, we know, the solar system generates energy in DC voltage whereas we need an AC voltage to be suitable for household usage, therefore an 500W inverter has been used to convert the DC voltage into AC voltage. Thus taking the component sequence into account, the solar PV array, lithium ion battery, PWM functional solar charge controller and a DC-AC inverter concludes the generation portion of the system.

II. Grid Representation

Representing the grid in our prototype is a big challenge, which we have overcome using a 12 Volt battery, DC-AC inverter, a single phase static kilowatt hour meter and a generic light bulb along with its holder. The aforementioned challenge is two-folded one; ensuring power supply taken from the grid when the solar generation system is not capable enough to provide for the household loads and to take the power supply from the solar generation system whenever there is excess production. To demonstrate this in our prototype, we have two separate branches working in tandem; while the household loads exceed the capacity of the solar generation system, excess power is taken from the grid. This is achieved via a 12 Volt battery, DC-AC inverter and a single phase static kilowatt hour meter; whenever power is taken from the grid we can observe the readings on the static meter but when no supply is taken from the grid, the null readings on the meter represents this reality. On the other hand, to demonstrate any surplus power taken from the grid, we have used a generic light bulb which represents any load connected to the national grid and is being supplied through the surplus production of our solar generation system. Thus, the glowing of this light embodies the fact that surplus power supply from our solar generation system is being delivered to the grid.

III. Household representation

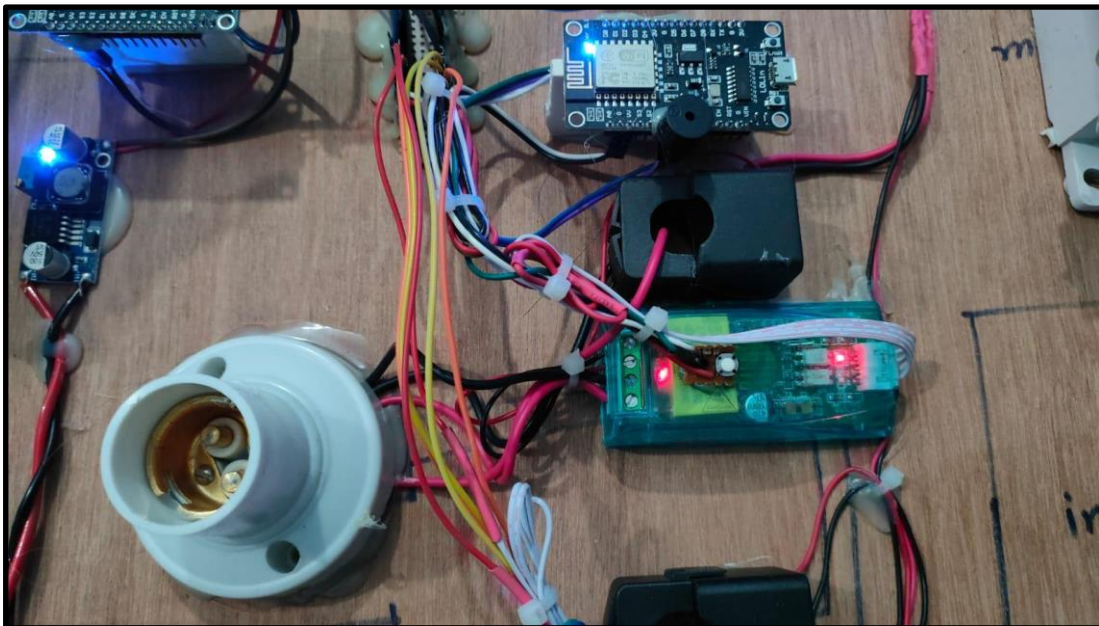


Fig. 5.3 Household representation

For our prototype, we have decided to demonstrate only two households; any further additions will work exactly the same way discussed below. Each of the households will consist of a PZEM-004T AC meter, an ESP-8266 and the loads associated with that household. For our households, the load used is only a generic light bulb as the inverter used in our prototype is extremely inefficient demonstrating below average performance. Moving on to the next piece of the puzzle, the PZEM-004T is a unique AC Meter that has the capability to measure AC parameters such as Voltage, Current, Power Factor, Energy Consumption etc. These parameters are measured in real time and stored in a specific google sheet to be used for corresponding electricity bill calculations. Here, the ESP-8266 acts as a wifi-module to send the data to the required google sheet. Furthermore to increase protection, the idea is to have a box which encloses the whole AC Meter and ESP-8266; as the box remains shut a push button remains closed and while the box is opened the push button gets released. Based on the status of this push button, we can say if any household meter is being vandalized or not. Such a situation is being represented in our prototype with only a push button as enclosing the whole AC Meter makes troubleshooting problems harder. In a nutshell, if this push button is pressed meaning someone is tampering with the meter, there will be “DAMAGED” status of our meter in the google sheet enforcing the idea of any unexpected access to the household meter.

IV. Data Monitoring and Storage Mechanism

It is of paramount importance that all required parametric values are measured in real time and stored in a secure place to be utilized for bill calculations. In the previous segment, the storing of individual household data was discussed but there is another general AC Meter in play which also needs to be accounted for. This AC Meter is of the same model as used for the households in the community, it also stores the same parametric values mentioned in the above segment in another Google Sheet, but this specific meter monitors the production of our solar generation system. Such a meter is important to determine individual rights to the overall production and thus bill calculations. We also have the capability to monitor the DC production parameters of our solar generation system; this is achieved via a DC Voltage sensor, DC Current Sensor and Arduino UNO. This aforementioned microcontroller also comes in handy to take the decisions on the overall energy and power flow distribution system as discussed below. Following the pathway of household meters, the sending of data to a Google Sheet is accomplished using ESP-8266 which serially communicates with Arduino UNO to get the necessary parametric values in a specific format.

V. Energy and power flow Distribution System

Ensuring correct power and energy flow was one of the biggest challenges while designing our prototype. The lack of a solar grid tied inverter is the main reason behind this challenge, the aforementioned type of inverter has a lot of desirable features. It itself matches the solar output to that of the grid while maintaining unity power factor ensuring smooth transmission of surplus power to the grid but due to expense of such an inverter we had to use cheaper inverters which do not have any of the mentioned features. Unlike grid tied inverters, our inverter can not itself make decisions based on parametric reading about when to supply or take power from the grid. Thus we had to design our own energy flow and distribution

system using relays, analysis of load profile and solar generation. Upon doing the analysis of solar generation and load profile, we can find out the switching point of different parameters such as Power; based on this parameter we have coded the switching of relays (using Arduino UNO) on whether to supply power to the grid or take power from it. To sum up, we can say that observing parameters such as power based on our system analysis we can decide whether power needs to be delivered or taken from the grid.

5.3 Evaluate the solution to meet desired need

Upon implementation of both the software and hardware prototype design, we have simulated and manually experimented on the designs and analyzed the derived data. The evaluation and validation of the designs are depicted below:

Evaluation of Software Simulation:

For the final design prototype we have implemented the Community Net Metering system which we have formulated and simulated beforehand on MATLAB. The simulated Energy vs. Time graph and data of the first three months from the software simulation are represented below in order to evaluate if the desired solution is authenticated.

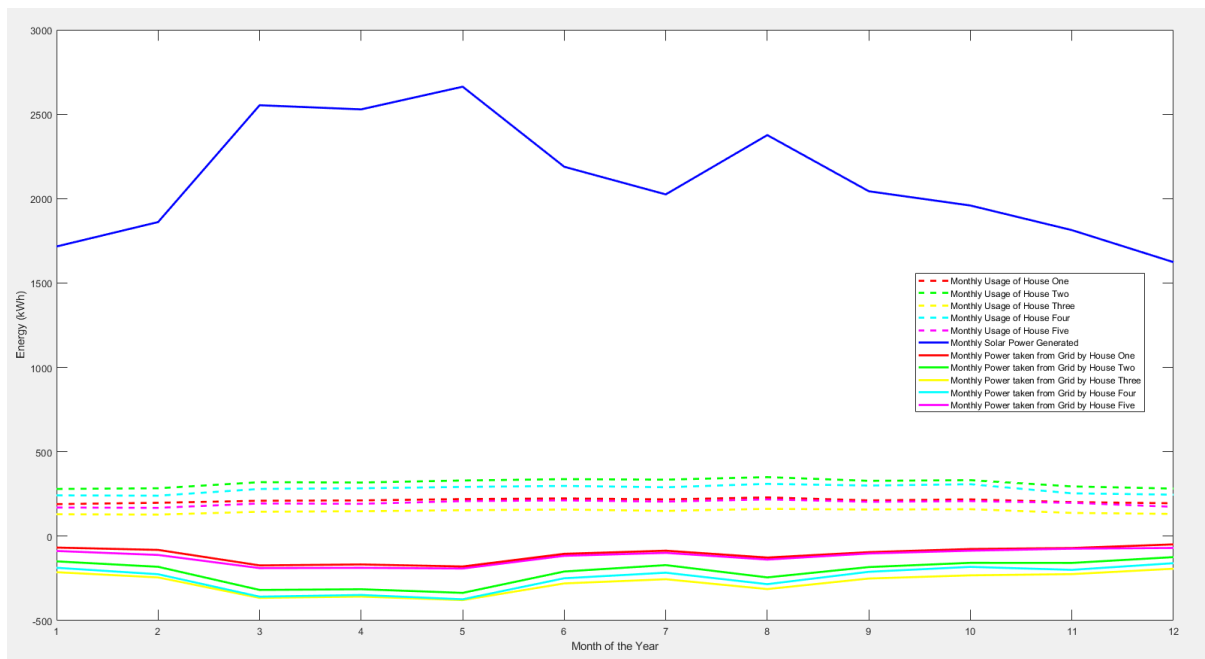


Fig. 5.4 Energy vs month graphs for community net metering system

The energy vs. month curve generated from the software design shows the monthly solar PV generated power, monthly energy consumption rates for each family and the monthly power delivered to the grid by each home. It is quite apparent that the household's monthly energy consumption rate exhibits a nearly consistent pattern as per their pre-allocated load profile. On the other hand, the curve of the PV generated energy varies according to the typical weather and temperature for each month.

TABLE 5.1 Community net metering system simulated data sheet and feasibility verification

Month	Household	Allocated maximum transmitted energy from PV (kWh)	Consumed energy of households (kWh)	Surplus energy sold to grid (kWh)
January	1	257.4	190	67.4
	2	429	280	149
	3	343.2	130	213.2
	4	429	242	187
	5	257.4	170	87.4
February	1	279.15	198	81.15
	2	465.25	284	181.25
	3	372.2	128	244.2
	4	465.25	240	225.25
	5	279.15	168	111.15
March	1	382.95	210	172.95
	2	638.25	320	318.25
	3	510.6	145	365.6
	4	638.25	280	358.25
	5	382.95	194	188.95

The simulated output for the MATLAB implemented community net metering system for only the first three months have been depicted above in order to observe and validate the data flow. Here, according to the predetermined share, each home can utilize a maximum quantity of energy, which is displayed under "Allocated maximum transmitted energy from PV (kWh)". "Consumed energy of homes" displays the energy consumption over time for each home, in accordance with their load profile. The term "surplus energy sold to grid" refers to excess energy that has been added to or taken out of the system. The system derives the surplus energy by subtracting the consumed amount from the allocated maximum consumption amount and sends it back to the grid. For each of the cases, it is noticed that a certain amount of surplus energy is created thus indicating the ability to economic feasibility over an elongated period satisfying the purpose of this system.

Evaluation of Hardware Prototype:

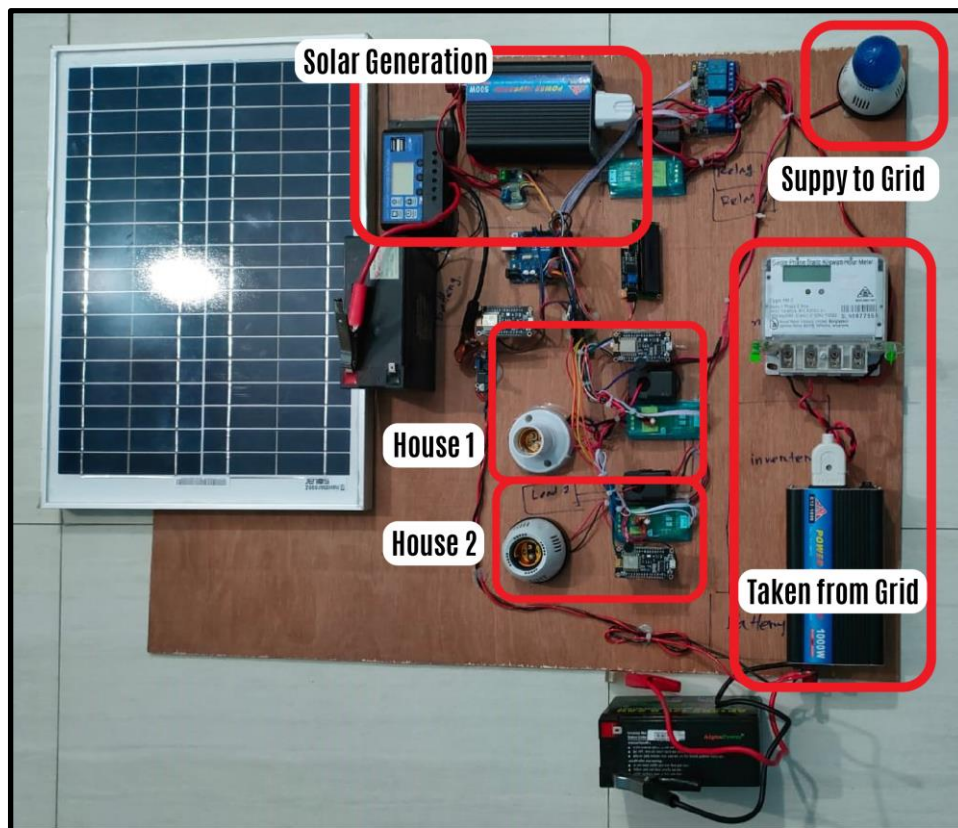


Fig. 5.5 Prototype in idle stage

The above figure demonstrates our prototype in idle stage where the top right light represents any supply given to the grid; the bottom right inverter, battery and meter represents any supply taken from the grid; the top inverter, battery and PWM adjustable solar controller represents solar generation; and the light bulb holders along with the AC meters in its vicinity represents the different households in our system. It is evident from the displayed figure that both the battery supply are not connected meaning our designed prototype is currently offline.

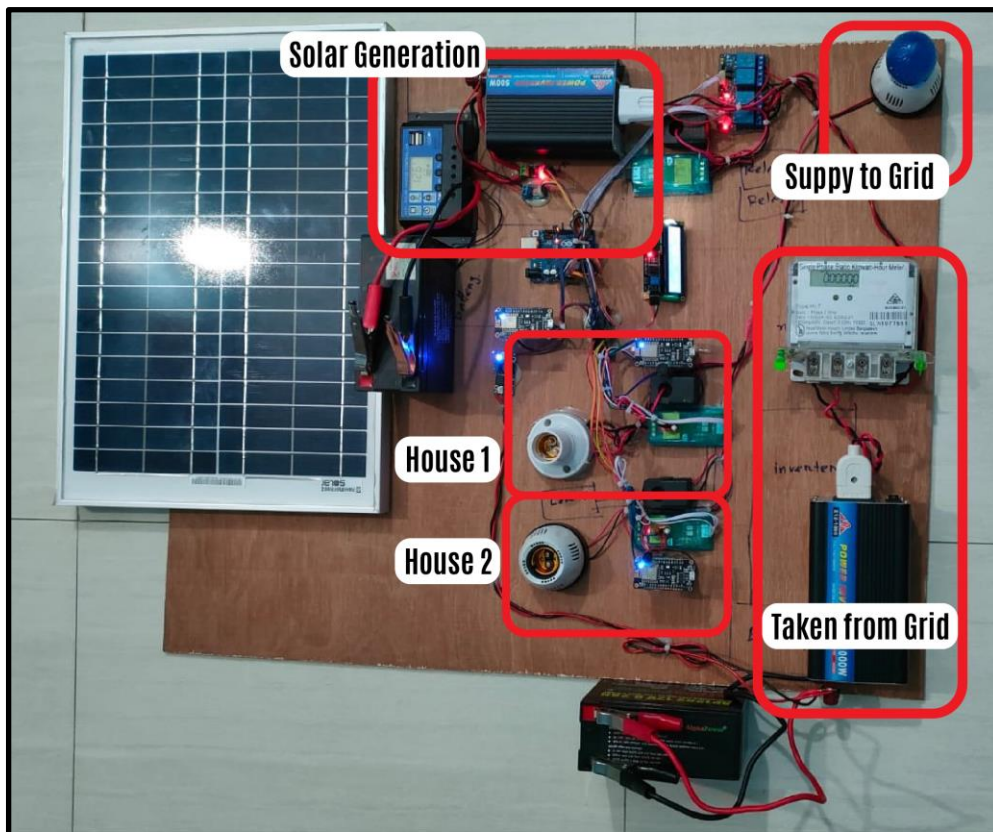


Fig. 5.6 Grid turned on (prototype in working stage)

Moving on, as the grid representative part is now connected and providing power, all of our components are now in operation. It is quite visible that components such as ESP-8266, AC meters, relays and display are now fully functional and sending the required parametric data to our designated google sheet. Our design is built to take all the necessary power of the components from the grid through a buck conductor and a bus bar containing all the positive and negative terminals of the equipment used. Use of this bus bar made our project easier to design and demonstrate in front of an audience.

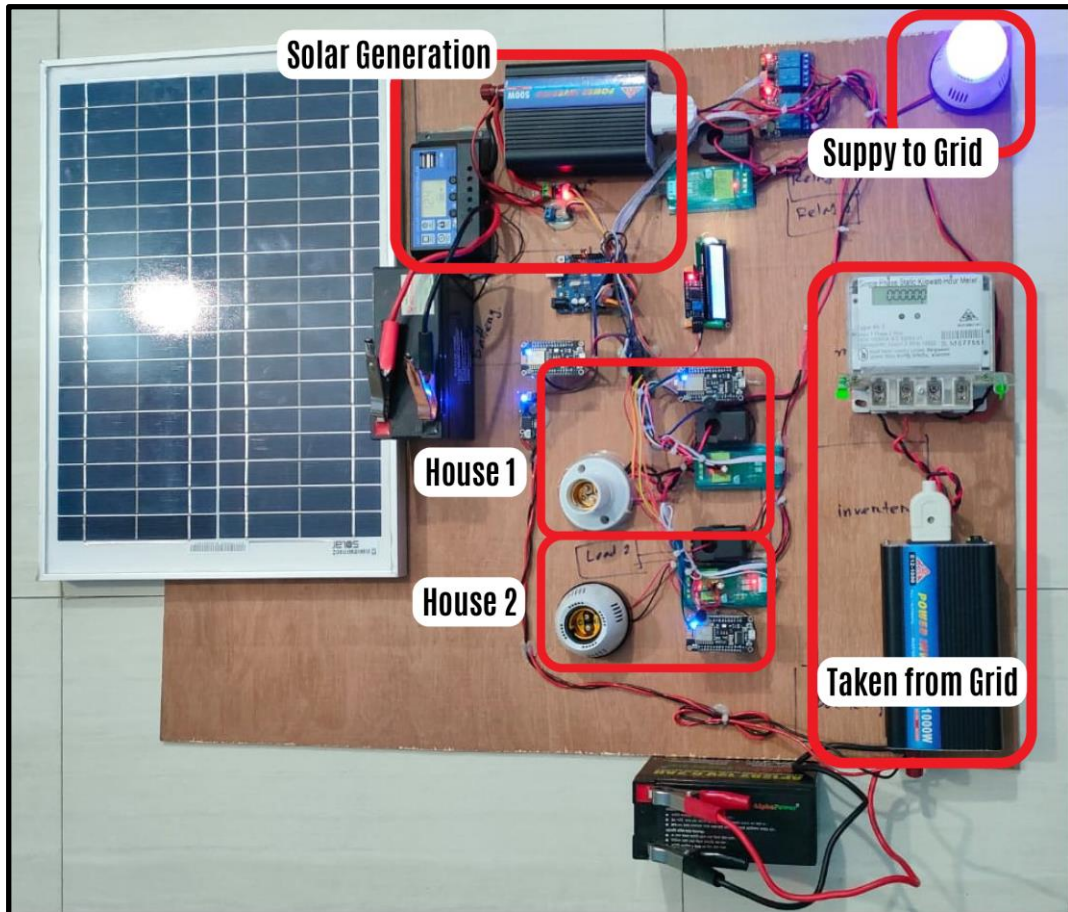


Fig. 5.7 Solar inverter on (supply of solar power)

Consequently, when the solar inverter is turned on it indicates that there is now solar power being produced in our prototype. Furthermore, as there are no loads attached to any of the households, it means that there is now excess power being generated which needs to be supplied to the grid. We can see that this is being achieved as the top right light is glowing which is our representative of any supply given back to the grid.

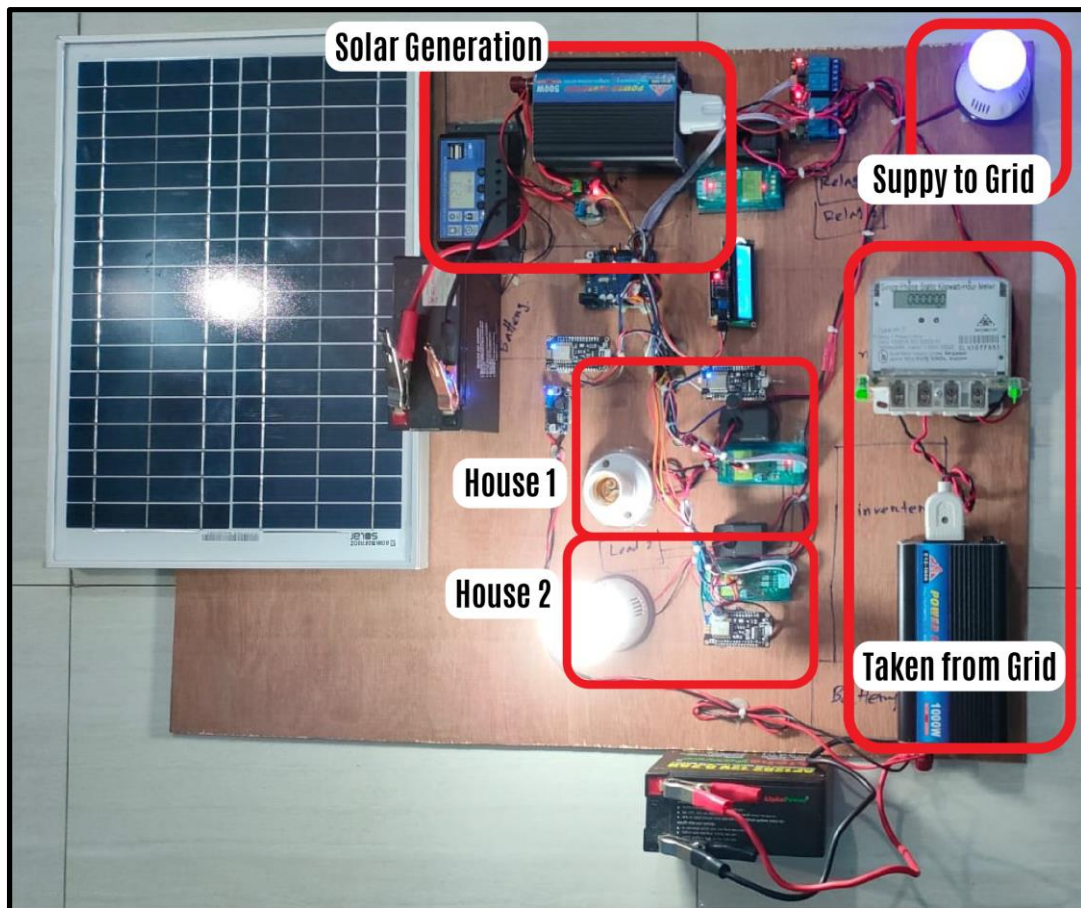


Fig. 5.8 Some load turned on (but still power supplied to grid as sufficient power generated)

Progressing through the different scenarios of our prototype, we have now connected some load to one of the households; yet we can see that some power is being supplied to the grid (as represented by the glowing of the light at the top right). This indicates that our solar generation system is not only capable of supplying household loads but also to supply excess power to the grid. In other words, the household demands have not exceeded the solar generation capacity meaning there is a surplus production which is being delivered to the grid.

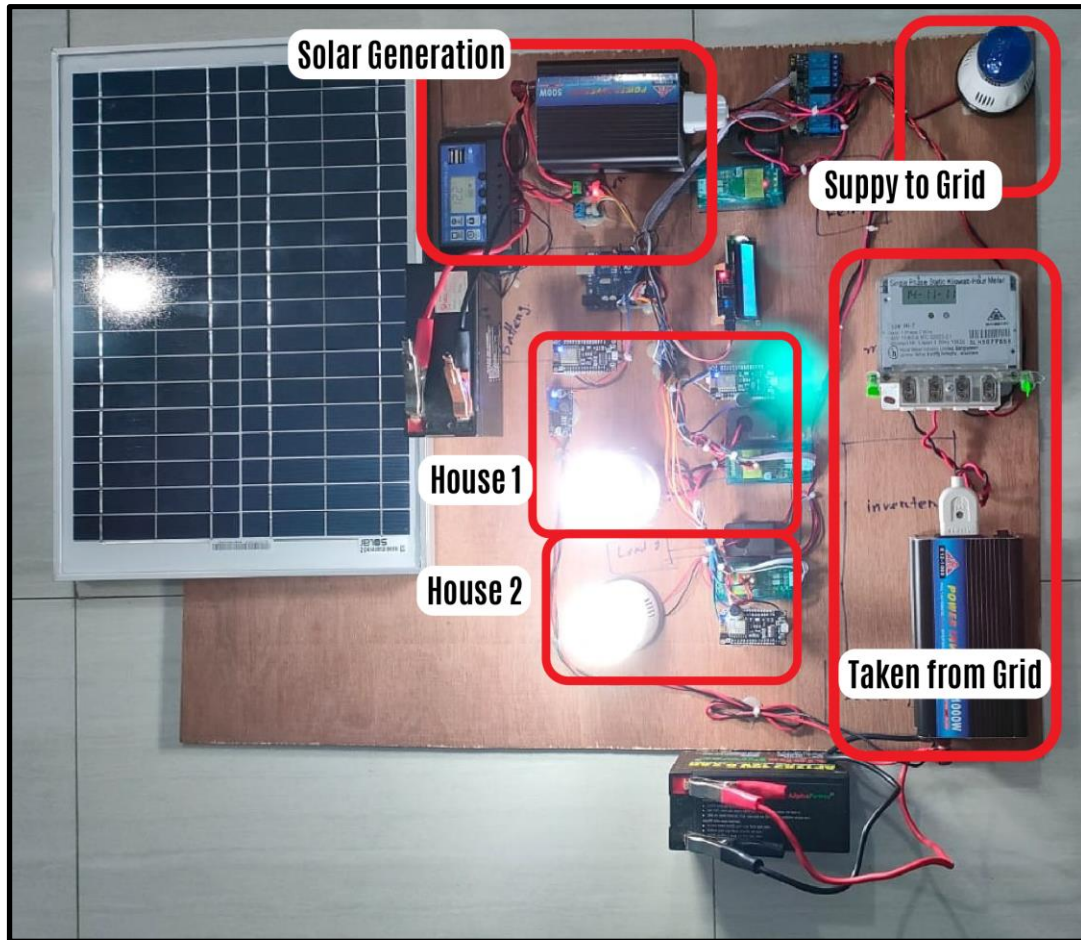


Fig. 5.9 More load turned on (solar panel cannot supply the required power thus power taken from grid)

Subsequently, as we attach more load to the household, it can be seen that there is no supply to the grid (as represented by the top right light not glowing); instead now power is being taken from the grid. The increment of loads beyond the capacity of solar generation paints an obvious picture that there is now no surplus power to be supplied to the grid but instead there is a deficiency of power which needs to be fulfilled by the grid and such is the case for our designed prototype.

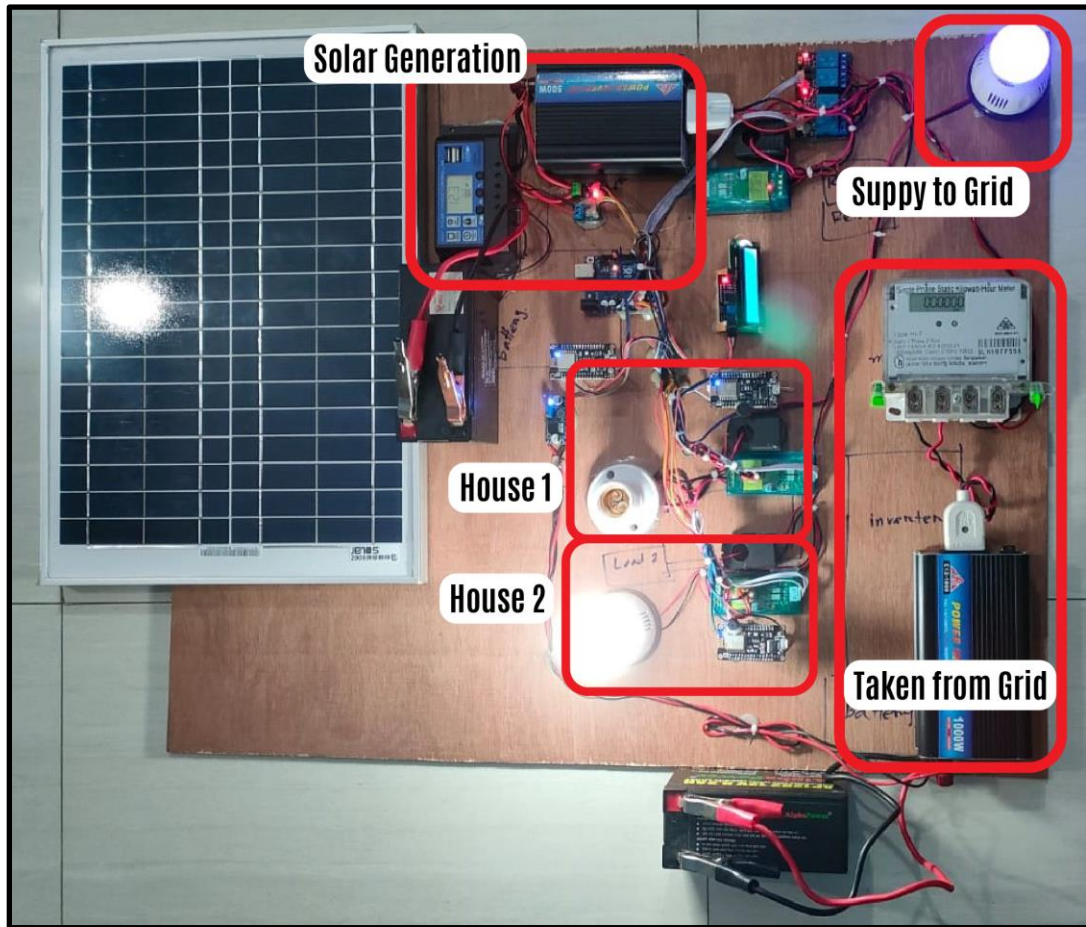


Fig. 5.10 Some load taken off (supply to grid starts again)

Again, as we take off some of the loads from any of the households, bringing the demand of the households below the level of solar generation capacity there is now again surplus power being produced which is supplied back to the grid (as represented by the glowing of the top right light). At this stage, there is no need to take any supply (unlike the previous stage) from the grid as our solar generation system is capable of supplying the required energy demands of the households and has excess to give back to the grid.

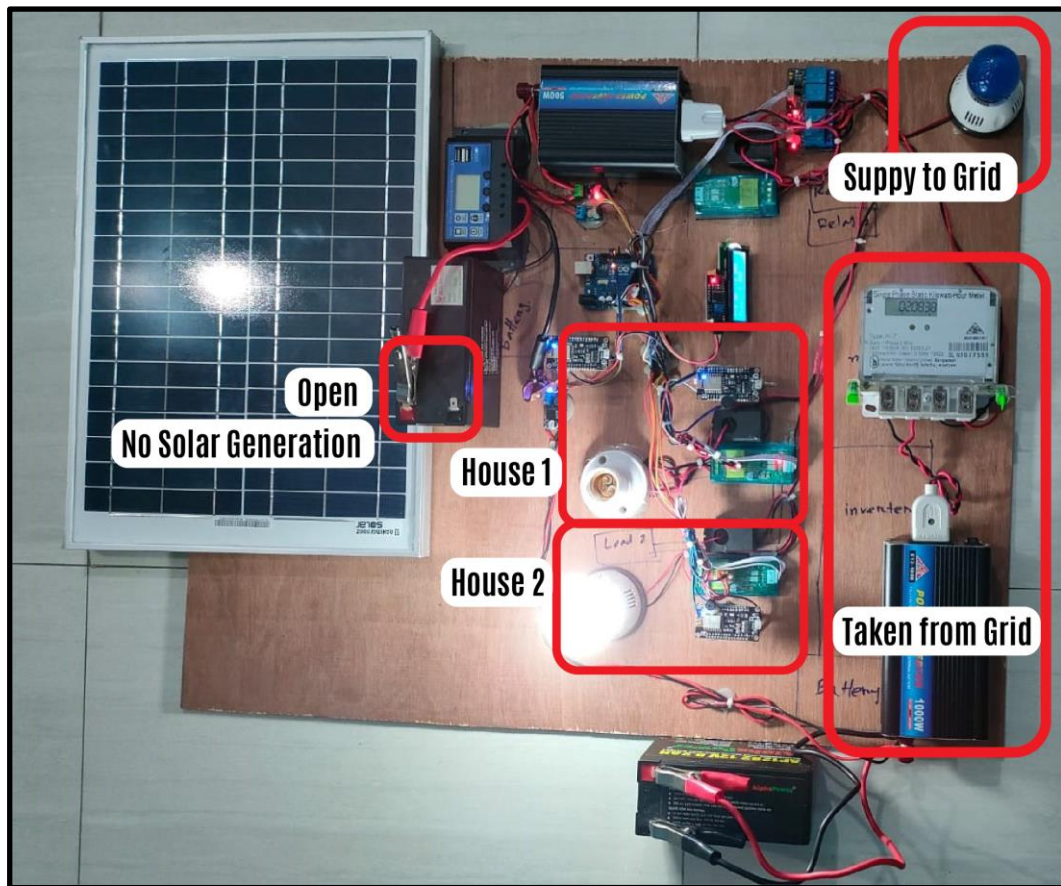


Fig. 5.11 Simulating night time when no solar power generated (power taken from grid)

The above setup of our prototype is used for demonstrating our system functionality at night time when there will be no solar generation (this is done by opening the DC battery supply of our solar generating representative system). As the solar generation at this time is zero, all the required energy demands of the households are now supplied by the grid; it is also obvious that there can not be any excess solar power to be supplied to the grid as the solar production is now completely null. Being an on-grid system, this is the time of the day where our system is solely dependent on the functioning of the national grid.

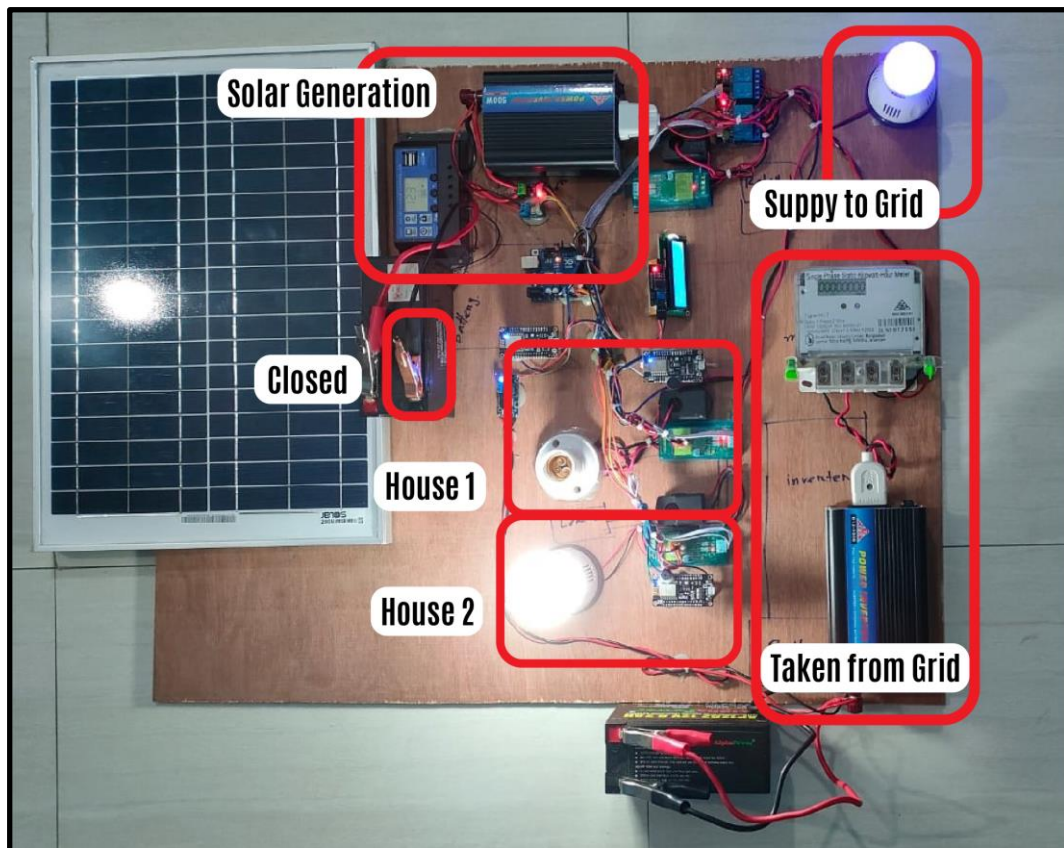


Fig. 5.12 Solar power generation begins during daytime (power taken from solar panel and extra supplied to grid)

Lastly, as the sun rises in the morning, there again will be solar power generation and depending on the amount of power generation there might be excess production ready to be supplied to the grid. In the case, demonstrated above there is presence of excess power production which is being supplied to the grid (as represented by the glowing of light at the top right).

Evaluation of the Simulated Data from Server

For the prototype design, we have updated the data measured from the meters via a wifi-module. The module sends the data to the network server which is accessible online by the host software Google sheet. The measurement parameters that are assessed include the Voltage and Current measures in both RMS and Average (DC), Apparent Power (VA), Real Power (W), Energy generated (kWh), Power Factor, Frequency (Hz) for allocated date and time. The data measured for the Generation system, Household 1 and Household 2 are demonstrated and evaluated below in a tabular formation:

TABLE 5.2 Simulated data of the generation system extracted from the server

Date	Time	V(rms)	I(rms)	VA	W	PF	kWh	Hz	I (DC)	V(DC)
26-Aug-2022	12:14:20 PM	204.1	0.144	29.31	11.7	0.4	0.005	52	1.925	12.16
26-Aug-2022	12:14:23 PM	202.4	0.142	28.69	11.6	0.4	0.005	52	1.924	11.4
26-Aug-2022	12:14:26 PM	201.5	0.142	28.56	11.7	0.41	0.005	52.1	1.923	12.13
26-Aug-2022	12:14:29 PM	201.6	0.142	28.58	11.7	0.41	0.005	52.1	1.916	12.04
26-Aug-2022	12:14:32 PM	202.8	0.143	28.94	11.6	0.4	0.005	52.2	1.919	12.13
26-Aug-2022	12:14:35 PM	202.7	0.143	28.92	11.6	0.4	0.005	52.2	1.925	12.45
26-Aug-2022	12:14:38 PM	202.3	0.143	28.86	11.6	0.4	0.005	52.2	1.925	11.79
26-Aug-2022	12:14:41 PM	202.4	0.143	28.88	11.6	0.4	0.005	52.2	1.916	12.33
26-Aug-2022	12:15:16 PM	217.4	0.062	13.41	0	0	0.005	52.2	0.488	12.94
26-Aug-2022	12:15:19 PM	210	0.142	29.76	7	0.24	0.005	52.2	1.489	12.62
26-Aug-2022	12:15:22 PM	209.1	0.142	29.65	7.1	0.24	0.005	52.2	1.492	12.7
26-Aug-2022	12:15:26 PM	208.7	0.141	29.4	7.1	0.24	0.005	52.2	1.498	11.91
26-Aug-2022	12:15:29 PM	212.4	0.141	29.91	0.9	0.03	0.005	52.2	0.913	12.7
26-Aug-2022	12:15:31 PM	212.6	0.141	29.94	0.9	0.03	0.005	52.3	0.912	13.04
26-Aug-2022	12:15:34 PM	212.7	0.141	29.95	0.8	0.03	0.005	52.4	0.917	12.57
26-Aug-2022	12:15:37 PM	212.7	0.141	29.95	0.9	0.03	0.005	52.4	0.901	12.87
26-Aug-2022	12:15:40 PM	212.7	0.141	29.95	0.8	0.03	0.005	52.3	0.905	13.01
26-Aug-2022	12:15:43 PM	212.7	0.142	30.15	0.9	0.03	0.005	52.4	0.909	12.99

26-Aug-2022	12:15:46 PM	212.7	0.142	30.15	0.9	0.03	0.005	52.4	0.913	12.67
26-Aug-2022	12:15:49 PM	212.7	0.142	30.15	0.8	0.03	0.005	52.4	0.908	12.48
26-Aug-2022	12:15:52 PM	212.7	0.142	30.15	0.9	0.03	0.005	52.4	0.933	11.99
26-Aug-2022	12:15:55 PM	212.7	0.142	30.15	0.9	0.03	0.005	52.4	0.91	12.99
26-Aug-2022	12:15:58 PM	212.7	0.142	30.15	0.8	0.03	0.005	52.4	0.902	12.92
26-Aug-2022	12:16:01 PM	212.7	0.142	30.15	0.8	0.03	0.005	52.4	0.981	12.77
26-Aug-2022	12:16:04 PM	212	0.141	29.85	0.9	0.03	0.005	52.4	0.992	12.74

The data sheet accessed from the server demonstrates the measurement extracted from the energy meter attached with the Solar PV generation system. The measurement data is updated after every 3 seconds and shows the corresponding time and date. The RMS and the average ratings of voltage and current measurements are extracted from the AC energy meter and DC meter respectively. It is quite prominent from the chart that the power factor ratings are quite less than expected indicating the presence of harmonic current in the system. This particular phenomena is resulted from the technical inefficiency of the DC-AC inverter indicating a loss of power in the system. Furthermore, the desired frequency output is 50 Hz which is required to be maintained in order to connect the system with the real-time grid system whereas the frequency data measured are fluctuating a little over 50Hz. In addition, as we have used a prototype load system consuming a very little amount of energy, the amount of energy generated in kWh units is quite less with only 0.005 kWh.

TABLE 5.3 Simulated data of the household-1 extracted from the server

Date	Time	V(rms)	I(rms)	VA	W	PF	kWh	Hz	Meter Status
23-Aug-2022	03:06:04 PM	230.07	0.084	19.27	11.1	0.58	0.003	50.8	OK
23-Aug-2022	03:06:34 PM	229.77	0.085	19.46	11	0.57	0.003	50.7	DAMAGED
23-Aug-2022	03:07:05 PM	229.37	0.085	19.42	11.1	0.57	0.004	50.6	OK
23-Aug-2022	04:17:44 PM	217.2	0.047	10.2	4.8	0.47	0.003	50.7	OK
23-Aug-2022	04:18:14 PM	217.09	0.047	10.19	4.9	0.48	0.003	50.7	DAMAGED
24-Aug-2022	03:33:38 PM	206.13	0.071	14.61	4.9	0.34	0.003	52.2	OK
24-Aug-2022	03:34:07 PM	205.63	0.071	14.57	4.9	0.34	0.003	52.3	OK
24-Aug-2022	03:34:38 PM	209.35	0.07	14.65	0.4	0.03	0.003	52.4	OK

24-Aug-2022	03:35:07 PM	212.47	0.072	15.25	1.4	0.09	0.003	52.4	OK
24-Aug-2022	03:35:38 PM	212.67	0.072	15.27	1.3	0.08	0.003	52.4	OK
24-Aug-2022	03:36:08 PM	212.57	0.072	15.26	1.4	0.09	0.003	52.4	OK
24-Aug-2022	03:36:38 PM	209.45	0.071	14.85	0.4	0.02	0.003	52.5	OK
24-Aug-2022	03:37:08 PM	205.93	0.072	14.79	4.9	0.33	0.003	52.4	OK
24-Aug-2022	03:43:13 PM	205.83	0.068	14.02	1.3	0.09	0.003	52.3	OK
24-Aug-2022	03:43:43 PM	210.56	0.07	14.73	1.3	0.09	0.003	52.4	OK
24-Aug-2022	04:03:30 PM	206.03	0.074	15.17	6.7	0.44	0.003	52.2	OK
24-Aug-2022	04:04:00 PM	212.37	0.071	15.05	1.4	0.09	0.003	52.4	OK
24-Aug-2022	04:31:24 PM	198.79	0.072	14.27	6.6	0.46	0.003	52.1	OK
24-Aug-2022	04:32:24 PM	199.89	0.073	14.54	6.7	0.46	0	52.4	OK
24-Aug-2022	04:32:54 PM	199.39	0.073	14.5	6.7	0.46	0	52.4	OK
24-Aug-2022	04:51:57 PM	207.24	0.08	16.6	6.7	0.4	0	56.5	OK
24-Aug-2022	04:52:27 PM	219.61	0.101	22.24	6.9	0.31	0	56.5	OK
24-Aug-2022	05:00:04 PM	219.31	0.101	22.21	6.9	0.31	0	56.5	OK
24-Aug-2022	05:00:34 PM	207.64	0.075	15.67	6.7	0.43	0	52.1	OK
24-Aug-2022	05:01:04 PM	221.22	0.103	22.81	6.9	0.3	0	56.5	OK

The issued data table exhibited above shows the measured rating for the load system household-1 extracted from the energy meter. The parameters of measurement for the household systems are evidently similar to the generation system except only RMS ratings of voltage and current are focused as per the load system requirement. The energy consumption rate of this household is limited to only 0.003 kWh due to the prototype load system being at a small-scale. The power factor continues to fluctuate near 50Hz indicating the presence of harmonic current and certain power loss.

Furthermore, for the protection system of the households as elaborated previously, the parameter stating Meter Status has been included to indicate if the system is stable or has been disrupted unauthorisedly. After conducting a manual test of the meter protection system shown in the table, the meter status is showing “DAMAGED” implying that the protection system of the meter has been breached and showing “OK” by default if it is not.

TABLE 5.4 Simulated data of the household-2 extracted from the server

Date	Time	V(rms)	I(rms)	VA	W	PF	kWh	Hz	Meter Status
23-Aug-2022	04:17:44 PM	217.6	0.045	9.81	6.3	0.64	0.003	50.7	OK
23-Aug-2022	04:18:14 PM	217.6	0.046	10.01	6.4	0.64	0.003	50.7	DAMAGED
24-Aug-2022	03:33:38 PM	206.63	0.032	6.66	6.3	0.95	0.003	52.2	OK
24-Aug-2022	03:34:08 PM	206.13	0.032	6.64	6.3	0.95	0.003	52.3	OK
24-Aug-2022	03:34:38 PM	209.95	0.032	6.76	6.3	0.93	0.003	52.4	OK
24-Aug-2022	03:35:08 PM	212.97	0	0	0.9	1	0.003	52.4	OK
24-Aug-2022	03:35:38 PM	213.17	0	0	1	1	0.003	52.4	OK
24-Aug-2022	03:36:08 PM	213.07	0	0	0.9	1	0.003	52.4	OK
24-Aug-2022	03:36:38 PM	209.95	0.032	6.76	6.4	0.94	0.003	52.4	OK
24-Aug-2022	03:37:08 PM	206.53	0.032	6.65	6.4	0.96	0.003	52.4	OK
24-Aug-2022	03:43:13 PM	206.33	0.032	6.65	6.3	0.95	0.003	52.3	OK
24-Aug-2022	03:43:43 PM	211.06	0	0	0.9	1	0.003	52.4	OK
24-Aug-2022	04:03:30 PM	206.63	0.024	4.95	4.5	0.92	0.003	52.2	OK
24-Aug-2022	04:04:00 PM	213.07	0	0	0.9	1	0.003	52.4	OK
24-Aug-2022	04:32:25 PM	200.5	0.071	14.21	14	0.98	0.003	52.4	OK
24-Aug-2022	04:32:54 PM	199.99	0.071	14.18	13.8	0.97	0.003	52.4	OK
24-Aug-2022	04:51:58 PM	207.54	0.072	14.9	14.2	0.95	0.003	56.5	OK
24-Aug-2022	04:52:27 PM	220.11	0.07	15.4	14	0.91	0.003	56.5	OK
24-Aug-2022	05:00:04 PM	219.81	0.071	15.58	13.9	0.89	0.003	56.5	OK
24-Aug-2022	05:00:34 PM	208.14	0.024	4.98	4.6	0.93	0.003	52.1	OK
24-Aug-2022	05:01:04 PM	221.62	0.026	5.71	4.6	0.81	0.004	56.5	OK
24-Aug-2022	05:01:34 PM	210.56	0.024	5.04	4.6	0.92	0.004	52.3	OK
24-Aug-2022	05:35:56 PM	212.67	0	0	0	0	0.004	52.2	OK
24-Aug-2022	05:36:25 PM	212.57	0	0	0	0	0.004	52.3	OK
24-Aug-2022	05:36:55 PM	212.47	0	0	0	0	0.004	52.4	OK

As the parameters of the Household-1 and the Household-2 at the load system’s end have remained similar, the status of the measured data has remained quite similar with a considerable difference. Although, the power factor rating for this household shows an improved outcome. The energy consumption is 0.003 kWh as well as the energy requirement of the light bulbs for both of the households were the same. The meter protection system has been manually tested for this house as well showing the meter status to be “DAMAGED” at the corresponding time.

SWOT Analysis of the prototype design:

The executed hardware prototype design has been further evaluated with the assistance of SWOT analysis thus observing its corresponding strengths, weaknesses, opportunities and threats. Various elements have been considered throughout this process including its design complexity, availability and efficiency of components, bidirectional implementation, data measurement accuracy and validation, alternative approaches etc. A concise representation of the SWOT Analysis diagram is demonstrated below:

TABLE 5.5 SWOT analysis of the prototype design

<p style="text-align: center;">Strengths</p> <ul style="list-style-type: none"> ● Implementation of bidirectional distribution of energy ● Protection mechanism of the load systems ● Data accessible from online server ● Various measurement parameters ● Processing speed of the control mechanism 	<p style="text-align: center;">Weaknesses</p> <ul style="list-style-type: none"> ● Alternative implementation of grid system ● Power loss within the system ● Frequency fluctuation ● Unavailability of bidirectional Net Meter ● Continuity of internet connection
<p style="text-align: center;">Opportunities</p> <ul style="list-style-type: none"> ● Power factor improvement ● Increment of system capability and real time implementation ● Economic feasibility analysis 	<p style="text-align: center;">Threats</p> <ul style="list-style-type: none"> ● Power factor complexity ● Technical inefficiency of components ● Complication of distribution mechanism

5.4 Conclusion

Based on the measured data and performance speculation, it is quite perceptible that the community net metering system has been implemented successfully executing different criteria for both hardware and software design. In both of the designs, the bidirectional power flow, feedback implementation via surplus energy dispatching to the grid, efficient control and distribution mechanism and accurate data measurement have been processed. Upon analyzing the data and design progress, we have further investigated the results with SWOT analysis to summarize its strengths, weaknesses, opportunities and potential hazards thus overall performance.

Chapter 6

Impact Analysis and Project Sustainability [CO3, CO4]

6.1 Introduction

Every project when introduced has its share of impacts that make the project strong and vulnerable at the same time. When we analyzed our project, we categorized the impacts of our project into various segments such as societal, legal, safety, cultural etc which has been explained in detail in the segment below. Furthermore, SWOT analysis has also been performed to take a deeper dive into the impact of our project. The strength of our project includes the source which is solar energy, a form of green energy that will not lead to any form of air or land pollution. Simultaneously, the enhancement of solar prospects in our country will be extremely beneficial for our power industries. The concept of a net metering scheme that our project portrays will intrigue many investors to make solar a turning point. But like all other projects ours also has some weaknesses that consists of the initial huge cost for establishments requiring the need of plenty of investors. Also as this is a new concept so the governmental policies regarding net metering are still conservative to freely apply. Moreover, the return on investment takes a long time so profit making will surely take longer. But we believe that even with all the weaknesses, our project has enough strength to illuminate the houses of many.

6.2 Assess the impact of solution

Impact of the net metering systems regarding societal, health, safety, legal and cultural concerns are reviewed below

- Societal - The adaptation of community net metering will allow the people of underprivileged areas who are often neglected from the electrical supply to enjoy the benefit of consistent supply of electrical supply to the fullest extent. The potential of solar energy can be promoted in society via a better manner through the usage of community net metering. The potential adopters will only be willing to utilize the new approach of solar power only with appropriate information and context necessary to participate fully. Thus leading to the enhancement of knowledge in the underprivileged areas. Likewise, introducing community net metering in such areas will create new job opportunities for individuals, decreasing the unemployment rate of the given area and reaching economies of scale. For instance, workers are needed to plan the project, develop and implement the project, build the solar energy plant, manage the equipment and operate the facility. Moreover, Bangladesh tends to maximize the usage of oil when it comes to generation of electricity, but if we implement solar energy programs by adopting community net metering policy, the dependency on oil would reduce. Thus, lesser purchase of foreign oil and coal.
- Health - The countryside of Bangladesh consists of maximum greenery and minimum pollution. But if the generation sites continue growing in these areas using fossil fuel

as the main source of fuel then it will not be long before pollution deteriorates the health of the settlers of the given area. So in order to prevent this fearful outcome community net metering will be a great approach. Solar power is a form of clean power thus the utilization of solar power with the approach of community net metering has the potential to contribute in the formation of a decarbonizing, equitable, and resilient electricity system. Therefore, switching to solar generation by an affordable way such as community net metering will indeed be a blessing for the residents of the given countryside.

- Safety - The arrangement of our system involves electrical components such as combiner boxes, disconnect switches, inverters, net meters, some of which might have voltages over 50 volts proving to be very risky when these come in contact. In order to avoid the risk of contact, appropriate levels of warning signs on all electrical components based on the level of danger determined by the voltages and current potentials are specified. Another safety issue could be an electrical explosion caused by a short circuit called an arc flash. This explosive release of energy causes a flash of heat and a shockwave, both of which can cause serious injury or death. In order to properly maintain safety, only trained and equipped technicians and electricians are allowed to safely install, test, and repair PV systems. Still risks of injury remain in case of dealing with hazardous voltages and currents. Moreover, untrained individuals of the given locality are strictly prohibited to inspect, test, or repair any aspect of the system at time of crisis due to the high risks involved. Furthermore, there are possibilities of fires resulting from PV systems that may trigger concern among the communal residents. However, concern over solar fire hazards should be limited because only a small portion of materials in the panels are flammable, and those components cannot self-support a significant fire. These components include the thin layers of polymer encapsulates surrounding the PV cells, plastic junction boxes on the rear of panel, and insulation on wiring. The rest of the panel is composed of non-flammable components, notably including one or two layers of protective glass that make up over three quarters of the panel's weight.
- Legal - Net metering is a new concept that is promoting the generation from renewable energy. Thus many net metering policies are updating to increase the flexibility of the implementation of net metering. The applicants of community net metering have to abide by the rules, regulations and policies set by the country. For instance interconnection standards: shall comply with the interconnection rules and standards set by the utility or other relevant governing authority. Moreover, the eligible consumers have to prepare all the documents from beforehand and follow the procedure of applying for a net metering agreement to the utility. Once the application is issued no further complications are there to implement community net metering.
- Cultural - The cultural heritage will always remain as the most visible sign of collective identity. Each energy source creates new bases for collective identity: coal created working class consciousness, whereas oil and gas resulted in the universalization of credit so that we all see ourselves and others today as consumers.

The culture of consumption is much more concerned about the future than were the cultures of the two preceding modern energy sources. It seems like the introduction and spread of solar usage through community net metering in countryside areas will steadily grow sharper as renewable energy continues to increase users and decrease prices with its cutting edge culture of stewardship.

Tentative impact of net metering systems in terms of various concerns are reviewed below upon SWOT analysis.

TABLE 6.1 SWOT analysis of the net metering system regarding tentative impacts

<p style="text-align: center;">Strengths</p> <ul style="list-style-type: none"> ● Expanding access to green energy ● Empowering solar sector and job sector ● Decentralizing generation network, less independence on main power grid ● Promoting local investments in solar energy ● Increased generation capacity 	<p style="text-align: center;">Weaknesses</p> <ul style="list-style-type: none"> ● The corresponding installation or administrative costs ● Requirement of initial investments ● Imposing restrictive policies ● Economic disadvantage for distribution companies (depends on tariff rates) ● Time period required to gain profit
<p style="text-align: center;">Opportunities</p> <ul style="list-style-type: none"> ● Urban growth ● Improvement of services (Load shedding, Electricity Losses) ● Investment in large-scale generation plants 	<p style="text-align: center;">Threats</p> <ul style="list-style-type: none"> ● Inefficient data management system ● Insufficient investments ● Possible lobbying of distribution companies

I. Potential Strength

Net metering systems possess numerous potential strengths that would benefit the consumers as well as the overall power distribution system in emerging countries like Bangladesh. This system increases the power generation capacity in the distribution system meeting the energy demands of the mass population. It further assists in providing solar-produced energy, letting the local and small consumers have access to green energy sources eliminating the pressure on fossil fuel-produced energy. The system introduces diversification towards the distribution system thus decentralizing the production network. Moreover, it requires lesser transmission capacity. One of the advantages of this system is that it structures the consumers as generation sources themselves, compromising the dependency on central power plants. Furthermore, establishing the net metering gradually throughout areas and districts will result in the solar industry thriving thus increasing job slots in different sectors such as maintenance and operation of the plants, etc. This particular industry allows promoting small and private investments of the consumers as it provides financial advantages via achieving economies of scale [22]. Expanding investments in the net metering system will unlock

the scope for it to be implemented on a large scale such in factories and industrial areas which will reach a milestone in terms of utilizing green energy resources.

II. Tentative Weaknesses

To elaborate on the possible weaknesses of the net metering system, policy-based or technical constraints are worth reflecting light on. Policies imposed by the Bangladesh Government, for example, the net metering system is limited to only three-phase electricity customers would weaken the expansion of this issued system. According to the NEM guideline of 2018, the maximum allowed AC capacity of power systems produced under NEM is bound to only 10MW, etc. technical restrictions add up to the weakness of this system [22] Additionally, the consumers have to bear corresponding administration costs such as maintenance and operation costs for their generation panels. Furthermore, the chances of limited profit accounted for by the distribution companies might discourage the investors although it depends on the tariff rates and associated costs of these stakeholders [22]. The time period required to gain profit for the consumers via achieving economies of scale can be considered as a factor regarding its limitations.

III. Possible Opportunities

Firstly, most areas outside of major cities in Bangladesh tend to be deprived of technological improvement and modernization, due to the residents being oblivious of this knowledge of upgrades. So, the idea of community net metering will create opportunities for them to learn and expand their idea of advancement. This attempt will gradually urbanize the rural areas. Secondly, load shedding being a common problem from which residents of such areas suffer on a daily basis will be relieved with the introduction of community net metering. Moreover, electricity access will increase and loss will decrease and the surplus amount from the PV system will be imported to the utility grid and the residents will get credited for this according to their investment. Thirdly, political motives will also be fulfilled. The idea of net metering will create ways and opportunities for renewable energy development and sustainable cities [22]. The idea of net metering proves that once implemented it will pay off, as users will get a return on investment eventually. Thus, as people have some advantages to using renewable energy via net metering, they will be interested in supporting the generation of electricity using renewable energy. Therefore, fulfilling the target of the government to maximize the usage of renewable energy in Bangladesh.

IV. Tentative Threats

Lobbying from distribution companies can be considered as one of the threats that aim to weaken the individual customers and businesses adopting net metering policies which allow covering the expenses of installation by selling unused power back to the grid. Rooftop solar poses a threat to electricity companies because they do not profit from the energy provided by rooftop panels. Utilities are increasingly concerned that lowering prices and increasing the availability of clean solar power would jeopardize their business model, which is based on the amount of capital invested in the system and, in some cases, the amount of electricity sold. This has made many utilities in some states use their money and power to push legislators to undercut solar power and make it

difficult for small businesses and homeowners to produce their own clean energy. Some utilities even used power to twist public policy in their favor. Inefficient data management and regulation, on the other hand, can harm the purpose of this system as supervising the amount of electricity used and supplied in this bidirectional system and computing the profit is one of the crucial aspects of this system [22]. A lack of investors and investment funds can pose a huge threat to the growth of net metering worldwide.

6.3 Evaluate the sustainability

In terms of practical implementation of the net metering system, it raises corresponding sustainability issues which should be discussed and evaluated in detail regarding numerous aspects. Few of the issues regarding in sustainability in terms of environmental, economical and social aspects has been evaluated as such:

I. Environmental Sustainability

Our proposed solar net metering system is extremely environmentally sustainable as it produces green electricity. It does not emit any harmful gasses, unlike coal-powered generating stations. Furthermore, other methods of electricity generation like nuclear-based power stations have to deal with everlasting concern for the disposal of nuclear waste at the end of its lifecycle. To make our project a completely environmentally sustainable one we even avoided the use of batteries as we went for an on-grid system instead of an off-grid or hybrid system. Batteries made typically of lithium-ion at the end of their usage create a huge environmental concern regarding its disposal. On the other hand, the solar net metering system will save tons of carbon-di-oxide emissions during the project's life cycle. This gives us an idea about the environmental effect that can be achieved through the widespread use of solar net metering systems.

II. Economical Sustainability

The main target audience of our project is the middle to lower income people and they will be hugely economically benefited through the use of solar net metering systems. Considering the low usage of electricity in such income level households and the use of a semi-large net metering system, all the households in that community will not have to pay electricity bills for the lifetime of the metering system. Moreover, at the end of the fiscal year according to the Net Metering Guideline of 2018, the community will be compensated based on the amount of electricity exported and a preset tariff rate. This extra cash injection will boost the process of return on investment and subsequently act as a good source of income for the consumers involved.

On the other hand, from the perspective of the government, this could be a very sustainable and viable proposition. All the electricity supplied in Bangladesh is significantly subsidized by the Bangladeshi government. This is a very expensive and logistically sophisticated process whose usage could be greatly diminished through the widespread use of solar net metering systems. The government could set electricity tariff rates on the net metered electricity a bit less than the cost required for subsidizing electricity and save tremendous amounts of money to be spent elsewhere for the betterment of the country.

III. Social Sustainability

Community net metering in countryside areas is hugely socially sustainable as it provides households of all demographic, sizes, and incomes to take part in the net metering system based on their interest and affordability. While in individual net metering systems, low-income families will not be able to partake but through community net metering they can less individual capital is required. This enhances the equality of opportunity which could be further assured through proper government invigilation. Furthermore, we have already mentioned the potential extra source of income our net metering system can generate which could be used by the middle to lower income population to improve their standards of life and accelerate the urban growth of their neighborhood. Looking from a different point of view, this field could attract great investment as the solar panel keeps on improving, increasing the profit margin of such an operation. As a result, this sector could be responsible for a huge job market in the near future.

6.4 Conclusion

The effectiveness of a project is accounted for by the measure of how sustainable a project stands out to be. Investing time, effort and money behind something that will not sustain long is not a meaningful task to do. Likewise we scrutinized our project to find out the level of sustainability that our project displayed. Fortunately enough, our one is environmentally, economically and socially very much sustainable. This is because it would not cause adverse effects on the environment of any sort. Like, air pollution due to release of gasses like carbon dioxide or nuclear disposal of any sort. More importantly, economically, our project would help in cutting down electricity bills with the help of energy data stored in the server. Moreover, if solar surplus energy is sold to the grid it could be a potential way of income for many people if planned and executed in the right way. As a result this will also bloom urbanization in many parts of Bangladesh.

Chapter 7

Engineering Project Management [CO11, CO14]

7.1 Introduction

The process through which an idea is transformed into a proposal then eventually into something tangible is not a work possible by an individual. It always takes many minds to come together in order to achieve something that initially feels impossible to achieve. This engineering project was also a team effort. But when we work in a team, team management and planning is something very important. Without a proper plan, management and team orientation, execution disputes are meant to occur leading to the failure of a project. Thus we arranged assigned tasks and represented it in a gantt chart which was circulated to each of the members in our group. This timeline was strictly followed through the project. But we did support each other in times of need to bring out the best outcome in each and every step.

7.2 Define, plan and manage engineering project

TABLE 7.1 Tentative project plan of the final year design project

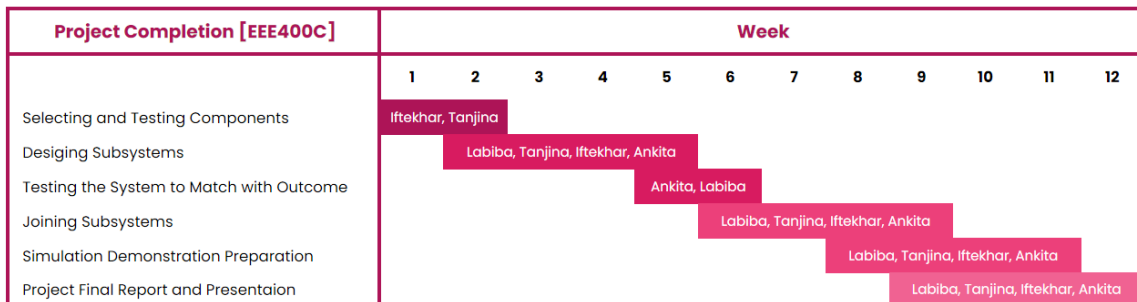
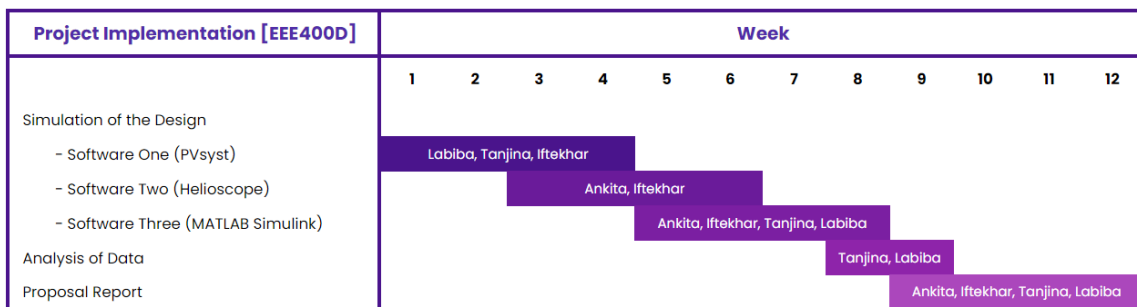
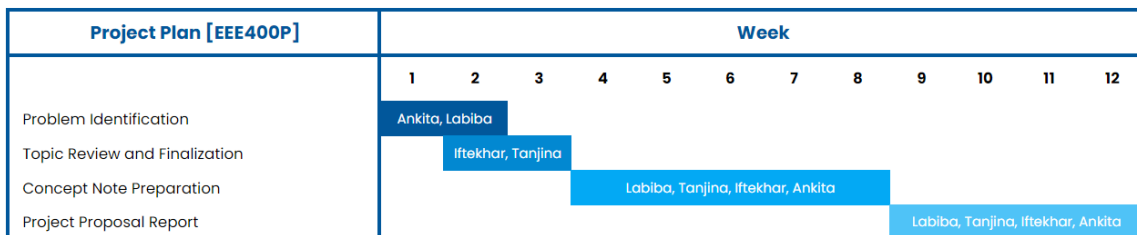
Tentative Project Plan			
EEE 400P			
Task	Start Date	End Date	Duration (Days)
Problem Identification	9/10/21	23/10/21	14
Topic Review and Finalization	16/10/21	30/10/21	14
Concept Note Preparation	30/10/21	04/12/21	35
Project Proposal Report	04/12/21	01/01/22	28
EEE 400D			
Task	Start Date	End Date	Duration (Days)
Simulation Using Software One (PVsyst)	29/01/22	26/02/22	28
Simulation Using Software Two (Helioscope)	12/02/22	12/03/22	28
Simulation Using Software Three (MATLAB Simulink)	26/02/22	26/03/22	28
Analysis of Data	26/03/22	09/04/22	14
Final Adjustments	09/04/22	23/04/22	14

EEE 400C			
Task	Start Date	End Date	Duration (Days)
Selecting and Testing Components	16/06/22	26/06/22	10
Designing Sub Systems	26/06/22	20/07/22	24
Testing the system to match with Outcome	14/07/22	28/07/22	14
Joining Sub Systems	28/07/22	08/08/22	11
Simulation Demonstration Preparation	08/08/22	31/08/22	23
Project Final Report	10/08/22	04/09/22	25

Gantt Chart:

TABLE 7.2 Gantt chart followed throughout the final year design project semesters

Gantt Chart



7.3 Evaluate project progress

Observing the tentative pre-arrange timeline of the project and the actual workflow throughout the semester, a brief comparative evaluation of the development is illustrated below along with the progress status and commentary:

TABLE 7.3 . Comparative evaluation of the project progress and status

Duration	Tentative plan	Actual progress	Progress status	Comment
16/06/22 - 26/06/22	Confirming optimal design and plan the workflow	1. Optimal design confirmed and workflow distributed	Completed	N/A
	Assembling and testing components	1. DC and AC monitoring components assembled 2. Learning Arduino code	Partially completed.	Unavailability and inefficiency of components recorded
26/06/22 - 20/07/22	Designing Sub Systems	1. Completing DC and AC monitoring system 2. Assembling and testing solar meter	Partially completed	Bidirectional system implementation yet to complete
14/07/22 - 28/07/22	Testing the system to match with Outcome	1. Assembling a primal design project 2. DC and AC monitoring system tested and presented	Partially Completed	Few portions of design yet to finish and test.
28/07/22 - 08/08/22	Joining Sub Systems	1. Distribution system implemented 2. Arranging and optimizing efficiency of each sub system 3. Fixing power factor issue	Completed	N/A
08/08/22 - 31/08/22	Simulation Demonstration Preparation	1. Troubleshooting the hardware design 2. Code optimization 3. Testing the overall outcome	Completed	N/A
10/08/22 - 04/09/22	Project Final Report	1. Finalizing the completed design 2. Preparing final report	Completed	N/A

7.4 Conclusion

Initially, a timeline chart was designed including the tasks and assigned individuals' names for those tasks. This was discussed, agreed on by each member and circulated. The tasks listed in 400P were accomplished with ease following the timeline chart. Thus the same thing was repeated in 400D and that gantt chart was distributed among all the members. As it was followed everything went systematically and smoothly as planned. We are repeating the same scenario currently in 400C to achieve similar satisfactory results.

Chapter 8

Economical Analysis [CO12]

8.1 Introduction

A project is only recognized by stakeholders, customers, investors and everyone else when it turns out to be economically viable. As it is highly unlikely that anyone would want to waste their time and resources on a project that will be a lost case. Therefore, in order to ensure the widespread use of a project idea, it has to be financially rewarding. When the project idea is introduced the implementation costing and investment needed has to be deduced along with the timeline that will be required to obtain the return on investment. Additionally, further analysis has to be done to showcase the profitability of the project with time. In our project, the main idea being the promotion of solar net metering in Bangladesh will only attract attention if we can successfully show that it is economically feasible, given that the initial costing of our project will be quite high meaning a good amount of investment would be needed.

8.2 Economic analysis

The major problem with a shift towards renewable energy is the extra financial burden it creates in comparison to its current non-renewable counterpart. Thus it is important to incentivize this transition through methods such as tax rewards, promotion, and any other government assistance required. Furthermore, to be economically viable our designed community net metering system needs to be significantly large; the greater the size of the solar generation system the more profitable it is including a faster payback period. On the other hand, building such a huge system comes with problems of its own; as even with a significant number of participants the initial investment becomes a red flag to potential new participants. In a bid to decrease this initial investment, if more and more consumers are introduced then the profit margin becomes negligible with a significantly larger payback period. As mentioned above, it is of utmost importance that the government provides tax reductions, promotes net metering through changes in the legislation and make application procedures for net metering easy and transparent as from their perspective it is a golden opportunity to provide less subsidized electricity; thus economically benefiting them in the process.

8.3 Cost-benefit analysis

The cost benefit analysis has been conducted in terms of real time implementation of the net metering system as well as the hardware prototype that has been developed. The cost analysis from economic aspects is elaborated in the proceeding:

Real Life Scenario

For our budgeting calculation we have taken help from the official SREDA (Sustainable and Renewable Energy Development Authority) website calculator as it factors in important parameters like maintenance cost, replacement of components, change in retail electricity

tariff rate over the twenty-year life period of the net metering system. This online calculator is the most comprehensive and reliable one currently in the context of the Bangladeshi market and its new set of net metering policies and guidelines

TABLE 8.1 Cost analysis of the major components of our net metering scheme [23]

Features	Unit
Sanctioned load of the customer	25 kW
Maximum capacity of the solar system as per Net Metering Guideline-2018	17.5 kW
Installed Capacity of Solar Module to achieve 17.5 kW system (1.2 times the AC Output Capacity)	17.5×1.2 = 21 kWp
Approximate Installation Cost of 17.5 kW [21 kWp] system [DC Capacity 21 kWp \times 50 Thousand Tk/kWp]	1050000 Taka
Inverter and some other parts replacement cost (Typically in the 11 th year)	143000 Taka
Maintenance Cost (From SREDA) (5% of Annual Return) (Around 20 Years)	180000 Taka
Total Insurance Cost [0.5% of the approximate installation per year] (For a period of 12 Years)	5250 Taka per Year 63000 Taka In Twelve Years
Total Project Cost (Over 20 Years)	1436000 Taka

Although the budgeting done by SREDA is thorough it expects the consumer to have its own land as it mainly specializes in rooftop solar net metering systems which unfortunately might not be the case for community net metering in most areas of Bangladesh. Considering this land expense thus is also important in our project. Typically, there is significant free unused land in the underpopulated areas of our country and they are conservatively priced as well compared to their city counterparts. The exact effect on the payback period will differ from system to system based on the location and size of the designed solar net meter. The bigger the system the lesser the effect based on achieving economies of scale. Another important factor is that some forms of our proposed net metering systems use more net meters than others and also require more wiring compared to other designs. But this factor has not been considered while budgeting as it would not make any significant change to the overall cost. This step was done to further ensure uniform budgeting for all of our design approaches making comparisons between them easier to understand and visualize.

Prototype

TABLE 8.2 Cost analysis of the utilized components in our prototype

Subsystem	Component	Model	Quantity	Cost per Quantity (Tk)	Total Cost (Tk)	Comment
Solar	PV Panel	-	1	950	950	Generic 12V Solar Panel
	PWM Adjustable Solar Controller	-	1	550	550	Generic PWM Solar Charge Controller
	Inverter	500W	1	750	750	Typical 12V DC to 220 AC Inverter
	Battery	12V 7.5Amp	1	1450	1450	Generic DC Battery
DC Monitoring and Distribution	Voltage Sensor	-	1	120	120	Typical DC Voltage Sensor
	Current Sensor	ACS712	1	150	150	Typical DC Current Sensor
	Micro Controller	Arduino UNO	1	1100	1100	Typical Microcontroller
	Wifi Module	Esp 8266	1	390	390	General Microcontroller used as an Wifi Module
	Relay	-	2	125	250	Typical Two Channel Low Level Trigger Relay
	Display (with I2C)	-	1	350	350	Common 16 × 2 LCD Display
Solar Meter For Two Households	AC Meter	PZEM 004T	3	3500	10500	Unique Multi-function AC Power Meter
	Wifi Module	Esp 8266	2	390	780	General Microcontroller used as an Wifi Module

	Buzzer	-	2	15	30	Standard Monotone Buzzer
	Switch	-	2	15	30	Typical Push Switch
Grid Representation	Meter	HI-7	1	1250	1250	Static Kilowatt-Hour Meter
	Inverter	1000 W	1	1500	1500	Typical 12V DC to 220 AC Inverter
	Battery	12V 7.5Amp	1	1450	1450	Generic DC Battery
	Bulb	-	1	25	25	Generic Light Bulb
Miscellaneous	Wires	-	-	350	350	Typical Connecting Wires
	Board	-	1	500	500	Common Wooden Board
	Buck Converter	LM2596	1	90	90	Typical DC to DC Power Converter
	Plug	2 PIN	2	30	60	Generic 2 PIN Plug
	Light Bulb Holder	-	2	30	60	Generic Light Bulb Holder
	Light Bulb	5 Watt Bulbs	2	150	300	Generic Light Bulb
Total Cost					22,955 Tk	

8.4 Evaluate economic and financial aspects

To evaluate economic and financial aspects we have taken help from the official SREDA website where we simulated a 17.5 kW system and part of the results are attached below while some other features were mentioned in the above segment. It is important to note that the simulation was done with the locality of Pabna district in mind and thus for other regions of the country the results will vary to some extent.

TABLE 8.3 Economic and financial analysis of our net metering scheme [23]

Features	Unit
Annual approximate electricity generation from the proposed 21 kWp solar system at 100% Module Efficiency	25200 kWh
Total solar electricity production in 20 years	457783 kWh
Total savings amount in 20 years (considering tariff rate of Pabna locality at the current stage)	3603000 Taka
Return on first year's electricity production in current form	284000 Taka
Payback period of the proposed net metering system	5.77 Years
Payback solar generation units	140416 kWh
Power generation amount up to 20 years after payback period	317367 kWh
Net Present Value (NPV) of the project (After payback units)	2168000 Taka
Internal Rate of Return (IRR) of the project	26.02%

From the above table it can be observed that for our 17.5 kW simulated system, we have obtained via SREDA that the total investment required would be 1436000 Taka with a payback period of around 5.77 years and a total estimated profit of the user of around 2168000 Taka after twenty years of operation. From this, we can state that for larger solar generation systems such as the one designed in our simulation the financial and economical aspects appear to be quite encouraging and will only go in a positive direction following more technological advancements in the solar sector; but unfortunately the same can not be said about small scale solar generation systems.

8.5 Conclusion

The idea of our project being solar net metering is specifically focused on our country Bangladesh, so the economical analysis is done accordingly. The economic and financial aspects of the project are very important considering the perspective of Bangladesh's population. If our project is not financially feasible there would be less participation and interest towards it, the more economically viable the project is the more would be potential consumers. Unfortunately, after thorough analysis using SREDA, the authentic national database of renewable energy sites of Bangladesh, we came to the conclusion that a large solar generation system will be financially very rewarding compared to the small scale generation system. Nevertheless, a large-scale solar generation system will be fruitful enough to attract the potential participants which has already been portrayed above.

Chapter 9

Ethics and Professional Responsibilities [CO13, CO2]

9.1 Introduction

Ethics in project management requires values of honesty, respect, responsibilities and fairness. During the making of a project it is important to ensure the decision-making process is honorable and choices that are made are within the interest of all parties in mind, rather than the individual. If we work ethically and share the responsibilities and fulfill those responsibilities like professionals then it will greatly help prevent a conflict of interest between individuals by putting the best interests of stakeholders first. With all these lessons in mind we did our part ethically and shared responsibilities like professionals throughout the time of the project. The main thing is that we never missed out in giving credibility to the resources we utilized in order to achieve an honest outcome for our project.

9.2 Identify ethical issues and professional responsibility

The idea of this project's main component being the solar panel will turn out to be the most expensive element when the project is implemented. Thus, looking for ways to reduce the cost of implementation is a common scheme. According to the idea of the project, the target audience being the middle to lower income people are not aware of the concept of net metering. Therefore, fooling them using low-cost devices, elements and panels will definitely be an unethical act to commit. Moreover, without introducing and providing clear knowledge to the residents about net metering, implementation is not a just thing to do. So firstly, tutorials should be taken on the concept of net metering so that they can knowingly choose or not choose to support the idea, simultaneously suggesting and putting their input to it. All these works will require team effort in order to be accomplished. The responsibilities have to be shared in a professional manner so that confusions are avoided during the delivery of the final result. For example, the budget allocation can be someone's responsibility and the tutorial arrangement to familiarize the customers could be the responsibility of someone else. It should be assured that every assigned task is well informed to every party in order to avoid miscommunication and negligence of any type. As a small misunderstanding can lead to downfall in a group project. Furthermore, for the installation of solar panels and its implementation, a high budget is required. So along with government subsidies, there will be large scale and small-scale investments by the residents. It is important to ensure not to discriminate between the small scale and large-scale investors and to give them equal importance regardless of their potential influence as this will be the moral thing to do. In order to install the solar panel, it is vital to find adequate land. After successfully finding it, we have to make sure that we obtain the land owner's consent before starting the work. Finally, the authentication of the tracking of energy generated and exported via bidirectional meters is a crucial agenda. We have to ensure that the data is precise in order to avoid any kind of fraud measurement that can hinder the return on investment. This sort of cheating will definitely blur the main motive of our project that is to provide facilities on the electricity billing mechanism.

9.3 Apply ethical issues and professional responsibility

There are several risks associated with the project in terms of installation procedure, construction materials and maintenance that should be monitored carefully. Few of which can be prevented by taking sufficient measurements while installing the project and few of them should be monitored after the installment at an expense of maintenance. The exploration of risks related to the project is one of the foremost tasks to attend. As working in order to suppress the risks elements of the initiated project falls under ethical considerations. The following shows the ethical ways we thought of for mitigating the risks associated during the implementation of the project.

- A. Unintentional islanding is a complication that occurs when the solar PV system continues supplying electricity to the power location even if the grid power is absent. This is a safety issue because the power line that is supposed to be off, might still be powered. In order to make the system automatically disconnect from the grid in case of a power outage, an anti-islanding enabled inverter is installed. Anti-islanding is a built-in feature in an inverter that trips the flow of energy to the grid-on-grid failure. Therefore choosing an inverter which contains this built-in feature is crucial in this regard.
- B. During the generation process, if the amount of power generated is quite high and the consumer's usage is low, the direction of the electricity can be reversed due to voltage increase and it can flow towards the higher voltage end through the transformer. This condition can cause overheating and damage to the transformer equipment and in the transmission lines. To avoid this from occurring, interconnection disconnected switches are to be installed to cut the reverse flow of energy to the grid whenever required. These switches will be used upon rating the voltage fluctuation and fault current requirements.
- C. It is important to use properly sized wires and cables to avert excess heat. Fuses and circuit breakers are essentially used to protect the PV system wiring from getting too hot and catching fire, also used for protection of appliances from electricity. Additionally, as we know solar panels are more prone to being destroyed by lightning, lightning arresters are to be installed to protect the generation panel in this case.

If the responsibility is shared while dealing with each risk, likewise all the other tasks then accomplishing a safe and successful result is a clear scenario easy to achieve. But if instead a single person tends to take all the burden upon the outcome will definitely be disoriented. Thus professionalism has to be showcased in every step of the way to obtain a fruitful outcome.

9.4 Conclusion

The crucial part of any project is to share responsibilities with teammates and work together to achieve successful results. But when working we had to keep in mind that we did not deviate from ethical ideologies. There were no unethical deeds like falsifying information and not providing proper reference to the research work we utilized. This was carefully carried out to make our work authentic.

Chapter 10

Conclusion and Future Work

10.1 Project summary

The overabundant use of non-renewable energy resources not only causes environmental pollution but also creates an impending problem of the shortage of non-renewable resources. With the rising power crisis we can not afford to lose the non-renewable resources left as this will push the future generation in despair. As a result Bangladesh needs to seek and promote alternative energy sources as soon as possible. In order to limit the severity of this problem our project utilizes an alternative energy that is solar energy with the mechanism of net metering. Solar energy is a form of renewable energy and its usage can be promoted using net metering mechanisms. Solar net metering mechanism is a way in which solar energy from the sun is converted to electricity for homes and the surplus electricity not used is sold back to the utility company. An intriguing idea that will attract potential customers and help increase generation via solar energy.

There are multiple approaches to designing solar net metering. This includes: community net metering, aggregate net metering and virtual net metering. In community net metering, there are multiple consumers with multiple metering systems. The whole community is treated as a single customer and the power is distributed among the consumers of the community. Secondly, aggregate net metering systems allow a single consumer with multiple meters to offset electricity using only one generation. Lastly, virtual net metering system allows the consumers to be from various sites and still avail the benefits of net metering.

We portrayed the net metering features and advantages for our different design approaches using the following software tools: PVsyst, Helioscope and MATLAB simulink. The PVsyst software provided us with monthly irradiation data and helped us make an analysis on per kWh energy cost in USD at different locations of Bangladesh. Then we utilized the software called Helioscope to do the design of the solar panel in the desired location and analyzed the shading losses for that specific location. This software used satellite imaging to provide authentic results for drawing conclusions. Finally, MATLAB and MATLAB simulink were used to make the custom build blocks via code implementation to acquire the values for the net energy transfer to and from the utility grid as per our system was designed. The designs provide us with energy vs time graphs for analysis and comparison among all the multiple design approaches. After thorough analysis of the different results obtained from different softwares we were able to determine that the virtual net metering system gives a better performance, supplying the most amount of energy, but unfortunately this system is currently illegal in Bangladesh as per the net metering policies set by the Bangladesh's government. Thus, the community net metering system turned out to be the optimal design implemented for communal purposes.

Our designed prototype has a few segments such as generation system, grid system, load system or households, data monitoring and storage system, and finally power flow

distribution of the system. All these segments work in tandem to show the results of different scenarios our system is expected to experience during its operation life cycle. We overcame problems such as the lack of a grid tied inverter, ability to connect to an actual grid, poor performing inverters. indoor working conditions and unavailability of net meters in innovative ways to not only demonstrate supply of surplus solar generation to the grid but also take power from the grid when required. Simulating night time or low solar power generation times were also accomplished through our prototype. Furthermore, all the necessary parametric values required for bill calculations were successfully stored in google sheets to be used at the end of every month. Other notable features of our prototype includes real time updating of the required parametric values, protection of household AC meters and keeping track of any vandalism efforts on the aforementioned AC meters.

In this dire time of power crisis, the thought of uncertainty regarding the availability of adequate amounts of energy in future was creeping in the minds of many. This exact thought is what prompted us to come up with our idea of increasing power generation by using renewable energy that is readily available in our country, Bangladesh. The energy form being solar, has great potential in our country if proper manpower and investment is put into it. So we decided to attract the utilization of solar energy by linking it to a fresh concept like net metering. The greatest way to fight against this battle of power crisis is to lean towards renewable energy. This way we can also save the reserve of non-renewable resources for our future generations. Thus to accomplish this we proposed our project “ A design of feasible solar net metering system in the perspective of Bangladesh” . In this time of power shortage we wanted our project to be the hope of light in the midst of darkness.

10.2 Future work

As times progress, most systems and technologies advance and improve to reach a newer level; such is the plan for our project as well. Two such ways of advancement is listed below:

Comparison of DC Solar Output with the expected outcome:

Our prototype has a DC monitoring feature that monitors and stores the level of DC Solar Output from the solar generation system at all times. Furthermore, with the help of PVsyst we have collected solar irradiance values all throughout Bangladesh; meaning we can easily predict the amount of solar power a system of a specific size using certain types of components in a given area should generate. This makes a comparison between expected and actual output a simple reality and any discrepancies found can be dealt with appropriate actions. To make this comparison more accurate and reflective we can write a code including depreciating factors of the different components, updated solar irradiance values also taking into account any replacement of equipment. Furthermore, with machine learning using predictive weather conditions we can more accurately predict and compare the solar output of our PV panel generation system.

Fully Automated Web Bill Representation:

As our net metering scheme includes multiple consumers sharing the same generation system; electricity bill calculations become an issue. To solve this problem, we have sent all the required parametric values in separate google sheets to be used for bill calculation. The parameter of utmost importance is the total energy consumed in KWh which is also present in google sheets; using this value and their predefined ratio of solar generation ownership we can easily calculate the bill. Unfortunately to protect the privacy of data we used separate google sheets for individual households and general AC Meter meaning the last step of bill calculation needs to be done manually. But in the future, the total energy consumed in KWh of each household can be taken into a separate server for all the consumers to see where we can program a code to automatically do the calculations mentioned above and display the electricity bills at the end of every month.

Chapter 11

Identification of Complex Engineering Problems and Activities

The proposed project incorporated few complex engineering activities and issued in various aspects such as conflicting resources and analysis, innovation, codes and regulations etc of which a few has been identified and categorized with profound elaboration in the proceeding:

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

Attributes of Complex Engineering Problems (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 issued project requires profound knowledge and expertise in different spheres of complex engineering. For instance, operating the microprocessor Arduino UNO for the distribution system requires the detailed knowledge of embedded programming language. The hardware prototype implementation further requires expertise in power systems and components usage such as inverter, PWM based solar controller, wifi module etc.

P3. Depth of analysis required: The assemblage and simulation of the distribution system using relay has provided a conflicting issue in terms of implementing a bidirectional system among the load and grid system requiring further analysis which has been optimized afterwards. The power factor of the generation system has required detailed evaluation as well in terms of improvising and troubleshooting.

P4. Familiarity of issues: For a developing country like Bangladesh, the availability of electricity especially implementing renewable energy has not been advanced efficiently yet. As the net metering system provides the possibility of achieving economic feasibility as well, it will ensure eradicating electricity unavailability issues for a major number of consumers.

P5. Extent of applicable codes: To implement this system in practical, a numerous number of government imposed codes and regulations have to be maintained. There are further legal

requirements and conditions that have been imposed and should be monitored implementing different design approaches.

P7. Interdependence: The distinctive portions or the systems of the design such as generation system, load system, distribution system depend on each other in terms of construction and achieving the desired results. The data monitoring system can also be revised under this category.

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 resource: Both the hardware and software implementations required a wide range of resources. For the MATLAB software designs the resources required and assembled are load profiles for each of the households and solar irradiation data for certain regions of Bangladesh. For the hardware prototype, various components such as energy meters, microprocessors, server hosts tools etc have been used.

A2. Level of interaction: The project has required major social interaction at a large scale in terms of supplement, hardware construction, and knowledge assimilation.

A3. Innovation: The project has availed and utilized innovative attribution at a certain degree in numerous ranges. The bidirectional system implementation and distribution system in the hardware prototype includes this criteria.

A4. Consequences for society and the environment: As aforementioned thoroughly in the impact analysis, implementation of the net metering system provides numerous positive consecutive benefits for the society and environment. The application of renewable energy ensures environmental advantages and the economic profit achieved in cost reduction benefits the socio-economic aspect at a large scale in the long run.

A5. Familiarity: Although the net metering system has been established by few consumers in government and semi-government sectors, it is not well implemented at a large enough scale yet and the citizens are nevertheless unaware about the systems, its aspects and the benefits it provides thus validates the purpose of this project.

References

- [1] R. Górniewicz and R. Castro, "Optimal design and economic analysis of a PV system operating under Net Metering or Feed-In-Tariff support mechanisms: A case study in Poland," *Sustain. Energy Technol. Assessments*, vol. 42, no. 100863, p. 100863, 2020.
- [2] I. A. Sajjad, M. Manganelli, L. Martirano, R. Napoli, G. Chicco and G. Parise, "Net Metering benefits for Residential Customers," *IEEE Industry Applications Magazine*, 2017.
- [3] W. ur Rehman, I. A. Sajjad, T. N. Malik, L. Martirano, and M. Manganelli, "Economic analysis of net metering regulations for residential consumers in Pakistan," *IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 2017.
- [4] Abolhosseini, Shahrouz & Heshmati, Almas & Altmann, Jörn, "A Review of Renewable Energy Supply and Energy Efficiency Technologies," *IZA Discussion Papers 8145*, Institute of Labor Economics (IZA), 2014.
- [5] J. W. Stoutenborough and M. Beverlin, "Encouraging pollution-free energy: The diffusion of state net metering policies," *Soc. Sci. Q.*, vol. 89, no. 5, pp. 1230–1251, 2008.
- [6] "Bangladesh's power crisis: Not just a national issue," July 22, 2022, Dhaka Tribune.
- [7] Haque, M. A., & Rahman, J, "Power crisis and solution in Bangladesh", *Bangladesh Journal of Scientific and Industrial Research*, vol. 45(2), 155–162, 1970.
- [8] Crisis. "Bangladesh: Power crisis ongoing nationwide amid a supply shortage and severe heat as of July 26," *Crisis24*, September 10, 2022.
- [9] United Nations. (n.d.). "Achieving sustainable energy targets in Bangladesh," United nations, Retrieved April 29, 2022, from <https://www.un.org/en/chronicle/article/achieving-sustainable-energy-targets-bangladesh>
- [10] Hossain, S. and Rahman, M., "Solar Energy Prospects in Bangladesh: Target and Current Status," *Energy and Power Engineering*, 13, 322-332., 2021, doi: 10.4236/epe.2021.138022
- [11] S. A. Chowdhury and M. Z. R. Khan, "The net metering guideline of Bangladesh-potential and way forward," in 2020 11th International Conference on Electrical and Computer Engineering (ICECE), 2020
- [12] A. J. Lawson, "Net Metering: In Brief," Library of Congress, Congressional Research Service, Nov. 2019.
- [13] Zahid, H., Umer, F., Rashid, Z., Raheem, A., Shakoor, R., & Hussain, G. A. "Critical Analysis and Application of Net-Metering Practice in MEPCO," *International Journal of Photoenergy*, 1–13, 2020, <https://doi.org/10.1155/2020/4135860>
- [14] E. Doris, S. Busche, and S. Hockett, "Net Metering Policy Development and Distributed Solar Generation in Minnesota: Overview of Trends in Nationwide Policy Development and Implications of Increasing the Eligible System Size Cap," *Tech. Rep.*, National Renewable Energy Lab. (NREL) Tech. Reports, Golden, CO (United States), 2009.
- [15] B. Yosiana, "The Rise of the Energy Prosumers," *The ASEAN*, 2018.
- [16] "Bangladesh's net-metering policy: Jump starting the solar rooftop market?" (n.d.). Gov.Bd. Retrieved September 10, 2022.
- [17] W. Masoud, "Net-Metering Reference Guide for Electricity Consumer", AEDB (Ministry of Water & Power)
- [18] J. Thakur and B. Chakraborty, "Smart net metering models for smart grid in India," 2015 International Conference on Renewable Energy Research and Applications (ICRERA), 2015, pp. 333-338, DOI: 10.1109/ICRERA.2015.7418720
- [19] Umar, Najib & Bora, Birinchi & Banerjee, Chandan, "Comparison of different PV power simulation softwares: case study on performance analysis of 1 MW grid-connected PV solar power plant," 2018.

- [20] Tan, Rodney & Chow, T.L., "A Comparative Study of Feed in Tariff and Net Metering for UCSI University North Wing Campus with 100 kW Solar Photovoltaic System," *Energy Procedia*. Vol. 100., 2016, 86-91. [10.1016/j.egypro.2016.10.136](https://doi.org/10.1016/j.egypro.2016.10.136)
- [21] PEng, Mizanoor & Rakib, Md. Farhad & Howlader, Sujan. "Assessment of Average Household Utility Consumption in Khulna City of Bangladesh," *Journal of System and Management Sciences*. Vol. 7, 2017.
- [22] Istiaque, A. and Khan, S.I., "Impact of Ambient Temperature on Electricity Demand of Dhaka City of Bangladesh. *Energy and Power Engineering*," 10, 319-331, 2018. <https://doi.org/10.4236/epe.2018.107020>
- [23] Md. Rashedul Alam, & Sustainable and Renewable Energy Development Authority (SREDA), "Installed Statistics of Net Metering System," 2020. E-Service Desk for Solar. <https://solar.sreda.gov.bd/>

Appendix A.

Related codes

Code for ESP-8266 of House One

```
#include <WiFiManager.h>
#include <PZEM004Tv30.h>           // PZEM004Tv3 library

#include <WiFiClientSecure.h>
String readString;
const char* host = "script.google.com";
const int httpsPort = 443;
WiFiClientSecure client;
String GAS_ID = "AKfycbyiiA44tVD-wwi6DXWbVBqgYGBcmoUv6xry5J8Qdoq3Y32zT-4";

char* esp_ssid = "HOUSE - 1";
char* esp_pass = "1234567890";

#define vCal 1.006                // voltage calibration coefficient(default=1.0)
#define iCal 0.9205              // current calibration coefficient(default=1.0)

#define entPin D5                // enter button
#define buzzer D6                // buzzer
#define pzemRX D1                // receive data (connect to PZEM TX)
#define pzemTX D2                // send data (connect to PZEM RX)

PZEM004Tv30 pzem(pzemRX, pzemTX); // Pin11 to TX, Pin12 to RX

unsigned int rangeTable[8] = {1, 2, 5, 10, 30, 60, 120, 300}; // time Interval Table
int rangeNumber;
int Log;
int previousMillis = 0;

float Vx, Ax, VAx, Wx, kWhx, PFx, Hzx, VARx; // measured value
char buff[8]; // character format buffer
unsigned int logInterval; // log interval
volatile boolean t2Flag = false; // timing sync variable

const int Erasing_button = 0;

void configModeCallback (WiFiManager *myWiFiManager) {
  Serial.println(WiFi.softAPIP());
  Serial.println(myWiFiManager->getConfigPortalSSID());
}

void setup() {
  Serial.begin(9600);
```

```

pinMode(entPin, INPUT_PULLUP);           // enter button
pinMode(Erasing_button, INPUT);
pinMode(buzzer,OUTPUT);
pinMode(D4, OUTPUT);
noTone(buzzer);

for (uint8_t t = 4; t > 0; t--) {
  digitalWrite(D4, LOW);
  delay(500);
  Serial.println(t);
  digitalWrite(D4, HIGH);
  delay(500);
}

// Press and hold the button to erase all the credentials
if (digitalRead(Erasing_button) == LOW)
{
  WiFiManager wifiManager;
  wifiManager.resetSettings();
  ESP.restart();
  delay(1000);
}

WiFiManager wifiManager;
wifiManager.setAPCallback(configModeCallback);
if (!wifiManager.autoConnect(esp_ssid, esp_pass)) {
  Serial.println("failed to connect and hit timeout");
  ESP.restart();
  delay(1000);
}
Serial.println("connected...yeey :)");
digitalWrite(D4, LOW);
client.setInsecure();

rangeNumber = 4;
if (rangeNumber > 7) {                   // abnormal range number will be
  rangeNumber = 0;                       // set to 0
}
logInterval = rangeTable[rangeNumber];

Serial.println();                       // start message
Serial.println(F(" , PZEM-004V3 Power meter start V0.5"));
Serial.println(F(" , sec, V(rms), I(rms), VA, W, PF, kWh, Hz"));
Serial.flush();

measure();                               // get value from PZEM-004Tv3
logPrint();                              // data out serial port
}

void loop() {

```



```

Log = digitalRead(entPin);
if (Log == HIGH)
{
  tone(buzzer,800);
}
else{
  noTone(buzzer);
}
measure(); // get value from PZEM-004Tv3
unsigned long currentMillis = millis();

if (currentMillis - previousMillis >= (logInterval*1000)) {
  previousMillis = currentMillis;
  logPrint();
  if(String(Vx) != "nan"){
    writing();}
}
}

void writing() {
  Serial.print("connecting to ");
  Serial.println(host);
  if (!client.connect(host, httpsPort)) {
    Serial.println("connection failed");
    return;
  }
  String asdf;
  if (Log == HIGH)
  {
    asdf = "DAMAGED";
  }
  else{
    asdf = "OK";
  }
  String url = "/macros/s/" + GAS_ID + "/exec?value1=" + String(Vx, 2) + "&value2=" +
String(Ax, 3) + "&value3=" + String(VAx, 2) + "&value4=" + String(Wx, 1) + "&value5=" +
String(PFx, 2) + "&value6=" + String(kWhx, 3) + "&value7=" + String(Hzx, 1) +
"&value8=" + asdf;
  Serial.print("requesting URL: ");
  Serial.println(url);
  client.print(String("GET ") + url + " HTTP/1.1\r\n" +
    "Host: " + host + "\r\n" +
    "User-Agent: BuildFailureDetectorESP8266\r\n" +
    "Connection: close\r\n\r\n");
  Serial.println("request sent");
  while (client.connected()) {
    String line = client.readStringUntil('\n');
    if (line == "\r") {
      Serial.println("headers received");
      break;
    }
  }
}

```

```

    }
  }
  String line = client.readStringUntil('\n');
  if (line.startsWith("{\"state\":\"success\"}")) {
    Serial.println("esp8266/Arduino CI successful!");
  } else {
    Serial.println("esp8266/Arduino CI has failed");
  }
  Serial.println("reply was:");
  Serial.println("=====");
  Serial.println(line);
  Serial.println("=====");
  Serial.println("closing connection");
}

```

```

void measure() { // read values from PZEM-004T v3
  Vx = vCal * pzem.voltage(); // voltage(apply calibration correction)
  Ax = iCal * pzem.current(); // current(apply calibration correction)
  VAx = Vx * Ax; // calculate apparent power
  Wx = vCal * iCal * pzem.power(); // effective power(Use the value after calibration
correction)
  PFx = pzem.pf(); // power factor
  kWhx = vCal * iCal * pzem.energy(); // sum of energy(Use the value after calibration
correction)
  Hzx = pzem.frequency(); // line frequency
}

```

```

void logPrint() { // serial out for log
  static long t = 0;
  Serial.print(F(" , ")); // this for the separator for terminal software timestamp
text
  Serial.print(t); Serial.print(F(", ")); // time in second
  Serial.print(Vx, 1); Serial.print(F(", ")); // voltage
  Serial.print(Ax, 3); Serial.print(F(", ")); // current amps
  Serial.print(VAx, 2); Serial.print(F(", ")); // VA value
  Serial.print(Wx, 1); Serial.print(F(", ")); // wattage
  Serial.print(PFx, 2); Serial.print(F(", ")); // power factor
  Serial.print(kWhx, 3); Serial.print(F(", ")); // total energy
  Serial.print(Hzx, 1); // frequency
  Serial.println();
  t += logInterval; // increment accumulated time
}

```

Code for ESP-8266 of House Two:

```

#include <WiFiManager.h>
#include <PZEM004Tv30.h> // PZEM004Tv3 library

#include <WiFiClientSecure.h>

```

```

String readString;
const char* host = "script.google.com";
const int httpsPort = 443;
WiFiClientSecure client;
String          GAS_ID          =          "AKfycbyIGi4JNLuSNVzru6YK2o--
m3STo23jhTfzbfvfGwYDsxKJYHE";

char* esp_ssid = "HOUSE - 2";
char* esp_pass = "1234567890";

#define vCal 1.006          // voltage calibration coefficient(dafault=1.0)
#define iCal 0.9205        // current calibration coefficient(dafault=1.0)

#define entPin  D5          // enter button
#define buzzer  D6          // buzzer
#define pzemRX  D1          // recieve data (connect to PZEM TX)
#define pzemTX  D2          // send data (connect to PZEM RX)

PZEM004Tv30 pzem(pzemRX, pzemTX);          // Pin11 to TX, Pin12 to RX

unsigned int rangeTable[8] = {1, 2, 5, 10, 30, 60, 120, 300}; // time Interval Table
int rangeNumber;
int Log;
int previousMillis = 0;

float Vx, Ax, VAx, Wx, kWhx, PFx, Hzx, VARx; // measured value
char buff[8];          // character format buffer
unsigned int logInterval;          // log interval
volatile boolean t2Flag = false;          // timing sync variable

const int Erasing_button = 0;

void configModeCallback (WiFiManager *myWiFiManager) {
  Serial.println(WiFi.softAPIP());
  Serial.println(myWiFiManager->getConfigPortalSSID());
}

void setup() {
  Serial.begin(9600);
  pinMode(entPin, INPUT_PULLUP);          // enter button
  pinMode(Erasing_button, INPUT);
  pinMode(buzzer,OUTPUT);
  pinMode(D4, OUTPUT);
  noTone(buzzer);

  for (uint8_t t = 4; t > 0; t--) {
    digitalWrite(D4, LOW);
    delay(500);
    Serial.println(t);
    digitalWrite(D4, HIGH);
  }
}

```

```

    delay(500);
}

// Press and hold the button to erase all the credentials
if (digitalRead(Erasing_button) == LOW)
{
    WiFiManager wifiManager;
    wifiManager.resetSettings();
    ESP.restart();
    delay(1000);
}

WiFiManager wifiManager;
wifiManager.setAPCallback(configModeCallback);
if (!wifiManager.autoConnect(esp_ssid, esp_pass)) {
    Serial.println("failed to connect and hit timeout");
    ESP.restart();
    delay(1000);
}
Serial.println("connected...yeey :)");
digitalWrite(D4, LOW);
client.setInsecure();

rangeNumber = 4;
if (rangeNumber > 7) {           // abnormal range number will be
    rangeNumber = 0;           // set to 0
}
logInterval = rangeTable[rangeNumber];

Serial.println();           // start message
Serial.println(F(" , PZEM-004V3 Power meter start V0.5"));
Serial.println(F(" , sec, V(rms), I(rms), VA, W, PF, kWh, Hz"));
Serial.flush();

measure();           // get value from PZEM-004Tv3
logPrint();           // data out serial port
}

void loop() {
    Log = digitalRead(entPin);
    if (Log == HIGH)
    {
        tone(buzzer,800);
    }
    else{
        noTone(buzzer);
    }
    measure();           // get value from PZEM-004Tv3
    unsigned long currentMillis = millis();
}

```

```

if (currentMillis - previousMillis >= (logInterval*1000)) {
  previousMillis = currentMillis;
  logPrint();
  if(String(Vx) != "nan"){
    writing();}
}
}

void writing() {
  Serial.print("connecting to ");
  Serial.println(host);
  if (!client.connect(host, httpsPort)) {
    Serial.println("connection failed");
    return;
  }
  String asdf;
  if (Log == HIGH)
  {
    asdf = "DAMAGED";
  }
  else{
    asdf = "OK";
  }
  String url = "/macros/s/" + GAS_ID + "/exec?value1=" + String(Vx, 2) + "&value2=" +
String(Ax, 3) + "&value3=" + String(VAx, 2) + "&value4=" + String(Wx, 1) + "&value5=" +
String(PFx, 2) + "&value6=" + String(kWhx, 3) + "&value7=" + String(Hzx, 1) +
"&value8=" + asdf;
  Serial.print("requesting URL: ");
  Serial.println(url);
  client.print(String("GET ") + url + " HTTP/1.1\r\n" +
    "Host: " + host + "\r\n" +
    "User-Agent: BuildFailureDetectorESP8266\r\n" +
    "Connection: close\r\n\r\n");
  Serial.println("request sent");
  while (client.connected()) {
    String line = client.readStringUntil('\n');
    if (line == "\r") {
      Serial.println("headers received");
      break;
    }
  }
  String line = client.readStringUntil('\n');
  if (line.startsWith("{\"state\":\"success\"}")) {
    Serial.println("esp8266/Arduino CI successful!");
  } else {
    Serial.println("esp8266/Arduino CI has failed");
  }
  Serial.println("reply was:");
  Serial.println("=====");
  Serial.println(line);
}

```

```

Serial.println("=====");
Serial.println("closing connection");
}

void measure() { // read values from PZEM-004T v3
  Vx = vCal * pzem.voltage(); // voltage(apply calibration correction)
  Ax = iCal * pzem.current(); // current(apply calibration correction)
  VAx = Vx * Ax; // calculate apparent power
  Wx = vCal * iCal * pzem.power(); // effective power(Use the value after calibration
  correction)
  PFx = pzem.pf(); // power factor
  kWhx = vCal * iCal * pzem.energy(); // sum of energy(Use the value after calibration
  correction)
  Hzx = pzem.frequency(); // line frequency
}

void logPrint() { // serial out for log
  static long t = 0;
  Serial.print(F(" , ")); // this for the separator for terminal software timestamp
  text
  Serial.print(t); Serial.print(F(", ")); // time in second
  Serial.print(Vx, 1); Serial.print(F(", ")); // voltage
  Serial.print(Ax, 3); Serial.print(F(", ")); // current amps
  Serial.print(VAx, 2); Serial.print(F(", ")); // VA value
  Serial.print(Wx, 1); Serial.print(F(", ")); // wattage
  Serial.print(PFx, 2); Serial.print(F(", ")); // power factor
  Serial.print(kWhx, 3); Serial.print(F(", ")); // total energy
  Serial.print(Hzx, 1); // frequency
  Serial.println();
  t += logInterval; // increment accumulated time
}

```

Code for Arduino UNO of The General AC Meter:

```

#include <LiquidCrystal_I2C.h>
#include <PZEM004Tv30.h> // PZEM004Tv3 library
#include <Robojax_AllegroACS_Current_Sensor.h>
#include <SoftwareSerial.h>

const int VIN = A0; // define the Arduino pin A0 as voltage input (V in)
const float VCC = 5; // supply voltage
const int MODEL = 0; // enter the model (see above list)

Robojax_AllegroACS_Current_Sensor robojax(MODEL, VIN);
LiquidCrystal_I2C lcd(0x27, 16, 2);
SoftwareSerial mySerial(12, 13); // RX, TX

#define vCal 1.006 // voltage calibration coefficient(dafault=1.0)
#define iCal 0.9205 // current calibration coefficient(dafault=1.0)

```

```

//#define entPin D5 // enter button
//#define selPin D1 // select button
#define pzemRX 2 // recieve data (connect to PZEM TX)
#define pzemTX 3 // send data (connect to PZEM RX)

PZEM004Tv30 pzem(pzemRX, pzemTX); // Pin11 to TX, Pin12 to RX

unsigned int rangeTable[8] = {1, 2, 5, 10, 30, 60, 120, 300}; // time Interval Table
int rangeNumber;
int timeToLog;
int previousMillis = 0;
int pp = 0;

float II;
float Vx, Ax, VAx, Wx, kWhx, PFx, Hzx, VARx; // measured value
char buff[8]; // character format buffer
unsigned int logInterval; // log interval

#define RELAY1_PIN 4
#define RELAY2_PIN 5
#define RELAY3_PIN 6
#define RELAY4_PIN 7

#define ANALOG_IN_PIN A1
float adc_voltage = 0.0;
float in_voltage = 0.0;
float R1 = 30000.0;
float R2 = 7500.0;
float ref_voltage = 5.0;
int adc_value = 0, asd = 0;

void setup() {
  mySerial.begin(9600);
  Serial.begin(9600);
  pinMode(RELAY1_PIN, OUTPUT);
  pinMode(RELAY2_PIN, OUTPUT);
  pinMode(RELAY3_PIN, OUTPUT);
  pinMode(RELAY4_PIN, OUTPUT);

  digitalWrite(RELAY1_PIN, HIGH);
  digitalWrite(RELAY2_PIN, HIGH);
  digitalWrite(RELAY3_PIN, HIGH);
  digitalWrite(RELAY4_PIN, HIGH);

  lcd.init();
  lcd.backlight();

  rangeNumber = 4;
  if (rangeNumber > 7) { // abnormal range number will be
    rangeNumber = 0; // set to 0
  }
}

```

```

}
logInterval = rangeTable[rangeNumber];

Serial.println();           // start message
Serial.println(F(" , PZEM-004V3 Power meter start V0.5"));
Serial.println(F(" , sec, V(rms), I(rms), VA, W, PF, kWh, Hz, DI, DV"));
Serial.flush();

measure();                 // get value from PZEM-004Tv3
logPrint();                // data out serial port
}

void loop() {
  if (Wx > 12 || in_voltage < 10 || asd == 0) {
    digitalWrite(RELAY1_PIN, LOW);
    digitalWrite(RELAY2_PIN, LOW);
    digitalWrite(RELAY3_PIN, HIGH);
    digitalWrite(RELAY4_PIN, HIGH);
  }
  else if (Wx < 6) {
    digitalWrite(RELAY1_PIN, HIGH);
    digitalWrite(RELAY2_PIN, HIGH);
    digitalWrite(RELAY3_PIN, LOW);
    digitalWrite(RELAY4_PIN, LOW);
  }
  else {
    digitalWrite(RELAY1_PIN, HIGH);
    digitalWrite(RELAY2_PIN, HIGH);
    digitalWrite(RELAY3_PIN, HIGH);
    digitalWrite(RELAY4_PIN, HIGH);
  }
  measure();               // get value from PZEM-004Tv3
  unsigned long currentMillis = millis();

  if (currentMillis - previousMillis >= 1000) {
    previousMillis = currentMillis;
    if (pp >= logInterval) {
      pp = 0;
      logPrint();
    }
    else {
      float Power = (in_voltage * II);
      lcd.setCursor(0, 0);
      lcd.print("V:");
      lcd.print(in_voltage, 2);
      lcd.print(",I:");
      lcd.print(II, 3);
      lcd.print(" ");
      lcd.setCursor(0, 1);
      lcd.print("Power :");
    }
  }
}

```



```

    lcd.print(Power, 3);
    lcd.print(" ");
    pp++;
  }
}
} // end of loop

void measure() { // read values from PZEM-004T v3
  adc_value = analogRead(ANALOG_IN_PIN);
  adc_voltage = (adc_value * ref_voltage) / 1024.0;
  in_voltage = adc_voltage / (R2 / (R1 + R2));

  if (in_voltage < 2.50) {
    in_voltage = 0;
  }

  II = robojax.getCurrentAverage(300);
  if (II < 0.10) {
    II = 0;
  }
  Vx = vCal * pzem.voltage(); // voltage(apply calibration correction)
  Ax = iCal * pzem.current(); // current(apply calibration correction)
  VAx = Vx * Ax; // calculate apparent power
  Wx = vCal * iCal * pzem.power(); // effective power(Use the value after calibration
  correction)
  PFx = pzem.pf(); // power factor
  kWhx = vCal * iCal * pzem.energy(); // sum of energy(Use the value after calibration
  correction)
  Hzx = pzem.frequency(); // line frequency

  if (Vx >= 0) {
    asd = 1;
  }
  else {
    asd = 0;
  }
}

void logPrint() { // serial out for log
  static long t = 0;
  Serial.print(F(" , ")); // this for the separator for terminal software timestamp
  text
  Serial.print(t); Serial.print(F(", ")); // time in second
  Serial.print(Vx, 1); Serial.print(F(", ")); // voltage
  Serial.print(Ax, 3); Serial.print(F(", ")); // current amps
  Serial.print(VAx, 2); Serial.print(F(", ")); // VA value
  Serial.print(Wx, 1); Serial.print(F(", ")); // wattage
  Serial.print(PFx, 2); Serial.print(F(", ")); // power factor
  Serial.print(kWhx, 3); Serial.print(F(", ")); // total energy
  Serial.print(Hzx, 1); Serial.print(F(", ")); // frequency
}

```

```

Serial.print(II, 3); Serial.print(F(" ")); // DC current
Serial.print(in_voltage, 2); // voltage
Serial.println();
t += logInterval; // increment accumulated time

String sms = "#" + String(Vx, 1) + "@" + String(Ax, 3) + "@" + String(VAx, 2) + "@" +
String(Wx, 1) + "@" + String(PFx, 2) + "@" + String(kWhx, 3) + "@" + String(Hzx, 1) +
"@ + String(II, 3) + "@" + String(in_voltage, 2) + "*";
if (Vx >= 0) {
  Serial.println(sms);
  mySerial.println(sms);
}
}

```

Code for ESP-8266 of The General AC Meter:

```

#include <WiFiManager.h>
#include <WiFiClientSecure.h>

String readString;
const char* host = "script.google.com";
const int httpsPort = 443;
WiFiClientSecure client;
String          GAS_ID          =          "AKfycbyv0-
w_Uke1MNiVeBXj_btCRmZk1E1dRjYwRTGDfNSSDXtu1wI";

char* esp_ssid = "NET METER";
char* esp_pass = "1234567890";

String smss, sms, sms1, sms2, sms3, sms4, sms5, sms6, sms7, sms8, sms9;
int temp = 0, n = 0, k = 0, j = 0, jj = 0, jjj = 0, jjjj = 0, jjjjj = 0, jjjjjj = 0, jjjjjjj = 0,
jjjjjjjj = 0, jjjjjjjjj = 0, asd = 0;
char str[700], msg[700];

const int Erasing_button = 0;

void configModeCallback (WiFiManager *myWiFiManager) {
  Serial.println(WiFi.softAPIP());
  Serial.println(myWiFiManager->getConfigPortalSSID());
}

void setup() {
  Serial.begin(9600);
  pinMode(Erasing_button, INPUT);
  pinMode(D4, OUTPUT);

  for (uint8_t t = 4; t > 0; t--) {
    digitalWrite(D4, LOW);
    delay(500);
    Serial.println(t);
    digitalWrite(D4, HIGH);
  }
}

```

```

    delay(500);
}

// Press and hold the button to erase all the credentials
if (digitalRead(Erasing_button) == LOW)
{
    WiFiManager wifiManager;
    wifiManager.resetSettings();
    ESP.restart();
    delay(1000);
}

WiFiManager wifiManager;
wifiManager.setAPCallback(configModeCallback);
if (!wifiManager.autoConnect(esp_ssid, esp_pass)) {
    Serial.println("failed to connect and hit timeout");
    ESP.restart();
    delay(1000);
}
Serial.println("connected...yeey :)");
digitalWrite(D4, LOW);
client.setInsecure();
}

void loop() {
    serialEvent();
}

void serialEvent()
{
    while (Serial.available())
    {
        char ch = (char)Serial.read();
        str[n++] = ch;
        if (ch == '*')
        {
            temp = 1;
            break;
        }
    }
}
if (temp == 1)
{
    for (int i = 0; i < n; i++) {
        if (str[i] == '#') {
            j = i;
        }

        if (str[i] == '@') {
            if (asd == 0) {
                jj = i;
            }
        }
    }
}

```

```

    asd++;
}
else if (asd == 1) {
    jjj = i;
    asd++;
}
else if (asd == 2) {
    jjjj = i;
    asd++;
}
else if (asd == 3) {
    jjjjj = i;
    asd++;
}
else if (asd == 4) {
    jjjjjj = i;
    asd++;
}
else if (asd == 5) {
    jjjjjjj = i;
    asd++;
}
else if (asd == 6) {
    jjjjjjjj = i;
    asd++;
}
else if (asd == 7) {
    jjjjjjjjj = i;
    asd++;
}
}

if (str[i] == '*')
{
    k = i;
    break;
}
}
int l = 0;
sms = String(str);
sms1 = sms.substring(j + 1, jj);
sms2 = sms.substring(jj + 1, jjj);
sms3 = sms.substring(jjj + 1, jjjj);
sms4 = sms.substring(jjjj + 1, jjjjj);
sms5 = sms.substring(jjjjj + 1, jjjjjj);
sms6 = sms.substring(jjjjjj + 1, jjjjjjj);
sms7 = sms.substring(jjjjjjj + 1, jjjjjjjj);
sms8 = sms.substring(jjjjjjjj + 1, jjjjjjjjj);
sms9 = sms.substring(jjjjjjjjj + 1, k);
temp = 0;

```

```

    n = 0;
    asd = 0;
    writing();
}
}

void writing() {
    Serial.print("connecting to ");
    Serial.println(host);
    if (!client.connect(host, httpsPort)) {
        Serial.println("connection failed");
        return;
    }

    String url = "/macros/s/" + GAS_ID + "/exec?value1=" + sms1 + "&value2=" + sms2 +
"&value3=" + sms3 + "&value4=" + sms4 + "&value5=" + sms5 + "&value6=" + sms6 +
"&value7=" + sms7 + "&value8=" + sms8 + "&value9=" + sms9;
    Serial.print("requesting URL: ");
    Serial.println(url);
    client.print(String("GET ") + url + " HTTP/1.1\r\n" +
        "Host: " + host + "\r\n" +
        "User-Agent: BuildFailureDetectorESP8266\r\n" +
        "Connection: close\r\n\r\n");
    Serial.println("request sent");
    while (client.connected()) {
        String line = client.readStringUntil('\n');
        if (line == "\r") {
            Serial.println("headers received");
            break;
        }
    }
    String line = client.readStringUntil('\n');
    if (line.startsWith("{\"state\":\"success\"}")) {
        Serial.println("esp8266/Arduino CI successful!");
    } else {
        Serial.println("esp8266/Arduino CI has failed");
    }
    Serial.println("reply was:");
    Serial.println("=====");
    Serial.println(line);
    Serial.println("=====");
    Serial.println("closing connection");
}
}

```