Applied Chemical Engineering (2024) Volume 7 Issue 1
doi: 10.24294/ace.v7i1.2342

ORIGINAL RESEARCH ARTICLE

Design and techno-economic evaluation of hybrid renewable energy system for an Upazilla Health Complex (UHC) in Bangladesh

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ABSTRACT

Upazilla Health Complex (UHC) offers the primary level health care facilities for rural communities. Every day thousands of patients come here for health care. The Health complex needs 24 hours electric supply. The national Grid cannot provide continuous electricity supply. Rural areas face various disturbance such as load shedding, blackouts problems and bad weather situation. In this paper, we report on the techno-economic assessment of net metering based On-grid photovoltaic system for Kaunia Upazila Health Complex in Rangpur District, Bangladesh. The analysis is based on the grid-connected photovoltaic system without battery storage. The HOMER software is used to obtain the overall analysis and the load study is carried out by HOMER powering tools. It suggests that the selected health complex requires a 34 kW PV system. The system's net present cost (NPC) and the levelized cost of energy (COE) are \$35,524 and \$0.048 respectively. In this proposed system, renewable energy provides 99% of the total power requirements, while the generator and grid provide only 1%. The system produces 53,736 kWh a year of electricity where the system's surplus electricity is 3226 kWh per year which can be sold to the national grid using a net-metering system.

Keywords: on-grid; HOMER Pro; HOMER powering tool; photovoltaic system; net present cost (NPC); cost of energy (COE); net metering system

ARTICLE INFO

Received: 1 July 2023
Accepted: 19 October 2023
Available online: 14 December 2023

1. Introduction

The sustainable development goals (SDGs), also known as the global goals, were innovated by the United Nations in 2015. The government of Bangladesh has taken initiative to achieve these goals. Good health is one of the major goals to develop a country[1]. So, the government of Bangladesh developed Upazilla Health Complex (UHC) facilities for ensuring an improved quality of life to fulfil SDGs. It offers primary-level health care facilities for rural communities. It serves various health care facilities indoor as well as outdoor treatment such as maternity facilities, obstetric delivery, and surgical operations. One of the major fundamental needs in the medical complex is electricity. A report about the death of women during pregnancy and childbirth which ~~is~~ happens due to lack of a medical facilities. If enough lighting and operating equipment were available, maternal mortality would be reduced by 70%[2]. Most of the medical components are operated by electricity. So the medical center needs a reliable, secure power supply. But the power supply of the national grid cannot access regular electricity. Various disturbances of line, load shedding, blackouts, and bad weather situations are the main reason for not having electricity. In the rural area, this problem occurs frequently. Recently, due to the pandemic situation COVID-19, the number of patients admitted to the health complex is increasing[3]. As a result, the energy demand is also increasing. Currently, the primary source of electricity in Bangladesh is fossil fuels such as natural gas, oil, coal. The main difficulties of these sources are limited and sources are gradually decreasing[4–8]. On the other hand, the electricity production cost and pollutant gas are increasing day by day. The use of fossil fuels hurts the environment as they produce greenhouse gases that are responsible for climate change. Climate change has a demolish effect on the existence and survival of human beings[9]. The global community has moved and received various policy persuasive that advocated shifting from fossil fuel energy to renewable energy sources[10–14]. Bangladesh policymakers also want to depend on renewable energy sources to fulfill energy demand and sustainable development criteria. At present, the Government of Bangladesh has inaugurated mega projects such as solar irrigation, rooftop solar system, to produce 40% of total energy from renewable resources within 2041[15,16]. Renewable energy provides a credible and continuous electricity supply. To address all the reasons, encourage the photovoltaic hybrid grid system has done around the world to produce secure, cost-effective, and environmentally friendly.

Kuddus et al.[11] analyzed the feasibility of a solar PV microgrid system in Iraq that can supply electricity during both grid availability and outage periods, aiming to address the country’s daily electricity shortages. The study uses HOMER software and five different control strategies to assess the techno-economic and environmental aspects of the system. The results show that the most economical configuration components include a 5.8 kW PV system, 16 batteries, and a 5 kW converter that is connected to the national grid. The NPC (net present cost) of this configuration is $29,713, which is the total cost of the system over its lifetime. Ahmmed et al.[12] investigated the techno-economic viability of a hybrid energy system (HES) for powering a rural health clinic in Nigeria, using solar PV, wind, diesel generator, and batteries. The paper presents the results of a techno-economic viability assessment of different hybrid energy system configurations for powering a rural healthcare facility in Nigeria. The PV/DG/battery HES with specific specifications (5.43 kW PV, 2 kW DG, 3.06 kW power converter, and 10 units of batteries) emerged as the optimum system with the minimum net present cost of 16,457 and Cost of Energy of 0.259/kWh compared to other system cases. This system also had lower carbon dioxide emissions compared to other configurations. Rahman et al.[13] analyzed of the grid-connected photovoltaic (GCPV) system for the hospital building in Malaysia was performed using the HOMER software. The analysis considered net present cost (NPC), levelized cost of energy (LCOE), and annual interest rate. The total NPC represented the life cycle cost of the system, while the revenue included income from selling power to the grid. The cost analysis compared the optimal configuration of the load grid-connected system and the GCPV system. The sensitivity analysis varied the annual interest rate from 1 to 4 over a 20-year project lifetime. Rahman et al.[14] concluded in their study that the proposed hybrid energy system, consisting of photovoltaic panels, a diesel generator, and a battery bank, is an economically viable solution for off-grid health clinics in remote areas. The optimal size of the components for the hybrid system is determined to be 2.52 kW of PV, 2 kW of DG, 2 kWh of battery, and 1.66 kW of inverter. The cost of energy for the optimal system is found to be 0.105 kWh, which can increase to 0.120 kWh in areas with poor solar radiation. Abdulrazak et al.[15] emphasized the importance of using hybrid power sources based on renewable energy for powering rural healthcare centers in Morocco. An important consideration is the diesel running and maintenance cost, which is projected to be 10 MAD/h for a 30 kW diesel generator. The HOMER model makes the assumption that cost per hour is independent of electricity output. A levelized cost of energy (LCOE) of 6.69 MAD/kWh was determined.

Kamruzzaman and Haque[16] analyzed the economic feasibility of hybrid renewable energy systems for rural electrification in Peru. The optimal configurations resulted in net present costs (NPC) of USD 227,335. The cost of energy (COE) for the optimal configurations was 0.478 USD/kWh 0.460 USD/kWh and 0.504 USD/kWh.

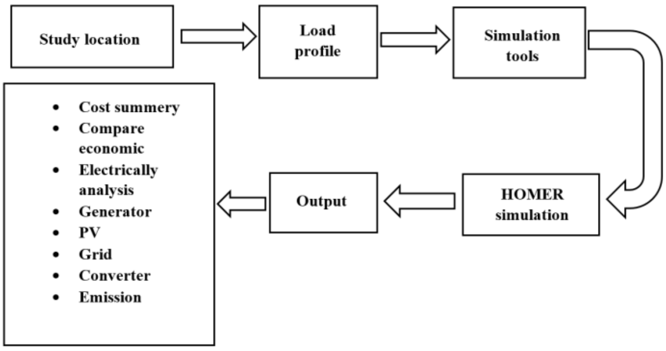
Kapoor et al.[17] analyzed an on-grid solar energy harvesting system for Fatehpur village in India, aiming to provide necessary power for the community's energy demand while minimizing environmental impact. The economic analysis is conducted using Homer-pro software, which calculated the net present cost was $119,716.93 and the levelized cost was $0.023/KWh where the carbon emission was 85,193 kg/year. Masrur et al.[18] discussed the importance of renewable energy for the development of Bangladesh and its progress in achieving the Sustainable Development Goals (SDGs) in the renewable energy sector. In their study, the net present cost was $3,198,708 and the cost of energy was $0.246. Hossain et al.[19] analyzed that the PV-wind-diesel generator hybrid system delivers the best optimal design for Saint Martin Island in terms of cost of energy (COE), followed by PV-Diesel Generator, Wind-PV, Wind alone, and PV alone system.

The simulation of renewable energy using HOMER has been the subject of numerous articles. However, Kaunia Upazila health complex facility is the first attempt to model a hybrid PV system and conduct a techno-economic analysis in order to determine one of the best approach to power provide in the health center. This study's goals were to choose a location, determine its total load, simulate one the best power supply options to meet a healthcare facility's electrical demands for the least amount of money, and assess the generation from a technical and financial standpoint. The remainders of the paper are structured as follows: Methodology describing the evaluations of the simulation tools, study location, load analysis, and economic model are provided in section 2. The simulation results and a discussion of various settings are offered in section 3. Section 4 represents the operating strategy. Finally, section 5 presents the conclusions.

2. Methodology

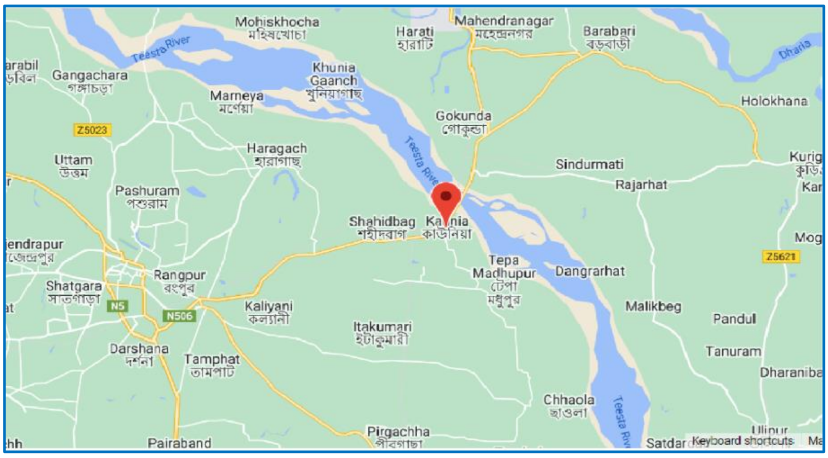
2.1. Study location

The study location of Kaunia Upazilla 50-bed hospital is located in the Rangpur district in Bangladesh. It is near the Teesta River on the Rangpur Kurigram Highway. **Figure 1a** shows the flow chart of this study which represents the each step of this study. **Figure 1b** has been collected from google map. In this location, latitude is 25.775°N and longitude is 89.424°E. In March the average temperature is 24.5 degree and 9.51 hours of sunshine is available per day. In January there is an average of 8.04 hours of sunshine. The solar radiation intensity is high from February to May which is 6.28 kWh/m^2/day[20]. Elsewhere lowest solar radiation recorded in December which was about 3.92 kW/m^2/day. The average value of radiation was 4.86 kWh/m^2/day. **Figure 2** has shown the selected area's monthly average global radiation taken from National Renewable Energy Laboratory (NREL)[21].



(a)

Figure 1. (*Continued*).



(b)

Figure 1. (a) flow chart of the study; **(b)** Upazila Health Complex Kaunia, Rangpur.

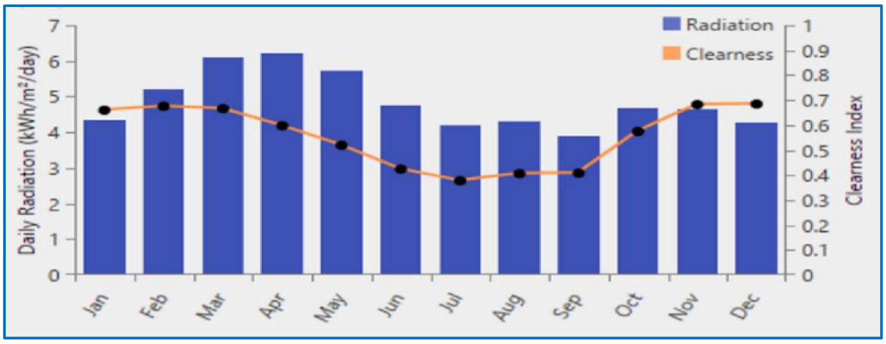


Figure 2. Monthly average solar radiation.

2.2. Simulation tools

2.2.1. HOMER powering health tool

The HOMER powering Health Tools is a free online model developed by NREL, a system optimization algorithm of HOMER[22]. It is used to design a project that simplifies the cost based on the given input from the health care center. The tools creating the primary model designing the electric power system for the health complex. The tools designed by the engineers and financier developer. The programmer simulates the optimal combinations of power supply alternatives to meet the electrical loads of a healthcare facility at the loads based on the inputs given. It examines various solar photovoltaic (PV), diesel, gasoline, or propane-powered generator set designs, batteries (lead acid and lithium ion) systems, and grid electricity. The model is online and can be used an endless number of times without requiring registration or downloading any software.

2.2.2. HOMER pro software

The Hybrid optimization Model for Electric Renewables (HOMER), originally developed by the National Renewable Energy Laboratory, United States, is the world's one of best micro-grid simulation models for optimal planning and design of energy systems in on-grid or off-grid models. The software simulates many system models to determine one of the best system combinations based on the lowest net present cost, cost of energy, renewable fraction, system emission, and appropriate technical role. Numerous resources, including solar PV, wind turbines, biomass, different energy storage technologies, and converters, are part of HOMER. The software needs technical information on energy source, energy storage, and control scheme parameters. Input parameters for the software include things like capital and replacement costs, component type, efficiency, and life cycle[23,24].

2.2.3. Load analysis

The area of the hospital is 20,234.5 m^2. It consists of an administration room, emergency room, out-patient treatment room, maternity ward, obstetric ward, laboratory room, operation theatre, internal pharmacy room, covid isolation ward, general ward, doctor consultation room, nurse room, etc. Actual data of the hospital was taken out by physical survey. The primary loads were light, fan, vaccine fridge, sterilization equipment, suction machine, air conditioner, cautery diathermy, X-ray machine, ultrasound, water pump, sterilization autoclave, surgery spotlight. The maximum amount of power increase when the capacity of the patient increases so that the energy consumption of the hospital is high. In health care load is maintained at a minimum load obtained from 12 am to 6 am. The peak load is received in the morning because of the lifestyle of the rural area of people who often visit the health complex in the morning. The load demand decreases from 6 pm to 12 am gradually. The hospital daily load demand profile shown in **Figure 3**. The daily average power consumption is 79.295 kWh/day and the average electric load is 3.3 kW. **Figure 4** has shown average scaled monthly peak load is 21.59 KW. The load factor is 0.1530. The load analysis computation is represented in **Table 1**.

Table 1. UHC load analysis.

Load description	Quantity A	Power (W) B	Total power (W) C = A × B	On-time(h/d)\D	Total energy (kWh/days) E = (C × D)/1000
Vaccine refrigerator	3	60	180	24	4.3
Light	118	20	2400	7.5	18.0
Sterilization equipment	3	1000	3000	0.67	2.0
Suction	3	80	240	0.5	0.1
Water heater	2	1000	2000	0.5	1.0
Ceiling fan	32	50	1600	8	12.8
Autoclave	3	1866.67	5600	0.5	2.8
TV/DVD	2	70	140	6	0.8
Refrigerator	4	100	400	24	9.6
Centrifuge (large)	2	200	400	1	0.4
Microscopes	2	20	40	2	0.1
Laptop	4	45	180	4	0.8
Blood chemical	2	75	150	2	0.3
Computer desktop	6	100	600	6	3.6
Printer	6	50	300	2	0.6
Exhaust fan	6	40	240	12	2.8
Air conditioner	4	1000	4000	2	8.0
Surgery spotlight	3	100	300	4	1.2
Ventilator	2	150	300	4	1.2
Anaesthetic machine	1	100	100	3	0.3
Incubator	2	200	400	3	1.2
Cautery diathermy	1	100	100	2	0.2
Pulse oximeter	4	20	80	2	0.2
X-ray machine	1	1000	1000	1.2	1.2
Water pump	2	2984	5968	1.5	7.2
Total			29,558		80.5

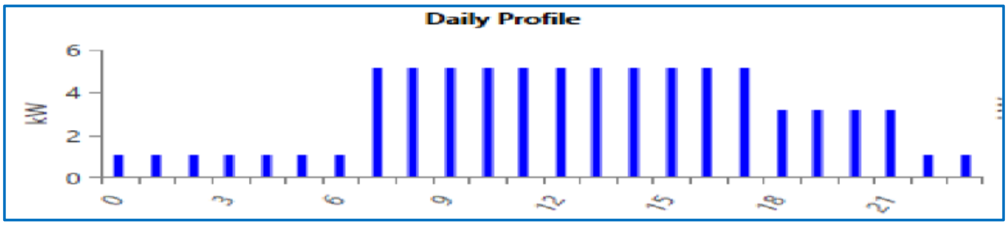


Figure 3. Daily profile of electric demand load.

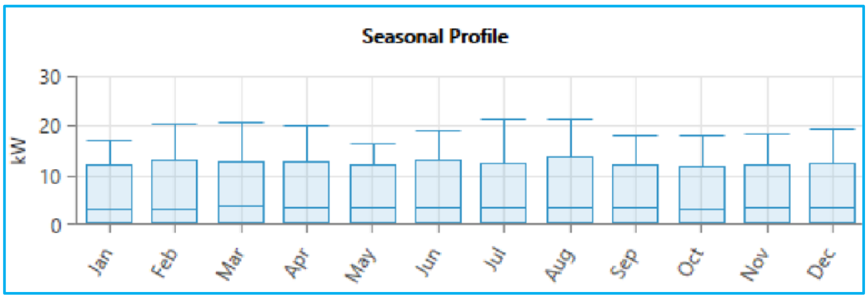


Figure 4. Average scaled monthly load.

2.2.4. Economical key terms

The economical perception of HOMER pro software has the following key terms related to designing and planning micro-grid and their economics which are discussed in the subsections.

a) **Net present cost (NPC):** The net present cost is a cost of analysis while dealing with all costs and revenues that operates the project lifetime. The total NPC is calculated by the equation[25].

$$\text{NPC} = \frac{Ctot, ann}{CRF(i, Tp)} \tag{1}$$

where $Ctot, ann$ is the total annualized cost ($/year), i is the real interest rate (%), Tp is the project warranty (year) and CRF is the capital recovery factor derived by[25]

$$\text{CRF} = \frac{i(1+i)^{Tp}}{(1+i)^{Tp}} \tag{2}$$

b) **Cost of energy (COE):** It is defined as the average cost per kWh of the total amount of electric load that the energy system generates in given equations[25].

$$\text{COE} = \frac{Ctot, ann}{Etot, ann} \tag{3}$$

where, $Etot, ann$ represents the total annual electricity generated that served the load.

c) **Operating cost:** The cost is a derived mathematical equation. This is the difference between the total annualized cost of the component and its capital cost.

From[25] the equation given

$$C_{operating} = C_{ann,tot} - C_{cap,tot} \tag{4}$$

where, $C_{ann,tot}$ = total annualized cost; $C_{cap,tot}$ = total capital cost.

d) **Operation and maintenance cost (O & M):** It is defined as the total amount of operating cost and maintenance of the appointed component of the micro-grid model that analyzes the cost difference between total power buying the grid and various renewable energy sources.

3. Result and discussion

3.1. Design Specification

The system consists of the necessary loads, a photovoltaic (PV) system, an inverter, a diesel generator, net metering, and all of these components. The hybrid power system consists of two buses—the AC bus and the DC bus. The main grid is the primary source of power for the loads, and the photovoltaic power system and energy storage device act as secondary sources of power. The loads are connected to the AC bus, which means that they receive power in the form of alternating current. The photovoltaic power system and energy storage device are connected to the DC bus, which means that they provide and store power in the form of direct current. Bi-directional energy transfer, which means that energy can flow in both directions between two buses—the DC bus and the AC bus. DC bus does not supply any load in the future, it might be possible to use the DC bus to supply some loads. The hybrid photovoltaic system consists of a solar power system, a diesel generator, a converter, a grid, and load components. DC electric power is produced by PV modules using solar radiation. The output power is provided by PV modules. When there is no grid access or when there is an electrical power outage, diesel generators are employed as backup energy sources. Energy is moved from the AC bus to the DC bus inside the system using a bidirectional power converter. The converter has a dual function, acting as both an inverter and a rectifier, depending on the system's energy requirements. The power only required only for the health care. The load is collected from this area. The proposed system is done by HOMER pro. The system consists of solar PV panels, a diesel generator, a converter and a grid connection. The schematic diagram of the analyzed system is presented in **Figure 5**.

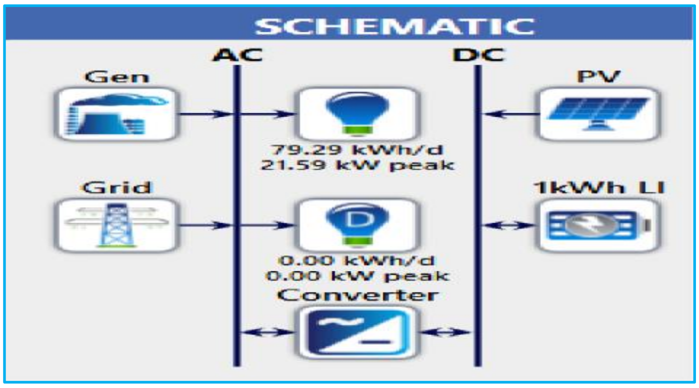


Figure 5. Schematic diagram of proposed system.

3.2. Optimization result

The data and the daily demand of the considered health complex facility equipment were implemented for the analysis of the optimal system configuration. There several possible configurations were suggested by HOMER powering health tool. We searched to design a system for the Upazilla complex that will fulfill our demand for electricity as well as is environmentally friendly and cost-effective. Comparing results based on net present cost, levelized cost, operating cost, renewable fraction, unmet load, capacity shortage, and harmful gas emissions were taken into consideration. In this analysis, six cases are considered for meeting up the load. It was evident from the result shown in **Table 2**.

Table 2. Comparison of various configurations.

Configuration	**PV (KW)**	**Generator (KW)**	**Grid (kW)**	**Storage (kW·h)**	**Converter (kW)**	**Initial capital ($)**	**Total net present cost ($)**	**Operating cost ($/yr)**	**COE ($/kWh)**	**Fuel (L/yr)**	**Generator (hrs/yr)**
PV/Storage	31	-	-	461	21	30,455	32,915	75	0.035	0	0
Genset/PV/Storage/ Grid	34	24	500	300	20	35,696	35,524	5	0.025	71	12
Genset/PV/Storage	30	24	-	292	24	34,320	35,857	50	0.038	125	19
PV/Storage/Grid	64	-	500	228	15	49,076	51,312	68	0.029	0	0
Genset/Storage/Grid	-	24	500	75	21	15,923	118,4573	3138	0.125	10	2

Case 1. PV-Storage-based. This system only uses a 31 kW PV panel. The parameters of this PV panel has been shown in **Table 3**. The net present cost and the cost of energy of the system are $32,915 and $0.035 per kWh respectively. The operating cost of this system is estimated $75/year. The total production of electricity in the system per year is 49,385 kWh. The system has an electricity capacity shortage of 28 kWh per year and has unmet load of 4 kWh per year. Since only PV panels are used, the system will not emit any harmful gases. The system is only used for electricity in the daytime. But it cannot meet the demand for electricity at night in the selected hospital.

Table 3. Parameters of PV panel.

Electrical data	**STC***	**NMOT***
Nominal Maximum Power (Pmax)	540 W	403 W
Opt. Operating Voltage (Vmp)	41.0 V	38.2 V
Opt. Operating current (Imp)	13.18 A	10.55 A
Open circuit Voltage (Voc)	49.2 V	46.3 V
Short circuit current (Isc)	13.9 A	11.21 A
Module Efficiency	21.1%	
Operating Temperature (°C)	−40 °C~+85 °C	
Power Tolerance	0~+10 W	
Temperature Coefficients of Pmax	−0.35%/°C	
Temperature Coefficients of Voc	−0.27%/°C	
Temperature Coefficients of Isc	0.05%/°C	
Nominal Module Operating Temperature	42 ± 3 °C	
Dimensions	2254 × 1135 × 35	mm

Case 2. Genset-PV-Storage-Grid. During the simulation, it is observed that the net present cost of this system is $35,524. The operating cost that operates every year of the system was $5. The levelized cost of energy is $0.023. The total production of electricity is 53,736 kWh per year from the system. It is observed that the optimum size of the generator, PV, and inverter was found 24 kW, 34 kW, and 500 kW respectively. Almost 99% of electricity is generated from the PV system, while the rest of the electricity is produced using a diesel generator and a grid. After fulfilling the electricity demand the excess energy can be sold at the national grid. Per year average fuel consumption is estimated at 71 L. The system emits 244 kg CO_2 per year.

Case 3 Genset-PV-Storage: In this system, the net present cost of the system is $35,857. Per year operating cost of the system is $50. The levelized cost of the system is $0.038 per kilowatt. The total amount of electricity produced 48,275 kWh per year. It is observed that the optimum size of the generator and PV was found 34 kW, 24 kW respectively. Almost 98% of produced electricity from PV panels and backup service was provided by a generator. The system also emits CO_2 gas and other harmful gases that are 1.40% higher than that in case 2. Excess electricity is generated at 16,378 kWh/year but without grid connected system so much electricity is wasted.

Case 4. PV-Storage-Grid. This system is PV-Grid connected system. The net present value of operating the system is $51,312 and the operating cost of the system is $68 per year. The levelized cost of energy is $0.029 per kilowatt. It is observed that the optimum size of the generator and PV are 30 kW, 24 kW respectively. The total amount of electricity is 101,582 kWh/year. The unmet load is 14 kWh/year and capacity shortage is 27 kwh/year. When power outages occurs, there is no alternative way to fill the electricity problem.

Case 5. Storage-Grid. This system is only grid connected system with net present value of $107,995 per year. The operating cost is $3265 and levelized cost of energy per kilowatt is $0.125. This system generates total $30,599 kilowatt of electricity per year. Every year electricity shortage is 27 kW. Besides, the system emits 19,338 kg of CO_2. In this system, the system will not work if there is load shedding.

Case 6. Genset-Storage-Grid. In this system NPC and COE are obtained to be $184,573 and $0.125 per kilowatt respectively. The operating cost to operate the system is $3138 per year. It is observed that the optimum size of the generator and grid are found 24 kW, 500 kW respectively. With the help of this system, the total produced electricity is almost 30618 kWh per year. In this system, high amount of CO_2 and other harmful gases are emitted which are harmful to the environment. Besides, the system is very expensive.

From the above cases, it is obvious that, case 2 is more acceptable due to low cost, meeting the electrical needs of the hospital as well as environment friendly.

3.2.1. Solar panel

The photovoltaic panel is used to generate from the health complex load. The amount of energy generated by a PV panel hourly basis is determined by PV characteristics and cell temperature. In this paper, we used Generic flat plat solar cell adopts new technology to improve the efficiency of modules which offers a better aesthetic appearance, making it perfect for rooftop installation. We used the Canadian Solar.ModelCS6W-540MS and power 540 WpH[26]. The monocrystalline solar panel has 21.1% efficiency. It has maximum power current 13.18 A, Maximum power voltage 41.0 V, Open circuit voltage 49.2 A and Short circuit current 11.21 A. Its advanced glass and cell surface textured design ensure excellent performance in low-light environment[27]. The component cost are described the **Table 4**. From the market survey the panel price, replacement cost, O & M and derating factor are found to be $590, $531, $0.01 and 80% respectively.

Table 4. Constants and worth of PV panels.

Component	**Specifications**
Solar panel	$590
Replacement amount	$531
Derating factor	80%
Operation & Maintenance	$0.01
Life time	25 year
Sizes considered	0.1
Slope	25.774 degree
Tracking system	Fixed

3.2.2. Converter

A converter is the one of the important components of the system. Because, without this we cannot convert solar PV panels output DC into AC supply. The converter basically transforms direct current into alternating current. The selected converter Sungrow brand and model is SG 20RT provides a 20 kW 3 phase converter having an efficiency of 98.50%[26]. The capital cost and the replacement cost is $140. The warranty of the converter is 15 years. The overall specifications of this converter has been shown in **Table 5**.

3.2.3. Diesel generator

Auto-sized generators uses diesel for designing a model. The diesel price is estimated at $0.872/liter[28]. As shown in **Table 6**, the component capital cost is $160 and replacement cost is $128 and the maintenance and operation cost is $0.01 per hour.

Table 5. Specifications of converter.

Component	Specifications
Capital	$140.00
Replacement	$140.00
O & M	$0.00
Lifetime	15 year
Sizes to consider	1000 kW
Inverter can parallel with AC generator	Yes

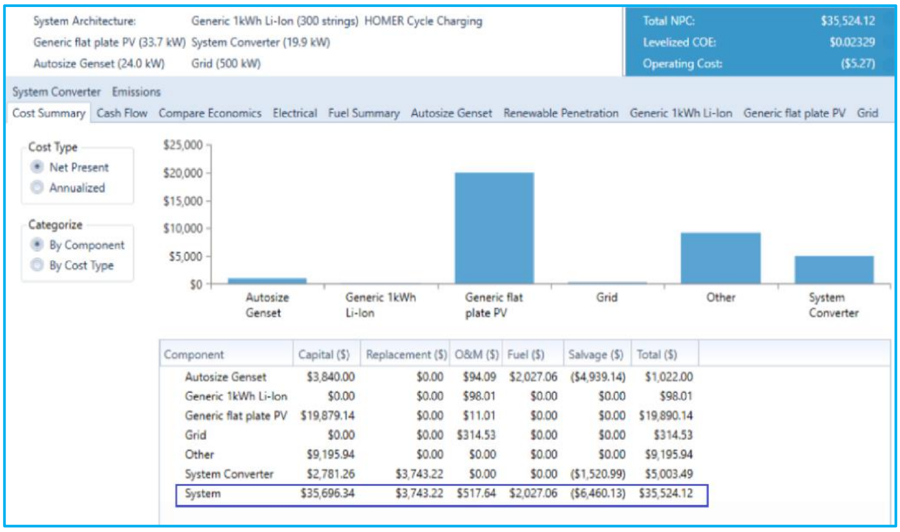
Table 6. Constants and worth of diesel generator.

Component	Specifications
Capital	$160.00
Replacement	$128.00
O&M	$0.01
Warranty	15,000 h
Size to consider	24
Diesel price	$0.87/L
Lower heating value	43.2 MJ/kg
Density	820.00 kg/m^3
Carbon content	88.0%
Sulfur content	0.4%

Diesel generators are used as substitute energy sources in the case when there is no access to the grid. Diesel generators, which are also preferred as backup power, provide a robust and reliable energy supply due to structures.

3.3. HOMER data analysis

The cost summary has been shown in **Figure 6**. All components have capital cost, replacement cost, operation & maintenance cost, fuel cost, and salvage cost. In system the total capital cost, replacement cost, operation & maintenance cost, fuel cost, salvage cost, total net present cost are $35,696.34, $3743.22, $517.64, $2027.06, $6460.13 and $35,524.12 respectively.



System Architecture: Generic 1kWh Li-Ion (300 strings) HOMER Cycle Charging
Generic flat plate PV (33.7 kW) System Converter (19.9 kW)
Autosize Genset (24.0 kW) Grid (500 kW)

Total NPC: $35,524.12
Levelized COE: $0.02329
Operating Cost: ($5.27)

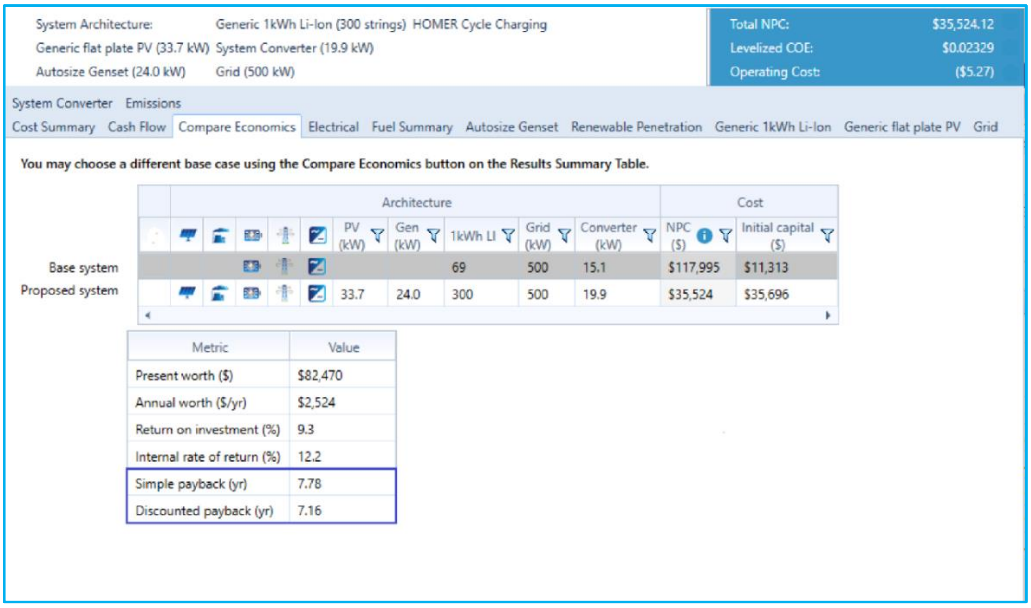
Cost Type
● Net Present
○ Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Autosize Genset	$3,840.00	$0.00	$94.09	$2,027.06	($4,939.14)	$1,022.00
Generic 1kWh Li-Ion	$0.00	$0.00	$98.01	$0.00	$0.00	$98.01
Generic flat plate PV	$19,879.14	$0.00	$11.01	$0.00	$0.00	$19,890.14
Grid	$0.00	$0.00	$314.53	$0.00	$0.00	$314.53
Other	$9,195.94	$0.00	$0.00	$0.00	$0.00	$9,195.94
System Converter	$2,781.26	$3,743.22	$0.00	$0.00	($1,520.99)	$5,003.49
System	$35,696.34	$3,743.22	$517.64	$2,027.06	($6,460.13)	$35,524.12

Figure 6. Cost summary.

Comparison based on economics has been shown in **Figure 7**. It is the best solution from the different combinations. 33.7 kW PV system, a 24 kW generator, 500 kW grid and 19.9 kW converter based system is proposed in this study. Its present worth, annual worth, return of investment and payback period are $82.470, $2524, 9.3% and 7.16 years respectively.



System Architecture: Generic 1kWh Li-Ion (300 strings) HOMER Cycle Charging
Generic flat plate PV (33.7 kW) System Converter (19.9 kW)
Autosize Genset (24.0 kW) Grid (500 kW)

Total NPC: $35,524.12
Levelized COE: $0.02329
Operating Cost: ($5.27)

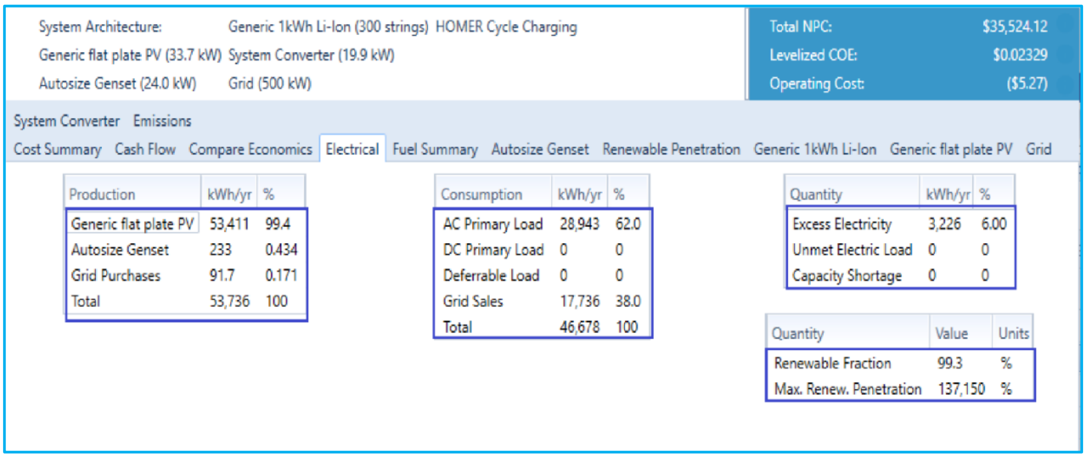
You may choose a different base case using the Compare Economics button on the Results Summary Table.

	Architecture					Cost	
	PV (kW)	Gen (kW)	1kWh LI	Grid (kW)	Converter (kW)	NPC ($)	Initial capital ($)
Base system			69	500	15.1	$117,995	$11,313
Proposed system	33.7	24.0	300	500	19.9	$35,524	$35,696

Metric	Value
Present worth ($)	$82,470
Annual worth ($/yr)	$2,524
Return on investment (%)	9.3
Internal rate of return (%)	12.2
Simple payback (yr)	7.78
Discounted payback (yr)	7.16

Figure 7. Compare economics.

Figure 8 represents the electrically analysis report. In this report, the total electricity production is 53,736 kWh/year by the generic flat plate PV, autosize genset and grid purchased. Total power consumption is 46,678 kWh/year by AC primary load. 3226 kW of electricity is surplus every year. The quantity of renewable function of the system is 99.3%.



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Total NPC: $35,524.12
Levelized COE: $0.02329
Operating Cost: ($5.27)

Production	kWh/yr	%
Generic flat plate PV	53,411	99.4
Autosize Genset	233	0.434
Grid Purchases	91.7	0.171
Total	53,736	100

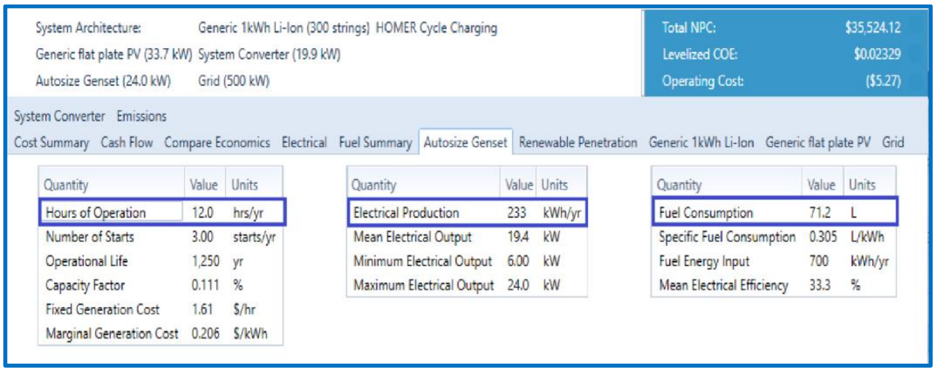
Consumption	kWh/yr	%
AC Primary Load	28,943	62.0
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	17,736	38.0
Total	46,678	100

Quantity	kWh/yr	%
Excess Electricity	3,226	6.00
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	99.3	%
Max. Renew. Penetration	137,150	%

Figure 8. Electrically analysis report.

In **Figure 9**, the Auto Size Genset has been presented. It has a capacity of 24 kW. It generates 233 kWh of electricity annually. Every year, 72 liters of fuel are consumed.



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Total NPC: $35,524.12
Levelized COE: $0.02329
Operating Cost: ($5.27)

Quantity	Value	Units
Hours of Operation	12.0	hrs/yr
Number of Starts	3.00	starts/yr
Operational Life	1,250	yr
Capacity Factor	0.111	%
Fixed Generation Cost	1.61	$/hr
Marginal Generation Cost	0.206	$/kWh

Quantity	Value	Units
Electrical Production	233	kWh/yr
Mean Electrical Output	19.4	kW
Minimum Electrical Output	6.00	kW
Maximum Electrical Output	24.0	kW

Quantity	Value	Units
Fuel Consumption	71.2	L
Specific Fuel Consumption	0.305	L/kWh
Fuel Energy Input	700	kWh/yr
Mean Electrical Efficiency	33.3	%

Figure 9. Auto size genset.

Figure 10 describes the generic flat plate PV. The rated capacity and capacity factor of PV is 33.7 kW and 18.1% respectivly. The production of electricity is 53,411 kWh per year by generic flat plate PV. The PV penetration is 185%. The levelized cost of PV is $0.0114 kWh. The PV power output has shown in the **Figure 10**.

System Architecture: Generic 1kWh Li-Ion (300 strings) HOMER Cycle Charging
Generic flat plate PV (33.7 kW) System Converter (19.9 kW)
Autosize Genset (24.0 kW) Grid (500 kW)

Total NPC: $35,524.12
Levelized COE: $0.02329
Operating Cost: ($5.27)

Quantity	Value	Units
Rated Capacity	33.7	kW
Mean Output	6.10	kW
Mean Output	146	kWh/d
Capacity Factor	18.1	%
Total Production	53,411	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	33.0	kW
PV Penetration	185	%
Hours of Operation	4,378	hrs/yr
Levelized Cost	0.0114	$/kWh

Figure 10. Generic Flate plate PV.

Figure 11 shows the state of the Grid. In this system, energy is sold to grid and energy purchased from the grid are 17,796 kWh/yr and 17,644 kWh respectively. Net energy purchases from the grid is 92 kWh.

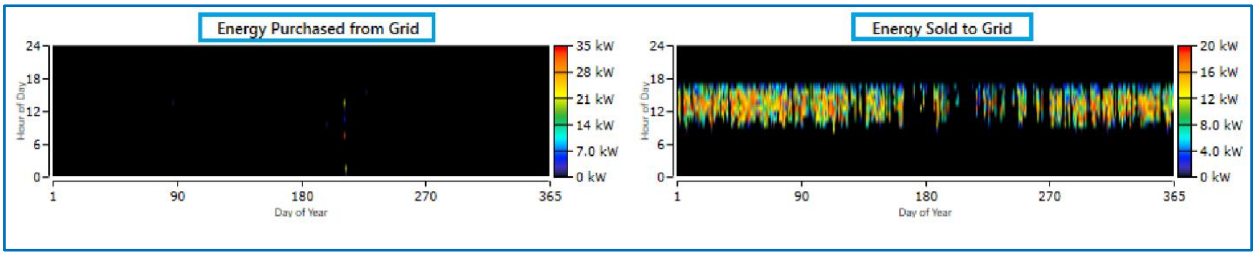
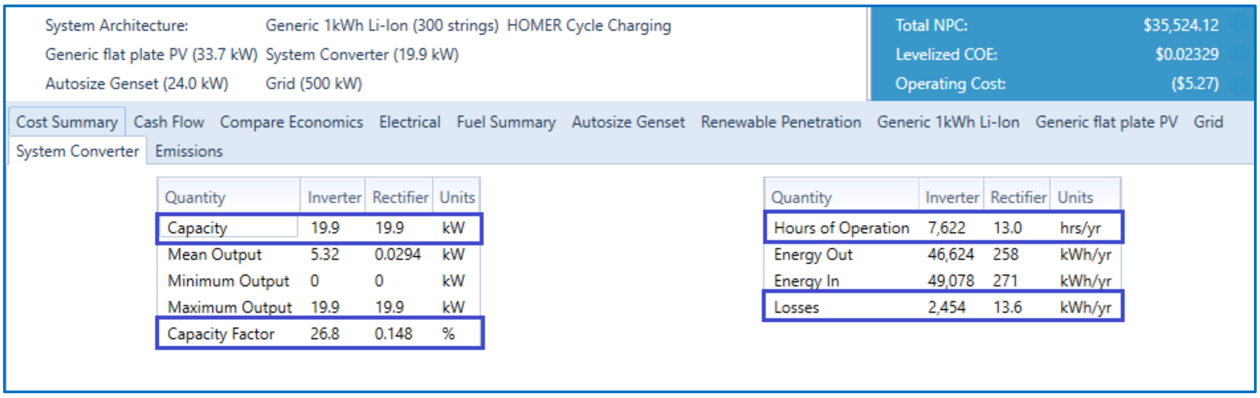


Figure 11. State of grid.

Figure 12 presents the output of the system converter and rectifier. The capacity of the converter system is 19.9 kW. The capacity factor of the inverter is 26.8%. It operates 7622 h per year. The rectifier operates 13 h per year.



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Generic flat plate PV (33.7 kW) System Converter (19.9 kW)
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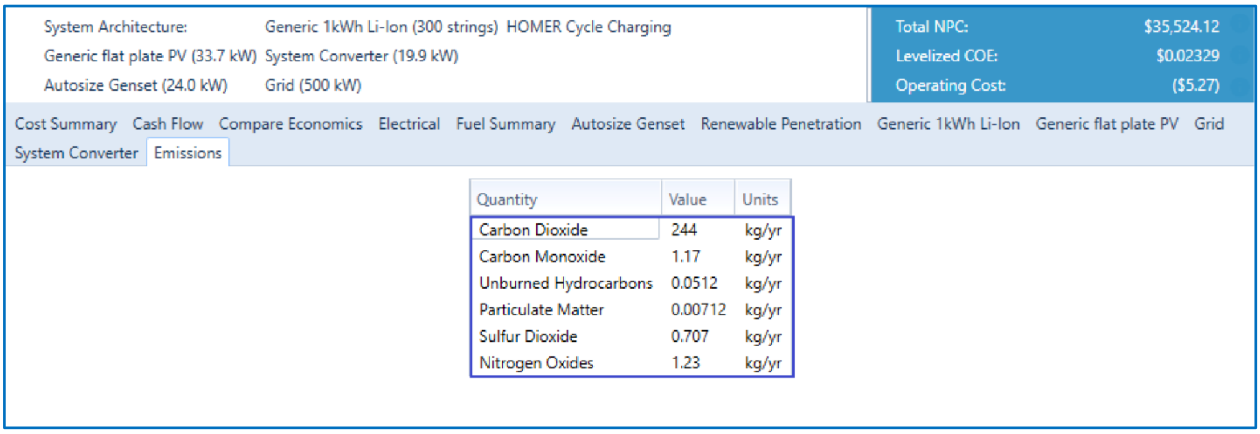
Total NPC: $35,524.12
Levelized COE: $0.02329
Operating Cost: ($5.27)

Quantity	Inverter	Rectifier	Units
Capacity	19.9	19.9	kW
Mean Output	5.32	0.0294	kW
Minimum Output	0	0	kW
Maximum Output	19.9	19.9	kW
Capacity Factor	26.8	0.148	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	7,622	13.0	hrs/yr
Energy Out	46,624	258	kWh/yr
Energy In	49,078	271	kWh/yr
Losses	2,454	13.6	kWh/yr

Figure 12. The output of the Converter.

Figure 13 is about Gaseous emission, the whole system emitted various pollutant gases. The emission of carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen monoxide, and unburned hydrocarbons are 244 kg/year, 1.17 kg/year, and 1.23 kg/year, 0.707 kg/year and 0.0512 kg/year respectively.



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Total NPC: $35,524.12
Levelized COE: $0.02329
Operating Cost: ($5.27)

Quantity	Value	Units
Carbon Dioxide	244	kg/yr
Carbon Monoxide	1.17	kg/yr
Unburned Hydrocarbons	0.0512	kg/yr
Particulate Matter	0.00712	kg/yr
Sulfur Dioxide	0.707	kg/yr
Nitrogen Oxides	1.23	kg/yr

Figure 13. Emissions.

3.4. Calculation

The panel has 25 years warranty and 1st year power degradation is no more than 2% and subsequent 2nd year to 25th year annual power degradation are no more than 0.55%. As a result, the calculated value is 25 year. The total production of electricity is 1,240,287.97 kWh. So, actual per unit cost given from the study of Mat Isa et al.[29] as follows:

$$\text{Levelized cost of energy} = \frac{\text{Net present cost} + (\text{Annualized cost} + \text{levelized cost of energy}) \times \text{year}}{\text{total electricity production}}$$

$$= \frac{35524 + (1087 + 0.023) \times 25}{1240287.97}$$

$$= 0.0505.$$

The calculated Levelized cost is $ 0.0505.

Payback period

The term payback period refers to the amount of time it takes to recover the cost of an investment. So, in this system total power generation is 53,736 kWh per year and the electricity cost is $0.97 per unit[28].

From the work of Mat Isa et al.[29], the total saving per year can be measured as follows:

Total saving per year = 1st year PV output × per unit electricity cost in Bangladesh in USD = 53736 × 0.097 = $5212.40

$$\text{Payback period} = \frac{\text{net present cost}}{\text{tatal saving per year}} = \frac{\$35524}{5212.4} = 6.82 \cong 7$$

The payback period is 7 years. In this system, the government of Bangladesh, actually can save cost as net present cash flow which is either comparable with the cost for using photovoltaic system.

4. Operating strategy

Net metering is a billing method that allows an electricity user to install solar panels on his business premises and then feeds the excess electricity back into the utility grid after use. In 2018, The government of Bangladesh launched a net metering guideline to promote rooftop solar power systems[30]. The proposed system uses a PV/Grid/Diesel generator that is an on grid system. Because in this proposed system battery is not considered. So, this system is easy to be installed with net-meter. With the use of net metering, electricity users can attach their rooftop solar systems to the distribution grid. When this system is successfully implemented, the dependency on the grid power will reduce. The difference between production and consumer power is adjusted in the billing system at the closing of the financial year then Excess load power is expressed by

$$P_{\text{load}} = P_{\text{production}} - P_{\text{consumer}} \tag{5}$$

From Equation (5), if $P_{\text{load}} > 0$ the solar power is exported to the grid, and if $P_{\text{load}} < 0$ the consumer imports power from the grid. The **Figure 14** shows the net metering solar PV system in Upazila Health Complex.

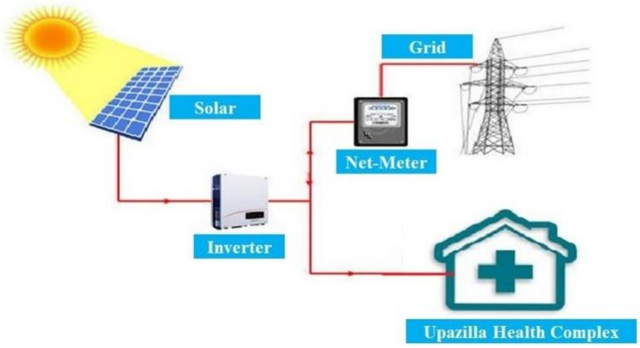

Figure 14. On-grid net metering solar PV system.

The total solar power generation in one year is 53,736 kWh and the total power consumed in the selected area is 46,678 kWh/year. The surplus electricity of 3226 kWh solar power~~s~~ will be sold to the grid.

5. Conclusions

Rural health centers are healthcare facilities that provide essential preventive and curative care to rural communities. This paper aims to assess whether it is technologically and economically feasible to use renewable energy sources to Kaunia Upazilla Health Care Center. The study evaluated six distinct cases, each with a unique arrangement of solar panels, diesel generators grid connection and net meter. The main result of this article is summarized as follows:

1) The optimal size of the component was a 34 kW PV module, 24 kW diesel generator, and 20 kW inverter.
2) The optimal system NPC and COE were $35,524, and $.0505 respectively.

3) The system produced energy was 53,736 kWh per year and energy consumption was 46,678 kWh per year. The excess energy of electricity was 3226 kWh per year that could be sold to the grid.
4) From a sustainability point of view, the system provided 99 percent renewable energy, in the project lifetime it could save 697.23 tones CO_2 emissions. So it might contribute the fill sustainable development goals.
5) For the system will application, almost 7.16 years would be needed for full return of installation cost of the photovoltaic on grid system.

Author contributions

Conceptualization, MFR; methodology, AI, MFR, AKMMH, PA, MHA, MRI, MKH and ABMI; software, AI, MFR, AKMMH, PA, MHA, MRI, MKH and ABMI; validation, AI, MFR, AKMMH, PA, MHA, MRI, MKH and ABMI; formal analysis, AI, MFR, AKMMH, PA, MHA, MRI, MKH and ABMI; investigation, XX; resources, XX; data curation, AI, MFR, AKMMH, PA, MHA, MRI, MKH and ABMI; writing—original draft preparation, AI, MFR, AKMMH, PA, MHA, MRI, MKH and ABMI; writing—review and editing, AI, MFR, AKMMH, PA, MHA, MRI, MKH and ABMI;; visualization, AI, MFR, AKMMH, PA, MHA, MRI, MKH and ABMI; supervision, MFR. All authors have read and agreed to the published version of the manuscript.

Funding

By getting no specific grants this research was done from funding agencies in the non-profit sectors including public and marketable.

Acknowledgments

The authors are satisfied to Department of Electrical and Electronic Engineering Begum Rokeya University, Rangpur 5400, Bangladesh due to using Advanced Energy Materials and Solar Cell Research Laboratory.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare no conflict of interest.

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