SOLAR HOME ROOF-TOP SYSTEM WITH NET-METERING: A PATHWAY TO SUSTAINABLE AND COST-EFFECTIVE ENERGY SOLUTIONS

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

I hereby declare that this project “**Solar Home Roof-Top System with Net-Metering: A Pathway to Sustainable and Cost-Effective Energy Solutions**” represents my own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

Signature of the candidates

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APPROVAL

The project entitled **"Solar Home Roof-Top System with Net-Metering: A Pathway to Sustainable and Cost-Effective Energy Solutions"** submitted by **Shah Mohammed Ajmain (193-33-1009)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **September, 2023.**

Signed

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Dedicated

To

MY PARENTS AND SIBLINGS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

PV	Photovoltaic
NEM	Net Energy Metering
BPDB	Bangladesh Power Development Board
HOMER	Hybrid Optimization for Multiple Energy Resources
COE	Cost of Energy
RES	Renewable Energy Systems
REF	Renewable Fraction
NPC	Net Present Cost

LIST OF SYMBOLS

Symbol	*Name of the symbol*
i	Annual Interest Rate
N	Project Lifetime
CRF	Capital Recovery Factor
fpv	Derrating Factor

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I want to begin by giving thanks to **Allah, the All-Mighty**. He authorized me to complete our work to the best of my ability.
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ABSTRACT

In emerging nations around the world, power consumption is significantly increasing. Fossil fuels, which are not environmentally friendly and produce greenhouse gases that contribute to global warming, are presently used to produce the majority of the power in the world. Only 3% of Bangladesh's overall energy requirements are met by renewable energy sources.

In this research framework, we have used HOMER Pro to design and optimize a grid-tied solar rooftop home system with net metering. Our calculations show that the residence needs 6.55 kWh per day, peaking at 0.91 kW. We have a scaled average clearness index, and daily radiation is summarized 0.521 and 4.65 kWh/m2/day, respectively.

We have obtained two optimum configurations: a PV system without a battery and a PV system with a battery.

We have considered the later one after considering present load shedding, which includes a 6 kW PV panel, a 4 kW inverter, and a battery string with a 12 V and 1.7 kWh. The system has a cost of energy (COE) of 2.39, a 64% COE cost reduction, a renewable energy fraction (REF) of 84.9%, an annual capital recovery of 9.28%, payback period of approximately 11 years and a 41.88-tonne greenhouse gas duction. Hence, the system is sustainable and cost-effective.

Keywords: RES, PV, NEM, COE, NPC, HOMER, REF

CHAPTER 1

INTRODUCTION

1.1 Background

The financial growth of a nation depends on its access to electrical energy. Per-capita electricity consumption has increased due to rapid urbanisation and population growth; hence, the established limit should be increased globally at a similar pace. About 75% of people in Bangladesh don't seek political office [1]. For the country's financial development and the delivery of essential public services like healthcare and education, a reliable electricity supply is necessary. Access to dependable and common power may help sustain revenue-generating activities, particularly the water system for agriculture, which accounts for 16% of the nation's GDP (gross domestic product) [2].. The public authority of Bangladesh has made a number of efforts to ease the power shortage in rural areas by utilising sustainable power sources, particularly photovoltaic (PV) systems that are powered by sunshine. However, the main barriers to this zap are: moderate for the lower segment; limitations on using the energy for beneficial purposes because the frameworks frequently suffer from the negative effects of abundance limits because they are curiously large to ensure high dependability; and the frameworks are not flexible regarding use and installment strategies. In addition, a field-based focus revealed several flaws, the bulk of which occurred at the application stage, such as improper setup, subpar components, and a lack of value control frameworks. The South Asian nation of Bangladesh is located between latitudes 20.30° and 26.38° N and longitudes 88.04° and 92.44° E [3]. Bangladesh receives enough sunlight to generate sun-oriented power. The majority of power is produced from combustible fuel and petroleum derivatives. However, the Bangladeshi government is actively working to increase its reliance on renewable energy sources. In Bangladesh, the annual sunlight-based lighting, which is 1700 kWh/m2, is sufficient to provide the necessary electricity from sun-oriented PV. Bangladesh could change its power-creating system to one that is based on environmentally friendly electricity as a result, reducing its reliance on traditional power sources. A microgrid (MG) framework or an ecologically friendly power-based crossover framework can be used to energise the area in remote locations where traditional lattice access is unattainable.

High framework losses, delays in the construction of new plants, low plant proficiency, erratic power supply, power theft, power outages, and a lack of resources for influence plant assistance are some of the problems in Bangladesh's electric power sector. Generally speaking, over the past 10 years, the country's ageing plants have not been able to meet the country's food demands. Only 45% of the 168 million houses in the nation's 168 million dwellings had power restored by dark on October 4, 2022 [4]. In the 2021–present global energy crisis, 77 petroleum gas power plants lacked sufficient fuel to meet their demands, resulting in a shortage of combustible gas. Regular gas is crucial to Bangladesh's power industry. In June 2022, the public authority stopped buying melted gaseous fuel at spot prices; this year, they were taking in 30% of their LNG on the spot market, down from 40% last year. They are still importing LNG through FTA trade channels.

1.2 Microgrids for Electricity

Low-voltage transmission systems with distributed energy resources, as well as stocked electronics and adjustable loads, are typically seen in microgrids [5]. Both matrix-associated (on-network) and off-lattice (island) working modes are possible with these frameworks. When the typical lattice is accessible and power is needed for the concentrated regions' amazing utilisation, the matrix-associated technique is only practicable. If there is more electricity generated by the microgrid than is needed, it is transferred to the conventional infrastructure; if not enough power is generated, the microgrid acts as a weight on the conventional infrastructure. The island mode is considered when the network's supply is insufficient or the close affiliation with the system is unavailable. Microgrids may be used in public infrastructure, such as framework-related microgrids [5]. Off-framework microgrids primarily provide capacity to residents in areas where network construction is neither time- nor cost-effective. As a result, the impact of off-matrix microgrids is assessed not only by the decline in that state of mind in remote and constrained locations but also, furthermore, by the degree to which personal pleasure increases.

A microgrid is a limited-size matrix network that has the flexibility to operate independently or in concert with other small power cross-sections [6]. Terms like "gathered," "dispersed," "decentralised," "city," and "embedded energy" all imply the use of smaller than anticipated systems. Any restricted-size, decentralised power plant with its own age, limit, and definable cutoff points is a smaller than usual organisation. It is implied that the little organisation functions as a combined scaled-down system if it can be connected to the city's important power cross-section. Smaller than planned systems are frequently utilised as backup power or to enhance the important power grid during peak hours, and they are frequently powered by generators, endless breezes, and daylight-based energy sources. A tiny network method that supports localised wind or solar power generation will make central utilities evidently tedium while also reducing the vulnerability of the primary system to local catastrophes. The microgrid's architecture is seen in "Figure 1.5. Microgrids may be divided into two categories: off-grid and grid-tied microgrids [7].

1.2.1 Off-grid Microgrid

Off-grid microgrids are built in areas with a great need for electricity but no legal authorization for a widespread electrical network [8]. Islands that are too far from the focal region frequently have their own microgrid to supply them. In the past, island microgrids were often powered by diesel or heavy-fuel oil generators. These abilities may end up being pricey despite how easily they can be transported and stored. Regardless, a number of islands continue to rely heavily on these generators since there is no practical substitute. Islands have a significant amount of wind and sun. Undoubtedly, however, it can be difficult to organise massive amounts of solar arrays and wind turbines on an island's electrical grid. They have the capacity to enthusiastically meet the island's fluctuating electricity demand. Strangely, wind turbines only generate energy when there is wind. Sun-powered chargers function while the sun is out [9]. A second source of power should be available to quickly meet the need for electrical weight in the anticipation that the breeze will lessen and again in the event that fog temporarily blocks the sun. This type of innovative organisation needs sophisticated authoritative controls and high-level power devices since it is ancient and solicitous enough. In the past, choosing island construction with a limited scope wasn't a rational choice. Today's utilities on islands are able to combine higher amounts of erratic, limitless resources, including solar and wind, thanks to modern microgrid characteristics. In order to control the flow of energy between irregular resources and conventional generators, a set energy limit that is expressly stated is very helpful. Island utilities discover that integrating assets into a cutting-edge microgrid offers a number of advantages. Islands have the opportunity to lower their fuel prices and the regular local effects associated with the use of such unfriendly power sources by producing more notable power from an abundance of resources. Island utilities may cut maintenance costs, boost efficiency, and, frequently, reduce the estimated number of generators on the island by including their generators in a more planned fashion. Additionally, the electrical infrastructure is more reliable, leading to greater aid quality and fewer frequent blackouts.

1.2.2 Grid-tied Microgrid

The microgrid is connected to the utility lattice by a power inverter unit in a matrix-associated microgrid structure, which enables it to function in tandem with the electrical utility network [10]. An electrical connection is made between the sources in a framework-related framework, often referred to as a network-tied or "on-lattice" framework, and the neighbouring mains power matrix, which supplies electricity back into the network. The main benefits of a lattice-related structure are ease of use, cheap operating and maintenance costs, and low power consumption. The drawback is that enough sources must be installed in order to provide the necessary amount of extra electricity**.**

Since most grid-connected systems transmit their power directly back into the network, they may function without purchasing expensive backup batteries. Furthermore, since this kind of framework is inextricably linked to the grid, there are a tonne of different possibilities available and no need to estimate energy consumption or measure the framework.

1.3 Net-metering Scheme

The implementation of a billing method known as net metering plays a pivotal role in the promotion and adoption of renewable energy sources such as solar and wind power [11]. In contrast to conventional energy sources, which can be readily utilised as required, renewable energy sources such as solar and wind are contingent upon the capricious nature of weather patterns. Net metering circumvents this constraint by enabling consumers to receive compensation for the surplus power they contribute to the grid.

The necessity for implementing net metering is readily apparent in light of the intermittent nature of wind and solar energy generation. Under appropriate conditions, such as during periods of ample sunlight or strong winds, these sources have the potential to generate supplementary energy. Nevertheless, this energy is typically not exhausted instantaneously. One potential approach to optimising the effectiveness of renewable energy sources is the use of net metering.

Customers that employ monthly net metering have the opportunity to derive advantages from the surplus energy generated by their solar panels during evenings characterised by high wind or abundant sunlight. This surplus energy may be utilised to compensate for their energy consumption during other periods within the same month. The flexibility inherent in this approach ensures that renewable energy resources are effectively employed to meet the energy demands of customers over the course of a month, hence minimising wastage.

The concept of annual net metering is one that provides support for this idea. This system enables the accumulation of a net credit of kilowatt-hours across a 12-month period. Customers have the ability to access this credit, which has the potential to be retained and utilised in subsequent months, enabling them to consume the energy they produced during a certain period in a different season. For example, the power generated by wind turbines during the spring season may be effectively harnessed and exploited during the month of August, which experiences the highest wind speeds. Similarly, the energy derived from solar panels during the sun-drenched month of July can be stored and employed during the fewer daylight hours of December.

Let us contemplate a homeowner who has lately installed a rooftop photovoltaic (PV) system. The present system has the potential to produce an excess of energy during daylight hours, surpassing the energy demands of the household. Net metering allows for the extra energy generated by a household to be sent back into the electrical grid, resulting in a reversal of the energy meter's direction. Consequently, this leads to an augmentation in the credit obtained by users in offsetting their energy consumption from the grid during periods characterised by heightened demand, such as evenings or overcast days.

Customers that choose to embrace net metering become energy producers since they are compensated solely for their "net" energy consumption, which refers to the discrepancy between the energy they generate and the energy they use from the grid [12]. Customers that generate a surplus of renewable energy relative to their use may qualify for utility company credits or monetary compensation, in addition to the benefit of avoiding further costs. Net metering confers an additional benefit by obviating the need for battery storage devices, an essential component for several off-grid solar initiatives. Rather than depending on expensive and time-consuming battery systems, net metering allows for the efficient storage of surplus energy inside the utility grid, which can be readily accessed by customers when required.

Net metering fundamentally changes the dynamics between energy providers and consumers. This technology enables both individuals and companies to effectively harness the capabilities of renewable energy sources by transforming intermittent electricity into a consistent and dependable energy supply. The use of this novel billing approach has facilitated the establishment of net metering as a fundamental component in the transition towards a more dependable and environmentally conscious energy landscape.

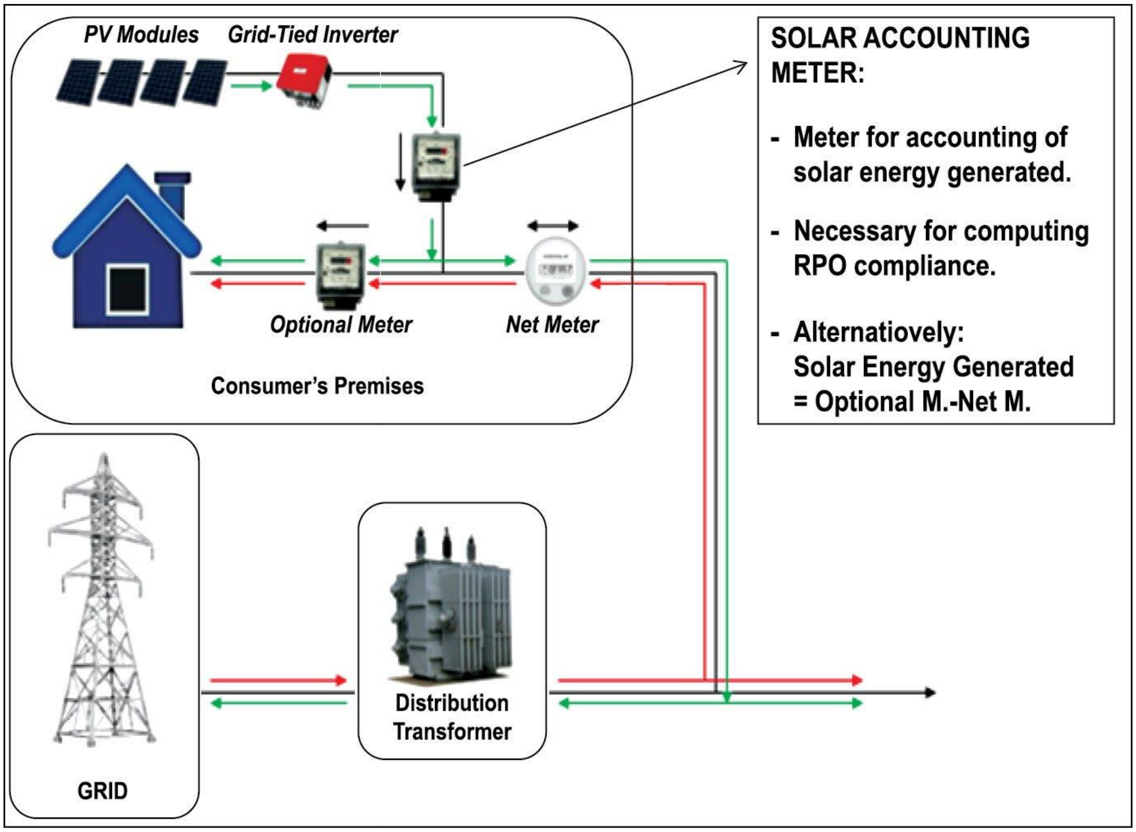


Fig. 1.1 Architecture of Net-metering [13]

CHAPTER 2

LITERATURE REVIEW

2.1 Power Sector of Bangladesh

In the spring of 2018, Bangladesh was classified as a non-modern nation in terms of its economy and social structure. Bangladesh has met all three requirements to be classified as an emerging nation. The world's most densely inhabited region is Bangladesh, where 166 million people live on a surface measuring 148,460 square kilometres. The desire for power increases as the population does. As of September 2019, the utility power area of Bangladesh has one public organisation with a gross presented limitation of 21,419 MW. The 20,000 MW (combined daylight-based power) gross limit is shown. The energy sector in Bangladesh is suffering. The 2.4 GW Rooppur nuclear power project is currently under construction in Bangladesh and is scheduled to be finished in 2023 [14]. The Bangladesh Power Progression Board reported in July 2018 that 90% of the population was moving towards power. Bangladesh, on the other hand, uses relatively little power per person. The primary source of energy for the majority of the nation's economic activity is power. The final power age limit for Bangladesh as of January 2017 was 15,351 MW, with a target of 20,000 MW in 2018, and it is productive. In Bangladesh, organisations and the private sector use the most electricity, followed by commercial and rural areas. In 2015, 92 percent of urban residents and 67 percent of rural residents had access to electricity. In Bangladesh, 77.9% of the populace went in the direction of power. Bangladesh would need 34,000 MW of capacity by 2030 in order to continue its over 7% monetary progress [15]. In Bangladesh's electric impact market, problems include high structural disasters, delays in the development of new plants, poor plant performance, intermittent impact supply, energy theft, blackouts, and a lack of resources for impact plant maintenance. The nation's outdated plants haven't been able to meet machine demand for the past ten years.

For the next four and a half years, throughout the tenure of the current administration, the Power and Energy Ministry has been preparing to give BDT 400 billion ($5.88 billion) to provide 5,000 MW of capacity [16]. In order to avoid load shedding in December, the Bangladesh Electricity Development Board (BPDB) proposed to gas-end 500 MW of electricity between July and December 2009. According to the game plan, the PDB would enlist a warmer oil-based 1,000 MW force from the private region from January 2010 to June 2010. An 800 MW power plant breaking point based on radiator oil would be presented by the public authorities in 2011. According to a top PDB official, the experts will look for a suitable location to extend the facility. To keep load shedding at a manageable level, the public body said it will also use another diesel- or radiator oil-based power plant that had a cutoff of 700 MW in 2012. However, the public authority is also considering constructing four coal-fired power plants in the Rajshahi and Chittagong regions, each with a capacity to generate 500 MW of power.
Installed Capacity in Bangladesh Categorized by Plant and Fuel can be seen in “table 2.1.”

Table 2.1 Installed Capacity in Bangladesh Categorized by Plant and Fuel [17]

Plant Type		Fuel Type	
Hydro	230 MW (1.04%)	Hydro	230 MW (1.04%)
Gas Turbine	1,211 MW (5.50%)	Gas	11,450MW (51.97%)
Steam Turbine	3,268 MW (14.83%)	Power Import	1,160 MW (5.27%)
Combined Cycle	7,933 MW (36.01%)	Furnace Oil	6,004 MW (27.25%)
Power Import	1,160 MW (5.27%)	Diesel	1,290 MW (5.86%)
Reciprocating Engine	8,100 MW (36.77%)	Solar PV	129 MW (0.59%)
Solar PV	129 MW (0.59%)	Coal	1,768 MW (8.03%)
Total	22,034 MW (100%)	Total	22,034 MW (100%)

2.2 Renewable Energy in Bangladesh

Sustainable energy, often known as environmentally friendly power, is energy that is obtained from reasonable sources that are normally restored within the human time horizon. These combine energy sources including solar, wind, water progress, and geothermal energy. While most power sources are appropriate and safe for the ecology, others are not. For instance, certain biomass sources are seen as being impractical at the present pace of development. Renewable energy sources occasionally power systems for heating and cooling of the air and water.

Feasible energy development projects are frequently very large scale, but they are also wise for rural, remote, and non-modern nations, where energy is frequently essential for human new development. The portion of controllable electricity in the total power supply increased from 20% to 28% between 2011 and 2021. Nuclear energy dropped from 12% to 10% while fossil energy fell from 68% to 62%. While the share of wind and solar energy increased from 2% to 10%, the share of hydropower decreased from 16% to 15% [18]. Geothermal and biomass increased from 2% to 3% [18].

Bangladesh's ability to generate power seems unimaginable, especially given the country's reliance on solar energy. In any event, eco-friendly energy will continue to be connected to the continuous energy beginning through unmanageable regular procedures indefinitely. However, solar-powered development may anticipate to play a significant role in rescuing consumers who reside outside of the public sphere or in places where system access is restricted. The current limit for green electricity introduced in Bangladesh is 950.86 MW, as shown in "table 2.1."

Table 2.2 Renewable Energy Installed Capacity in Bangladesh [18]

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	356.86	375.64	732.5
Wind	2	0.9	2.9
Hydro	0	230	230
Biogas to Electricity	0.69	0	0.69
Biomass to Electricity	0.4	0	0.4
Total	**359.95**	**606.54**	**966.49**

2.2.1 Solar Energy

Between 20°34' and 26°39' North and 80°00' and 90°41' East is where Bangladesh, a nation in South Asia, is located. As a result, it is an excellent location for using solar energy [19]. Furthermore, because it is a subtropical region, 70% of the year is spent with plenty of sunshine. As a result, solar-powered chargers are crucial in Bangladesh. The average daily solar radiation is 4-6.5 kWh/m2, with springtime (April) seeing the greatest levels and winter (December–January) seeing the lowest. Therefore, using solar energy might be a potential response to Bangladesh's power crisis. Additionally, energy derived from sunlight has a few notable qualities that make it appropriate for conveyed power applications and don't result in waste or transmission. The government authority has just discovered a few approaches to figure out what's going on. Several non-regulatory organisations are also working to provide customers with extremely conservative sunlight-based regulated chargers.

2.2.2 Wind Energy

Wind power is the process by which wind energy is transformed by wind turbines into a useful form of energy, such electrical or mechanical energy. The strength and breeze speed are the same. By utilising the special energy provided by moving air, the breeze is utilised to generate electricity. This is transformed into electrical energy using wind turbines or wind energy converters. The sharp edges of a turbine are struck by contort first, causing them to turn and the turbine to which they are connected to turn shortly after. Two areas in Bangladesh are powered by wind turbines; Kutubdia and Feni both have 1.9 MW of wind electricity. A 150 KW wind turbine is expected to produce 133 MWh and 160 MWh of energy each year at Kutubdia and Kuakata, respectively, while a 250 KW station is expected to produce 200 MWh and 230 MWh [20].

2.2.3 Hydroelectric Energy

Hydroelectric energy is obtained from the development of water. The bulk of water. Since water has mass, it falls because of gravity. When it runs, it has enough motor power to be restrained. Movement is the power of dynamic energy. Bangladesh's most essential sustainable energy source is hydropower, but wind energy is set to overtake it. In most cases, hydropower uses water that is moving quickly from a high point on a large stream. It then turns the turbine blades of a generator to produce electricity.

Huge hydropower facilities, often known as über dams, are usually seen as non-sustainable power sources on a worldwide scale. Dams divert and diminish streams, limiting access for populations of people and other aquatic life. Because just a little portion of the stream is diverted, the meticulously managed small hydro plants (with an installed maximum of under 40 megawatts) often do less climate change impact.

2.2.4 Biomass

Using organic materials from waste from forestry, agriculture, and energy crops, biomass energy is a flexible and sustainable energy source. The organic resources can be converted into biofuels, a sustainable substitute for fossil fuels, or they can be burnt directly to provide heat or power. Plants take in energy from the sun and transform it into chemical energy, which is the foundation of biomass energy, through photosynthesis. The generation of biofuels like bioethanol and biodiesel is one of the main uses for biomass energy. While biodiesel is produced from vegetable or animal fats, bioethanol is sourced from crops including maize, sugarcane, and wheat. In transportation and current cycles, both biofuels can replace conventional petrol derivatives, lowering greenhouse gas emissions and preventing climate change.

2.3 Grid Connected Solar PV Systems

In recent years, there has been significant emphasis given to the incorporation of grid-connected solar photovoltaic (PV) systems into the global energy environment [21]. The objective of this literature review is to present a comprehensive examination of significant research discoveries, patterns, obstacles, and progressions pertaining to grid-connected solar photovoltaic (PV) systems.

01. The Impact of Technological Advancements on Efficiency Enhancement

Recent research has elucidated significant progressions in solar photovoltaic (PV) technologies, including enhancements in the efficiency of solar cells, the design of modules, and the field of power electronics [22]. The energy production of photovoltaic (PV) systems has been notably enhanced by the implementation of more efficient solar cell technologies, such as Passivated Emitter and Rear Cell (PERC) and bifacial modules. Furthermore, advancements in Maximum Power Point Tracking (MPPT) algorithms and inverter technologies have facilitated the ability of grid-connected photovoltaic (PV) systems to optimise energy generation and adjust to changing circumstances, hence improving the overall efficiency of the system.

02. Challenges and Solutions in the Integration Process

The issue of integrating grid-connected solar PV systems with pre-existing electricity networks has garnered significant attention in academic circles [23]. Numerous investigations have been conducted to examine topics such as voltage fluctuations, grid stability, and reverse power flows. Proposed as a means to address these difficulties are advanced control techniques, including smart inverters equipped with reactive power support and anti-islanding characteristics. Furthermore, scholarly investigations have examined the effects of photovoltaic (PV) variability on the stability of electrical grids, as well as the possible advantages of implementing energy storage devices to mitigate changes in power production.

03. The Economic and Environmental Consequences

A plethora of scholarly investigations have been conducted to assess the economic feasibility and ecological advantages of grid-connected solar photovoltaic (PV) systems. The broad adoption of photovoltaic (PV) systems has been encouraged by cost reductions resulting from the decline in PV module prices and the availability of incentives. Moreover, it has been shown via life cycle analyses that the deployment of solar photovoltaic (PV) systems leads to a noteworthy decrease in greenhouse gas emissions, so making a valuable contribution to the advancement of sustainable energy transitions [24].

04. Examination of Policy and Regulatory Frameworks

Policy and regulatory issues are of utmost importance in influencing the development of grid-connected solar photovoltaic (PV) systems. The field of literature has extensively examined the concepts of feed-in tariffs, net metering rules, and incentives pertaining to the installation of renewable energy systems in residential, commercial, and utility-scale settings. Various comparative studies conducted in different countries have evaluated the efficacy of these policies in facilitating the adoption of solar photovoltaic (PV) systems, with a particular emphasis on the significance of consistent and supportive regulatory frameworks.

05. Techno-Economic Analyses

Various techno-economic evaluations have been undertaken to assess the viability of different grid-connected solar photovoltaic (PV) setups [25]. Various studies have conducted comparisons between centralised and decentralised systems, household and utility-scale installations, as well as standalone and integrated energy storage options. The aforementioned evaluations take into account several elements, including capital expenditures, operational and maintenance costs, energy production, and financial gains, in order to offer valuable insights into the most advantageous approaches to system design and implementation.

06. Prospects for the Future and Areas of Further Research

The existing body of literature suggests a positive outlook for the future of grid-connected solar photovoltaic (PV) systems. Current research is centred around the integration of sophisticated forecasting methods, demand-side management strategies, and artificial intelligence (AI) technologies in order to improve the predictability of energy systems and optimise energy generation [26]. Furthermore, the investigation of emerging materials, such as perovskite solar cells, and inventive implementation strategies, such as community solar projects, persistently influence the development of solar photovoltaic (PV) technology.

In summary, the existing body of research emphasises the significant importance of grid-connected solar photovoltaic (PV) systems in facilitating the worldwide shift towards cleaner and more sustainable energy alternatives. The multifaceted nature of this field is underscored by technological advancements, integration challenges, economic considerations, policy frameworks, grid resilience, and future prospects. These aspects offer valuable insights for researchers, policymakers, and stakeholders who are committed to promoting the widespread adoption of solar PV and its smooth integration into the energy landscape.

2.4 Solar Projects in Bangladesh

Solar park projects can be seen in “table 2.3.”

Table 2.3 Solar Park Projects in Bangladesh [18]

SL	Name of the Project	Location	Agency
01	30MW (AC) Solar Park by Intraco CNG Ltd & Juli New Energy Co. Ltd.	Gangachara, Rangpur	BPDB
02	100 MW (AC) Solar Park by Energon Technologies FZE & China Sunergy Co.Ltd (ESUN)	Mongla, Bagerhat	BPDB
03	Sirajganj 6.13 MW (AC) Grid Connected Solar Photovoltaic Power Plant	Sadar, Sirajgonj	NWPGCL
04	35 MW AC Solar Park by Consortium of Spectra Engineers Limited & Shunfeng Investment Limited	Shibalaya, Manikganj	BPDB
05	50 MW (AC) Solar Park by HETAT-DITROLIC-IFDC Solar Consortium	Gauripur,Mymensingh	BPDB
06	20MW (AC) Solar Park by Joules Power Limited (JPL)	Teknaf, Cox's Bazar	BPDB
07	100 MW Solar Power Plant at Madarganj in Jamalpur District	Madarganj, Jamalpur	RPCL (Ongoing)

08	Sirajganj 68 MW Solar Park	Sadar, Sirajgonj	NWPGCL (Ongoing)
09	50 MW solar power plant by Consortium of IBV Vogt GmbH & SS Agro Complex Ltd.	Dhamrai, Dhaka	BPDB (Planning)
10	Matarbari 50 MW Grid Tied Solar Power Plant Project	Maheshkhali, Cox's Bazar	CPGCBL (Planning)

CHAPTER 3

RESOURCE AND LOAD MODELING IN HOMER PRO

3.1 Baseline Solar Data

The effective utilization of solar energy for power generation hinges on the availability of solar radiation. Solar radiation, which is the energy emitted by the sun in the form of electromagnetic waves, is harnessed through solar panels to produce electricity. The measurement of solar radiation, often accompanied by the clearness index, helps assess the potential solar energy that can be harvested in a particular location.

We can estimate the solar energy potential at a certain site using the clearness index and solar radiation statistics. These criteria are essential for determining the viability of solar energy projects, planning system capacity, and making well-informed decisions. It's crucial to remember that these numbers might change depending on your location, climate, and other factors. To determine the solar resource, location-specific data including latitude, longitude, and time zone are crucial inputs.

In the given example, the coordinates were set at 23°52.2' N latitude, 90°19.1' E longitude, with a time zone of UTC+6. The solar resource data is tabulated on a month-by-month basis, showcasing the clearness index and daily radiation in kilowatt-hours per square meter per day (kWh/m²/day), in table 3.1 and "fig. 3.1." These figures offer insight into the intensity and availability of solar radiation throughout the year.

Table 3.1 Solar Radiation Data with Clearness Index

Month	Clearness Index	Daily Solar Radiation
		(kWh/m^2/day)
January	0.632	4.360
February	0.616	4.920
March	0.599	5.590
April	0.552	5.760
May	0.481	5.300
June	0.405	4.530
July	0.382	4.230
August	0.404	4.290
September	0.415	4.020
October	0.517	4.320
November	0.601	4.280
December	0.644	4.210
Average	0.521	4.65

The scaled average clearness index and daily radiation are summarized as 0.521 and 4.65 kWh/m²/day, respectively. These values provide a consolidated representation of the solar resource's magnitude and consistency over the year.

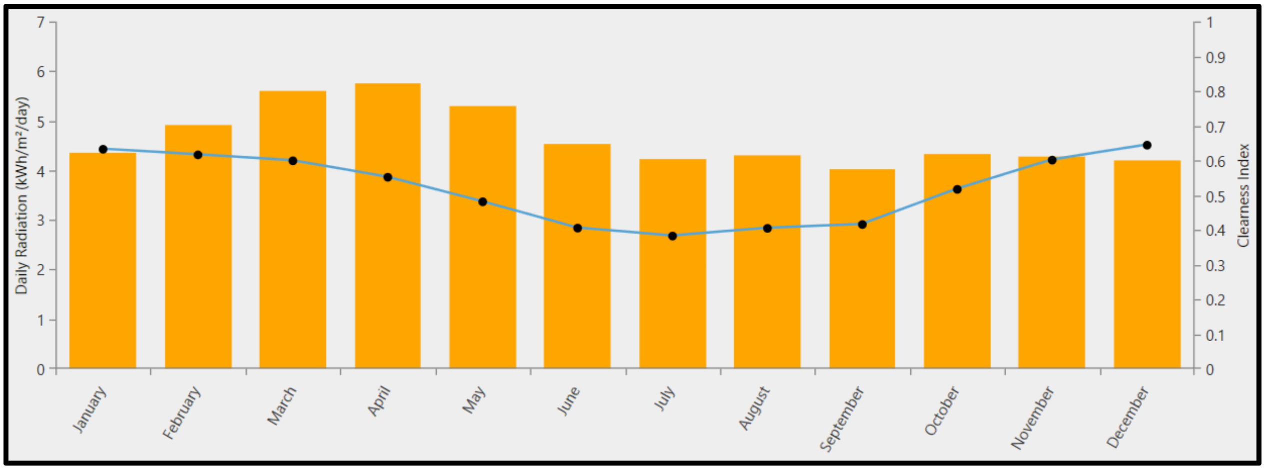


Fig. 3.1 Solar Radiation with Clearness Index

3.2 Electric Load Profile

We have taken a flat having four rooms, as a case study, the electrical appliances can be listed in “table 3.2.”

Table 3.2 List of the Electrical Appliances

SL	**Name of Appliance**	**Rating**	**Number of Appliances**
		W	
01	Light	20	5
02	Ceiling Fan	75	2
03	Table Fan	60	3
04	Mobile Charger	18	1
		22	2
		30	3
05	Laptop	45	2
		65	2

3.2.1 Summer Energy Consumption

The period from March to October is classified as the summer season. During this time, the sun's intensity and duration are relatively higher, often leading to increased cooling and comfort needs. This season is associated with higher energy consumption due to factors like air conditioning, and increased daylight hours. On weekdays during the summer season, the energy consumption averages at 7.987 kilowatt-hours (kWh). This higher energy demand reflects the usage of cooling systems, lighting, and appliances throughout the workweek. Over weekends in the summer months, the energy consumption rises slightly to an average of 8.522 kWh. The uptick in consumption can be attributed to extended periods spent at home and engaging in activities that require energy usage. Tables 3.3 and 3.4 can display the total energy usage of all the electric appliances.

Table 3.3 Summer Energy Consumption for Weekdays (March to October)

SL	Name of Appliance	Energy Consumption
		kWh/day
01	Light	0.760
02	Ceiling Fan	2.550
03	Table Fan	1.920
04	Laptop	2.355
05	Mobile Charger	0.402
	Total	7.987

Table 3.4 Summer Energy Consumption for Weekends (March to October)

SL	Name of Appliance	Energy Consumption
		kWh/day
01	Light	0.680
02	Ceiling Fan	2.925
03	Table Fan	2.160
04	Laptop	2.355
05	Mobile Charger	0.402
	Total	8.522

3.2.2 Winter Energy Consumption

From November to February, the winter season takes center stage. This period is characterized by shorter daylight hours and lower outdoor temperatures, leading to specific energy consumption patterns. Weekday energy consumption during the winter season reduces to an average of 3.787 kWh. With milder weather and shorter days, the need for energy-intensive cooling systems decreases, leading to lower overall energy usage. Energy consumption during winter weekends reaches an average of 2.355 kWh. During this time, individuals may spend more time indoors, and indoor lighting, which contributes to a slightly higher energy demand compared to weekdays. Tables 3.5 and 3.6 can display the total energy usage of all the electric appliances.

Table 3.5 Winter Energy Consumption for Weekdays (November to February)

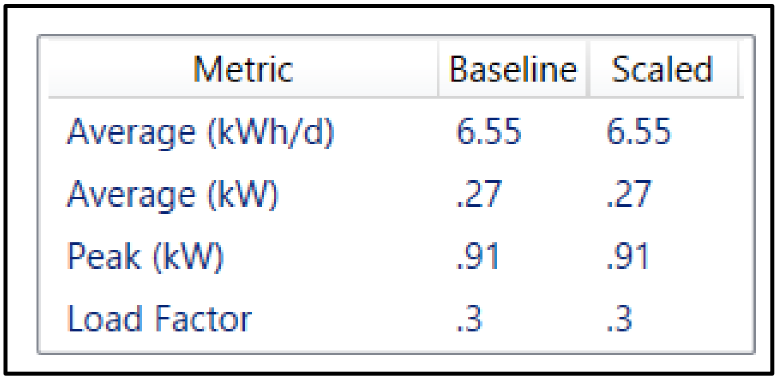
SL	Name of Appliance	Energy Consumption
		kWh/day
01	Light	0.760
02	Ceiling Fan	0.150
03	Table Fan	0.120
04	Laptop	2.355
05	Mobile Charger	0.402
	Total	3.787

Table 3.6 Summer Energy Consumption for Weekdays (November to February)

SL	Name of Appliance	Energy Consumption
		kWh/day
01	Light	0.680
02	Ceiling Fan	0.300
03	Table Fan	0.240
04	Laptop	2.355
05	Mobile Charger	0.402
	Total	3.977

3.3 Load Modeling in HOMER Pro

A thorough grasp of key indicators is essential for effective energy management since it clarifies the nuances of power consumption and use trends. The average daily power use, peak load, and load factor are three such indicators that each offer different perspectives on energy use. In this context, the average daily power consumption is 6.55 kilowatt-hours (kWh), which is the measurement of energy utilised during a 24-hour period. This measure acts as a fundamental baseline and provides an overview of the daily energy requirements for various appliances, gadgets, and lighting systems. Concurrently, the peak load, which reaches 0.91 kW, symbolises the peak in power consumption and often happens when several devices are using power at once. This crucial number is essential for electrical system sizing since it guarantees that they can efficiently meet the greatest power requirements without overflowing or experiencing interruptions. Furthermore, by contrasting the average load with the peak load, the load factor, at 0.3, emphasises how efficiently energy is consumed. This indicator clarifies the reliability and efficiency of the use of the available power capacity. These measurements add up to a thorough understanding of energy consumption trends that allows for resource allocation and strategic energy planning. Through the use of "fig. 3.2," which offers a graphical depiction that improves understanding of the correlations and consequences of various measures, it is possible to visualise how they interact.



Metric	Baseline	Scaled
Average (kWh/d)	6.55	6.55
Average (kW)	.27	.27
Peak (kW)	.91	.91
Load Factor	.3	.3

Fig. 3.2 Baseline and Scaled Data

Seasonal profile and Daily profile can be illustrated in “Fig. 3.3” and “Fig. 3.4,” respectively.

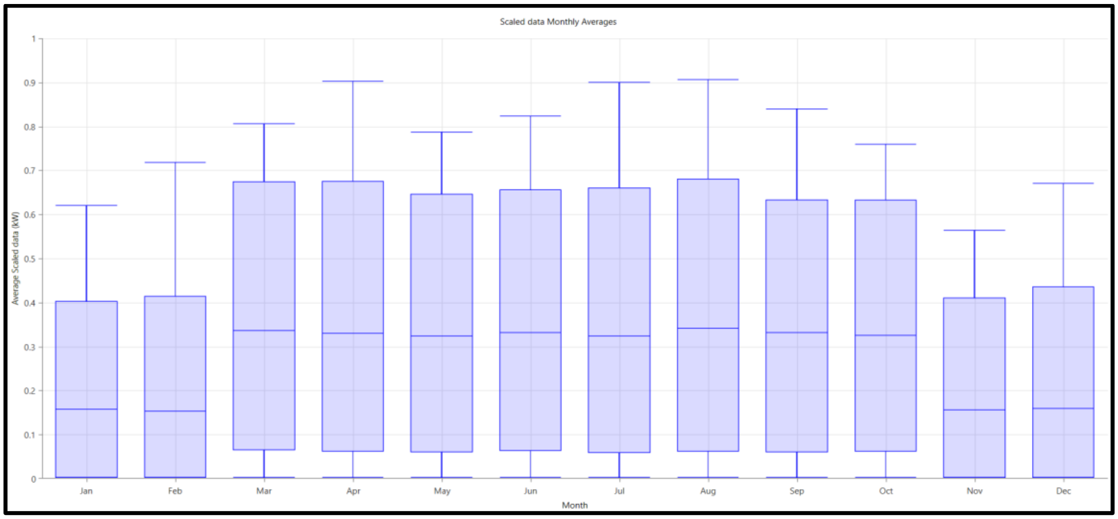


Fig. 3.3 Seasonal Profile

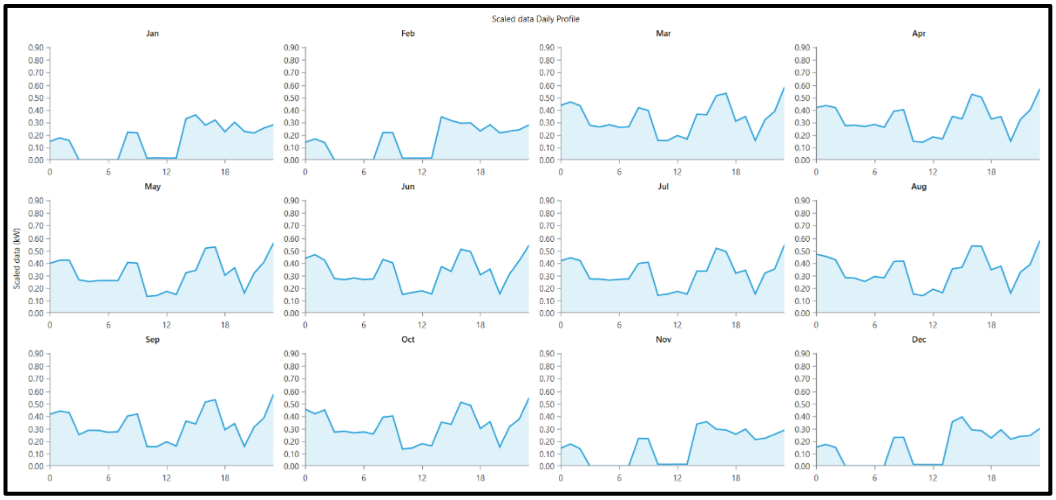


Fig. 3.4 Daily Profile

CHAPTER 4

COMPONENTS DETAILS

4.1 Solar Photovoltaic (PV) Panel

The following table 4.1, illustrates techno-economic details of the solar PV panel. These details provide a comprehensive overview of the flat plate photovoltaic module and its associated costs, performance, and characteristics. It's important to note that solar technology is continually evolving, so factors such as costs and lifetimes might change over time. The comprehensive overview delves into each point, emphasizing the significance of techno-economic considerations in the realm of solar PV panels. It underscores the evolving nature of solar technology, a factor that necessitates adaptability and continuous evaluation in the pursuit of optimal energy generation solutions.

Table 4.1 Techno-Economic Parameters of PV Array [22]

Photovoltaic Module	
	Value
Module Type	Flat Plate
Capital Cost	86,032 BDT/kW
Replacement Cost	86,032 BDT/kW
O & M Cost	1,075 BDT/kW
Lifetime	25 years
Derating Factor	85%
Tracking System	No

The table can be described below:

01. Module Type: The meticulous evaluation of solar photovoltaic (PV) options led us to consider flat plate PV panels. A flat plate photovoltaic module represents a distinguished variety of solar panel design, characterized by a structure that houses solar cells within a typically rectangular, flat configuration. This design showcases solar cells embedded seamlessly within the module's surface, which efficiently captures sunlight and transforms it into electricity through the photovoltaic effect. Notably, these flat plate modules are extensively employed across a spectrum of applications, spanning from residential households to commercial establishments and even industrial enterprises. Their versatility, simplicity, and adaptability make them a preferred choice for harnessing solar energy across diverse contexts.

02. Capital Cost: The capital cost, a fundamental aspect of solar deployment, stands as the initial investment requisite for the establishment of one kilowatt (kW) of solar power generation capacity

using flat plate photovoltaic modules. In this particular case, the capital cost is calculated at 86,032 Bangladeshi Taka (BDT) per kW. This comprehensive value encompasses an array of crucial expenses, including the procurement of the photovoltaic modules themselves, the intricate process of installation, the intricate wiring infrastructure, the robust mounting systems required for stability, and an array of associated components essential for the system's optimal operation. The capital cost underlines the financial commitment necessary to materialize solar energy generation.

03. Replacement Cost: The replacement cost emerges as a pivotal financial consideration, particularly as the operational life of the flat plate photovoltaic module approaches its conclusion or its efficiency undergoes a substantial reduction. This cost, quantified at 86,032 BDT per kW, embodies the anticipated expenditure linked to the eventual replacement or upgrading of the module. Notably, the significance of this cost rests in its role in securing the ongoing functionality and energy output of the solar installation. Accounting for replacement costs becomes an essential aspect of long-term planning to ensure that the system continues to contribute efficiently to the energy requirements.

04. Operation and Maintenance Cost: The continuum of solar energy generation is intrinsically tied to the domain of Operation and Maintenance (O&M) costs. These costs encapsulate the financial resources allocated for sustaining the optimal functionality and effectiveness of the solar system over time. This inclusive category comprises a range of activities, from the periodic cleaning of panels to systematic inspections, repairs, and diverse maintenance tasks. The specified cost of 1,075 BDT per panel per year reflects the anticipated annual expenditure dedicated to maintaining the performance and longevity of each individual solar panel. Effective management of O&M costs is indispensable for safeguarding the system's consistent energy production.

05. Lifetime: The projected lifespan of a flat plate photovoltaic module is emblematic of its operational duration during which it is expected to perform at its peak, consistently generating electricity. The specified lifetime of 25 years underscores the calculated period within which the module's efficiency remains intact and contributes to energy production. This timeframe serves as a reference point for system planning, maintenance scheduling, and potential upgrade decisions, with the understanding that after a decade of operation, efficiency may decrease or replacement might become necessary.

06. Derating Factor: The derating factor, a metric of paramount significance, encapsulates the concept of the module's performance degradation throughout its operational lifecycle. An 85% derating factor symbolizes that, by the culmination of the module's designated lifespan, its capacity to produce energy will be reduced to 85% of its original potential. This essential factor is often integrated into calculations to ascertain the solar system's anticipated energy output across the long term. By acknowledging the derating factor, estimations become more accurate, reflective of the module's evolving performance over time.

07. Tracking System: A tracking system epitomizes innovation within solar energy technology. This advanced mechanism empowers solar panels to follow the sun's trajectory as it traverses the sky during the course of the day. This dynamic alignment optimizes the panels' exposure to sunlight, thereby amplifying energy generation. The "No" designation in this context signifies the

absence of a tracking system within the flat plate photovoltaic modules. While fixed installations (devoid of tracking) are renowned for their simplicity in installation and maintenance, it's crucial to recognize that such installations might not attain the same energy yield as tracking systems. This distinction is particularly notable in regions characterized by fluctuating solar angles, highlighting the importance of strategic installation choices.

4.2 Inverter

In the provided table 4.2, we present a detailed exploration of the key attributes that shape the "On-grid Pure Sine" inverter. An inverter serves as a crucial component, transforming the direct current (DC) generated by solar panels into alternating current (AC), a form of energy suitable for powering structures, businesses, and integrating with the grid. An in-depth comprehension of the intricate specifications of an inverter holds the key to achieving efficient energy conversion and optimizing the overall performance of the solar energy system.

Table 4.2 Techno-Economic Parameters of Inverter [22]

Inverter	
Parameter	Value
Type	On-grid Pure Sine
Capital Cost	30,111 BDT/kW
Replacement Cost	30,111 BDT/kW
O & M Cost	430 BDT/kW
Lifetime	18 years
Efficiency	90 %
Rectifier Capacity	95 %
Rectifier Efficiency	85 %

The table can be described below:

01. Type: The inverter referenced in the table falls under the category of "On-grid Pure Sine." This classification highlights an inverter that is seamlessly aligned with the grid's operations. Such an on-grid inverter demonstrates its capacity to synchronize with the utility grid, allowing the surplus energy generated by the solar system to be channeled into the grid. The term "Pure Sine" is significant as it denotes the inverter's capacity to produce an alternating current (AC) waveform that impeccably replicates the smooth, predictable waveform characteristic of grid-supplied electricity. This quality renders the inverter particularly suited to operate harmoniously with delicate electronics and appliances.

02. Capital Cost: Embedded within the capital cost of the "On-grid Pure Sine" inverter is the initial investment associated with the acquisition and installation of one kilowatt (kW) of inverter

capacity. This cost, standing at 30,111 Bangladeshi Taka (BDT) per kW, encapsulates not only the procurement expenses for the inverter unit but also the intricacies of seamlessly integrating it into the solar energy system. The capital investment assumes paramount importance in facilitating the efficient conversion of DC power, generated by solar panels, into usable AC power.

03. Replacement Cost: The concept of replacement cost revolves around the projected expenditure required for replacing or upgrading an inverter as its operational lifecycle reaches its conclusion or its efficacy experiences a substantial decline. With a reported replacement cost of 30,111 BDT per kW, the inherent challenges in sustaining an effective energy conversion system become apparent. This cost consideration underscores the necessity of prudent planning to ensure the inverter's continued role within the energy generation framework.

04. Operation and Maintenance Costs (O&M): O&M costs stand as the continuous financial commitments directed toward maintaining the inverter's optimal functionality and operational efficiency. These expenses encompass a spectrum of activities, encompassing routine maintenance, swift interventions, as well as comprehensive inspections. The specified O&M cost of 430 BDT per kW denotes the projected annual expenses designated to uphold the inverter's peak performance, ensuring consistent energy conversion and system integrity.

05. Lifetime: The projected duration during which an inverter is anticipated to operate efficiently and effectively is encapsulated by its lifetime. With a recommended lifetime of 18 years, this metric serves as a benchmark for assessing the inverter's durability and formulating strategies for future replacements or upgrades. A properly maintained inverter is a cornerstone of reliable energy conversion and streamlined integration with the grid.

06. Efficiency: Efficiency stands as a pivotal parameter that gauges an inverter's efficacy in converting solar panel-generated DC power into usable AC electricity. An inverter boasting a 90% efficiency rating signifies its capacity to convert 90% of the incoming DC power into AC power, with only a minor fraction dissipated as heat during the conversion process. Higher efficiency values denote heightened energy conversion efficacy.

07. Rectifier Capacity: The term "Rectifier Capacity" denotes an inverter's competence in converting AC electricity back into DC power. This aspect becomes crucial when surplus energy needs to be channeled back into the grid. An inverter endowed with a rectifier capacity of 95% signifies its ability to rectify 95% of incoming AC power into usable DC electricity for seamless grid integration.

08. Efficiency of Rectifiers: The rectifier efficiency is a reflection of the rectification process through which AC power is adeptly transformed into DC power. An inverter demonstrating an 85% efficiency in this rectification procedure implies its adeptness in retaining 85% of the input AC power as usable DC power, with the remaining 15% being released as heat.

4.3 Battery

The following table 4.3, elucidates key technical and financial attributes associated with the "Lead Acid" battery. Batteries constitute a vital component in energy storage systems, holding the capacity to store and release electricity as required. Understanding the specifications and characteristics of a battery is pivotal in optimizing its utilization and integrating it effectively within the broader energy ecosystem.

Table 4.3 Techno-Economic Parameters of Battery [23]

Battery	
Parameter	Value
Type	Lead Acid
Capital Cost	27,208 BDT
Replacement Cost	27,208 BDT
O & M Cost	1,075 BDT/Year
Nominal Voltage	12 Volt
Nominal Capacity	1.7 kWh
Round-trip Efficiency	85%
Maximum Charge Current	21.8 A
Maximum Discharge Current	230 A

The table can be described below:

01. Type: The battery type denoted in the table is the "Lead Acid" battery. Lead-acid batteries are a traditional and widely used type of rechargeable battery. They consist of lead dioxide as the positive electrode and sponge lead as the negative electrode, with an electrolyte solution of sulfuric acid. They are known for their robustness, cost-effectiveness, and versatility in various applications.

02. Capital Cost: The capital cost signifies the initial investment required to acquire the battery. For the "Lead Acid" battery, this cost is set at 27,208 Bangladeshi Taka (BDT). This expense covers the procurement of the battery unit itself, reflecting the upfront financial commitment necessary to integrate energy storage within the system.

03. Replacement Cost: The replacement cost pertains to the projected expenditure for replacing or upgrading the battery unit, typically when its operational life nears its end or its performance declines. With the specified replacement cost of 27,208 BDT, the financial considerations of sustaining a reliable energy storage system become evident. Prudent planning for replacement is essential to maintain consistent energy availability.

04. Operation and Maintenance Costs (O&M): Operation and Maintenance (O&M) costs constitute ongoing expenditures aimed at ensuring the battery's operational efficiency and longevity. These expenses encompass various activities, including regular inspections, upkeep,

and minor repairs. The stipulated cost of 1,075 BDT per year represents the estimated yearly expenses required to uphold the battery's optimal performance.

05. Nominal Voltage: The nominal voltage represents the average voltage level of the battery during its normal operation. In the case of the "Lead Acid" battery, the nominal voltage is maintained at 12 volts. This voltage level serves as a crucial reference for designing systems that involve the use of this battery, ensuring compatibility and seamless integration.

06. Nominal Capacity: The nominal capacity signifies the maximum amount of energy that the battery is capable of storing and delivering. For the "Lead Acid" battery, the nominal capacity is quantified at 1.7 kilowatt-hours (kWh). This capacity parameter serves as a foundational metric in determining the battery's ability to fulfill energy requirements.

07. Round-trip Efficiency: Round-trip efficiency quantifies the efficiency of energy storage and retrieval within the battery system. An 85% round-trip efficiency indicates that when energy is stored and subsequently retrieved from the battery, approximately 85% of the stored energy is effectively utilized, while a minor fraction is lost due to inefficiencies in the charging and discharging process.

08. Maximum Charge Current: The maximum charge current signifies the highest rate at which the battery can be charged. In this context, the "Lead Acid" battery can be charged at a maximum rate of 21.8 amperes (A). This parameter is essential for designing charging systems that optimize the battery's performance and longevity.

09. Maximum Discharge Current: The maximum discharge current denotes the highest rate at which the battery can release energy. For the "Lead Acid" battery, the maximum discharge current is set at 230 amperes (A). This parameter is crucial for applications that require high-power energy release.

4.4 Grid

A detailed breakdown of consumer groups, unit consumption ranges, and associated energy prices in Bangladeshi Taka (BDT) per kilowatt-hour (kWh) may be found in table 4.4 below. The pricing structure for using electricity is defined by these categories and rates, with different fees depending on how much energy is used.

Table 4.4 Tariff Rate of Bangladesh Power Development Board [24]

Consumer Type	Unit Range	Energy Rate	Demand Rate
		(BDT/kWh)	(BDT/kW/month)
Life Line	0-50	4.35	35.00
First Class	0-75	4.85	
Second Class	**76-200**	**6.63**	
Third Class	201-300	6.95	
Fourth Class	301-400	7.34	

Fifth Class	401-600	11.51	
Sixth Class	600-above	13.26	

The table can be described below:

01. Life Line: People or families with a modest energy consumption pattern fall under the "Life Line" consumer group. This group, which has a unit range of 0 to 50 kWh, includes those who use power sparingly. The cost associated with each kWh of power used is 4.35 BDT/kWh, or the energy rate. This discounted pricing aims to give economical access to power for necessities.

02. First Class: Consumers that fall into the "First Class" group have energy usage between 0 and 75 kWh per month. The utilisation is somewhat greater due to this wider range than the "Life Line" category. The "First Class" segment's energy cost is 4.85 BDT/kWh. This price reflects a competitive pricing model designed to support increased energy demand while keeping costs manageable.

03. Second Class: The unit consumption range for the "Second Class" consumer category is from 76 to 200 kWh. Moderate energy consumers, such as modest houses or enterprises, fall within this group. 6.63 BDT/kWh is the energy rate for the "Second Class" section. This rate indicates a greater charge per unit in recognition of the increased energy use.

04. Third Class: The "Third Class" customer group includes kWh sizes between 201 and 300. This category is intended for users who regularly utilise a substantial quantity of power, such as bigger households or smaller businesses. The "Third Class" segment's energy rate is 6.95 BDT/kWh, which acknowledges the greater pattern of energy usage.

05. Fourth Class: Customers in the "Fourth Class" group use between 301 and 400 kWh of power per month. Larger homes or medium-sized businesses may fall into this group. 7.34 BDT/kWh is the energy rate for the "Fourth Class" category. This rate modifies the fee in accordance with the more significant energy use.

06. Fifth Class: People who use between 401 and 600 kWh of electricity fall under the "Fifth Class" consumer group. Medium-sized companies or other places with significant energy requirements may fall into this group. The "Fifth Class" segment's energy rate is 11.51 BDT/kWh. This rate has significantly increased as a result of the rising degree of energy use.

07. Sixth Class: Consumers that spend 600 kWh or more of energy are considered to be in the "Sixth Class" group. Larger enterprises, industries, or institutions with high energy demands may fall under this category. The expense of delivering power to large numbers of customers is reflected in the energy tariff for the "Sixth Class" segment, which is 13.26 BDT/kWh.

08. Demand Rate: An important component of energy billing that relates to the cost associated with the highest quantity of power a consumer takes from the grid over a given time period is the statement "Demand rate of our consumer is 35 BDT/kW/month". Understanding this rate is crucial for correct invoicing and effective energy management, and it is especially pertinent in commercial and industrial environments where power demand might fluctuate.

CHAPTER 5

DESIGN, SIMULATION AND OPTIMIZATION

5.1 System Architecture

Solar photovoltaic (PV) technology dominates this integrated system, integrating with an inverter, a load of electricity, and the traditional grid. The solar PV array collects the sun's limitless energy and converts it into clean, sustainable electricity. This produced power enters the inverter, where it is changed from direct current (DC) to alternating current (AC), enabling it to meet the needs of the electric load. The converted energy is subsequently used by the electric load, which might include a wide range of devices and appliances, to meet its operating requirements. The unique feature of this system is how it interacts with the grid dynamically: any excess energy generated by the solar panels may be recycled back into the system, therefore lowering the need for non-renewable resources. Similarly, the grid offers a dependable source of power to augment the load during times of poor solar output. This integrated system demonstrates the peaceful coexistence of renewable energy production, effective energy conversion, and uninterruptible power supply. It also advances the greater objective of a more robust and environmentally friendly energy ecosystem. The designed system can be illustrated in "fig. 5.1."

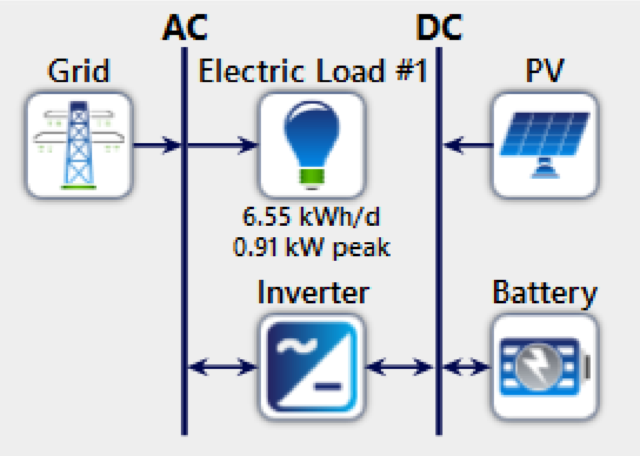
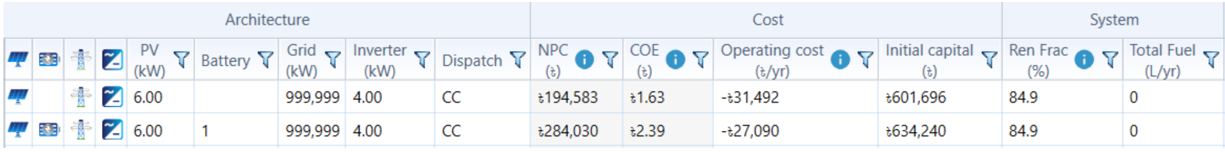


Fig. 5.1 System Architecture

5.2 Simulation

We have fed HOMER Pro all the data and obtained the following results in "fig. 5.2."



Architecture									Cost				System	
				PV (kW)	Battery	Grid (kW)	Inverter (kW)	Dispatch	NPC (৳)	COE (৳)	Operating cost (৳/yr)	Initial capital (৳)	Ren Frac (%)	Total Fuel (L/yr)
				6.00		999,999	4.00	CC	৳194,583	৳1.63	-৳31,492	৳601,696	84.9	0
				6.00	1	999,999	4.00	CC	৳284,030	৳2.39	-৳27,090	৳634,240	84.9	0

Fig. 5.2 Simulation Results in HOMER Pro

Within the realm of meticulous engineering and energy optimization, the most finely tuned dimensions for this system have emerged, presenting a triumphant trifecta of sustainable power.

The crowning jewel is a robust assembly of 6 kW solar photovoltaic (PV) panels, which stand as sentinels, dutifully capturing the sun's radiance and converting it into a stream of clean, renewable energy. This elegant dance of innovation extends its embrace to a 4 kW inverter, an ingenious orchestrator of energy's transformation from its sun-soaked origin to a form that powers our modern lives. This dynamic duo forms a seamless bridge between the potential of sunlight and the functional demands of our technological age.

But the symphony doesn't conclude here; it introduces a new instrumental player in the form of a singular battery, a compact reservoir of power with a voltage of 12V and an impressive capacity of 1.7 kWh. This battery, an embodiment of energy storage innovation, holds within its unassuming exterior the capability to store surplus energy generated during the sun's zenith and gracefully release it when the world turns dark. This dance of charging and discharging ensures a constant rhythm of power supply, providing a harmonious balance between energy creation and consumption.

Uniting these components transcends mere engineering; it signifies the culmination of human ingenuity in service to both our immediate needs and the longevity of our planet. As the 6 kW PV panels bask in the sun's embrace, the 4 kW inverter conducts its transformative alchemy, and the battery stands ready as a guardian of energy continuity, we witness a manifestation of sustainable synergy. This optimized trio, founded upon meticulous research and precision, shines as a beacon guiding us towards a future where our energy aspirations are met in a way that echoes nature's own elegance.

5.3 Optimization

We have two grid-connected systems to analyze, one is without battery and another one is with battery. We will discuss them, separately.

5.3.1 Grid-Connected System without any Energy Storage

At the nexus of modern energy dynamics, the grid-connected photovoltaic (PV) system emerges as a transformative force, intertwining environmental responsibility with financial acumen. A visionary venture such as this commences with an upfront investment, a strategic commitment of BDT 601,696. This capital infusion stands as a pivotal down payment on a future propelled by sustainable energy practices. It lays the cornerstone for a system where sunlight's boundless potential converges with innovative technology to illuminate not just bulbs, but also the path to a greener tomorrow.

Central to the narrative is the renewable energy fraction (REF), a metric that quantifies the system's potency in harnessing renewable sources. A resounding resonance of 84.9% showcases the PV system's prowess in capturing the sun's energy, reducing dependency on conventional power grids. This emblematic statistic encapsulates a future-forward approach, where clean energy sources intertwine with everyday life, forging a sustainable energy symbiosis.

The economic and environmental realms harmonize seamlessly, as evidenced by the cost of energy (COE) index. A mere BDT 1.63 for every unit of energy produced manifests as both an ecological victory and a testament to fiscal sensibility. This figure redefines energy economics, showcasing the feasibility of integrating sustainable energy sources into the conventional grid.

In the intricate mosaic of financial investments, operational efficiency, renewable resonance, and energy cost innovation, the grid-connected PV system transcends the realm of technology. It becomes an emblem of progress, symbolizing a world where electricity surges with the vitality of the sun, where energy expenditures mirror environmental virtues, and where the marriage of technology and conscientiousness shapes a future that is both enlightened and sustainable.

5.3.2 Grid-Connected System with Energy Storage

Embedded within the dynamic fabric of modern energy landscapes, the grid-connected photovoltaic (PV) system adorned with a battery emerges as a transformative cornerstone, fusing environmental conscientiousness with fiscal prudence. Embarking on this visionary expedition necessitates an initial investment of BDT 634,240. This financial foundation serves as a catalyst, propelling the integration of clean energy into the heart of conventional power structures. The capital commitment embodies the foresight that converts sunlight into a form of currency with lasting dividends, securing both our future and the planet we call home.

Within this meticulously woven tapestry, the renewable energy fraction (REF) emerges as a luminous thread, woven seamlessly at 84.9%. This fraction illuminates the capacity of the PV system and battery to capture and store the sun's radiance, crafting a sustainable energy ecosystem that stands as a testament to human ingenuity in harmony with nature's elegance.

The economic prism through which this system is viewed reflects a reimagining of energy worth. The cost of energy (COE) index, standing at BDT 2.39, signifies a value proposition that transcends mere numbers. It encapsulates a vision where energy's cost isn't solely defined in currency units but also in environmental dividends reaped through reduced carbon footprints.

In this multidimensional symphony of capital infusion, operational ingenuity, renewable vitality, and cost innovation, the grid-connected PV system with a battery transcends its physical form. It becomes a narrative of progress, an ode to a future where energy ceaselessly flows, where financial and environmental harmony are no longer mere ideals but tangible realities, and where the fusion of technology and stewardship redefines the very essence of power.

5.4 Selection

By considering the present load shedding condition, we have chosen to select the system with battery. For the grid-only system and the system we developed, the levelized cost of electricity (COE) was ৳2.39 and ৳6.63, respectively. This formula may be used to determine the difference:

$$\%DifferenceofCOE = \frac{GridonlySystem - ProposedSystem}{GridonlySystem} \times 100\% (6.1)$$

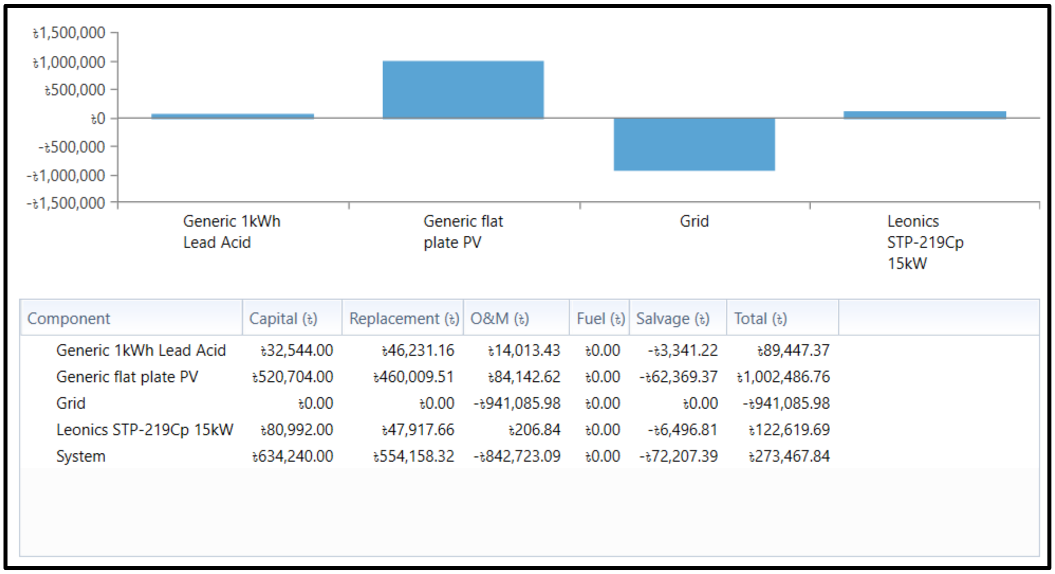
With our designed system we can reduce the COE by 64%.

CHAPTER 6

PROPOSED SYSTEM

6.1 Cost Summary of the System

"Fig. 6.1" shows the system's cost breakdown, with the PV panels coming in at the top of the list. The grid is kept apart from the other components since it provides backup energy and is not cost-dependent. The decision-making process for investments in renewable energy is aided by this graphical depiction, which provides insightful information about the distribution of financial resources throughout the system.



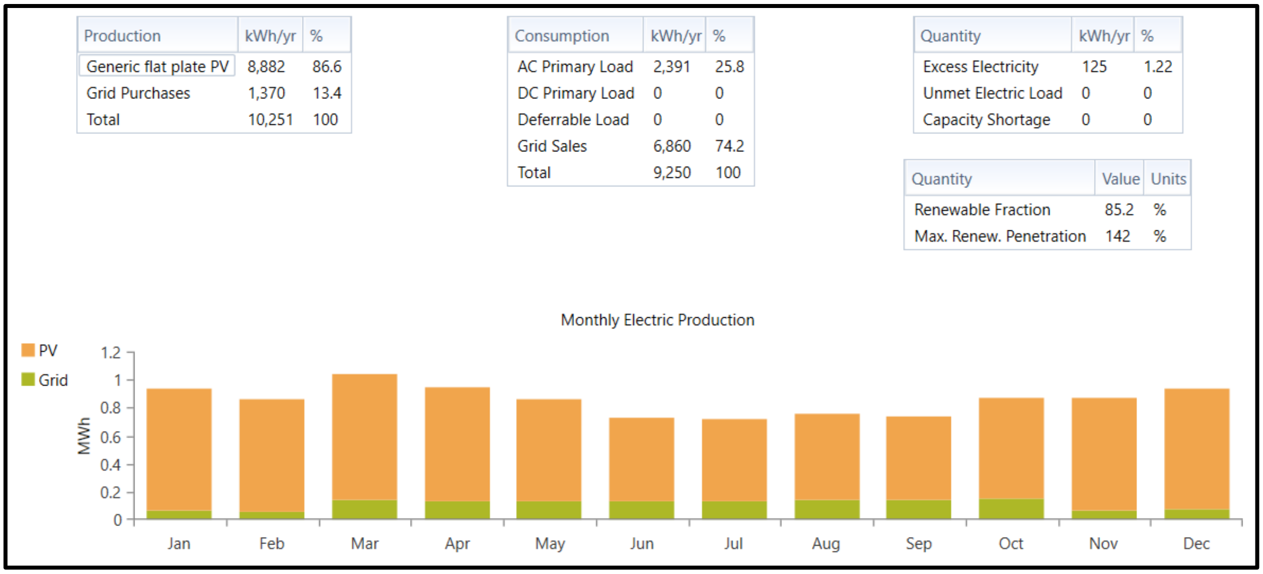
Component	Capital (৳)	Replacement (৳)	O&M (৳)	Fuel (৳)	Salvage (৳)	Total (৳)
Generic 1kWh Lead Acid	৳32,544.00	৳46,231.16	৳14,013.43	৳0.00	-৳3,341.22	৳89,447.37
Generic flat plate PV	৳520,704.00	৳460,009.51	৳84,142.62	৳0.00	-৳62,369.37	৳1,002,486.76
Grid	৳0.00	৳0.00	-৳941,085.98	৳0.00	৳0.00	-৳941,085.98
Leonics STP-219Cp 15kW	৳80,992.00	৳47,917.66	৳206.84	৳0.00	-৳6,496.81	৳122,619.69
System	৳634,240.00	৳554,158.32	-৳842,723.09	৳0.00	-৳72,207.39	৳273,467.84

Fig. 6.1 Cash Flow Summary (Component Type)

6.2 Electric Production from the System

The average monthly generation of electricity is depicted in the diagram referred to as "Fig. 6.3". The bar graph makes it clear that photovoltaic (PV) and biomass energy sources had a significant influence during the whole year. However, there were several months where there was a persistent need on grid energy, punctuating the system's normally strong self-sufficiency.

We've engineered a cutting-edge grid-connected PV system that boasts remarkable efficiency. This innovative system demonstrates its prowess by generating a substantial 8882 kWh, which accounts for an impressive 86.6% of the total electricity produced. A testament to its ingenuity, our PV system remains notably eco-conscious, drawing a mere 1370 kWh (13.4%) of electricity from the grid.



Production	kWh/yr	%
Generic flat plate PV	8,882	86.6
Grid Purchases	1,370	13.4
Total	10,251	100

Consumption	kWh/yr	%
AC Primary Load	2,391	25.8
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	6,860	74.2
Total	9,250	100

Quantity	kWh/yr	%
Excess Electricity	125	1.22
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	85.2	%
Max. Renew. Penetration	142	%

Fig. 6.2 Monthly Average Electric Production

A defining feature of our endeavor lies in the consummate synergy between our PV system and the electricity demand of our operations. The diligent interplay ensures that our load embraces sustainability, consuming 2391 kWh (25.2%) of the generated electricity. This harmonious partnership not only serves our power needs but also underlines our commitment to responsible energy usage.

What truly sets our initiative apart is the dynamic role we play in the larger energy ecosystem. By harnessing the proficiency of our PV system, we have achieved an extraordinary feat – the sale of 6860 kWh (74.2%) of surplus electricity back to the grid. This symbiotic exchange underscores our dedication to renewable energy and positions us as contributors to the grid's stability and environmental equilibrium.

6.3 Profit Calculation

In the realm of energy economics and revenue analysis, a powerful tool emerges in the form of a straightforward yet pivotal formula. This formula unveils the intricate relationship between energy consumption, pricing, and the resultant annual revenue. It serves as a compass guiding us through the intricate labyrinth of energy markets and fiscal projections. With this formula at our disposal, the annual revenue from energy sales or consumption can be accurately ascertained, shedding light on the financial prospects of an energy-based venture.

Let us consider a practical application of this formula within the context of a microgrid system. This microgrid, an autonomous energy entity, stands as a beacon of sustainable energy generation. Annually producing a commendable 8882 kilowatt-hours (kWh) of power, it radiates promise and potential. Leveraging the predictive power of the formula, we embark on estimating the inaugural year's financial horizon.

$$Annualincome = (EnergySold \times EnergyPrice) \qquad (6.1)$$

Harnessing the formula's prowess, we calculate the projected revenue:

$$Annualincome = (8882kWh \times 6.63) \qquad (6.2)$$

At this juncture, anticipation meets calculation as we place our trust in the energy pricing dynamics. And lo, with a calculated energy price, the formula unveils its magic, yielding a figure that resonates in the realm of financial reality:

First Year's Income ≈ 58,888 BDT

In the realm of financial analysis and investment assessment, a series of illuminating formulas serve as guiding beacons, shedding light on the intricate path towards assessing the viability and profitability of a venture. These formulas, akin to keys unlocking the doors of financial insight, enable us to navigate the landscape of capital recovery, payback periods, total revenue, and lifetime profits. Each equation reveals a different facet of the financial journey, helping us decipher the potential gains that await. The initial step in this financial voyage involves the calculation of the first year's capital recovery. This pivotal metric is unveiled through the elegant formula:

$$\%Firstyearcapitalrecovery = \frac{Firstyearincome}{Capital} \times 100\% (6.3)$$

Within this formula, the symbiosis of the first year's income and the capital invested harmoniously intertwines. Through meticulous calculation, a numerical representation emerges, painting the picture of capital recovery. As the numbers converge, the result crystallizes, indicating that a notable 9.28% of the initial capital can be recuperated within the span of a solitary year.

Expanding our vista, we embark on the quest to unveil the elusive payback period – the temporal horizon needed to reclaim the capital invested. This endeavor, simplified yet profound, is illuminated by the equation

$$Paybackperiod = \frac{Capital}{AnnualIncome} (6.4)$$

With focused attention on the interplay between capital and annual income, this formula manifests as a bridge connecting financial outlay and incoming revenue. Delving into the realm of numbers, the calculation unfurls a revelation: the initial investment shall be restored in a period of approximately 11 years, an undeniable testament to the project's promising financial dynamics.

6.4 Environment Analysis

In our relentless pursuit of environmentally conscious energy solutions, it's imperative to grasp the profound impact our choices can have on the world around us. When deriving a single unit of electricity from conventional fossil fuels, several green-house gases (GHG) are unleashed into the atmosphere, perpetuating the cycle of environmental degradation, shown in “table 6.1.”

Table 6.1 Emissions Data [25]

Emissions	Quantity
GHG Gas	Kg/kWh
Carbon dioxide (CO_2)	0.632
Sulphur dioxide (SO_2)	2.740
Nitrogen oxide (NO)	1.340

Since, our system is capable of producing 8882 kWh from renewable energy sources. Therefore, the system is able to reduce the emissions to a great extent, depicted in “table 6.2.”

Table 6.4: Emissions Reduction

Emissions	Reduction
GHG Gas	Tons
Carbon dioxide (CO_2)	5.61
Sulphur dioxide (SO_2)	24.37
Nitrogen oxides (NO)	11.90

Hence, our revolutionary PV system ushers in a new era of sustainability. With the capacity to generate an impressive 8882 kWh of electricity from the boundless energy of the sun, it effectively serves as a bulwark against GHG emissions. This pivotal contribution encapsulates our commitment to fostering a greener, healthier planet for both current and future generations, marking a stride towards a more harmonious coexistence between technological advancement and ecological preservation.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Renewable energy sources have drawn a lot of attention recently as a potential response to the problems of climate change and energy security. Photovoltaic (PV) systems stand out among them because of their propensity to capture solar energy and transform it into electricity. Net-metering, a process that permits surplus energy to be fed back into the grid and lowers users' Cost of Energy (COE), is a critical component of optimizing PV systems. This essay examines the economic, environmental, and practical ramifications of a carefully planned and simulated grid-connected PV system with net-metering and a battery storage option.

Two optimum configurations—a PV system without a battery and a PV system with a battery—are the results of the engineers' work. The former had a 4 kW inverter and an ideal PV capacity of 6 kW. In the later design, a battery string with a 12 V and 1.7 kWh capacity was added as a new element. The outstanding 84.9% renewable energy fraction (REF) for both systems, which measures how much of total energy consumption is provided by renewable sources, demonstrates their effectiveness in utilizing clean energy.

The statistics provide a convincing narrative when it comes to economic viability. The COE of the PV system without a battery was BDT 1.63, whereas the COE of the PV system with battery storage was 2.39. Contrary to expectations, the latter design was chosen despite the COE appearing to be unfavorable because of a crucial factor: the common problem of load shedding. In many locations, load shedding—a scenario in which the amount of electricity supplied to consumers is purposefully reduced—occurs frequently, frequently as a result of inadequate power generating or distribution capacity. In this situation, a PV system with battery storage can successfully reduce the COE by an amazing 64% while reducing the effects of load shedding.

The chosen PV system with battery storage requires a BDT 634,240 initial expenditure. However, this initial investment promises significant returns in terms of energy production. The system is expected to produce 8882 kWh of electricity per year. The load will use 25.8% of the power generated, directly benefiting the consumer. Additionally, a sizable 74.2% of the excess energy can be fed back into the grid, lowering end users' energy costs while simultaneously improving the grid's general stability and reliability.

The payback period of the PV system, a critical indicator of how long it will take for the system's savings to cover the initial investment, serves as a reminder of its financial viability. The payback period in this instance is 11 years, demonstrating a steady but progressive return on the investment. A remarkable 9.28% of the initial investment can be returned within the first year, proving the system's effectiveness in providing quick advantages.

The PV system with battery storage makes a substantial contribution to environmental sustainability outside of the financial sphere. The system can annually offset 41.88 tons of GHG emissions during operation, thereby lowering its carbon footprint. This environmental advantage highlights the system's contribution to a cleaner and greener energy landscape and fits in perfectly with international efforts to address climate change.

A grid-connected PV system with battery storage that has been painstakingly planned and simulated is a monument to the complex interplay between economic feasibility, environmental effect, and practicality. Even though a battery storage solution appears to have a higher COE, its resistance to load shedding makes it a game-changer. The system demonstrates its effectiveness in utilizing renewable energy with an amazing REF of 84.9%. The system's all-encompassing advantages are highlighted by the combination of quick returns, progressive payback, and significant carbon offset. This improved PV system is a prime example of the route toward a cleaner and safer energy future in a world that is becoming more and more concerned with sustainable solutions.

7.2 Challenges and Future Recommendations

The shift towards renewable energy sources has gained widespread recognition as a vital stride towards a more sustainable and environmentally conscious future. Among the various renewable options, photovoltaic (PV) systems have garnered significant attention due to their capacity to convert sunlight into electricity. Despite the widely acknowledged benefits of PV systems, a notable obstacle remains: the initial investment required for installation. This discourse investigates the obstacles encountered by middle-class families in embracing PV systems due to the considerable upfront expenses, and proposes potential strategies to enhance the accessibility of solar energy for this demographic.

The dedicated efforts of engineers in designing and simulating a grid-connected PV system integrated with battery storage have yielded promising outcomes. These outcomes underline the viability of such systems in terms of energy production, load reduction, and environmental influence. However, the economic aspect cannot be disregarded. The projected initial cost of BDT 634,240 presents a substantial challenge for middle-class families, who frequently contend with financial constraints.

In a reality where day-to-day expenditures and fundamental necessities often consume a significant portion of income, a substantial upfront investment can seem overwhelming. Middle-class households constantly seek to strike a balance between providing for their loved ones and making eco-friendly choices. While the long-term advantages of decreased energy bills and a reduced carbon footprint hold appeal, the immediate financial strain can act as a deterrent to their adoption of solar energy.

Given these challenges, it is imperative to explore mechanisms that can facilitate the affordability of PV systems for middle-class families. Government incentives and subsidies play a pivotal role in this context. Through providing financial aid or tax incentives for PV installations, governments can effectively alleviate the financial burden on families. Such incentives not only render the initial investment more manageable but also advance the broader objective of transitioning towards renewable energy on a national scale.

Financial institutions also contribute to democratizing solar energy. Tailored loan products featuring favorable interest rates for PV system installations can offer families a means to invest in solar energy without bearing the entire upfront cost. These loans can be structured in a manner that ensures monthly repayment amounts are within the families' existing budget.

Furthermore, the concept of communal or group solar initiatives presents a compelling solution. Families can combine their resources to collectively invest in a larger PV system, thereby sharing the benefits of reduced energy costs and diminished carbon emissions. This approach not only distributes the financial burden but also fosters a sense of community engagement and responsibility towards the environment.

In conclusion, while the feasibility of grid-connected PV systems integrated with battery storage is evident, the challenge lies in making these systems attainable for middle-class families. The considerable initial capital required can pose a hindrance, particularly given the weight of everyday financial obligations. Government incentives, collaboration with financial institutions, and community-driven initiatives emerge as potential strategies to address this challenge. By tackling the financial barriers, society can work towards not only encouraging the adoption of renewable energy but also ensuring that the advantages of solar power are accessible to a wider cross-section of the population. The voyage towards a sustainable future should be all-encompassing, encompassing every societal segment and empowering them to contribute to a more environmentally friendly planet.

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