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A Study on Hybrid Power Plant (Solar & Biomass)

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Abstract

We have designed an on-grid hybrid power plant that combines solar and biomass energy sources. The solar plant has a capacity of 6 MW, and the biomass plant has a capacity of 2 MW. The hybrid solar-biomass power plant is still a recent renewable technology. It is an ongoing investigation that not only proposes dispatchable power generation but also benefits from having a flexible input source, including solar and bioenergy. We aimed to successfully design a hybrid project using proper analysis, to reduce the cost of power generation through a grid-connected hybrid system, while also reducing greenhouse gas emissions. We used PVsyst software to simulate the solar plant and created the PV mounting structure and Single Line Diagram (SLD) using AutoCAD software. We have used Microsoft Excel software to carry out the cost analysis. We also calculated how much biomass waste and gas the biomass plant will need. We have been able to successfully design our hybrid power plant and, at the same time, reduce the power generation cost comparatively. The hybrid system design has made it possible to ensure the most convenient arrangement of electricity.

Keywords: AutoCAD Diagram, Lower Per Unit (kWh) Cost, PVsyst Simulation, Reduced CO2 Emission, Solar PV with Biomass Hybrid System.

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Introduction

The hybrid solar-biomass power plant is still a recent renewable technology and ongoing investigation, which not only proposes a dispatchable power generation but also benefits from having a flexible input source, including solar and bioenergy (Mohaghegh et.al., 2021). In the present scenario use of a diesel generator (DG) is not a very effective alternative for power generation due to several issues like movement in fuel price, fuel transportation issues, and high

running expenditure. Furthermore, diminution of the conventional resources (fossil fuel) and environmental issues, renewable energy is a better alternative for power generation and it also prevents pollution emissions (Sawle et.al., 2017). In 2020, the total capability of solar power in the world was 773.20 GW. By 2050, solar power generation will be the largest among renewable energy sources and 85 percent of the total global electricity market will come from renewable energy sources. According to the data of 2022, about 4 to 6.50 kilowatts of solar energy is received per square meter per day in Bangladesh. If this energy is harnessed, half of the total electricity demand can be met by solar power. It is achievable to fulfill the energy requirements of all the people of the world with the quantity of solar energy that arrives on the earth. However, due to the low density of this energy on earth, it is still not profitable to use this energy on an enormous scale. Biomass is an organic renewable energy source. Biomass is available from various sources such as agricultural activities, forest resources, organic waste, etc. The popularity of biomass as a source of renewable energy is expanding day by day. According to 2022 data, biomass meets a total of 10 percent of the world's energy demand. Ethiopia, Congo, Tanzania, and Nigeria produce the largest share of total energy from biomass. Bangladesh is a developing country in southern Asia with 152 million residents.

In recent years, fast economic development, and increasing industrialization and development have improved the country’s demand for electricity (Ahsan-Uz-Zaman et.al., 2018). Renewable energy resources are environment pleasant, exhaustive, and efficiently available energy sources in nature. They contribute nearly 13.5% of the global energy market. Bangladesh can only provide electricity access to 62% of the total population including renewable energy usage (Bhatt et.al., 2015). A comparative analysis demonstrates that instead of building a solar or biomass power plant separately, installing a hybrid power plant in combination significantly decreases electricity consumption and environmental impact. So, we will design a hybrid power plant (solar and biomass) and also investigate the cost of setting up the power plant and the annual electricity consumption to show how much it will decrease financially and how much it will be beneficial for the environment.

India boasts a charming resource of solar energy. There are about 250-300 sunshine days yearly with ordinary solar radiation of 200 MW/km^2. Each year, India produces between 450 and 500 million tons of biomass. Biomass currently accounts for 32 percent of total primary energy use in the country. The power generated by biomass in India is estimated to be over 18000 MW. The biomass scope is defined as high as 50000 MW. (Ghosh et.al., 2021) China has great solar energy resources due to its broad areas with affluent solar radiation. The annual received solar energy is 1.7×10^{12} on the whole land surface in China. The annual surface absorption of solar resources is as much as 280 periods the total coal reserves in China, which demonstrates that the enormous solar resource is a profitable alternative to renewable energy for energy transformation. According to the Solar Energy Resources Center of China Meteorological Administration, the average radiation in China is 1492.6 kWh/m^2 yearly, with over 2000 sunshine hours. However, the received solar radiation is not evenly distributed and is greatly diverse across the entire country. (Jia et.al., 2020) Biomass resources are very rich in China. At present, more than 1300 biomass power plants have been put into operation. The installed biomass capacity reached 29,520 MW and the power generation reached 13,260 GWh in 2020. (Guo et.al., 2022) Pakistan gets a longer time duration of sunlight, ranging from 8 to 10 hours a day. The annual equivalents of 151,014 kWh of solar radiation may be created up to 1600 GW of solar energy.

The total annual worldwide horizontal irradiance of 2000 kWh/m2 in the Pakistan region is 90%. Pakistan Meteorology Department, because of its extended summer season with over 300 bright days each year. (Ahmad et.al., 2022) Currently, biomass is the primary energy source, producing 10.56 GWh compared to 564.46 GWh last year, representing a 146.10 GWh increase in 2021 (Rahman et.al., 2020). Waste streams from the energy sector are being used by developed nations as a feedstock for the creation of renewable energy. (Tahir, F., 2023) Malaysia's Ministry of Energy and Natural Resources took up this environmentally pleasant initiative on October 6, 2016, governed by the Energy Commission and administered by the Sustainable Energy Development Authority (SEDA) Malaysia (SEDA). According to the World Energy-BP Statistical Report, the total installed solar energy power in 2021 is 700GW, which has increased to 94% from 2010. Malaysia is not lagging in this current outgrowth of solar energy with successful solar initiatives but is moving forward and becoming one of the leading countries in the Southeast Asian region. (Govindarajan et.al., 2023) Biomass in Malaysia contributes about 14% of the approximately 340 million barrels of oil equivalent (boe) of energy used every year. The types of biomasses being used, the research works on biomass conversion into energy, and the present biomass energy projects in Malaysia. (Chuah et.al., 2006)

This paper sets out from the literature review that the construction cost of a hybrid power plant related to solar and biomass is relatively high. The solar plant has a capacity of 6 MW and the biomass plant has a capacity of 2 MW. We will design a hybrid power plant so that the installation costs, as well as the power consumption, are comparatively more reduced and the installation process will be relatively easy. Also, greenhouse gas emissions will be significantly reduced. We will show how much it would cost to build a power plant for such a hybrid system and therefore we will find out how much load there is in an area and calculate accordingly. Above all, we will highlight in this paper which is relatively more beneficial for the environment.

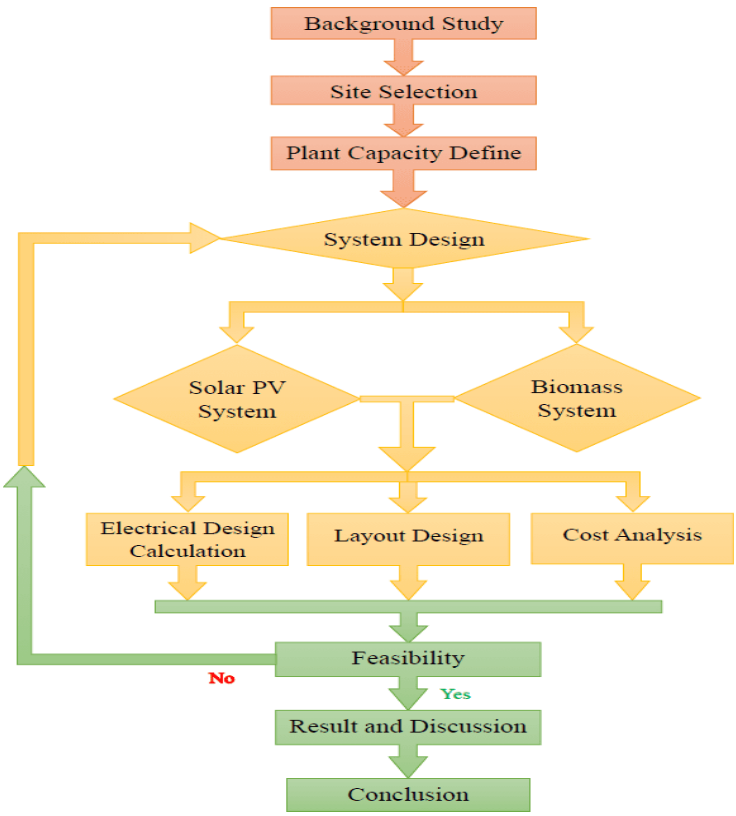


Figure 1. Block diagram of methodology

Considerations for Site Selection

In terms of setting up a hybrid power plant involving solar and biomass, the conditions under which we select suitable places are: site close to the grid, higher radiation area, should be avoided agricultural land and forest, availability of well communication system, availability of skilled technical and administrative human resources, availability of raw materials for Biomass Plant.

Project Location

Our project location is the CCNUST area, which is located in Comilla Sadar Dakshin. Upazila under the Comilla District. According to the data obtained from the analysis of the area, the area fulfills all the conditions prescribed for a solar biomass plant. Its Latitude is 23.4172°, Longitude is 91.1246°, Altitude is 26m, and Area is 32 acres. The project site is potentially convenient for the grid-connected solar PV and biomass project.

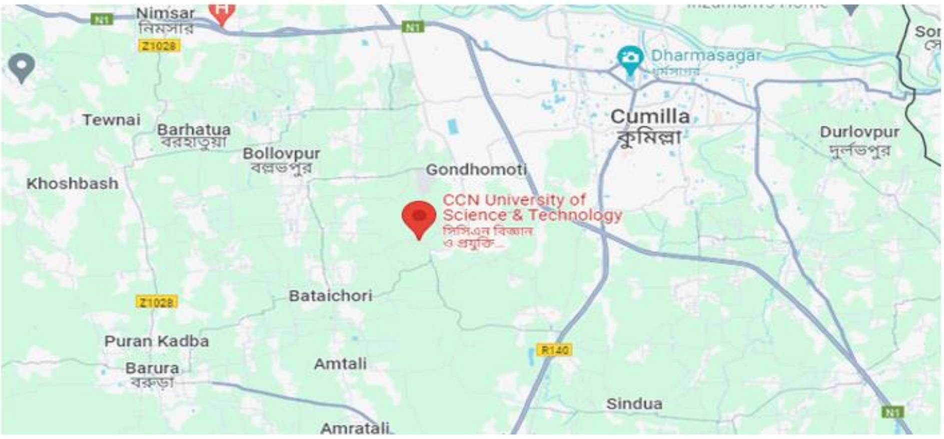


Figure 2. Arial View of the Location
(Courtesy: Google Maps)

Design Considerations for the Solar System

The solar system employs REC340TP72 modules with 16.9% efficiency and warranties of up to 10 and 25 years. Centralized SPI1000K-B inverters (6) and Fuji Electric transformers (3) are utilized. Lightning arresters protect the system, while a pyranometer measures solar irradiance. Additionally, a cup anemometer accurately measures wind speed without requiring alignment with wind direction. The solar panel generates direct current (DC) from solar energy and supplies it to the inverter. The inverter converts the DC into alternating current (AC). The inverter supplies the AC voltage to the power transformer. The power transformer steps up the voltage and transmits it to the grid. This is how on-grid connected solar plants work.

Block Diagram of Solar Plant

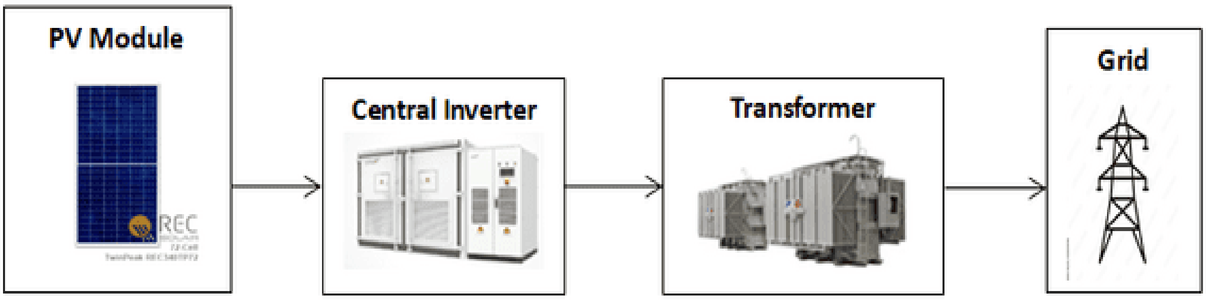


Figure 3. Block diagram of the solar system

Technical Analysis for Solar

System Choice of Mounting

Structures

Solar PV panels can be mounted on hollow rolled structures or can be mounted on the tracking system. The tracking system has the following advantages and disadvantages:
The tracking system comes out with higher yields considering the same installed capacity of solar PV panels. On the other hand, it requires higher maintenance.
Considering the size and nature of the system it is decided to go for a fixed mounting system.

Design Calculation for Mounting Structure

Evaluation of shadow impact in PV array strategy is crucial, especially during the winter solstice. To mitigate shading, spacing between rows of PV arrays should be significant, ensuring shadows don't obstruct arrays behind from 8 a.m. to 5 p.m. In this project, employing a vertical layout with two rows horizontally spaced at 3.5 meters before and after the PV arrays helps optimize energy generation. Row spacing has to be double of height of the mounting structure to eliminate the shading effect. For height 1.86m the row spacing is found at 3.72m is described in Figure 4.

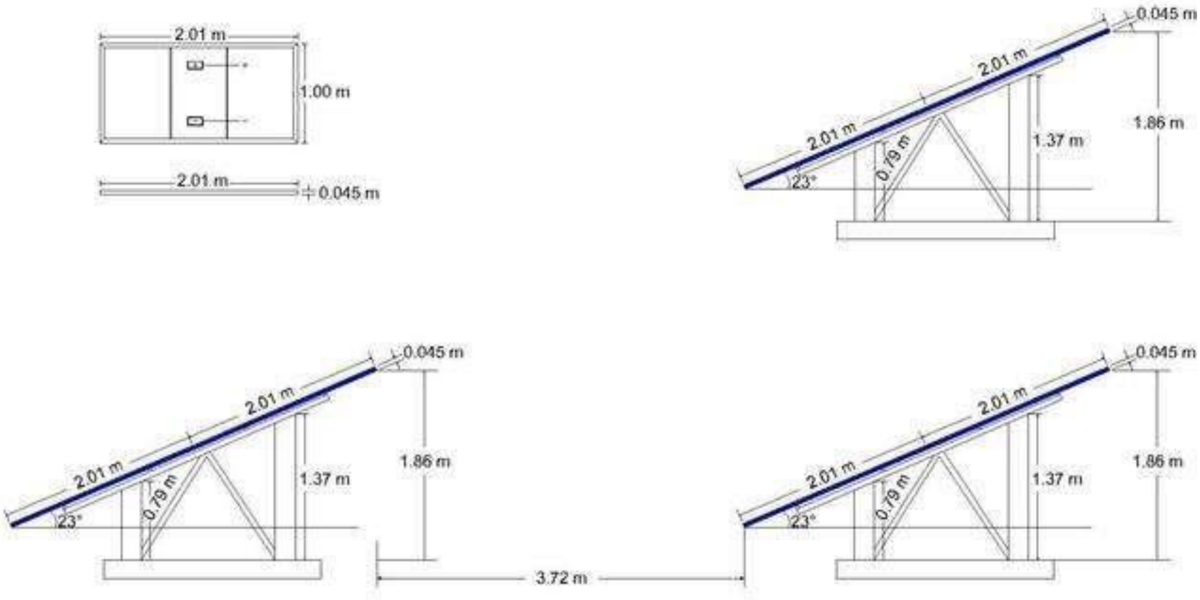


Figure: Mounting Structure of Solar Panel

Design Calculation for Inverter & String

The number of PV modules in series per string is 20 considering the DC voltage of the Inverter 900V (for safety) and Panel open circuit voltage 46.3 V. Thus, the total number of strings is 177. Again, per panel power rating is 340Wp.
So, Total DC power across a single inverter from PC modules = (177× 20 □ 340) Wp
= 1203600 W = 1.204 MW
Finally, AC output power from a single Inverter = 1000 KW = 1MW
And, Total AC power across a single Cluster from 2 Inverters = 2 □ 1 MW = 2 MW

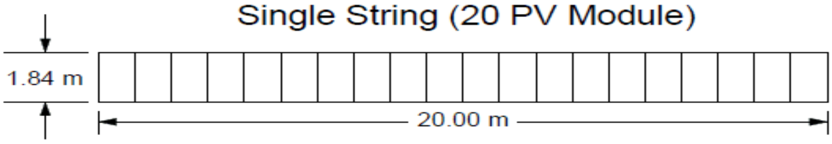


Figure 5. Single string

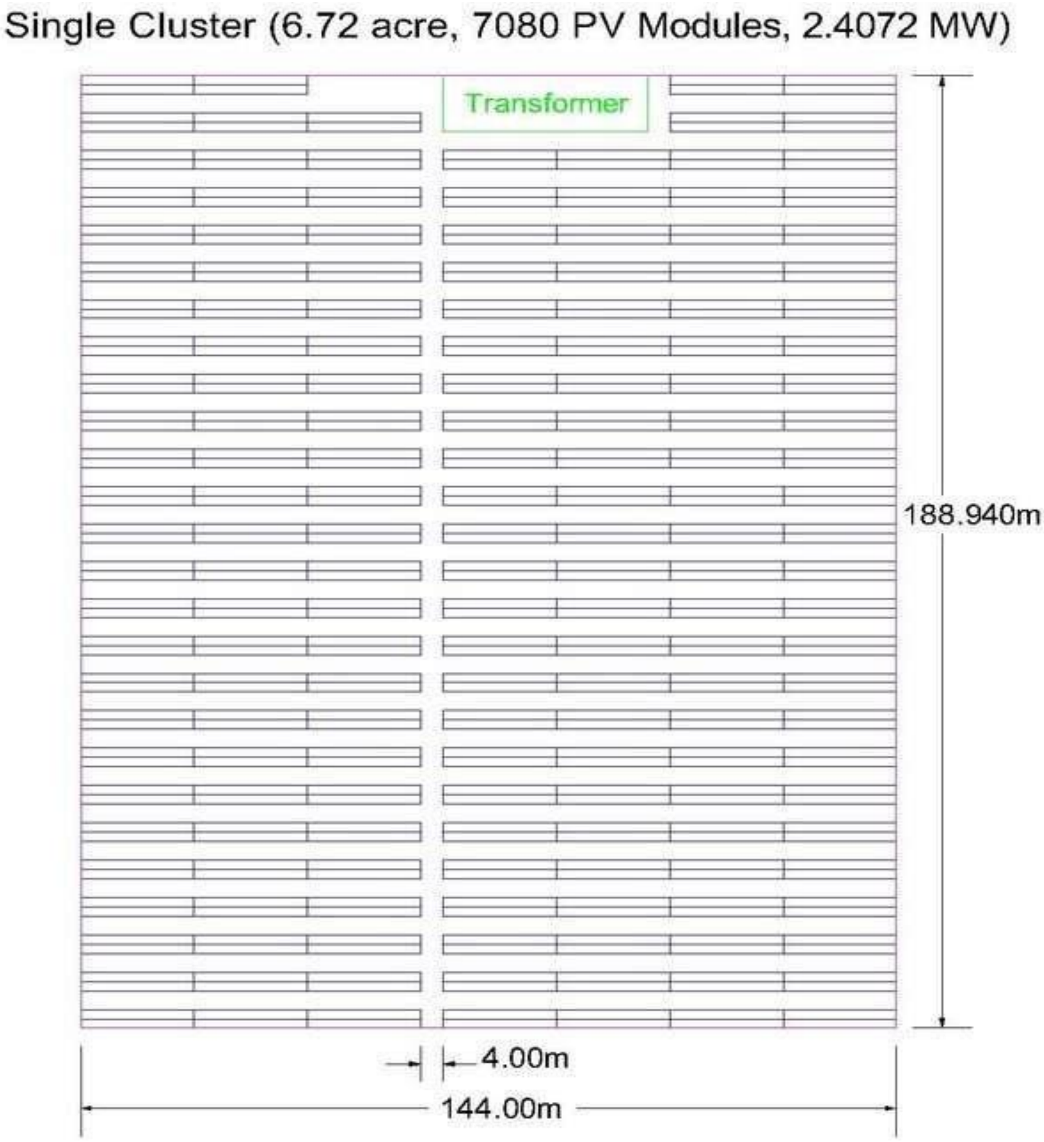


Figure 6. Single cluster

Single Line Diagram of Single Cluster

Shown is the single-line diagram of a 2 MW single cluster using 354 solar PV modules. 177 PV modules are connected to inverter-1. Other modules are connected to inverter-2. A 400 amp ACB and a transformer are used in the single-line diagram.

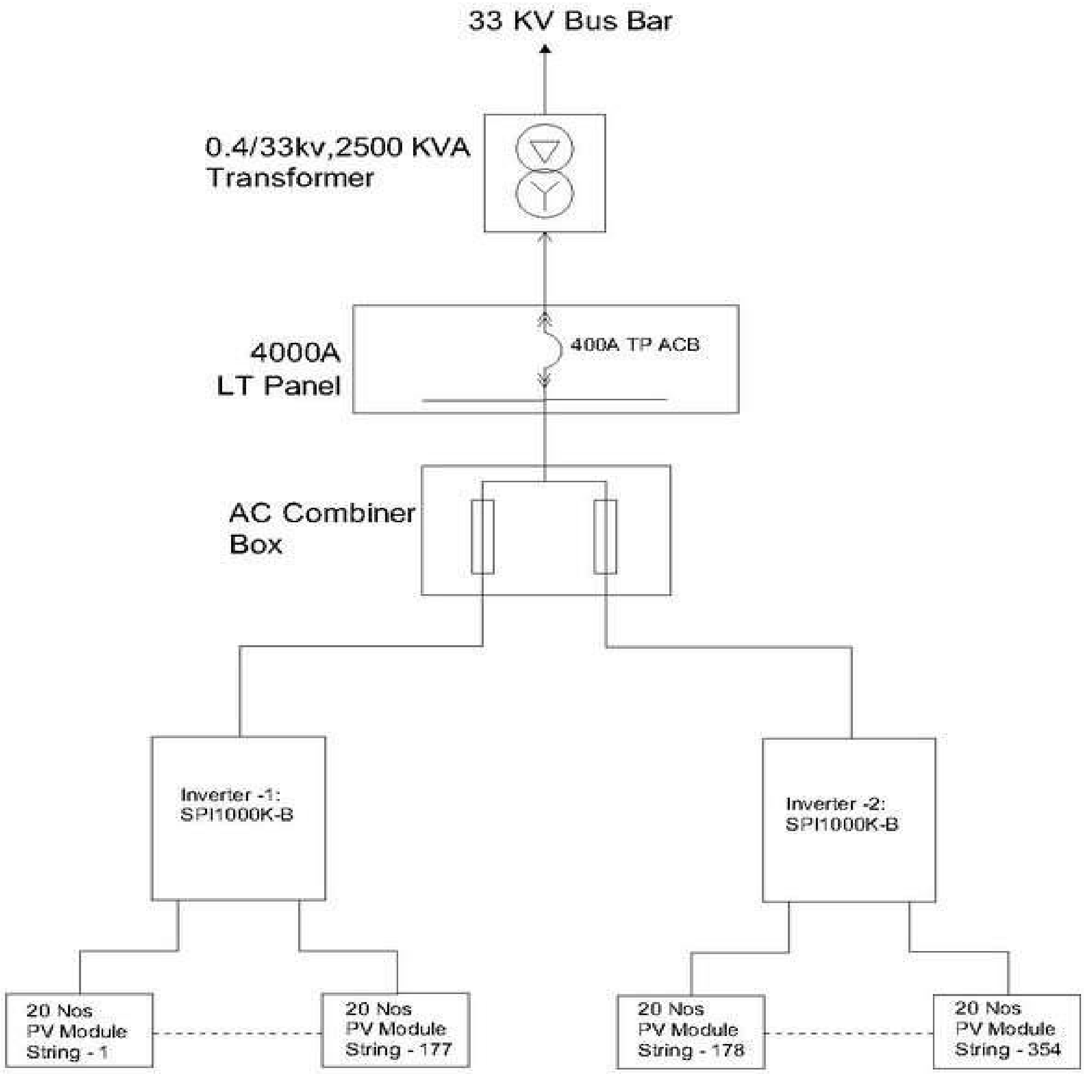


Figure 7. Single-line diagram of a single cluster

Solar Plant Layout

Grid-attached photovoltaic systems integrate solar energy into power grids via centralized or distributed inverters, converting DC power to AC for grid use. Monitoring voltage, waveform, and frequency ensure grid stability and safety standards adherence. Safety mechanisms, like automatic disconnection, activate if grid conditions deviate to prevent electrical hazards.

Data Calculation for Whole Solar PV System:

Required plant capacity = 6 MW (AC) So, No. of Cluster = 6 MW □ 2 MW = 3
No. of Transformers = 3
No. of Inverters = 6 MW □ 1 MW = 6
Finally, Total DC power from PV modules = 21240 □ 340Wp = 7221600 W = 7.2216 MW Total AC power from Inverters = 6 □ 1 MW = 6 MW

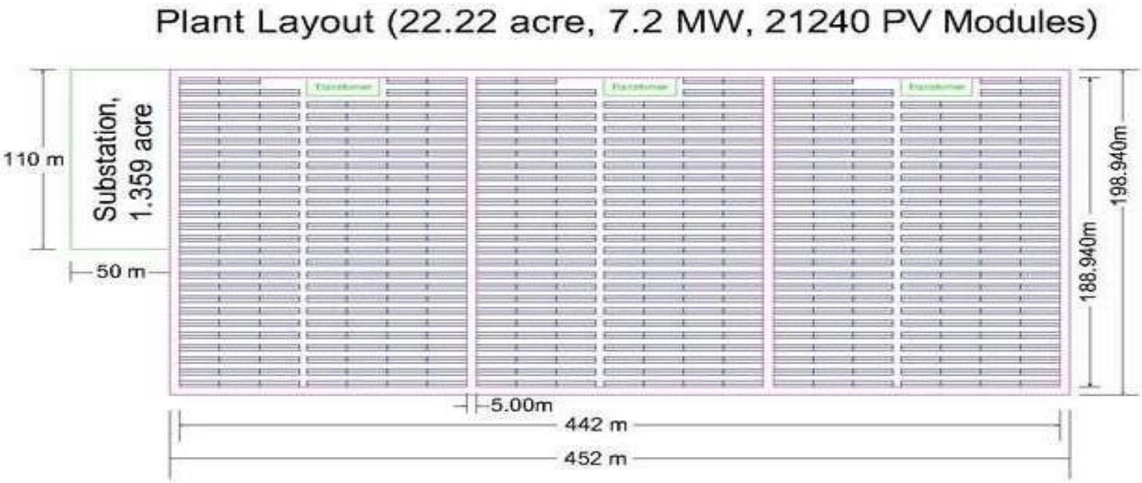


Figure 8. Solar System Layout

Single-Line Diagram of the Solar Plant

20 PV modules of 340 Wp each form a string, totaling 177 strings feeding into a 1000 kW PV inverter. Every 20 module strings connect to a combiner box. Each inverter serves 3540 solar PV modules, with a total capacity of 1204 kW, generating 400V, 50 Hz AC power. Two central inverters' output connects to a 2.5 MVA, 0.4/33 kV transformer for voltage elevation. Power at 33 kV is routed via underground cables. The power is transmitted to the CCN-UST campus via 33 kV lines. The power is integrated into the 132/33 kV grid substation.

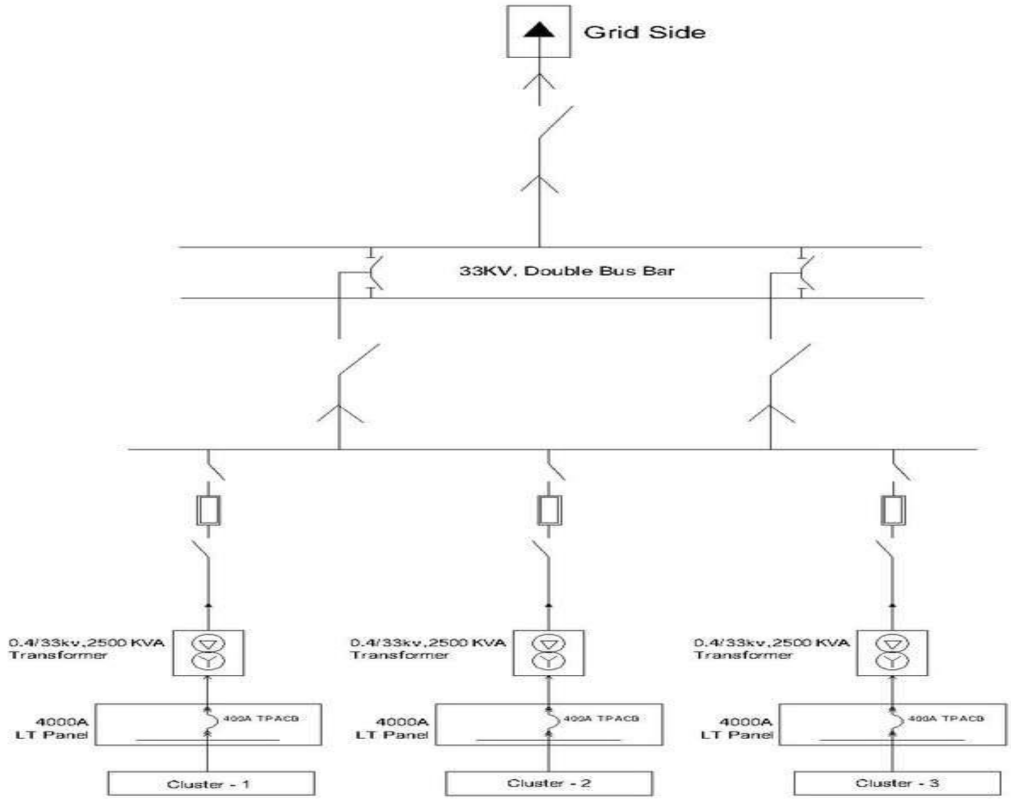


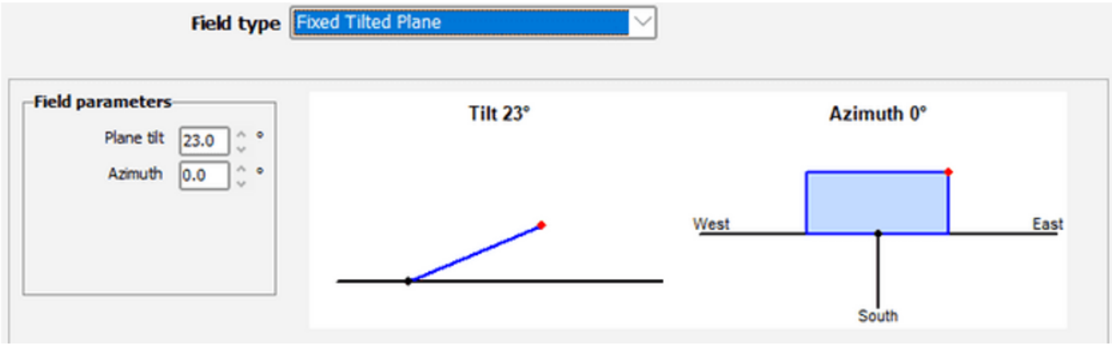
Figure 9. Single-line diagram of the solar plant

PVSyst Simulation

Various results of solar projects are shown through PVSyst software and various losses of solar plants are also highlighted through it.

PV Module Inclination

Considering Cumilla's latitude of 23º in the northern hemisphere, PV modules should be tilted at an angle equal to the local latitude and oriented southward to maximize sunlight absorption and energy yield.



Effect of Ambient Temperature and Humidity on Performance

Increasing cell temperature hurts the crystalline Si solar PV panel performance. With the increase of cell temperature for crystalline Si solar cells short circuit current increases a little (Isc increases by about 0.066 % / K) but open circuit voltage decreases (Voc sinks by about 0.3 % / K). Overall, the output power decreases with the increase in cell temperature (P sinks by about 0.36 % / K). The performance of the PV module hurts excessive humidity in the atmosphere too. When it is bad, the humidity of the panel starts at night and the dust is deposited in the panel, which reduces the amount of solar radiation that reaches the solar cell. Therefore, solar panels should be given special consideration for cleaning this plant will reduce power output. Here, the power output from the PV plant is considered the effect of moisture in the count. Humidity readily affects the efficiency of the solar cells and creates a minimal layer of water on its surface. It also decreases the efficiency by 10-20% of the total power output produced. The temperature and humidity data are shown in Figure-11 & Figure-12 from January to December 2023 resulting the better performance for this hybrid system. (Hamra, 2023)

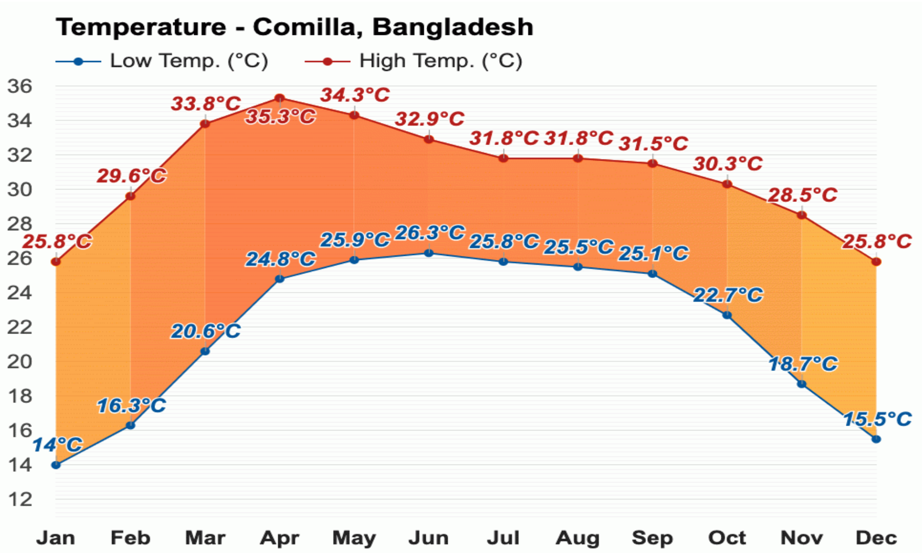


Figure 11. Monthly Max. and Min. Temperature at Cumilla

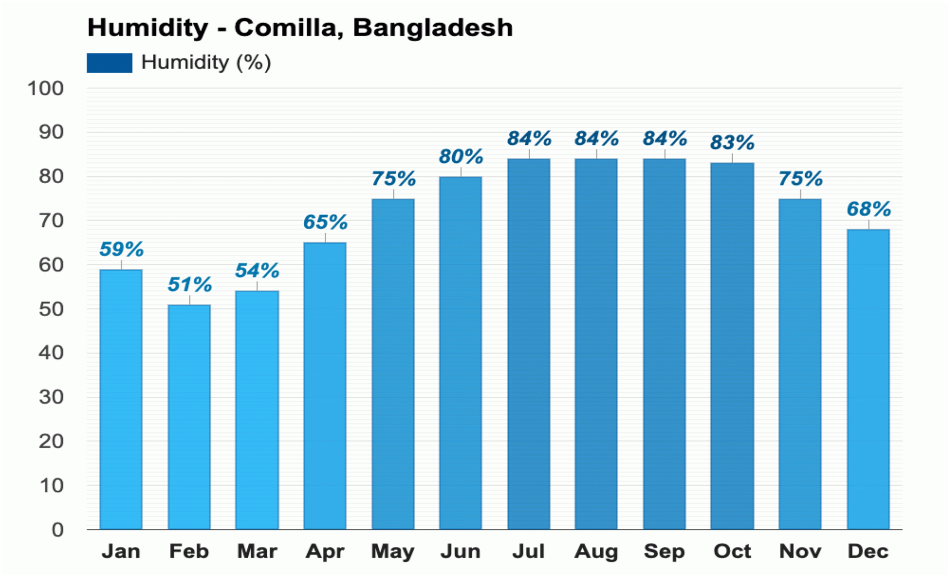


Figure 12. Monthly Average Relative Humidity at Cumilla

Precipitation

Rainfall can have both positive and negative effects on the efficiency of solar panels. On the other hand, rain can reduce the power production and irradiance of solar panels. According to the latest data of December 2023, the status of Cumilla is shown. The wettest month (with the highest rainfall) is July (224mm). The driest month (with the least rainfall) is January.

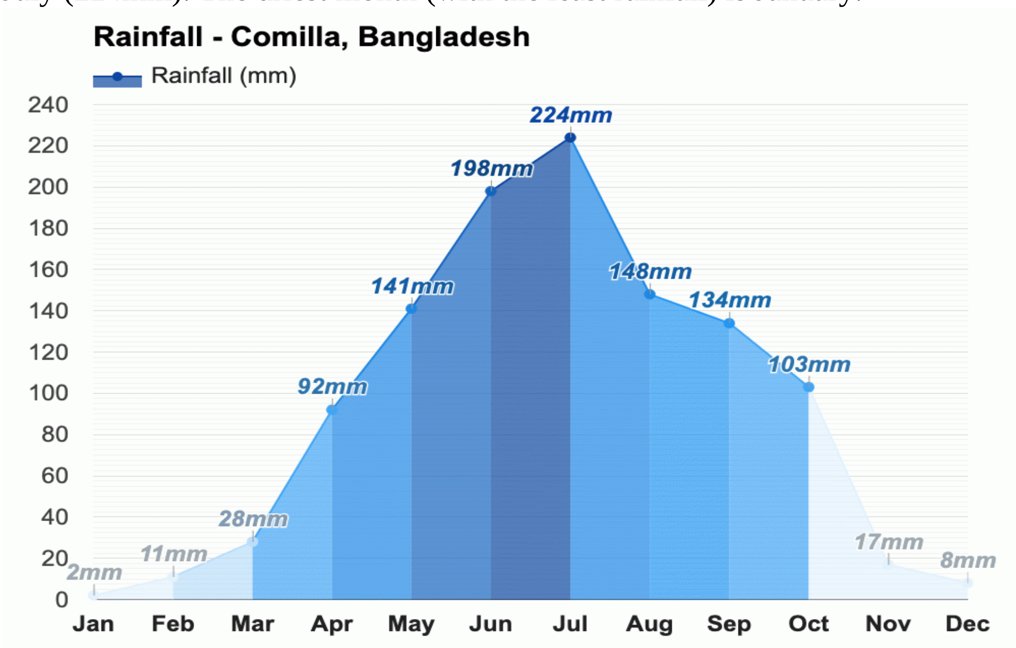


Figure 13. Monthly Average Rainfall at Cumilla (Hamra, 2023)

Wind Speed

PV panels with wind speed can generate a higher output power than those without wind speed. According to the latest data of December 2023, the status of Cumilla is shown. The windiest month (with the highest average wind speed) is July (13.6km/h). The calmest month (with the lowest average wind speed) is November (6.1km/h).

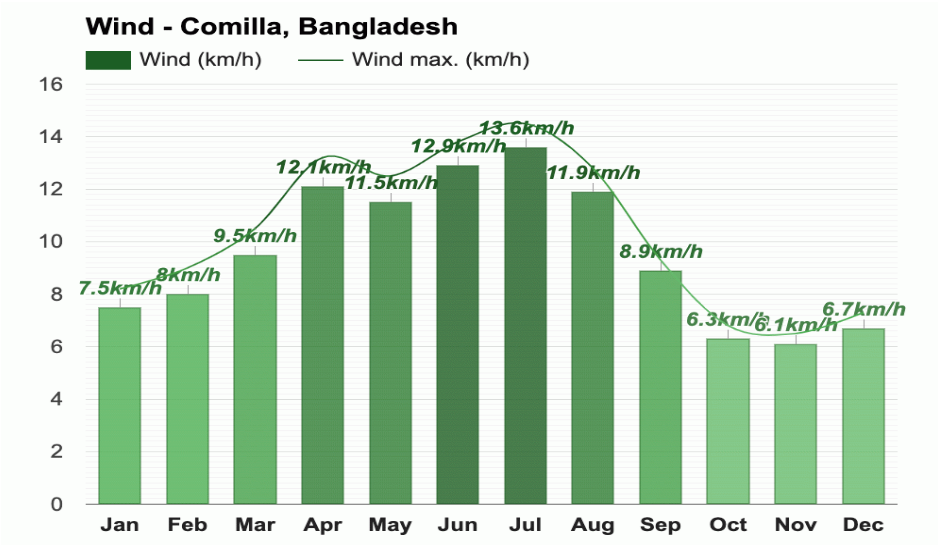


Figure 14. Monthly Average Wind Speed at Cumilla (Hamra, 2023)

Design Considerations for Biomass Plant

Main Components Used in Biomass Plant

Raw materials are stored in storage tanks. From there the raw materials are supplied to the digester. In the digester, the raw materials are converted into biomass gas. The gas generated from the digester undergoes gas purification through the gas purifier and the pure gas is supplied to the gas engine for power generation. (Fischer et.al., 2001)

Gas Engine Specification

A gas engine is an inner combustion engine that operates on a fuel gas, such as producer gas, landfill gas, coal gas, natural gas, or hydrogen. The gas can be utilized in a gas engine to transform the energy in the gas into electricity. Five numbers of gas engines are used in the plant.
Model: SG500 **Brand:** Generac.

Table 1. Technical Data for Engine

Input Data	
Parameter	**Value**
Net Engine Power	462 km
No. of Cylinder and Position	12, Vee
Recommended Fuel	Natural Gas
Combustion System	Electric spark injection
Compression Ratio	10: 1
Fuel Consumption	
Full Load (Standby)	128.4 m^3/hr
75% Load	102.8 m^3/hr
50% Load	76.1 m^3/hr
Output Data	
Parameter	**Value**
Prime Power Output	500 KVA / 400 kW
Frequency	50 Hz
Voltage	415 V
Power factor	0.8 (lag)
Phase	3

Alternator Specification

An alternator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current. Five numbers of gas alternators are used in the plant.

Table 2. Technical Data of Alternator

Parameter	Value
Voltage	415 V
Frequency	50 Hz
Rated Speed	1500 rpm
Rated Current	695 Amp
Power Factor	0.8 (lagging)
Poles	4
Phase	3 phase / 4 wire
Voltage regulation	± 1% with 4% engine governing
Design ambient temperature	50 °C
Overload capability	10% for 1 hour in every 12 hours of operation
Maximum over speed	120% for 2 mins
Excitation current at No Load	0.6 A
Excitation current at Full Load	2.50 A
Efficiency @ 100 % Load	93.5 %
Efficiency @ 75 % Load	94.1 %

Transformer Specification

One transformer of the same type specified for the solar plant will be used in the Biomass Plant. The transformer is a power transformer of 2 MW capacity. It converts low voltage to high voltage. Only one power transformer will be used for the biomass plant as it has a capacity of 2 MW.

Gasifier Specification

Gas purifiers eliminate impurities from gases, with the Down-draft Gasifier chosen for efficient biomass gasification. This process converts biomass into purified gas, powering generators to provide electricity in underserved areas. The downdraft design, featuring a co-current reactor, optimizes gas production from a variety of biomass sources. (Rahman et.al., 2020)

Model: HBF-1200W **Type:** Downdraft type fixed bed

Table 3. Technical Data for Gas Purifier

Parameter	Value
Type	Downdraft-type fixed bed
Gas output	1200m^3/h
Consumption Material	600kg/h
Gas caloric value	4600-5200KJ/m^3
Self-consumption electricity	40kw
Gasification efficiency	>80%

Digester Specification

Anaerobic Digestion employs microorganisms to break down biomass, yielding methane (CH4). The fixed-dome biogas plant, chosen for low cost and durability, feature underground structure that stabilizes temperature and create local job opportunities. (Aigbodion et.al., 2018)

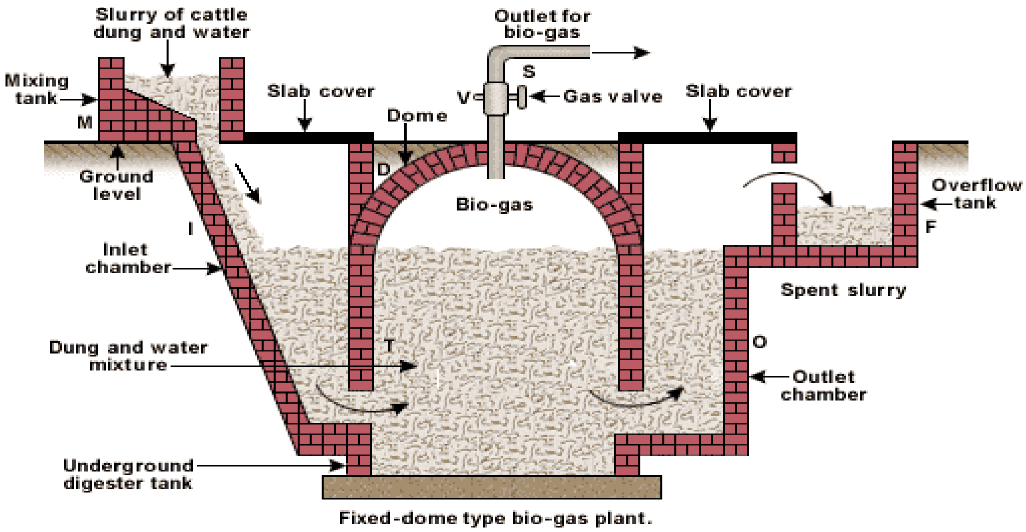


Figure 15: Fixed-Dome Type Biogas System

Block Diagram of Biomass Plant

In a biomass plant, raw materials are stored in a tank and fed into the digester as needed. The digester produces gas, purified by a gas purifier before being used by a gas engine for electricity generation. Residual raw material is diverted to a fertilizer sump for agricultural use. Generated electricity is stepped up by a power transformer before being transmitted to the grid, illustrating the operation of on-grid connected solar plants.

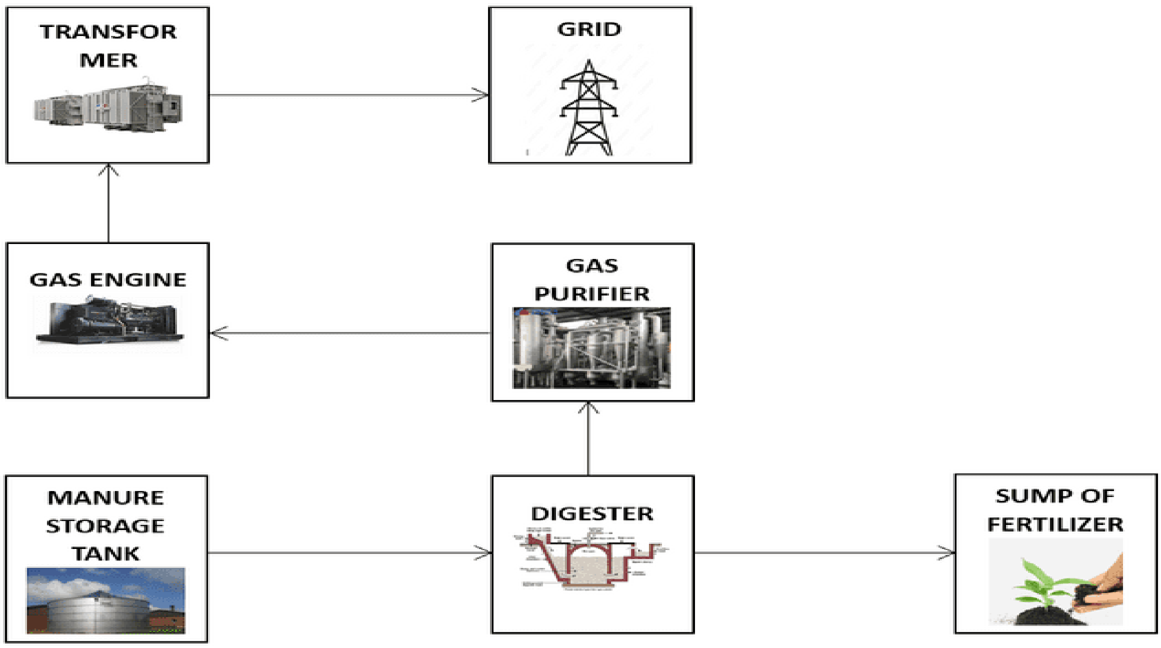


Figure-16: Block Diagram of Biomass System

Table 4: Specification of Raw Materials for the Biomass System. (Hafid et.al., 2022)

Raw Material	Production Rate	Gas Yield m^3/Kg of Dry Matter	Collection	Solid Content
Cow dung	15 Kg/day/head	0.34	70%	65%
Poultry manure	0.06 Kg/day/head	0.46	18%	60%

Design Calculation for Biomass System:

The biogas comes from cow dung 70%, and poultry manure = 30%, The stability of the plant is 25 Years, and Peak hours in a day in Bangladesh are 6 hours (almost from 5:00 PM to 11:00 PM). [operating the plant daily during peak hours]

Fuel Consumption at Full Load (Standby) per Gas Engine = 128.4 m^3/hour

Considering an additional 20% for losses in gas production processing.

Fuel Consumption at Full Load (Standby) per Gas Engine (128.4 × 1.2) = 154.08 m^3/hour and (770.4 × 6) = 924.48 m^3/day.

Fuel Consumption at Full Load (Standby) per Gas Engine in a day from cow dung (924.48 × 0.7) = 647.136 m^3/day and (924.48 × 0.3) = 277.344 m^3/day.

Total raw Materials needed for operating a biomass cluster of the plant for 25 years (2506.27×365×25) = 22869713.75 Kg = 22869.713 Ton and 114348.6Ton for 5 doms considering the data declared in Table-4.

Single Line Diagram of the Biomass Plant

The system is designed for a 2 MW biomass power plant with a single-bus 33kV bus line. It comprises five biomass clusters, each with a 400 MW capacity, supplied from manure storage. Each cluster operates a gas engine independently, totaling five gas engines of 400 MW capacity. Their output is connected to a 2.5 MVA, 0.4/33 kV step-up transformer before being drawn to the evacuation switchyard via underground 33 kV cables. Finally, power is transmitted to the nearby CCN-UST campus, Kotbari, Cumilla, through 33 kV transmission lines, as illustrated in the Single-line diagram Figure-17.

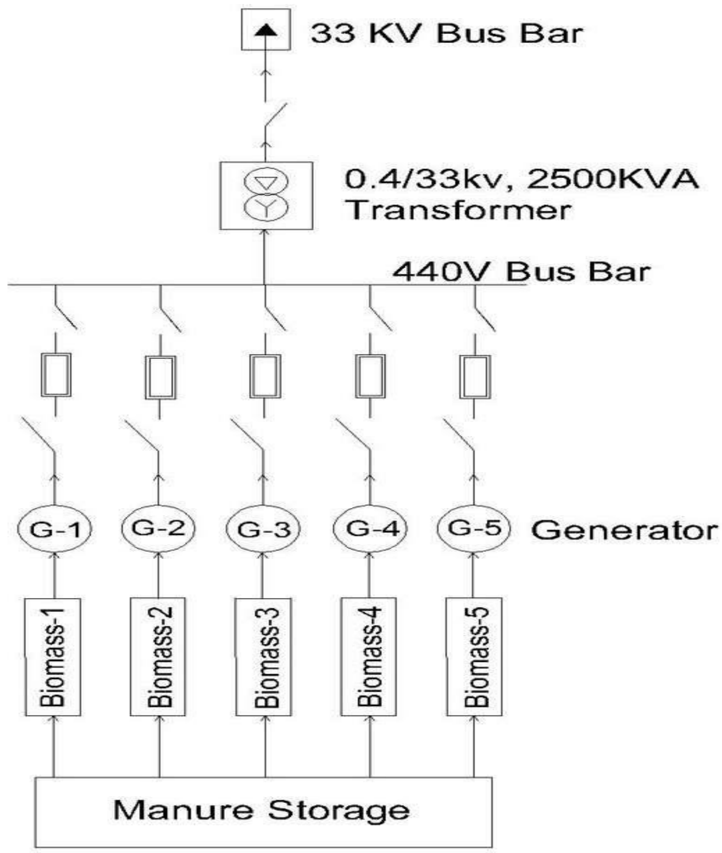


Figure-17: Single Line Diagram of the Biomass System

Effect of Temperature on Biogas Production

Temperature plays a critical role in biogas production as it affects the activity and growth of the microorganisms responsible for anaerobic digestion. The optimal temperature for biogas production depends on the type of microorganisms involved and the composition of the feedstock. Here is how temperature influences biogas production: where, psychrophilic Range (0-20°C): Some microorganisms can function at low temperatures (psychrophilic), but biogas production is typically slow and less efficient in this range. Cold temperatures can also inhibit the activity of methanogenic bacteria, leading to a decrease in biogas production, Mesophilic Range (20-45°C): The optimal temperature for mesophilic bacteria is around 35-37°C. At this temperature, biogas production is efficient, and the digestion process is relatively stable, Thermophilic Range (45-65°C): Thermophilic bacteria are active at higher temperatures, typically between 50-60°C. Biogas production in the thermophilic range is faster than in the mesophilic range, but the process can be more sensitive to fluctuations in temperature and pH.

Total gas production was greatest at 34 °C, and a temperature decrease from 34 to 25 °C resulted in a decreased biogas production (40% higher at 34 °C in comparison with 25 °C). (Babaei et.al., 2019)

Effect of C/N Ratio on Biogas Production

When the C/N ratio is too high, biogas yield does not show the optimum due to acidogenic bacterium rapidly consuming nitrogen compared with methanogenic bacteria. When the C/N ratio is too low, most microbes rapidly consume nitrogen for growth, although this has a positive effect on the methane production rate. (Choi et.al., 2020)

Effect of Precipitation pH on Biogas Production

PH factor is one of the essential parameters for biogas production. The struvite precipitation is economically integrated with biogas production. The optimum pH was 9, giving the highest yield and purity of struvite precipitates. The addition of 5% wt% struvite to the feedstock increased the methane yield in CSTR. (Wadchasit et.al., 2023)

Effect of Humidity and Temperature on Biogas Production

High humidity can cause moisture to condense on the active carbon filter media and affect its absorption capacity, underscoring the vital need for drying. Too low humidity, on the other hand, significantly drops filtration efficiency, as carbon's structure changes when too dry, especially in ambient temperatures. (Wiśniewska et.al., 2020)

Block Diagram of the Hybrid Plant

The block diagram design of a hybrid power plant consisting of a combination of solar and biomass energy is shown. It is a hybrid power plant with a total capacity of 8 MW with 6 MW from solar energy and 2 MW from biomass energy.

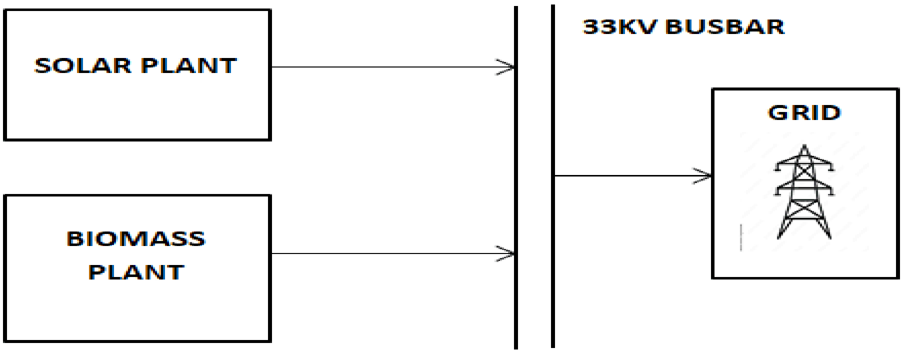


Figure 18: Block Diagram of the Hybrid Plant

Cost Analysis

We have used "Microsoft Excel" to do the cost analysis.

Economic Assumptions

Current Exchange Rate at	22-January-24	109.60	[1 USD = BDT 109.60 as of 22 January 2024]
US Inflation		3.35%	[Average of last 10 years is 2.65%]
Bangladesh Inflation		7.90%	[Average of last 10 years is 6.20%]

Power Production Assumptions (PPA)

Installed Capacity	7.2216	MW
Annual Energy Yield from Simulation (PVsyst)	95,58,061	kWh/Yr
Performance Ratio from Simulation (PVsyst)	80.44%	

Operating Cost Assumptions

Solar Inverter Change- Phase-1	10th Year	15%
Solar Inverter Change- Phase-2	11th Year	15%
Solar Inverter Change- Phase-3	12th Year	15%
Solar Inverter Change- Phase-4	13th Year	15%
Captive Lighting	4 Year Cycle	40%
Evacuation Switchyard	5 Year Cycle	2.5%
DC/AC Cable	5 Year Cycle	10%
SCADA System	5 Year Cycle	20%
Water Supply System	7 Year Cycle	20%
Radiation Measurement Sys.	10 Year Cycle	100%
Data Logging System	10 Year Cycle	100%
Gas Engine	5 Year Cycle	15%
Gas Purifier	5 Year Cycle	10%
Digester	3 Year Cycle	10%

Fixed O&M Assumptions

Salary & Allowances:

A total salary of Tk 75,36,000 will be required to operate the hybrid power plant per month. The details are presented in tabular form.

Position	Number of Employees	Salary/month BDT	Monthly Salary BDT	Annual Salary BDT
Plant Manager	1	2,00,000	2,00,000	24,00,000
Assistant Engineer	4	50,000	2,00,000	24,00,000
Sub Assistant Engineer	8	45,000	3,60,000	43,20,000
Driver	6	32,000	1,92,000	23,04,000
Technician	6	30,000	1,80,000	21,60,000
Cleaner cum maintenance assistance	4	15,000	60,000	7,20,000
Security Service	8	15,000	1,20,000	14,40,000
Total	**37**		**13,12,000**	**1,57,44,000**

Other General & Administrative Expenses

General and admin expenses per year total Tk 5,76,000. Details are presented in tabular form.

Admin Expense	6,00,000	BDT/year
Plant & Office Maintenance	6,00,000	BDT/year
Fuel & Vehicle Maintenance	5,00,000	BDT/year
Utilities Expenses	3,00,000	BDT/year
Total Gen. & Admin Exp.	**20,00,000**	BDT/year

Land Lease Cost

A total of 35 acres is required including 25 acres for solar plants and 10 acres for biomass plants. The table shows the land cost per year and the land cost increment every 5 years.

Land Lease Payment	9,00,000	BDT/year/acre
Land Area (25+5)	30	Acre
Cost Increment	10%	each 5 years

Total Amount of Land Lease Cost					
	Lease Years 1 to 5	Lease Years 6 to 10	Lease Years 11 to 15	Lease Year 16 to 20	Lease Year 21 to 25
Land Lease Payment	900000	900000	900000	900000	900000
Lease Increment index	1.00	1.10	1.20	1.30	1.40
Sub-Total Cost	157500000	173250000	189000000	204750000	220500000
Total Land Lease cost for 25 years	94,50,00,000				

Project Cost

Hybrid (Solar & Biomass) Plant Equipment

The hybrid power plant system will produce electricity for $0.54 per watt. The cost details are mentioned in the table.

Item	Unit	Unit Cost (USD)	Unit Cost (BDT)	Number of Units	Total Cost (BDT)	Total Cost (USD)
Solar PV Module	MWp	$600,000	6,57,60,000	7.2	47,34,72,000	$43,20,000
Solar Grid Connected Inverter	MWp	$60,500	66,30,800	6	3,97,84,800	$3,63,000
DC Cables & Associated DC Equipment	MWp	$9,600	10,52,160	7.2	75,75,552	$69,120
Monitoring and SCADA System	Units	$25,000	27,40,000	1	27,40,000	$25,000
Captive Lighting (LED)	Units	$200	21,920	200	43,84,000	$40,000
AC systems up to the evacuation switch yard (0.4/33 kV XFR)	Lot	$20,00,000	21,92,00,000	1	21,92,00,000	$20,00,000

Lightning Protection System	LS	$40,000	43,84,000	1	43,84,000	$40,000
Radiation Measurement Equipment	Units	$700	76,720	5	3,83,600	$3,500
Data Logging System	Units	$4,500	4,93,200	2	9,86,400	$9,000
33 kV double ckt evacuation line	Km	$22,000	24,11,200	10	2,41,12,000	$2,20,000
Bay and associated switchgear, protection, control, metering, and monitoring at the CCN-UST area 132/33 kV SS	Lot	$14,000	15,34,400	2	30,68,800	$28,000
Fuel storage and handling equipment	Units	$30,000	32,88,000	1	32,88,000	$30,000
Digester equipment	Units	$15,000	16,44,000	5	82,20,000	$75,000
Gas purifier	Units	$120,000	131,52,000	5	6,57,60,000	$6,00,000
Gas Engine	Units	$3,36,861	3,69,19,966	5	18,45,99,830	$16,84,305
				Total-	**104,19,58,982**	**$95,06,925**

Civil Works of Hybrid Plant (Solar & Biomass)

The total cost of civil works for the construction of the hybrid power plant is 27 lakh 11 thousand 845 dollars. Cost details are presented in tabular form.

Particulars	Unit	Unit Cost (USD)	Unit Cost (BDT)	Number of Units	Total Cost (BDT)	Total Cost (USD)
Supply and erection of pole [Pre-stressed RCC- 10 m long and 0.4 m dia]	Per pole	$1500	1,64,400	2,712	44,58,52,800	$40,68,000
Steelworks per pole (Panel mounting structure)	Per pole	$1400	1,53,440	2,712	41,61,29,280	$37,96,800
Erection of manure storage tank	One tank	$6000	6,57,600	1	6,57,600	$6,000
Erection of digester	Per digester	$1800	1,97,280	5	9,86,400	$9,000

Barbed wire over the plant boundary	Rm	$40	4,384	704	30,86,336	$28,160
2.5 m earthen walkway	Rm	$41	4,494	704	31,63,776	$28,864
4 m HBB plant service roads	Rm	$60	6,576	480	31,56,480	$28,800
4 m BC roads	Rm	$901.35	98,788	32	31,61,216	$28,844
Electrical cable Trays	Rm	$21.23	2,327	1,440	33,50,880	$30,572
Dormitory/ Residential buildings	Sft	$74.52	8,168	640	52,27,520	$47,693
Guest house	Sft	$88.93	9,747	800	77,97,600	$ 71,144
Water supply system with overhead tanks for panel cleaning [4" HBPE with riser at 200 m intervals]	Rm	$18.03	1,977	960	18,97,920	$17,309
				Total-	**89,44,67,808**	**$81,61,186**

Operational and Maintenance Cost

The total operational maintenance cost to run the plant for 25 years is Tk.200680772. Cost details are presented in tabular form.

Year No.	**Replacement Cost (BDT)**	**Year No.**	**Replacement Cost (BDT)**	**Year No.**	**Replacement Cost (BDT)**
1st Year		10th Year	3,37,30,252	19th Year	
2nd Year		11th Year	59,67,720	20th Year	3,54,83,852
3rd Year	8,22,000	12th Year	85,43,320	21st Year	12,01,584
4th Year	17,53,600	13th Year	59,67,720	22nd Year	
5th Year	3,23,60,252	14th Year	3,79,584	23rd Year	
6th Year	8,22,000	15th Year	3,31,82,252	24th Year	25,75,600
7th Year	3,79,584	16th Year	17,53,600	25th Year	3,23,60,252
8th Year	17,53,600	17th Year			
9th Year	8,22,000	18th Year	8,22,000		
Total Operational and Maintenance Cost (BDT) -				**20,06,80,772**	

Results and Discussion

PVsyst Simulation Result for Solar System

Summary of Project, System & Result

Our 6 MW solar plant uses 21240 PV modules and 6 inverters. According to the data obtained from the simulation, the total nominal power of the solar modules is 7.2 MW and the total nominal power of the inverters is 6 MW. The nominal power ratio is 1.204. The performance ratio is 80.44%.

Table 6: PVSyst Simulation Result

Result Summary	
Nominal Power (P_{Nom}-DC)	7222 KW
Nominal Power (P_{Nom}-AC)	6000 KW_{AC}
Nominal Power Ratio	1.204
Produced Energy	9558061 kWh/Year
Specific Production	1324 KWh/KW_P/Year
Performance Ratio (PR)	80.44 %
Horizon	
Latitude	23.42^{O} N
Longitude	91.12^{O} E
Altitude	26 m
Diffuse Factor	1.00

Main Results

According to the information obtained from the image of the main result, the energy production from the solar plant will be 9558.061 MW per year. The position of the performance ratio is identified in each month in the figure.

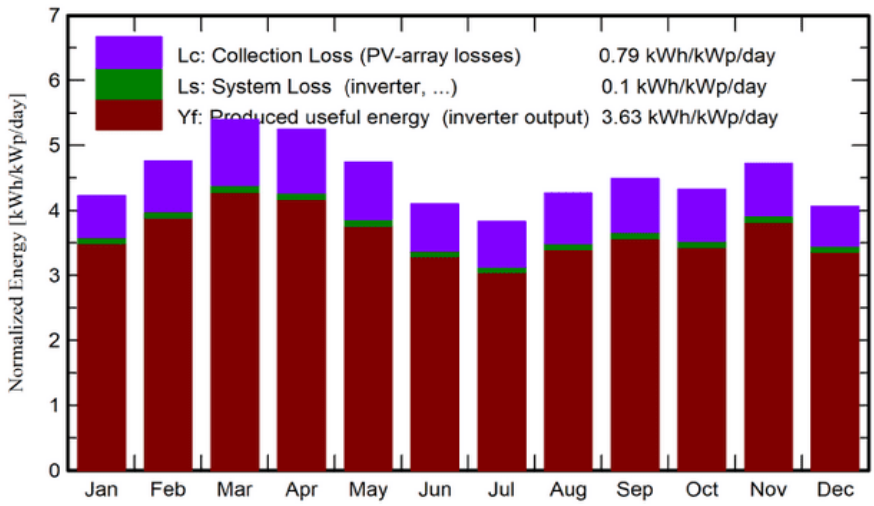


Figure-19: Normalized Production (Per Installed KW_P)

PVsyst TRIAL

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	105.5	53.55	17.42	130.9	125.3	803734	782979	0.829
February	115.1	63.90	21.22	133.3	127.6	806564	786305	0.817
March	154.9	77.85	25.82	167.0	159.8	984051	958817	0.795
April	157.6	90.53	27.69	157.4	149.9	926986	903985	0.795
May	156.0	95.20	28.36	146.8	139.7	865577	843220	0.795
June	133.0	94.31	28.11	123.0	116.7	733000	713644	0.803
July	127.2	79.77	28.50	118.7	112.7	701655	682189	0.796
August	136.8	86.51	28.65	132.3	125.7	782253	761972	0.798
September	130.3	75.87	27.97	134.5	128.2	794573	773649	0.796
October	120.3	66.38	27.20	134.0	128.0	790910	769719	0.795
November	114.2	52.42	23.11	141.5	135.6	849035	827290	0.809
December	100.8	57.30	19.20	125.9	120.5	773815	754292	0.830
Year	1551.7	893.59	25.29	1645.3	1569.7	9812153	9558061	0.804

Figure 20: Balances and Main Results

System Losses

The iron loss of the transformer is 6.04 kVA and the copper loss is 84.25 kVA obtained by simulation.

Loss Diagram

The loss diagram shows the losses of a solar plant at a glance, along with the number of losses.

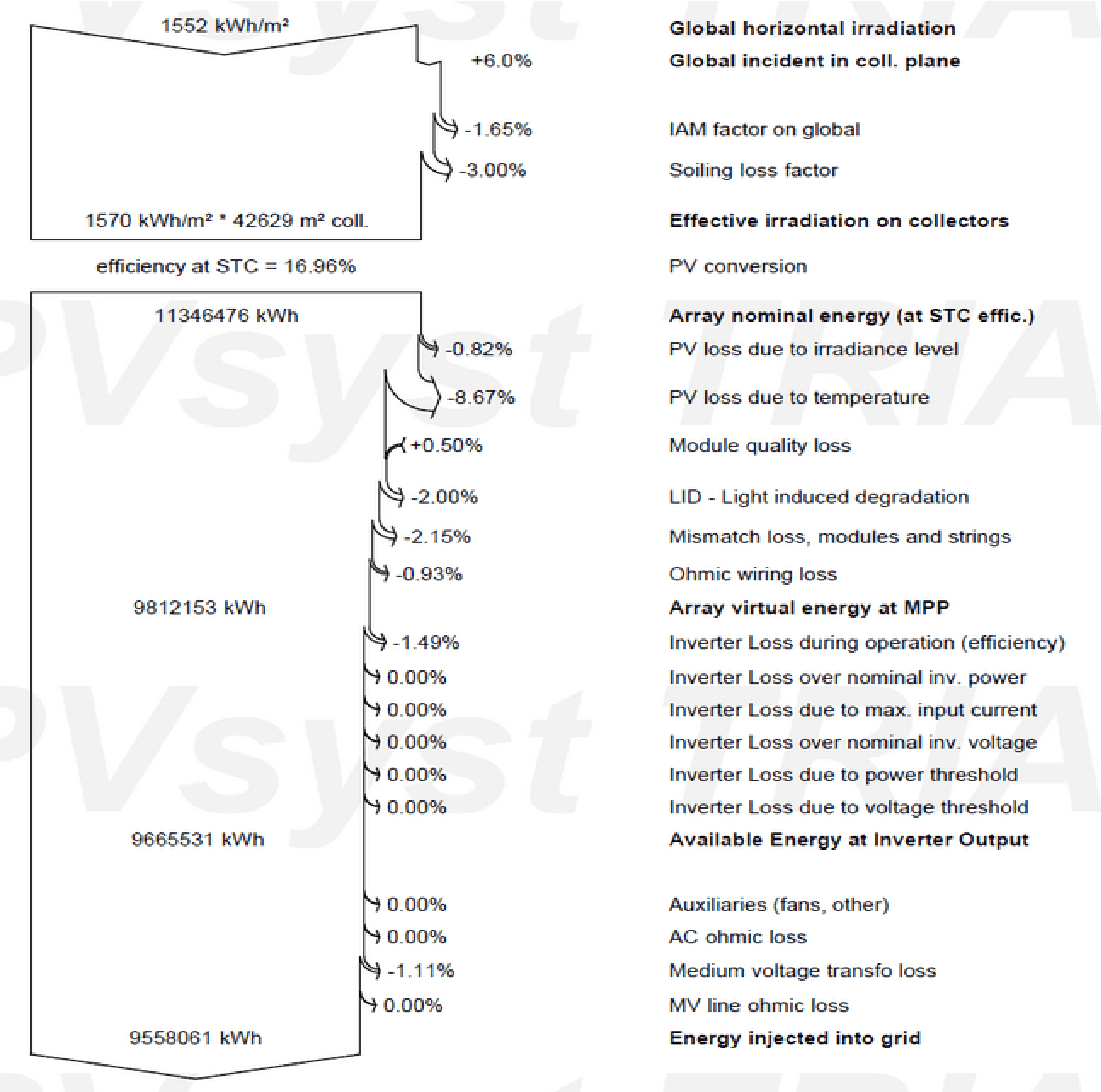


Figure-21: Loss Diagram

Amount of Energy Production from Hybrid Plant

The total energy production of the hybrid power plant in 25 years is 34,69,51,525 kWh. 23,89,51,525 kWh produced from solar plants and 10,80,00,000 kWh produced from biomass plants in 25 years.

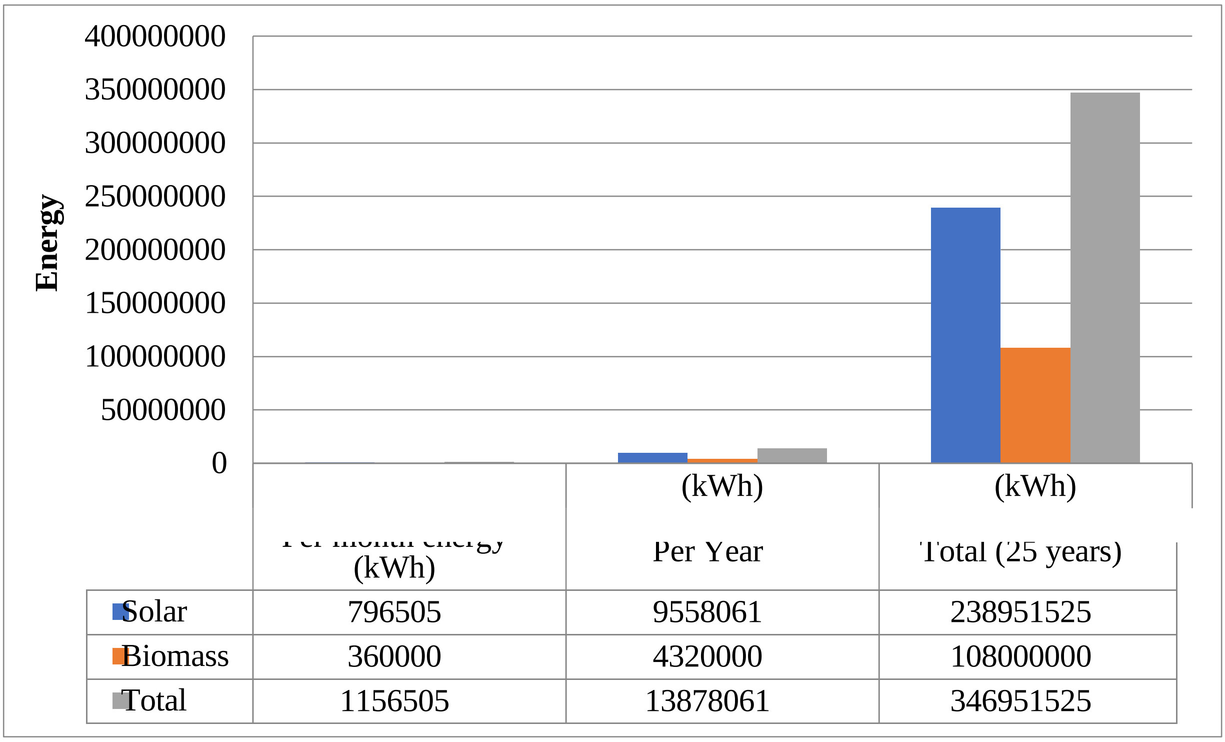


Figure-22: Amount of Energy Production from Hybrid Plant

Total Plant Cost

Total plant cost is 324,08,38,884 Tk for 25 years. The production cost per unit of electricity of the hybrid power plant is 9.34 Tk. Details are presented in tabular form.

Table 7: Total plant cost summary

S.I.	Particulars	Total Cost (BDT)	Total Cost (USD)
1.	General and Administrative Expenses	5,00,00,000	456,205
2.	Land Lease Cost	94,50,00,000	8,622,263
3.	Hybrid Plant Equipment	104,19,58,982	9,506,925
4.	Civil Works of Hybrid Plant	89,44,67,808	8,161,186
5.	Operational Maintenance Cost	20,06,80,772	18,31,029
6.	Furniture and Fixture	2,74,00,000	250,000
7.	Utility Connections	39,51,519	36,054
8.	Vehicles	11,72,71,456	1,069,995
9.	Pre-Operating Expense	10,98,25,119	1,002,054
10.	Miscellaneous Charges for Import and Transportation	5,09,64,000	465,000
11.	Others	27,40,00,000	2,500,000
	Total Plant Cost	**344,15,19,656**	**3,14,00,711**
	Per Unit (kWh) Cost	**9.92**	**0.091**

Conclusion

The appropriate use of land for power generating while minimizing costs and negative environmental effects is the aim of this research. The best option for this may be a hybrid power plant design. This concept can be boosted by using renewable energy as a source. For spanning 35 acres constructed at a cost of Tk.324,08,38,884, it promises sustainability for 25 years, generating an impressive 34,69,51,525 units of electricity shown in **Table 7**. It results in a capacity of 8 MW through the integration of solar and biomass energy sources and stands as a beacon of innovation. The hybrid power plant, boasting a commendably low unit energy consumption of Tk.9.92, exemplifies cost-efficiency and environmental responsibility. Harnessing the reliability and safety of renewable energy, particularly solar and biomass, this project addresses pressing global energy challenges while minimizing emissions. Leveraging AutoCAD software, the design ensures precision and optimal layout, setting a precedent for Bangladesh's renewable energy endeavors.

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