# Techno-Economic Evaluation Of Grid-Connected 10 KW Solar Photovoltaic Power System For A Household In Rivers State

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Abstract- In this work, techno-economic evaluation of grid-connected 10 kW solar photovoltaic (PV) power system for a household in Rivers State is presented. The solar PV installation site is located at latitude of 4.5 °N , longitude of 7.0° E and altitude of 15 m and the site has 1489.9 kWh/m^2 total global solar irradiation on the horizontal plane in a year. The solar power system consist of 76 units of 285 Wp Si-poly PV modules and 15 kW Siemens inverter. The technical analysis results show that the total energy yeild for a year is 22604 kWh, the total load demand for a year is 83957 kWh, the total energy supplied to the user for a year is 21298 kWh, the total energy supplied to the grid for a year is 1305.7 kWh and the mean solar fraction for a year 0.269, this means that means that 26.9 % of the energy supplied to the load is supplied from the solar power while 73.1 5 are suplied from the grid. According to the economic analysis, the PV module cost is 850 Naira per Wp power while the inverter cost is 880 Naira per Wp power. Also, 22 % tax is adopted with 25 years life cycle time. The results show that the unit cost of the energy is 261 Naira per kWh while the total yearly cost of the energy is 5,906,039 Naira.

Keywords— Techno-Economic, Grid-Connected Solar Power, Photovoltaic System , unit cost of the energy

### **1. INTRODUCTION**

In recent years, there has been increasing adoption of solar power system across Nigeria [1.2]. This has been occasioned by the poor power supply from the grid [3,4,5] and the fact that a good number of Nigerians do not have access to the grid [6,7]. However, nowadays, the need for affordable clean solar energy is driving researchers and designers to carefully select the system components in the design of solar power system [8,9]. Accordingly, in this work, PVSyst simulation software is used to conduct a technical and economic analysis of a grid connected solar power system [10,11,12]. Notably, the technical analysis is used to select the system components sizes and also to determine the energy yield, energy consumptions, losses and other performance parameters [13,14] while the economic analysis is used to determine the cost of implementation and maintenance of the system and also to determine the unit cost of the energy [15,16,17. The details of the technical and economic analysis are performed using PVsyst software.

#### 2. METHODOLOGY

The focus in this work is to evaluate a grid-connected solar PV system designed for a household in Rivers State Nigeria. The geo-location of the solar PV installation site for the extraction of the meteorological dataset is latitude 4.5 °N, longitude 7.0° E and altitude of 15 m, as shown in Figure 1. The geo-location data are used to PVSyst software meteorological data download tool to download the global solar irradiation on the horizontal plane and the ambient temperature from NASA weather data portal. The downloaded monthly mean of the meteorological data of the solar PV installation site is shown in Figure 2.The dataset shows that the annual mean ambient temperature is 26.14 °C while the total of the monthly mean global solar irradiation on the horizontal plane in a year is 1489.9 kWh/m<sup>2</sup>. The optimal tilt angle for the PV array and the corresponding transposition factor are determined using the PVSyst PV orientation tool. According to the PVsyst software, the optimal tilt angle for the PV array at installation site is 15 ° with a transposition factor of 1.02, as shown in Figure 3. That means the irradiation hitting the PV array on the optimal tilt angle is about 102% of the one on the horizontal plane ( which amounts to total of the monthly mean global solar irradiation on the tilted plane as 1,519.698 1489.9 kWh/m^2).

The schematic diagram of the grid-connected solar (GCS) power system is shown in Figure 4. According to the schematic diagram, the main components of the GCS power system are the electrical load, the inverter and the PV array. The electrical load is captured as the daily load demand in Figure 5 and it consists of a constant 10 kW power that runs for 24 hours every day and this amounts to 240 kWh energy demand per day or average energy demand of 7200 kWh.month.

Comment Port Harcourt, Synthetic Hourly data		
Site Port Harcourt (Nigeria)	Graphs Tables	
Latitude : 4.5°N Altitude : 15 m Longitude : 7.0°E Time zone :1		
Data Characteristics	Variables	
Beginning 01/01/90 00h00 Solar Time End 31/12/90 23h00 Syn. data Year 1990 indicates generic data, i.e. not related to a particular year	<ul> <li>✓ Horiz. Global</li> <li>☐ Horiz. Diffuse</li> <li>☐ Horiz. Beam</li> <li>☐ Normal Beam</li> </ul>	Global Tilted Plane Clearness Index Kt Ø Amb. temperature Wind velocity
Source file Name : synthetic data		,,
Time Step 1 hour	Values C Hourly C Daily	Irradiation Unit
parameters : Diffuse from model Ambient Temper	Monthly	

Figure 1 The geo-location of the solar PV installation site for the extraction of the meteorological dataset

Meteo File Port_Harcourt_SYN.MET	, Monthly accumulations	- 🗆 X
Close Print Export		
м	eteo for Port Harcourt, Synthetic da	ta
Interval beginning	GlobHor	T Amb
	kWh/m².mth	°C
January	130.2	26.20
February	125.0	27.60
March	139.9	26.80
April	134.5	26.90
Мау	136.9	26.90
June	115.9	25.50
July	108.6	25.50
August	107.1	25.10
September	118.1	25.30
October	122.0	25.70
November	120.9	26.10
December	130.8	26.20
Year	1489.9	26.14

Figure 1 The meteorological data of the solar PV installation site











Figure 5 The daily load demand profile for the GCS power system

### 3. RESULTS AND DISCUSSION

The design and evaluation of the grid-connected solar (GCS) power system is conducted using PVsyst software. The sizing of the PV array and inverter are conducted using the PVSyst's system components selection dialogue window, as shown in Figure 6. According to the PVsyst dialogue window in Figure 6, the 15 kW Siemens inverter, model Sinvert 20 is used and its details are presented in Figure 7. In addition, from the PVsyst dialogue window in Figure 6, the 285 Wp Si-poly PV module manufactured by ASE with model number as ASE-300-DG-FT- (285) 17 is used and its details are presented in Figure 8. In all, a total of 76 PV modules are used whereby 38 PV modules are connected in series and there are two sets of such 38 PV modules that are connected in parallel, as shown in Figure 8

Grid system definition , Variant "New simulation	n variant"		-	
Silobal System configuration         1          Number of kinds of sub-fields         ?          Simplified Schema	Global system su Nb. of modules Module area Nb. of inverters	<b>immary</b> 76 184 m² 1	Nominal PV Power Maximum PV Power Nominal AC Power	21.7 kWp 21.9 kWd 15.0 kWa
Presizing Help C No Sizing Enter planned power C 2	21.7 kWp,	or avaia	ble area C 184	m² <u>?</u>
Select the PV module Sort modules ( Power — C Technolog 285 Wp 14V Si-poly ASE-300-DG-FT ( Sizing voltages	285) 17 ASE 285) 17 ASE 5 Vmpp (60°C) 1 Voc (-10°C) 2	anufacturer <b>4.0</b> ∨ <b>2.7</b> ∨	All modules 💽	Dpen
Select the inverter         Sort inverters by: <ul> <li>Power</li> <li>C Voltage (m</li> <li>15 kW</li> <li>450 - 750 V</li> <li>50/60 Hz</li> <li>Sinvert 20</li> </ul> Nb. of inverters <ul> <li>Description</li> <li>Input maximum</li> </ul>	age: <b>450-</b> ayotage: 3	anufacturer Siemens 750 V Glob 900 V Mas	All inverters	50 Hz 60 Hz 0 pen 15.0 kWac Slave
Design the array         Number of modules and strings         should be         Mod. in series         38         in series	Operating condition Vmpp (60°C) Vmpp (20°C) Voc (-10°C)	ns 533 V 652 V 863 V	Master / Slave operatio of inverters should be a (or modify the numbe	on: the number a multiple of 11 er of slaves)
Nbre strings     2       Overload loss     1.1 %       Pnom ratio     1.44	Plane irradiance Impp (STC) Isc (STC)	1 <b>000 ₩/m²</b> 34.6 A Max 37.7 A a	C Max. in data operating power at 1000 W/m² and 50°C	STC 19.4 kW
Nb. modules 76 Area 184 m²	Isc (at STC)	36.8 A Arra	nom. Power (STC	21.7 kWp
🐀 User's needs Detailed losses 🛛	<del>ت</del>	X Cancel		🗸 ок

Figure 6 The PVSyst's system components selection dialogue window for the GCS power system

lain parame	eter Secondary paramete	er Efficienc	ycurve   9	Sizes   Commercia	e l		
Model	Sinvert 20		_	Manufacturer	Siemens		
File name	Sinvert_20.0ND			Data source	Photon Mag. 20	06	
Input sid	le (DC PV field)			Output sid	de (AC grid)		
Minimu Min. Vol	m MPP Voltage tage for PNom	<b>450</b>	<b>*</b>	Type C Mono C Tripha C Bipha	phased ased sed	Frequence 50 H 60 H	z z
Maximu	Im MPP Voltage	750	v	Grid Vol	tage	400	v
Absolu	te max. PV Voltage	900	v	Nominal		15.0	k₩ k₩
Power	Threshold	200.0	w	Nominal A	Courrent	22.0	
Contract	tual specifications, withou	tt		Maximum	AC current	25.0	
real phy: Nominal Maximur Maximur	sical meaning PV Power 1 n PV Power 1 n PV Current N	? Re 6.0 kV 8.0 kV 1/A A	equired ✓ ✓ □ □	Efficiency Maximum EURO eff	efficiency iciency cy defined for 3	95.0 % 92.7 % voltages	č <u>?</u>

Figure 7 The details of the 15 kW Siemens inverter, model Sinvert 20 used in the GCS power system design

Nodel ASE	E-300-DG-FT (285	5) 17	Manu	acturer [	ASE			?	
File name ASE	E_300DGFT2851	7.PAN	Data	source [	Manufa	cturer			
Nom. Power (at STC)	285. Wp	Tol. 0.0 %	6 Tec	hnology	Si-poly			•	
anufacturer	specifications	or other M	leasuren	ents			<b>A</b> 1	Model summary	
Reference con	ditions: Gl	Ref 1000	W/m²		TRef	25	*c 🕺	Main parameter	?
Short-circuit cu	rrent I	sc 18.40	A C	pen circu	uit Voc	20.00	v	R shunt Bsb(G=0)	55 ohm 200 ohm
Max Power Poi	nt: In	16.80	A		Vmpp	17.00	v	B serie model	0.01 ohm
Temperature co	oefficient mu	lsc 18.0	mA/*C					R serie max.	0.06 ohm
	or mu	lsc 0.10	%/*C	Nb	cells	36 x 6	5	R serie apparent	0.07 ohm
								Model parameter	1 1 4
nternal model	result tool						•1	loRef	105 nA
Operating cond	litions GO	per 1000		₹ TI	Oper 🕻	25 ÷	•c 🍊	muVoc	-78 mV/*C
Max Power Poi	nt Pr	npp 286.0	i w	Temp	per. coe	ff <b>O.</b> 4	41 %/°C		
Sh	Current In	npp 17.05		Volta	age Vmp	op 16			
Efficiency	/ Cells a	rea 13.24	%	/ Mo	dule an	a 11.	78 %		

Figure 8 The details of the 285 Wp Si-poly PV module manufactured by ASE with model number as ASE-300-DG-FT- (285) 17

The main results on the technical evaluation of the GCS power system are presented in Figure 9 and the results show the monthly available solar energy yeild (E Avail), the energy demand of the load (E Load), the energy supplied to the load or user (E User), the energy supplied to the grid (E Grid and the solar fraction (SolFrac) which is the fraction of the load demand that is supplied from the soalr power. According to the results, the total E Avail for a year is 22604 kWh, the total E Load for a year is 83957 kWh, the total E User for a year is 21298 kWh, the total E Grid for a year is 1305.7 kWh and the mean SolFrac for a year 0.269. Essentially, solar fraction is the ratio of E User to E Load (21298/83957 = 0.253677478) and E avail is the susm of E user and E Grid, that is 21298 + 1305.7 =

22603.7 kWh. Also, solar fraction of 0.269 means that 26.9 % of the energy supplied to the load is supplied from the solar power while 73.1 5 are suplied from the grid.

The key input dataset for the economic evaluation of the GCS power system are presented in Figure 10 while the main results on the economic evaluation are presented in Figure 111. According to the economic analysis input

dataset in Figure 10, the cost of the PV module is 850 Naira per Wp power while the inverter cost is 880 Naira per Wp power. Also, 22 % tax is adopted with 25 years life cycle time. The results show that the unit cost of the energy is 261 Naira per kWh. Meanwhile, the energy used by the load is 21.3 MWh per year while the energy sold to the grid is 1.3 MWh per year. The total yearly cost of the energy is 5,906,039 Naira.

 Simulation variant: New simulation variant
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 New simulation variant

 Energy use and User's needs

 Image: Simulation variant
 Energy use and User's needs

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 E Load
 E User
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 SolFrac

 KWh
 KWh
 KWh
 KWh
 KWh
 SolFrac

	E Avail	E Load	E User	E Gridl	SolFrac
	kWh	k₩h	kWh	kWh	
January	2072	7131	1916	156.3	0.291
February	1929	6441	1798	130.8	0.299
March	2123	7131	1953	170.1	0.298
April	1988	6901	1859	129.1	0.288
May	1989	7131	1934	54.8	0.279
June	1678	6901	1650	28.0	0.243
July	1566	7131	1526	39.7	0.220
August	1567	7131	1514	52.9	0.220
September	1793	6901	1693	99.9	0.260
October	1889	7131	1782	106.6	0.265
November	1898	6901	1765	132.9	0.275
December	2112	7131	1907	204.7	0.296
Year	22604	83957	21298	1305.7	0.269

Figure 9 The main results on the technical evaluation of the GCS power system

Economic evaluation							×
Project and Simulation variant           Project:         Household Power Supp           Simulation         New simulation variant           PV Array, Pnom =         21.7 kWp           PV module :         ASE-300-DG-FT (285) 17	lly Syste Invert	m: Grid-Connec er: Sinvert 20	sted Sys	stem	C Gk C By	obal ເຈີ B piece (C B	yWp ym²
Investment							
PV modules 76 units of 285 Wp	850.00	Naira / WI	B				
Supports / Integration	520.00	Naira / Wp					
Inverter 1 unit of 15.0 kW	880.00	Naira / W/T	B				
Settings, wiring,	450.00	Naira / Wp					
Others, miscellaneous Details	450.00	Naira / Wp					
Substitution underworth	0.00	Naira / Wp		1		-	
Gross investment, (excl. taxes)	3150.00	Naira / Wp		Loan		Lurrency	
Financing				Duration 25	- v	Nigeria	-
Taxes 22.00 %	693.00	Naira / Wp		hate [5.0	~	🔗 R.	ator
Subsidies –	0.00	Naira / Wp		Ann. factor 7.1	J %cap./yr		NC3
Net investment	3843.00	Naira / Wp		Energy cost			
Annuities	272.67	Naira / Wp		Used Energy	2	1.3 MWh/	year
Running Costs, Maintenance, insur.	0.00	Naira / Wp		Yearly cost	a 5906(	1.3 MWh/	year
Total yearly cost	272.67	Naira / Wp		Energy cost	2	261 Naira /	kWh
	OD F	inancial Balan		Erint	¥ Cance	a   📿	ОК

Figure 10 The key input dataset for the economic evaluation of the GCS power system

PVSYST V5.20			19/05/23	Page
Grid-Cor	nected Syster	m: Economic evaluation		
Project : House	hold Power Supp	bly		
Simulation variant : New si	mulation variant			
Main system parameters PV Field Orientation PV modules PV Array Inverter User's needs	System type tilt Model Nb. of modules Model daily profile	Grid-Connected 12° azimuth ASE-300-DG-FT (285) 17 Pnom 76 Pnom total Sinvert 20 Pnom Constant over the year global	0° 285 Wp 22 kWp 15 kW ac 84.2 MWh/	year
Investment				
PV modules (Pnom = 285 Wp) Supports / Integration Inverter (Pnom = 15.0 kW ac)	76 units 1 units	242250 Naira / unit 1841 148200 Naira / modu 1126 19080800 Naira / unit 1908	1000 Naira 3200 Naira 0800 Naira	
Settings, wiring,		974	7000 Naira	
Substitution underworth Gross investment (without taxes)		6822	-0 Naira 9000 Naira	
Financing				
Gross investment (without taxes) Taxes on investment (VAT) Gross investment (including VAT) Subsidies Net investment (all taxes include	Rate 22.0 %	6822 501 8323 8323	9000 Naira 0380 Naira 9380 Naira -0 Naira 9380 Naira	
Annuities Annual running costs: maintenance,	( Loan 5.0 % insurances	over 25 years) 590	8039 Naira/y 0 Naira/y	ear
Total yearly cost		590	6039 Naira/y	ear
Energy cost				
Used Energy Energy sold to the grid Cost of produced energy			21.3 MWh / 1.3 MWh / 261 Naira /	year year kWh

Figure 11 The main results on the economic evaluation of the GCS power system

## 4. CONCLUSION

Techno economic evaluation of a grid connected solar power system is conducted using PVSyst simulation software. The work involved sizing of the PV array and the inverter, and also to determine the lifecycle cost of the system based on the prevailing cost of the components. The system is designed based on solar radiation data of a site in River State and with a constant 10 kW daily load demand. In all, the results obtained from the simulation show that unit cost of energy is less than 300 Naira per kWh.

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