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Design and performance analysis of standalone solar photovoltaic power system for health facility in EKET using PVSYST simulation software

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Abstract

In this research, design and performance analysis of standalone solar photovoltaic (SSPV) power system for health facility in Eket using PVSyst simulation software is presented. Specifically, standalone solar photovoltaic (SSPV) power system was designed and simulated with PVsyst for two scenarios for a hospital in Eket Akwa Ibom State. In the first scenario, the SSPV power system was design to eliminate loss off load without any alternative energy source other than the SSPV power system. In the second scenario, the SSPV power system was design to allow for some loss off load giving room for alternative back-up energy source other than the SSPV power system. The case study hospital has daily load demand of 455,754.00 kWh per day which approximates to a 24 hours a day energy consumption of an average load of 18989.75 Watt load. The annual total solar radiation of the site is 1717.2 kWh/m^2 while the annual mean for the ambient temperature is 24.9°C. The results shows that the scenario 1 has about 7.9% energy output above that of scenario 2. The unused energy in scenario 1 is about 26.5 % higher than that of scenario 2. The energy supply in scenario 2 is about 2% short of the load demand while the scenario 1 has no energy supply shortage. The energy supply shortage in scenario 1 cause the 2 %missing energy or loss of load with the attendant 179 hours of loss of load duration. In all, with detailed loss of load analysis up to hourly level, it is possible to make adequate prior arrangements for managing the expected loss of load incidences.

Keyword: Solar-Powered Health Facility; Standalone Solar Power; Loss of Load; PVSYST Software Photovoltaic Power System; Loss of Load

1. Introduction

Nowadays, electricity is an increasingly essential commodity in remote healthcare facilities [1,2,3]. Increasingly, refrigerators and electronic diagnostic tools are part of the standard of care in many clinics throughout the world [4,5,6,7]. Recent improvements in the distribution of vaccines and other cold chain-dependent supplies that requires refrigerators, as well as the global push to deliver antiretroviral drugs and services to HIV-positive patients worldwide, have introduced new demands for electricity in sites with little or no access to reliable electrical power [8,9,10]. Unfortunately, in Nigeria, most health care facilities do not have access to reliable electricity [11.12]. Most of health facilities surveyed in Akwa Ibom are relying on generators to provide the needed power. Among the health facilities relying on generators, none of them reported being able to run the generators for long periods of time mainly due to the high cost of fuel and diesel.

Remarkably, the lack of electricity has a devastating impact on the health workers ability to provide patients with quality care eHealth Africa [13,14,15,16]. Poor infrastructure can delay the delivery of critical medical supplies, and inclement weather can make it difficult for patients to access the clinic. An unreliable energy source adds to these challenges

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[17,18]. Power disruptions result in a disruption of treatment programs or the inability to reliably use electrical appliances such as laboratory equipment [19,20,21]. Selecting an appropriate source of reliable and sustainable energy can help mitigate some of the challenges inherent in operating a health facility in the developing world.

Fortunately, for health facilities in Akwa Ibom State, photovoltaic (PV) systems may offer the most practical , environmental-friendly and effective way to access electricity [22,23]. Photovoltaic systems represent a silent, safe, none pollutant and renewable source of electrical energy [24,25]. According to World Health Organization (HWO) access to health care can be enhanced and made more reliable through off-grid renewable energy systems [19,20]. Particularly in remote, resource-poor settings, renewable energy sources can supply basic electricity for lifesaving procedures that might not otherwise be feasible. In off-grid rural health dispensaries, for example, PV systems oftentimes are an appropriate way to run many low-power, high-value appliances and equipment, from lamps and vaccine refrigerators to water pumps, television sets, and computers[12,35].

Accordingly, in this research, the focus is on the design and performance analysis of standalone solar photovoltaic (SSPV) power system for health facilities in Akwa Ibom state. The analyses are conducted through the use of professional solar power system simulation software, called PVSyst [26,27,28,29]. The research will provide requisite design options along with performance assessment that can guide the government of Akwa Ibom state and other stakeholders to take decision regarding the use of appropriate PV system to provide electric power to the health facilities in the cities and remote villages across Akwa Ibom State. It will also provide essential knowledge for further research on improving the electric power supply in the cities and remote villages of Akwa Ibom and in the diversification of electric power sources across Akwa Ibom State.

2. Methodology

The research focus is to use PVSyst simulation software to design and evaluate the performance of a standalone solar photovoltaic (SSPV) power system for a health facility, which in this case is a typical popular hospital in a city location.

2.1. Select the case study hospital and determine the installation site geo-location parameters for the solar power system

The selection of the case study health facility is the first step in the research process. In this case, the criteria used for the selection includes that the health facility is popular in the area and that it is located in the city where there are much population to be served and there is access to the grid. In this study, the Google Maps is used to locate the hospital in Eket in Akwa Ibom State and as shown in Figure 1, a cluster of about 12 hospitals are captured on the map in the section of Eket that is zoomed by on the map [36,37]. Out of the 12 health facilities, the Emmanuel General Hospital is selected. The hospital is a government owned hospital and some worked have been published by [30,31,32] on the load profile for a solar power system for the hospital. The map location of the case study Emmanuel General Hospital in Eket, Akwa Ibom State is presented in Figure 2.

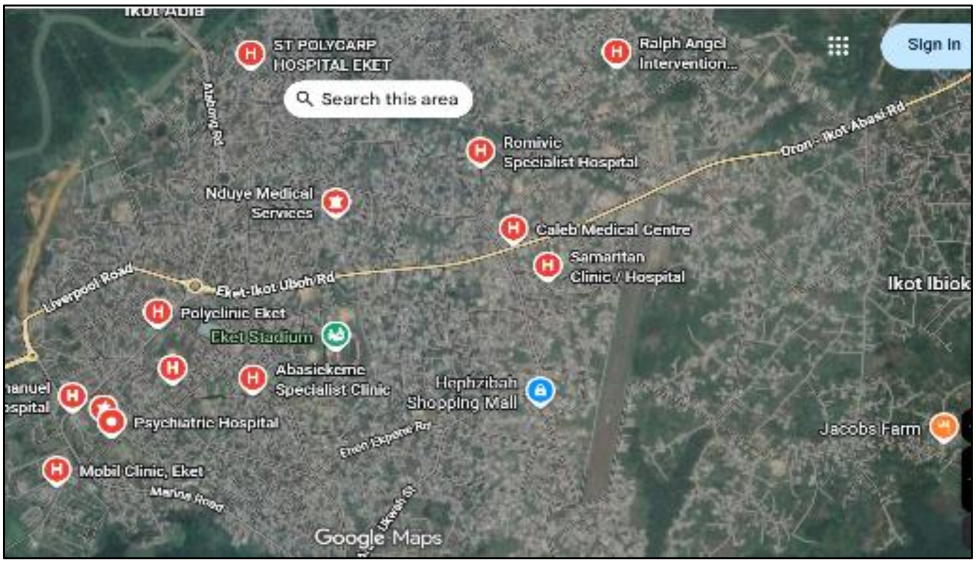


Figure 1 A cluster of hospitals located in a section of Eket in Akwa Ibom State

Figure 2 The map location of the case study Emmanuel General Hospital in Eket, Akwa Ibom State

2.2. The daily load demand profile of the health clinic

In this research, the load profile of the case study health facility is presented in Table 1. The load profile is adapted from the one published by [23,32,34]. For Emmanuel Hospital Eket. The load profile is adapted from the work by. The load profile presents a daily load demand of 455,754.00 kWh per day which approximates to a 24 hours a day energy consumption of an average load of 18989.75 Watt load. However, the peak power demand according to Table 1 is 23,171.00.

The power system is for a standalone solar photovoltaic (SSPV) power system. The essence of the load profile is to capture mainly the electrical load items that are crucial for the operation of the hospital for which constant electrical power supply is required. Therefore, the load profile does not account for all the electrical loads that are in the hospital.

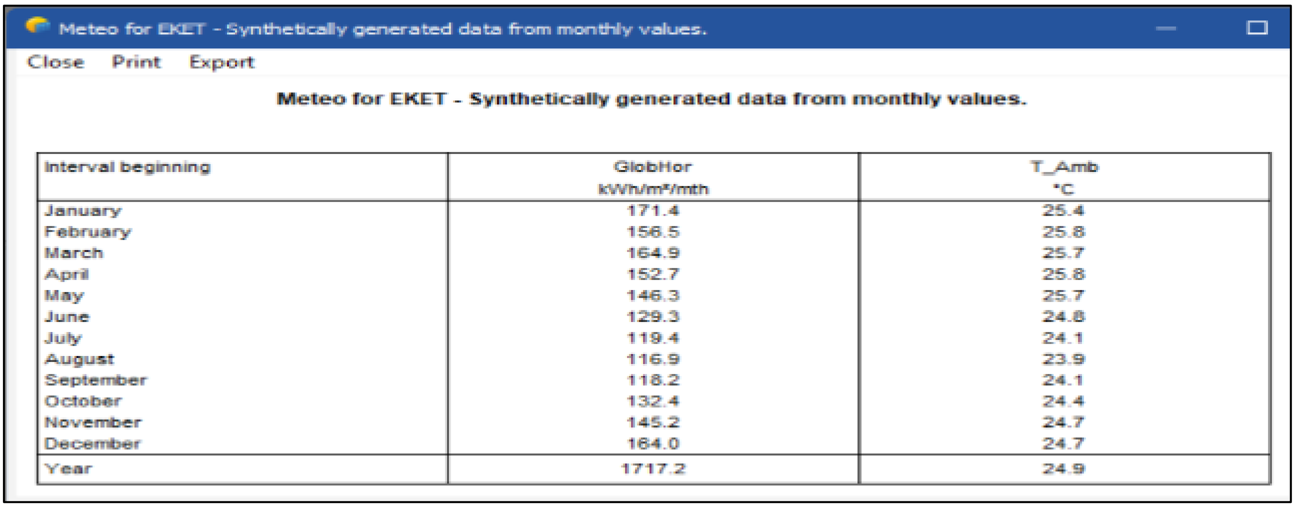
Table 1 The Load Profile of the Health Clinic

S/N	Appliance Description	Qty.	Rated Power (Watts)	Number of Hours Operated	Total Power (Watts)	Total Energy in Wh per day	Total Energy in kWh per day
1	Blood bank Fridge	3	50	24	150	3600	3.6
2	Vaccine Fridge	3	80	24	240	5760	5.76
3	Microscope	2	15	10	30	300	0.3
4	Operating Lamp	3	125	10	375	3750	3.75
5	Hematology Mixer	3	28	10	84	840	0.84
6	Incubators	4	400	24	1600	38400	38.4
7	Curing light	2	90	10	180	1800	1.8
8	Microwave	2	700	10	1400	14000	14
9	Medical Centrifuge	2	578	10	1156	11560	11.56
10	Washing Machine	2	450	24	900	21600	21.6
11	Syringe Pumps	2	600	2	1200	2400	2.4
12	Lighting	54	100	24	5400	129600	129.6
13	Air conditioners	6	746	24	4476	107424	107.424
14	Drier	3	500	24	1500	36000	36
15	PC and Printer	3	120	24	360	8640	8.64
16	Vaccine Refrigerator/Freezer	2	60	24	120	2880	2.88

17	Small Refrigerator (non-medical use)	4	400	24	1600	38400	38.4
16	Ceiling Fan	24	100	12	2400	28800	28.8
	Total				23,171.00	455,754.00	455.75

2.3. The solar radiation and ambient temperature of the installation site

The monthly and annual mean solar radiation and ambient temperature of the site are presented in the screenshot in Figure 3. The annual total is 1717.2 for the solar radiation and while the annual mean is 24.9 for the ambient temperature. The scatter plot of the daily mean radiation is presented in Figure 4 while the line graph of the daily mean ambient temperature is presented in Figure 5



Interval beginning	GlobHor kWh/m²/mth	T_Amb °C
January	171.4	25.4
February	156.5	25.8
March	164.9	25.7
April	152.7	25.8
May	146.3	25.7
June	129.3	24.8
July	119.4	24.1
August	116.9	23.9
September	118.2	24.1
October	132.4	24.4
November	145.2	24.7
December	164.0	24.7
Year	1717.2	24.9

Figure 3 The monthly and annual mean solar radiation and ambient temperature of the site

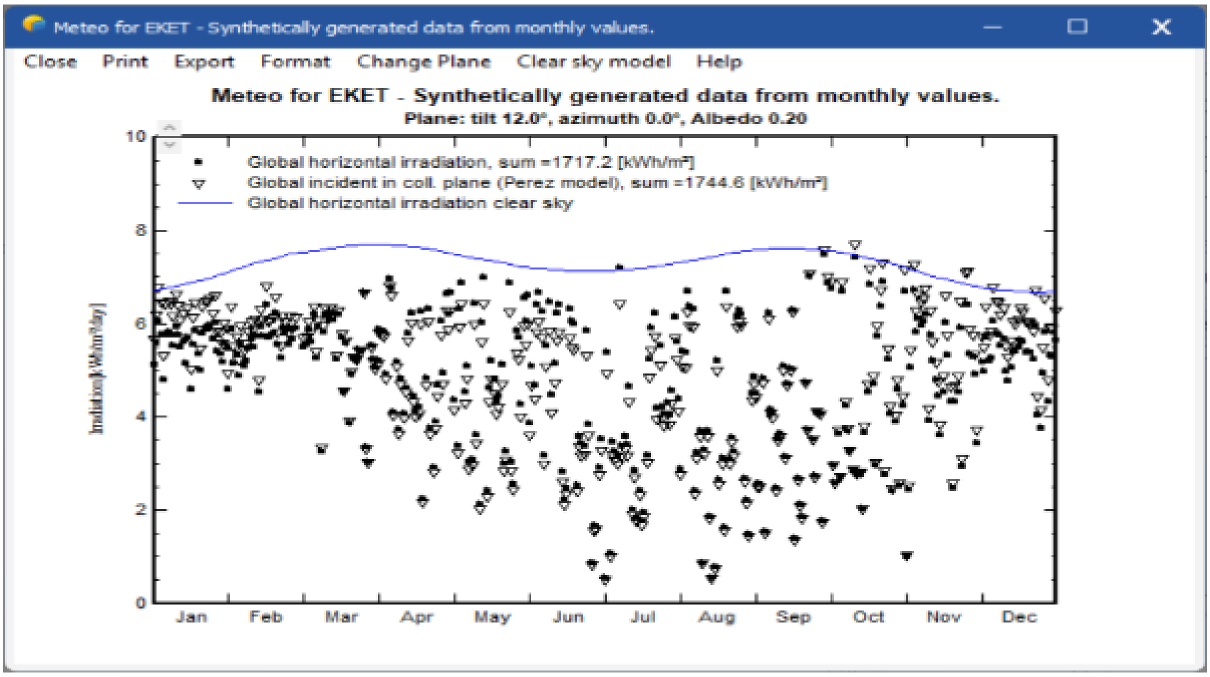


Figure 4 The scatter plot of the daily mean radiation

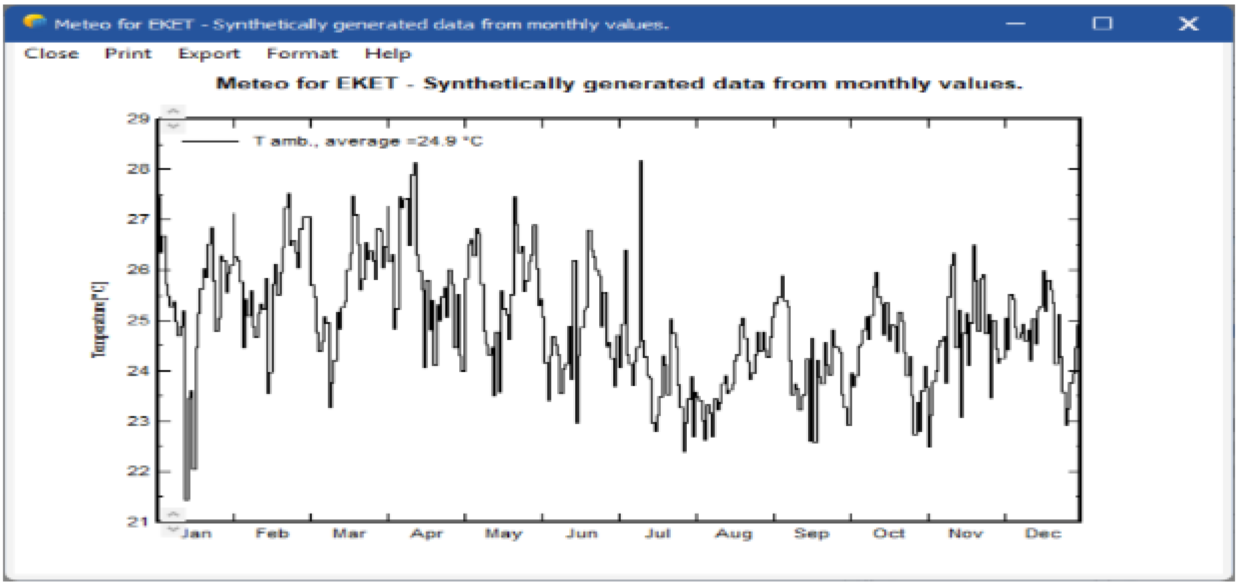


Figure 5 The line graph of the daily mean ambient temperature

2.4. The setting for the optimal tilt angle of the PV modules

The yearly fixed optimal tilt angle of 12° with azimuth angle of 0° was selected as shown in Figure 6.

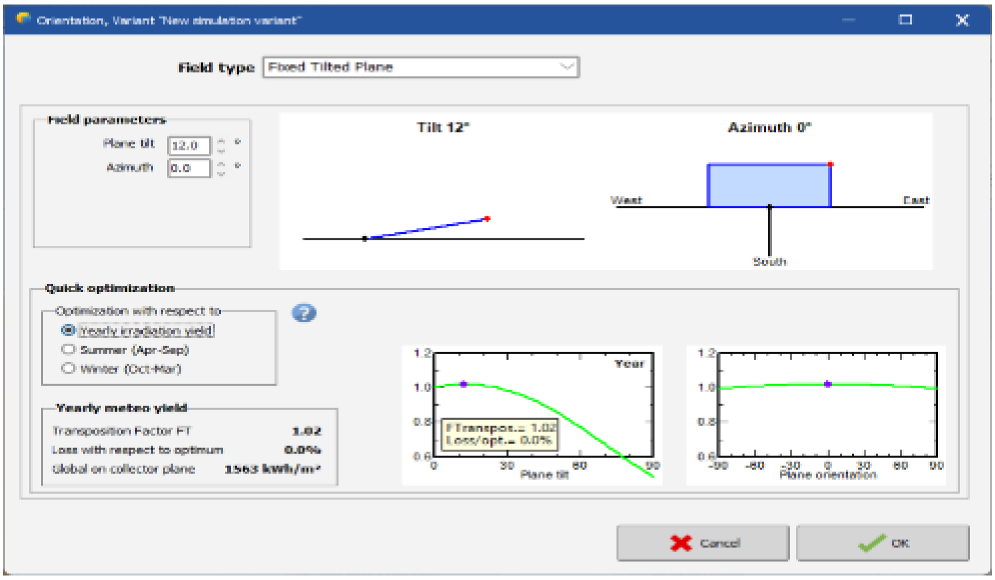


Figure 6 The yearly fixed optimal tilt angle of 11° with azimuth angle of 0°

2.5. The setting for load demand

The load demand was set at an hourly average of 18990 W running for 24 hours which gives a daily energy demand of 455760 which is about the same as the daily energy demand (of 455,754.00) stated in Table 1.

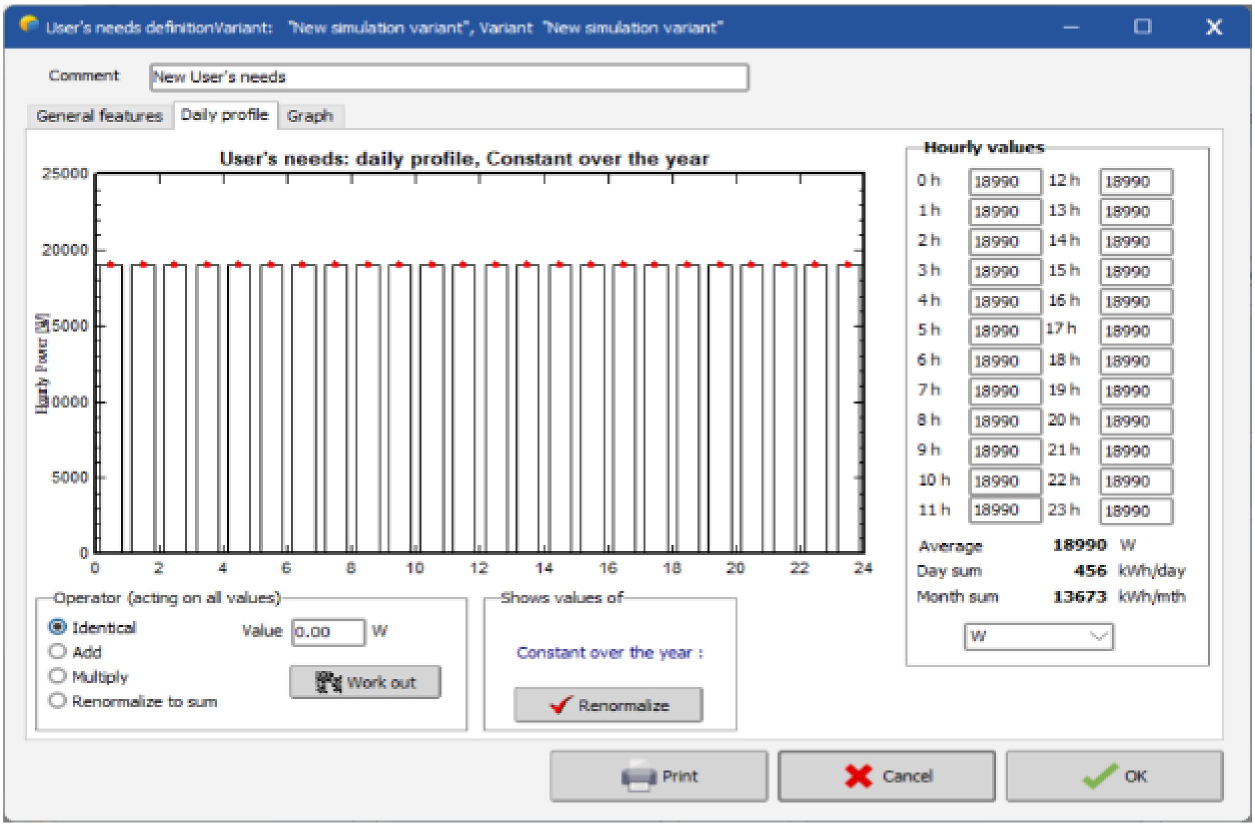


Figure 7 The hourly average load demand for the hospital

2.6. The settings for the solar power system configurations and simulation of the solar power system

The layout of the Standalone Solar Photovoltaic Power (SSVP) system with battery storage and no back-up generator is presented in Figure 8. It shows a standalone system without any back-up generator. The SSVP is designed for two scenarios; the first case is designed with 1% loss of load (LOL) and 7 days power autonomy while the second scenario is designed with 5% loss of load (LOL) and 3 days power autonomy. The first case is meant to ensure that there is no significant or noticeable power outage all through the year. In the second scenario, some hours of power outage can be tolerated. However, the system predicts the data for the expected power outage as well as the specific time of the day the outage will occur so that contingency plan can be made ahead of the scheduled power outage.

The PV array setting for design scenario 1 having 1% loss of load (LOL) and 7 days power autonomy is presented in Figure 9 while Figure 10 shows the battery bank setting. The number of PV array in series is 4 and the number of the strings in parallel is 220 giving a total of 880 PV modules in the PV array. Also, the number of batteries in series is 8 and the number of the battery strings in parallel is 140 giving a total of 1120 battery units in the battery bank.

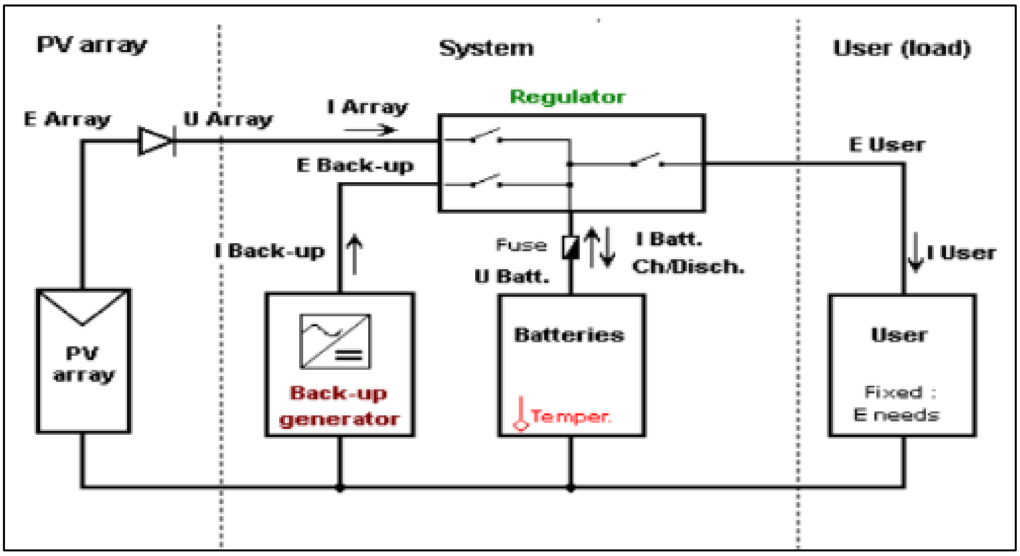


Figure 8 The layout of the Standalone Solar Photovoltaic Power (SSVP) system with battery storage and no back-up generator

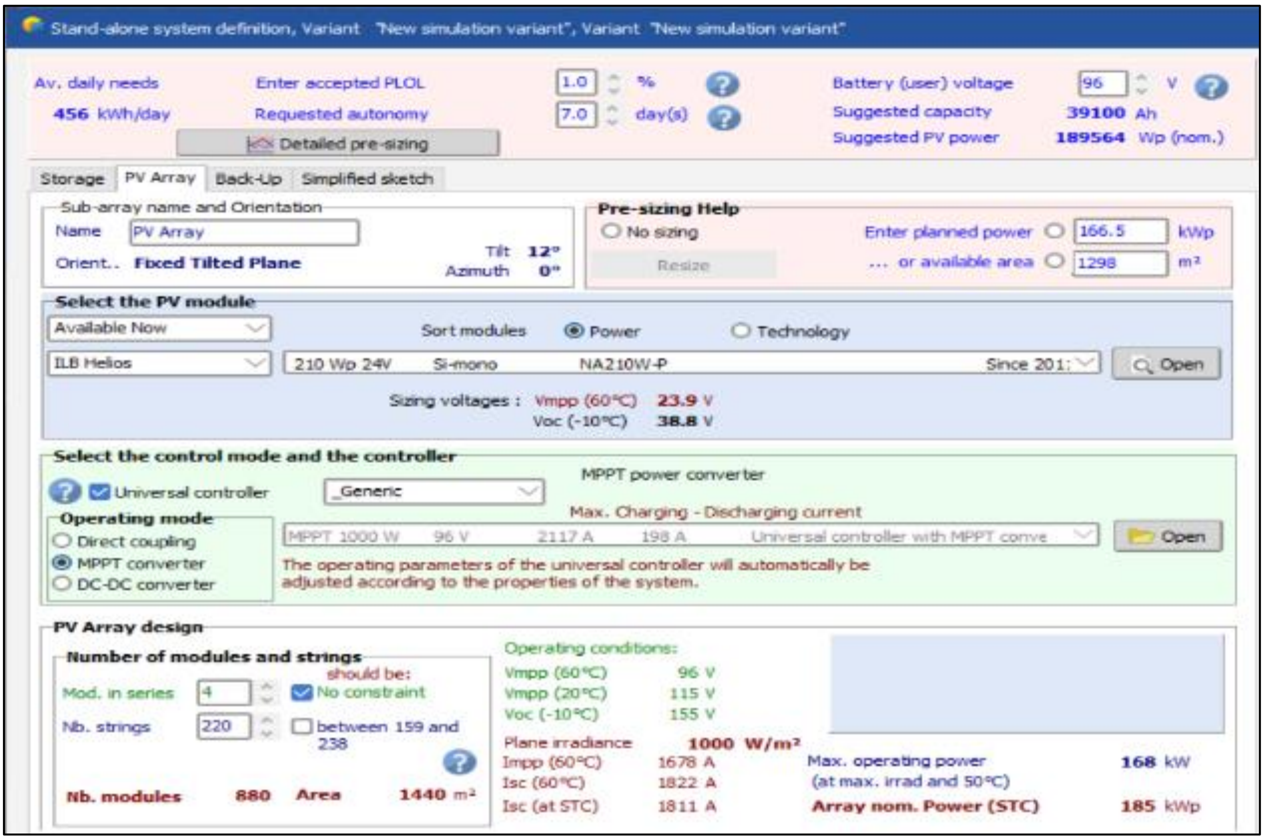


Figure 9 The PV array setting for design scenario 1having 1% loss of load (LOL) and 7 days power autonomy

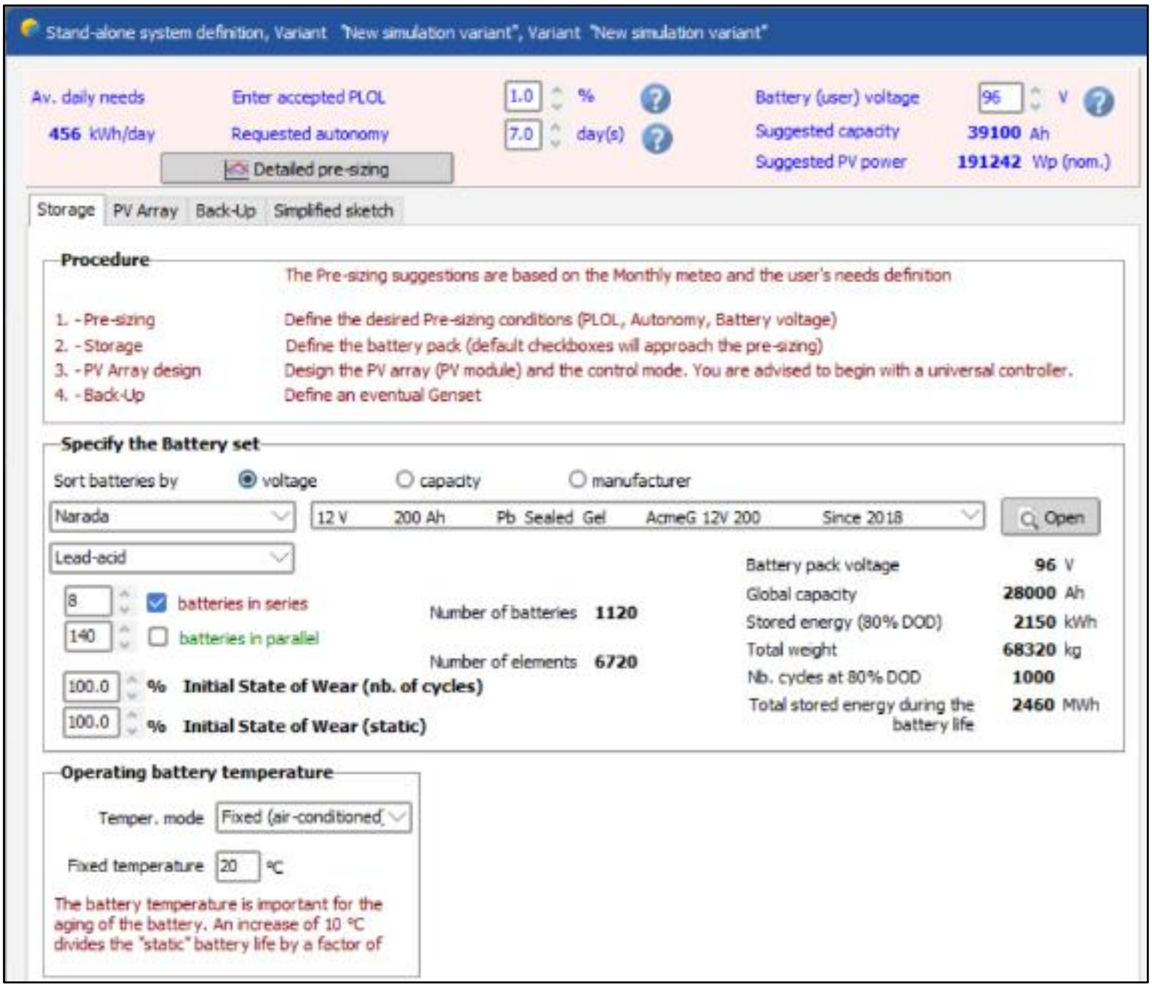


Figure 10 The battery bank setting for design scenario 1having 1% loss of load (LOL) and 7 days power autonomy

The PV array setting for design scenario 2 having 5% loss of load (LOL) and 3 days power autonomy is presented in Figure 11 while Figure 12 shows the battery bank setting. The number of PV array in series is 4 and the number of the strings in parallel is 203 giving a total of 812 PV modules in the PV array. Also, the number of batteries in series is 8 and the number of the battery strings in parallel is 140 giving a total of 1120 battery units in the battery bank.

After setting the PV array and the battery bank number and capacities, the PVSyst is used to simulate the SSPV system for each of the two scenarios. The simulation results are presented in chapter 4.

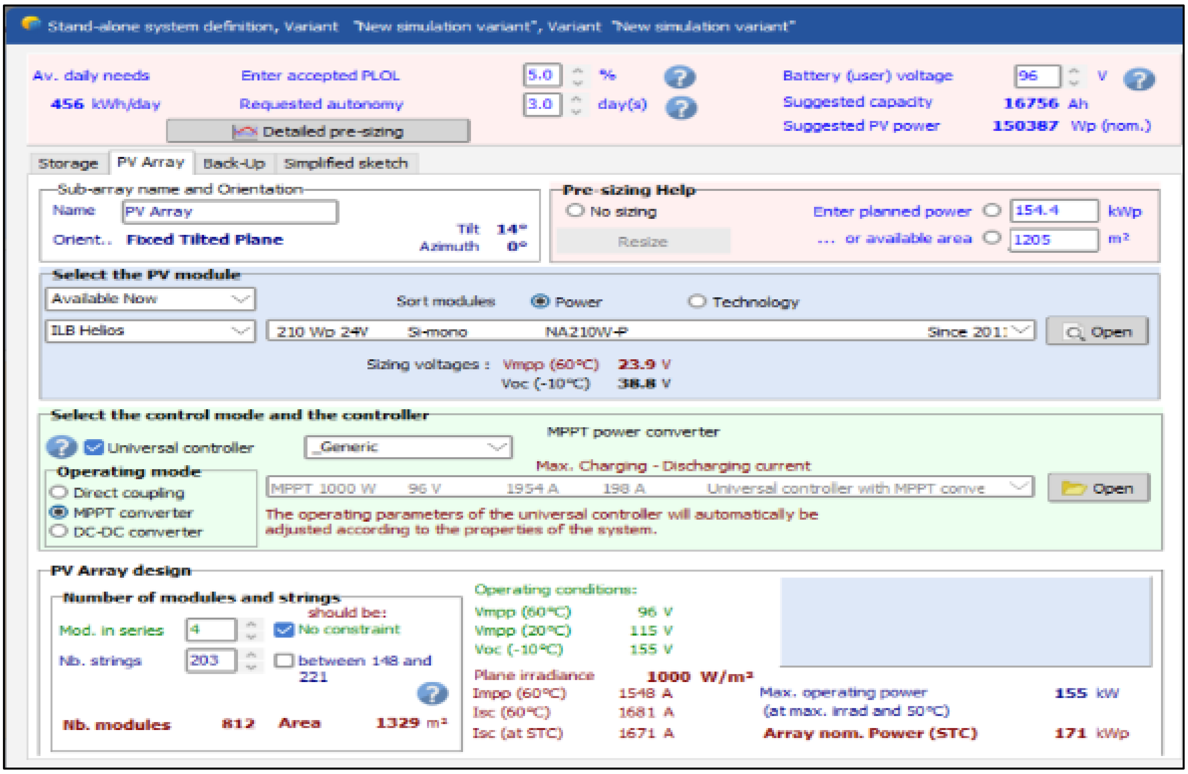


Figure 11 The PV array setting for design scenario 2 having 5% loss of load (LOL) and 3 days power autonomy

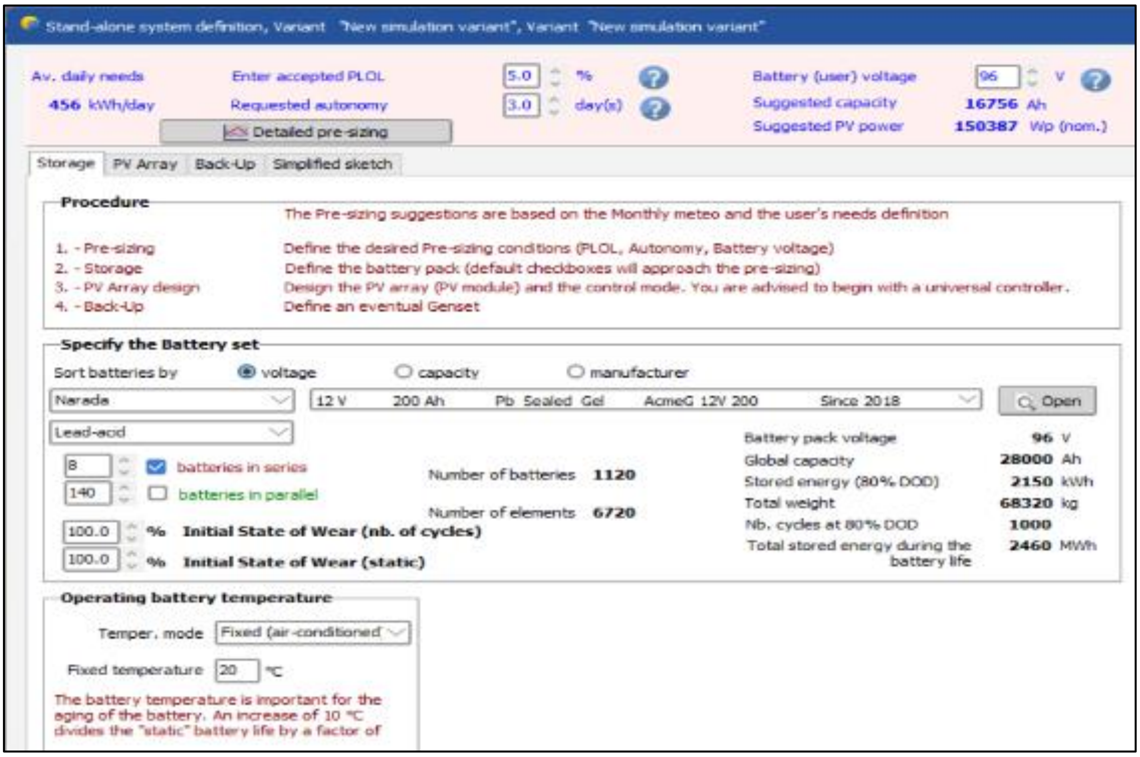


Figure 12 The battery bank setting for design scenario 2 having 5% loss of load (LOL) and 3 days power autonomy

3. Results and discussion

3.1. Comparison of the results of the two pv system design scenarios

The comparison of the results of the two PV System design scenarios are presented in this section beginning with the comparison of the number of PV modules, the PV array power rating and the PV array area for the two design scenarios, as shown in Table 2 and Figure 13. The number of PV modules, the PV array power rating and the PV array area in the scenario 2 are about 7.7 % lower than those of scenario I without LOL. Essentially, it requires about 7% more PV module to ensure that design number 2 can be without LOL.

Table 2 The comparison of the PV rating, area and number of modules for scenario design scenarios

	Scenario 1: PV system with no loss of load	**Scenario 2: PV system with loss of load**
Number of PV Modules	880	812
Power Rating of PV Array (kWp)	185	171
Area occupied by PV Array (m^2)	1264	1166

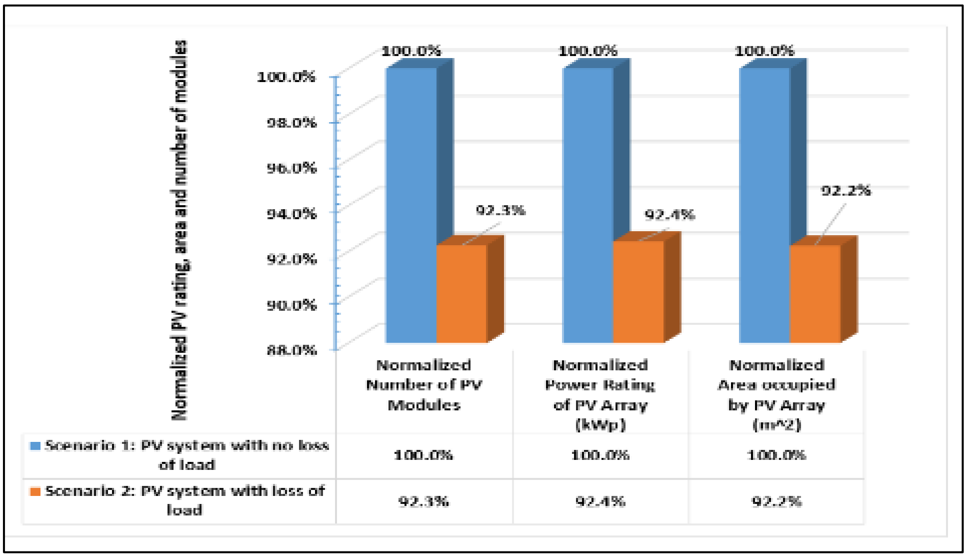


Figure 13 The comparison of the normalized PV rating, area and number of modules for scenario design scenarios

Comparison of the normalized energy output of the PV array, the unused energy, the energy delivered to the load and the fraction of energy demand that are supplied by the PV system for scenario design scenarios, are shown in Table 2 and Figure 14. The results shows that the scenario 1 has about 7.9% energy output than scenario 2. The unused energy in scenario 1 is about 26.5 % higher than that of scenario 2. The energy supply in scenario 2 is about 2% short of the load demand (shown as missing load in Figure 15) while the scenario 1 has no energy supply shortage. The energy supply shortage in scenario 1 cause the missing energy the 2 % loss of load shown in Figure 16 with the attendant 179 hours of loss of load duration, as shown in Figure 16.

Table 3 Comparison of the energy output of the PV array, the unused energy, the energy delivered to the load and the fraction of energy demand that are supplied by the PV system

	E_Avail (kWh)	EUnused (kWh)	E_Miss (kWh)	E_User (kWh)	SolFrac (ratio)
PV with NO LOL	229229	54303	0	166352	1
PV with LOL	211093	39936	3392	162960	0.98

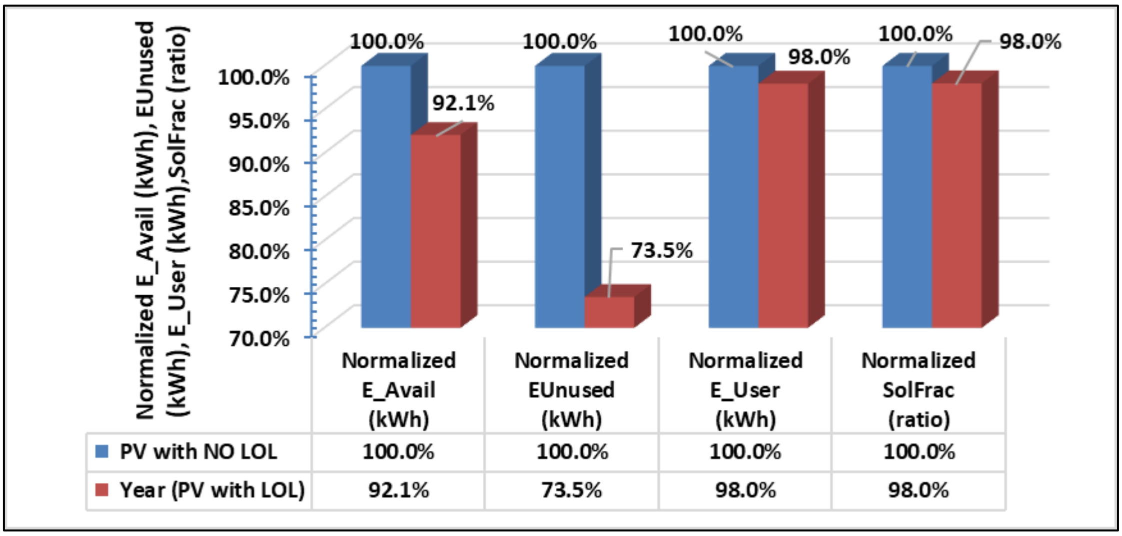


Figure 14 Comparison of the normalized energy output of the PV array, the unused energy, the energy delivered to the load and the fraction of energy demand that are supplied by the PV system

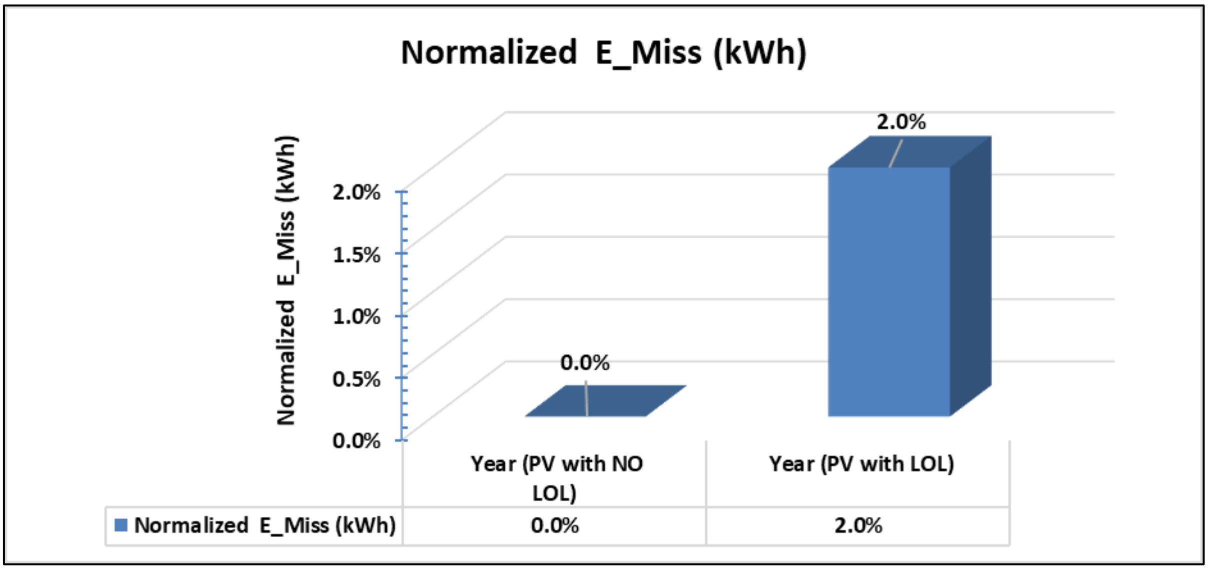


Figure 15 Comparison of the normalized missing energy for the two design scenarios

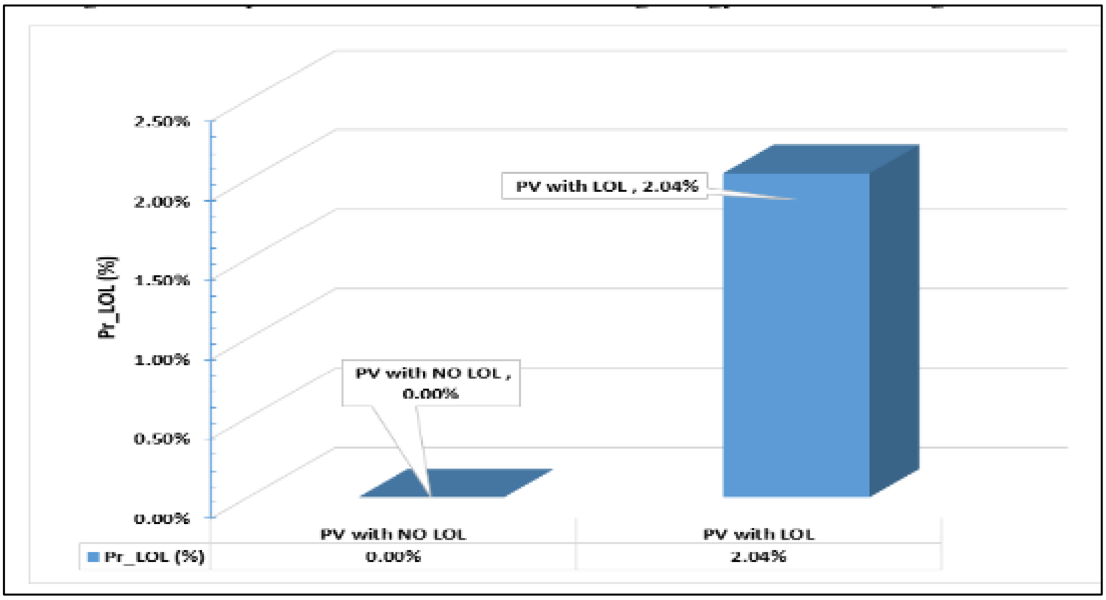


Figure 16 Comparison of the loss of load for the two design scenarios

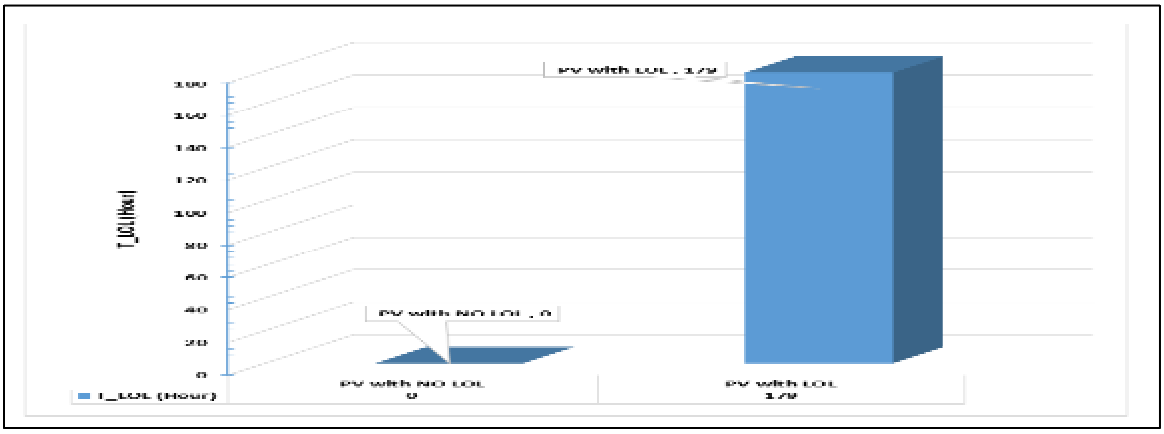


Figure 17 Comparison of the duration of loss of load for the two design scenarios

Comparison of the monthly hourly sums of the energy delivered to the load for the two design scenarios is presented in Table 14 and Figure 12. The results show that while the scenario 1 maintained steady maximum energy delivery of 6931 kWh the scenario 1 energy supply per hour varied from 6741 kWh to 6817 kWh.

Table 4 Comparison of the monthly hourly sums of the energy delivered to the load for the two design scenarios

HOUR	Monthly Hourly sums for E_User [kWh] for PV with NO LOL	Monthly Hourly sums for E_User [kWh] for PV with LOL	HOUR	Monthly Hourly sums for E_User [kWh] for PV with NO LOL	Monthly Hourly sums for E_User [kWh] for PV with LOL
0H	6931	6817	12H	6931	6777
1H	6931	6800	13H	6931	6791
2H	6931	6798	14H	6931	6802
3H	6931	6794	15H	6931	6817
4H	6931	6779	16H	6931	6817

5H	6931	6777	17H	6931	6817
6H	6931	6752	18H	6931	6817
7H	6931	6741	19H	6931	6817
8H	6931	6741	20H	6931	6817
9H	6931	6741	21H	6931	6817
10H	6931	6741	22H	6931	6817
11H	6931	6749	23H	6931	6817

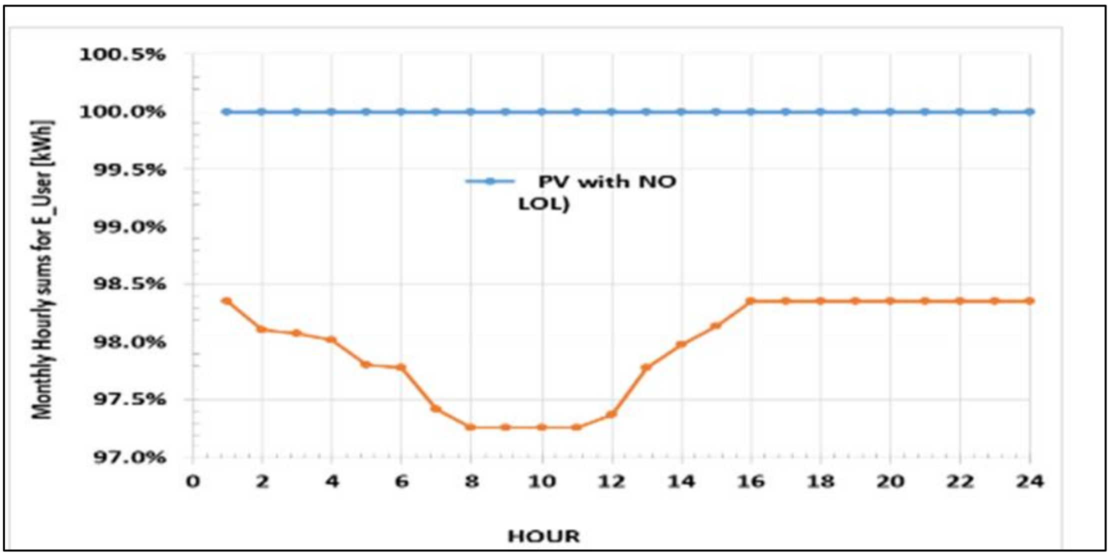


Figure 18 Comparison of the monthly hourly sums of the energy delivered to the load for the two design scenarios

Comparison of the performance coefficients for the two design scenarios is presented in Table 15 and Figure 12. The results show that the scenario 2 with LOL has high performance ratio of 61.30% while the scenario 1 with performance ratio of 57.80%.

Table 5 Comparison of the performance coefficients for the two design scenarios

	Lu (kWh/kWp/day)	**Lc (kWh/kWp/day)**	**Ya (kWh/kWp/day)**	**Ls (kWh/kWp/day)**	**Yf (kWh/kWp/day)**	**PR (%)**
Year (PV with NO LOL)	0.81	1.55	2.72	0.25	2.47	57.80 %
Year (PV with LOL)	0.64	1.39	2.88	0.27	2.62	61.30 %

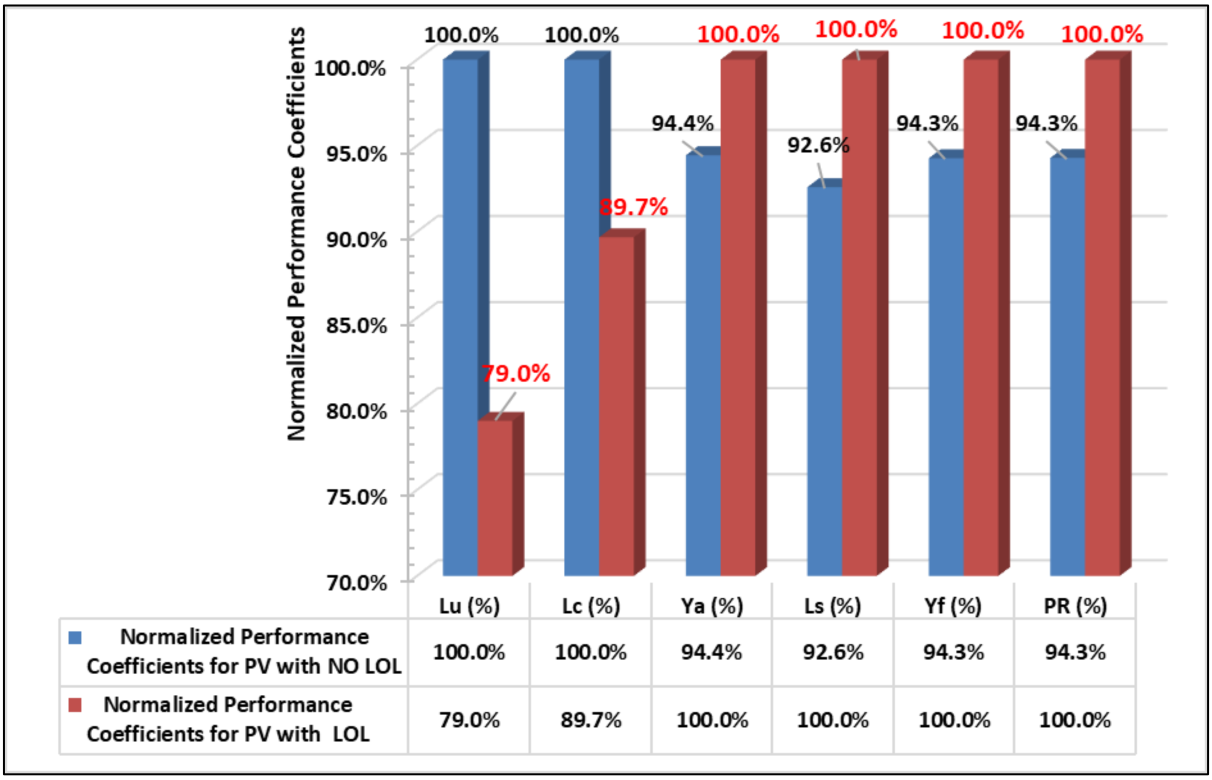


Figure 19 Comparison of the normalized performance coefficients for the two design scenarios

In all, the results of the two design scenarios shows that by adopting no loss of load option, more PV panels will be required and more loss of energy due to excess unused energy will be more. However, by adopting some tolerance of power outage, the losses due to unused excess energy ir reduced and the system performance can be evaluated to know the duration of the expected power outage and the expected date in the year. This will allow for making contingency plan even before the power outage occurs.

Specifically, for the scenario 2 with loss of load, the missing energy by month for scenario 2 will occur in the months of July and September, as shown in Figure 13.

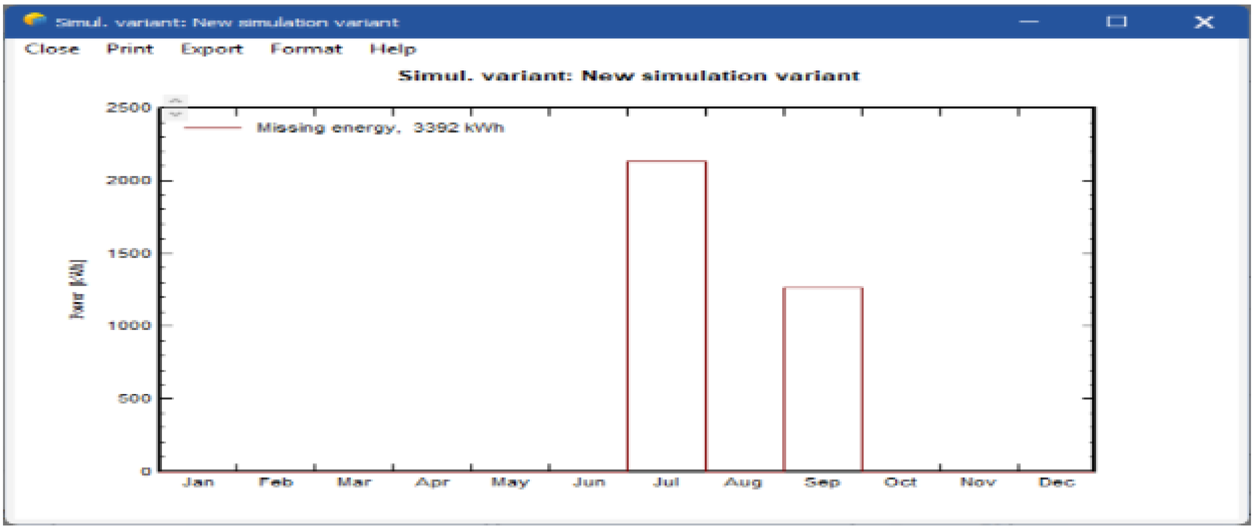


Figure 20 The missing energy by month for scenario 2

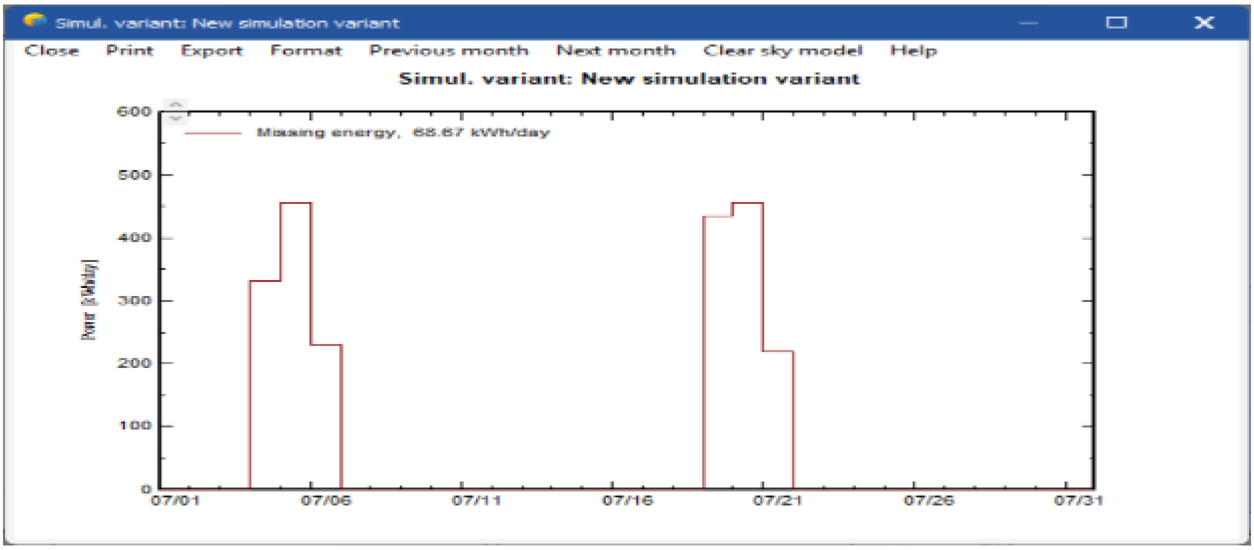


Figure 21 The missing energy for the month of July for scenario 2

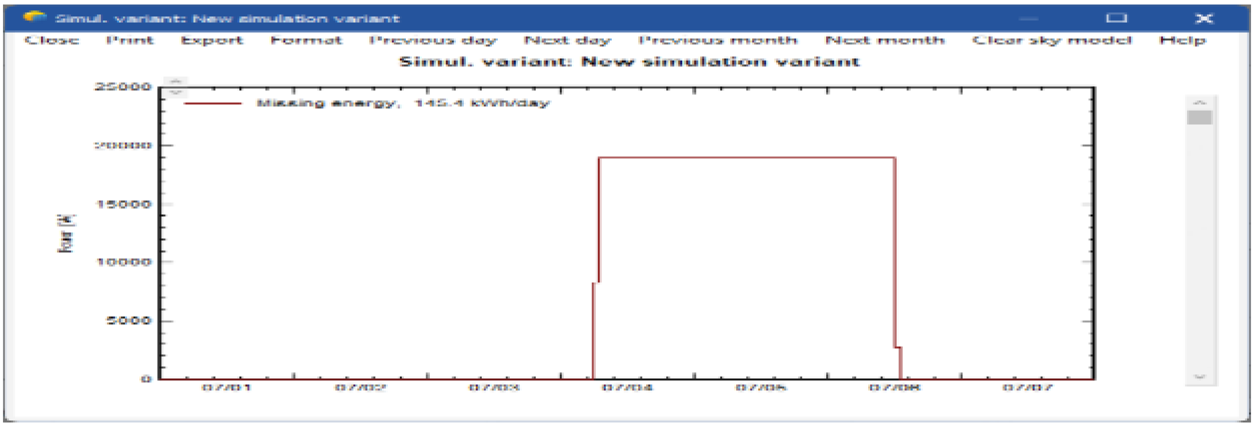


Figure 22 The hourly missing energy for the month of July for scenario 2 showing the first incidence of missing in the month of July which will occur from 4th to 6th of July

The details of the missing energy for the month of July for scenario 2 are presented in Figure 14, Figure 15, and Figure 16. In Figure 15, the hourly missing energy for the month of July for scenario 2 showing the first incidence of missing in the month of July which will occur from 4th to 6th of July are presented. Also, in Figure 16, the hourly missing energy for the month of July for scenario 2 showing the second incidence of missing in the month of July which will occur from 18th to 21th of July are presented.

The details of the missing energy for the month of September for scenario 2 are presented in Figure 17, Figure 18, and Figure 19. In Figure 18, the hourly missing energy for the month of September for scenario 2 showing the first incidence of missing in the month of September which will occur from 5th to 6th of September are presented. Also, in Figure 19, the hourly missing energy for the month of September for scenario 2 showing the second incidence of missing in the month of September which will occur from 15th to 16th of September are presented.

In all, with the detailed loss of load analysis up to hourly level, it is possible to make adequate prior arrangements for managing the expected loss of load incidence.

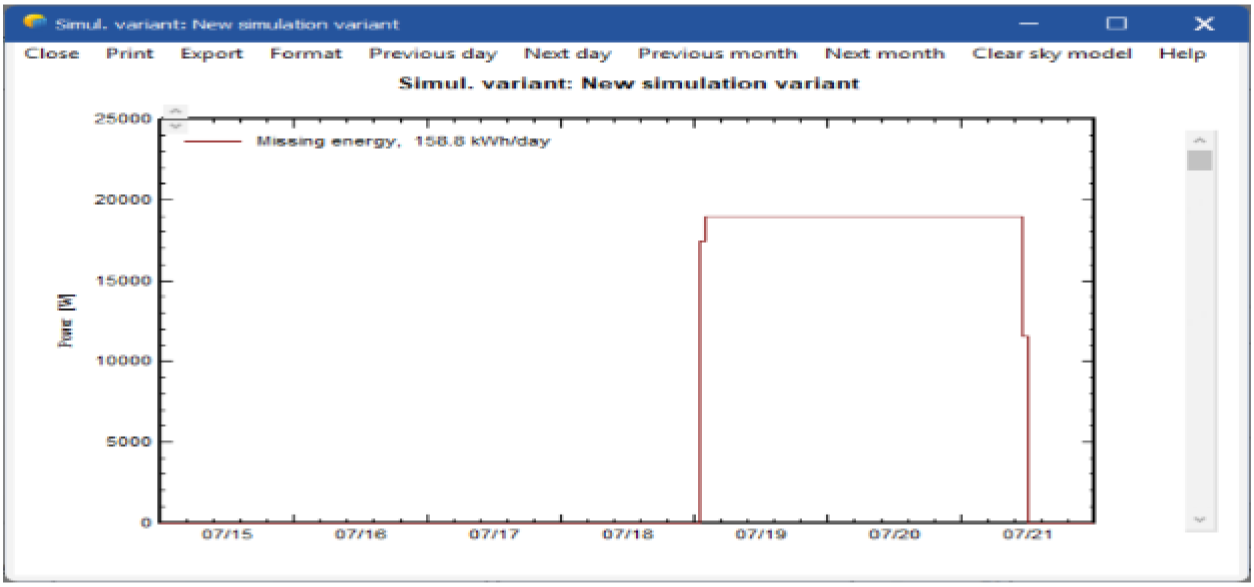


Figure 23 The hourly missing energy for the month of July for scenario 2 showing the second incidence of missing in the month of July which will occur from 18th to 21th of July

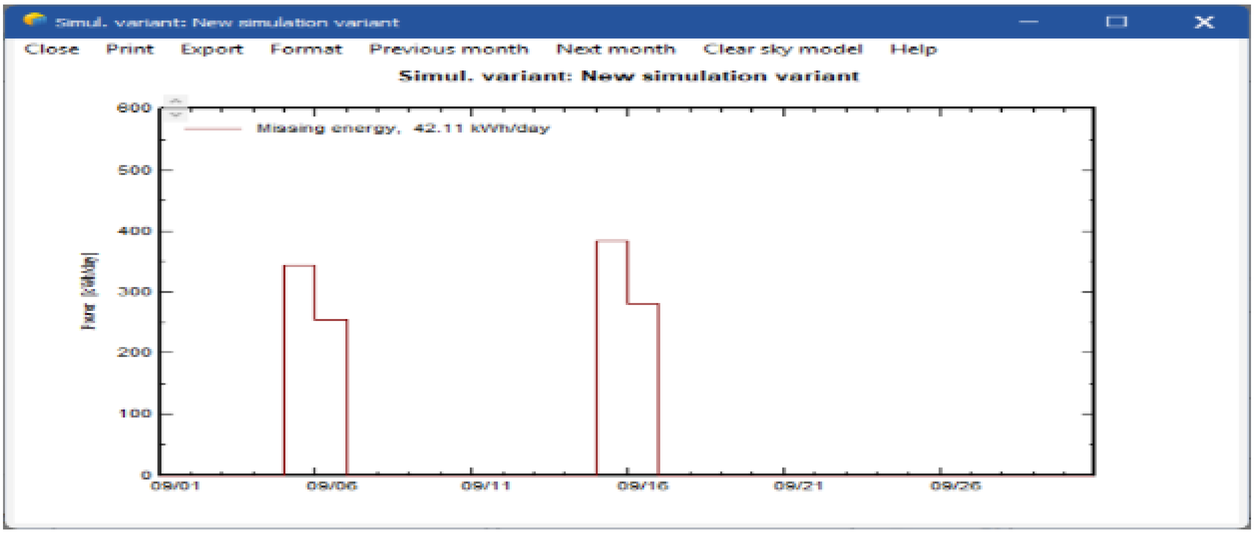


Figure 24 The missing energy for the month of September for scenario 2

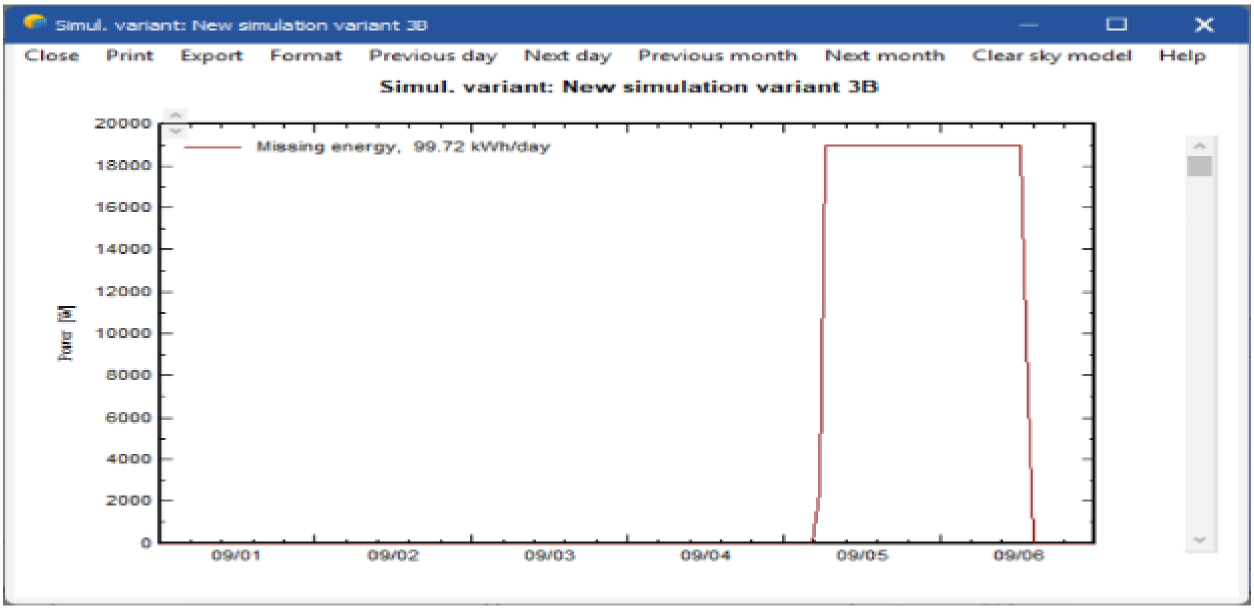


Figure 25 The hourly missing energy for the month of July for scenario 2 showing the first incidence of missing in the month of September which will occur from 5th to 6th of September

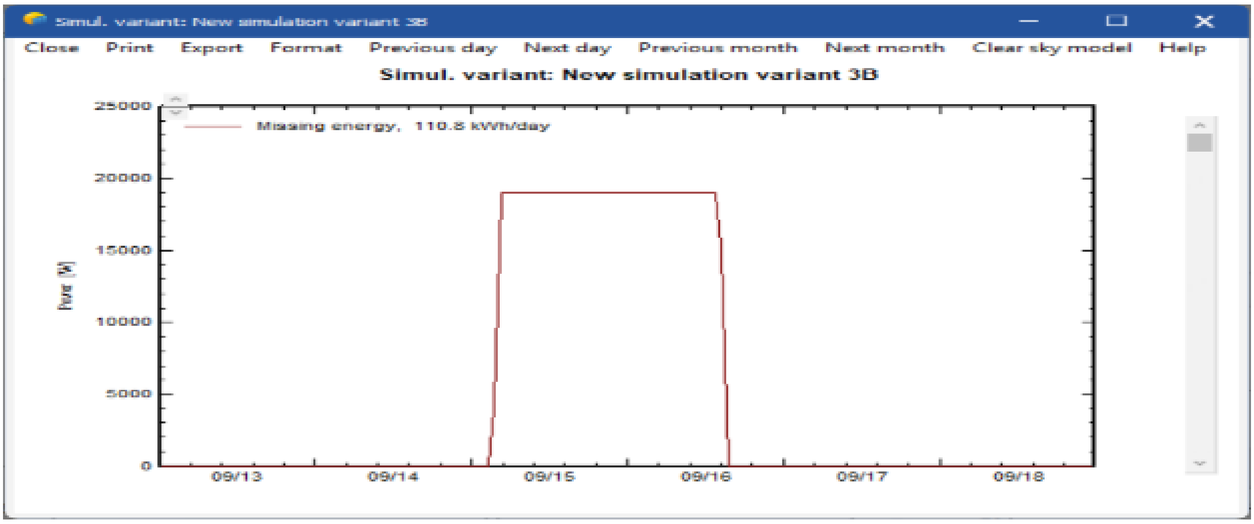


Figure 26 The hourly missing energy for the month of July for scenario 2 showing the second incidence of missing in the month of September which will occur from 15th to 16th of September

4. Conclusion

In this research, stand-alone photovoltaic (SAPV) system was designed and simulated with PVsyst for two scenarios for a hospital in Eket Akwa Ibom State. In the first scenario, the SSPV power system was design to eliminate loss off load without any alternative energy source other than the SSPV power system. In this case, a higher days (7 days) of power autonomy was selected with very low loss of load probability of about 0.01. In the second scenario, the SSPV power system was design to allow for some loss off load giving room for alternative back-up energy source other than the SSPV power system. In this case, a low days (3 days) of power autonomy was selected with low loss of load probability of about 0.05.

The study examined the detailed performance analysis of the two SSPV power systems designed for the case study hospital. The operating loss of load and loss of load duration were analysed and the specific day of potential loss of load all through the year were determined for the second scenario. The unused energy loss and the performance ratio of the two SSPV power systems were also compared. The various loses in the system and the battery bank efficiency were also determined and discussed. In all, all the set objectives of the research were all achieved based on the different aspects of the SSPV power system for which results were presented and discussed.

Compliance with ethical standards

No conflict of interest to be disclosed.

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