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Pvsyst Software-Based Comparative Techno-Economic Analysis Of PV Power Plant For Two Installation Sites With Different Climatic Conditions

Usah, Emmamuel Okon[1]
Department of Physics
University of Uyo

Ozuomba, Simeon[2]
Department of Electrical/Electronic and Computer Engineering
University of Uyo
simeonozuomba@uniuyo.edu.ng
simeonoz@yahoo.com

Enobong Joseph Oduobuk[3]
Department of Physics
University of Uyo

Etinamabasiyaka Edet Ekott[4]
Department of Physics
University of Uyo

Abstract— **In this paper, PVSyst software-based comparative techn-economic analysis of photovoltaic (PV) power plant for two installation sites with different climatic conditions is presented. The installations sites are in Bayelsa State and Sokoto State . Bayelsa State has annual average Peak Sun Hour (PSH) of 4.12 hours whereas Sokoto State has annual average PSH of 6.24 hours. Also, the annual average temperature of Sokoto State is 27.1 °C which is higher than that of Bayelsa State (which is25.5 °C). In the analysis, a constant daily load demand that consists of 2000 W power that runs for 24 hours every day in the whole year is adopted. For the installation at Bayelsa State, a total of 310 batteries and 362 PV panels are required to meet the stringent load demand specifications of zero loss of load. On the other hand, at Sokoto , a total of 310 batteries and 362 PV panels are required to meet the same load demand and this is about 142 units (39.22%) reduction in the PV modules. This resulted in gives 25Naira/kWh (13.44 %) reduction in the unit cost of energy for the PV installation in Sokoto State. Furthermore, Bayelsa State has a total of 3082.3 kWh unused energy per year , performance ratio (PR) of 64.3 % and 0.0% loss of load probability (Pr LoL) while Sokoto State has a total of 3.274 kWh unused energy per year , performance ratio (PR) of 69.9 % and 0.0% loss of load probability (Pr LoL). . In all, the results showed that it is more expensive to install and run PV power system in Bayelsa State than in Sokoto State. The idea presented in this study can facilitate policy framework for optimal site for large scale PV installation across Nigeria.**

Keywords— Solar Energy, Loss of Load , PVSyst Software, Techno-Economic Analysis, Photovoltaic Power, Life Cycle Cost Analysis

1. Introduction

Photovoltaic solar power system is a renewable energy system which converts sunlight energy into electricity [1,2]. Notably, solar energy has the potential to adequately provide the present and future global energy demands [2,3,4,5,6]. This can be realized through effective and sustained research and technological advancement which will help in boosting the harvesting and harnessing of the solar energy wherever there is sufficient sunlight. Study has recommended that the solar energy received at Earth's atmosphere is approximately 342 W m^{-2}, which about 30% is scattered or reflected back to space, while about 70% (239 W m^{-2}) of the energy remains to be harvested [7,8,9,10.11]. Essentially, the effective annual solar irradiance globally varies from 60 to 250 W m^{-2} [12,13]. Studies have shown that Africa has the sunniest places on the planet [13,14,15,16]. In addition, other available research findings indicated that the potential photovoltaic cell (PV) and concentrated solar power (CSP) energies in Africa is about 660 and 470 petawatt hours (PWh), respectively [13]. Consequently, in Nigeria, effort is increasingly being made to take advantage of the abundant solar energy to address the acute energy shortage.

In any case, one of the key challenges to wide adoption of PV power systems is the high initial investment cost. As such, some available research publications are focused on finding ways to minimize the initial investment cost and unit cost of energy for PV power systems by appropriate sizing of the PV power system components. Accordingly, in this paper, the component sizing and economic analysis of a 2000 W PV power plant is presented. The techno-economic analysis is conducted using PVSyst software [17,18].

The analysis is conducted for the same PV power plant using the annual average solar radiation and temperature data of two States in Nigeria. The two States are Bayelsa State with low solar radiation and temperature values and Sokoto State with high solar radiation and temperature values. The essence of the study is to examine how the different climatic conditions can impact on the key components sizes and on the initial investment cost as well as on the unit cost of energy in those case study areas. The study will specifically examine the effect of the climatic conditions on the number of PV modules that will be used to satisfy the same daily load demand in each of the study sites. The idea present in this paper will facilitate further studies on the selection of optimal location for large scale PV power installation across Nigeria.

2. Analytical approach to technical and economic analysis of the PV Power Plant

2.1 Determination of the Daily Power and Energy Demand

The system is rated as a 2000 W or 2 kW power supply which at a power factor of 0.8 amounts to 2.5 KVA power systems. This means that the system will power a load of 2 kW or equivalent AC load of 2.5 KVA. The system is meant to have sufficient battery bank so as to power the load for 24 hours in a day. Hence, the daily energy demand, denoted as E_d is 24 *x* 2000 = 48000 Wh/day.

2.2 Sizing of the PV array

Due to some energy overheads consumed in the various subsystems before the energy gets to the load, the effective daily energy demand from the PV array , dented as E_{dPV} is higher than the daily energy demand at the load and it is given as;

$$E_{dPV} = \frac{\text{Dailyenergydemandattheload}}{\text{Subsystemefficiency andderatingfactors}} = \frac{E_d}{\eta_{subsystDerat}} \quad (1)$$

Where ;

$$\eta_{subsyst} = (\eta_{bat})(\eta_{chacont})(\eta_{inv})(\eta_{CabLoss}) \quad (2)$$

η_{inv} is the $ChargeControllerEfficiency$

η_{bat} is the $BatteryEfficiency$

$\eta_{chaCont}$ is the $InverterEfficiency$

$\eta_{CabLoss}$ is the $CableLoss$.

According to Alfahed *et al.*, [19] cable loss is 3% (which gives efficiency of 97 %), battery efficiency is 90% , inverter/charger efficiency is 98.5 % and charge controller efficiency is 98.5 %. The daily Peak Sun Hours (PSH) is calculated as follows [19];

$$PSH = \frac{\text{Daily average of the solar irradiance in kWh/m}^2}{\text{Peak solar radiation which is 1 kW/m}^2} \quad (3)$$

In this work, Bayelsa State with the lowest annual average of daily average of the solar irradiance is considered. The worst month daily average of the solar irradiance is 3.11kWh/m^2 and it occurred in the month of July. The required PV array output peak power is denoted as P_{PVPK} and it is given as;

$$P_{PVPK} = \frac{E_{dPV}}{PSH} \quad (4)$$

In order to account for safety factor of about 20% , the effective required PV array output peak power is denoted as P_{PVePK} becomes;

$$P_{PVPK} = P_{PVPK}(Safety\ Factor) \quad (5)$$

Similarly, in view of the safety factor, the effective required daily PV array output energy is denoted as E_{dePV} becomes;

$$E_{dePV} = E_{dPV}(Safety\ Factor) \quad (6)$$

The total dc current, I_{dc} is computed as;

$$I_{dc} = \frac{P_{PVePK}}{V_{dcSYS}} \quad (7)$$

Where V_{dcSYS} is the DC voltage of the system which in this case is 48V. Therefore

The PV module watt peak power rating at standard test condition is denoted as W_{PVPK} and module rated voltage (denoted as V_{PV}) , The selected PV module has $W_{PVPK} = 370\text{ W}$ and $V_{PV} = 12\text{ V}$. Then, the module numbers in series, denoted as N_{PVS} is given as:

$$N_{PVS} = \frac{V_{dcSYS}}{V_{PV}} \quad (8)$$

The total number of PV modules in the system is denoted as N_{PVT} and it is given as;

$$N_{PVT} = \frac{P_{PVePK}}{W_{PVPK}} \quad (9)$$

Then, the module numbers in parallel, denoted as N_{PVP} is given as:

$$N_{PVP} = \frac{N_{PVT}}{N_{PVS}} \quad (10)$$

2.3 Sizing of the Battery Bank (Storage)

The battery bank capacity (B_{cap}) is determined as follows:

$$B_{cap} = \frac{(\text{Total energy need})(\text{Days of autonomy})}{(\text{Battery efficiency})(\text{BatterySystemVoltage})(\text{DOD})} \quad (11)$$

Where DOD is the maximum depth of discharge. The recommended DOD for an off-grid solar power system is between 20-50%. DOD of 50 % was used in the calculation and days of Autonomy were chosen as 3 day. So, the number of batteries in series (N_{bs}) is given as;

$$N_{bs} = \frac{\text{BatterySystemVoltage}}{\text{Battery nominal voltage}} \quad (12)$$

Total number of batteries (N_{bt}) is given as ;

$$N_{bt} = \frac{\text{BatteryCapacity}}{\text{Battery rated capacity (in Ah)per bettery}} \quad (13)$$

Number of batteries in parallel (N_{bp}) is given as;

$$N_{bp} = \frac{\text{Total number of batteries}}{\text{Number of batteries in series}} = \frac{N_{bt}}{N_{bs}} \quad (14)$$

2.4 Inverter Sizing

In inverter sizing, the critical factor which must first be considered is the peak load capacity in terms of consumption rate. This is determined by adding (summing up) all the loads that is expected to run at the same duration, and perhaps consider also some inductive load, which in most cases will double the starting power and cause surge in the system. Therefore, by so doing the inverter capacity is determine. However, in this work the total load capacity in is 2000W. Though, the actual inverter capacity is 2kW, but considering the tolerance or safety factor an inverter capacity of 2.5kW is adopted.

2.5 Economic Analysis of the PV Power Plant : Life Cycle Costing (LCC) Analysis

Life cycle cost approach is used for the economic analysis of the PV power plant. The Life Cycle Costing (LCC) of solar PV power system is given as [20] ;

$$Lcc = CI + CO\&M + CBR \quad (15)$$

- the initial investment cost (CI) ,
- the present value of the cost of maintenance/operation (CO&M)
- the present value of the cost of battery replacement (CBR)

3. Techn-economic Analysis of the PV Power Plant Using PVSyst Software

In this paper, the techno-economic analysis was conducted using PVSyst software version 5.74. The technical analysis was focused on the determination of the system components' sizes while the economic analysis was based

on the lifecycle cost analysis model which was used to determine, among other things, the unit cost of energy.
Specifically, the analysis in this paper was conducted to assess the technical and economic impact of the climatic conditions on a given PV power plant installation in two different States in Nigeria. The PVSyst map interface showing the two study location is given in Figure 1. The meteorological data obtained from NASA web portal for the two sites are given in Figure 2.

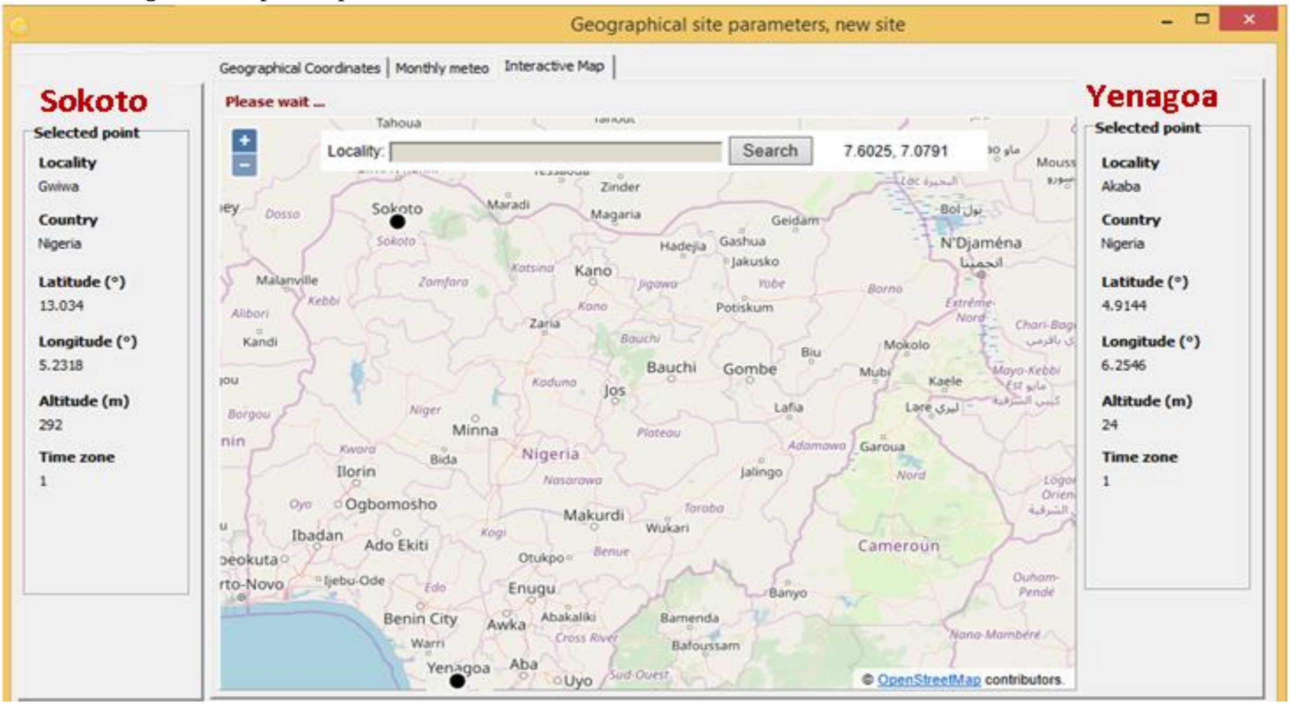

Figure 1: PVSyst map interface showing the two study locations.

NASA-SSE Satellite Data

Yenagoa

	Global [kWh/m².day]	Diffuse [kWh/m².day]	Temper. [°C]
January	5.24	1.87	25.8
February	5.13	2.10	26.1
March	4.73	2.30	26.2
April	4.50	2.29	26.3
May	4.09	2.17	26.2
June	3.45	2.03	25.5
July	3.11	1.98	24.7
August	3.42	2.12	24.4
September	3.22	2.13	24.7
October	3.60	2.13	25.0
November	4.18	2.04	25.3
December	4.88	1.86	25.6
Year	**4.12**	**2.08**	**25.5**

Sokoto

	Global [kWh/m².day]	Diffuse [kWh/m².day]	Temper. [°C]
January	5.47	1.28	23.5
February	6.41	1.29	25.6
March	6.87	1.55	29.4
April	7.15	1.75	31.5
May	7.03	1.81	30.5
June	6.91	1.79	27.8
July	6.26	2.04	25.9
August	5.73	2.21	25.5
September	6.01	1.96	26.3
October	6.03	1.58	28.2
November	5.79	1.24	27.2
December	5.25	1.24	24.3
Year	**6.24**	**1.65**	**27.1**

Figure 2: The meteorological data obtained from NASA web portal for the two study sites .

The first State considered is Bayelsa in the South-South Part of Nigeria. According to the meteorological data obtained from NASA web portal, across Nigeria, Bayelsa has the lowest annual average Peak Sun Hours. The second State considered in this study is Sokoto which has the highest annual average Peak Sun Hours (which is derived from the global solar radiation on the horizontal plane using, as given in Equation 3). According to Figure 2, Bayelsa State has annual average Peak Sun Hour (PSH) of 4.12 hours whereas Sokoto State has annual average PSH of 6.24 hours. Also, according to Figure 2, the annual average temperature of Sokoto State is 27.1 °C which is higher than that of Bayelsa State (which is25.5 °C).

A constant daily load demand that consists of 2000 W power that runs for 24 hours every day in the whole year is adopted, as shown in Figure 3. The schematic diagram of the standalone PV power system is given in Figure 4 while the selected system components and their key parameter values are given in Figure 5

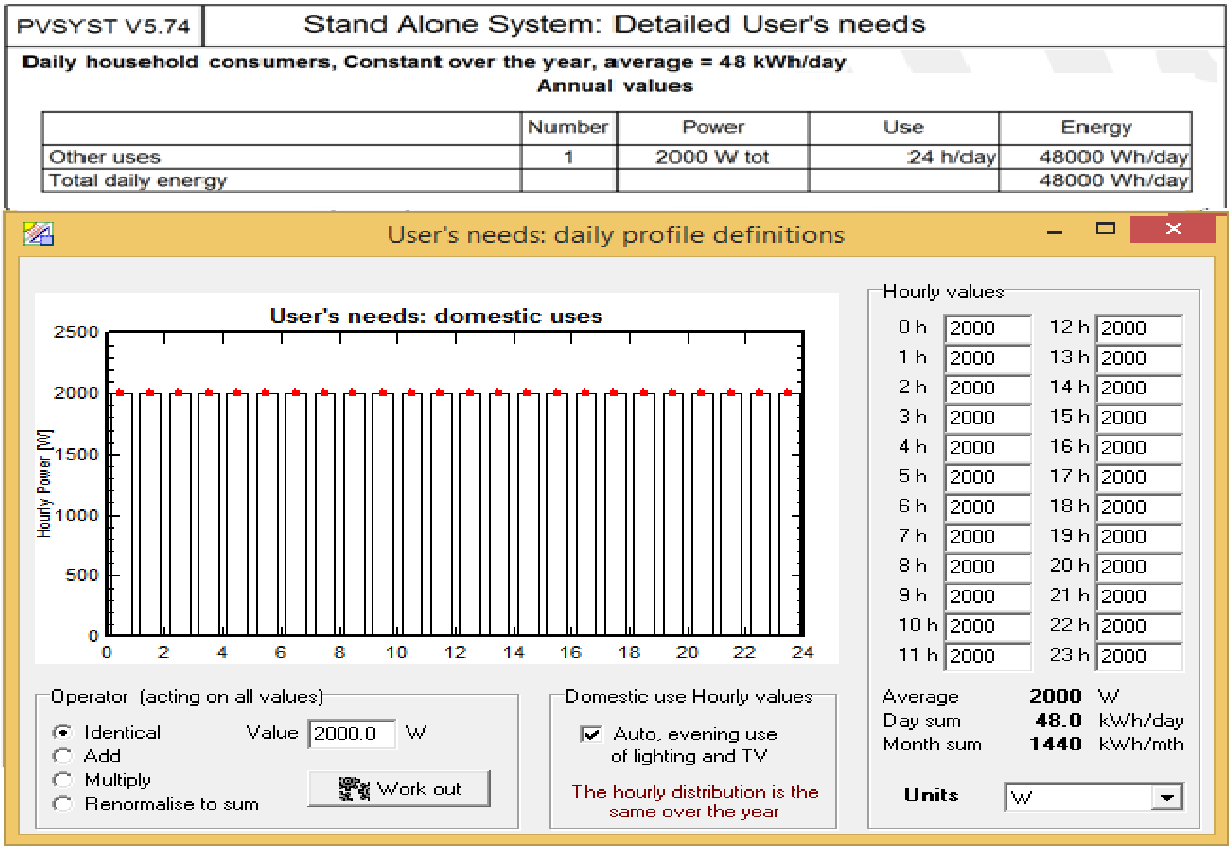

Figure 3 The daily load demand profile for the PVpower system

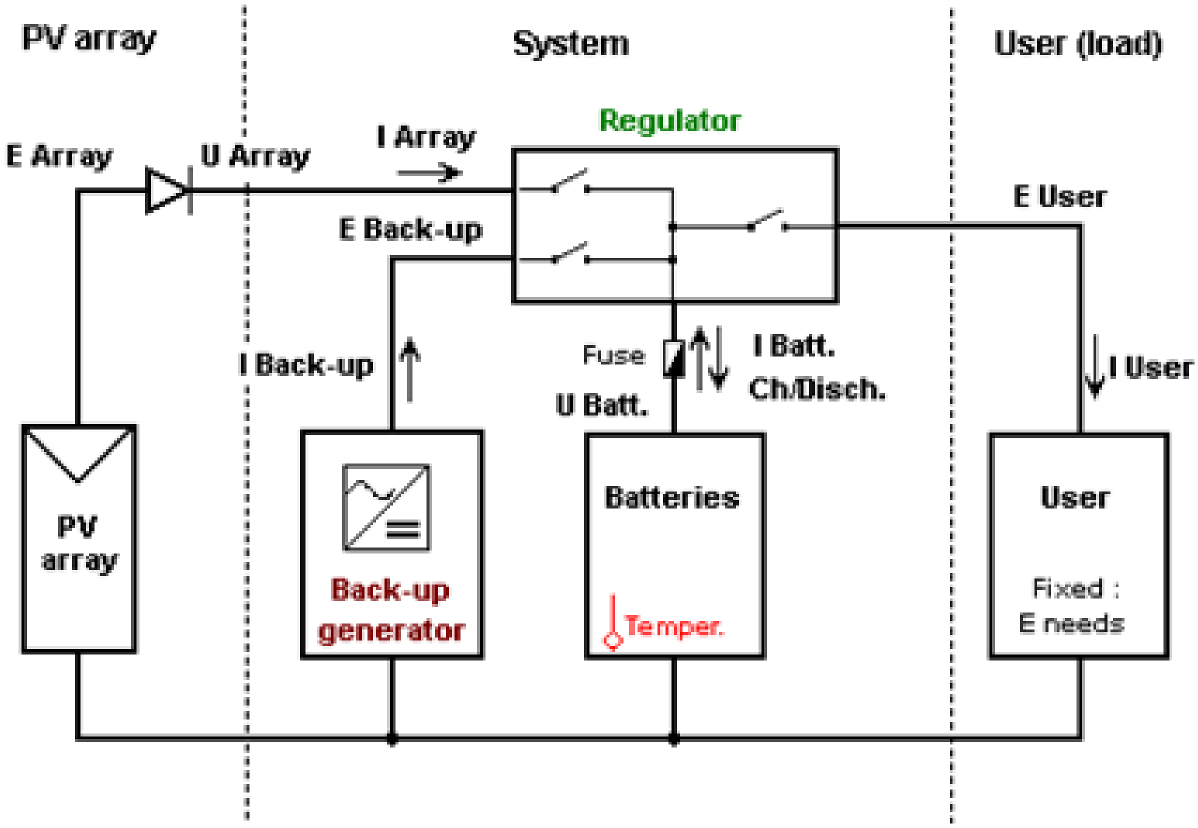

Figure 4 The schematic diagram of the standalone PV power system

PVSYST V5.74	Stand Alone System: Simulation parameters				
Simulation parameters					
Collector Plane Orientation		Tilt	0°	Azimuth	0°
PV Array Characteristics					
PV module	a-Si:H tandem	Model	**Millenia MST 50 MV**		
		Manufacturer	BP Solar		
Number of PV modules		In series	2 modules	In parallel	181 strings
Total number of PV modules		Nb. modules	362	Unit Nom. Power	50 Wp
Array global power		Nominal (STC)	**18.10 kWp**	At operating cond.	16.56 kWp (50°C)
Array operating characteristics (50°C)		U mpp	134 V	I mpp	123 A
Total area		Module area	**298 m²**		
PV Array loss factors					
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)				NOCT	56 °C
Wiring Ohmic Loss		Global array res.	19 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss				Loss Fraction	5.0 %
Module Mismatch Losses				Loss Fraction	1.5 % (fixed voltage)
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05
System Parameter		System type	**Stand Alone System**		
Battery		Model	**Volta 6SB100**		
		Manufacturer	Volta		
Battery Pack Characteristics		Voltage	120 V	Nominal Capacity	3100 Ah
		Nb. of units	10 in series x 31 in parallel		
		Temperature	Fixed (20°C)		
Regulator		Model	General Purpose Default		
		Technology	Undefined	Temp coeff.	-5.0 mV/°C/elem.
Battery Management Thresholds		Charging	135.0/130.8 V	Discharging	117.6/126.0 V
		Back-Up Genset Command	118.2/129.0 V		
User's needs :		Daily household consumers	Constant over the year		
		average	48 kWh/Day		

Figure 5 The selected system components and their key parameter values

3.1 Sizing of the PV System Components For the Installation at Bayelsa State and Sokoto State

The actual component sizing in PVSyst for the specific PV installation at Bayelsa State is shown in Figure 6. According to Figure 6, the selected loss of load (LoL) probability is 0.0% which means that the power supply is designed to supply the demanded daily load of 48 kWh/day without any outage all through the year. Also, 7 days of autonomy is specified for the system. For the installation at Bayelsa State, a total of 310 batteries and 362 PV panels are required to meet the stringent load demand specifications.

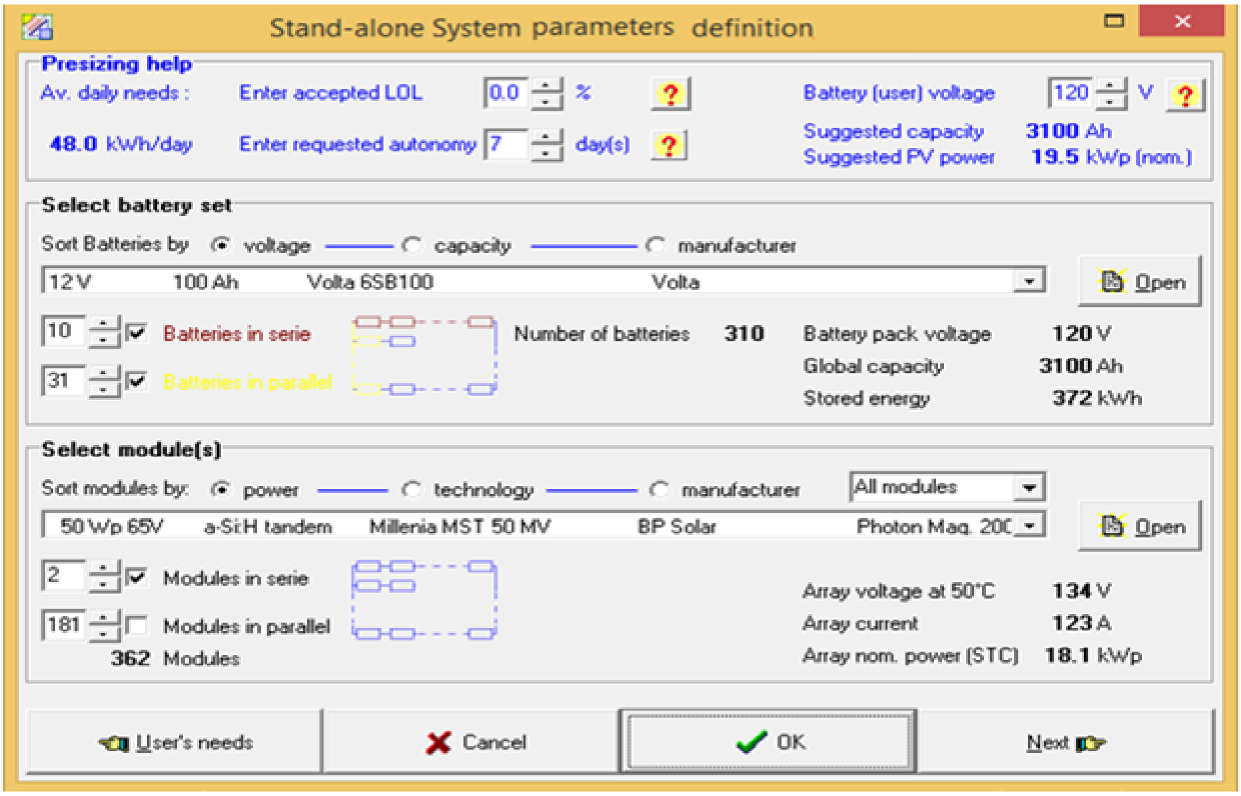

Figure 6 The actual component sizing in PVSyst for the specific PV installation at Bayelsa State

The same component sizing of Figure 6was adopted for PV installation in Sokoto State but the warning message from the PVSyst software was that "the PV array power is strongly oversized" as shown in Figure 7. This is because Sokoto State has much higher PSH value which means that a smaller number of PV modules are required to deliver the same daily load demand like the PV installation at Bayelsa State. Accordingly, a second PV array sizing was conducted for the Sokoto State, as shown in Figure 8. In this second case, all other components sizes are kept constant except the PV array which is adjusted and it now has just 220 PV modules in the array, as shown in Figure 8..

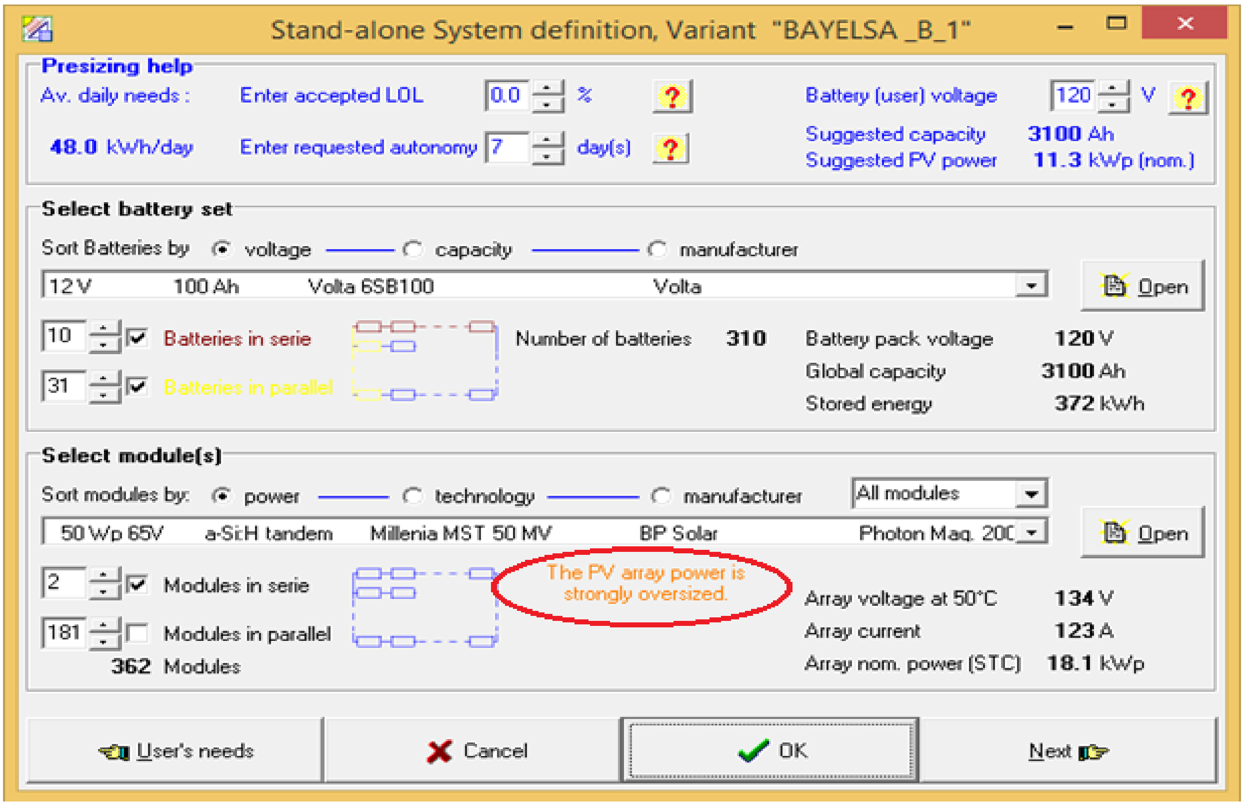

Figure 7 The first version of the component sizing in PVSyst for the specific PV installation at Sokoto State

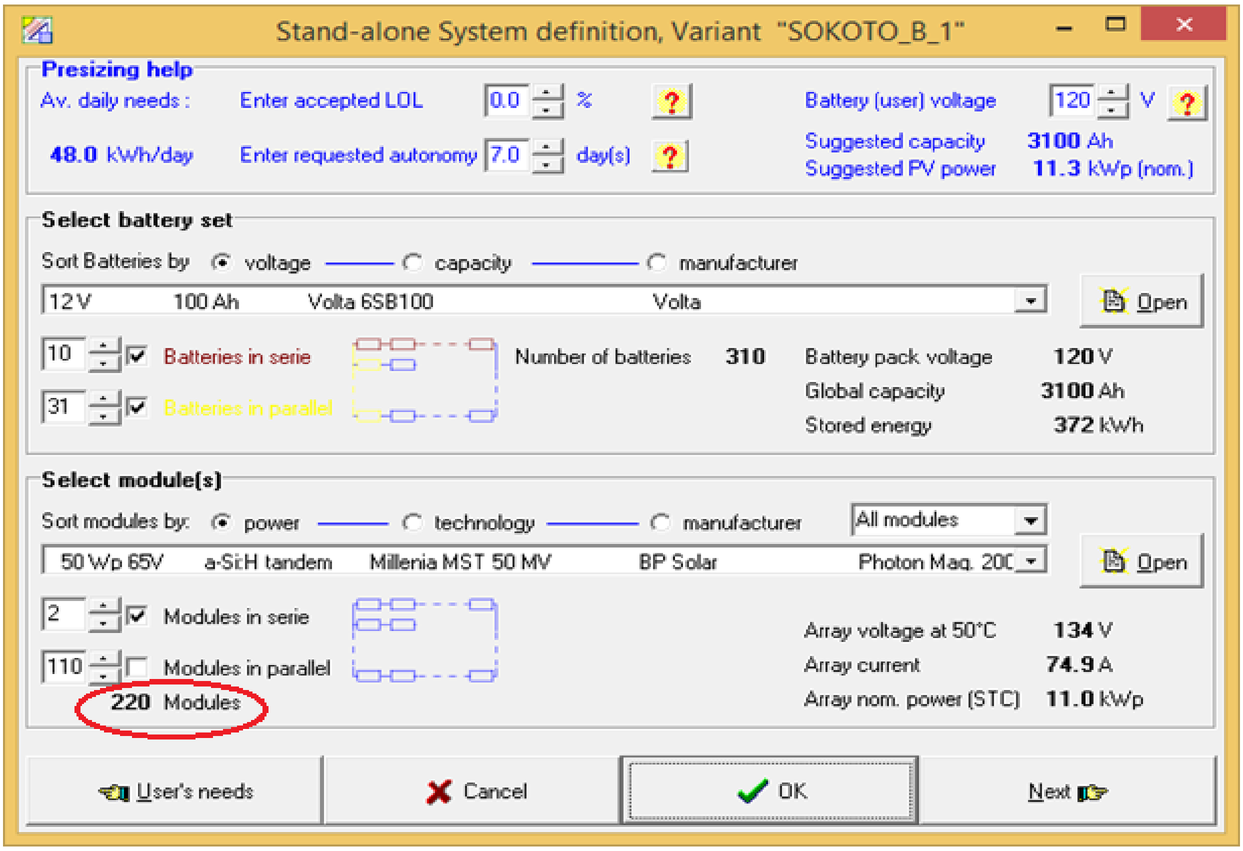

Figure 8 The second version of the component sizing in PVSyst for the specific PV installation at Sokoto State

3.2 Economic Analysis For the Installation at Bayelsa State and Sokoto State

The economic analysis for the PV power plants in the two selected States was conducted in using the economic analysis tool in PVSyst and the economic analysis input dialogue box in the PVSysts is given in Figure 9. The same input data for the economic analysis was used for the three scenarios, namely, the PV installation in Bayelsa State and the first and the second components sizing configurations for the PV installation in Sokoto State.

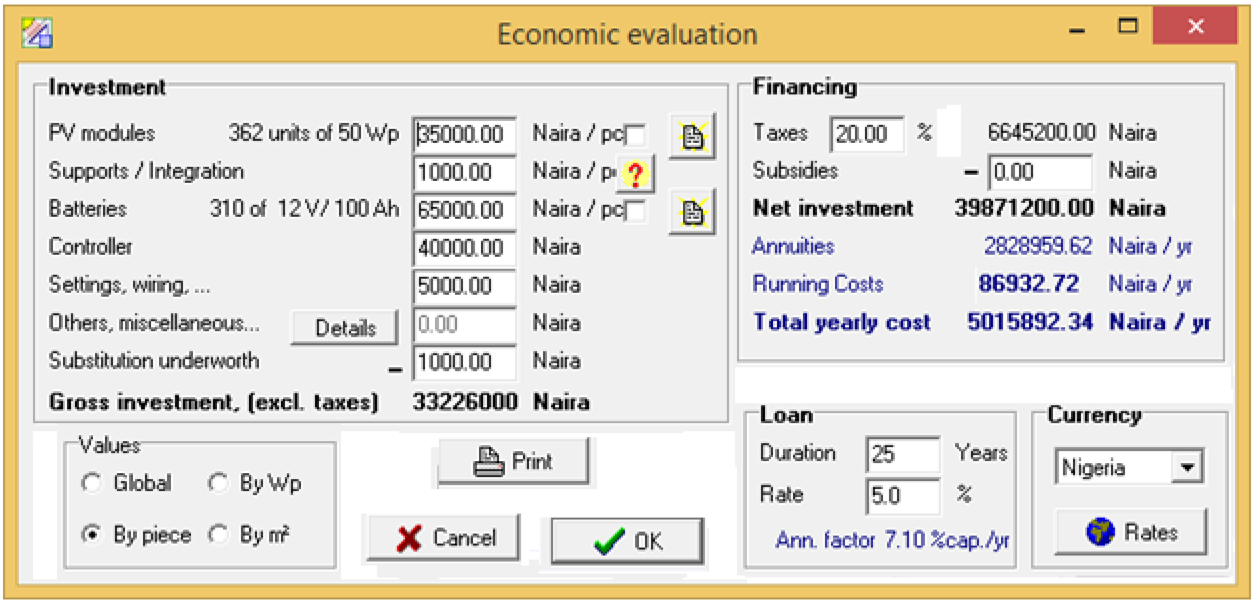

Figure 9. The economic analysis input dialogue box in the PVSysts is given in

4 Results and Discussions

The summary of the PVSyst main system parameters for the three simulation scenarios (Bayelsa State, Sokoto State Version I PV array configuration and Sokoto State Version II PV array configuration) are captured and shown in Figure 10. According to Figure 10, for Bayelsa State and Sokoto State Version I PV array configuration the number of PV modules used is 362 units and number of batteries used is 310 units. On the other hand, for the Sokoto State Version II PV array configuration the number of PV modules used is 220 units and number of batteries used is still the same 310 units (same as in the previous two cases). In essence, there is about 142 units (39.22%) reduction in the PV modules used in the Sokoto State Version II PV array configuration.

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Stand Alone System: Main System Parameters

Main system parameters Bayelsa	System type	**Stand alone**		
PV Field Orientation	tilt	0°	azimuth	0°
PV Array	Nb. of modules	362	Pnom total	**18.10 kWp**
Battery	Model	Volta 6SB100	Technology	sealed, tubular
battery Pack	Nb. of units	310	Voltage / Capacity	**120 V / 3100 Ah**
User's needs	Daily household consumers	Constant over the year	global	17.52 MWh/year
Main system parameters Sokoto V.1	System type	**Stand alone**		
PV Field Orientation	tilt	0°	azimuth	0°
PV Array	Nb. of modules	362	Pnom total	**18.10 kWp**
Battery	Model	Volta 6SB100	Technology	sealed, tubular
battery Pack	Nb. of units	310	Voltage / Capacity	**120 V / 3100 Ah**
User's needs	Daily household consumers	Constant over the year	global	17.52 MWh/year
Main system parameters Sokoto V.2	System type	**Stand alone**		
PV Field Orientation	tilt	0°	azimuth	0°
PV Array	Nb. of modules	220	Pnom total	**11.00 kWp**
Battery	Model	Volta 6SB100	Technology	sealed, tubular
battery Pack	Nb. of units	310	Voltage / Capacity	**120 V / 3100 Ah**
User's needs	Daily household consumers	Constant over the year	global	17.52 MWh/year

Figure 10. The summary of the PVSyst main system parameters for the three simulation scenarios; Bayelsa State, Sokoto State Version I PV Array Configuration and Sokoto State Version II PV Array Configuration

The reduction in the number of PV modules for the Sokoto State Version II PV array configuration resulted in significant reduction in the unit cost of energy (shown in Figure 11), from 186 Naira/kWh (for the Bayelsa State and Sokoto State Version I PV array configuration) to 161Naira/kWh (for the Sokoto State Version II PV array configuration). That gives 25Naira/kWh (13.44 %) reduction in the unit cost of energy. Also, according to thr results in Figure 11, the initial investment cost is reduced from 33226000 Naira (for the Bayelsa State and Sokoto State Version I PV array configuration) to 28114000 Naira (for the Sokoto State Version II PV array configuration). That gives 5112000 Naira (15.39 %) reduction in the initial investment cost of the system. Also, the results in Figure 11, Tabkle 1 and Table 3 show that the case of Bayelsa State has a total of 3082.3 kWh unused energy per year , performance ratio (PR) of 64.3 % and 0.0% loss of load probability (Pr LoL), Sokoto State Version I PV array configuration has a total of 14524 kWh , performance ratio (PR) of 42.5 % and 0.0% loss of load probability (Pr LoL), and Sokoto State Version II PV array configuration has a total of 3.274 kWh unused energy per year , performance ratio (PR) of 69.9 % and 0.0% loss of load probability (Pr LoL),

PVSYST V5.74	Stand Alone System: Economic evaluation **Bayelsa**	
Investment		
Gross investment	(without taxes)	**33226000 Naira**
Financing		
Net investment (all taxes included)		**39871200 Naira**
Total yearly cost		**5015892 Naira/year**
Energy cost		
Used solar energy		17.5 MWh / year
Excess energy (battery full)		3.1 MWh / year
Used energy cost		186 Naira / kWh

PVSYST V5.74	Stand Alone System: Economic evaluation **Sokoto V.1**	
Investment		
Gross investment	(without taxes)	**33226000 Naira**
Financing		
Net investment (all taxes included)		**39871200 Naira**
Total yearly cost		**5015892 Naira/year**
Energy cost		
Used solar energy		17.5 MWh / year
Excess energy (battery full)		14.5 MWh / year
Used energy cost		186 Naira / kWh

PVSYST V5.74	Stand Alone System: Economic evaluation **Sokoto V.2**	
Investment		
Gross investment	(without taxes)	**28114000 Naira**
Financing		
Net investment (all taxes included)		**33736800 Naira**
Total yearly cost		**4580642 Naira/year**
Energy cost		
Used solar energy		17.5 MWh / year
Excess energy (battery full)		0.0 MWh / year
Used energy cost		161 Naira / kWh

Figure 11. The summary of the PVSyst economic evaluation results for the three simulation scenarios; Bayelsa State, Sokoto State Version I PV Array Configuration and Sokoto State Version II PV Array Configuration

Table 1 The results on the performance ratio related parameters of the PV systems

	Horizontal global irradiation	Ambient Temperature	Unused energy (full battery) loss	PV loss due to temperature	Normalized System Losses	Performance Ratio
	GlobHor kWh/m²	**T Amb** °C	**EUnused** kWh	**TempLss** kWh	**Ls**	**PR**
Bayelsa	1505.4	25.48	3082.3	2817.9	0.211	0.643
Sokoto V. 1	2277.1	27.14	14524	5772.6	0.399	0.425
Sokoto V-2	2277.1	27.14	3.276	3508.2	0.148	0.699

Table 2 The results on the loss of load related parameters of the PV systems

	Available Solar Energy	Energy need of the user (Load)	Energy supplied to the user	Unused energy (full battery) loss	Solar fraction	Missing energy	Loss of Load Probability	Loss of Load Duration
	E Avail kWh	**E Load** kWh	**E User** kWh	**EUnused** kWh	**SolFrac**	**E Miss** kWh	**Pr LOL** %	**T LOL** Hour
Bayelsa	21998	17520	17520	3082.3	1.000	0.000	0.00	0
Sokoto V. 1	34678	17520	17520	14524	1.000	0.000	0.00	0
Sokoto V-2	18118	17520	17520	3.276	1.000	0.000	0.00	0

In essence, the three PV systems were able to deliver the required 48 kWh/day daily load demand but the Sokoto State Version II PV array configuration gave the lowest overall cost and performance. In all, the results showed that it is more expensive to install and run PV power system in Bayelsa State than in Sokoto State.

5. Conclusion

The sizing of PV power plant in Bayelsa and Sokoto as well as the economic analysis are presented. The analysis was done using PVSyst software. The focus of the paper is to determine the minimum number of PV modules that can satisfy the daily load demand without loss of load. The analysis used the peak sun hour (PSH) data of Bayelsa and Sokoto States and the data showed that Sokoto has much higher PSH value than Bayelsa. As such, the results showed that

the number of PV modules required for Sokoto State is much smaller than that of Bayelsa State. Also, the results showed that the overall cost of PV power system, including the initial investment cost and the running cost are higher for Bayelsa State when compared to those of Sokoto State.

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