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Design And Evaluation Of Standalone Solar Power System For Autocad Laboratory At University Of UYO

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***Abstract*— In this work, standalone solar power system design and evaluation for AUTOCAD Laboratory at University of Uyo is presented. The power system design and evaluation was conducted using PVSyst software. The AUTOCAD Laboratory site has geographical coordinates of 5.041322, 7.974553 with 4.7 kWh/m^2 as the annual mean global solar radiation and annual mean of daily temperature of 24.9 °C. The laboratory has daily energy demand of 121.640 kWh/day. The simulation results showed that the system had annual mean solar fraction of 0.997 which is equivalent to annual mean loss of load of 0.3 %. All the power outage occurred in the month of July alone, with missing energy of about 144.2 kWh, loss of load duration of 40 hours and 5.2 % loss of load probability. Also, the unused energy is 13.4 %, PV array loss is 16.2%, the battery charging loss is 5.5 % while the energy supplied to the user is 64.8 %. Notably, the results presented in this work will assist in the energy management and planning, especially in making arrangement for alternative power in those days with high probability of power outage.**

Keywords — Standalone Power System, Energy Demand Profile, Renewable Energy, Solar Power System, PVYsts Software

1. INTRODUCTION

In recent years, in addition to the traditional manual pencil and drawing board approach, students in many Nigerian universities have learnt to draw with AUTOCAD software [1,2]. This enables them to quire design skills that are in high demand in many engineering profession and industries. As such, nowadays, many institutions have setup computer-based drawing studio equipped with computer systems, projectors, and other amenities that make it conducive for learning [3,4]. However, the major challenge to such setup is lack of effective power supply [5].

Notably, Nigeria is faced with perennial power problem with epileptic power supply that rarely serve the purpose [6,7]. Accordingly, alternative energy supply is required to maximize the use of such AUTOCAD laboratory setup in the universities. Therefore, in this paper, solar power system is presented for powering the AUTOCAD laboratory in the faculty of engineering university of Uyo.

Specifically, the solar power is designed to be stand alone and the focus is to use PVSyst software to design and evaluate the solar power system performance with major emphasis on the power outage or loss of load probability [8,9]. The system design is based on the daily load demand of the AUTOCAD laboratory and the meteorological data of the site. In all, the ideas presented in this work is expected to assist in the planning, design and implementation of solar power solution for the case study AUTOCAD laboratory and also for power supply to similar facilities.

2. METHODOLOGY

2.1 Description of the AUTOCAD laboratory location and meteorological dataset

The AUTOCAD laboratory is located in the building housing drawing studio at the Faculty of Engineering University of Uyo which has the geographical coordinates of 5.041322, 7.974553. The Google map visualization of the site is given in the screenshot shown in Figure 1 while the solar paths chart for the AUTOCAB laboratory at engineering drawing studio UNIUYO is shown in Figure 2.

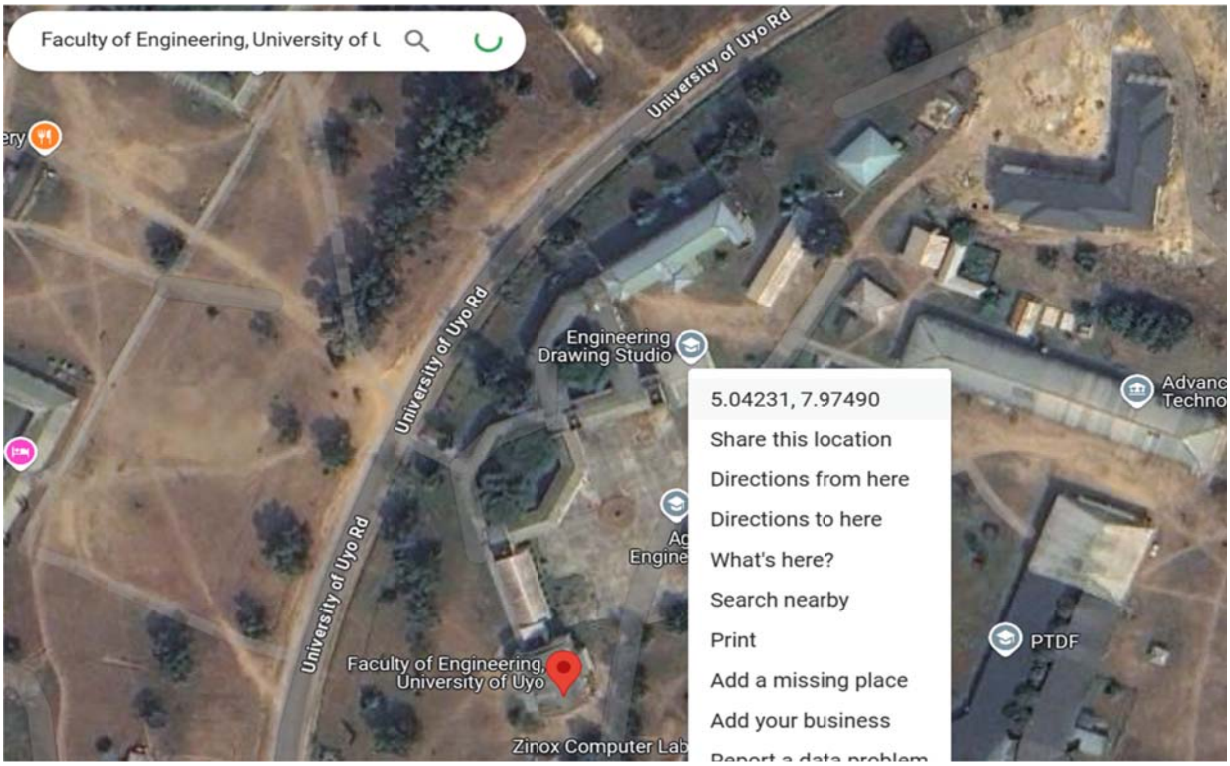


Figure 1 The Google map visualization of the AUTOCAD laboratory located in the building housing drawing studio at the Faculty of Engineering University of Uyo

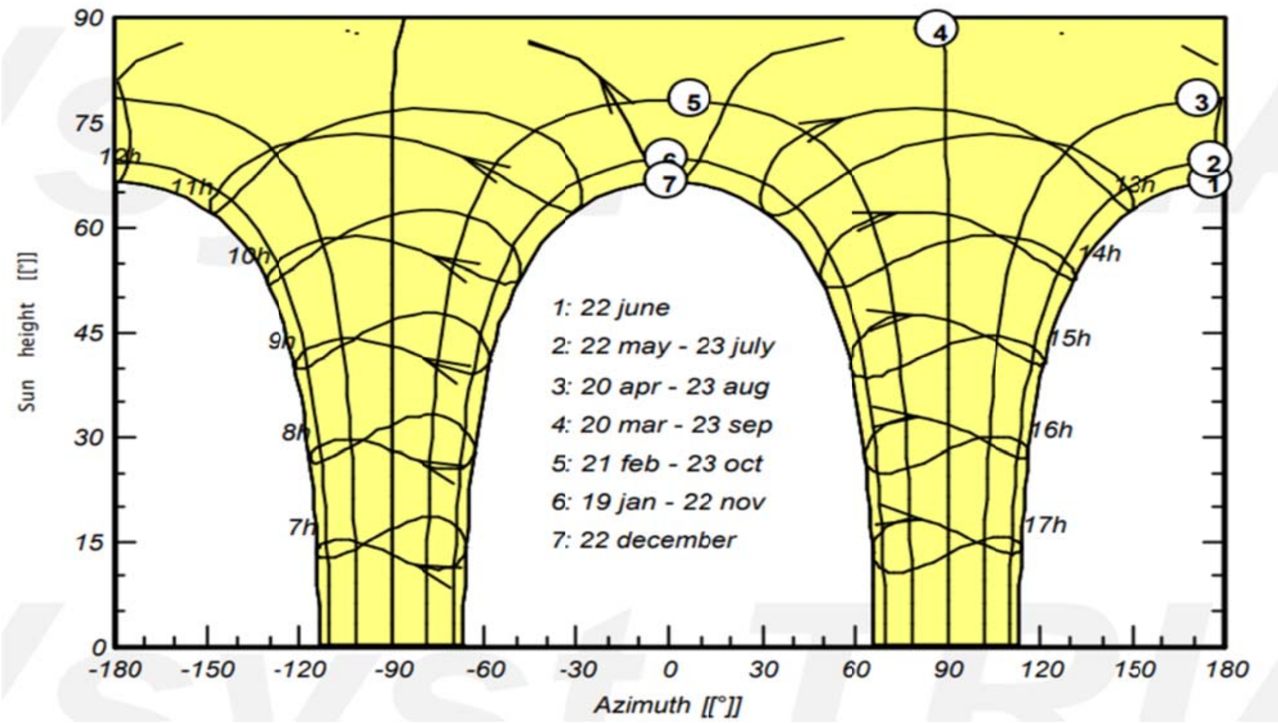


Figure 2 The solar paths for the AUTOCAB laboratory at Engineering drawing studio UNIUYO

The monthly mean values of the meteorological parameters for the AUTOCAB laboratory site at UNIUYO is given in Table 1 which shows 4.7 kWh/m^2 as the annual mean global solar radiation on the horizontal plane for the site. Again, the mean daily atmospheric temperature for the AUTOCAB laboratory at Engineering drawing studio UNIUYO is shown in Figure 3 which showed annual mean of daily temperature of the site as 24.9 °C.

Table 1 The monthly mean values of the meteorological parameters for the AUTOCAB laboratory at Engineering drawing studio UNIUYO

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	5.53	5.59	5.32	5.09	4.72	4.31	3.85	3.77	3.94	4.27	4.84	5.29	4.70	kWh/m².day
Hor. diffuse	1.73	1.97	2.22	2.27	2.18	2.11	2.13	2.20	2.27	2.17	1.95	1.71	2.08	kWh/m².day
Extraterrestrial	10.08	10.42	10.52	10.20	9.66	9.30	9.40	9.88	10.32	10.40	10.14	9.92	10.02	kWh/m².day
Clearness Index	0.549	0.536	0.506	0.499	0.488	0.463	0.410	0.382	0.382	0.411	0.477	0.533	0.470	
Amb. temper.	25.4	25.8	25.7	25.8	25.6	24.8	24.1	23.9	24.1	24.4	24.7	24.7	24.9	°C

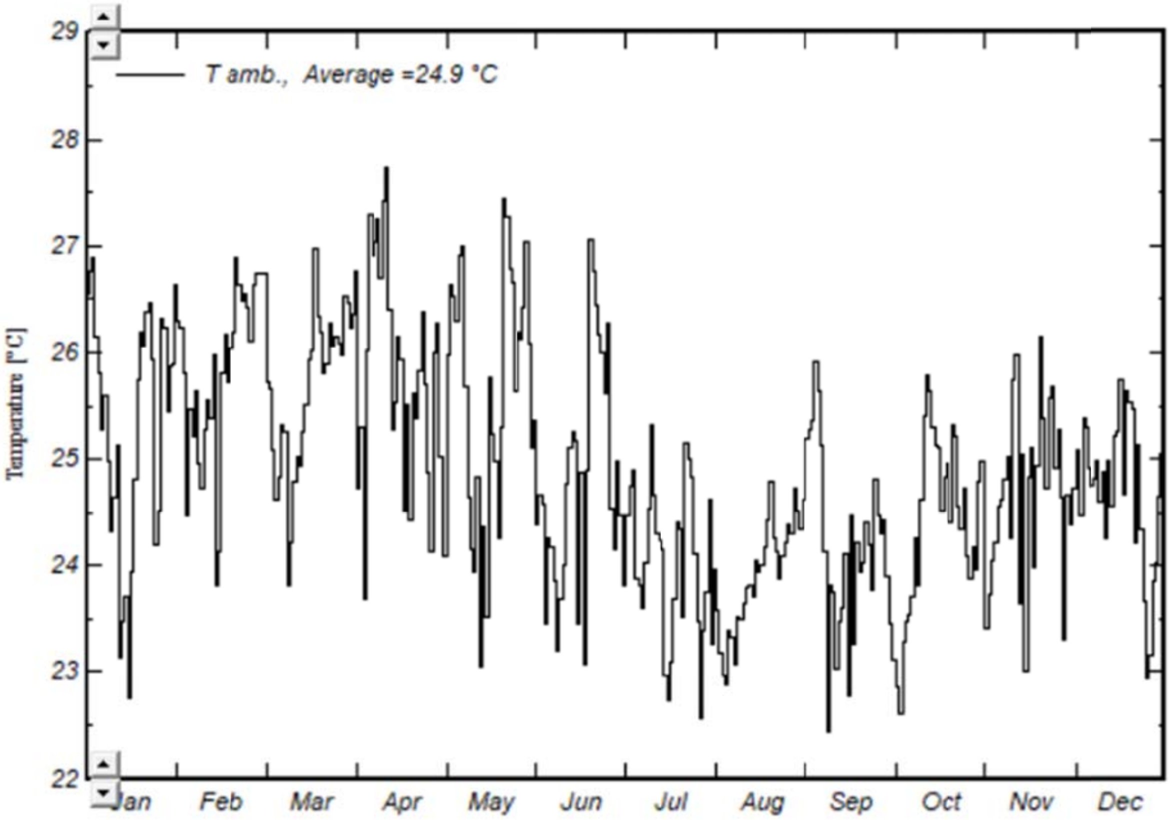


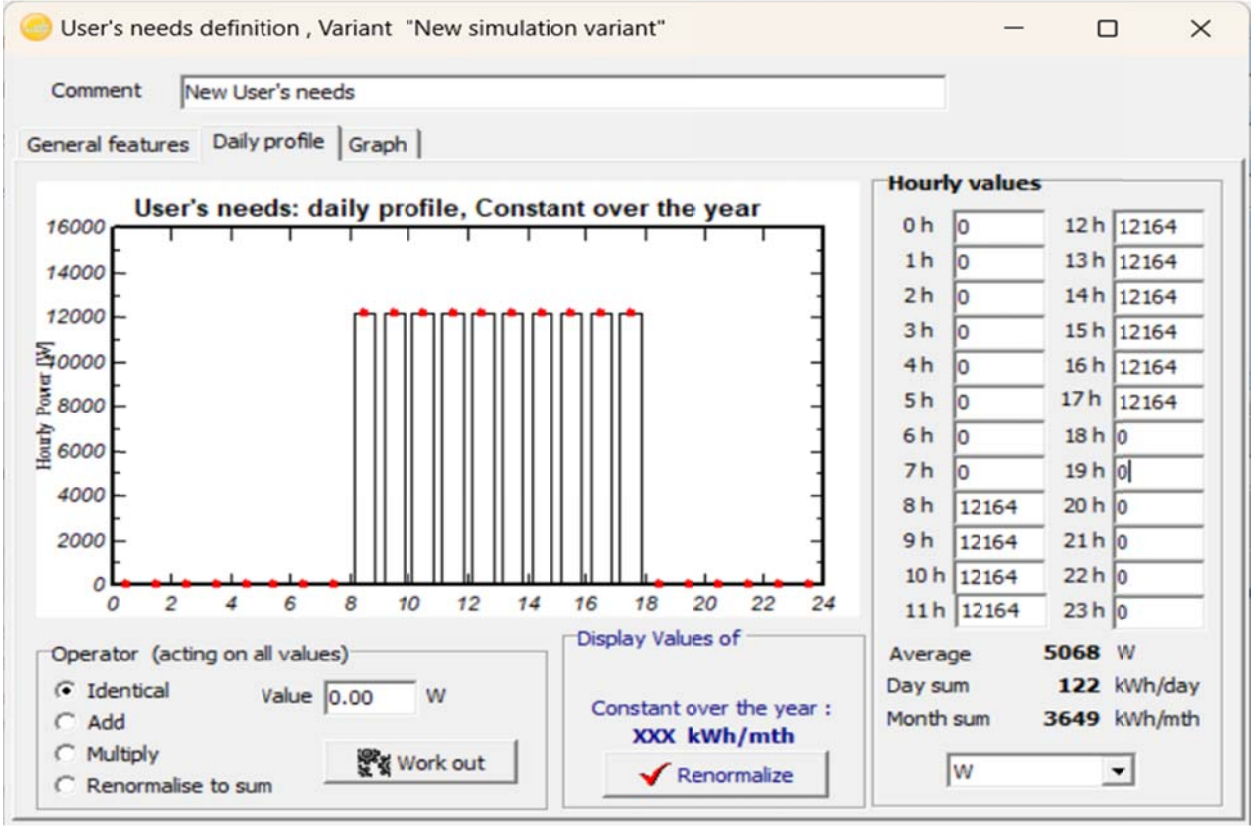
Figure 3 The mean daily atmospheric temperature for the AUTOCAB laboratory at Engineering drawing studio UNIUYO

The load profile of the AUTOCAB laboratory at Engineering drawing studio UNIUYO is given in Table 2. According to Table 2, the laboratory has about 12.22 kW of power demand which gives daily energy demand of 121.640 kWh/day when the laboratory operates for about 10 hours per day. The PVSyst simulation model of the energy demand is captured in the screenshot of Figure 4 which approximated the daily energy demand to 122 kWh/day.

The schematic diagram of typical standalone solar power system is shown in Figure 5. However, unlike the PVSyst typical solar power system model shown in Figure 5, in this study, the solar power system designed has no backup power generator. As such, the analysis will examine the possible incidences of power outages in the system.

Table 2 The load profile of the AUTOCAB laboratory at Engineering drawing studio UNIUYO

S/N	Load Item	Rated Power (W)	Quantity	Hours of operation per day	Power demand (W)	Energy Demand (wh/day)
1	Computer Systems with AUTOCAD software	120	50	10	6000	60000
2	Printers	80	1	3	80	240
3	Air Conditioner	1205	4	10	4820	48200
4	Fan	60	10	10	600	6000
5	Light	30	20	10	600	6000
6	Projector	120	1	10	120	1200
	TOTAL				12,220.00	121,640.00



Fgure 4 The screenshot of the PVSyst simulation model of the energy demand of the AUTOCAB laboratory at Engineering drawing studio UNIUYO

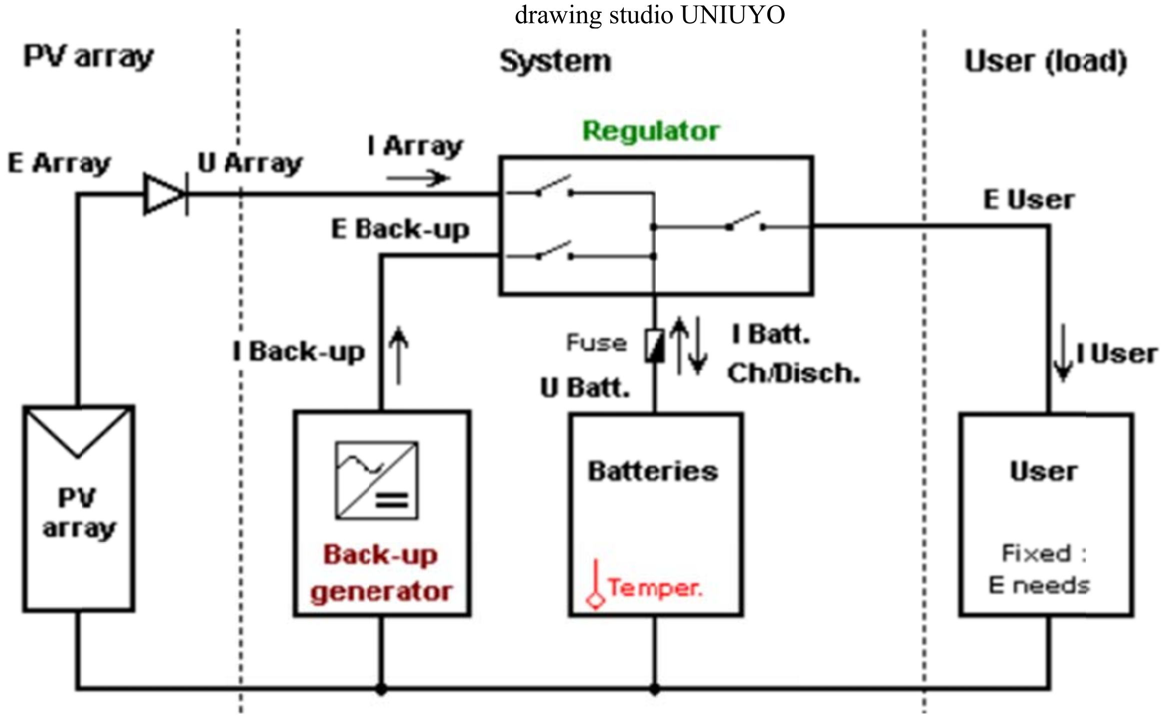


Figure 5 The schematic diagram of typical standalone solar power system

The PVSyst solar system components sizing tool was used to select and determine the battery capacity and solar panel array capacity and the charger controller. The details of the characteristics of the selected PV panel shown in Figure 6 while the details of the characteristics of the selected battery and the graphical plot of the battery are shown in Figure 7 while the graph of battery voltage versus charging time is shown in Figure 8. The selected solar module panel is a 150 Wp rated Polycrystalline silicon PV panel with module area conversion efficiency of 9.4 %. Also, the selected battery is a 12 V 100 Ah lead-acid sealed Gel battery with 97 % efficiency.

The general characteristics of the selected universal charger controller with Maximum Power Point Tracking (MPPT) technology are given in Figure 9 while the efficiency profile of the charger controller is given in Figure 10. It showed that the selected charger controller has maximum efficiency of about 97 %. Based on the selected components and with 5 % maximum allowable loss of load and 3 days of power autonomy settings, the PVSyst software was then used to simulate the solar power system for the energy yield and the attendant losses and system performance evaluation.

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Characteristics of a PV module

Manufacturer, model :	**Canadian Solar Inc., CS6P - 150**
Availability :	*Prod. from 2009 to 2009*
Data source :	*Photon Mag. 2009*

STC power (manufacturer)	**Pnom**	**150 Wp**	**Technology**		**Si-poly**
Module size (W x L)		*0.982 x 1.638 m²*	*Rough module area*	*Amodule*	*1.61 m²*
Number of cells		*1 x 60*	*Sensitive area (cells)*	*Acells*	*N/A m²*
Specifications for the model (manufacturer or measurement data)					
Reference temperature	*TRef*	*25 °C*	*Reference irradiance*	*GRef*	*1000 W/m²*
Open circuit voltage	*Voc*	*35.6 V*	*Short-circuit current*	*Isc*	*5.90 A*
Max. power point voltage	*Vmpp*	*28.6 V*	*Max. power point current*	*Impp*	*5.25 A*
=> maximum power	*Pmpp*	*150.2 W*	*Isc temperature coefficient*	*muIsc*	*3.5 mA/°C*
One-diode model parameters					
Shunt resistance	*Rshunt*	*220 ohm*	*Diode saturation current*	*IoRef*	*1.22 nA*
Serie resistance	*Rserie*	*0.60 ohm*	*Voc temp. coefficient*	*MuVoc*	*-127 mV/°C*
			Diode quality factor	*Gamma*	*1.04*
Specified Pmax temper. coeff.	*muPMaxR*	*-0.45 %/°C*	*Diode factor temper. coeff.*	*muGamma*	*0.000 1/°C*
Reverse Bias Parameters, for use in behaviour of PV arrays under partial shadings or mismatch					
Reverse characteristics (dark)	*BRev*	*3.20 mA/V²*	*(quadratic factor (per cell))*		
Number of by-pass diodes per module		*2*	*Direct voltage of by-pass diodes*		*-0.7 V*
Model results for standard conditions (STC: T=25°C, G=1000 W/m², AM=1.5)					
Max. power point voltage	*Vmpp*	*27.8 V*	*Max. power point current*	*Impp*	*5.44 A*
Maximum power	*Pmpp*	*151.1 Wc*	*Power temper. coefficient*	*muPmpp*	*-0.44 %/°C*
Efficiency(/ Module area)	*Eff_mod*	*9.4 %*	*Fill factor*	*FF*	*0.719*
Efficiency(/ Cells area)	*Eff_cells*	*N/A %*			

PV module: Canadian Solar Inc., CS6P - 150

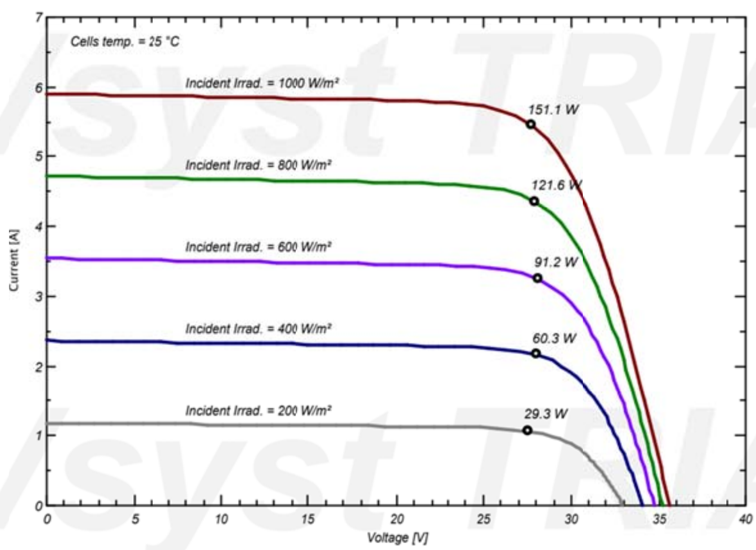
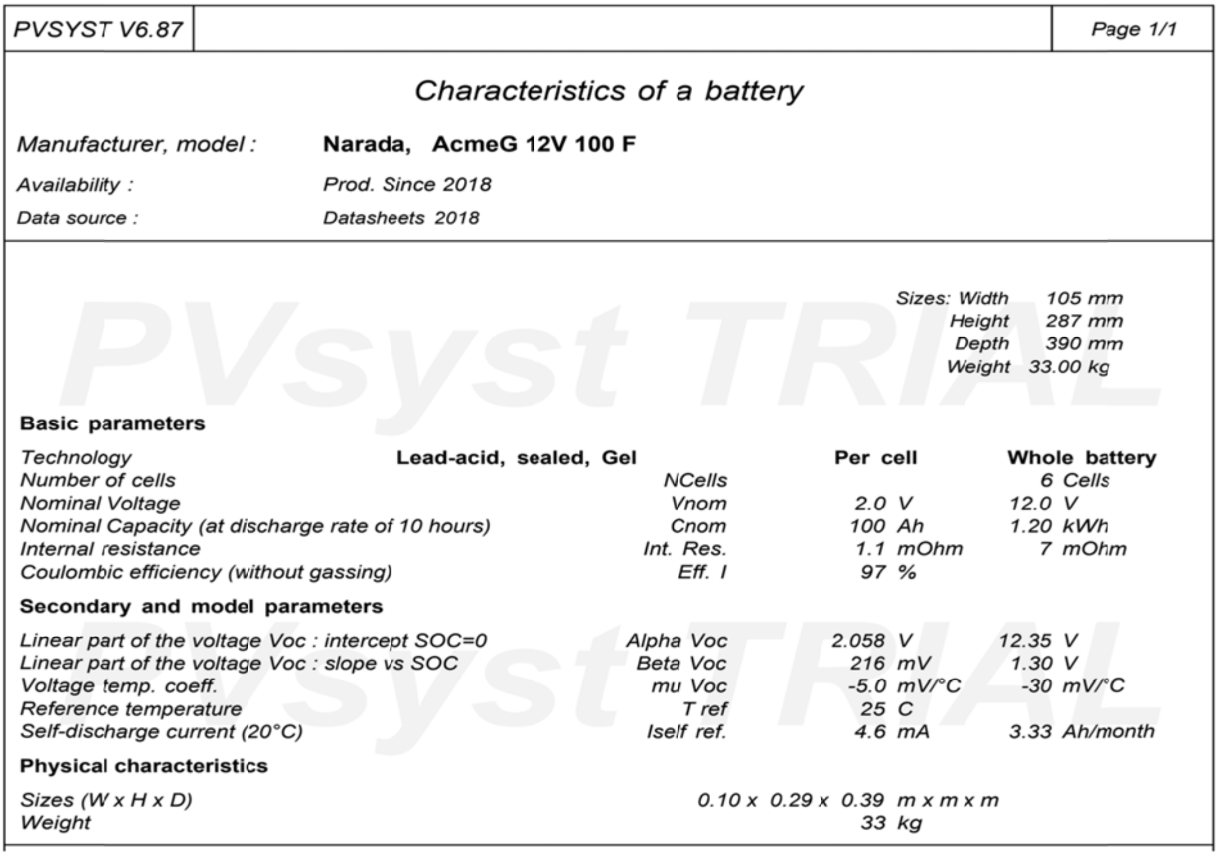


Figure 6 The details of the general characteristics of the selected PV panel



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Characteristics of a battery

Manufacturer, model :	**Narada, AcmeG 12V 100 F**
Availability :	*Prod. Since 2018*
Data source :	*Datasheets 2018*

Sizes: Width	*105 mm*
Height	*287 mm*
Depth	*390 mm*
Weight	*33.00 kg*

Basic parameters

Technology	**Lead-acid, sealed, Gel**		**Per cell**	**Whole battery**
Number of cells		*NCells*		*6 Cells*
Nominal Voltage		*Vnom*	*2.0 V*	*12.0 V*
Nominal Capacity (at discharge rate of 10 hours)		*Cnom*	*100 Ah*	*1.20 kWh*
Internal resistance		*Int. Res.*	*1.1 mOhm*	*7 mOhm*
Coulombic efficiency (without gassing)		*Eff. I*	*97 %*	

Secondary and model parameters

Linear part of the voltage Voc : intercept SOC=0	*Alpha Voc*	*2.058 V*	*12.35 V*
Linear part of the voltage Voc : slope vs SOC	*Beta Voc*	*216 mV*	*1.30 V*
Voltage temp. coeff.	*mu Voc*	*-5.0 mV/°C*	*-30 mV/°C*
Reference temperature	*T ref*	*25 C*	
Self-discharge current (20°C)	*Iself ref.*	*4.6 mA*	*3.33 Ah/month*

Physical characteristics

Sizes (W x H x D)	*0.10 x 0.29 x 0.39 m x m x m*
Weight	*33 kg*

Figure 7 The details of the characteristics of the selected battery and the graphical plot of the battery

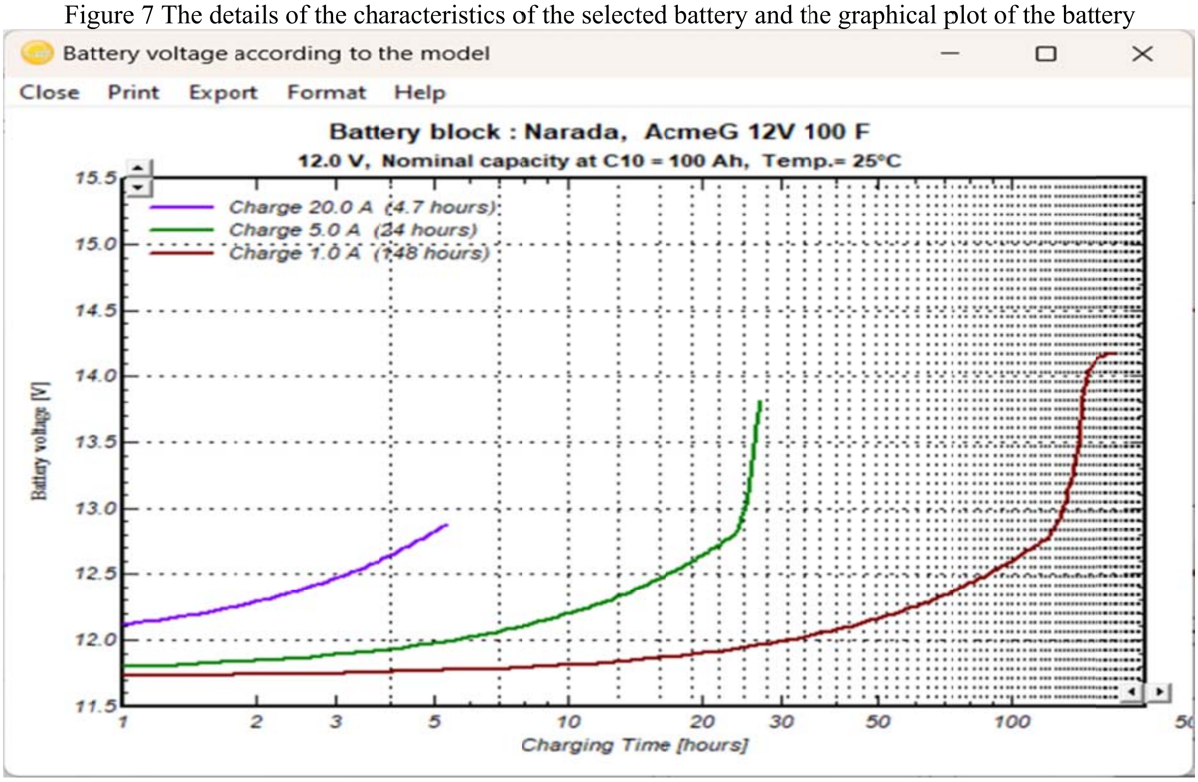
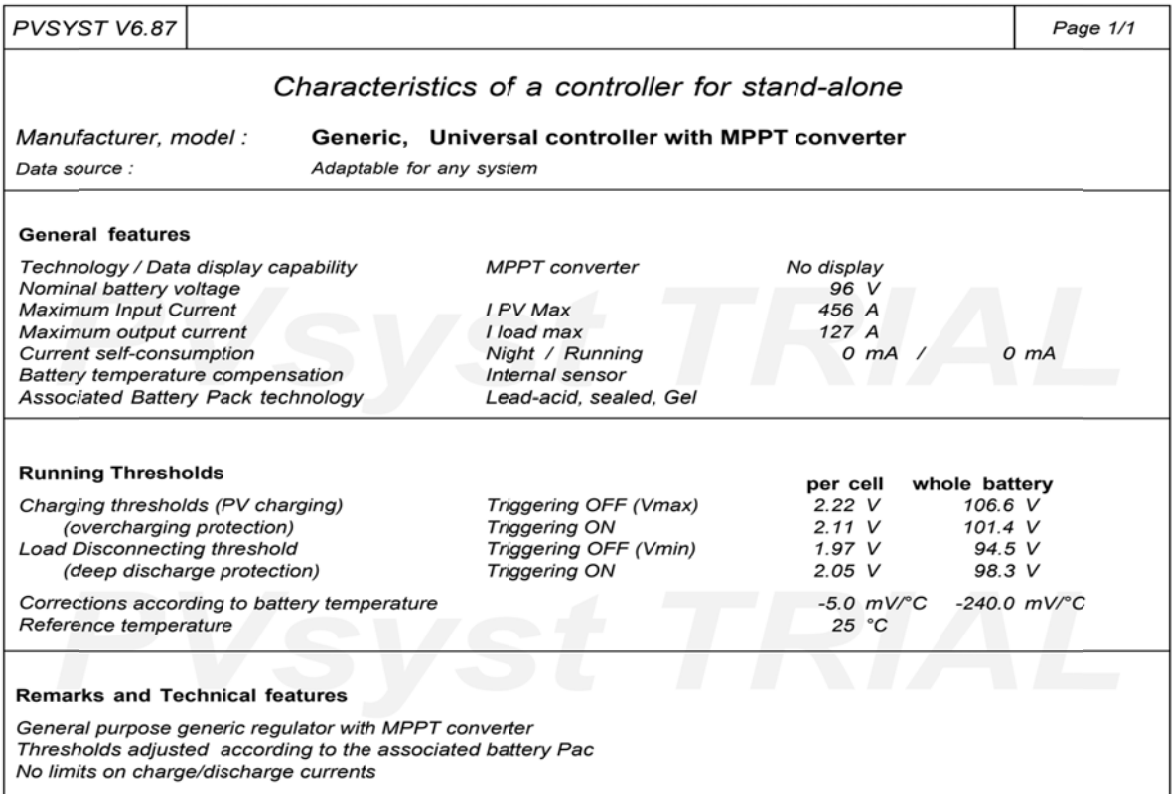


Figure 8 The battery voltage versus charging time



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Characteristics of a controller for stand-alone

Manufacturer, model : **Generic, Universal controller with MPPT converter**
Data source : Adaptable for any system

General features

Technology / Data display capability	MPPT converter	No display
Nominal battery voltage		96 V
Maximum Input Current	I PV Max	456 A
Maximum output current	I load max	127 A
Current self-consumption	Night / Running	0 mA / 0 mA
Battery temperature compensation	Internal sensor	
Associated Battery Pack technology	Lead-acid, sealed, Gel	

Running Thresholds

		per cell	whole battery
Charging thresholds (PV charging)	Triggering OFF (Vmax)	2.22 V	106.6 V
(overcharging protection)	Triggering ON	2.11 V	101.4 V
Load Disconnecting threshold	Triggering OFF (Vmin)	1.97 V	94.5 V
(deep discharge protection)	Triggering ON	2.05 V	98.3 V
Corrections according to battery temperature		-5.0 mV/°C	-240.0 mV/°C
Reference temperature		25 °C	

Remarks and Technical features

General purpose generic regulator with MPPT converter
Thresholds adjusted according to the associated battery Pac
No limits on charge/discharge currents

Figure 9 The details of the general characteristics of the selected charger controller

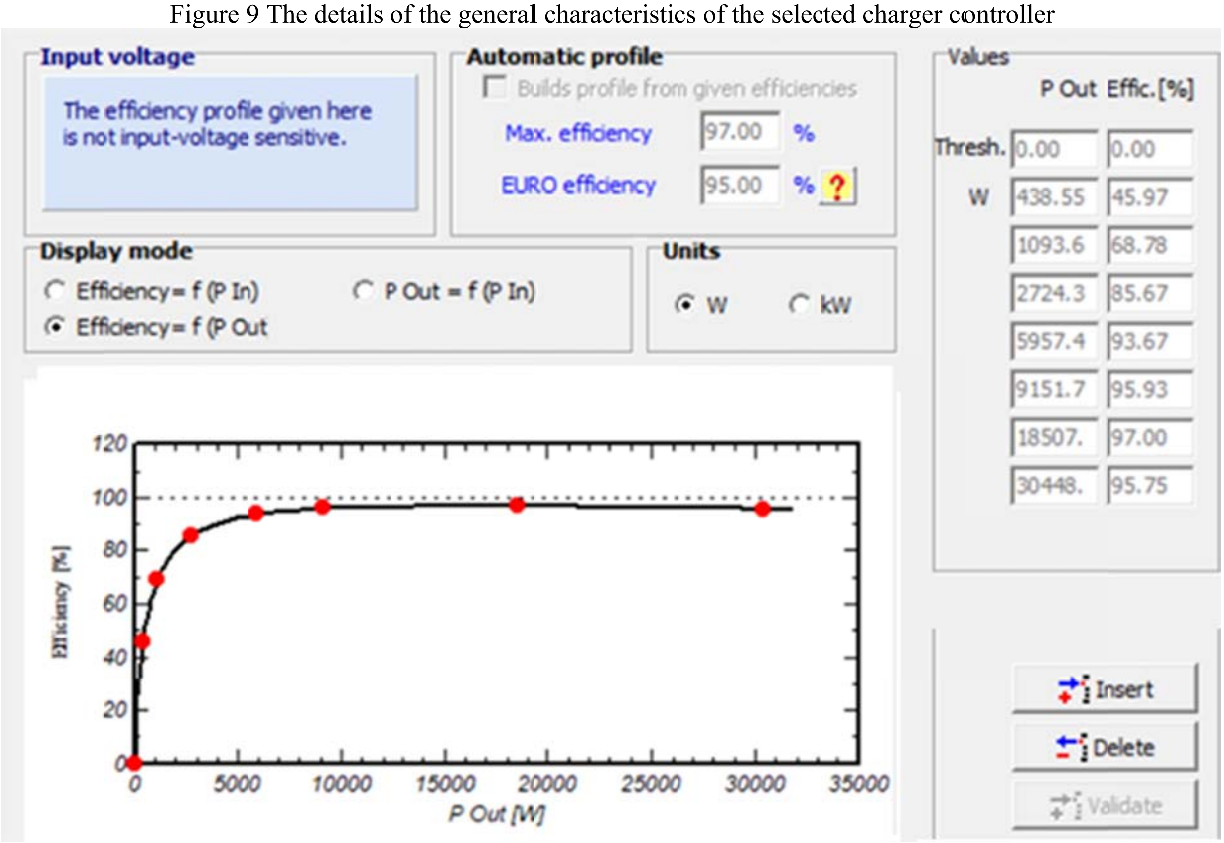

Figure 10 The efficiency profile of the selected charger controller

3. RESULTS AND DISCUSSION

The results of the PVSyst simulation are presented; first, the energy balance results are presented in Table 3 which show that the system had annual mean solar fraction of 0.997. This means that the solar power system was able to supply the desired load demand about 99.7 % of the time in a year. Hence, only in about 0.3 % of the total time in a year. Specifically, according to the results in Table 3, this power outage occurred in the month of July alone, with missing energy of about 144.2 kWh. As shown in Table 4, the July power outage resulted in loss of load duration of 40 hours in July with the resultant 5.2 % loss of load probability in that month. However, the annual loss of load is 0.3 % which is very good with respect to the maximum allowable annual loss of load of 5 % stated in the design specification.

The graph of loss of load duration for the months of June, July and August is presented n Figure 11 while the graph of the daily loss of load duration for the months July is presented in Figure 12. According to the loss of duration plots, the loss of load in the month of July is expected on the 21st, 22nd , 23rd and 24th day in July. This information is essential for the planning of load shading, load scheduling and for making arrangement for alternative power supply for the AUTOCAD laboratory.

Table 3 The PVSyst energy balance results of the simulated solar power system

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac
January	171.4	166.0	5479	1346	0.0	3771	3771	1.000
February	156.5	151.8	5013	1444	0.0	3406	3406	1.000
March	164.9	160.0	5252	1353	0.0	3771	3771	1.000
April	152.7	148.1	4873	1079	0.0	3649	3649	1.000
May	146.3	141.1	4676	783	0.0	3771	3771	1.000
June	129.3	124.9	4182	439	0.0	3649	3649	1.000
July	119.4	114.5	3855	150	144.2	3627	3771	0.962
August	116.9	112.4	3771	247	0.0	3771	3771	1.000
September	118.2	113.8	3753	0	0.0	3649	3649	1.000
October	132.4	127.7	4227	153	0.0	3771	3771	1.000
November	145.2	140.6	4655	785	0.0	3649	3649	1.000
December	164.0	159.5	5317	1373	0.0	3771	3771	1.000
Year	1717.2	1660.4	55053	9152	144.2	44254	44399	0.997

Table 4 The results for the loss of load duration and the loss of load probability

	E_Miss kWh	T_LOL Hour	Pr_LOL %
January	0.0	0	0.00
February	0.0	0	0.00
March	0.0	0	0.00
April	0.0	0	0.00
May	0.0	0	0.00
June	0.0	0	0.00
July	144.2	40	5.32
August	0.0	0	0.00
September	0.0	0	0.00
October	0.0	0	0.00
November	0.0	0	0.00
December	0.0	0	0.00
Year	144.2	40	0.45

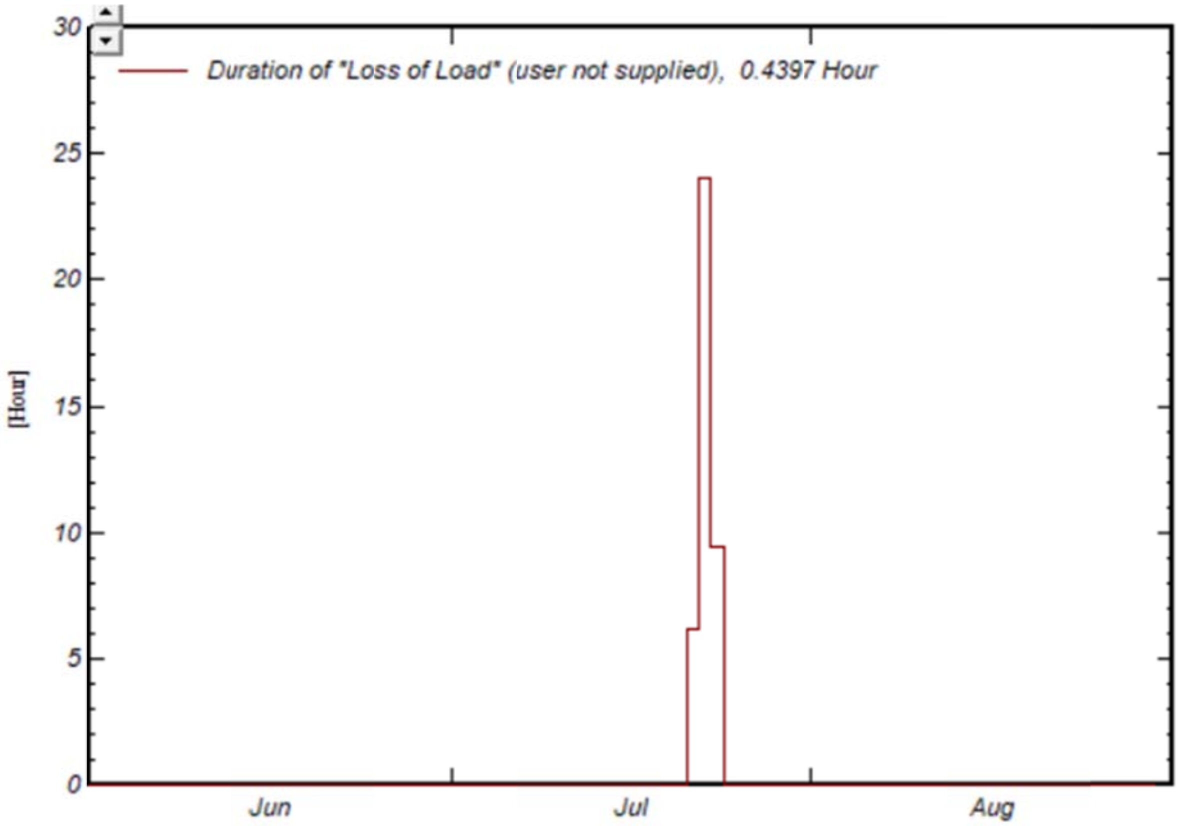

Figure 11 The graph of loss of load duration for the months of June, July and August

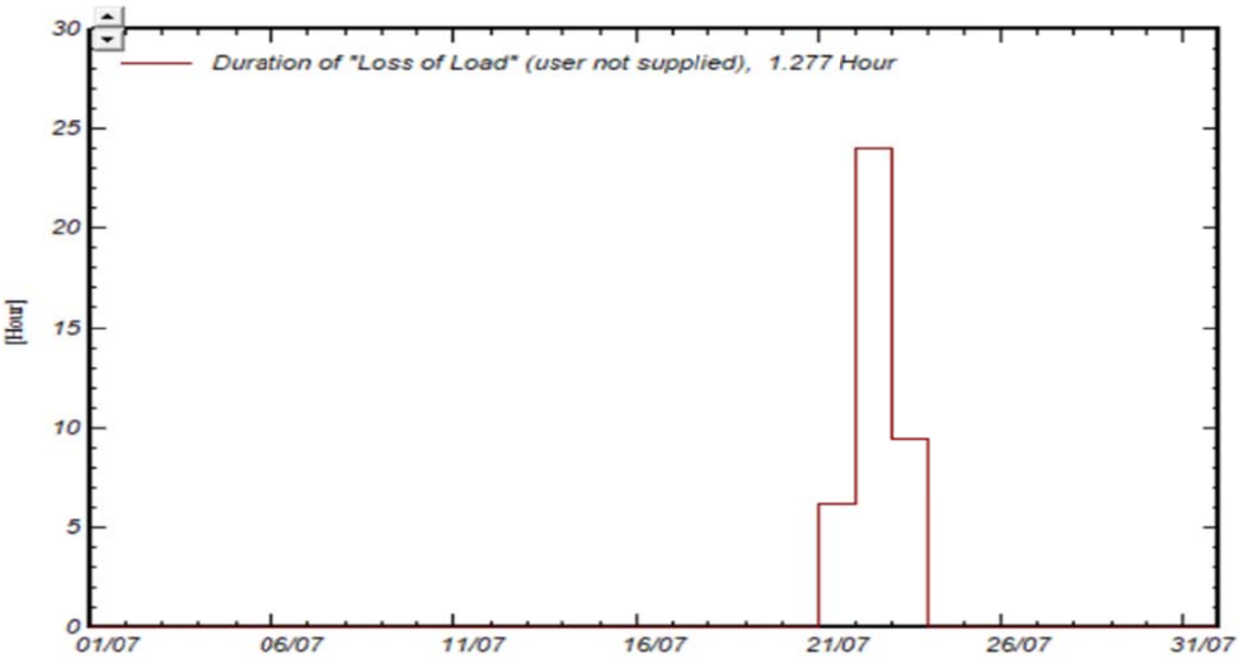

Figure 12 The graph of the daily loss of load duration for the months July

The results of the system components configuration parameters are shown in Figure 13. Accordingly, there is a total of 480 batteries and a total of 265 PV models that occupy a total area of 426 m^2.

The results of the normalized energy per installed kWp are presented in Figure 14. The normalized energy per installed kWp by the battery is 0.63 kWh/kWp/day, normalized energy supplied to the user is 2.05 kWh/kWp/day, the normalized energy lost in the PV array is 0.76kWh/kWp/day while normalized energy lost due to battery charging efficieny is 0.26 kWh/kWp/day.

The results of the normalized energy production and loss factor are presented in Figure 15. According to the results in Figure 15, the unused energy is 13.4 %, PV array loss is 16.2%, the battery charging loss is 5.5 % while the energy supplied to the user is 64.8 %.

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Stand alone system: Simulation parameters

Project : AUTOCAD LAB SOLAR POWER

GeographiMechanical Engineering Workshop UNIUYO — *Country* **Nigeria**

Situation — *Latitude* 0.00° N — *Longitude* 0.00° E
Time defined as — *Legal Time* Time zone UT — *Altitude* 0 m
Albedo 0.20

Meteo dataMechanical Engineering Workshop UNIUYO — *NASA-SSE satellite data 1983-2005 - Synthetic*

Simulation variant : New simulation variant
Simulation date 18/01/25 01h05

Simulation parameters — *System type* **Stand alone system with batteries**
Collector Plane Orientation — *Tilt* 5° — *Azimuth* 0°
Models used — *Transposition* Perez — *Diffuse* Perez, Meteonorm
User's needs : — *daily profile* Constant over the year
average 122 kWh/Day

	0 h / 12 h	1 h / 13 h	2 h / 14 h	3 h / 15 h	4 h / 16 h	5 h / 17 h	6 h / 18 h	7 h / 19 h	8 h / 20 h	9 h / 21 h	10 h / 22 h	11 h / 23 h	
Hourly load	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.16	12.16	12.16	12.16	kW
	12.16	12.16	12.16	12.16	12.16	12.16	0.00	0.00	0.00	0.00	0.00	0.00	kW

PV Array Characteristics

PV module Si-poly	Model	**CS6P - 150**		
Original PVsyst database	Manufacturer	Canadian Solar Inc.		
Number of PV modules	In series	5 modules	In parallel	53 strings
Total number of PV modules	Nb. modules	265	Unit Nom. Power	150 Wp
Array global power	Nominal (STC)	**39.8 kWp**	At operating cond.	35.5 kWp (50°C)
Array operating characteristics (50°C)	U mpp	123 V	I mpp	289 A
Total area	Module area	**426 m²**		

System Parameter	System type	**Stand alone system**		
Battery	Model	**AcmeG 12V 100 F**		
	Manufacturer	Narada		
Battery Pack Characteristics	Nb. of units	8 in series x 60 in parallel		
	Voltage	96 V	Nominal Capacity	6000 Ah
	Discharging min. SOC	20.0 %	Stored energy	475.0 kWh
	Temperature	Fixed (20°C)		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0 / 95.0 %		
Battery Management control	Threshold commands as	SOC calculation		
	Charging	SOC = 0.90 / 0.75	i.e. approx.	106.8 / 101.4 V
	Discharging	SOC = 0.20 / 0.45	i.e. approx.	94.5 / 98.3 V

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	7.2 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.5 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Figure 13 The results of the system components configuration parameters

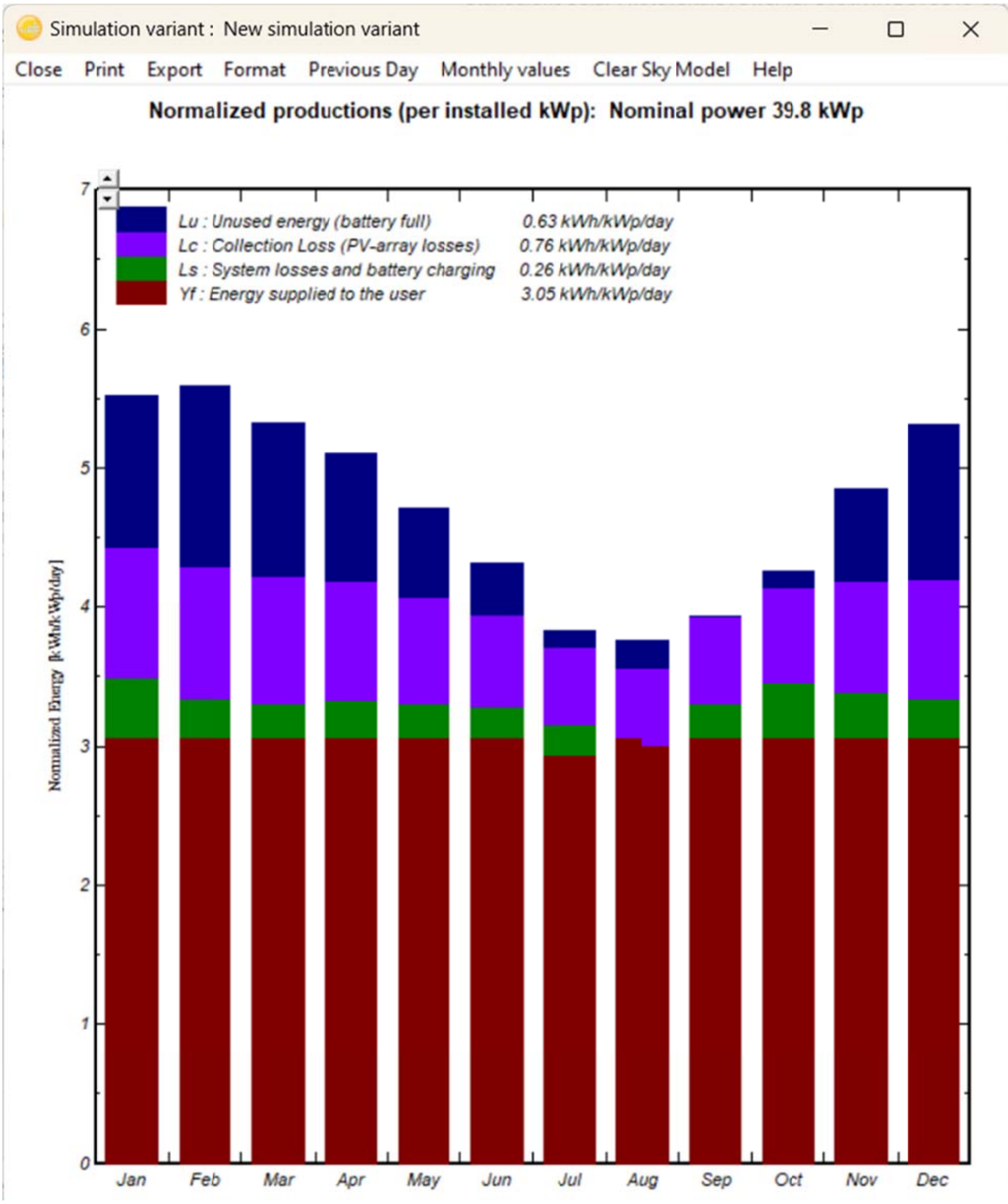

Figure 14 The results of the normalized energy per installed kWp

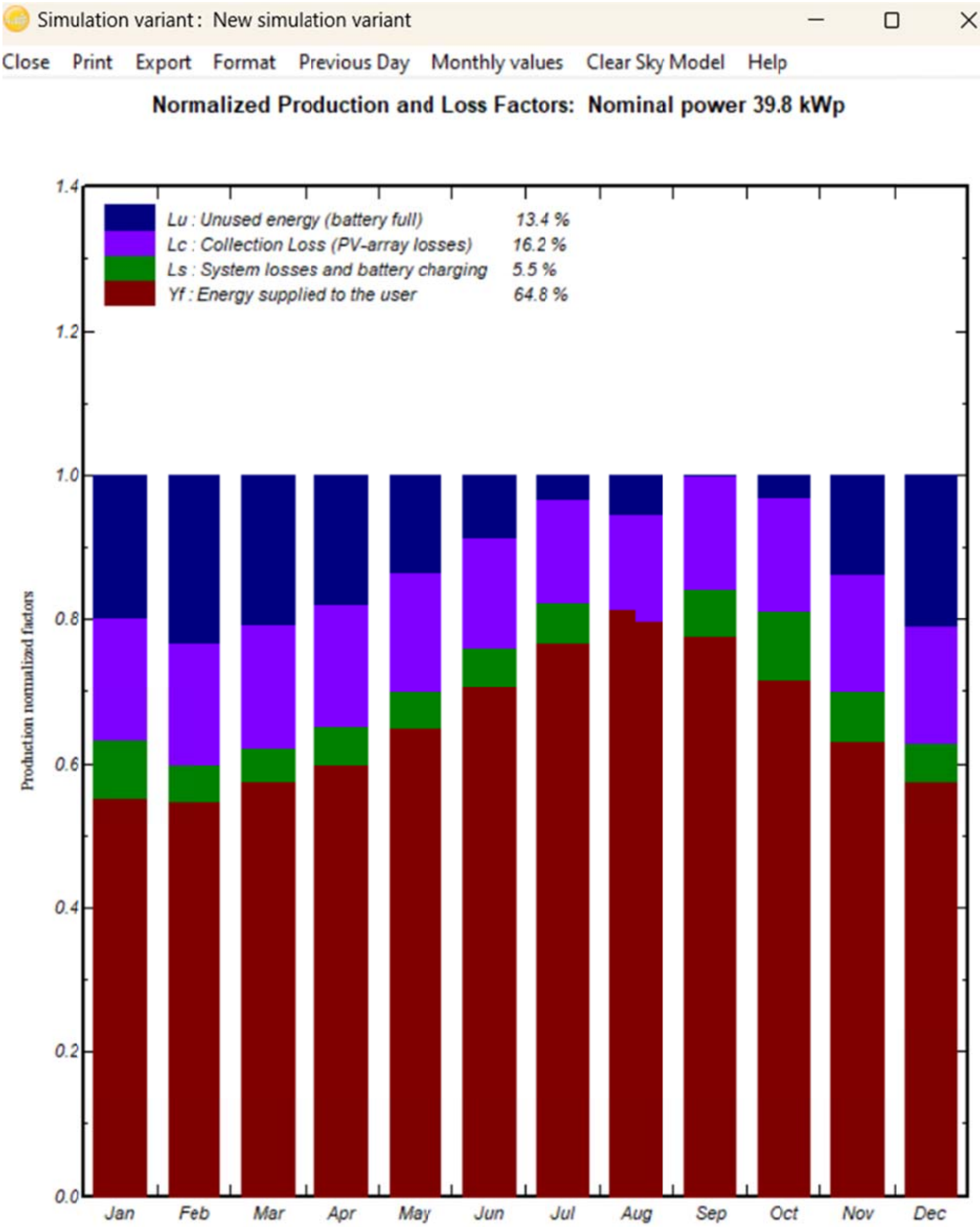

Figure 15 The results of the normalized energy production and loss factor

4. CONCLUSION

In this study, the design and performance analysis of solar energy system for powering an AUTOCAD laboratory is presented. The PVSyst software was used to determine the solar power system's components sizes as well as the determination of the energy yield, energy supplied and energy losses. Specifically the loss of load was determined along with the loss of load duration, and the specific days in the year the loss of load occurred. Notably, the results presented in this work will assist in the energy management and planning, especially in making arrangement for alternative power in those days with high probability of power outage.

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