Design and simulation of a building-based off-grid photovoltaic microgrid using PVsyst: A case study

Case Study

Anjana Saikia
Tezpur University,
Research Scholar, Department of Electronics and Communication Engineering
Napam, Sonitpur, India
anjana.saikia113@gmail.com

Santanu Sharma
Tezpur University,
Faculty of Engineering, Department of Electronics and Communication Engineering
Napam, Sonitpur, India
santanu.sharma@gmail.com

Abstract *– In the absence of a main or central grid, an off-grid renewable energy-based system could be a viable solution to address the electricity demand of a particular region by utilizing the available renewable energy sources (RES) of that area. This also leads society to a step toward sustainable energy development. A planned RES-integrated microgrid system not only fulfills the energy crisis and reduces electricity costs but also plays a significant role in the conservation of fossil fuels. Therefore, the design and simulation of RES integrated systems are indispensable as this type of analysis determines the vital parameters of the system e.g., the system performances including electricity output, energy conversion efficiency, yearly energy potential, and the system losses before being involved in practical implementation. Further, the cell temperature of the Photovoltaic (PV) panel based on regional weather conditions, the system life cycle based on the uncertainty factor of weather, total system installation cost with a full account of the annual savings and payback etc. can also be determined by designing and simulating such systems. This paper presents a design of a 40 kW off-grid photovoltaic (PV) microgrid system according to the load requirements at the Department of Electronics and Communication Engineering (ECE), Tezpur University, India using PVsyst software. The proposed design has been created to meet the daily peak load demand of 37 kW of the department. The energy available through the generating units of the proposed designed PV system is 45.46 MWh/Year and the system performance ratio in terms of efficiency over the year is 0.814. The overall performance analysis and simulation results would be helpful in determining the efficiency and viability of the proposed PV system while implementing it practically in the near future.*

***Keywords**: Load estimation, Photovoltaic (PV), PVsyst software, Renewable Energy System (RES), Sustainable development*

1. INTRODUCTION

In today's world, economic, industrial, and social developments define the overall progress of a country. However, the integration of different RES with electric power systems is also a crucial factor in the economic growth and development of a country. As conventional power generating systems are not sufficient to fulfill all the power uncertainties and have shown serious impacts on the environment, significant importance should be given to the penetrations of non-conventional generating sources to the small independent electric power systems such as renewable energy-based microgrids [1]. According to the annual report of the World Bank, till 2021, approximately 770 million people of the total world population still live without access to electricity, whereas in India, 13% of Indian households still do not have access to central grid-connected electrification [2]. Hence, it seems that people of places that are not included in the central electricity grid system yet are mainly dependable on battery-based systems or renewable energy-based systems [3]. India is a tropical country with a significant amount of solar insolation rate and excellent solar energy potential with 300 sunny days [4]. India has a total RES capacity of 106.37 GW as per the report of the central authority of Electricity India in February 2022, among them 50.7 GW is the total solar capacity i.e., 48% of the total RES capacity [5]. Fig.1 shows the breakups of various RES capacities in India. Hence in India, photovoltaic microgrid has the potential to overcome the load demand along with the high cost and high power loss that would be charged by the main grid while extending their feeders. Moreover, the long life of Photovoltaic panels (25 years) makes the PV-based system more affordable for common people providing clean and green energy with zero environmental impact, faster electrification with low maintenance costs and reliable power supply with low energy loss. Literature shows a wide number of researches in the field of PV-based systems highlighting their energy assessments, performance analysis, and improved efficiencies over a long period. A PV system designed for cities in Nigeria is found in [6] showing the economic viability of the solar energy potential for that place. In [7] technical and economic assessment of a grid-connected PV system is mentioned for household application. In [8] review of the life cycle assessment of the PV system is designed for sustainability and environmental performance.

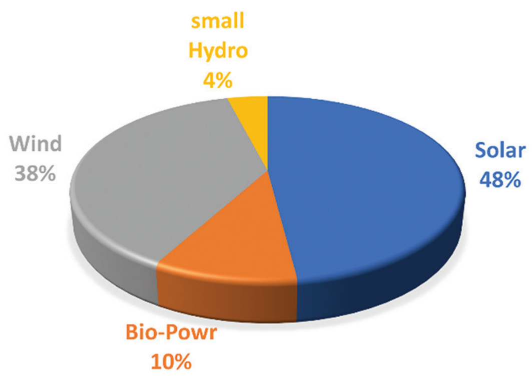

Fig. 1. Various RES capacities in India [5]

The design and monitoring of PV systems are explained in [9]. In [10], the design and cost analysis of a 1 kWp Photovoltaic system based on actual performance in an Indian Scenario has been explained. In [11] solar potential assessment using PVsyst software in the Northern zone of Morocco is performed and multiple geographical locations have been analyzed. In [12] design and simulation of a standalone solar PV system using PVsyst Software is evaluated but the required energy according to the load demand is a little less. A solar energy potential and performance analysis of a standalone PV system are explained in [13]. Performance analysis of a 700 KWp PV plant in Afghanistan is presented using PVsyst software in [14]. The design analysis of a grid-connected PV system has been performed in [15]. Case studies of two regions with improved design procedures to obtain structural optimization and load flow-based parametrizes have been marked in [16]. A design and simulation of a 5 MW PV system using PVsyst and HOMER software has been compared in [17]. A hybrid microgrid design and simulation is also performed in [18-20].

Microgrid is designed as a small distribution system and its distribution feeders are short-ranged compared to other conventional systems [21]. Generally, the loads connected to the small-scale microgrid feeders are unbalanced and hence it causes a higher R/X ratio of the feeder and a low short circuit capacity problem resulting in jeopardized stability of the system [22]. Hence to overcome this problem accurate estimation of loads is required while designing and sizing a microgrid. Moreover, the intermittent nature of RES such as PV, wind, etc. used in microgrids causes higher uncertainty. Hence, proper design and sizing are also necessary to defeat the uncertain characteristics of RES-based power plants.

This work aims to design a realistic PV microgrid that can be implemented practically soon. The key action involves accurate estimation of the load and simulation using PVsyst software to establish the viability of the proposed system. The proposed work presents the design and simulation of a 40 kW off-grid PV system for the departmental building of Electronics and Communication Engineering, at Tezpur University in India. From the simulation results, it can be observed that the proposed system has 81.4% efficiency and is able to fulfil the load demand of the departmental building. Detailed data can be obtained on the basis of solar potential, electrical energy generation and loss analysis of the PV panels and inverters over the year based on various environmental factors including irradiance, temperature, wind velocity etc.

The paper is organized as stated: In the first section a brief introduction of the PV-based systems and a throwback of their energy assessments using PVsyst software has been discussed. In the second section, the system design and the detail methodology for the case study have been explained following the results and discussion in the third section. The fourth section explains the conclusion and future work.

2. SYSTEM DESIGN

A photovoltaic system is dependent on the solar potential of a certain location [23]. However, the inclination, orientation, and quality parameters of the PV panels and the selection of the inverters along with the Maximum Power Point Tracking (MPPT) controller involved in the system also play a significant role in the design and sizing of the system. In this section, the methodology for designing, sizing, and simulating a 40 kW PV off-grid microgrid for the Department of Electronics and Communication Engineering, Tezpur University (India) using PVsyst software is discussed. The design of the overall system is based on the following factors:

- Critical load estimation: For load estimation, the department of ECE, Tezpur University (latitude 26.64° N and longitude 92.80° E and 61 meters above the sea level) is chosen and all the linear and nonlinear loads with single phase and 3-phase loads (i.e., the three-phase motors with different power factors used in the departmental Workshop and the Laboratories) are taken into account and total energy consumption per day in kWh/day has been calculated.

- From the state-of-the-art design and sizing of the Microgrid system, based on the load estimation, the sizing of PV panels and inverters has been estimated using PVsyst software, and the solar irradiation of the mentioned geographical area is calculated. PVsyst is a software that enables the optimization and design of any PV-based system. This software has been considered for meteorological databases; thus, it helps to estimate the annual energy generation of a PV-based system, and the yearly solar irradiance data. Moreover, the accurate estimated load profile data are achieved along with the daily power demand.

2.1. SYSTEM DESIGN

A PV-based off-grid microgrid system consists of PV panels, MPPT controllers, inverters and energy storage devices and the loads have been described in Fig 2.

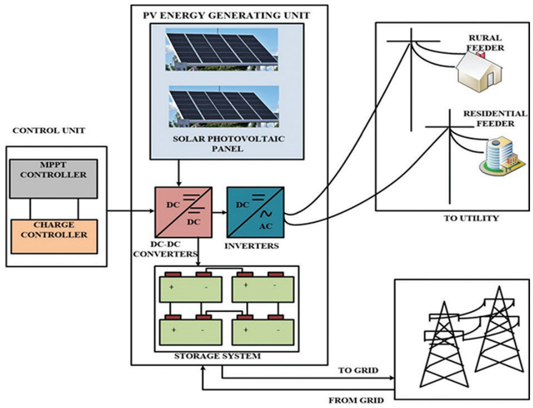

Fig. 2. Schematic diagram of a PV microgrid system

2.2. LOAD ESTIMATION OF THE SYSTEM

Load estimation is a challenging task for any distribution system operation and planning problems. A proper load estimation requires detailed parameters of the connected loads and the time interval over which the load variation is to be estimated [24]. To estimate the overall load demand, the load data of the department of ECE, Tezpur University is collected manually. Types and quantities of electrical appliances, their operating time in 24 hours duration and the maximum power consumption in watt (W) has been noted. With this information gathered, the total load data is estimated as shown in Table 1. The total energy consumed by the system loads per day is 366.97 kWh/day and the total power consumption per day is 36.985 kW. Hence to sufficiently fulfil the estimated load demand a 40 kW microgrid design and sizing is proposed with the provision of some spare capacity to use if future expansion is required.

Table 1. Load estimation in the Dept. of Tezpur University

Sl No.	Appliances	Quantity	Power (W)	Total power (kW)	Run time Day (hr)	kWh in Day	Run time Night (hr)	kWh in Night	Total Energy Consumption (kWh/Day)
1.	LEDs	21	15	0.315	4	1.2	12	3.7	4.9
2.	Tubes	100	55	5.5	8	44	12	66	110
3.	Fans	96	100	9.6	8	76.8	5	48	124.8
4.	AC	9	1500	13.5	6	81	0	0	81
5.	Motors	6	747.08	4.4	1	4.4	0	0	4.4
6.	Pcs	36	80	2.8	8	23	5	14.4	37.4
7.	Printers	6	45	0.27	1	0.27	0	0	0.27
8.	Other Appliances	10	60	0.6	6	3.6	1	0.6	4.2
	Total			**36.985**		**234.2**		**132.7**	**366.97**

2.3. PVSYST SOFTWARE

PVsyst is a simulation software for configuring a PV system. The users can design and size a standalone, grid-connected, and PV-pumped-based system in a user-friendly environment. The main input variables for the simulations are the geographical location and the load requirement of the system. Further, the PV panels and the inverter selection and sizing are to be done accordingly. The software stores location-wise meteorological databases from all around the globe. The post-simulation results can be obtained including the solar potential data for a particular location, performance ratios and loss analysis of the system both in tabular and diagram form. The step-by-step system design methodology is explained in Fig 3. The solar potential of the selected area can be generated by providing the geographical location of that area using latitude, longitude, and altitude. Plant orientation has fixed the tilt and azimuth angle associated with PV Panels. Based on the solar potential and the load requirement of the selected area, the selection and sizing of the PV panels, inverters, and MPPT controllers are provided. The system specification of the proposed design is systemized in Table 2.

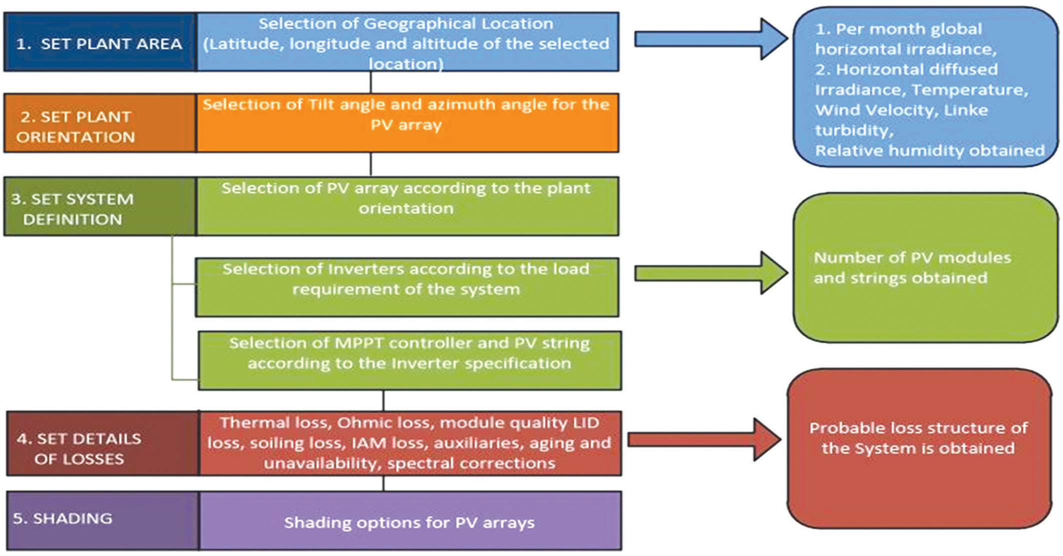

Fig. 3. Step-by-step procedures for PVsyst simulation Analysis

Table 2. The system specification

Category	Parameters	Value
Geographical location	latitude	26.70° N
	longitude	92.83° E
	Altitude	48m
	Time Zone	UTC+5.5
	Albedo	0.2
PV field Orientation (Fixed)	Tilt/ Azimuth angle	26/0°,26/0°
System input	PV module	120 Units (STP-335-A60-Wnhb)
	Module Capacity	335 Wp per module at 50ºC
	Technology	Si-Poly
	Nominal Power	40.2 kW
	Module Area	202 m^2
	V_{mpp} (50°C)	611 V
	I_{mpp} (20°C)	29 A
	Number of inverters	02
	Inverter type	Solar Inverter RPI M20A
	Inverter Rating	200-820 V, 50 Hz

2.3.1. Geographical Location

In Table 2, the system input parameters for geographical location are categorized. The Department of Electronics and Communication Engineering, Tezpur University is located at the latitude 26.70° N and longitude 92.83° E and 48 m altitude (location height from the sea level) in India using the time zone of UTC+5.5 and albedo 0.2.

2.3.2. Tilt and Azimuth Angle

Tilt angle and azimuth angle decide the orientation and inclination of the PV panels in the PV generating unit. Tilt angle is the angle of inclination of the PV panel where it is to be mounted. Tilt angle depends on the latitude of the location and is taken as approximately equal to it. It can be seasonal considering the changing position of the sun with the season. The azimuth angle is the angle by which the PV panel can be mounted as south-facing for the northern hemisphere and north-facing for the Southern hemisphere. The optimized value of both these angles is required to get optimum energy from the PV panels. In the proposed system tilt angle is taken as 26º and the azimuth angle is taken as 0° for two strings of PV panels.

2.3.3. PV specification

Panels are selected to be 120 units with an output of 335 W. The panels are made of Si-polycrystalline technology and module no is STP-335-A60-Wnhb with an MPPT voltage of 611 V and current of 29 A. The 120 units of PV panels with the mentioned specification are connected in two parts with 2 Strings × 60 series connected panels.

2.3.4. Inverter Specification

For the 40 kWp PV microgrid the inverter required is of 2 numbers with a power rating of 200-820 V,50/60 Hz. The inverter model is Solar Inverter RPI M20A. The DC power input at MPPT is 17.45 kW and the maximum AC power generated is 21 kW for both the inverter.

3. RESULTS

The report provides a detailed performance analysis of the proposed 40 kW PV microgrid through diagrams and tables generated by PVsyst software. To satisfy 40 kWp of load the system required 120 units of PV panels of 335 Wp capacity as generating units and two numbers of inverters having the capacity of 200-820 V,50 Hz with a conversion efficiency of 96%. To get optimized energy output from the PV-generating units, two MPPT controllers are used with each inverter. Applying all the necessary conditions the simulation has been performed in the software. The software calculated the solar irradiance data for the proposed system. The yearly global horizontal irradiance is 1408.4 kWh/m^2 on average as mentioned in Table 3. The monthly diffused horizontal irradiance, ambient temperature, global incident irradiance, effective array energy, the energy available on the load side and performance ratios for all over the year can be obtained from Table 3.

Table 3. Measured data of various irradiances, ambient temperatures, array energy, energy available on the load side and performance ratio

Month	Global Horizontal Irradiance (kWh/m²)	Diffused Horizontal Irradiance (kWh/m²)	Ambient Temperature (°C)	Global Incident Irradiance (kWh/m2)	Effective Array Energy (MWh)	The energy available in the load (MWh)	Performance ratio
January	93.0	48.75	17.05	103.5	3.420	3.330	0.838
February	95.0	59.68	19.76	101.6	3.322	3.235	0.829
March	135.2	85.76	23.24	139.6	4.509	4.389	0.819
April	121.2	78.58	24.40	121.8	3.917	3.809	0.814
May	127.1	88.57	26.71	124.6	3.980	3.870	0.809
June	135.7	75.42	27.78	131.7	4.173	4.053	0.802
July	120.1	84.23	28.64	117.2	3.713	3.609	0.802
August	149.2	85.34	28.91	147.9	4.680	4.549	0.801
September	117.4	69.36	27.80	120.1	3.805	3.699	0.802
October	115.2	62.69	26.09	122.2	3.895	3.791	0.808
November	105.2	50.21	21.67	117.7	3.815	3.717	0.822
December	94.1	48.05	18.40	106.5	3.496	3.406	0.833
Year	1408.4	836.65	24.23	1454.2	46.726	45.456	0.814

The average Incident radiation data on a collected plane is 1454 kWh/m^2, temperature is 24°C and effective array energy is 46.7 MWh over the year. Fig. 4 shows the daily produced useful energy over the year for the designed system is 3.24 kWh/kWp/day and results show the highest energy generation is in the months of March and August while the PV array losses and system losses are 0.65 kWh/kWp/day and 0.09 kWh/kWp/day respectively.

The performance ratio is represented in Fig 5. The lowest performance ratio is for the month of August at 80.1% and the highest is 83.8% for the month of January. The overall performance ratio over the year is 81.4%.

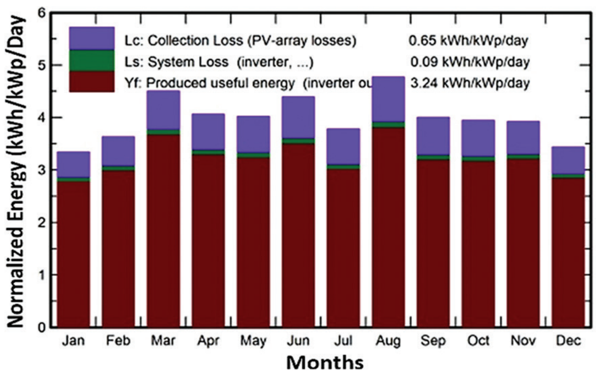

Fig. 4. Graphical analysis of normalized energy distribution over the year

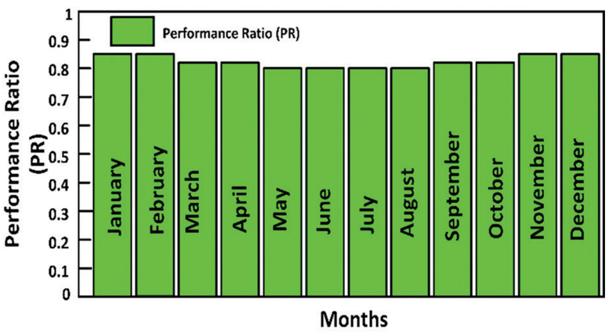

Fig. 5. Performance Ratio Analysis

The hourly consumption of the energy is shown in Fig. 6 in 24-hour format. The designed system has a peak load demand in the 15th hour measured at approximately 25 kW according to the load demand of the system and lowest in the 6th to 10th hours showing nearly 0 kW.

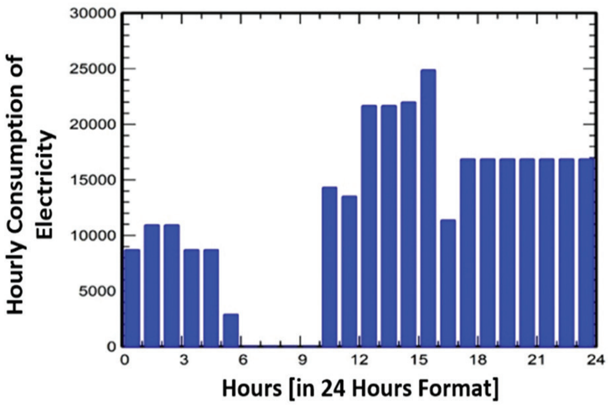

Fig. 6. Hourly consumption of energy

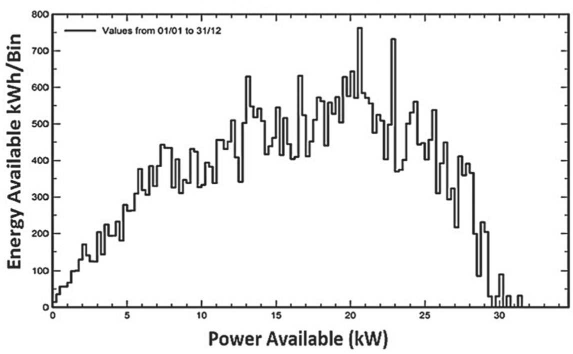

Fig. 7. Daily energy and power available on the inverter side

The yearly energy available in kWh/Bin versus the available power of the inverter side in kW is graphically represented in Fig. 7 showing the yearly energy available in the PV panel versus the energy available to inject to the grid.

Fig 8 explains the graphical analysis of the energy produced over the year including the PV array losses and system losses. The various losses due to wiring, soil factor, and temperature mismatch in the system are 0.82%, 3% and 5.89% of the total generated energy respectively.

The other losses of the system are calculated by the software according to the geographical location and sizing of the system. After the analysis of various losses present in the system, the energy obtained in the load side is analyzed by the software and the value is 1362 kWh while the energy generated by the generating unit is 1408 kWh.

From the above analysis, it has been clear that the data simulated in this work is detailed data of the designed PV system using PVsyst simulation software to implement the proposed designed PV microgrid practically. The insertion of more PV panels leads the system to generate more PV energy to inject into the central grid system. Accordingly, all the measured data of irradiances, available array energies, performance ratios and their average value every month over a year can be evaluated.

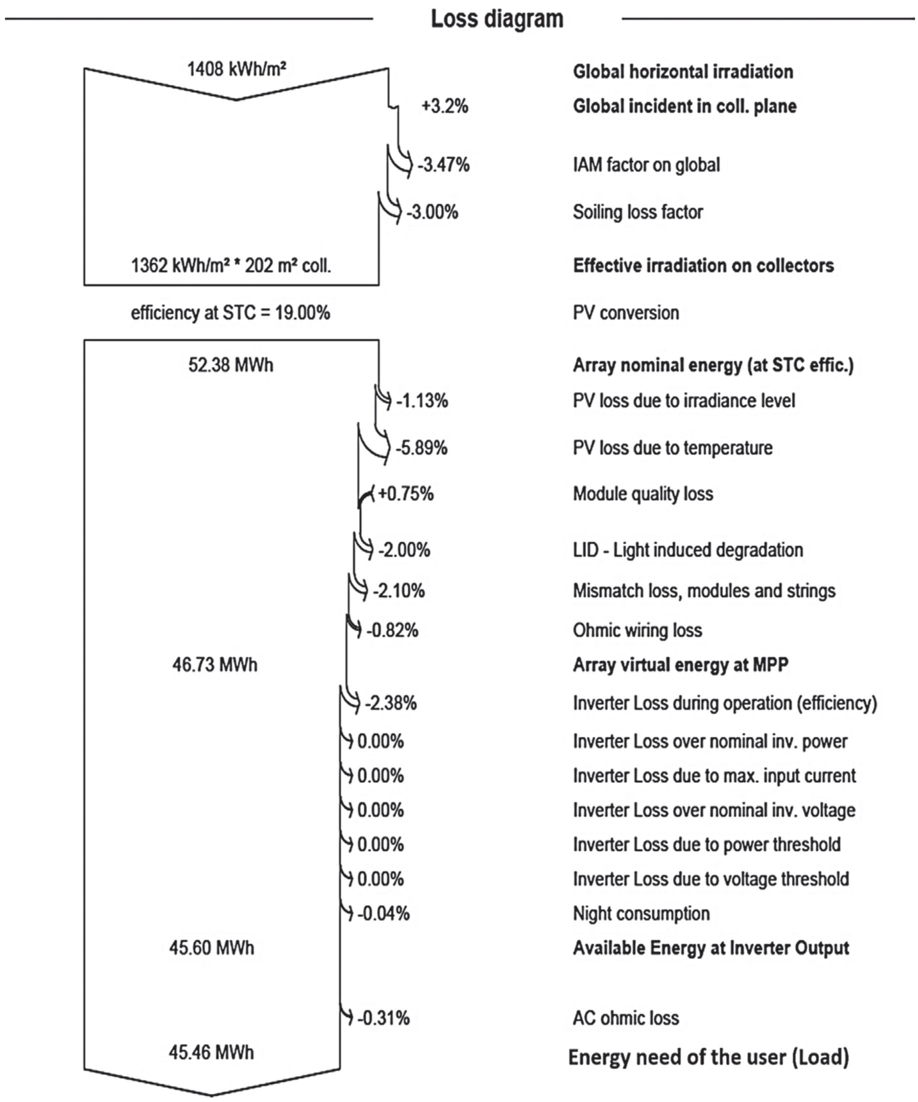

Fig. 8. Loss analysis of the proposed designed system

4. CONCLUSION

The design and simulation of a 40 kW photovoltaic microgrid system using PVsyst software are presented in this paper. The results are based on the solar potential and load analysis of the aforementioned area. The PVsyst software-based performance ratio for the system is 0.814 which shows that the mentioned area is well-fitted for a PV-fed system and it acquires a good solar potential. The PVsyst software result can provide reliable sizing for the departmental building at the time of installation and can be helpful while choosing the ratings and quantities of the PV panels, inverters, MPPT controllers and batteries to fulfil the load demand. This kind of analysis can help the researcher and industrialist design a PV-based microgrid while installing it in different locations. In the future, grid-connected PV systems with large capacities would be preferred to obtain an energy assessment by designing via PVsyst software with a better performance ratio to fulfill the power demand of the grid.

List of abbreviations:

Abbreviations	Definitions
AC	Alternative Current
DC	Direct Current
GW	Gigawatt
Hz	Hartz
IAM	Incident angle losses
I_{mpp}	Current at maximum power point
LID	Light-induced degradation
MPPT	Maximum Power Point Tracking
kW	Kilowatt
kWh	Kilowatt-hour
MW	Megawatt
MWh	Megawatt hour
PV	Photovoltaic
RES	Renewable Energy Sources
V_{mpp}	Voltage at maximum power point
W	Watt

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