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ENERGY AND ECONOMIC EVALUATION OF THE 3000KWP GRID CONNECTED PHOTOVOLTAIC POWER PLANT IN UMUOGHARA QUARRY INDUSTRIAL CLUSTER, NIGERIA

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Abstract

In this study, Energy and Cost analysis of Umuoghara Quarry Industrial Cluster using diesel and a grid connected solar photovoltaic plant has been carried out. The simulation in this work was done using PVsyst 7.2.14 Energy analyzing software. The simulated system comprises 6818 CIS PV modules with each module having a rating of 440Wp. All the PV modules were arranged in 487 strings, each made up of 14 modules in series. Five (5) solar inverters, each having a rating of 500KWac were used for interconnecting with the grid. The 3000KWp PV system generates 4222327KWh/year out of which 4098289KWh/year is injected into the grid. The performance ratio and its total impressed losses were also calculated. The performance ratio of 84% was obtained for the 3000KWp solar plant in the Umuoghara Quarry Industrial cluster. As regards diesel consumption, energy analysis indicates that the cluster uses 405600litres of diesel for nine (9) operating hours a day in a year at a prevailing cost of two hundred and twenty three million eighty thousand naira (₦223080000) and the use of solar Photovoltaic in the cluster will save this cost and at the same time reduce environmental pollution.

***Keywords*:** PVsyst, Grid; Cluster; GHGs emission; simulation; power plant etc

1. Introduction

In this 21st century, energy use has become an integral part of our lives as no one spends a day without making use of one form of energy or the other. Energy use has both positive and negative impact on the environment and that is why these concepts energy and environment should always be studied together. The energy requirements of the world are ever increasing and this increasing energy demands put a lot of pressure on the conventional energy sources. Hence, there is a need for alternative energy sources which can provide energy in a sustainable manner. The pronounced and considerable choice of a clean energy source, which is abundant and could provide security for future developments and growth, is the sun’s energy and here in Umuoghara, Ebonyi, South-Eastern Nigeria it is abundant. Currently, the government`s attention has now veered to the use of renewable and sustainable methods of power generation due to the risk of environmental pollutions occasioned by the use of traditional power plants that uses fossil fuels. An international protocol on December 11th, 1997, was assigned to most of the countries with the main aim of stabilization of greenhouse gas (GHG) concentration in the atmosphere [16]. This protocol, known as Kyoto Protocol, obliges countries to reduce the emission of GHGs, the main factor of global warming. The renewable capacity of solar technologies has experienced a sustained, globally strong growth over the last few years. Since the beginning of this decade, it has steadily grown at about 8-9% annually, which is more than double the average growth for non-renewable [6].
Solar energy is intermittent in nature, eco-friendly, and non-polluting. It is freely available throughout the world, particularly in India [2, 17]. Solar energy can be used for direct conversion to electricity for use in homes and industry (by

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photovoltaic cells) and into thermal energy. Scientists and System designers use simpler tools for sizing PV systems. Most of them use simulation tools to design and optimize a PV system before the field installation of the real one. Software tools related to photovoltaic systems can be classified into prefeasibility analysis, sizing, and simulation [11]. A wide variety of tools exist for the analysis of both grid connected and Stand-alone photovoltaic systems. The photovoltaic modules can provide a safe, reliable, a maintenance-free and environmentally benign source of power for a very long time. A successful implementation of solar PV systems involves the knowledge on their operational performance under varying climatic conditions [11]. Thin film photovoltaic (PV) modules (amorphous asi:H, CIS, CdTe, or µC-a:Si technologies) present the most promising opportunity to significantly decrease the prices of Photovoltaic in the future, as the thin films used are limited pure materials [2,20]. The PV systems are as grid connected and standalone. Grid connected photovoltaic systems feed electricity directly to the electrical network, operating parallel to the conventional energy source. Grid-connected systems generate clean electricity near the point of use, without transmission and distribution losses or the need for batteries [15]. Its performance depends on the local climate, orientation and inclination of the PV array, and inverter performance. Whereas a stand -alone system involves no interaction with a utility grid, the generated power is directly connected to the load [9]. In case the PV array does not directly supply a load, a storage device is needed such as a battery [8, 20]. The battery bank stores energy when the power supplied by the PV modules exceeds the load demand and releases it back when the PV supply is insufficient [15]. This stand-alone PV power generation is used in the home for the electrification purpose [5]. Economic feasibility and viability of implementing PV solar energy in the State of Kuwait was found that the energy resources used in producing traditional electricity were saved and the cost of CO_2 emissions was also saved [14]. The design and simulation of a proposed 500kW grid connected PV system using PVsyst which is desired to take care of 995,161 MWh annual load demand of the Faculty of Engineering, Rivers State University (FOERSU) between the official hours of 8am to 4pm daily using PVsyst 7.2.6 programming software and the excess energy is sold to the Power Holding Company of Nigeria (PHCN) through the grid network [19]. The University Community has a mean solar radiation of 4.55kWh/m^2/day as obtained from Nigerian Meteorological Agency (NIMET) and an average temperature of 26.61^{0}C. The method used is enumeration of electrical load of the Faculty of Engineering alongside their hour of operation to obtain the energy required per day in Watt hour (1523.768kWh) but 2726.48kWh is used for the purpose of selling the excess and also due to load forecast. The energy (2726.48kWh) was divided by an average sun hour of 4.5 hours and the result is again divided by a threshold frequency of 0.77 to get the peak power of the PV module (787kWp). This peak power, tilt angle of 50 , grid voltage (415V) are entered into the PVsyst programming software to chose the number of PV panels in series and parallel and the inverter. The simulation result shows that the annual DC energy the proposed plant generates per year is 1,140,796kWh while the actual AC energy exported to the grid network is 1,114,502kWh/year with a loss of approximately 20%. The effects of weather conditions on the overall performance were looked at. The proposed PV plant is viable and will address the lingering energy crisis in the faculty. A total of 1962 panels were used for the work with 18 panels in series and 109 panels in parallel. Multilevel inverter is used to track the maximum power from the PV array.
PVsyst is a dedicated PC software package for PV systems. The software was developed by the University of Geneva [13]. It integrates prefeasibility, design, sizing and simulation support for PV systems. First, the location and loads of PV systems are determined, then the product database is selected, and the software automatically calculates the size of the system [18]. In this study, Energy and Cost analysis were carried out on the 3000kWp grid-connected solar Power Plant with the use of PVsyst 7.2.14 Energy analyzing software for the simulation.

2. The Solar Cell

A solar cell is basically a P-N junction diode which converts solar energy (light energy) into electrical energy [10]. The maximum theoretical efficiency of a solar cell depends on the band gap (the energy necessary to transfer an electron from upper valence level to the conduction level). The band gap is inversely proportional to the cell`s efficiency. In principle, a solar cell is nothing but a light emitting diode (LED) operating in reverse. A light emitting diode is a specially made forward biased P-N junction diode which emits visible light when energized [10]. When a P-N junction diode is forward-biased, electron from n-side and hole from p-side move towards the depletion region and they recombine. During this process, energy is released because electrons make transition from conduction band (higher energy level) to valence band (lower energy level). If E_g is the semiconductor band gap, then the energy

$$\mathrm{Eg} = hv = \frac{hc}{\lambda} \quad (1)$$

is emitted in the form of radiation. The corresponding emission wavelength is given by

$$\lambda = \frac{hc}{\mathrm{Eg}} \quad (2)$$

2.1 Design Considerations for Solar PV Plant
The following considerations should be made when designing a PV solar plant.
1. Check for the availability of solar insolation (exposure to the sun's rays).
2. Check for availability of required land size for the desired plant capacity.
3. Check for any building/structures and tall trees that can make shading or cover the solar panels and sunshine.
4. Check for construction and installation cost.

2.2 Designing of the solar PV-GRID system
A grid-connected PV system consists of solar panels, inverters, a power conditioning unit, sometimes Battery bank and grid connection equipment. The system can be said to have effective utilization of power generated from solar energy, when there is no energy storage losses. The grid-connected PV system supplies the excess power, beyond consumption by the connected load to the utility grid [7]. The 3000kWp grid-connected solar Power Plant in Umuoghara Industrial Cluster covers approximate 15170 m² of land area.

2.3 Plant Layout
The power rating of the designed plant is 3000kWp and it covered over 15170 m^2 of land. The plant comprises of a total of 6818 modules in which 14 modules were in series and 487 strings in parallel. The module of the PV system is Si-Mono 440 Wp Twin 144 half-cells. The Inverters used are for DC-AC conversion which will be directly supplied to the grid. To maximize the solar insolation in PV array installation, the inclination angle should be kept equivalent to the latitude of the specified site.

2.4 Power conditioning units
In this work, five (5) inverters were used for DC-AC conversion. The inverter power rating is 2500 kW_{ac}, PV input maximum voltage is 1000 V, and supply DC 800 A is fed as input to inverter. The output AC voltage and current of the inverter are 400V and 723A, respectively. The output of the inverter is automatically synchronized with the same voltage and frequency as that of grid.

2.5 Geographical location of the site
A good geographical location is where the solar power plants can ingest more sun-based radiation for the whole year since the power generated by the solar power plants totally depends on the sun's insolation (the amount of solar radiation reaching a given area). The PV solar power plant is situated at a longitude of 8°1′ 9″E, latitude 6°18′41″N and at a height of 1011 meter.

3. Methodology
PVsyst software tool was used in the analysis of the power plant. The Energy requirement or need (Load demand) of the quarry industrial cluster was first determined. With the total wattage of the cluster, the system definition was done. The system variant were constructed by inputting the field type, plane tilt, and azimuth angle followed by planned power in kilo watt peak (KWp), type and number of PV modules, inverter type and number. This prompted the activation of the simulation button. The simulation which took a few minutes was performed and the result displayed and saved. From the detailed simulation results, the Energy Analysis was done followed by the cost analysis of the Industrial cluster using diesel and the PV system.

Umuoghara Quarry Industrial Cluster

3.1 PVsyst V7.2.14-PRO-Photovoltaic Systems Software

Software tools related to photovoltaic systems can be classified into pre feasibility analysis, sizing, and simulation. PVsyst is a dedicated PC software package for PV systems. The software was developed by the University of Geneva. It integrates pre feasibility design, sizing and simulation support for PV systems. First, the location and loads of PV systems are determined, then the product database is selected and the software automatically calculates the size of the system. Figure 2, is the PVsyst V7.2.14 user interface main page;

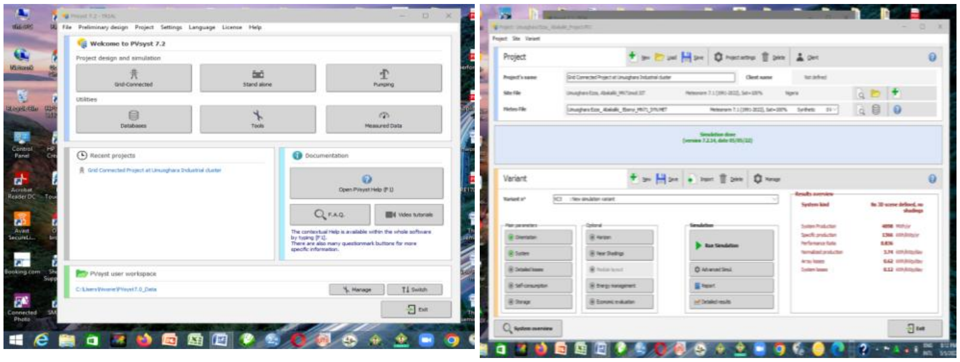

Figure 2: The user interface of PVsyst V7.2.14 Photovoltaic systems software

4. Results and discussion

4.1 Detailed Simulation Result of Umuoghara Quarry Industrial Cluster PV power plant System

The Performance ratio, balances and main simulation result is displayed in table 1**,**

Table 1 show the Balances and simulation result of the PV system. The overall performance of the system is determined by the energy production, solar resource and losses parameters. The performance ratio shows the proportion of the energy that is actually available for export to the grid after deduction of energy loss (e.g. due to thermal losses and conduction losses) and of energy consumption for operation. The performance ratio is the final yield divided by the reference yield. In this paper, the performance ratio of the solar PV power plant has been evaluated. The yearly average performance ratio of this PV system is minimum (0.829) in March and maximum (0.853) in July. Table 1 indicates that the average performance ratio annually is 0.836. A PV system with 0.836 of performance ratio means the PV plant is operating with 84% ›tained from the output of the PV array (EArray) is 4224.3 MWh.

Table 1: Balances and main result

Period	GlobHor **(kWh/m²)**	DiffHor **(kWh/m²)**	T Amb **(°C)**	GlobInc **(kWh/m²)**	GlobEff **(kWh/m²)**	EArray **(kWh)**	E_Grid **(kWh)**	PR
January	153.0	85.30	27.43	168.9	166.0	433848	421355	0.832
February	142.6	84.79	28.39	147.9	145.0	378889	368036	0.830
March	153.7	92.73	28.51	145.5	142.2	372866	361945	0.829
April	148.1	89.42	27.49	130.2	126.8	336349	326506	0.836
May	148.9	89.91	27.59	121.5	117.3	314415	304658	0.836
June	140.9	81.86	25.99	109.9	105.5	286059	277012	0.841
July	132.2	78.25	25.75	106.1	102.3	277670	268926	0.845
August	123.1	84.78	25.05	106.0	102.8	279940	271344	0.853
September	134.9	83.75	25.36	123.3	120.1	322542	312729	0.846
October	145.7	80.51	26.47	147.6	144.5	380511	368839	0.833
November	147.0	79.80	26.90	163.0	160.1	419197	407007	0.833
December	145.3	80.81	27.71	164.2	161.4	422042	409931	0.832
Year	**1715.4**	**1011.91**	**26.88**	**1634.0**	**1594.0**	**4224327**	**4098289**	**0.836**

4.2 Normalized Energy production

The plot of Normalized Energy productions per installed KWp monthly with Nominal power 3000 KWp and The loss diagram for a whole year is displayed in figures 3 and 4 respectively.

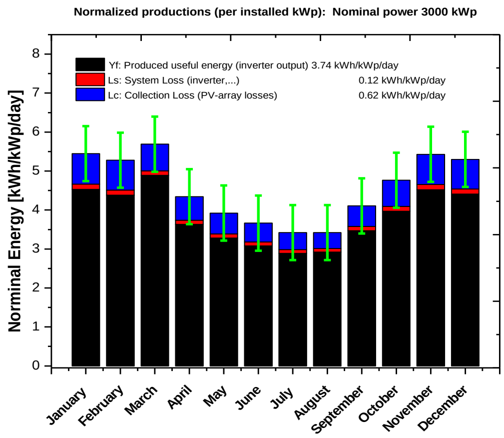

Figure 3: Normalized Energy production per installed KWp

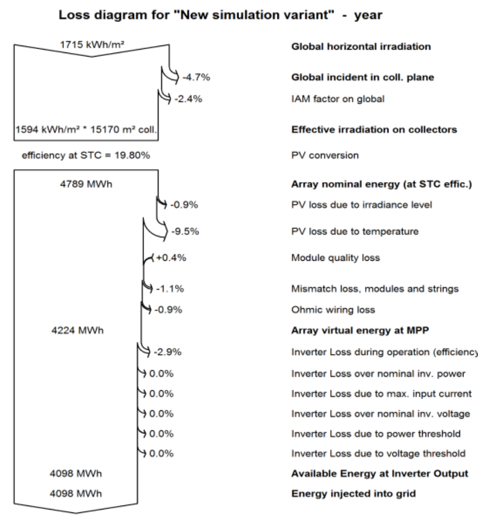

Figure 4: loss diagram over the entire year in the

The amount of system losses (Ls) is obtained from the difference between array yield (Ya) and final yield (Yf). In this work the value of system loss (Ls) is recorded as 0.12kWh/kWp/day and the array capture loss (Lc) value is recorded as 0.62kWh/kWp/day as displayed in figure 3. Figure 4 is the loss diagram over the entire year in Umuaghara Industrial cluster. From the diagram, Global irradiance on horizontal plane (GlobHor (kWh/m²)) obtained is 1715 kWh/m^2. Total incident energy which is incident on the collector plate (GlobInc (kWh/m²)) is yearly 1634.0kWh/m^2 with the effective irradiance on collector (GlobEff (kWh/m²)), 1594.0kWh/m^2. When this effective irradiance falls on the surface of a photovoltaic module or array, electricity or electrical energy is produced. After the PV conversion, array nominal energy at standard testing conditions (STC) obtained is 4789MWh while the annual array virtual energy at MPP is 4224MWh. This implies that the system is viable and capable of injecting the required energy in to the grid. The various losses that occur in this stage are 9.5 % losses due to temperature, 1.1 % loss due to module array mismatch and 0.9 % is the ohmic wiring losses. Available energy on annual basis at the inverter output facility is 4098MWh and the same is injected to grid. Here two losses were possible; one is inverter loss during inverter operation i.e. 2.9% and inverter loss over inverter nominal power which is 0.1%, this implies that the inverter power transfer function is up to 97% and suggests that the inverter has high performance efficiency. This is in agreement with [3].

4.3 Cost analysis of the cluster using diesel and the PV power Plant

Economic evaluation is the process of systematic identification, measurement and valuation of the inputs and outcomes of two alternative activities (here the use of diesel and solar plant), and the subsequent comparative analysis of these. The purpose of economic evaluation is to identify the best course of action, based on the evidence available [20]. Economic evaluation or Cost-effectiveness analysis can be used to identify, measure, value, and compare the costs and consequences of different alternative activities. Cost-effectiveness analysis is an important tool for identifying better ways and/or opportunities for redirecting resources to better use. This is a method of assessing the gain in two different approaches. The cost analysis of the Umuoghara quarry industrial cluster has been done using diesel and the PV power plant. There are fifty two (52) functional stone crushing plants in the cluster that runs for nine hours per day (i.e between 8.00am to 5.00pm daily), six (6) days a week, and fifty two (52) weeks a calendar year. It takes a plant twenty five (25) litres of diesel to operate for nine hours a day. In one year, one functional plant would consume a total of (6days×52weeks×25 litres= 7800litres) of diesel to be in operation nine hours a day. Since it takes one functional plant 7800litres of diesel to be in operation for nine hours a day, If one litre of diesel in Nigeria is sold at ₦550, it would be costing a plant (₦550×7800= ₦4, 290000) four million two hundred and ninety thousand naira to be in operation for a year. Hence, the fifty two functional plants in the cluster would not be consuming (7800×52= 405600litres) of diesel annually, and the cluster would be saving (₦550×405600= ₦223080000) two hundred and twenty three million eighty thousand naira if the design is implemented.

Conclusion

In this work, Energy and Cost analysis using diesel and a 3000 kWp grid-connected photovoltaic power plant at Umuoghara Quarry Industrial cluster, Nigeria has been carried out. From the result and analysis, on the annual basis, 4098289 KWh/year is the energy (E-Grid) that is injected into the grid while Annual array virtual energy at MPP is 4224327KWh. Maximum energy injected into the grid is in January (421355KWh), and the least energy is in July (268926KWh), This trend could be attributed to weather conditions in the location such as rainfall which is a major factor that reduces solar insolation in the location as no form of shading is observed. The average performance ratio (PR) of the CIS PV system is operated at 84% and suggests that the system has high performance efficiency. The Cost analysis indicates that it would take one functional plant about 7800litres of diesel to be in operation nine hours a day for one year and the cluster about 405600litres of diesel annually, at a prevailing cost of two hundred and twenty three million eighty thousand naira (₦223080000). This would be saved if a grid connected Photovoltaic power plant is used to run the cluster as no maintenance is needed. Also evident in the simulation result is that array/module maximum power output is a function of incident irradiance in W/m^2 and maintains a direct proportion. From the results, it can be concluded that this project is viable and can produce the required energy needed to keep the cluster in operation.

Conflict of Interest

The authors of this work declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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