Performance Evaluation of Supplying Electricity to an Off-Grid Rural Healthcare Center in Egypt Using PVSOL

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Abstract

Assessments of the techno-economic viability of the solar renewable energy system have been prompted by the frequent price fluctuations of fossil fuels, the environmental release of derivatives produced during fuel combustion, and the incredibly high installation cost of the current conventional photovoltaic energy system. This study reports on the techno-economic performance evaluations of a solar renewable energy system for a rural healthcare facility in Egypt. In this case, a micro-grid solar hybrid photovoltaic system will power a medical facility in Fayoum City. 400 Wp solar panels, a 5 kW bidirectional inverter, Lithium iron phosphate battery, connecting cables, a mounting system, and other accessories make up the open-space PV system. This proposed system is designed using MATLAB/SIMULINK. Modern PV design software, PVSOL Tool, has been used in this study to estimate load requirements and to evaluate the micro-grid system's techno-economic and environmental aspects. The load analysis showed that the chosen healthcare facility needed a 29.5 kW off-grid- solar PV system, with an anticipated net present cost of $13,105 and a levelized cost of energy of $0.0138. The predicted 11.982 MWh of real electricity produced by the PV system over a 25-year period will be more than the Fayoum health complex's electricity use during that time. The national grid or other institutions may purchase the additional 1.743 MWh of electricity generated by the solar system each year. The performance ration of this proposed system is 84%, PV cells efficiency is 19% and solar fraction is 100%. The total CO_2 emissions avoided against this proposed system is 474 kg/year. According to the load study, the hybrid PV system may be better than other power sources at supplying electricity for both routine operations and unexpected situations that come up in the daily operations of the healthcare industry. The government and other decision-making stakeholders are anticipated to benefit from the study's findings.

Keywords: Photovoltaic system; healthcare center; techno-economic analysis; PVSOL; CO_2 emissions

1. Introduction

Health care facilities in low- and lower-middle-income countries are thought to serve nearly 1 billion people without access to power or with unreliable energy. In addition to the most basic utilities like lighting, communications, and clean water supply, electricity is required to operate vital and life-saving medical devices. In addition to improving health through outcomes like safe childbirth, immunization, diagnostic capability, and emergency response, electricity is necessary for the availability and dependability of critical health services. About 12% and 15% [1] of medical facilities in low- and lower-middle-income South Asian and sub-Saharan African nations, respectively, lack power. Just 50% of hospitals in sub-Saharan Africa have consistent access to power. Health care institutions in rural and distant places face more energy access challenges. Electricity is necessary for the most basic operations of healthcare institutions, including lighting, communications, and the provision of clean water. Reliable power is also necessary for the medical equipment needed to administer most routine and emergency treatments, ensure vaccinations, and manage delivery. Access to dependable energy, particularly electricity, is a key component in enabling universal health coverage. Solar photovoltaic systems are one of numerous inexpensive, clean energy solutions that can be swiftly put into place to electrify healthcare facilities in a sustainable way and increase their climate resistance. Hospitals use almost three times as much energy as the average commercial building because they are always open, support life-saving equipment, lighting, HVAC systems, and more. While it is technically possible to convert these energy-intensive facilities to renewable sources like solar, wind, and geothermal, doing so will require careful planning and a substantial financial investment.

The idea of powering hospitals solely through renewable energy is gaining attention [2]. Over the last ten years, renewable energy has advanced remarkably in terms of dependability. Sustainable energy production is being led by advancements in solar and wind technology, and excess energy can now be stored for later use thanks to storage devices like batteries. But for vital institutions like hospitals, the sporadic nature of renewable energy presents a problem. Wind turbines need windy conditions to operate, and solar panels don't produce electricity at night. Hospitals could solve this by implementing hybrid systems that mix backup power from energy storage devices or other conventional sources with renewable energy. For example, battery storage has advanced greatly and can now store enough energy in the event that renewable sources aren't producing enough. Such hybrid solutions may provide the best of both worlds in hospitals where power outages could have potentially fatal outcomes: sustainability and backup system dependability. Micro-grids [3], which are localized grids that may function independently and separate from the conventional grid, are one possible remedy. These could be used by hospitals in conjunction with storage devices and renewable energy sources to guarantee power even in the event of larger grid outages. With this configuration, hospitals would be able to rely more on renewable energy sources without sacrificing dependability and become more resilient to interruptions. A clean and sustainable energy source that is becoming more and more popular, solar energy is being used in many different industries across the globe. The healthcare sector is one that stands to gain the most from solar energy utilization. The advantages of solar energy for the healthcare sector and its application will be discussed in this article. Saving money is one of the biggest advantages of solar energy for medical facilities [4]. An affordable and dependable substitute for conventional energy sources is solar energy. By using solar energy to produce electricity locally, hospitals and other healthcare facilities can lessen their dependency on the grid and save their energy costs. Frequently, the financial benefits might be substantial, enabling medical facilities to reallocate resources to other domains, such patient care. Hospital solar panels can drastically reduce reliance on the grid and monthly electricity expenditures by producing clean, on-site electricity. Long-term savings from this improve the hospital's operations and budget [5].

Healthcare Global, one of India's largest cancer treatment providers, put a 2.25 MW solar project in Karnataka into service in November 2022. The technology would help save about ₹4.2 crores annually and provide clean energy to two of HCG's top cancer centers. There are other healthcare organizations that have chosen to go solar besides HCG. Many hospitals have reduced their electricity costs in recent years by installing solar panels. Maternity wards and children's hospitals in rural areas rely on solar energy for vital power. Furthermore, the government of Bihar recently declared its intention to prioritize solarizing the state's hospitals. When it comes to solarizing healthcare facilities, one Indian state is setting all previous records. Chhattisgarh has been pushing hospitals to convert to solar power since 2009. Over 1432 government health centers already have panels installed by the state government, producing over 66,72,200 kWh of electricity annually [6]. Recent Solar Installations at Hospitals around the world are shown in table 1.

Table 1: Solar plants installations at hospitals around the world

Hospital Name	Location	Size
Lotus Hospital	Karur, Tamil Nadu	2.5 MW
Prachi Hospital Pvt. Ltd	Prayagraj, Uttar Pradesh	108 kW
Pluse Hospital	Amritsar, Punjab	101 kW
BL Aggarwal Healthcare Pvt Ltd	Sri Ganganagar, Rajasthan	94 kW
Shripal Hospital Bhigwan Road	Pune, Maharashtra	85 kW
Nirmal Dham Hospital	Karnal, Haryana	47 kW
Sanjivani Hospital	Churu, Rajasthan	21 kW

2. Literature Review

The growing demand for sustainable energy solutions has led to increased interest in renewable energy integration in healthcare facilities[7-9]. Hospitals require continuous energy supply, making reliability a key factor in system design. Several studies have explored solar, wind, and hybrid systems to ensure stable electricity, particularly in off-grid hospitals[10, 11]. Bizzarri [12] identified HVAC systems as primary energy consumers, highlighting the role of renewable energy in reducing costs. Islam et al. [13] demonstrated that a 32 kW solar-diesel hybrid system significantly reduced operational costs, while Ahmed et al. [14] found that a 24.3 kW solar PV system could meet 98% of hospital energy needs, reducing dependence on diesel generators. Off-grid hospital electrification has been less explored [15]. Dufo-López et al. [16] optimized a solar-diesel-battery system, reducing fuel costs by 54%. Ioannou [17] designed a 20.35 kWp solar PV system for a Texas hospital, achieving full grid replacement. These studies affirm solar energy's viability, especially for off-grid hospitals needing energy reliability. Solar PV systems are widely studied for hospitals[18-20]. Fthenakis et al. [21] found that solar PV could supply 75% of electricity needs, reducing reliance on unstable grids. Huang et al. [22] showed 50% operational cost reduction with solar adoption, with a payback period of less than five years. However, solar radiation variability impacts system reliability. Abdulkarim et al. [23] proposed a solar-wind hybrid system, achieving 90% renewable energy coverage with 30% lower total costs than diesel. Amoussou et al. [24] found solar-diesel hybrids to be more effective in areas with unstable solar radiation, ensuring better reliability. Hybrid renewable energy systems improve hospital energy stability [25, 26]. Nadeem et al. [27] found that solar-battery storage provided longer lifespan and lower maintenance costs than diesel-based alternatives. Miller and White [10] showed that smart microgrids integrated with solar PV reduced hospital energy demand by 35% while improving efficiency. Alotaibi et al. [28] explored biogas-solar hybrids, where biogas contributed 67.6% of hospital energy needs, demonstrating the importance of customized hybrid systems. Economic feasibility remains a key factor, as Ali and Chang [12] stressed careful system sizing to optimize solar-diesel consumption for cost efficiency. Battery storage is essential for solar-powered hospitals to ensure power supply during low-sunlight periods. Keshan et al. [29] found lithium-ion batteries to have longer lifespans and lower costs compared to lead-acid alternatives. White and Gordon [13] emphasized the importance of long-term financial sustainability in off-grid hospitals. Vilathgamuwa et al. [30] modeled battery degradation, highlighting the need for accurate lifespan estimations in system planning. Smart micro-grids and energy management enhance hospital energy efficiency [31-33]. Stluka et al. [34] demonstrated that smart microgrids improved load balancing and peak demand reduction. Bilir et al. [35] studied micro-grid-based solutions for disaster relief hospitals, emphasizing energy reliability. Elma et al. [36] found real-time energy monitoring increased efficiency by 20%, making renewable energy integration more effective. Medical equipment reliability is critical for solar-powered hospitals[37, 38]. Thavaraj et al. [39] demonstrated that a solar-powered neonatal warmer provided stable heating, mitigating power failure risks. Mazer [40] found solar-powered refrigeration maintained stable temperatures for over 100 hours, making them ideal for vaccine storage in rural hospitals. Mohanty et al. [41] emphasized hybrid systems with storage as critical for emergency preparedness, ensuring resilience against disruptions. Economic and environmental benefits further support solar adoption in hospitals. Tawalbeh et al. [42] found that solar PV reduced carbon emissions by 60%, significantly lowering environmental impact. Desai et al. [43] calculated 40% annual energy cost savings for solar-powered hospitals. Mohammad et al. [44] recommended renewable energy integration during hospital design stages, rather than as a retrofit, for maximum efficiency.

These studies collectively highlight solar PV, hybrid systems, and smart micro-grids as viable solutions for reducing costs, enhancing energy resilience, and minimizing environmental impact. While technical and financial challenges remain, improvements in storage, micro-grid integration, and hybrid configurations continue to drive renewable energy adoption in healthcare facilities. To reduce the initial cost and solve the blackout issue, photovoltaic system was investigated in this study, in which a battery would be used as a storage. The proposed system would function as an off-grid power plant for completely isolated locales and as an on-grid power system when it was connected to the electrical grid. Numerous studies on the simulation of renewable energy using PV design software have been published. To determine the best method of powering the health center at Fayoum city, Egypt; a techno-economic study and simulation using PV system design software is being attempted for the first time. This study aim is the design and techno-economic analysis of a micro-grid photovoltaic system for powering the Fayoum health facility in Egypt. The technical and financial data were analyzed using PVSOL Tool and MATLAB/SIMULINK. Selecting a location and calculating its overall load, simulating the optimal power supply combinations to meet a healthcare institution's electrical loads at the lowest feasible cost, and analyzing the generation from a technical and financial standpoint were the goals of this study. To satisfy the demands of the healthcare industry, new developments in solar energy technology are constantly being developed. Combining solar energy with battery storage technology is one of the latest innovations. This makes it possible for medical facilities to store extra solar energy produced during the day and use it at times when demand is highest, like at night or during blackouts. Healthcare facilities may improve energy security and drastically lower their energy expenses using this technology.

The structure of paper is as follows: introduction of healthcare units is provided in first part and past literature survey is shown in second section. The third section is methodology of system location details, meteorological data, load profile and simulation using PVSOL software. System components with details are presented in section 4. Section 5 illustrates modeling of this proposed system using MATLAB/SIMULINK tool and output curves. Section 6 has a full discussion of the findings and results. All conclusions with recommendations are exhibited in part 7.

3. Methodology

3.1 Geographical Location Data

Hospital 300 beds located in Fayoum city, Egypt. The city of Fayoum is located in Middle Egypt. Situated in the Fayoum Oasis, 100 kilometers (62 miles) southwest of Cairo in latitude 29o 23' North and longitude 30o 78' East, and with an elevation of 12 above sea level, it serves as the capital of the current Fayoum Governorate. The settlement of El Gharaq is located in a smaller depression south of the Fayoum Oasis. The Nile is also used to irrigate it. The agriculturally isolated settlement of El Gharaq in the Etsa district of Fayoum City is the subject of this study. However, there are a few small, dispersed towns in this area that prevent the grid system from providing energy. These communities will be able to supply electricity, enhance their standard of living, and irrigate crops thanks to the standalone photovoltaic pumping system.

3.2 Weather Data

PV systems can directly convert solar radiation into electrical power thanks to the photovoltaic effect, but their performance improves with the amount of solar energy that contacts their surface. With an annual worldwide radiation of 2000 kWh/m^2/day, Egypt's location in the Sunbelt region ensures exceptionally high radiation levels and the most sunny hours throughout the year [45, 46]. For the proposed case study, the irradiance distribution is sufficient. For this case study, hourly temperature and solar radiation data from 2021–2024 were collected by the National Aeronautics and Space Administration (NASA). Next, as shown in figures 1 and 2, the mean monthly solar radiation and ambient temperatures were calculated [47]. In summer, the average amount of sunlight each day is approximately nine hours, whereas in winter, it is four hours [48]. Based on the data collected, this case study provides a lot of promise for solar photovoltaic applications. The solar power performance of the panel is determined by its azimuth angle and horizontal orientation. Egypt's solar photovoltaic system would face the sun from the south. Changes in the azimuth angle of the system—the angle between the planet's normal and the south direction—have an impact on the rate of irradiation in every solar system. It is clear from Figure 1 that the selected site has a monthly average radiation level of 1.9055 kWh/m^2/month, with a minimum of 1.02 kWh/m^2/month in December and a maximum of around 2.56 kWh/m^2/month in May. This corresponds to periods of maximum demand for power and water. Furthermore, the highest recorded temperature was 30°C during the summer, while the lowest recorded temperature was 12°C during the winter. PV production is significantly impacted by these temperature values. These slow speeds reduce the amount of sand particle movement and the structural and mechanical costs of the system. This can help keep the PV modules' glass cover from getting scratched.

3.3 Load profile

From 9 p.m. to 5 a.m., rechargeable LED lights are used to keep the hospital's 300 beds from becoming overloaded at night. Table 2 displays an estimate of the hospital's load requirements. Figure 3 displays the profile of the daily load while figure 4 presents total energy curve around the year. Total consumption load profile in kW is illustrated in figure 5. With a load factor of 0.2, the daily load demand power and total energy are 2.9 kW and 91.108 kWh/day, respectively. A 10% time-step and 5% daily random variability were utilized for the simulation in PVSOL in order to improve the maximum load and take into account the unique load demand of the facility.

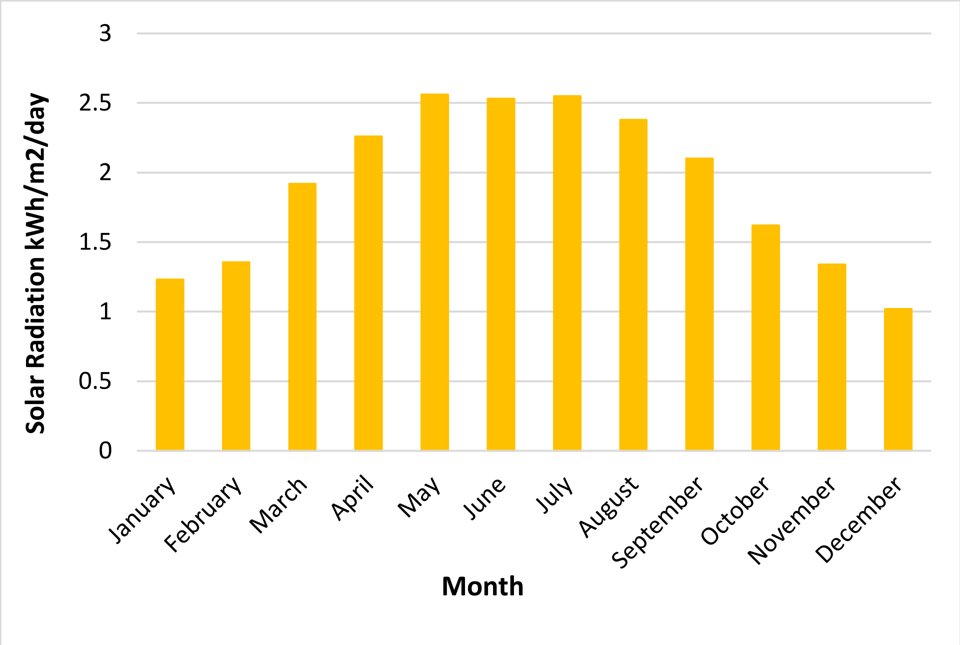


Fig.1: Solar radiation curve of Fayoum city

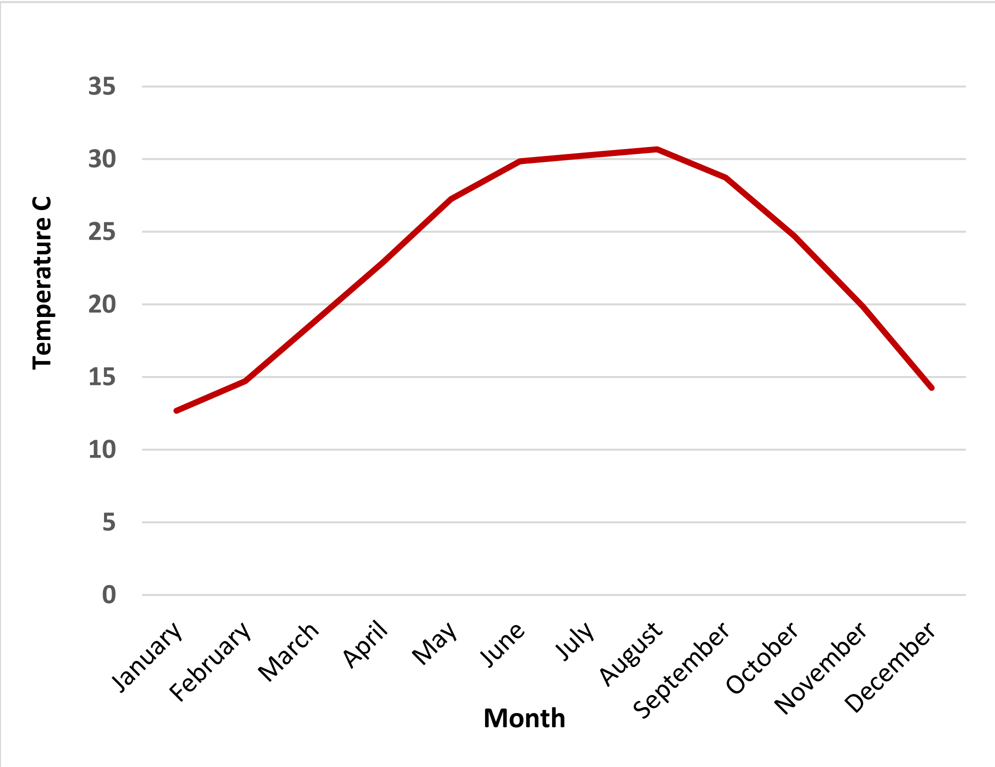


Fig.2: Temperature curve of Fayoum city

Table 2: Estimation of the load requirements of the hospital

Description	Power (W)	Quantity	Total Power (W)	Hours	Energy (kWh/day)
Vaccine Refrigerator	60	5	300	24	7.2
Domestic refrigerator	100	2	200	24	4.8
Lighting	15	100	1500	8	12
Equipment Suction	1400	3	4200	1	4.2
Incubator	200	1	200	2	0.4
Water Heater	1000	2	2000	1	2
Centrifuge	200	3	600	1	0.6
Microscope	20	2	40	5	0.2
X-ray machine	1000	1	1000	1	1
Surgery spot lights	50	5	250	4	1
Hematology analyzer	60	2	120	3	0.36
Laptop	60	3	180	5	0.9
TV	70	1	70	3	0.21
Printer	12	10	120	2	0.42
Air condition	1000	10	10000	3	30
Ventilator	150	1	150	2	0.3
Pulse Oximeter	30	4	120	3	0.36
Water Pump	2239	1	2239	2	4.478
Suction machine	80	1	80	1	0.08
Autoclave	1000	1	1000	1	1
Anesthetic machine	100	4	400	2	0.8
fan	40	50	2000	8	16
Electric oven	1000	1	1000	1	1
Clothes washer	500	2	1000	1	1
Clothes dryer	800	1	800	1	0.8
Total			29569		91.108

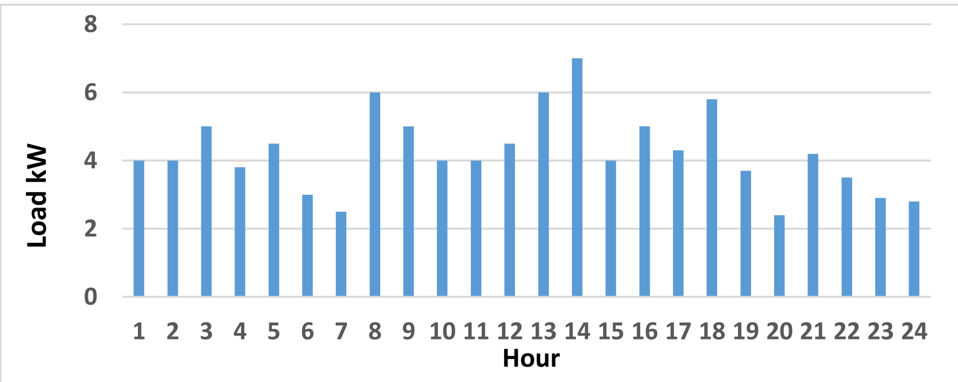


Fig.3: Daily load profile of 300 beds hospital

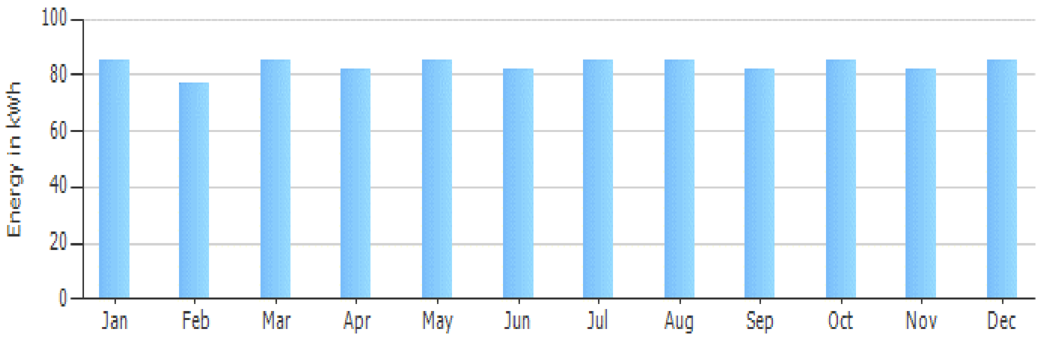


Fig.4: Monthly average of energy of load profile

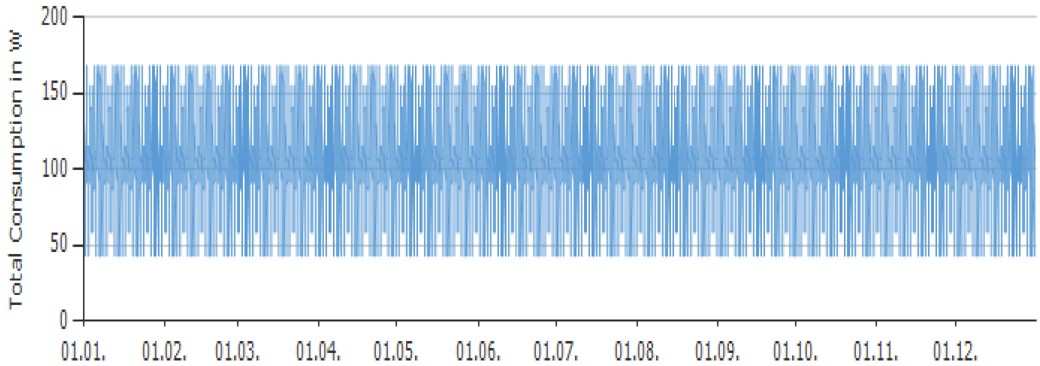


Fig.5: Total consumption curve of load profile around the year

3.4 Simulation using PVSOL software

Modern design, dynamic simulation, and yield estimation software is produced by Valentin Tools. This business provides design tools for heat pump (Geo TSOL), solar thermal (TSOL), and photovoltaic (PVSOL) systems [49]. Because PVSOL 2021 R8 [50] is an easy-to-use, fast, and dependable software program for simulating solar PV systems, it was employed for this investigation. A dynamic modeling program called PVSOL is used to develop and optimize solar systems in combination with electric vehicles, appliances, and battery systems. PVSOL can create and model any type of modern PV system, from tiny rooftop systems with a few modules to enormous solar parks with up to 100,000 modules. PVSOL finds the best connection between your PV modules and the inverter based on all pertinent variables, such as location, component specifications, site radiation statistics, and load profile. The software calculates the solar yield using the necessary annual PV energy, solar fraction, and solar yield data.

4. System Components

The overall proposed system scheme is shown in figure 6. PV arrays and modules are only one component of a PV system. Systems include mounting structures that line panels with the sun, as well as the parts that convert the direct-current (DC) electricity produced by modules into the alternating-current (AC) electricity required to power all of your home's appliances. The project will last for twenty-five years. The following are the elements of the suggested system.

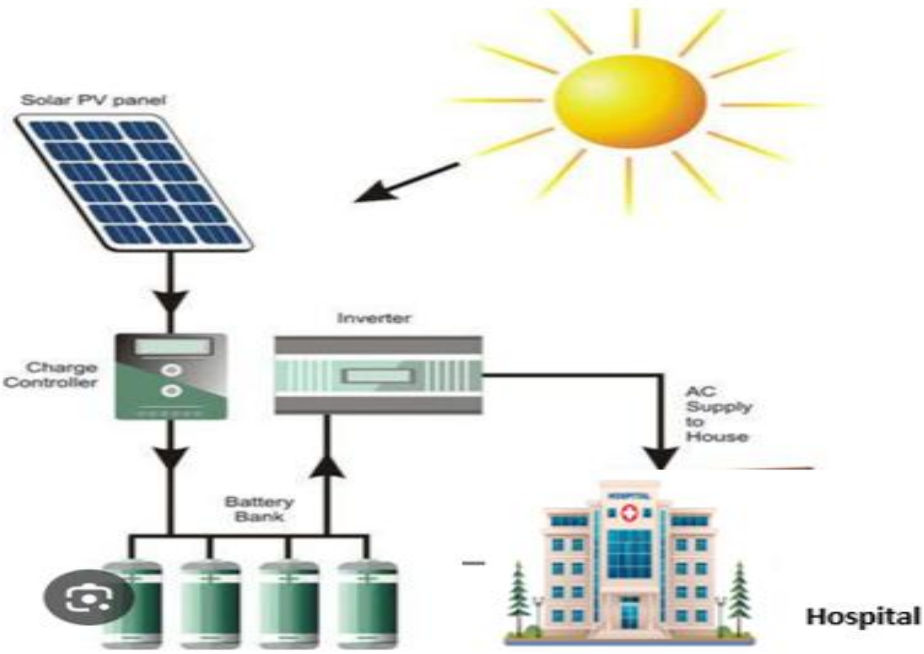


Fig.6: Proposed System scheme

4.1 PV Solar Panel

PV materials and equipment convert solar radiation into electrical energy. A single photovoltaic device is called a cell. A single solar cell typically produces only one or two watts of power. These cells are made of various semiconductor materials and are often thinner than four human hairs. PV cells are connected in chains to form larger units known as modules or panels, which boost the cells' power production. To generate arrays, modules can be used singly or in combination. One or more arrays are then connected to the electrical grid as part of a complete PV system. Because PV systems are modular, they may be built to meet almost any electric power need, no matter how big or little. The specifications of PV module used is presented in table 3. The P-V and I-V curves of this module are exhibited in figure 7 while temperature curve is shown in figure 8. Figure 9 describes degradation curve of PV module used here.

4.2 Inverter

A power inverter, often known as an inverter or invertor, is a power electronic device or circuitry that transforms direct current (DC) into alternating current (AC). The ultimate AC frequency depends on the particular device being utilized. Originally huge electromechanical devices, rectifiers convert AC to DC; inverters do the inverse. The specifications of inverter used is presented in table 4. The efficiency curve of inverter used here is shown in figure 10. Inverter check results of the proposed system is illustrated in figure11.

Table 3: Technical specification of the solar panel.

PV module	Si monocrystalline - HC
Power output	400 W
Efficiency	20.44 %
MPP voltage	32.2 V
MPP current	12.4 A
Open circuit voltage	36.98 V
Open circuit current	13.78 A
Length	1723 mm
Width	1134 mm
Installation method	Mounted open space
Fill factor	78.35 %
Inclination angle	30º
Orientation angle	180º
Lifetime	25 year

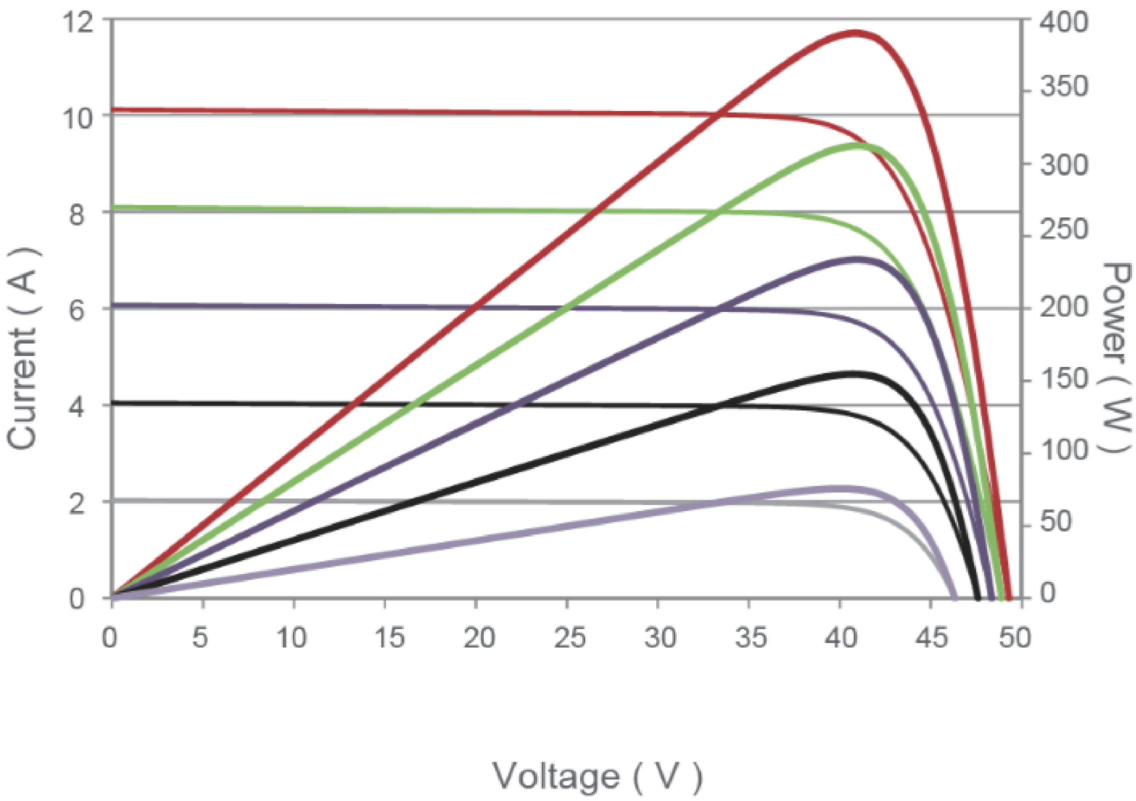


Fig.7: P-V and I-V curves of PV module used in this study

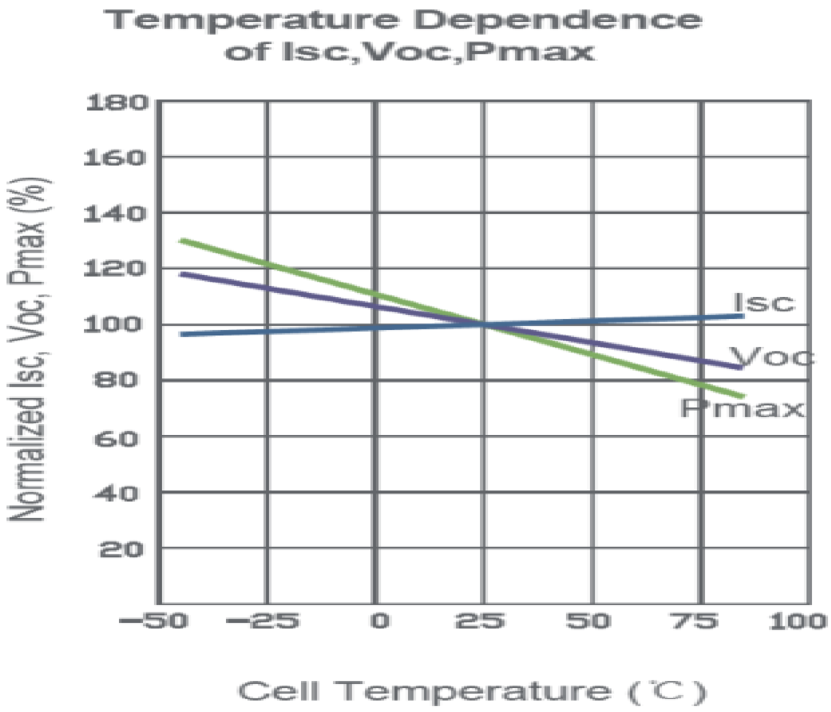


Fig.8: Temperature curve of PV cell used in this study

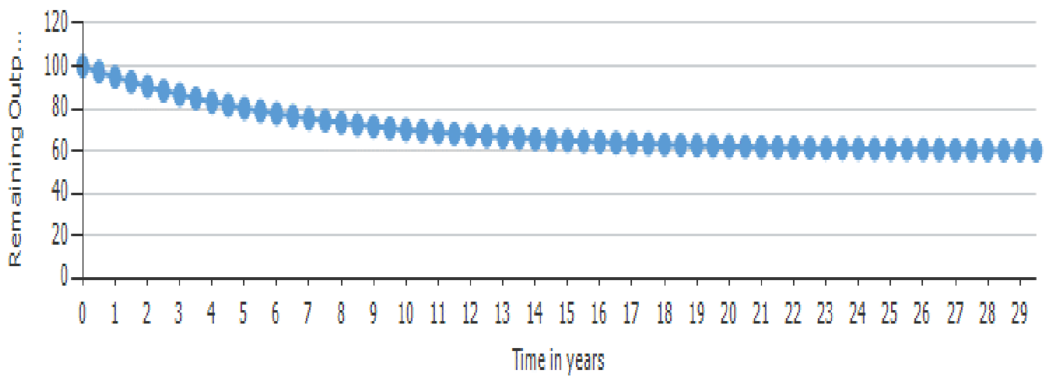


Fig.9: Degradation curve of PV module used in this study

Table 4: Technical specification of the inverter

DC nominal output in kW	5.1
Max DC power in kW	6
Nominal DC voltage in V	600
Max input voltage in V	900
Max input current in A	28
Max short circuit DC current in A	40
No of DC inlets	4
AC power rating in kW	5
Nominal AC voltage in V	230
No of phases	1
Count of MPP tracking	3
Lifetime in years	20

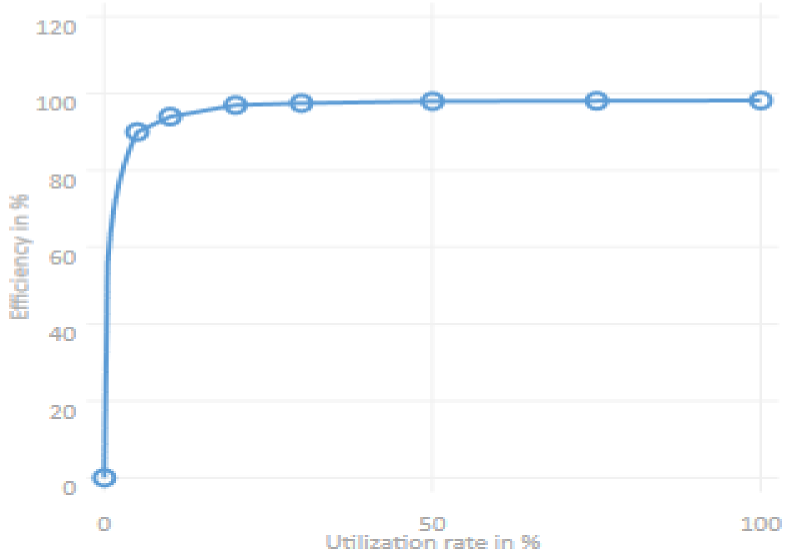


Fig.10: Inverter efficiency curve

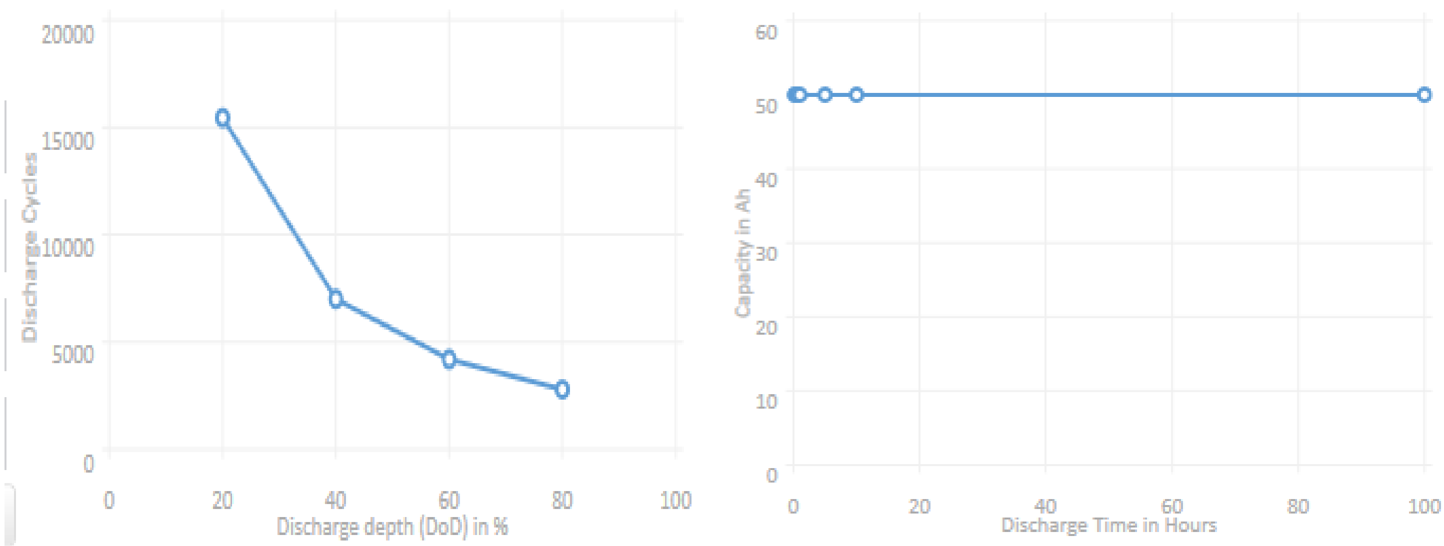
Fig.11: Inverter check results of the proposed system scheme

4.3 Storage battery

Technologies for battery storage are crucial to accelerating the switch to renewable energy from fossil fuels. Systems for storing batteries will become more and more important as renewable energy sources and meeting the need for electricity grow. Energy from renewable sources, like solar and wind, can be stored and then released when needed most via devices called battery storage or battery energy storage systems. Lithium-ion batteries, found in cell phones and electric cars, are currently the most widely employed storage technology for large-scale facilities that help power grids ensure a steady supply of renewable energy. Technical specification of battery used here is presented in table 5. The discharge cycle and capacity characteristics curves of this battery used here is shown in figure 12. Specification of Battery inverter used in this study is illustrated in table 6 and efficiency curve is presented in figure 13.

Table 5: Technical specification of the battery used

Battery name	Trina TRBM 2.5K-H
Battery type	Lithium iron phosphate
Cell voltage in V	3.2
No of cells in series	16
No of strings	1
Internal resistance in mOhm	9
Self-discharge in % month	3.5
Weight in kg	30.6
Length in mm	540
Width in mm	390
Autonomy days	2
Lifetime in years	10



Discharge cycle

Capacity characteristics

Fig.12: Battery curves

Table 6: Specification of Battery inverter used

Model No.	SolarMax 3000 ES-AC
Max. DC Power	3000 W
Max. DC Current	32 A
Nominal battery voltage	48 V
Maximum battery charging current	66 A
No of MPP Trackers	2
MPP(T) Voltage	230 V
Max. AC Power	3.96 kW
Max. Efficiency	97.6 %
Lifetime in years	5

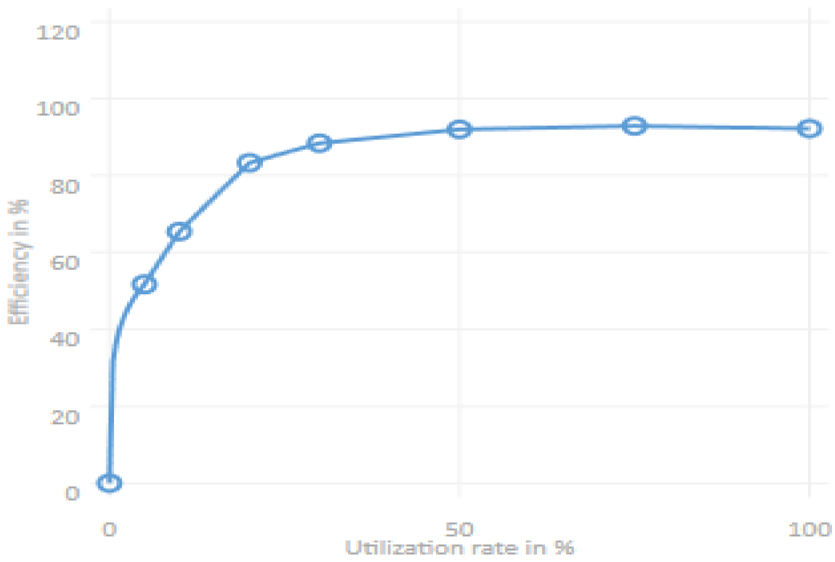
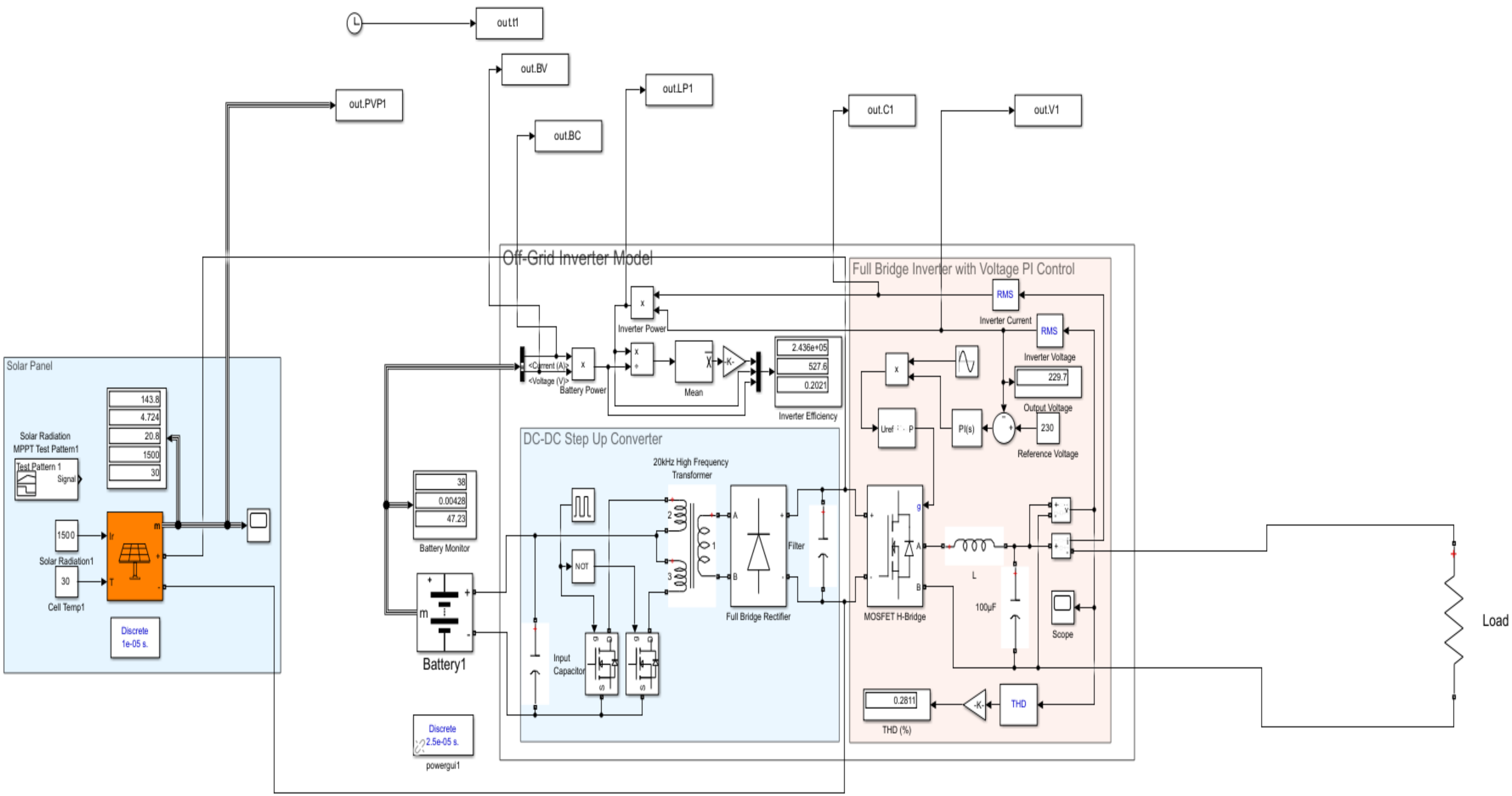


Fig.13: Efficiency curve of battery inverter used

5. System Design and Modeling

MATLAB/SIMULINK is used to model the suggested system. Simulink is a block diagram environment used for multi-domain simulation and Model-Based Design. It supports continuous embedded system testing and verification, simulation, automatic code creation, and system-level design. Simulink provides a graphical editor, solvers, and customizable block libraries for modeling and simulating dynamic systems. Its connection with MATLAB allows you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis. Simulink is a MATLAB-based graphical programming environment for modeling, simulating, and analyzing multi-domain dynamical systems. A graphical block diagramming tool and a collection of customizable block libraries make up its main interface. It offers tight integration with the rest of the MATLAB environment and may either drive or be programmed from MATLAB. Simulink is widely used in digital signal processing and automatic control for multi-domain simulation and model-based design. The MATLAB/SIMULINK model of this suggested system is displayed in Figure 14.



out.t1
out.BV
out.PVP1
out.LP1
out.BC
out.C1
out.V1
Off-Grid Inverter Model
Full Bridge Inverter with Voltage PI Control
Solar Panel
Solar Radiation
MPPT Test Pattern1
Test Pattern 1
Signal
143.8
4.724
20.8
1500
30
1500
Solar Radiation1
30
Cell Temp1
Discrete
1e-05 s.
Battery Monitor
38
0.00428
47.23
Battery1
Discrete
2.5e-05 s.
powergui1
Inverter Power
Battery Power
<Current (A)>
<Voltage (V)>
Mean
-K-
2.436e+05
527.6
0.2021
Inverter Efficiency
RMS
Inverter Current
RMS
Inverter Voltage
229.7
Output Voltage
PI(s)
230
Reference Voltage
DC-DC Step Up Converter
20kHz High Frequency
Transformer
NOT
Input
Capacitor
Full Bridge Rectifier
Filter
MOSFET H-Bridge
L
100µF
Scope
0.2811
THD (%)
THD
Load

Fig.14: MATLAB/SIMULINK model of proposed system

Figure 15 shows power curve from PV module every hour while figure 16 illustrates power produced PV module against the voltage. Figure 17 presented PV power and load curve and voltage curve against current along the day is exhibited in figure 18.

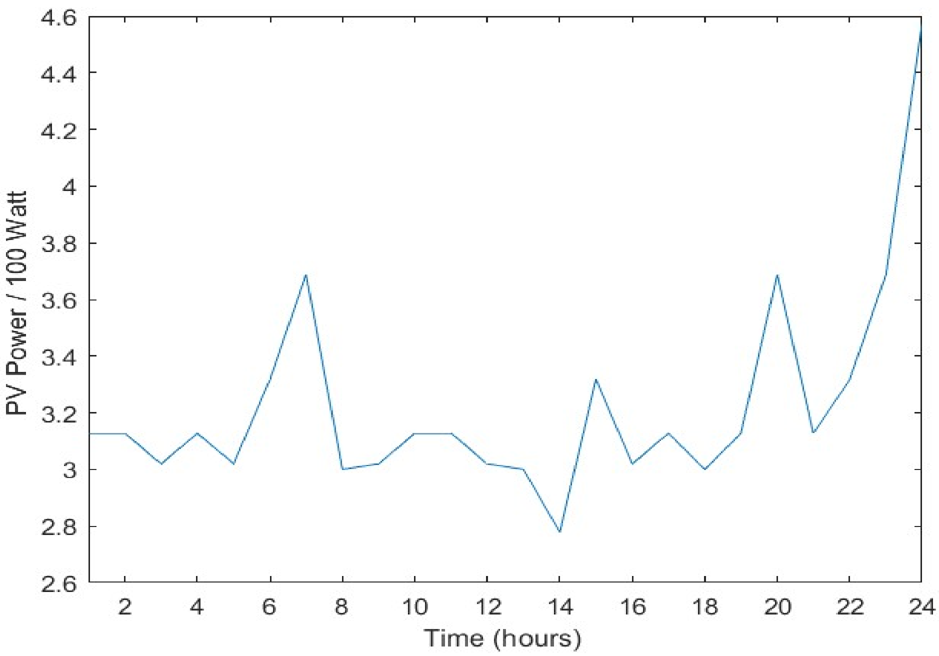


Fig.15: PV module power curve along day

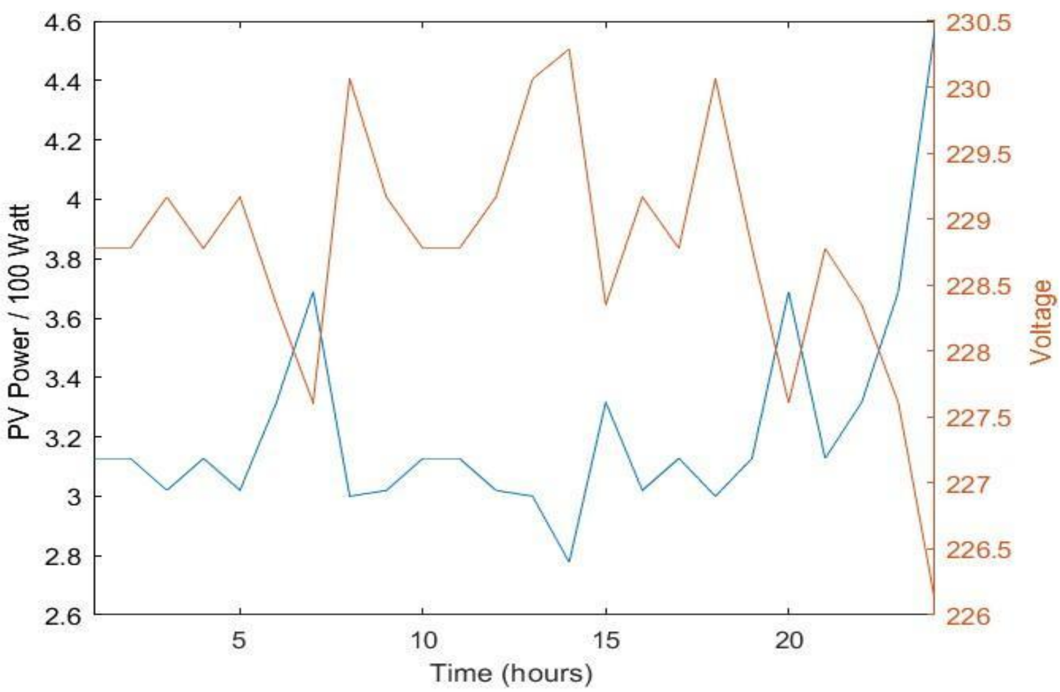


Fig.16: PV module power curve against voltage

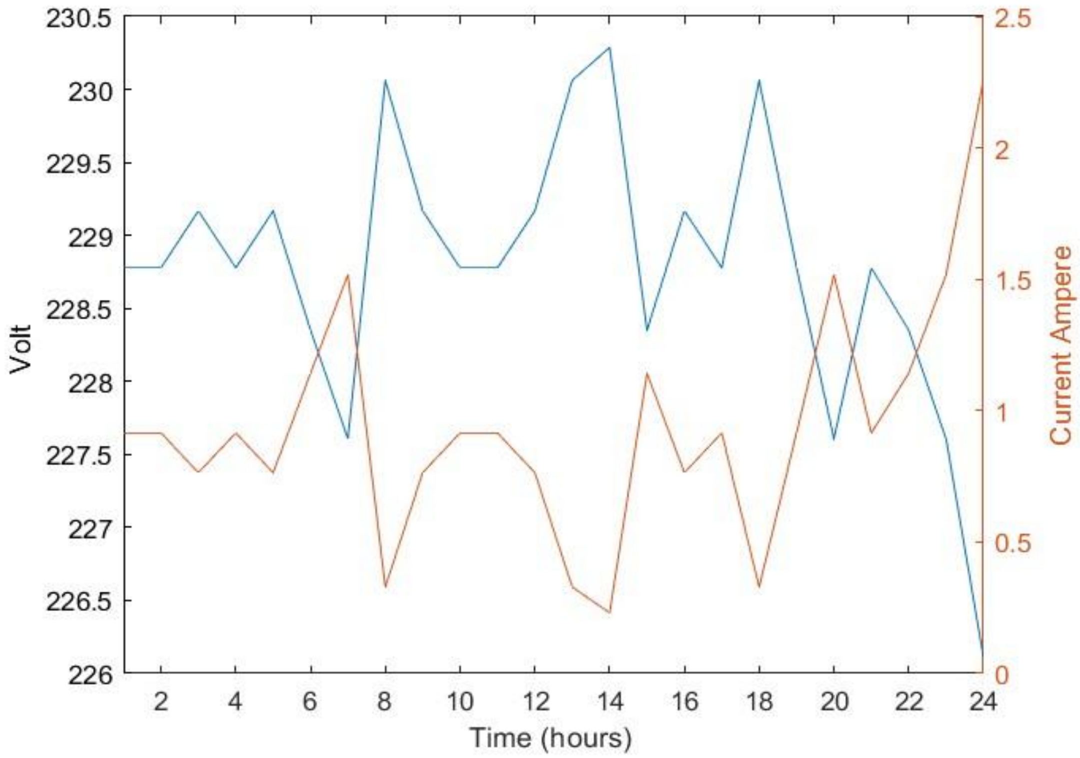


Fig.17: Voltage curve against current along the day

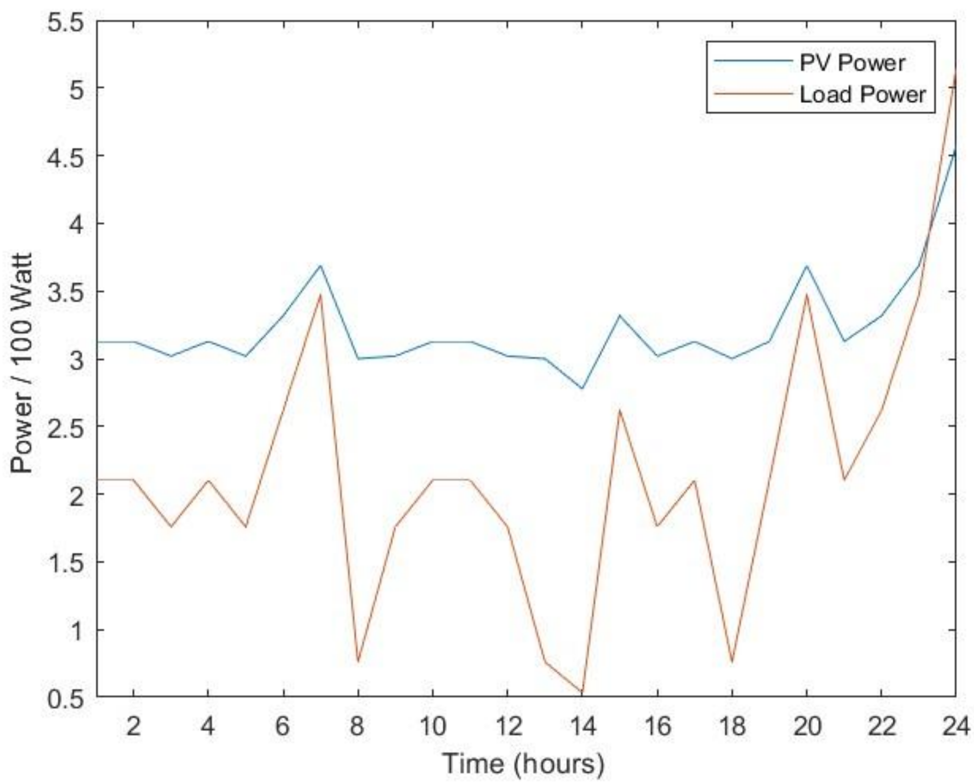


Fig.18: PV module power and load curve

6. Results and Discussion

The proposed system is designed and simulated and we present the results in this part. The bill of quantity is shown in table 7. The single line diagram of proposed system is exhibited in figure 19. The overall results of simulation is illustrated in table 8.

Table 7: Bill of quantity of proposed system

Item	Quantity
PV module 400 Wp-Si monocrystalline HC	24
Inverter 3 MPP-5100 W	2
Battery inverter 3000 ES-AC	1
Battery TRBM 2.5 KH	24
Feed in Meter	1

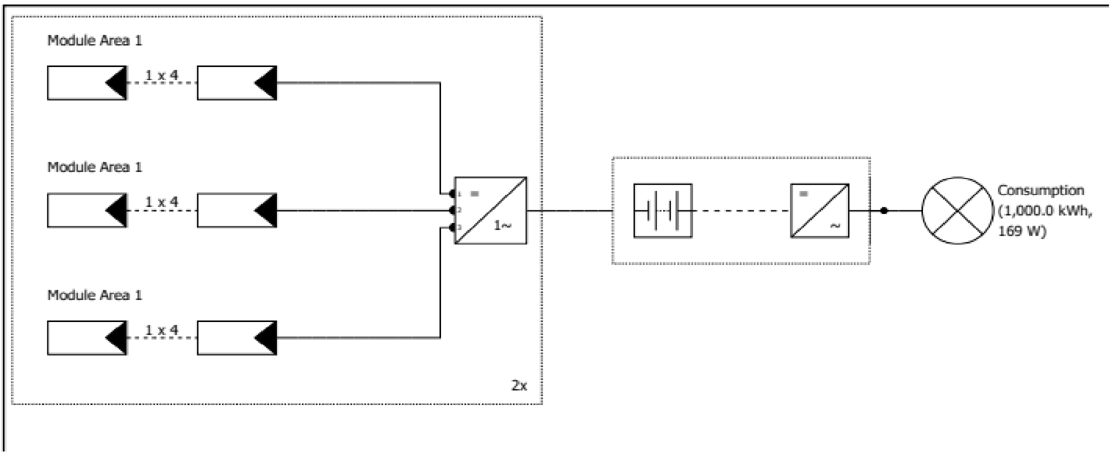


Fig.19: SLD of proposed system

Table 8: Proposed system results overview

PV generated energy	11982 kWh/year
Specific annual yield	1743 kWh/kWp
PV system efficiency	19 %
System performance ratio	86 %
Solar fraction	100%
Total investment cost	13000 USD
Cost of Energy	0.013 USD/kWh
CO_2 avoided	474 kg/year

The energy flow graph is shown in figure 20. The irradiance curve per module area is presented in figure 21. Figure 22 illustrates PV energy produced during system lifetime while figure 23 presents Monthly temperature module area of the proposed system. Monthly PV generator energy (AC grid) of proposed system is describes in figure 24. Figure 25 presents monthly average performance ration of proposed system. Energy from battery inverters is illustrated in figure 26 while figure 27 shows state of charge limit of batteries. Energy PV balance of system is presented in table 9 while figure 28 shows energy balance Sankey diagram. Production forecast with consumption and per inverter is described in figures 29 and 30.

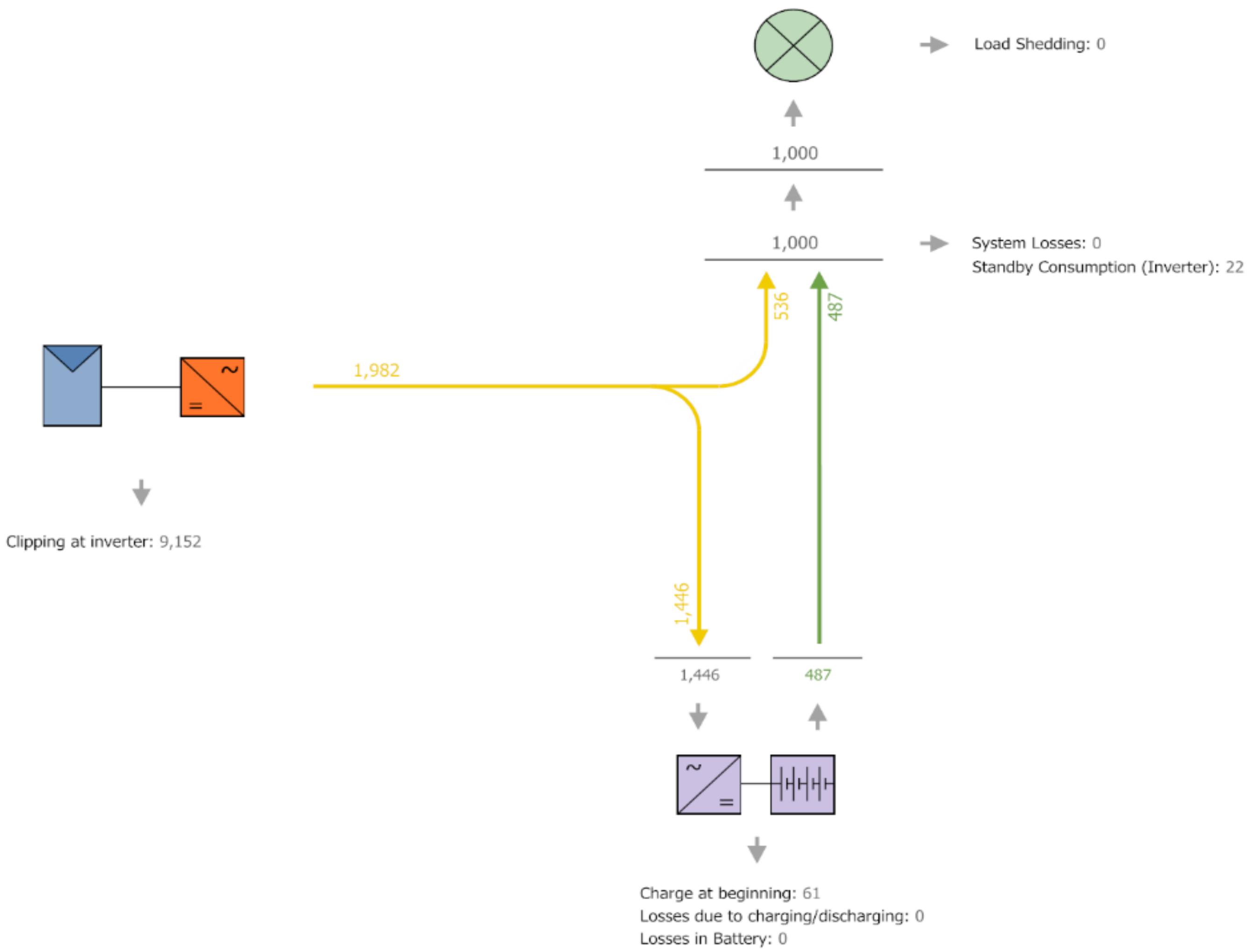


Fig.20: Energy flow Graph

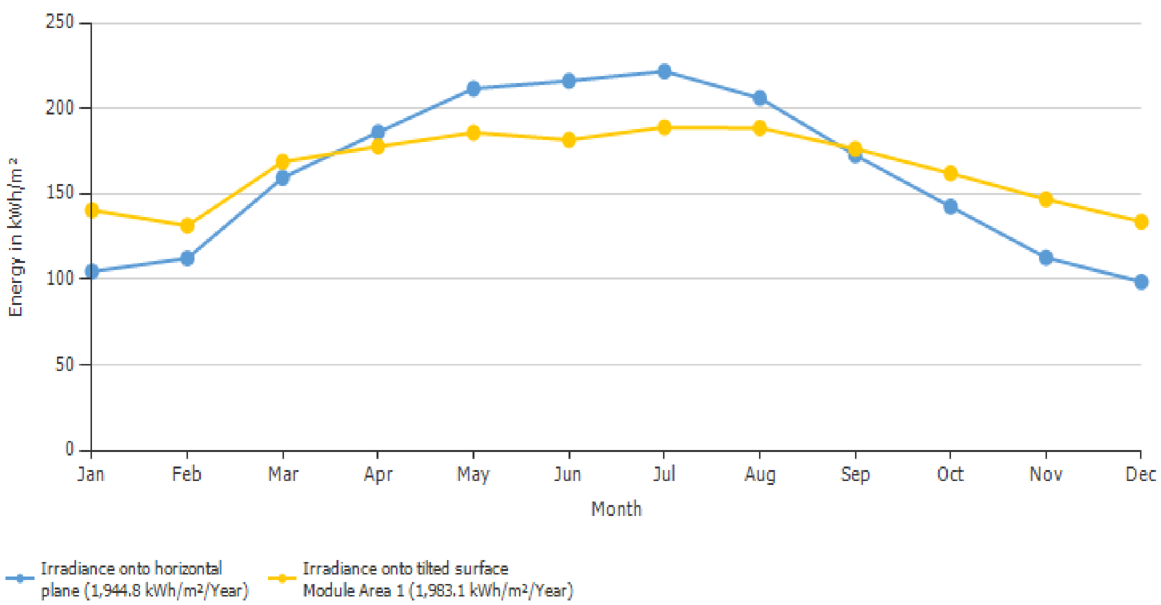


Fig.21: Irradiance per module area of proposed system curve

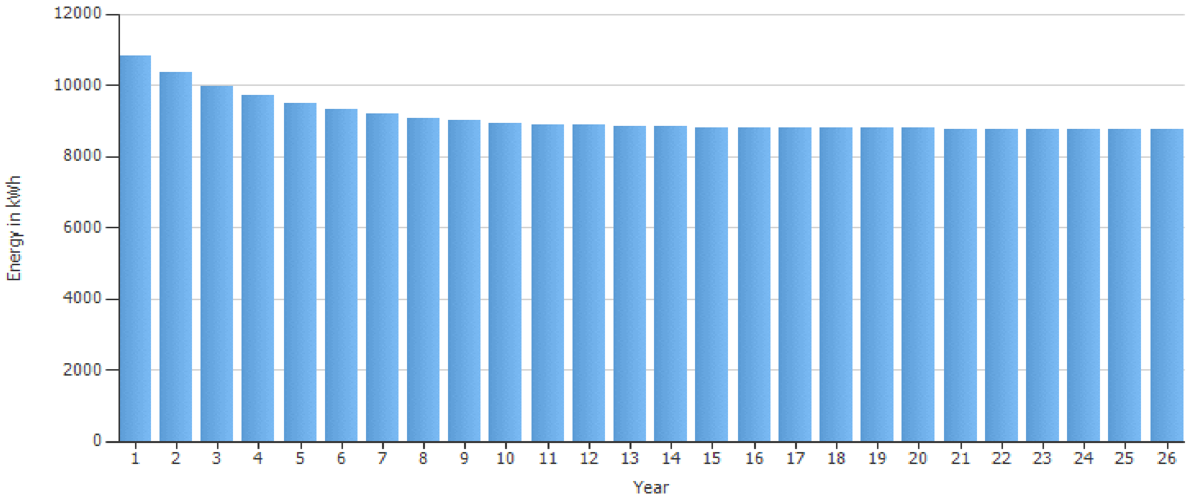


Fig.22: PV energy produced during system lifetime

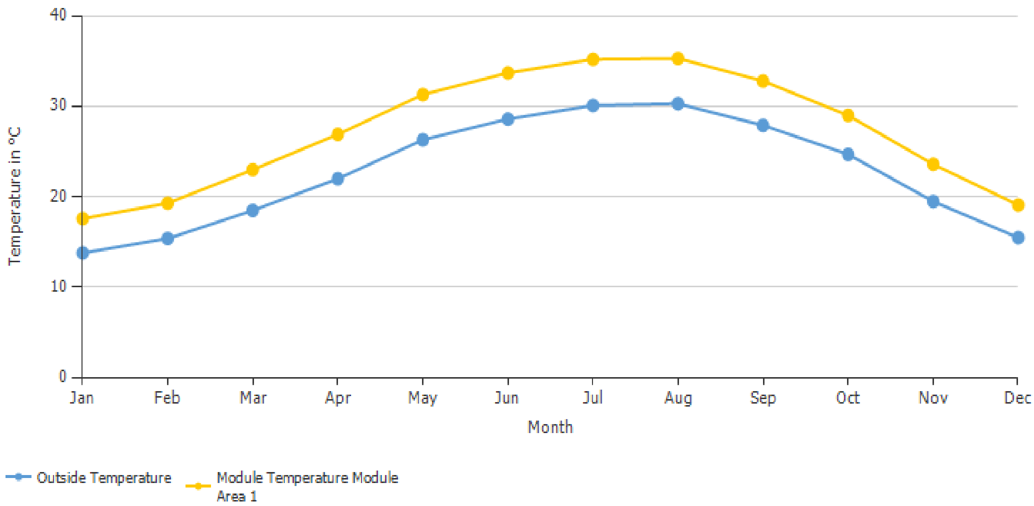


Fig.23: Monthly temperature module area of proposed system

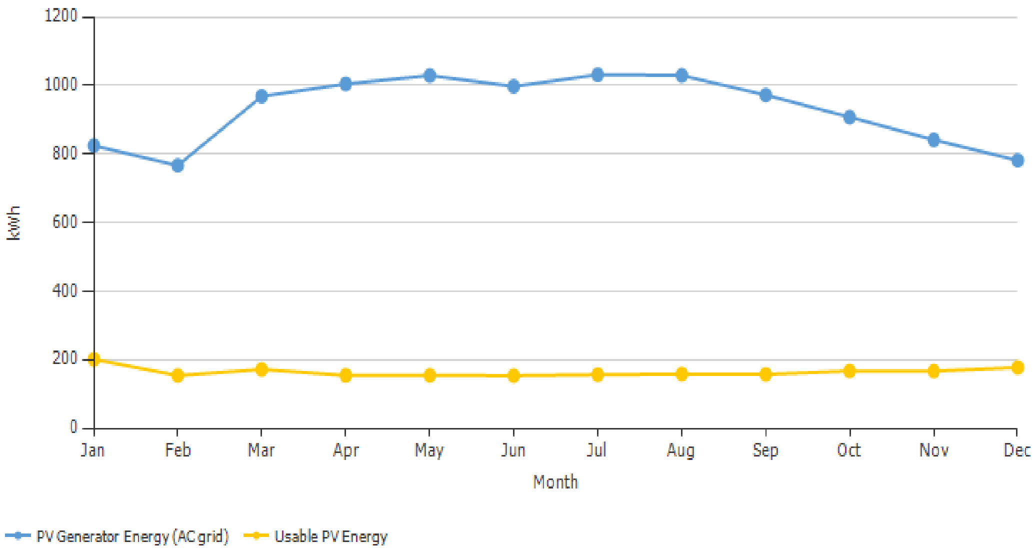


Fig.24: Monthly PV generator energy (AC grid) of proposed system

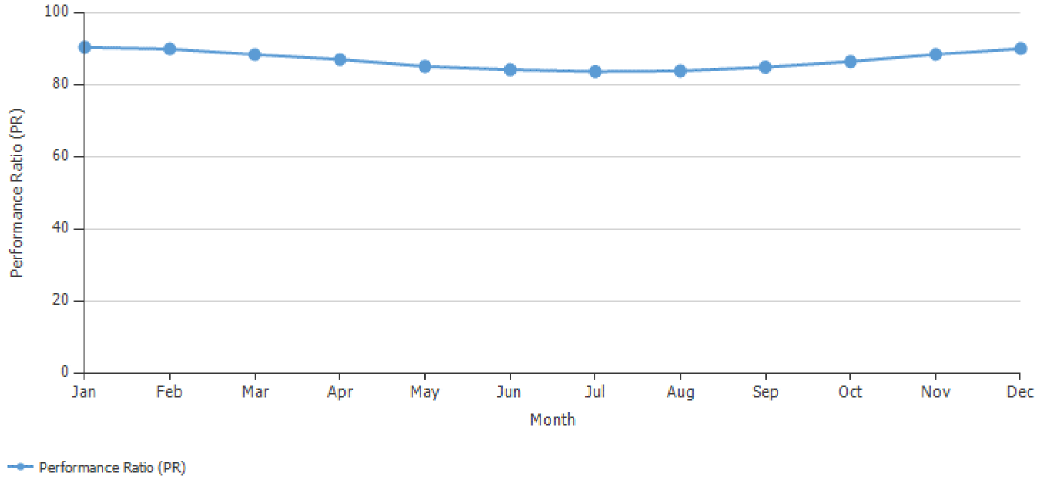


Fig.25: Proposed system performance ratio per inverter curve

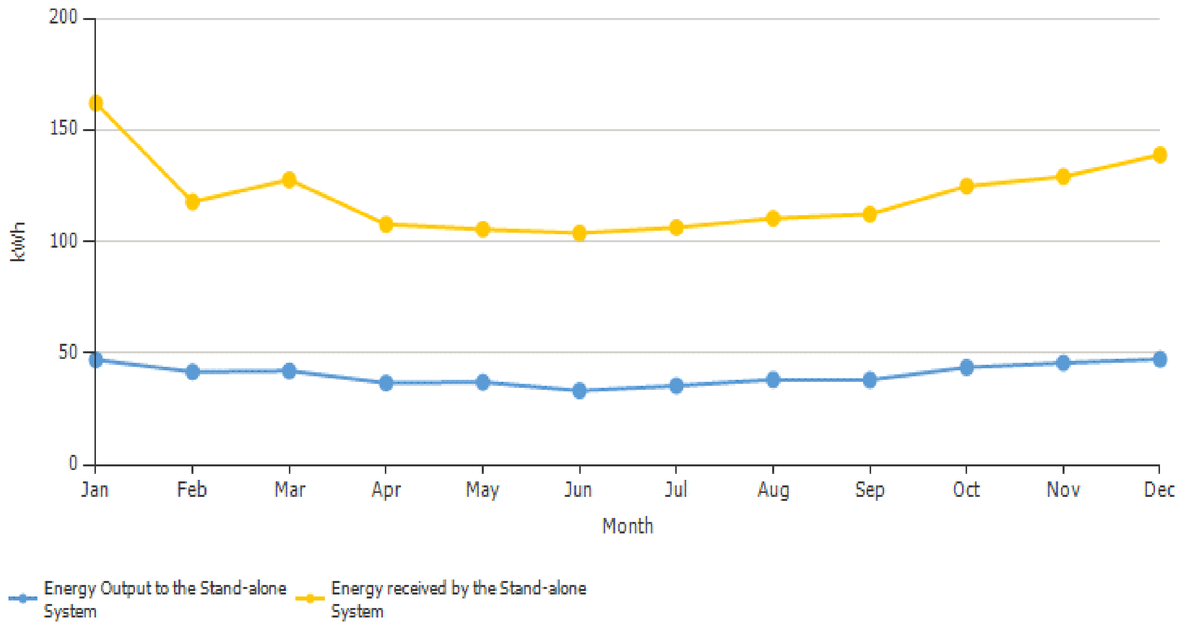


Fig.26: Energy from battery inverters

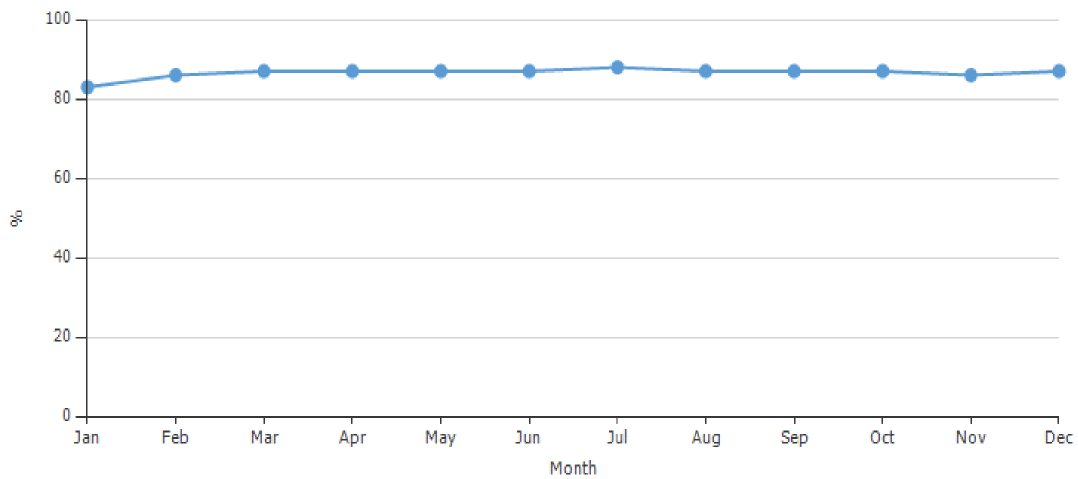


Fig.27: State of charge SOC curve of batteries

Table 9: PV system energy balance

Global radiation - horizontal	1,944.80	kWh/m²	
Deviation from standard spectrum	-19.45	kWh/m²	-1.00 %
Ground Reflection (Albedo)	25.79	kWh/m²	1.34 %
Orientation and inclination of the module surface	105.13	kWh/m²	5.39 %
Shading	-41.13	kWh/m²	-2.00 %
Reflection on the Module Surface	-32.04	kWh/m²	-1.59 %
Global Radiation at the Module	1,983.11	kWh/m²	
	1,983.11	kWh/m²	
	x 31.262	m²	
	= 61,996.36	kWh	
Global PV Radiation	61,996.36	kWh	
Soiling	0.00	kWh	0.00 %
STC Conversion (Rated Efficiency of Module 20.44 %)	-49,327.27	kWh	-79.56 %
Rated PV Energy	12,669.09	kWh	
Low-light performance	-68.32	kWh	-0.54 %
Deviation from the nominal module temperature	-742.67	kWh	-5.89 %
Diodes	-59.29	kWh	-0.50 %
Mismatch (Manufacturer Information)	-235.98	kWh	-2.00 %
Mismatch (Configuration/Shading)	0.00	kWh	0.00 %
PV Energy (DC) without inverter clipping	11,562.83	kWh	
Failing to reach the DC start output	-6.34	kWh	-0.05 %
Clipping on account of the MPP Voltage Range	0.00	kWh	0.00 %
Clipping on account of the max. DC Current	0.00	kWh	0.00 %
Clipping on account of the max. DC Power	0.00	kWh	0.00 %
Clipping on account of the max. AC Power/cos phi	0.00	kWh	0.00 %
MPP Matching	-11.56	kWh	-0.10 %
PV energy (DC)	11,544.94	kWh	
Energy at the Inverter Input	11,544.94	kWh	
Input voltage deviates from rated voltage	0.00	kWh	0.00 %
DC/AC Conversion	-389.14	kWh	-3.37 %
Standby Consumption (Inverter)	-22.47	kWh	-0.20 %
Total Cable Losses	0.00	kWh	0.00 %
PV energy (AC) minus standby use	11,133.33	kWh	
PV Generator Energy (AC grid)	11,155.80	kWh	

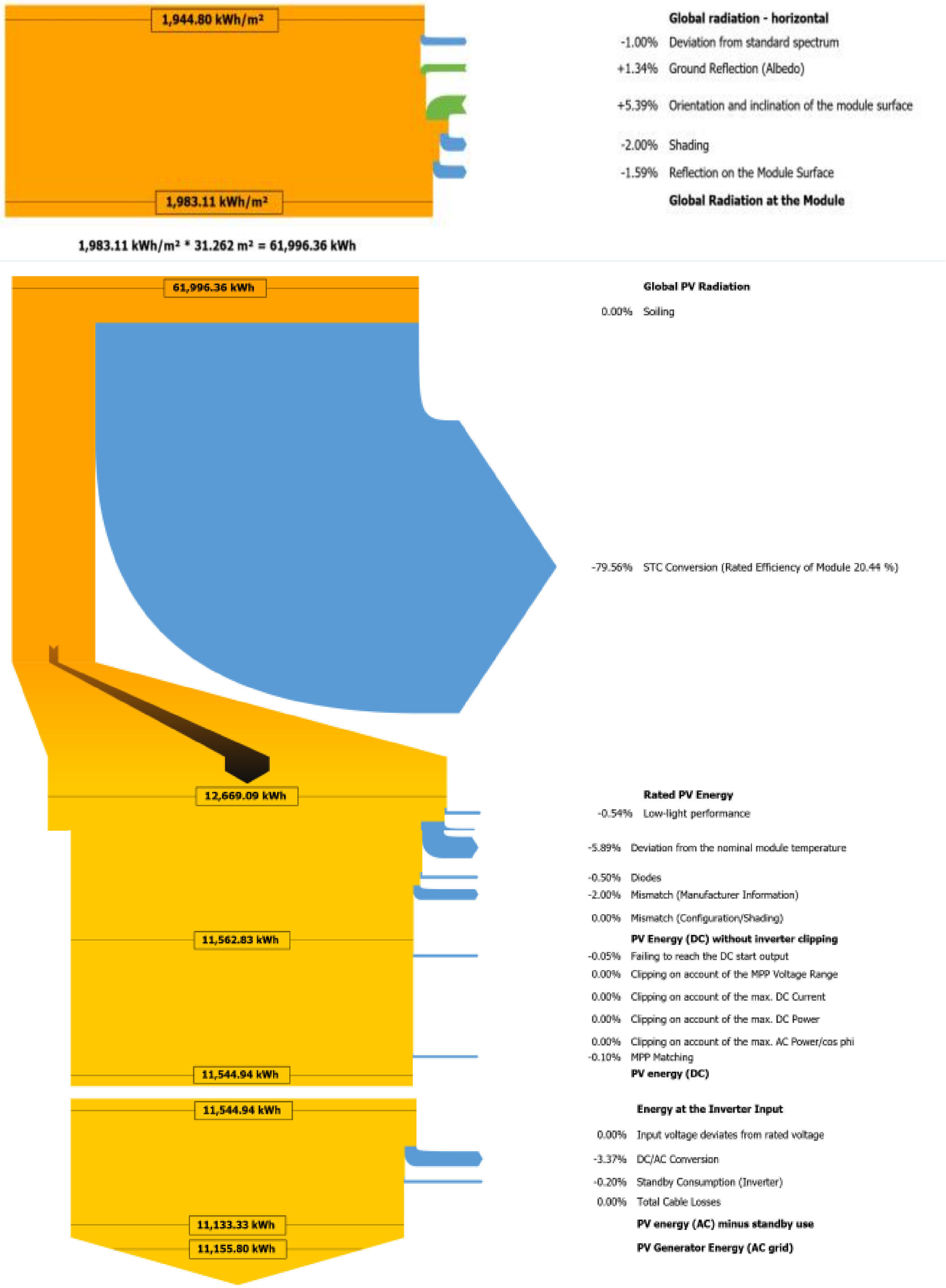


Fig.28: Energy balance Sankey diagram

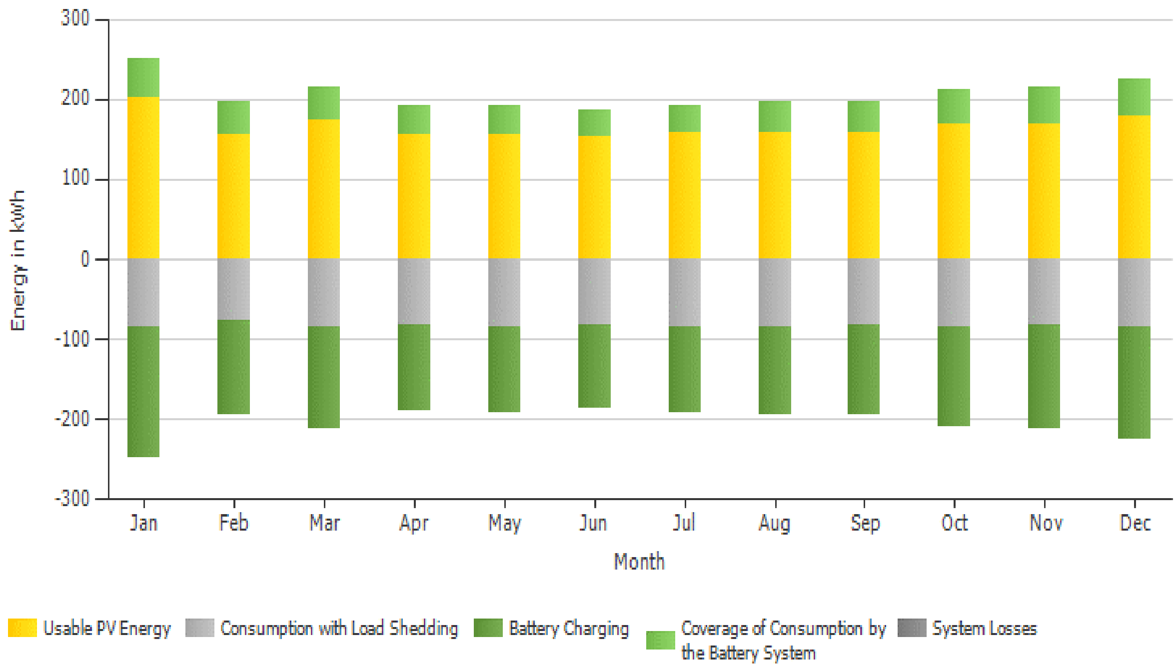


Fig.29: Production forecast with consumption

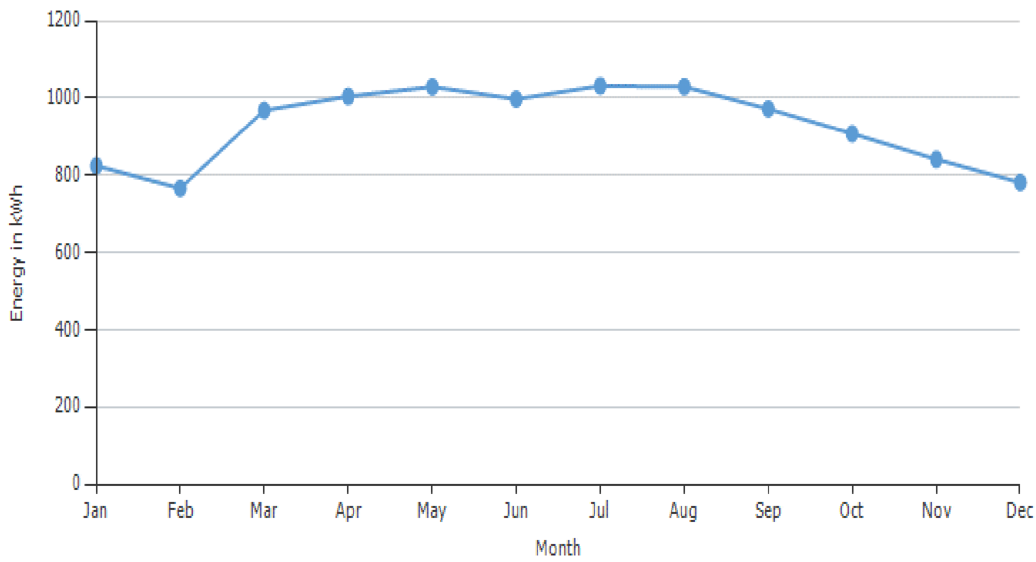


Fig.30: Production forecast per inverter

7. Conclusion

A lot of teamwork has been put into healthcare and vaccine during the COVID-19 epidemic. But in order to operate, these medical facilities also require sufficient power, which is severely deficient throughout Africa, particularly in rural regions. This study has conducted a thorough investigation to model, simulate, and analyze various hybrid energy system (HES) configurations for a rural healthcare center in Fayoum city, Egypt. In order to provide the optimal hybrid power system design for a remote sub-district hospital, this study makes use of the PVSOL Tool. This design has been the subject of a techno-economic analysis utilizing the MATLAB/SIMULIMK tool. When compared to Egypt's current electricity source, the analysis found that this micro-grid system would be the most economical and ecologically friendly choice. The following is a summary of the conclusion:

- The average annual temperature and solar radiation in Fayoum are 30 °C and 2.56 $KWh/m^2/day$, respectively. These figures indicate that the selected medical facility has a high probability of increasing its solar-powered electricity production.
- Over a 25-year period, the PV system is expected to generate 11.982 MWh of real electricity, which will exceed the electricity consumption of the Fayoum health complex. The extra 1.743 MWh of electricity produced annually by the solar system may be bought by the national grid or other organizations.
- The state of charge of battery is around 80%.
- The performance ration of this proposed system is 84%, PV cells efficiency is 19% and solar fraction is 100%.
- The total investment cost is 13000 USD and cost of energy is 0.013 USD/kWh.
- From environmental view, the total CO_2 emissions avoided against this proposed system is 474 kg/year.
- Because these economic parameters demonstrate a significant reduction in installation, operation and maintenance, and per-kilowatt-hour generation costs, state-run and privately owned hospital authorities are guaranteed to install the hybrid PV system in LDC and developing countries, like Egypt, where installation cost will be a prime commodity. The hybrid PV system also benefits the environment.
- This system's PVSOL analysis predicts that investment costs will be recovered in 7.5 year.

In order to identify the best option for a rural healthcare facility, this study examines various HES configurations. To handle the extra energy, future research must take grid extension's feasibility into account. Additionally, possible HES designs can be optimized and analyzed using computational techniques like genetic algorithm.

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