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Design and Validation of Off-grid Photovoltaic Systems for Domestic Applications: A Case Study

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Abstract

In this study, off-grid photovoltaic (PV) systems for domestic use in Visakhapatnam, Andhra Pradesh, India, were examined. PVsyst and MS Excel-based design tools are used to optimize the PV system setup while taking local considerations into consideration. For exact electrical circuit and comprehensive panel layout, AutoCAD is employed. Through thorough simulations that measure efficiency, energy output, and long-term economic feasibility, the PVsyst software is used to test and evaluate system performance. A sustainable and environmentally friendly alternative to traditional power sources, the study shows that off-grid PV systems have enormous potential for supplying Visakhapatnam's household energy demands. The suggested system suggests 13 panels, 12 batteries, a 1430 W inverter, and a 67.70 A charger controller based on Visakhapatnam's geographic coordinates (latitude: 17°, longitude: 83°), which are also taken into account, as well as the actual temperature (28 °C). The peak sun hours (PSH) are 2.83, providing customers with a steady source of energy all year long. Adopting renewable energy can help homes become more energy independent and lower their carbon impact. These findings contribute to the global promotion of sustainable energy practices and the acceptance of renewable solutions by offering useful insights for the implementation of off-grid PV systems in comparable locations.

Keywords

Off-grid photovoltaic systems, Photovoltaic technology, Sustainable energy, Energy independence, PVsyst software, Domestic applications

Nomenclature

β is Tilt angle (°C); α is Elevation angle (°C); δ is Declination angle (°C); S_M is Global tilted radiation; S_H is Global horizontal radiation; η is System efficiency (%); AD is Autonomy days; DOD is Depth of discharge; NOCT is Normal operating cell temperature; AH is Ampere hours; SF is safety factor; PF is power factor; $V_{battery}$ is Single battery voltage; V_{bus} is Bus voltage Reynolds number; T is Temperature (°C); X is Maximum shadow; I_{rated} is Rater current; I_{fuse} is Fuse current; I_{cable} is Cable current; $I_{C.B.}$ is C, B current; and $P_{total\ loads}$ is Power of total loads.

Introduction

The global shift towards renewable energy sources has been sparked by rising worries about energy security, environmental sustainability, and the negative impacts of fossil fuels. Among these, PV systems have come to be seen as a viable option for the decentralized production of power. Particularly interesting options for satisfying the energy needs of rural or underserved regions include off-grid PV systems, which give homes access to electricity without relying on the traditional electrical grid.

Off-grid PV system deployment in the context of household applications has the potential to not only assure a steady energy supply but also to lessen carbon emissions and ease the burden on conventional power infrastructure. Given its location and energy requirements, the Indian city of Visakhapatnam is a great case study for evaluating the viability and efficiency of such systems. Because of its year-round high levels of solar irradiation and tropical location, Visakhapatnam is an ideal location for capturing solar energy. Reasons for choosing Visakhapatnam for the study:

Geographical relevance: Due to Visakhapatnam's position in India, which receives plenty of sunlight throughout the year—a crucial component for PV system efficiency—the city is a good option for research on off-grid PV systems.

Domestic energy demand: The city's large population and rising energy consumption make it urgently necessary to look into sustainable and alternative energy options in order to lessen dependency on traditional power sources.

Renewable energy potential: Visakhapatnam is a desirable case study for evaluating the viability and efficiency of off-grid PV systems due to India's dedication to the development of renewable energy sources and its lofty solar energy ambitions.

Environmental effect: We may assess the potential for lowering carbon emissions and lessening the environmental effect of conventional energy sources by examining the deployment of off-grid PV systems in Visakhapatnam.

Research need: Studies explicitly addressing household applications in Visakhapatnam are scarce, despite the rising interest in off-grid PV systems. This study fills that need and makes a significant contribution to the body of knowledge.

The design and evaluation of off-grid PV systems specifically suited for household use in Visakhapatnam are the main topics of this research article. We used MS Excel-based tools, manual calculations, and AutoCAD for exact circuit layout when designing our systems. The PVsyst Software is also used to assess the intended system's performance in terms of energy output, efficiency, and financial feasibility. PVsyst is a popular piece of software for modelling, evaluating, and improving PV systems. It aids in the modelling of solar energy performance, the evaluation of system effectiveness, and the prediction of energy output depending on numerous variables including location, weather, panel characteristics, and shading effects. PVsyst is a useful tool for determining the viability and economics of PV projects, advancing the development and application of solar energy technologies globally. PVsyst is a software tool used for the design, simulation, and analysis of PV systems. It plays a crucial role in the renewable energy industry, particularly in the development and validation of PV projects. The importance of PVsyst lies in its ability to accurately model and predict the performance of PV systems under various conditions, helping to optimize system design, maximize energy production, and assess economic feasibility.

By doing this study, we hope to raise awareness about the advantages and practicality of off-grid PV systems as a sustainable energy option for household applications in Visakhapatnam and perhaps spur other global efforts in the same direction. The findings discussed here support continuing initiatives to encourage the use of renewable energy sources and to build a more sustainable and reliable energy future.

The advantages of off-grid PV systems for household applications have been underlined in several research. Particularly in distant or underserved locations, the decentralized nature of these systems enables households to attain energy independence. Wang et al. [1] highlighted the growing number of solar panels that are no longer in use and the need for better recycling methods to deal with issues such high prices and low recycling value. Rathi et al. [2] examined the pollution brought on by incorrect solar panel disposal and emphasized the need for appropriate installation and recycling in order to solve environmental problems. Macías et al. [3] introduced a hybrid system for isolated rural areas that combines PV solar and biomass gasifier technology. The system has manual controls for places with irregular energy supplies, allowing for effective functioning. Ndwali et al. [4] investigated cutting-edge cooling and control methods for improving photovoltaic-thermal (PV/T) energy systems, including heat storage water tanks and ice thermal energy storage. Tian et al. [5] proposed a ground-breaking cascade PV power generation system with hollow structures and complete spectrum splitting for excellent performance. Gupta and Pradhan. [6] introduced solar PV/T systems utilizing nanofluid technology, enhancing the PV solar thermal system's thermal, electrical, and total efficiency.

In 2021, Aarakit et al. [7], according to research on solar PV adoption in Uganda, rural regions have greater adoption rates that are driven by cost factors. To promote adoption, flexible payment methods and regulatory adjustments were recommended. Li et al. [8] introduced a high-capacity ice-making and dependable operation ice thermal retention technology in a solar direct-drive PV air conditioning system. Bamroongkhan et al. [9] analyzed the effects of water-cooling flow rate and volume on thermal and electric energy metrics in order to investigate direct solar energy harvesting. Arefeen and Dallas. [10] tensegrity was evaluated as a reliable racking alternative for solar PV arrays that would reduce material weight and facilitate solar energy applications with a large environmental impact. The PIPVT is a pavement-integrated PV system that combines two major solar pavements, according to Zhou et al. [11]. The PIPVT idea attempts to increase solar energy efficiency and PV cell lifespan. This review provides insightful analysis and novel viewpoints for ongoing research on energy-harvesting pavements. A PV-thermo-radiative coupled system with a concentrated solar spectrum was explored by Liang et al. [12], which resulted to the greatest production of 44.91% at low solar concentrations and optimal performance. For addressing building thermal energy requirements, Miglioli et al. [13] examined the most recent advancements in solar PV heat pump systems, stressing its dependability, flexibility, and resilience when combined with a second heat source.

In order to recuperate thermal losses and boost power output, hybrid thermoelectric-PV systems were suggested by Lorenzi et al. [14] after studying the efficiency of solar cells. It was discovered that wide-gap PV solar hybridization was

practically advantageous for efficiency gains. To overcome the drawbacks of standalone systems, Kebabsa and Lounici. [15] suggested a combined solar chimney and PV system, which increased turbine power by 8.91% by using PV heat to improve airflow. This technique works well in areas with a lot of solar potential, like the south of Algeria. High-concentration PV/T collectors were introduced by Moreno et al. in 2021 [16], displaying greater power conversion rates and lower thermal dependence coefficients than conventional PV/T systems. Buildings may be able to efficiently supply their electrical and thermal energy demands by adopting in situ PV/T production, according to simulations for various climates. Vivar et al. [17] evaluated the efficiency of solar disinfection against bacteria and came to the conclusion that the PV energy output of the hybrid system was equivalent to the reference frame. Because of the system's inactivation levels, it was possible to reuse water for a variety of uses, including industrial, urban, and agricultural ones.

A tri-generation system was suggested by Jalalizadeh et al. [18] to meet the thermal and electrical energy needs of residential constructions. The results of the dynamic simulation demonstrated that the recommended system greatly decreased energy consumption, providing 29% of the yearly energy requirements for the building with significant savings. Combining renewable energy sources, such as a 3.5 kVA biogas-fueled generator with a hybrid 1 kW solar PV system, was the subject of studies by Buragohain et al. [19]. The environmental research demonstrated a net reduction in CO_2 of 104.59 tons and $2090.31 in earned carbon credits, while the economic assessment revealed a high positive net present value of $1562.15 over a 25-year project lifespan. Research on home customers' desire to build solar and energy storage using incentive structures was presented by Huang et al. [20]. To evaluate the financial implications of using a recycled battery system for energy storage, they combined economic research with a model of the unpredictability in solar load. Based on the correlation between power consumption habits and solar radiation, the research recommends instructing residential consumers to install batteries. According to Rathod et al. [21], dust buildup on solar panels decreases their efficiency by restricting sunlight absorption, raising temperatures, and interfering with charge carrier mobility.

Rising pollution levels, which lessen the advantages of ideal environmental conditions for solar energy, make this problem worse. For instance, due to dust buildup, polycrystalline solar panels in Dehradun's Clement town neighborhood witnessed a 22.5% reduction in efficiency during a 45-day period. By using CuO and phycocyanin, Subramaniyan et al. [22] increased the transparency of ZnO nanopowders. They created ZnO-CuO nanocomposites using the sol-gel technique, examined their morphology and structure, and discovered that the crystallite size was just 24 nm. They increased transmission by manually grinding phycocyanin into the mixture, which decreased absorbance in the 550 - 750 nm region. This work supports phycocyanin incorporation for affordable, effective, and transparent nanostructures in metal oxide solar cells and increases the transparency of ZnO-based solar cells starting at 500 nm. With a focus on nanoparticles and nanofluids, Ahmed et al. [23] examines the most recent nanotechnology developments in PV/T solar systems. It looks at how they are prepared and how they are used in CPV/T and PV/T systems. The article outlines the possible benefits of using nanofluids and discusses crucial factors that can improve their performance. The need for using renewable energy, especially solar power, is emphasized by Shalwar et al. [24]. It examines the development of solar PV technology historically, as well as cell efficiencies, market branding, and performance.

Numerous PV generations, BIPV, CPV, module temperature control, and economic analysis are included in the literature study. The most important conclusions are the efficiency of passive cooling techniques like PCM, the continued use of first-generation PV, the necessity of cost reductions, the significance of recycling solar waste, and the requirement for modernizing governmental regulations. According to Jaiswal et al. [25], third-generation nanomaterial-based solar cells have an efficiency of up to 40%, revolutionizing first-generation silicon-based solar cells that had a 12 - 14% efficiency. In order to develop high-efficiency solar cells, they examine solar ideas, cell kinds, surge theory, and uses of nanomaterials.

Methodology

The methodology that is adopted for carryout this research is shown in figure 1. as flow chart. A detailed explanation about the adopted methodology.

- **Load assessment:** To assess the energy demand of the off-grid PV system, calculate the power and energy requirements of the residential loads.
- **Solar irradiance analysis:** Determine Visakhapatnam's peak sun hours to determine the amount of solar energy that is accessible for the PV system.
- **System efficiency calculation:** Determine the total ef-

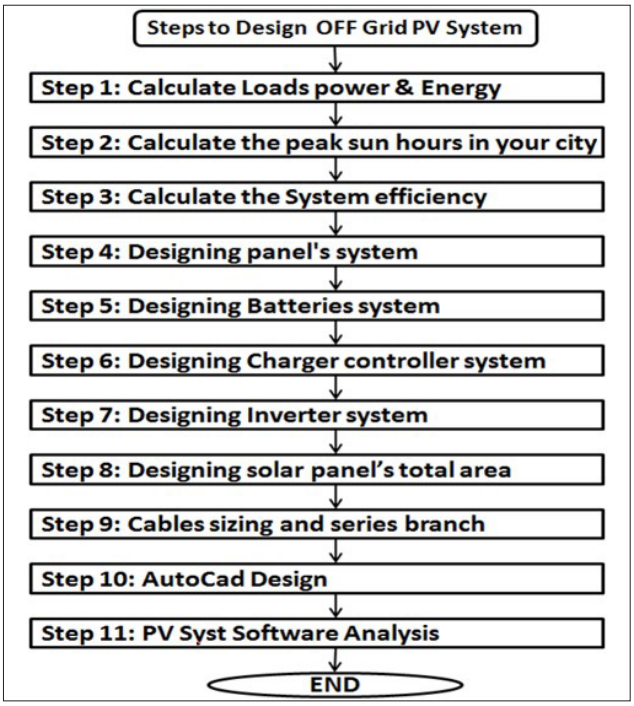


Figure 1: Flow chart for off-grid PV system steps.

fectiveness of the off-grid PV system while taking conversion and storage losses into consideration.

- **Panel system design:** To maximize energy production, design the PV panel system taking into account variables such panel capacity, orientation, and tilt angle.
- **Battery system design:** Select the right battery type and capacity to store extra solar energy for usage when it's not sunny.
- **Charger controller system build:** To effectively manage the battery charging process, choose and build the charger controller.
- **Design of the inverter system:** Create an inverter system that will transform DC electricity from the PV panels and batteries into AC power for household usage.
- Calculate the total solar panel area necessary to satisfy the household's energy needs using the solar irradiation that is currently available.
- **Cable sizing and series branch:** To reduce power losses and guarantee secure transmission, size the cables correctly. To improve system performance, arrange the panels in parallel and series branches.
- **AutoCAD design:** To ensure accuracy and the best possible arrangement, use AutoCAD software to build a precise layout of the electrical circuit and system components.
- **PVsyst program analysis:** Use the PVsyst program to simulate energy output, efficiency, and economic feasibility to verify the performance of the proposed off-grid PV system.

By following this methodology, the research paper aims to provide a comprehensive and validated design for an off-grid PV system tailored to domestic applications in Visakhapatnam (Andhra Pradesh, India).

The governing equations and formulas which are used in this system are:

Tilt angle (β) calculation

$$\beta = 90 - \alpha \quad (1)$$

$$\alpha = 90 - \Phi + \delta \quad (2)$$

$$\delta = 23.5 \text{ x } \sin\left[\frac{360}{365}(d + 284)\right] \quad (3)$$

Where, d is taken as the day number from the calendar sheet.

Getting peak sun hour value

$$S_M = S_H \frac{\sin(\alpha + \beta)}{\sin \alpha} \quad (4)$$

Where, S_H = from NASA database (depends on latitude and longitude); β = Constant = 40.5 °C ~ 45 °C; δ = at 21st of the month; α = depends on the declination angle; and S_M = depends on the β, S_H, and α.

Calculate the system efficiency

$$\eta = \frac{P_{out}}{P_{in}} \text{ x } 100 \quad (5)$$

$$P_{out} = P_{in} - \text{Total losses} \quad (6)$$

$$\text{Panel losses } \% = (T_{cell} - NOCT) \text{ x } TCP_{amp}\% \quad (7)$$

$$T_{cell} = T_{ambient} + G\frac{NOCT - 20}{800} \quad (8)$$

Design the panels system

$$\text{No. of panels} = \frac{P_{in}}{\text{Power of single panel}} \quad (9)$$

$$P_{in} = \frac{Energy}{\eta \text{ x } S_M} \quad (10)$$

Design the Batteries system

$$\text{Energy} = \text{Power x Time (Watt.hr)} \quad (11)$$

$$\text{Energy} = \text{Voltage x Current x Time (Volt.Amp.hr)} \quad (12)$$

$$\text{Energy} = \text{Voltage x AH} \quad (13)$$

$$\text{Total AH} = \frac{\text{Energy x AD}}{\eta \text{ x } V_{bus} \text{ x DOD}} \quad (14)$$

AH for single branch = Single battery AH x No. of batteries per branch (15)

$$\text{No. of parallel branch} = \frac{\text{Total AH}}{\text{AH for a single branch}} \quad (16)$$

Total no. of batteries = No. of parallel branches x No. of batteries in each branch (17)

Design the charger controller system

$$Charger_{min} = \frac{P_{panels}}{V_{bus}} \quad (18)$$

$$Charger_{min} = \frac{No.\ of\ Panels \text{ x } P_{single\ panel}}{V_{bus}} \quad (19)$$

Design the inverter system

$$P_{inverter} = \frac{P_{loads} \text{ x } Safety\ factor}{PF} \quad (20)$$

Design the solar panel's total area (Figure 2)

$$X = \frac{\sin(180 - (\alpha + \beta)) \text{ x } Y}{\sin \alpha} \quad (21)$$

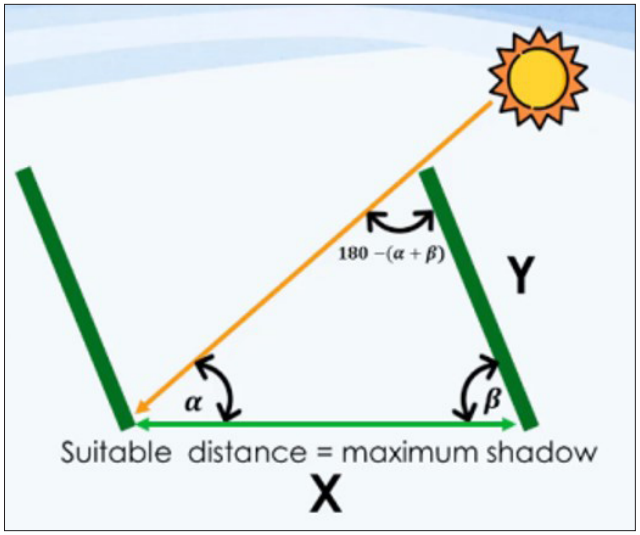


Figure 2: Design the solar panel's total area.

Single panel area = Panel width x X (22)

Total panel area = Single panel area x No. of panels (23)

Cables sizing and protection

$$I_{fuse} = 1.25 \times I_{rated} \quad (24)$$

Standard fuse ratings = {6, 10, 16, 20, 25, 32, 40, 50, 63, 80, 100, 125, 160, 200, 250, 320, 400, 500, 630, 800, 1000}

$$I_{cable} = \frac{I_{fuse}}{Derating\ factor} \quad (25)$$

For the main inverter output

$$S_{total\ load} = \frac{P_{total\ load}}{0.8} \quad (26)$$

$$I_{rated} = 1.5 \times S_{total\ load} \quad (27)$$

$$I_{C.B.} = I_{rated} \times 1.25 \quad (28)$$

C.B ratings = {6, 10, 16, 20, 25, 32, 40, 50, 63, 80, 100, 125, 160, 200, 250, 320, 400, 500, 630, 800, 1000}

$$I_{cable} = \frac{I_{C.B.}}{Derating\ factor} \quad (29)$$

Results and Discussion

The technique was carefully used in this study to build and verify an off-grid PV system specifically intended for household uses in Visakhapatnam (Andhra Pradesh, India). In-depth surveys were carried out to determine the Visakhapatnam households' energy and power needs as well as their monthly electrical power usage. This required identifying typical electrical appliances, calculating their daily energy use, and determining the system's overall energy demand. Lighting, a washing machine, a television, a refrigerator, a ceiling fan, and a computer are among the usual electrical items taken into account. The energy and total load for the typical electrical equipment in a residence in Visakhapatnam city are displayed in table 1 of this document.

From table 1, it is observed that the total power consumption is 990 Watts, and the total energy consumption is 7712-Watt hours. Later, the PSH particular to Visakhapatnam were determined using the local meteorological information and solar insolation tables. This made it possible to calculate the PV system's solar energy capacity accurately. Table 2 provides information on Visakhapatnam city's highest solar hours.

Validation of S_M for January

S_H = 5.06

Table 1: Total load power and energy for Visakhapatnam city (Andhra Pradesh, India).

Load	Power (Watt)	Quantity	Hours	Total power (Watt)	Energy (Watt hours/day)
Lamps	207	7	10	140	1400
Washing Machine	330	1	2	330	660
Television	57	1	8	57	456
Refrigerator	203	1	12	203	2436
Ceiling fan	70	2	12	140	1680
Computer	120	1	9	120	1080
Total				990	7712

Table 2: PSH for Visakhapatnam city (Andhra Pradesh, India).

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S_H	5.06	5.82	6.36	6.51	6.28	4.84	4.26	4.18	4.52	4.79	4.85	4.74
Latitude	17	17	17	17	17	17	17	17	17	17	17	17
Longitude	83	83	83	83	83	83	83	83	83	83	83	83
Day number	21	52	80	111	141	172	202	233	264	294	325	355
Declination	-20.15	-11.20	-0.34	11.65	20.21	23.49	20.44	11.70	-0.29	-11.8	-20.53	-23.49
Elevation	52.84	61.79	72.65	84.65	93.21	96.49	93.44	84.70	72.70	61.13	52.46	49.50
Beta	45	45	45	45	45	45	45	45	45	45	45	45
S_M	**6.29**	6.32	5.90	5.03	4.19	3.03	2.83	3.32	4.19	5.25	6.06	6.21
S_M (min)	2.83											
S_M (max)	6.32											
PSH	**2.83**											

β = 45 °C

$$ä = 23.5 \text{ x } \sin\left[\frac{360}{365}(d-284)\right]$$

$$ä = 23.5 \text{ x } \sin\left[\frac{360}{365}(21+284)\right]$$ =21st Jan = d = 21

for calendar sheet

δ = -20.18 °C

α = 90 – 17 – 20.18 = 52.82 °C

$$S_M = \{S_H * \sin(\alpha+\beta)\}/\sin(\alpha)$$

$$S_M = S_H \frac{\sin(\alpha+\beta)}{\sin\alpha} = 5.06\frac{\sin(52.82+45)}{\sin 45} = 6.29$$

By considering the latitude and longitude of the Visakhapatnam, the elevation angle, declination angle, and tilt angle were determined. Based on these values, the PSHs are determined, and the value is 2.83.

Later, several losses like thermal, electrical, and optical losses were taken into account to gauge the total system efficiency. An effective system setup was made possible by studying these losses. Soon after, PV panel capacities, orientations, and tilt angles were optimized to maximize energy output based on the solar irradiance data that had been gathered. The right kind and size of batteries were then chosen to store any extra solar energy and guarantee a constant power supply even when there was no sunlight. To effectively manage battery charging and enhance energy storage, a suitable charger controller was chosen. Following the accepted guidelines and empirical calculations, it is discovered that 13 panels and 12 batteries are needed, and that there are 12.6 total losses. The data pertaining to these calculations are shown in table 3, table 4, and table 5.

Later, taking into account the needed power output, the inverter system was created to convert DC electricity from the PV panels and batteries into AC power for home use. The entire solar panel area needed for the system was precisely determined by accounting for the available solar irradiation and energy consumption. The PV panels were set up in series and parallel branches for best performance, and appropriate cable size was used to reduce power losses during transmission. Table 6, table 7, and table 8 include the information pertaining to these parameters. Calculations reveal that the charger controller is 67.70 and the rated power is 1430 W.

After the system's design was finished, a thorough layout of the electrical circuit and parts of the off-grid PV system was made using AutoCAD software, assuring precise and effective integration. The electrical circuit and component layout for the off-grid PV system are shown in figure 3. Later, PVsyst software was used to validate the intended off-grid PV system. In-depth simulations were run to examine energy output, system effectiveness, and the suggested design's economic feasibility. The software uses the built-in data for the city's data, such as normalized productions, performance ratio solar fraction, etc., for simulation purposes. Figure 4 displays the panels' normalized productions. The normalized energy research was carried out month by month over the course of a year. It has been shown that energy losses are higher during non-summer

Table 3: Data related to panel design.

Parameter	Panel
Power(W)	250
$T_{ambient}$ (°C)	28
Solar irradiation (G) W/m²	800
NOCT (°C)	46
TCP	0.45
T_{cell} (°C)	54
Losses (W)	3.6
Number of panels	13

Table 4: Data related to battery design.

Parameter	Panel
$V_{Battery}$	12 V
AH	200
Autonomy days (AD)	1.7
Efficiency	0.9
V_{bus}	48 V
Depth of discharge (DOD)	0.6
Total AH	505.81
Number of parallel branches	3
Number of batteries per branch	4
Number of batteries	12

Table 5: Data related to losses.

Component	Losses
Panel	3.6
Charger	2
Inverter	4
Cables + Dust	3
Total losses	12.6

Table 6: Data related to inverter.

Parameter	Inverter
Safety factor	1.3
Power factor	0.9
Rated power	1430 W

Table 7: Data related to charger.

Parameter	Charge
I_{min}	67.70833 A

Table 8: Overall dimensions of the setup.

Parameter	Dimensions
Length	1.67 m
Width	1 m
Spacing	2.19 m²
Panel area	2.19 m²
Total	28.47 m²

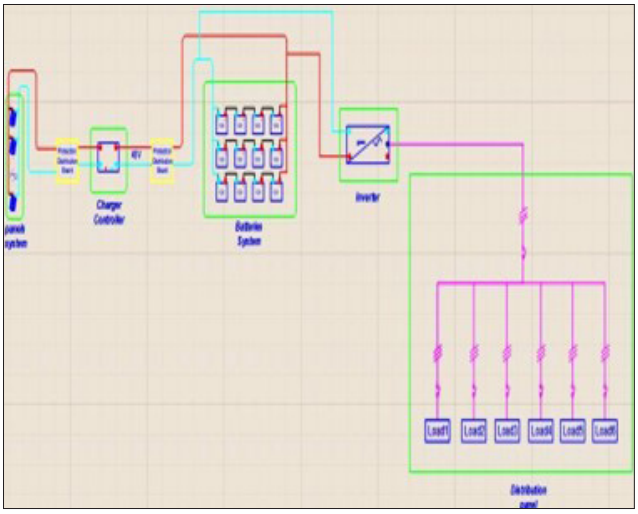


Figure 3: Layout of the off-grid PV system's electrical circuit and components.

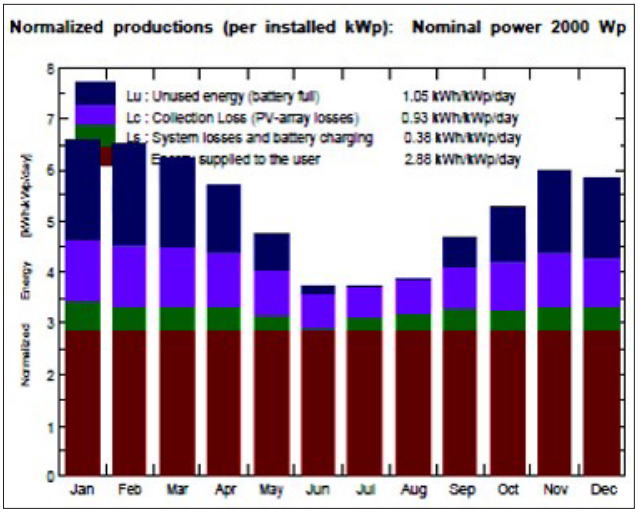


Figure 4: Normalized productions of panels.

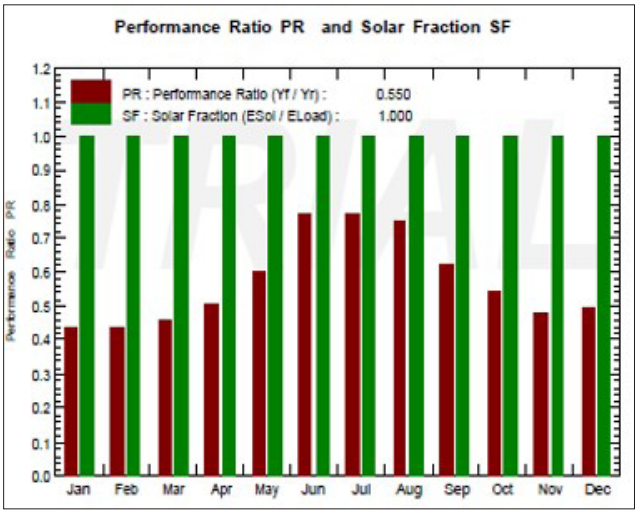


Figure 5: Performance ratio and solar fraction.

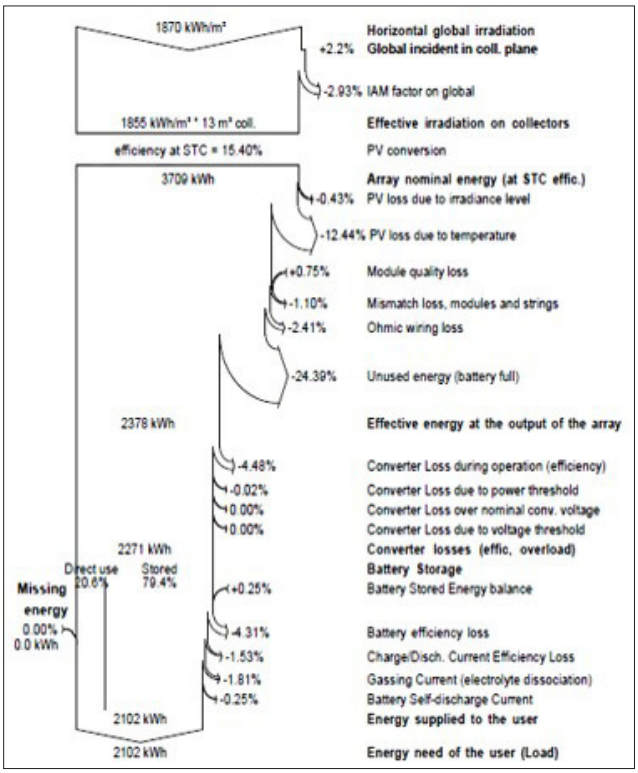


Figure 6: Loss diagram over the whole year.

months and lower during summer. On an average about 0.93 kWh/kWp/day are collection losses, 0.38 kWh/kWp/day care system and battery charging losses and finally about 2.88 kWh/kWp/day is energy supplied to the user. The nominal power is 2000 Wp for the current case. Figure 5 shows performance ratio, and solar fraction of the panels. Since the layout is done on PVsyst, it accurately designed the panels and capacity to meet the unit solar fraction and the corresponding performance ratio is obtained month-by-month through a year. From figure 4, it is observed that the performance ratios are maximum in the months of June and July with 0.78 and minimum is in the month between November to January at around 0.4. The loss diagram over the whole year is shown in figure 6.

The effective radiation on the collector is about 1855 kWh/m^2. This was obtained after considering the losses from the total irradiation of 1870 kWh/m^2. Th efficiency at STC is 15.40% and the corresponding nominal energy at the array is 3709 kWh. After this stage, the major losses are added by temperature loss and unused energy under full charge condition are 12.44% and 24.39% respectively. About 2378 kWh effective energy observed at the output of the array. Further, after deducting the losses due to battery self-discharge, gassing current, charge/discharge losses about 2102 kWh reached the end user. This is exactly the value for which the PVsyst designed the solar layout. Table 9 gives the detailed values of losses incurred under different categories month-wise across a year. Array virtual energy at max power point is observed to be high among all the losses. Unused energy losses are zero for the months of July and august.

Conclusions

The design and validation of an off-grid PV system intended for residential usage in Visakhapatnam (Andhra

Table 9: Energy losses of PV system month wise detailed tabular form.

	ModQual	MisLoss	OhmLoss	EArrMPP	EArUfix	EUnused	EArray
Jan	-2.578	3.810	9.157	333.4	333.4	120.0	213.4
Feb	-2.313	3.417	8.096	299.2	299.2	112.0	187.2
Mar	-2.435	3.598	8.267	315.2	315.2	108.5	206.7
Apr	-2.150	3.177	6.894	278.8	278.8	78.7	200.0
May	-1.861	2.749	5.503	241.7	241.7	44.4	197.3
Jun	-1.435	2.121	3.872	186.8	186.8	10.6	176.2
Jul	-1.489	2.200	3.966	193.8	193.9	0.0	193.8
Aug	-1.529	2.260	4.201	199.0	199.0	0.0	199.0
Sept	-1.772	2.618	5.438	230.0	230.0	32.9	197.0
Oct	-2.067	3.054	6.773	267.8	267.8	65.8	202.0
Nov	-2.286	3.377	7.776	295.9	295.9	96.7	199.2
Dec	-2.341	3.459	7.795	303.2	303.3	97.5	205.8
Year	-24.255	35.841	77.738	3144.7	3144.8	767.1	2377.6

Note: ModQual = Module quality loss; MisLoss = Module mismatch loss; OhmLoss = Wiring loss; EArrMPP loss = Array virtual energy at (Max Power Point); EArUfix = Array virtual energy at fixed voltage; and EUnused = Unused Energy (full battery) loss.

Pradesh, India), are successfully illustrated in this research article. This approach may be faithfully used to produce an effective and dependable PV system that can supply home energy needs. The outcomes demonstrated Visakhapatnam's high solar energy potential and supported the value of off-grid PV installations in the area. The study offers insightful information that will help to support the adoption of sustainable practices, lower carbon emissions, and promote the use of renewable energy sources. Based on Visakhapatnam's latitude of 17° and longitude of 83°, the proposed system suggests:

- The number of panels should be 13.
- The number of batteries should be 12.
- Rated power for the inverter should be 1430 W.
- I_{min} for the charger controller should be 67.70 A.
- PSHs should be 2.83 h.
- The graph between the production ratio and solar fraction reveals that the production ratio is constant at 1.0 for all months and the solar fraction is at its maximum in June at 0.78.
- In normalized production, the energy supplies to the user are constant at 2.8 for all months.

In conclusion, the study promotes the widespread use of off-grid PV systems as an important first step towards attaining energy independence and a more environmentally friendly future for communities all over the world.

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None.

Conflict of Interest

None.

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