Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 7 Issue 12, December - 2020

Simulated Grid-Connected Roof-Top Solar Power System Analysis: Case Study Of Superstore Building In Akwa Ibom

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***Abstract*— In this paper, simulated grid-connected roof-top solar power system analysis is presented and the case study was a superstore building in Akwa Ibom. The effective rooftop area for PV array installation at the case study superstore was about 18 m^2, the load demand was 33460 Wh per day and the horizontal global irradiation at the site was 1717.2 kWh.m^2 per month. The analysis was implemented using PVSyst solar power simulation software. According to the results, a total of 10 PV modules are required and this gave a total PV array module area of 16.4 m^2 and array cell area of 14.4 m^2. The power system has total energy production of 4305 kWh/year, the performance ratio of 82.84 % and solar fraction of 32.57 %. The operating efficiency of the PV modules was 17.99 % with respect to cell area which is different from the quoted value of 21.12 % on the PV datasheet. Also, the operating efficiency of the PV modules was 15.70 % with respect to module area which is different from the quoted value of 18.44 % on the PV datasheet.**

Keywords*— *Grid-Connected, PVSyst software, PV Array, Irradiance, Roof-Top Solar Power

1. INTRODUCTION

In the recent decades, the rising harmful impact of fossil fuel-based energy generators has prompted the global call for the adoption of more environmentally friendly energy sources [1,2, 3,4, 5,6,7,8,9,10,11,12,13]. While there are many options, in Nigeria, the most popular clean energy source in the solar of which photovoltaic option is the most dominant [14,15,16,17,18,19,202,21,22,23,24]. In this wise, photovoltaic (PV) panels are installed and used to capture solar energy and converts same to electric energy [25,26,27,28,29,30]. While such approach is good, the solar panels occupy space, especially due to the low conversion efficiency the PV panels and hence relatively large area of space that is needed to accommodate the solar panels for large energy harvest.

In order to conserve space while still adopting the solar PV option, rooftop installed PV panels are now being used in many places [31,32,33,34,35,36]. This is particularly useful in the cities where space is very scares and expensive. As such, in this paper, the focus is to determine the amount of energy generated from the available rooftop and also the operating efficiency of the rooftop installed PV panels. The PVSyst software is used in the study and it also used to generate other relevant performance parameters of the PV installation. The case study used was a superstore building in Akwa Ibom State in Nigeria.

2 METHODOLOGY

The effective area of the roof (A_{PVT}) is determined from the available roof area (A_{RFA}) after applying the various reduction factors, namelyr_{flat} (flat roof reduction factor, $r_{flat} = 1$), r_{peak} (peaked roof reduction factor usually, $r_{peak} = 0.5$), f_o (roof inclination reduction factor), f_s (unused and shaded roof area reduction factor roof area, typically, $0.3 \leq f_s \leq 0.9$), f_{flat} (flat roof fraction) and f_{peak} (peaked roof fraction). Then

$$A_{PVT} = (f_o)(f_s)(A_{TRF}) \quad (1)$$

Where,

$$f_o = (f_{flat})(r_{flat}) + (f_{peak})(r_{peak}) \quad (2)$$

The tilt angle, β_{opt} for optimal solar radiation capture on the PV module is calculated as follows;

$$\beta_{opt} = 3.7 + 0.69|\varphi| \quad (3)$$

Where φ is denotes the site latitude.

Researches have shown the cell temperature (T_{cell}) affect the PV module output. Furthermore, the ambient temperature (T_a), the absorption coefficient (α), the irradiance (G) incident on the PV module plane and the standard test condition module efficiency (η_{PVSTC}) all affect the cell temperature which is determined in this paper using the Faiman PV temperature model, where;

$$T_{cell} = T_a + \left(\frac{\alpha(G)(1-\eta_{PVSTC})}{U_0 + U_1\,(V_{wind})}\right) \quad (6)$$

Where the thermal loss factor values adopted close roof mount PV are; Uo =15, U1= 0.

The de-rating factor due to cell temperature (f_{temp}) is given as:

$$f_{temp} = 1 - (\gamma_{pv} * (T_a - T_{STC})) \quad (9)$$

Where T_{STC} is the Standard Test Conditions cell temperature in degrees Celsius, γ_{pv} dentes the temperature coefficient of the PV module, and T_a is the ambient temperature. Similarly, $f_{dc/ac}$ denotes the overall DC to AC de-rate factor where its value is usually about 0.8. Then , if η_{pv} is the operating PV module efficiency , E_L is the daily load demand and G_d denotes the average daily global solar on the PV module plane, then;

$$A_{PVT} = \frac{E_L}{(G_d * \eta_{pv} * f_{dc/ac} * f_{temp})} \quad (7)$$

Hence, the daily load that can be satisfied by the given effective roof area, A_{PVT} is given as;

$$E_L = A_{pv}\,(G_d * \eta_{pv} * f_{dc/ac} * f_{temp}) \quad (8)$$

3 RESULTS AND DISCUSSION

The detail PV power analysis was implemented using PVSyst software. The details of the meteorological data for the PV installation site, as captured using the PVSyst software is shown in Figure 1. The horizontal global irradiation at the site is 1717.2 kWh.m^2 per month. Figure 2. The load demand profile of the case study superstore is shown in Figure 2 which shows a daily energy demand of 33460 Wh per day, approximately, 33.5 kWh per day. The effective rooftop area for PV array installation at the case study superstore was about 18 m^2. Hence, the PV array selected does not exceed 18 m^2 and some rooms are given for pathways around the PV arrays.

The selected PV module for the system is the NU-RD 300 model PV module manufactured by Sharp and it is a 300 Wp 26V rated Si-mono PV module. The definition of the PV module basic parameters and rated efficiency is shown in Figure 3, the definition of the PV module size and technology is shown in Figure 4, while the definition of the PV module optimization, efficiency versus irradiance is shown in Figure 5. The PV module has 1.643 m^2 module area, 1.435 m^2 cell area, as shown in Figure 4. Also, the module has 21.12 % efficiency with respect to cell area, 18.44 % efficiency with respect to module area, as shown in Figure 3 and Figure 5.

The simulation parameters of the PV power system is given in Figure 6. According to Figure 6, a total of 10 PV modules are required and this gave a total PV array module area of 16.4 m^2 and array cell area of 14.4 m^2.

The section of the main simulation results of the PV system is given in Figure 7 which shows that the power system has total energy production of 4305 kWh/year, the performance ratio of 82.84 % and solar fraction of 32.57 %. The operating efficiency of the PV modules are shown in Figure 8 which shows that due to site specific losses in the PV array , the operating efficiency of the PV modules is 17.99 % with respect to cell area which is different from the quoted value of 21.12 % on the PV datasheet. Also, the operating efficiency of the PV modules is 15.70 % with respect to module area which is different from the quoted value of 18.44 % on the PV datasheet.

PVSYST V6.70 | 07/08/22 | Page 1/1

Hourly meteorological data

Meteo data : **AKWA IBOM STATE ;NASA-SSE satellite data, 1983-2005;Synthetic**
File AKWA IBOM STATE_Nasa_SYN.MET of 29/05/21 06h21

Situation Latitude 5.05° N Longitude 7.90° E
Time defined as Legal Time Time zone UT Altitude 56 m

Source file characteristics Synthetic Data generation, Monthly renormalisation

Monthly Meteo Values Source AKWA IBOM STATE _Nasa_1983.SIT -- NASA-SSE satellite dat

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	171.4	156.5	164.9	152.7	146.3	129.3	119.4	116.9	118.2	132.4	145.2	164.0	1717.2	kWh/m².mth
Hor. diffuse	53.6	55.2	68.8	68.1	67.6	63.3	66.0	68.2	68.1	67.3	58.5	53.0	757.7	kWh/m².mth
Extraterrestrial	295.0	281.8	323.1	312.2	312.6	294.6	306.5	315.8	310.7	314.4	289.2	288.4	3644.2	kWh/m².mth
Clearness Index	0.581	0.555	0.510	0.489	0.468	0.439	0.390	0.370	0.380	0.421	0.502	0.569	0.471	
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 1 The details of the meteorological data for the PV installation site

PVSYST V6.70		07/08/22	Page 2/4

Grid-Connected System: Detailed User's needs

Project : ROOF_TOP_PV_POWER

Simulation variant : SUPERSTORE _1

Annual values

	Number	Power	Use	Energy
Light	6	18 W/lamp	13 h/day	1404 Wh/day
TV	3	80 W/app	13 h/day	3120 Wh/day
Air Conditioner	2	780 W/app	13 h/day	20280 Wh/day
Fridge / Deep-freeze	2		24 Wh/day	1642 Wh/day
Fan	4		13 Wh/day	3120 Wh/day
Computer	3	125 W tot	10 h/day	3750 Wh/day
Stand-by consumers			24 h/day	144 Wh/day
Total daily energy				33460 Wh/day

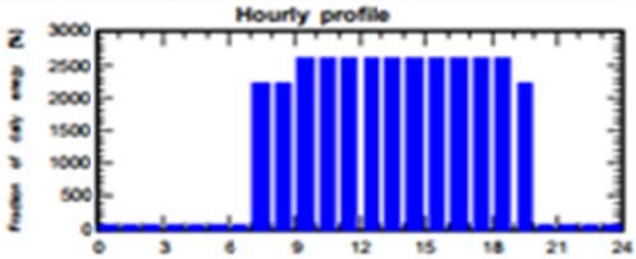


Figure 2 The load demand profile of the case study superstore

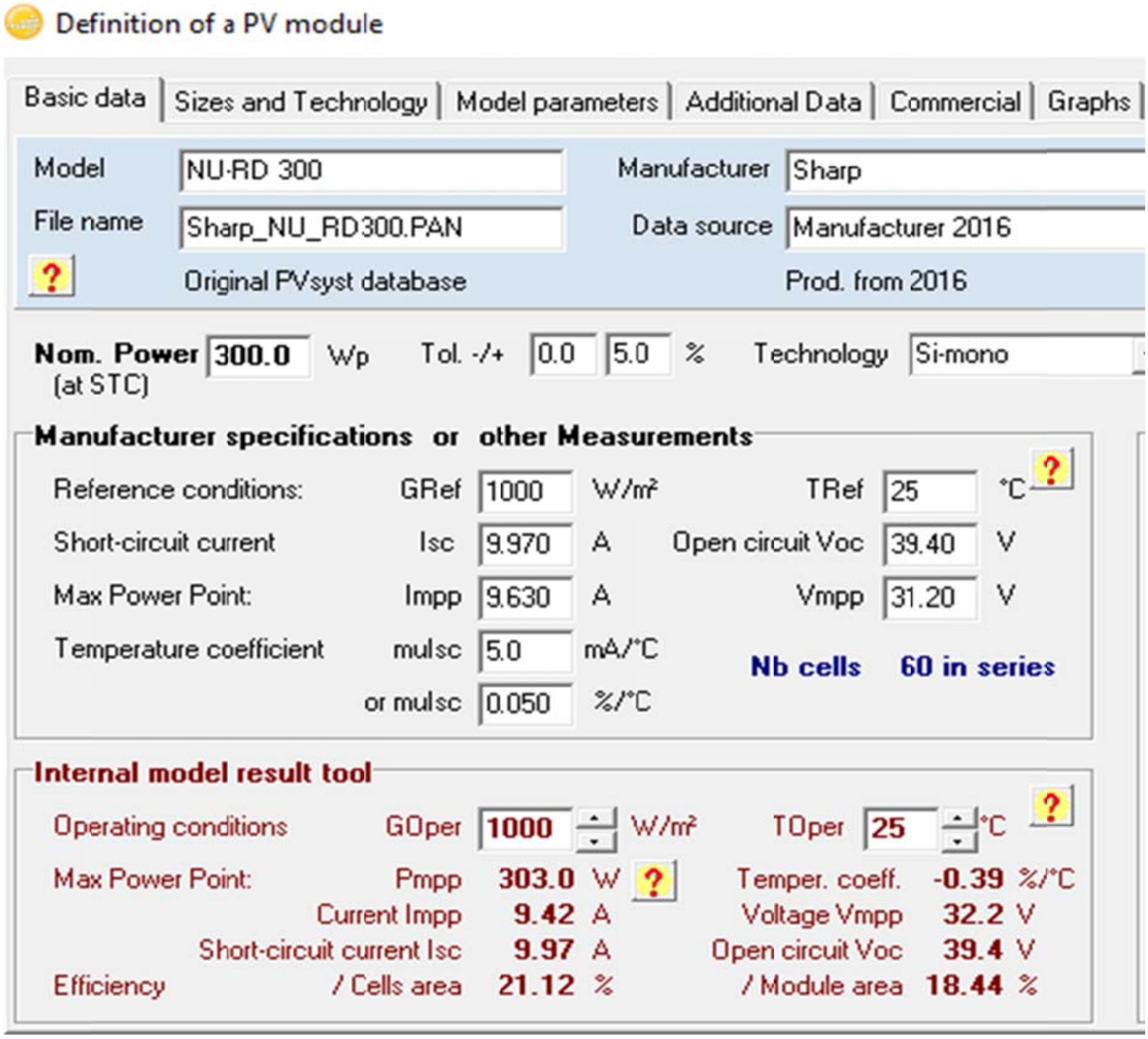


Figure 3 The definition of the PV module basic parameters and rated efficiency

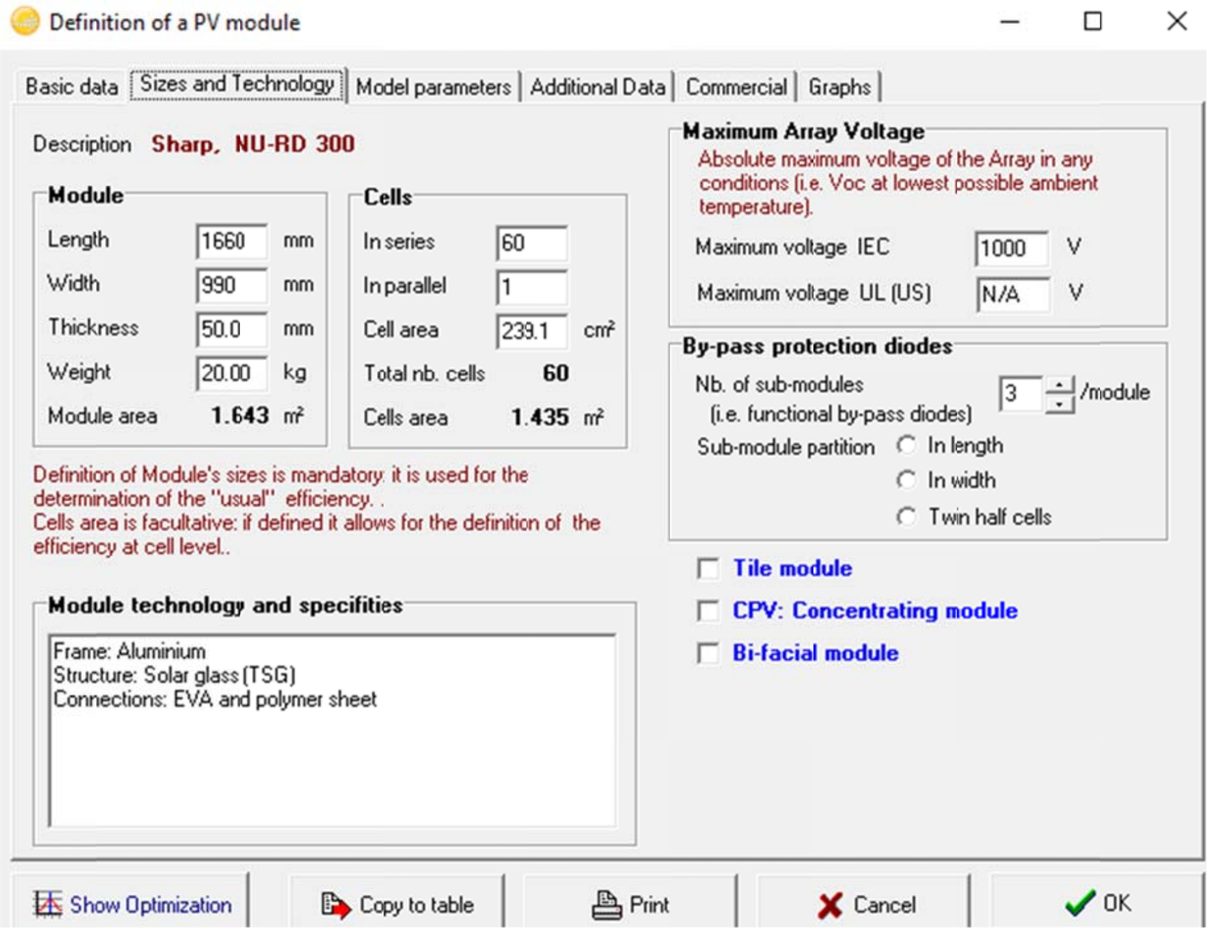


Figure 4 The definition of the PV module size and technology

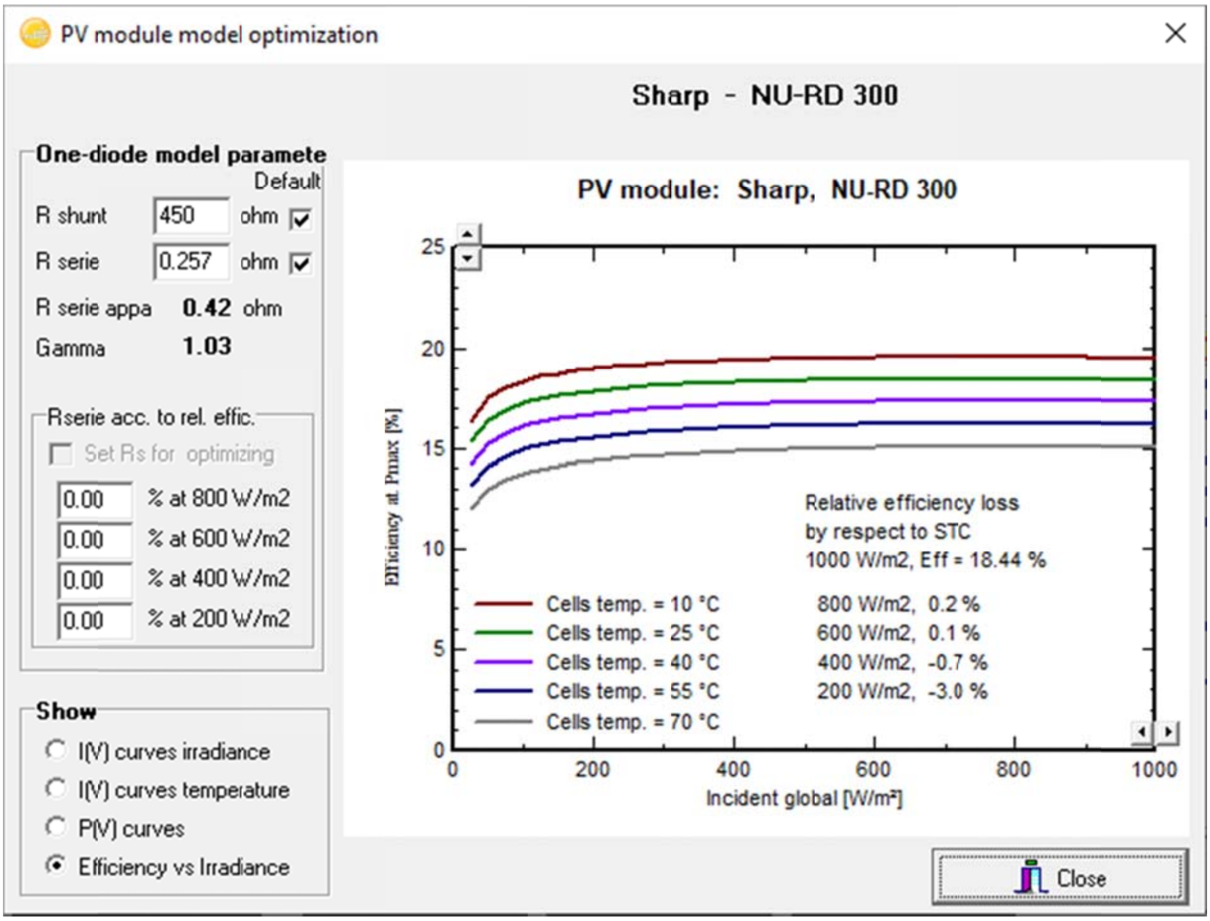


Figure 5 The definition of the PV module optimization, efficiency versus irradiance

PVSYST V6.70		07/08/22	Page 1/4

Grid-Connected System: Simulation parameters

Project :	**ROOF_TOP_PV_POWER**			
Geographical Site	**AKWA IBOM STATE**		Country	**Nigeria**
Situation	Latitude	5.05° N	Longitude	7.90° E
Time defined as	Legal Time	Time zone UT	Altitude	56 m
	Albedo	0.20		
Meteo data:	**AKWA IBOM STATE**	NASA-SSE satellite data, 1983-2005 - Synthetic		

Simulation variant :	**SUPERSTORE _1**			
	Simulation date	07/08/22 16h03		

Simulation parameters	System type	**No 3D scene defined**		
Collector Plane Orientation	Tilt	8°	Azimuth	0°
Models used	Transposition	Hay	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

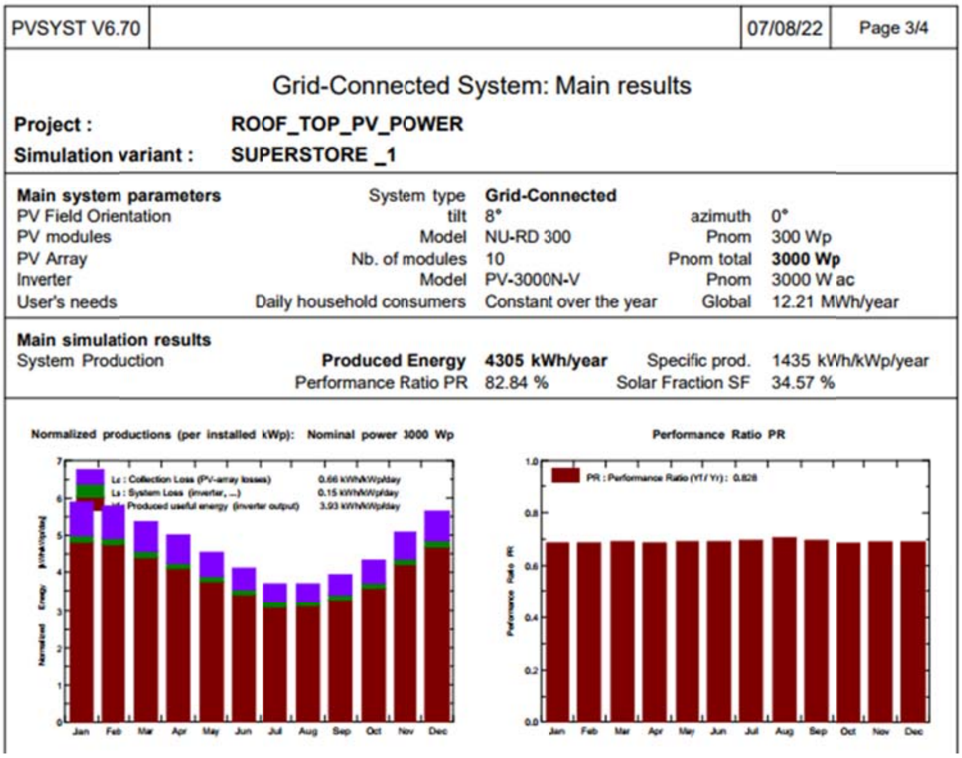
PV module Si-mono	Model	**NU-RD 300**		
Original PVsyst database	Manufacturer	Sharp		
Number of PV modules	In series	10 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	10	Unit Nom. Power	300 Wp
Array global power	Nominal (STC)	**3000 Wp**	At operating cond.	2725 Wp (50°C)
Array operating characteristics (50°C)	U mpp	288 V	I mpp	9.4 A
Total area	Module area	**16.4 m²**	Cell area	14.3 m²

Inverter	Model	**PV-3000N-V**		
Original PVsyst database	Manufacturer	PrimeVolt		
Characteristics	Operating Voltage	100-580 V	Unit Nom. Power	3.00 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	3.0 kWac
			Pnom ratio	1.00

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.	513 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.0 %
Module Quality Loss			Loss Fraction	-1.3 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs :	Daily household consumers	Constant over the year		
	average	33.5 kWh/Day		


PVSYST V6.70 | 07/08/22 | Page 3/4

Grid-Connected System: Main results

Project : ROOF_TOP_PV_POWER
Simulation variant : SUPERSTORE _1

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	8°	azimuth	0°
PV modules	Model	NU-RD 300	Pnom	300 Wp
PV Array	Nb. of modules	10	Pnom total	**3000 Wp**
Inverter	Model	PV-3000N-V	Pnom	3000 W ac
User's needs	Daily household consumers	Constant over the year	Global	12.21 MWh/year

Main simulation results				
System Production	**Produced Energy**	**4305 kWh/year**	Specific prod.	1435 kWh/kWp/year
	Performance Ratio PR	82.84 %	Solar Fraction SF	34.57 %

Figure 7 The section of the main simulation results of the PV system

	EffArrR %	EffArrC %
January	15.58	17.84
February	15.53	17.80
March	15.60	17.87
April	15.59	17.86
May	15.71	18.00
June	15.76	18.06
July	15.88	18.20
August	16.09	18.43
September	15.83	18.14
October	15.65	17.93
November	15.72	18.00
December	15.68	17.96
Year	15.70	17.99

Figure 8 The operating efficiency of the PV modules

4 CONCLUSION

The sizing of the components of the rooftop PV solar power installation on a superstore in Akwa Ibom state in Nigeria is presented. The focus was selecting the appropriate PV array size that will fit on the rooftop of the case study superstore and to determine the total energy generated, the solar fraction, and the operating efficiency of the PV modules, as well as the solar fraction and performance ratio. The analysis as implemented on PVSyst solar power simulation software.

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