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Assessment of a 50MW Photovoltaic Power Plant in Igabi, Kaduna State, Nigeria

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ABSTRACT

This paper presents the assessment of a 50MW Photovoltaic (PV) power plant in Igabi, Kaduna State of Nigeria. The assessment of a solar power plant involves the collection of data relating to satellite derived and land-based measurement, simulation and assessment of the PV power plant technology. The PV plant design was developed initially as part of a prefeasibility study, which was based on preliminary energy resource and generation estimate. For risk technical valuation purposes, there was need for a report of uncertainties related to the solar energy estimation and meteorological data inputs. The solar resource assessment study shows the probabilities of exceedance of minimum annual productions, with a confidence level of 90%, 95% or 99%. Meteorological data is collated with the help of a mounted MET-Station on site to identify losses (irradiation, electrical and system losses). The generation simulation was done using SolarGis TMY P50 file and PV SYST 6.61 pc software package for the study, sizing, simulation and data analysis of complete PV system. The results show specific key elements and environmental conditions to be used during the design phase of the PV system, the reliable detailed route survey report of 132kV double circuit transmission line at Igabi, which is the injection (feed-in) point of the expected power to be generated was confirmed and the amount of losses estimated between modules and feed-in point was also determined. Additionally, the uncertainties of the input parameters, i.e., assumed losses, available data and simulation models, which provided a more reliable estimation and knowledge about the system was understood. Typical meteorological year, P50 values for each month, the average climate changes and the most representation cumulative distribution function was used to collate data for intended PV plant assessment.

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1. Introduction

A power plant or a power generation station, is basically an industrial location that is utilised for the generation and distribution of electric power in mass scale, usually in the order of several 1000 watts. The Nigeria national grid has been dependent on mostly hydro power generation and some few gas generation plants insufficiently available. Until recently, the Nigeria power sector decided to see the long over-due advantage of the study location that is naturally blessed with excessive sunlight that can be used for easy generation of solar energy. However, the use of solar energy majorly amongst other various renewable energy sources to add on to our

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present inadequate national grid generation, may present significant advantages in its inherent ability of the availability and cost effectiveness over a long period if properly constructed and installed (Okundamiya et al., 2014; Okundamiya & Omorogiuwa, 2015; Wang & Donglai, 2010).

The PV effect is a semiconductor effect, whereby solar radiation falling into the semiconductor PV cells generates electron movement. The output from a solar PV cell is DC electricity. A PV power plant contains many cells connected together in modules and many modules connected together in strings to produce the required DC power output. Main sources of solar resource data are satellite derived and land-based measurement. The plant design is further improved during the feasibility study, which considers site measurements, site topography, and social-environmental conditions (Rhodes et al., 2004).

Since the commercial introduction of solar power plant in the 1970s, the need for Typical Meteorological Year (TMY) Data was driven by limitations of computing power and storage, while the applications focused on energy simulation of buildings and hot water systems. Stoffel et al. (2015) summarise the phase of development in the United State (US), starting with the first method by Sandia and later by National Renewable Energy Laboratory (NREL) with TMY2 and TMY3 (Okundamiya et al., 2014). New requirements came with energy simulation in photovoltaic and Concentrated Solar Power (CSP) systems. Simulation of a CSP system is complex, because of the non-linearity of thermal systems, capacity limitations and storage. Use of satellite-modelled solar resource data became standard (Thevenard et al., 2010). Choice of approach and input data for TMY, following the requirements which the data set is to be used. Hence, for these studies for assessment of PV Power Plant, TMY P50 approach is used to determine the average (normal) yearly generation, by ignoring extreme months. TMY generation, results in reduction of data information value. TMY is constructed from a time series data, with summary of their features, limitations and associated risks. SolarGIS method fulfils the criteria required in solar industry, such as geographical representativeness, consistency of solar radiation and meteorological parameters, and yield a good representation of the P50, P90 or any other Pxx cases (Friedrich, & Thomas, 2004).

This paper provides an introduction on the assessment of a 50MW PV technology, Solar Power Plant Network and how it compares to other available power generation sources with reference to Kaduna, Nigeria. The intention of the assessment of a 50MW PV power plant is to exploit the possibilities and realisations since Nigeria as a nation is just coming to the picture of using solar as a source to generate up to 50MW to add on to our existing Grid Transmission Network. It's essential that the solar technology if properly used, is equipped with a capacity for wider upgrade on our power generation network to support the requirement of tomorrow's technology and development (Okundamiya, 2015; Roland, 2005; Stackhouse et al., 2016).

2. Methods

The methods adopted in achieving the set objective are through the use of TYM P50 values for each month, the average climate conditions and the most representation cumulative distribution function to determine collated data for intended PV plant assessment; perform the generation simulation using SolarGis TMY P50 file and the use of PV SYST 6.61 pc software package for the study, sizing, simulation and data analysis of complete PV system and calculate the long-term power production of a PV system using several PV modelling software packages like System Advisor Model (SAM), Hybrid2 etc.

The simulation was performed using SolarGis TMY P50 file; a large amount of solar Tier 1 modules, inverters and tracking systems brands also evaluated as part of the development of the intended system and an essential aspect considered during the assessment includes reflection losses, weak irradiation, losses due to the temperature coefficient, mismatch, DC, AC, among others. Developing an assessment of a 50 Mega-watt (MW) PV Power Plant using different assessments variables describes the methodology adopted in achieving the evaluation of the irradiation data sources, accuracy, uncertainty, spatial resolution, inter-annual variability, mean value, ground measurements quality assessment, TMY P50 and TMY P90 availability was considered among other criteria.

2.1 Evaluation and Preparation of the Final Dataset

After a methodological review of the aforementioned irradiation sources the overall comparison between the pre-selected irradiation sources is shown in Figure 1. Due to SolarGis TMY P50, data set presents better introduced and explained uncertainty values, the generation assessment is carried out using this SolarGis solar resource analysis. Coincidentally, SolarGis TMYP50 data set also shows the lowest average Global Horizontal Irradiation (GHI) value of 2,097kWh/m² compared to the time series of all five Vaisala models. If the project owner is willing to perform a more conservative calculation, it is also possible to re-simulate using the TMY P90, for the difference between both values is 6.18%.

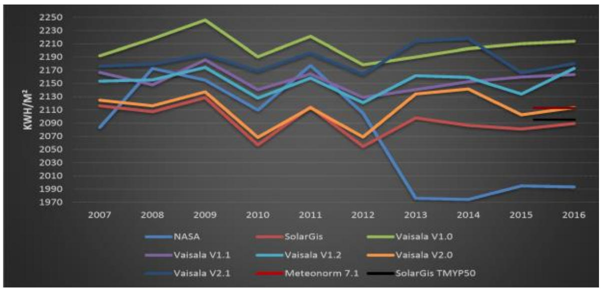

Figure 1. Pre-selected irradiation sources

As can be seen (Figure 2), 49.88% of the GHI is diffuse horizontal irradiation. Atmospheric conditions like clouds and pollution also increase the percentage of diffuse radiation. Diffuse horizontal irradiance is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions (Ineichen, 2011).

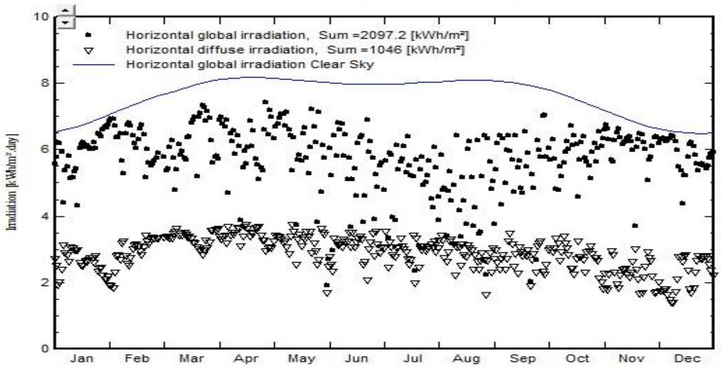

Figure 2. TMY GHI, DHI and clear sky (Source: PVsyst 6.61)

2.2 Design

Design Guidelines: The Grid-tie is a battery-less inverter system to process the energy. A group, or array, of PV panels are connected together in sub groups or strings. These strings are all connected together in a combiner box, which is located near the array. The DC electricity from the PV panels flows through combiner box to the inverter. At the inverter, the DC is converted to AC electricity then further pushed to a step-up substation for higher MW required voltages before transmitted to the 132kV line in Igabi, Kaduna State. Step-up transformers are used to connect large PV plants to the utility network. Their sizing should be accomplished not only taking into account the PV plant peak power, which would lead to grid instabilities, but also not limiting the size, which would create a bottleneck and reduce the optimal exploitation of the solar energy. The approach is based on the evaluation of initial and operating costs, the effects of the system in the utility network and taking into account power factor, loading capacity and transformer losses (Stackhouse Jr et al., 2016).

Ratio 1:1 of inverter output and transformer power rating is normal. The main consideration from the transformer perspective is the hot spot temperature in the winding and it´s profile over time since this will influence the aging in the insulation structure. It is recommended to use thermally upgraded insulation paper to increase the thermal rating and minimise the aging effect. However, this will allow a stronger derating, which leads to higher losses at inverter full capacity. This approach is more accurate for owners interested in operating the plant for its full lifetime, and might be a disadvantage for investors targeting a low capital expenditure (CAPEX).

Auxiliary Consumption: For fixed tilt variant services, inverters stand-by consumption/night-time power loss is less than 110W/day. Hence, annual losses is deduced as:

110W * 50 Inverters * 365 = 2.0MW/year

AC auxiliary supply [$3 * 400\,Vac + N, 50/60\,Hz$]

Similarly, for single axis tracking variant services, inverters stand-by consumption/night-time power loss is less than 110W/day.

110W * 50 Inverters * 365 = 2.0MW/year

AC auxiliary supply [$3 * 400\,Vac + N, 50/60\,Hz$]

Tracker power consumption: $\pm\, 500\ kWh/MWp/year$ (including stand-by mode)

$$\frac{500kWh}{MWp} * 65.92MWp = 32.96\ MWh = \mathbf{34.96\ MWh/year}$$

Land areas with slopes higher than 10°C; Excluded areas: area$1 = 9{,}498.54m^2$, perimeter = $394.94m$, area2 = $26{,}245.76m^2$, perimeter = $657.88m$. Table 1 gives an overview of all related losses between module and feed-in point

Table 1. Losses that occurred between module and feed-in point

Losses	Tilt Fixed Value	SAT Values	Calculated/Assumed
Irradiation losses			
Horizon shading	-	-	Not considered
Irradiation reduction due to mutual shading	0.9%	1.3%	Simulated via PV SYST 6.61
Soiling on the module surface	2.0%	2.0%	Assumption
Air pollution	0.0%	0.0%	Assumption
Electrical losses			
Yield loss due to irradiation reduction	0.1%	0.1%	Simulated via PV SYST 6.61
Reflection losses	3.7%	2.0%	Simulated via PV SYST 6.61
Weak irradiation	1.9%	0.1%	Simulated via PV SYST 6.61
Losses due to temperature	9.5%	9.9%	Simulated via PV SYST 6.61
Mismatch	1.0%	1.0%	Simulated via PV SYST 6.61
Deviation from the manufacturer specifications	0.0%	0.0%	Datasheet
DC cable losses	1.5%	1.5%	Assumption
MV AC cable losses	0.5%	0.2%	Assumption
Transformer losses (LV/MV)	0.8%	0.2%	Assumption
Transformer losses (MV/HV)	0.7%	0.2%	Assumption
Efficiency, MPP operation	1.0%	1.0%	Assumption
Light-induced degradation (LID)	1.5%	1.5%	Assumption
System losses			
Inverter availability loss	0.5%	0.5%	Assumption

Irradiation losses comprise of the following: horizon shading, near shading and mutual shading. The typical situations, in which the horizon shading occurs, are when mountains and hills are located in the vicinity of the power plant. For this particular project, the annual horizon shading is quantified with nearly 0% for a module inclination of 13° and an azimuth of 0°. Fixed tilt (FT) is 0%, Single axis tracking (SAT) is 0%. Near shading is considered the effect provoked by shading objects located close to the PV modules and impacting only certain parts of the system. This effect has been disregarded due to the absence of significant shading elements in and in the surroundings of the PV plant. Mutual shading also called "interrow shading" refers to the shadings that happen in the morning and in the evening. This shading depends directly on the tilt and pitch selected for the mounting structure of the PV modules. In the case of the SAT system, this effect depends on the pitch and the tracking range. FT is 0.9% and SAT is 1.3%.

Electrical losses consists of energy loss due to irradiation reduction, reflection losses, weak irradiation, losses due to temperature, mismatch, deviation from the module manufacturer specifications, cable losses, efficiency, maximum power point conformation, annual module degradation and light-induced degradation. Energy loss due to irradiation reduction effect depends on the electrical effect affecting the whole string when only part of the string is shaded. The final impact on the string output does not obey to a linearity between shaded surface and output loss, that´s why the final losses due to shading are not proportional to the irradiation reduction been rather higher: FT is 0.1% and SAT = 0.1%. On the other hand, in reflection losses, the Incidence Angle Modifier (IAM) is dependent on the amount of incident light that actually reaches the semiconductor material relative to the normal light. This loss obeys the law of Fresnel for the reflections and transmissions at the embedding material of the cell surface. PV SYST 6.61 generates the following an annual losses: FT = 3.7%, SAT = 2.0%. The efficiency of crystalline silicon (c-Si) modules decreases with weak irradiations. The higher the weak light fraction in the year, the higher the losses in the solar generator. The annual losses generated are FT = 1.9%, SAT = 0.1%. Losses due to temperature coefficient of the modules and their operating temperature, PV SYST 6.61 generates an annual loss of FT = 9.5%, SAT = 9.9%. The SAT generates higher losses due to the higher amount of direct irradiation reaching the cells.

Mismatch is caused by tolerance-dependent mismatch in modules and strings. PV SYST 6.61 generates an annual loss of: FT = 1.0%, SAT = 1.0%. For deviation from the module manufacturer specifications, the value is +5W according to the datasheet. The positive sorting avoids additional mismatch losses in the strings. A gain of 0.5% is assumed for both the fixed tilt variant and the SAT variant. DC cable losses value of 1.5% at STC (standard test conditions) has been considered for both the fixed tilt variant and the SAT variant. The losses relate to the cable losses between the module and the inverter. A value of 2.5% at STC has been considered for both the fixed tilt variant and the SAT variant for AC cable losses. The losses relate to the cable losses between the inverter and meter located at the HV site within the buildable area. A loss of 0.8% has been assumed at the 0.4/23kV transformer level and 0.7% at the 23/220kV level. The losses in the MV line between transformers is assumed as 0.5%. The losses in the HV line between meter and feed-in point have not been included in the PV SYST simulation. These losses will be adjusted to meet the 50MW (AC) at the injection point.

Efficiency and maximum power point conformation operating losses in the inverter are due to the maximum power point tracking (MPPT) efficiency of below 100%. The losses increase the longer the MPPT needs to find the MPP. The MPPT efficiency is rarely given by the inverter manufacturer. A value of 1.0% is assumed (there are several MPPTs in the inverter available) with FT = 1.0%, SAT = 1.0%. All crystalline PV modules are subjected to annual module degradation. A reasonable value is 0.4% per year for both the fixed tilt variant and the SAT variant. This loss has not been considered for the simulated PR, P50, P75 and P90 values. The light-induced degradation occurs once in the module's lifetime. After a few days sufficient irradiation has accumulated on the module level, so that the module stabilizes electrically. For this assessment, a typical value for poly-crystalline of 1.5% is assumed, for both the fixed tilt variant and the SAT variant. System Losses such as availability losses arise from failures due to heavy rainfall, grid instability, throttling by the network operator, damages of any kind, inverter unavailability and tracker unavailability. Since the plant is yet to be built, relevant failures will have to be recorded during the operating time. In the present assessment the grid unavailability has been disregarded. The availability loss of the inverters has been quantified with 0.5%. The tracker unavailability has been disregarded since a not properly orientated tracker does not necessarily lead to an interruption of the electrical generation.

2.3 Simulation

Description of the Simulation Software Used: In this assessment the simulation software, PV SYST 6.61 was used. PV SYST is one of the most mature and most widespread simulation programs that are currently available on the market. Originally developed in 1995 by the University of Geneva (Ineichen, 2011), it is now one of the most powerful programs in the industry. In recent years, the software has been continuously developed. However, because the program is very complex, the application in the development time has been improved by the introduction of a "multi-level approach". This makes handling of the various user groups easier. For each user group, there is an application level with different features. Both grid-connected and off-grid systems can be designed. The system simulation for rooftop, open-area or tracking systems can be carried out very explicitly. Alternatively, a rapid design and rapid generation estimate are possible for a rough calculation. For each site, solar altitude calculations are performed, and for the shading analysis, there is a horizon-shading program and a 3D tool for the surroundings. Weather data can be imported, as well as cost-effectiveness calculations are performed. The simulation of the generations is based on hourly measured meteorological values.

SolarGIS has developed a geographic information system to meet the needs of the solar industry. It integrates solar resources and meteorological data with tools for planning and performance monitoring of solar systems. Currently SolarGIS has about 5 satellites, which are responsible for the irradiation modelling. In the so-called PRIME region, which is part of Europe, the global irradiation data are generated at resolution of 15 minutes, the MFG and MSG satellites working here have been active since 1994. Solar GIS provides solar data (GHI, DNI, DIF and GTI), as well as other meteorological parameters (air temperature, relative humidity and wind speed) and geographical information of horizon shading. Today Solar GIS is considered one of the most reliable sources for the modelling of irradiation data (Perez et al., 1990).

Description of the Assumed Simulation Models: The total tolerance of the internal simulation algorithms of PV SYST, regardless of the used meteorological values and other project-specific values, variables and assumptions, is specified with a value of less than 2.2%. This value was determined at PI Berlin in 2015 in the context of a scientific study under consideration of real measured irradiation and generation values. The most relevant models, which are used in the simulation algorithms, are explained and described as follow:

Transposition model: for the conversion of the horizontal direct and diffuse irradiation on the inclined surface, the transposition model of Perez was used (Benavides & Chapman, 2008; Friedrich & Thomas, 2004). This is made up of direct, diffuse and ambient reflection irradiations. In the Perez model it is an anisotropic sky model, but a horizon brightening is considered here in addition to circumsolar radiation. The Perez model is used in PV SYST for conversion on the inclined plane of the synthetically generated hourly record of SolarGIS, which is used for the simulation in PV SYST 6.61.

Module string shading: in the PV generator, the current of each cell is limited by the current of the weakest cell in the string. That is, if only one cell is shaded, the entire string is affected, which also has a dramatic effect on the characteristic curve. Even using bypass protection diodes, this string involves only marginally in the yield production of the PV generator. Depending on the adjustment of the electrical effect, at a value of e.g. 75%, ¾ of the string is taken as electrically inactive, even if, for example, only 3 modules are shaded. The overall electrical behaviour of the modules and module strings under the influence of shading will be given as a non-linear, considering a value of 80%. This algorithm is used in PV SYST for the shading analysis in the 3D model. The albedo component is calculated in the same way in both transposition models (Olawore & Ojo, 2016), that is, as part of the global irradiation (albedo coefficient), weighted by the ratio of the horizontal and inclined plane which is a fraction of (1-cosi)/2 of the hemisphere (Source: PV SYST 6.61).

3. Results and Discussion

3.1 Simulation results for fixed tilt

The PV system with 65,920MW$_p$ installed capacity produces on the first year 1,692 kWh/kWp with a performance ratio of 78.5%. Table 2 shows the tolerance values of the assumed losses, requested data and used simulation models that have an impact on the result of the yield estimation.

Table 2. Tolerance of the assumptions and simulation models FT

Loss	Tolerance Value - FT
Irradiation values	***4%***
Irradiation losses	
Irradiation reduction due to mutual shading	Unknown
Soiling on the module surface	**1.0%**
Air pollution	0%
Electrical losses	
Yield loss due to irradiation reduction	Unknown
Reflection losses	0.5%
Weak irradiation	1%
Losses due to temperature	1%
Mismatch	1%
Deviation from the manufacturer specifications	0.5%
DC cable losses	0.5%

Table 2. Continuation

Loss	Tolerance Value - FT
MV AC cable losses	0.2%
Transformer losses (LV/MV)	0.2%
Transformer losses (MV/HV)	0.2%
Efficiency, MPP operation	1%
Annual module degradation	0.2%
Light-induced degradation (LID)	1%
System losses	
Inverter availability loss	0.5%
Used simulation models	
Perez model	2%
Module string shading	Unknown
Liu Jordan	Unknown
Albedo	Unknown

The P50 - P90 evaluation, shown in Figure 3, is a probabilistic approach for the interpretation of the simulation results over several years. This approach supposes that over several years of operation, the distribution of the annual generation will follow a statistical law, which is assumed to be the Gaussian or normal distribution. This simulation results shows an annual variability of σ = 5.24**%** (i.e. 5.24% * 112625 MWh = 5,903 MWh). For the following years of operation a degradation value of at least 0.4% is recommended.

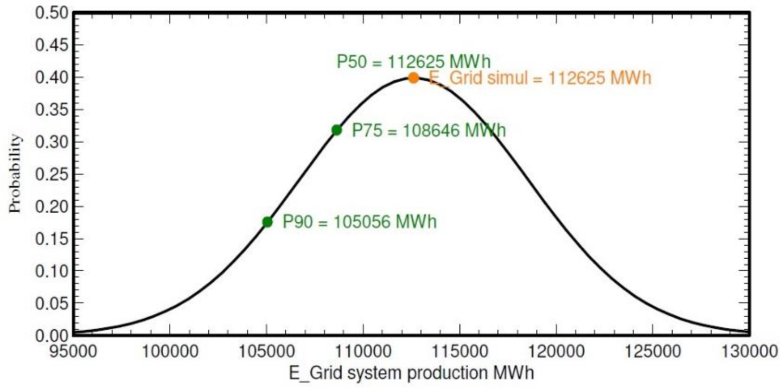

Figure 3. Probability function for a nominal power of 65,920 MWp for fixed tilt

In Table 3, the values for the preparation of the financial model are listed.

Table 3. P50, P75 and P90 value for the next 20 years of operation

Year	Peak Power %	MWh			kWh/kWp/yr		
		P50	P75	P90	P50	P75	P90
COD	100,00%	112625,00	108646,00	105056,00	1708,51	1648,15	1593,69
1	99,60%	112174,50	108211,42	104635,78	1701,68	1641,56	1587,31
2	99,20%	111725,80	107778,57	104217,23	1694,87	1634,99	1580,97
3	98,80%	111278,90	107347,46	103800,36	1688,09	1628,45	1574,64
4	98,40%	110833,78	106918,07	103385,16	1681,34	1621,94	1568,34
5	98,00%	110390,45	106490,39	102971,62	1674,61	1615,45	1562,07
6	97,60%	109948,89	106064,43	102559,74	1667,91	1608,99	1555,82
7	97,20%	109509,09	105640,17	102149,50	1661,24	1602,55	1549,60
8	96,80%	109071,05	105217,61	101740,90	1654,60	1596,14	1543,40

Table 3. Continuation

Year	Peak Power %	MWh			kWh/kWp/yr		
		P50	**P75**	**P90**	**P50**	**P75**	**P90**
9	96,40%	108634,77	104796,74	101333,93	1647,98	1589,76	1537,23
10	96,00%	108200,23	104377,56	100928,60	1641,39	1583,40	1531,08
11	95,60%	107767,43	103960,05	100524,88	1634,82	1577,06	1524,95
12	95,20%	107336,36	103544,21	100122,79	1628,28	1570,76	1518,85
13	94,80%	106907,01	103130,03	99722,29	1621,77	1564,47	1512,78
14	94,40%	106479,39	102717,51	99323,40	1615,28	1558,21	1506,73
15	94,00%	106053,47	102306,64	98926,11	1608,82	1551,98	1500,70
16	93,60%	105629,26	101897,41	98530,41	1602,39	1545,77	1494,70
17	93,20%	105206,74	101489,82	98136,29	1595,98	1539,59	1488,72
18	92,80%	104785,91	101083,86	97743,74	1589,59	1533,43	1482,76
19	92,40%	104366,77	100679,53	97352,77	1583,23	1527,30	1476,83
20	92,00%	103949,30	100276,81	96963,35	1576,90	1521,19	1470,92

3.2 Simulation results for Single Axis Tracking

The PV system with 65,920 MWp installed capacity produces on the first year 2,010 kWh/kWp with a performance ratio of 79.6%. Table 4 shows the tolerance values of the assumed losses, requested data and used simulation models that have an impact on the result of the generation estimation.

Table 4. Tolerance of the assumptions and simulation models - SAT

Loss	Tolerance Value - SAT
Irradiation values	***4%***
Irradiation losses	
Irradiation reduction due to mutual shading	Unknown
Soiling on the module surface	**1.0%**
Air pollution	0%
Electrical losses	
Yield loss due to irradiation reduction	Unknown
Reflection losses	0.5%
Weak irradiation	1%
Losses due to temperature	1%
Mismatch	1%
Deviation from the manufacturer specifications	0.5%
DC cable losses	0.5%
MV AC cable losses	0.2%
Transformer losses (LV/MV)	0.2%
Transformer losses (MV/HV)	0.2%
Efficiency, MPP operation	1%
Annual module degradation	0.2%
Light-induced degradation (LID)	1%
System losses	
Availability loss	0.5%
Used simulation models	
Perez model	2%
Module string shading	Unknown
Liu Jordan	Unknown
Albedo	Unknown

The P50 - P90 evaluation is a probabilistic approach for the interpretation of the simulation results over several years. This approach supposes that over several years of operation, the distribution of the annual generations will follow a statistical law, which is assumed to be the Gaussian or normal distribution as shown in Figure 4. The simulation results is an annual variability of σ = 5.24% ((i.e. 5.24% * 132505 MWh = 6945 MWh)). For the following years of operation a degradation value of at least 0.4% is recommended. In Table 5, the values for the preparation of the financial model are listed.

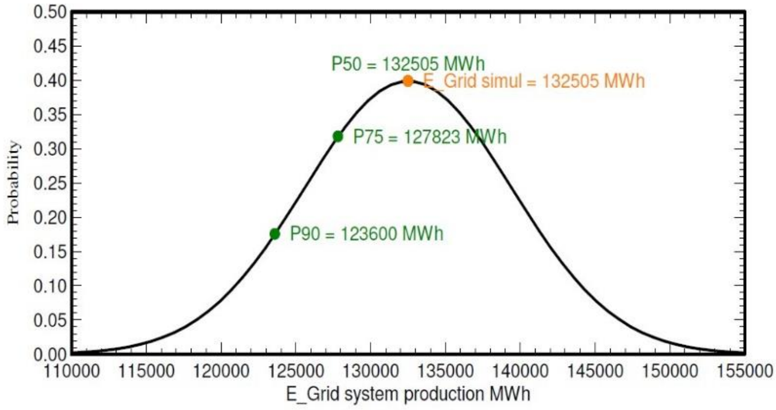

Figure 4. Probability function for a nominal power of 65,920 MWp for single axis tracking

Table 5. P50, P75 and P90 value for the next 20 years of operation

Year	Peak Power %	MWh			kWh/kWp/yr		
		P50	P75	P90	P50	P75	P90
COD	100,00%	132505,00	127823,00	123600,00	2010,09	1939,06	1875,00
1	99,60%	131974,98	127311,71	123105,60	2002,05	1931,31	1867,50
2	99,20%	131447,08	126802,46	122613,18	1994,04	1923,58	1860,03
3	98,80%	130921,29	126295,25	122122,72	1986,06	1915,89	1852,59
4	98,40%	130397,61	125790,07	121634,23	1978,12	1908,22	1845,18
5	98,00%	129876,02	125286,91	121147,70	1970,21	1900,59	1837,80
6	97,60%	129356,51	124785,76	120663,11	1962,33	1892,99	1830,45
7	97,20%	128839,09	124286,62	120180,45	1954,48	1885,42	1823,13
8	96,80%	128323,73	123789,47	119699,73	1946,66	1877,87	1815,83
9	96,40%	127810,43	123294,31	119220,93	1938,87	1870,36	1808,57
10	96,00%	127299,19	122801,14	118744,05	1931,12	1862,88	1801,34
11	95,60%	126790,00	122309,93	118269,07	1923,39	1855,43	1794,13
12	95,20%	126282,84	121820,69	117796,00	1915,70	1848,01	1786,95
13	94,80%	125777,70	121333,41	117324,81	1908,04	1840,62	1779,81
14	94,40%	125274,59	120848,08	116855,51	1900,40	1833,25	1772,69
15	94,00%	124773,50	120364,68	116388,09	1892,80	1825,92	1765,60
16	93,60%	124274,40	119883,23	115922,54	1885,23	1818,62	1758,53
17	93,20%	123777,30	119403,69	115458,85	1877,69	1811,34	1751,50
18	92,80%	123282,19	118926,08	114997,01	1870,18	1804,10	1744,49
19	92,40%	122789,07	118450,37	114537,03	1862,70	1796,88	1737,52
20	92,00%	122297,91	117976,57	114078,88	1855,25	1789,69	1730,57

4. Conclusion

To avoid risk in technical evaluations, there is a need for a report of uncertainties related to the solar energy estimation and meteorological data inputs. Hence, this assessment would help clear any technical doubt. This paper highlights the probabilities of exceedance of minimum annual productions, with a confidence level of 90%, 95% or 99% (depending on the requirements of financial institutions specification). As part of the development of the present system, a large amount of Tier 1 modules, inverters and tracking systems brands were evaluated. Reliable suppliers along with proper due diligence will bring added value to the bankability of the PV project. A total installed capacity of 65.92 MW was planned to achieve a 52.5 MW by means of a 25.56% of DC/AC ratio. The system configuration was designed using an industry standard 1000V arrangement, and a homogeneous replication pattern that allows faster deployment. For instance, a 1.318,4 MWp block is representative of above 90% of the plant layout, and is arranged in 12 combiner boxes of 16 strings and one combiner box of 14 strings. Each string connects 20 modules in series. This 1.318,4 MWp block adds up 4,120 modules in 206 strings. The portrait 13° tilt arrangement, pitch 7.6m as was proposed as first option. The portrait option offers higher flexibility while using smaller tables. This aspect represents an advantage in angular terrains that require splitting a high amount of tables. The assessment of the fix tilt results on specific production of 1,709 kWh/kWp with a performance ratio of 79.25% and annual variability of **σ = 5.24%** (5903 MWh). Additionally, a single axis tracking system with limit angle at 50° and pitch 5.5 m is suggested as an option for increasing the energy generation. The assessment for the single axis tracking system produces on the first year 2,010 kWh/kWp with a performance ratio of 79.6%. This simulation results on an annual variability of **σ = 5.24%** (6945 MWh).

Conflict of Interests

Authors declare that there is no conflict of interests regarding the publication of this paper.

References

Benavides, N. D., & Chapman, P. L. (2008). Modelling the Effect of Voltage Ripple on the Power Output of Photovoltaic Modules. *IEEE Transactions on Industrial Electronics, 55*(7), 2638-2643

Friedrich, S., & Thomas, E. (2004). Photovoltaic in Buildings, a Design Handbook for Architects and Engineers. *Fraunhofer Institute for Solar Energy Systems ISE*, Freiburg, Germany.

Ineichen, P. (2011). Five Satellite Products Deriving Beam and Global Irradiance Validation on Data from 23 Ground Stations, University of Geneva. IEA SHC Task, 36.

Okundamiya, M. S. & Omorogiuwa, O. (2015). Viability of a Photovoltaic Diesel Battery Hybrid Power System in Nigeria, *Iranica Journal of Energy and Environment, 6*(1): 5-12.

Okundamiya, M. S. (2015). *Modelling and Optimization of a Hybrid Energy System for GSM Base Transceiver Station Sites in Emerging Cities*, Ph.D. Thesis, University of Benin, Benin City, Nigeria.

Okundamiya, M. S., Emagbetere, J. O. & Ogujor, E. A. (2014). Assessment of Renewable Energy Technology and a Case of Sustainable Energy in Mobile Telecommunication Sector, *Scientific World Journal*, vol. 2014, 1-13.

Olawore, F., & Ojo, A. (2016). Environmental and Social Impact Assessment for the proposed 50MW PV power plant in Igabi, Kaduna State, Nigeria. Haskoning DHV Nigeria LTD, Nigeria.

Perez, R., Ineichen, P., Seals, R., Michalsky, J., & Stewart, R. (1990). Modelling Daylight Availability and Irradiance Components from Direct and Global Irradiance. *Solar energy, 44*(5), 271-289.

Rhodes, J., Upshaw, C., Cole, W., Holcomb, C., & Webber, M., (2004). A Multi-Objective Assessment of the Effect of Solar PV Arrays Orientation and Tilt on Energy Production and System Economics, *Solar Energy*, 30-35.

Roland, W. (2005). Modelling and Simulation of a Solar Energy System. Arizona: Johnson Perk Printing Press.

Stackhouse Jr., P. W., Chandler, W. S., Zhang, T., Westberg, D., Barnett, A. J., & Hoell, J. M. (2016). Surface Meteorology and Solar Energy (SSE) Release 6.0 Methodology Version 3.2. 0 June 2, 2016.

Stoffel, M., Khodri, M., Corona, C., Guillet, S., Poulain, V., Bekki, S., Guiot, J., Luckman, B. H., Oppenheimer, C., Lebas, N., Beniston, M., & Masson-Delmotte, V. (2015). Estimates of volcanic-induced cooling in the Northern Hemisphere over the past 1,500 years, *Nat. Geosci., 8*, 784–788, doi:10.1038/ngeo2526.

Thevenard, D., Driesse, A., Pelland, S., Turcotte, D., & Poissant, Y. (2010). *Uncertainty in Long-Term Photovoltaic Yield Predictions*. Natural Resources Canada

Wang, H., & Donglai, Z. (2010). The Stand-Alone PV Generation System with Parallel Battery Charger. *International Conference on Electrical and Control Engineering*, Shanghai, 4450-4454.