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Simulated Design and Evaluation of Centralized off Grid Street Light Solar Power System with Backup Generator

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ABSTRACT: In this paper, simulated design and evaluation of centralized off grid street light solar power system with backup generator is presented. The design of the street light solar power system takes into consideration the desired illumination level, the width of road, the coefficient of utilization, the maintenance factor, the desired distance between street light poles, the pole height, the pole space to pole height ratio and the total length of the street. The case study street light is located along IBB Avenue in Uyo, with latitude and longitude of 5.016982, 7.911769 respectively, path length of 2.2 km and daily energy demand of 125.8 kWh/day. The PVSyst simulation results show that the solar fraction is 0.993 which indicates that 99.3 % of the energy demand of the street light is supplied from the solar power while the remaining 0.7% of the energy demand is supplied form the backup generator. The total energy supplied by the generator is 375.7 kWh whereas the total annual energy generated from the PV array is 53739 kWh. The annual total of the energy demand is 46059 kWh while the annual total of the energy supplied to the street light from the solar power system is 46027 kWh. Also, the annual mean of the battery state of charge (SoC) is 80.3 %. Also, it is noted that the month of August alone has about 375.7 kWh energy supply from the backup generator with about 98 liters of fuel. Specifically, in a whole year, the backup generator will be used for only three days in August, namely, on the 13th, 14th and 15th of August, with the maximum supply of 239.8012 kWh occurring on the 14th day of August. Furthermore, the performance ratio (PR) of the system is 48.5%. In all, the results show that the solar power system is able to supply the required energy demand of the case study street light with only 0.7% deficit which is supplied from the backup generator.

KEYWORDS: Centralized solar power, Photovoltaic solar power, Loss of load, Off grid solar power, Solar fraction, Street light power system, Backup generator.

I. INTRODUCTION

In the field of electric energy, the role of the electric network is crucial. Physical laws dictate how it functions. Different voltage levels make up the fixed structure of the electric network; the higher levels are used for transmission, while the lower levels are employed for distribution (Nkan, Okpo, Akuru, & Okoro, 2020; Natala, Nkan, Okoro, & Obi, 2023; Okpo, & Nkan, 2016; Nkan, Okpo, & Inyang, 2023). Presently, the Nigerian power industry is undergoing restructuring, especially in the generation and distribution systems (Nkan, Okpo, & Nseobong, 2023; Abunike, Umoh, Nkan, & Okoro, 2021) and the economic growth and development of any nation are intrinsically tied to the availability of energy (Okoro, Abunike, Akuru, Awah, Okpo, Nkan, Udenze, Innocent, & Mbunwe, 2022; Nkan, Okoro, Awah, & Akuru, 2019). Access to a reliable electricity supply plays a pivotal role in empowering individuals and facilitating personal and economic development. Performance evaluation of asynchronous motor was conducted in (Nkan, Okoro, Obi, Awah, & Akuru, 2019). With the ongoing expansions and growth of the electric utility industry, including deregulation in Nigeria, numerous changes characterized by additional generating stations, increase in transmission lines and loads are experienced thereby pushing the transmission systems closer to their stability and thermal limits (Nkan, Okpo, & Okoro, 2021; Edifon, Nkan, & Macaulay, 2016; Edifon, Nkan, & Ben, 2016). Interestingly, AKS has enormous solar potential but the use of solar power is very insignificant when compared to the use of fossil fuel-based power supply (Omorogiuwa & Okpo, 2015; Abunike, Umoh, Okpo, & Okoro, 2020). One reason for this is insufficient knowledge of the solar potential of the state and the cost implication of such systems (Okpo, Okoro, Awah, & Akuru, 2019; Awah, Okoro, Nkan, & Okpo, 2022).

In recent years Akwa Ibom State has witnessed rapid development in infrastructure and has also maintained relatively peaceful environment when compared with other Niger Delta States in Nigeria (Ufot-Akpabio, Ofem, & Ufot-Akpabio, 2022; Ufot-Akpabio & Ofem, 2019; Ukpong & George, 2012; Oyosoro & Okene, 2021). This factors has led to the influx of visitors and migration of people to Akwa Ibom State (Ibaba, 2011; Akpakpan & Uboegbulam, 2023; Obot, 2010). In order to enhance the security of the State and improve on the night life, the government of Akwa Ibom has steadily increase street light installations across that State. Presently, most of the street lights in the State are powered using diesel generators. However, due to the recent sharp rise in the cost of diesel, the running and maintenance cost of the street light is becoming a big burden to Ministry of works Uyo, the agency responsible for the street lights. Moreover, the need for clean, steady energy supply system is also another reason why it has become necessary for the adoption of solar photovoltaic (PV) power system for the street light in Akwa Ibom State (Babatunde, Akinbulire, Oluseyi, & Emezirinwune, 2019; Szakonyi & Urpelainen, 2015; Olatomiwa, Mekhilef, Huda, & Sanusi, 2015).

In this paper, a case study street light for the IBB Avenue in Uyo metropolis is considered. The design and evolution of the street light for the IBB Avenue is presented. The design and evaluation is carried out using PVSyst simulation software (Bagir & Channi, 2022; Salmi, Baci, Menni, Lorenzini, & Al-Douri, 2022). The design of the street light solar power system takes into consideration the desired illumination level, the width of road, the coefficient of utilization, the maintenance factor, the desired distance between street light poles, the pole height, the pole space to pole height ratio and the total length of the street (Akindipe, Olawale, & Bujko; Swathika, Karthikeyan, Subramaniam, Hemapala, & Bhaskar, 2022).

II. METHODOLOGY

A. Analytical Expressions for Determination of the Daily Load Demand of the Street Light

The design of the street light solar power system takes into consideration the desired illumination level (DILV), the width (WRD) of the case study road, the coefficient of utilization (CoU), the maintenance factor (Mf), as well as the desired distance between street light poles (DBP), pole height (PH), pole space to pole height ratio (STHR) and the total length of the street (PL). Based on these parameters, mean lumen of the lamp (ML) for the street light is given as:

$$\mathrm{ML} = \frac{\mathrm{DILV(DBP)(WRD)}}{\mathrm{C_0U(mf)}} \quad (1)$$

Where

$$\mathrm{DBP} = \mathrm{PH(STHR)} \quad (2)$$

The wattage of the rating (WRL) for each of the street light is given as:

$$\mathrm{WRL} = \frac{\mathrm{ML}}{\mathrm{Leff}} \quad (3)$$

Where Leff represents the luminous efficiency of the lamp. The number (NL) of required street lights poles to cover the street length is given as:

$$\mathrm{NL} = \frac{\mathrm{PL+1000}}{\mathrm{Dbtwpl}} \quad (4)$$

Hence, the total power in watts (WTL) for the entire street lights and the daily energy demand (Eday) for Hday operating hours per day are given as:

$$\mathrm{WTL} = \mathrm{WRL(NL)} \quad (5)$$

$$\mathrm{Eday} = \mathrm{WTL(hday)} \quad (6)$$

B. The Case Study Street Light and Meteorological datasets

Based on the analytical models presented in Equations 1 to 6, a case study street was considered and the solar power system design and evaluation was conducted using PVSyst software. Specifically, the case study street light is designed for IBB Avenue in Uyo (with latitude and longitude of 5.016982, 7.911769 respectively). The street is about 2.2 km based on Google map distance measurement tool, as shown in Figure 1. The daily load demand of the IBB Avenue street light is computed based on the dataset in Table 1 and the Equations 1 to 6 and the value of the daily energy demand is 125.8 kWh/day which is approximated to 126 kWh/day in the PVSyst software model of the daily energy demand profile, as shown in Figure 2.

The meteorological data for the IBB Avenue , as captured from National Aeronautics and Space Administration (NASA) portal using the PVSyst software is shown in Table 2. Also, the time evolution plot of the global solar radiation data on the horizontal plane and on the optimal tilted plane of the PV module are shown in Figure 3 while the time evolution plot of the ambient temperature is shown in Figure 4. The schematic diagram of the off grid solar power with backup generator is shown in Figure 5.

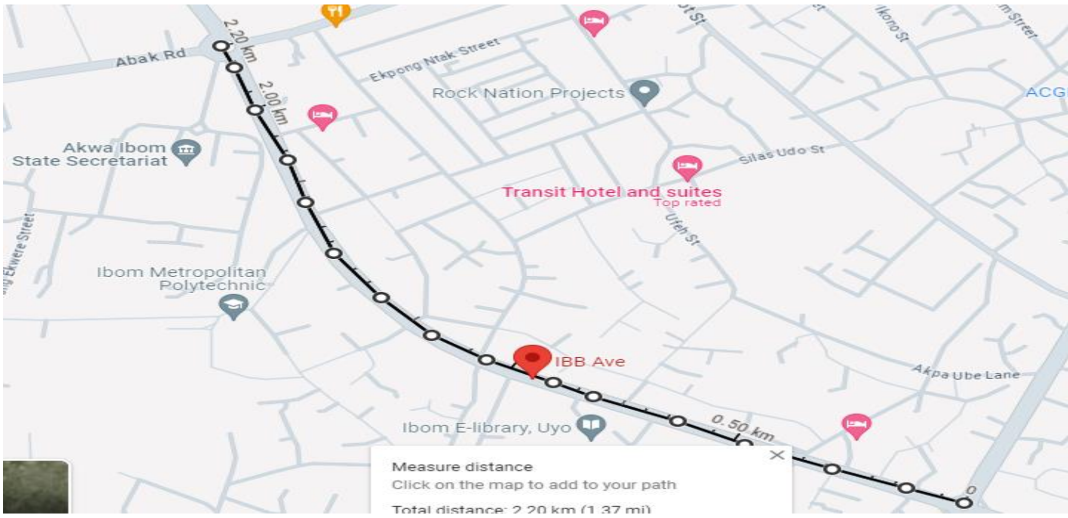

Figure 1. The Google map view of the case study IBB Avenue and path length of the street

Table 1 The case study IBB Avenue street light datasets

S/N	Parameter description	Parameter value
1	Luminous efficiency in lux/watt	124
2	Coefficient of utilization	0.77
3	Pole height in m	9
4	Required illumination lux level for the street in lux	42
5	Road width in m	8
6	Space to height ratio	2.5
7	Street light path length in km	2.2
8	Maintenance factor	0.8
9	Distance between the street light poles in m	22.5
10	Average required lumen of the lamp in lumens	12272.7
11	Wattage of each street light per pole in watts	99.0
12	Number of street light pole required	97.8
13	Total wattage of street light in kW	9.7
14	Number of operation hours per day	13.0
15	Daily energy demand of the street light in kWh	125.8

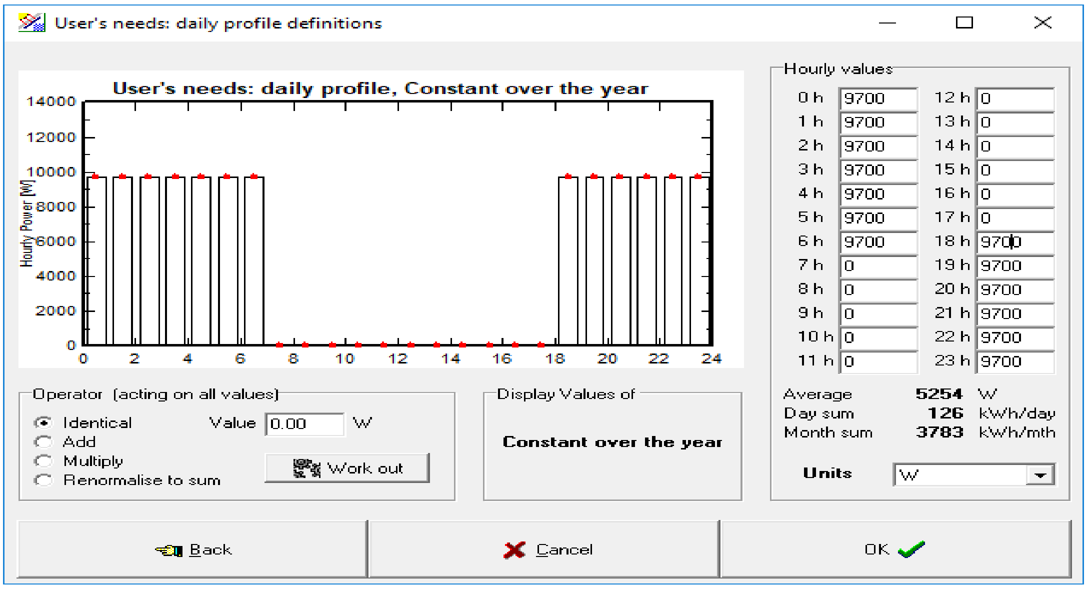

Figure 2. The PVSyst software model of the daily energy demand profile

Table 2. The meteorological data for the IBB Avenue

Meteo File NG_Ituk_Mbang_Uruan_SYN.MET, Monthly accumulations

Close Print Export Change Plane

Meteo for Ituk Mbang Uruan, Synthetic data

Plane: tilt 12°, azimuth 0°, Albedo 0.20

Interval beginning	GlobHor kWh/m².mth	GlobInc kWh/m².mth	T Amb °C
January	170.5	183.7	25.10
February	159.6	166.8	25.40
March	154.1	154.4	25.40
April	138.6	134.7	25.50
May	133.9	126.7	25.40
June	108.0	101.8	24.60
July	98.9	95.0	23.80
August	96.4	93.5	23.60
September	97.8	96.8	23.80
October	112.5	113.7	24.10
November	128.7	134.8	24.50
December	159.3	173.7	24.80
Year	1558.3	1575.6	24.66

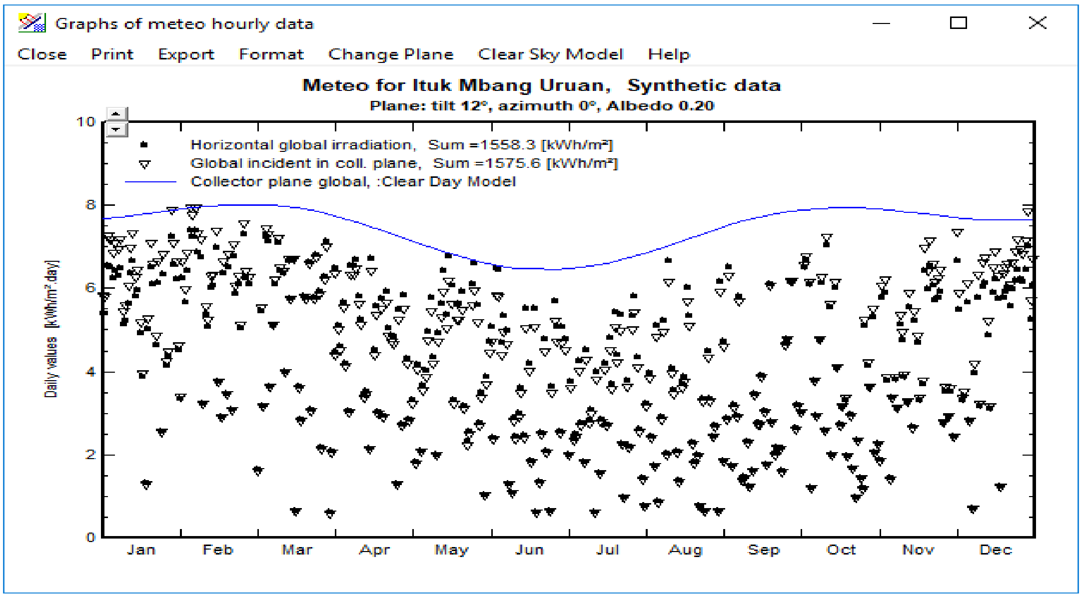

Figure 3. Time evolution plot of the global solar radiation data on the horizontal plane And on the optimaltilted plane of the PV module

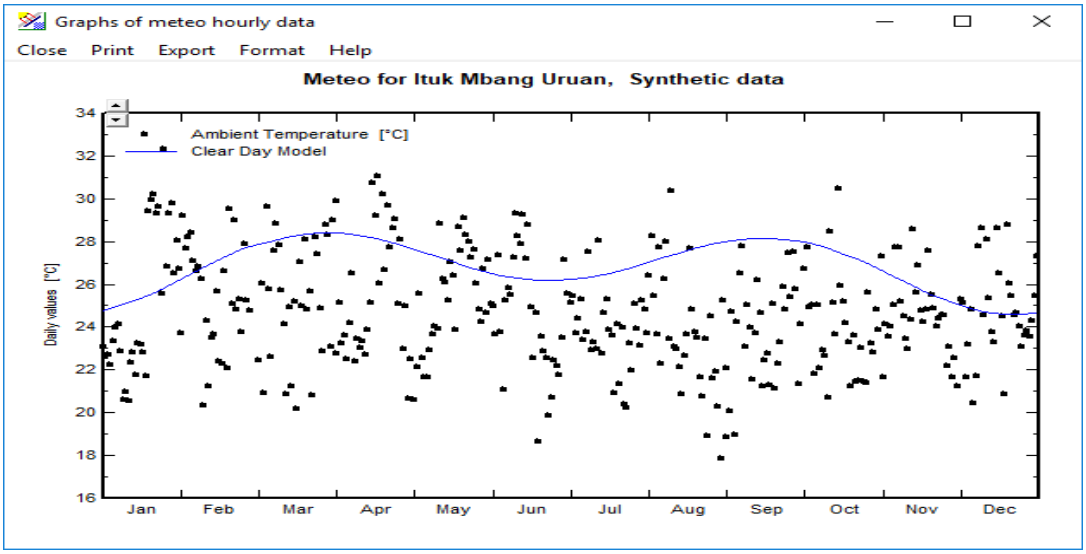

Figure 4 Time evolution plot of the ambient temperature

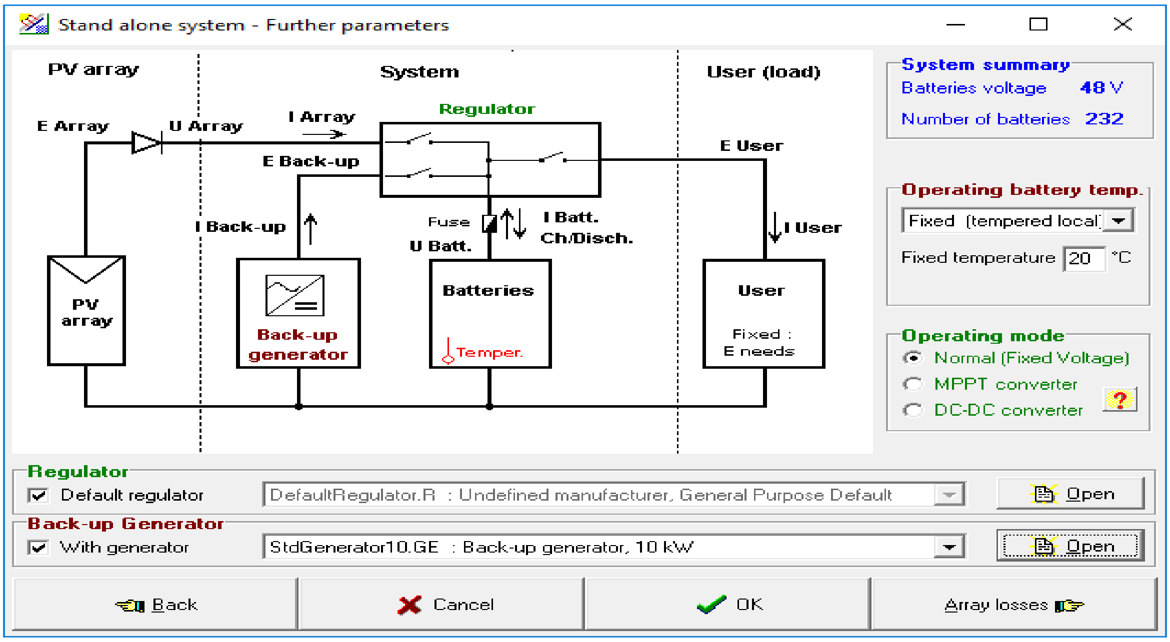

Figure 5. The schematic diagram of the off grid solar power with backup generator

III. RESULTS AND DISCUSSION

The simulated configuration of the case study street light in PVSyst software is shown in Figure 6. The results on energy use and solar fraction are shown in Table 3. It shows that the solar fraction is 0.993 which indicates that 99.3 % of the energy demand of the street light is supplied from the solar power while the remaining 0.7% of the energy demand is supplied from the backup generator. The total energy supplied by the generator is 375.7 kWh whereas the total annual energy generated from the PV array is 53739 kWh. The annual total of the energy demand is 46059 kWh while the annual total of the energy supplied to the street light from the solar power system is 46027 kWh.

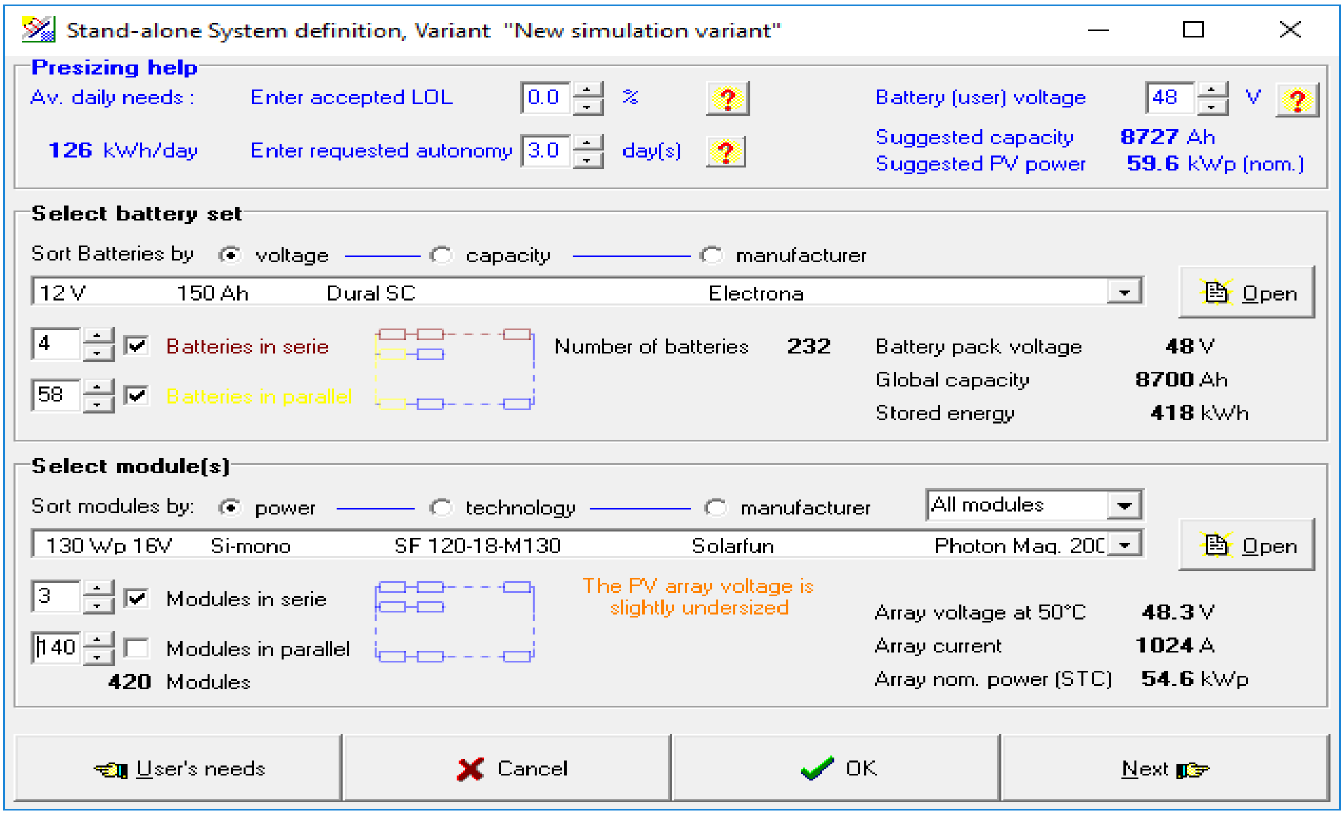

Figure 6. The simulated configuration of the case study street light in PVSyst software

Table 3 The results on energy use and solar fraction

	EArray kWh	E Load kWh	E User kWh	E BkUp kWh	SolFrac
January	4925	3909	3912	0.0	1.001
February	4287	3531	3533	0.0	1.001
March	4778	3909	3912	0.0	1.001
April	4419	3783	3786	0.0	1.001
May	4594	3909	3912	0.0	1.001
June	4275	3783	3786	0.0	1.001
July	4233	3909	3912	0.0	1.001
August	3996	3909	3912	375.7	0.905
September	4218	3783	3786	0.0	1.001
October	4522	3909	3912	0.0	1.001
November	4535	3783	3786	0.0	1.001
December	4959	3909	3912	0.0	1.001
Year	53739	46027	46059	375.7	0.993

Table 4. The results on the monthly distribution of the mean battery state of charge, backup generator energy supply and system performance ratio

	SOCmean	T BkUp Hour	E BkUp kWh	FuelBU liter	Lur	PR
January	0.816	0	0.0	0	0.010	0.388
February	0.828	0	0.0	0	0.007	0.396
March	0.839	0	0.0	0	0.013	0.433
April	0.818	0	0.0	0	0.009	0.470
May	0.810	0	0.0	0	0.026	0.522
June	0.819	0	0.0	0	0.013	0.575
July	0.702	0	0.0	0	0.021	0.634
August	0.686	37	375.7	98	0.029	0.573
September	0.793	0	0.0	0	0.023	0.594
October	0.837	0	0.0	0	0.030	0.534
November	0.845	0	0.0	0	0.032	0.453
December	0.848	0	0.0	0	0.009	0.402
Year	0.803	37	375.7	98	0.017	0.485

The results on the monthly distribution of the mean battery state of charge, backup generator energy supply and system performance ratio are shown in Table 4. The results show that the annual mean of the battery state of charge (SoC) is 80.3 %. Also, from the results in Table 4, it is noted that the month of August alone has about 375.7 kWh energy supply from the backup generator with about 98 liters of fuel. Furthermore, the performance ratio (PR) of the system is 48.5%. The results on the daily distribution of the backup generator energy supply in the month of August are shown in table 5 and Figure 7. The results show that backup generator is used for three days in August, namely, on the 13^{th}, 14^{th} and 15^{th} of August, with the maximum supply of 239.8012 kWh occurring on the 14^{th} day of August. On the other hand, the results on the daily distribution of unused energy in the month of August (shown in Table 6 and Figure 8) show that despite the low energy generation in August, there are still unused energy which are lost because the load is fully supplied, the battery is fully charged and still some excess energy is generated by the solar power which results in unused (lost) energy. In the month of August, the highest unused energy of 38.5122 kWh occurred on 17^{th} of August (as shown in Table 6 and Figure 8). In all, the results show that the solar power system is able to supply the required energy demand of the case study street light with only 0.7% deficit which is supplied from the backup generator.

Table 5. Results on the daily distribution of the backup generator energy supply in the month of August

Day in August	Backup generator energy (KWh/Day) with mean of 12.12 KWh/Day
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	20.0923
14	239.8012
15	115.7969
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0

Table 6 The results on the daily distributionof unused energy in the month of August

Day in August	Unused energy (Full battery) loss (KWh/day) with mean of 7.781 KWh/day
1	0.3478
2	0
3	0
4	0.5783
5	0
6	0
7	0.3096
8	0
9	0.8609
10	0.4217
11	0
12	0.6418
13	0
14	0.4183
15	31.0398
16	27.9859
17	38.5122
18	38.1713
19	21.6266
20	13.8908
21	0.5635
22	0
23	0
24	0
25	0.2661
26	0
27	0
28	0
29	0
30	13.6664
31	51.9055

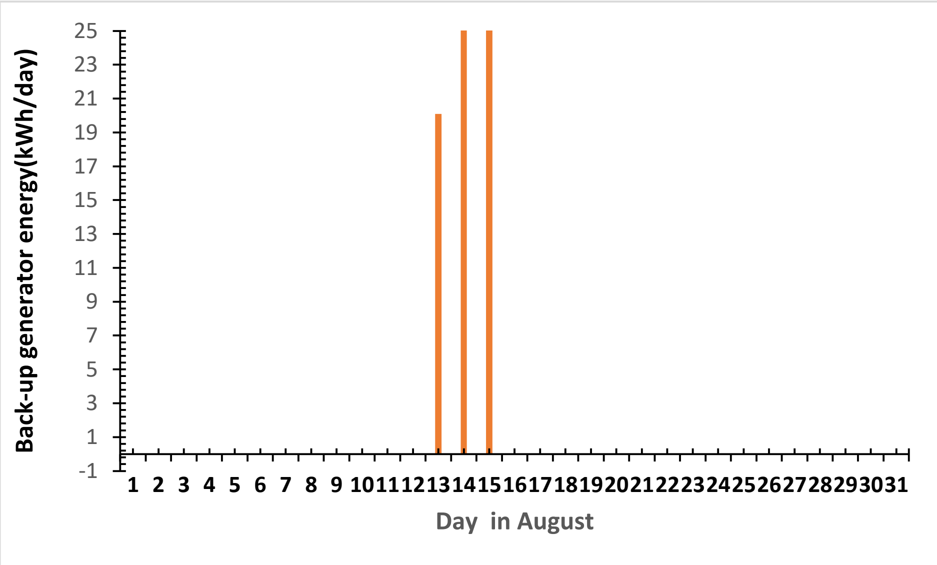

Figure 7. The bar chart of the daily distribution of the backup generator energy supply in the month of August

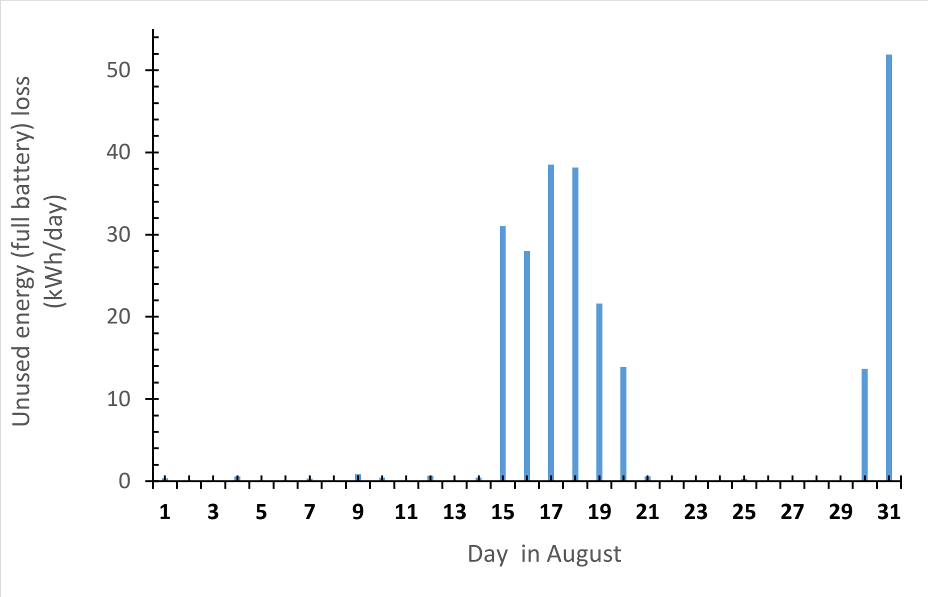

Figure 8. Bar chart of the daily distribution of unused energy in the month of August

IV. CONCLUSION

This paper presented the sizing of street light solar power system using PVSyst software and also the evaluation of key performance parameters of the solar power system. Some mathematical expressions for determining the daily energy demand of the street light are presented along with the case study streetlight design specifications. The PVSyst software simulation included backup generator to make up for loss of load incidence. The results showed that the solar power system was able to supply the load demand with over 99% solar fraction leaving only 0.7% of the power supply from the backup generator. Also, the month of August is the only month with power deficit from the solar power which prompted the use of the backup generator to makeup for the slight power supply deficit in August.

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