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Improving Hybrid Power Supply System for Telecommunication Service Providers in Nigeria

Odudu O. C.[1], Idoniboyeobu D. C.[2], Braide S. L.[3]
[1, 2, 3]*Department of Electrical Engineering, Faculty of Engineering, Rivers State University, Port Harcourt*

Abstract: The aim of this research is to use a combination of renewable energy sources and conventional diesel generator to model a cost effective, alternative energy source for telecommunication base stations in Nigeria. Actually, this study uses various theoretical and mathematical modelling tools, such as, Mat lab Simulink and HOMER software. In the same way, the study references several Base Transceiver Stations (BTS) from gsm providers at select geographical locations in Rivers State. The study references BTS infrastructure in locations such as Ogoni, Port Harcourt and Emohua. These locations were selected to reflect different climatic conditions in Rivers state. Against this background, various hybrid combinations comprising at least two sources of renewable energy e.g Wind Turbine generator(WTG) and Solar Photovoltaic (SPV) were modelled. Also, Fuzzy logic optimization algorithm was used in tracking the maximum power in the SPV. A sample Diesel Generator(DG) was studied to analyze which possible combination gives optimum performance and is most cost effective. The total cost for installation and maintenance of the hybrid system was also considered. Consequently, one of the common negative effects of conventional power generation and usage, which is environmental pollution, was also highlighted during the study. In the course of this research, Homer was used to model a hybrid system in which the initial capital Cost (ICC) was N101,517,040 for 96 nos battery, 1 no 10kw WTG, 1 no hydro-turbine, 48 nos converters, labour etc. The replacement cost for component has a depreciation of 30%; while maintenance for diesel is 30% of the ICC. Eventually, the results obtained from the simulations showed that with an increase in supply from renewable energy sources the overall cost spent when compared to using a diesel generator only is cut by 50%, while the pollution effects also dropped. In fact, the cost also reduces if the renewable energy system is designed efficiently to track and harness maximum power. Furthermore, it is also evident that the location of the base station site and the availability of Renewable energy source affects the efficiency and cost of the entire system. Hence, it is recommended that any telecommunication company which intends installing a hybrid power system for its base stations must carry out detailed feasibility studies using input parameters described here; especially, as it relates to siting of base stations in rural off-grid areas.

Keywords: Hybrid Power Supply System

I. INTRODUCTION

We are currently witnessing an unprecedented growth in the number of mobile subscribers in Nigeria, which has prompted mobile network operators to expand their cellular networks to provide mobile service to subscribers in rural areas, increasing the profitability of the operators. (Bagul, Salameh, & Borowy, 2009). However, operational expenditures and greenhouse gas emissions are a major concern of the mobile network operators because diesel generators are typically used to power the off-grid cellular base stations in remote areas (Celik, 2013), which challenges mobile network operators to find an economically feasible alternative power source that is also environmentally friendly. With the current progress in renewable energy, the key features of a power source, such as the cost effectiveness, sustainability, and reliability, as well as reduction of the greenhouse gas emissions, can be met (Celik, 2013). The increasing demand for energy, the continuous reduction in existent resources of fossil fuels and the growing concern regarding environmental pollution have compelled mankind to explore new production technologies for electrical energy using clean, renewable sources such as wind energy, solar energy, etc. Among these electric power technologies which use renewable sources, those based on the conversion of solar and wind energy are clean, silent and reliable, with low maintenance costs and small ecological impact. Sunlight and the kinetic energy of the wind for instance are free, practically inexhaustible, and involve no polluting residues or greenhouse gases emission. In spite of these, however, electric power production systems which comprise as their primary sources, solely, solar and wind energy, pose technical problems due to uncontrollable wind speed fluctuations, and the day-to-night and summer-to-winter alternations. As a consequence, in autonomous regimes, the power supply continuity of a local grid should be backed up by other reliable and non-fluctuating sources of primary energy, such as diesel generator sets. Such systems, designed for the decentralized production of electric power using combined sources of primary energy, are called hybrid systems.

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By combining several renewable energy sources like Wind, PV and Diesel to form a hybrid system, one would ensure increased reliability in the electricity power supply for consumption under optimum quality parameters, especially, under the condition of a minimum required electric power during an imposed time period. The increased interest in using diesel generator sets as the main energy source in isolated areas or as an emergency source in place of renewable-based power systems can be observed through the number of papers and studies carried out in this area. For a typical telecom service providers' installations, the problem of poor grid electricity supply is tackled by using diesel generators. These generators, however, entail a major problem in transportation and storage of diesel with noise pollution. Decentralized distributed generation technologies based on renewable energy resources such as Solar Photo Voltaic (SPV) or/and Wind Turbine Generators (WTG) address the above barriers to a large extent and are therefore considered as emerging alternate power solutions to telecommunication base stations. It is a well-known fact that the main source of energy consumption in a typical telecommunication service providers' infrastructure is their *Base Transceiver Stations* (BTS*)*. These *Base Transceiver Stations,* or *Base Stations* as they are popularly called, are said to have an estimated total network consumption share of somewhat greater than 50%. (Bagul, Salameh, & Borowy, 2009). In developing countries, most sites run on diesel due to weak or non-existing power grid supply.

From the above overview, it is evident that the lack of grid power supply in rural Nigeria poses a great challenge to all stakeholders in the development of improved hybrid power supply in Telecommunications Industry. Regrettably, available solutions can best be described as begging the issues. Actually, given the ongoing emphasis on conventional energy supplies like diesel generators, little or no attention has been paid to the exploitation of all other available energy (renewable) resources and, even the emerging technologies in the field which can essentially ramp up production in the rural areas. By referring to "Energy Optimization" here, it would imply the process of assessing the energy load demand of a BTS at any rural site and matching it with cost-effective and environmentally-friendly power supply system using theoretical and mathematical models. This goal was be pursued by selecting the best components and their sizing, and determining the best available energy option (in terms of economic and environmental costs) that effectively power specific base station sites. The selection of the best available energy option (from economic and environmental perspectives) means the design of the most effective economic configuration (combination of a number of power system components) from among a variety of options, like Diesel Generators, PV arrays, Wind Turbines, Micro-Hydro Power Plants, just to mention a few, available at the BTS site.

II. MATERIALS AND METHOD

The materials used for this study include the mathematical model; the simulation & Optimization software; and the supervisory controller for the energy management such a solar panels, wind turbine, diesel generator, power converters, the energy storage (battery). Following the description of the system components, a mathematical model would be formulated and developed using mathematical model techniques generated by Homer. In due course, an algorithm to model the Hybrid power generation system as well as cost model analysis would be presented. Below is a schematic diagram showing the hybrid composition.

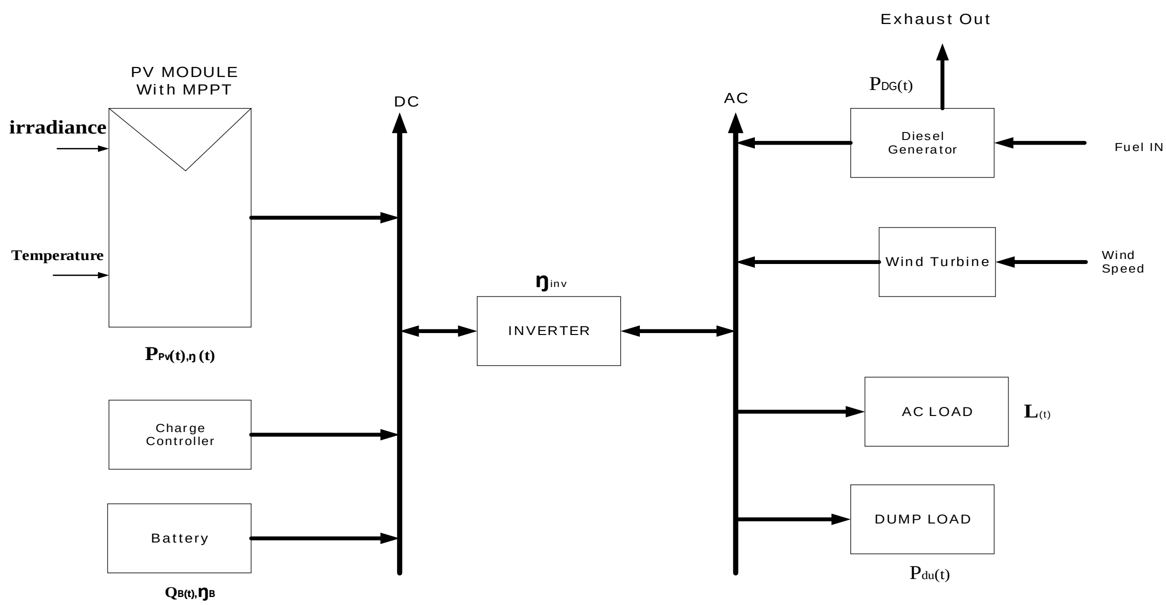

Figure 1: Schematic Layout Diagram of a Diesel -Photovoltaic –Battery Hybrid System

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The entire system is basically composed of a PV system, a Diesel Generator, and a Battery Bank with battery management system for efficient storage. A maximum power point tracker is also incorporated in the photovoltaic system to ensure the PV array is producing optimal power as it varies with irradiation and temperature. The diesel generator will use a combination of genetic algorithm which will be used to determine the best combination for the system to minimize fuel cost. A bidirectional inverter with Parallel mode of operation allows the photovoltaic array and the diesel generator to supply a portion of the load directly. The energy generated by photovoltaic array panels are stored in the battery bank when power from photovoltaic array is greater than the required load. Photovoltaic array and battery have preference to supply the load. When the battery is discharged to its minimum level, the diesel generator as a backup source is switched on to fulfil the demand of electricity. A charge controller is introduced to prevents the overcharging and discharging of the battery. In some cases, where generated energy exceeds the load requirement and the battery bank is fully charged during sunshine hours, this extra energy is consumed by the dump load. This affects the hourly energy flow sequence in the power supply system. It also affects the variation of battery sizing, diesel generator sizing and the amount of usable photovoltaic array energy at any given time. This model includes a time series simulation approach based on the overall energy balance of the system. It suffices to say that the net power generated is represented as the difference between the total power generated by the photovoltaic array ($P_{PV(t)}$) after taking inverter efficiency and power required by the load ($L_{(t)}$) and dumped power when there is excess generation of energy.

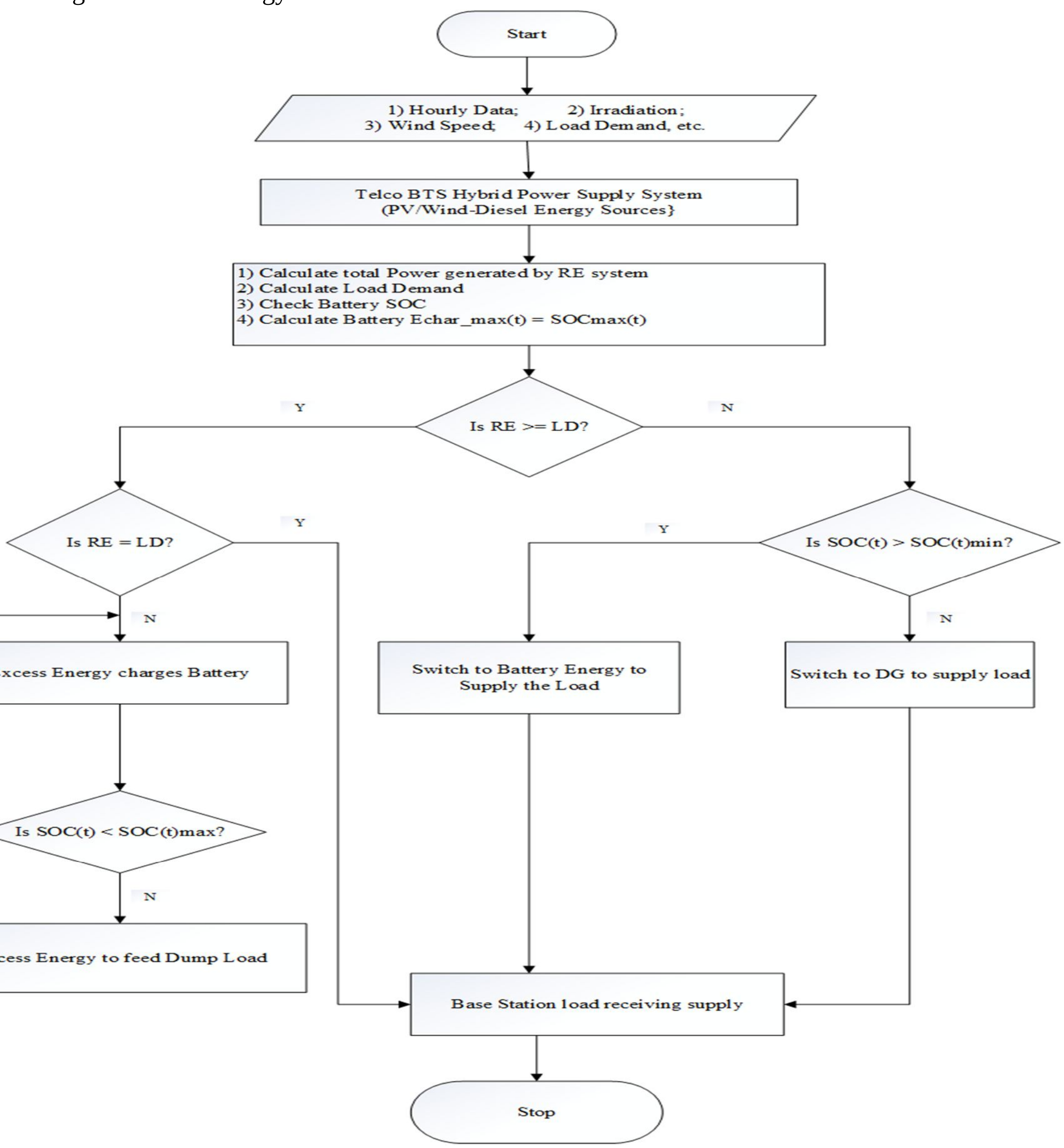

Figure 2: Hybrid PV/Wind-Diesel System Sizing Simulation Flow Chart

A. Hybrid Power Generation Model

Total hybrid power generated at any time t, is given by Equation 3.38. (Deepak & Dash, 2011).;

$$P(t) = \sum_{WEG=1}^{N_W} P_{WEG} + \sum_{PVG=1}^{N_P} P_{PVG} + \sum_{DEG=1}^{N_D} P_{DEG} \quad (1)$$

Where, N_W is the number of wind generators unit
N_P = is the number of PV cells unit
N_D =is the number of diesel generators unit?

This generated power will feed to the loads. The diesel generator has the constraint to always operate between 80 and 100% of their kW rating. When this generated power exceeds the load demand then the surplus of energy will be stored in the battery bank. This energy will be used when deficiency of power occurs in order to meet the load demand. The charged quantity of the battery bank has the constraint.

$SOC_{MIN} \leq SOC(t) \leq SOC_{MAX}$.The dump load will draw excess energy produced by the renewable generators or diesel generators but unused when the load does not need all the energy and the battery has reached its maximum capacity and cannot store more energy. The approach involves the minimization of a cost function subject to a set of equality and inequality constraints.

III. RESULTS AND DISCUSSIONS

Tables 1 – 3 show the classification of the simulation results according to:

1) The total Net Present Economic Costs (NPC in naira ₦). See Table 1,
2) The environmental impact (pollutant emissions in kg of CO_2). See Table 4.2, and
3) The electric energy (kWh) generated by each hybrid system type. See Table 4.3.

Table 1: Economic Costs [NPC in Billions of Naira (₦)]

SN	BTS Site location	Hybrid System Type [10^9]			
		1 PV/W + DG	2 PV only + DG	3 W only + DG	4 DG only
1	Emohua	3.05	3.07	3.66	3.69
2	Port Harcourt	2.78	3.03	3.46	3.69
3	Ogoni	3.17	3.23	3.62	3.69

The figures in the Table 1 above are classified in ascending order, from the least cost to the highest cost per hybrid type. The classification is also done as per locations. For instance, PV/W/+DG hybrid system type has the least NPC [2.78 port Harcourt]. This is followed by PV+DG [3.03 at Port Harcourt] and PV/W+DG [3.05 at Emohua]; while Diesel-only has the highest NPC [3.69] in all the BTS site location studied].

Table 2: Environmental Impact [(pollutant emissions in tons of CO_2)]

SN	BTS Site location	Hybrid System Type [10^9]			
		1 PV/W + DG	2 PV only + DG	3 W only + DG	4 DG only
1	Emohua	73.91	81.84	97.64	101.34
2	Port Harcourt	80.91	80.49	92.24	101.34
3	Ogoni	84.05	85.91	96.59	101.34

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Similarly, the figures in this Table 2 above are classified from the least environmental pollution to the highest environmental pollution per hybrid type as well as per location. For instance, PV/W+DG hybrid system type has the least environmental pollution [73.91 at Emohua]. This is followed by PV/W+DG [80.94 at Port Harcourt] and PV+DG [80.49 at Port Harcourt], while Diesel only has the highest environmental pollution [101.34 in all the BTS site location studied] as shown in the table.

Table 3: Percentage of Energy Generated by the Renewable Energy Hybrid Systems Components.

SN	BTS Site location	Hybrid System Type [%]			
		1 PV/W + DG	2 PV only + DG	3 W only + DG	4 DG only
1	Emohua	16/12/83	16/84	12/99	100
2	Port Harcourt	18/15/76	17/83	10/94	100
3	Ogoni	12/9/86	12/88	8/98	100

[*Contributions made by the hybrid system components are demarcated by forward slashes (/)*]

The same applies to the figures in this Table 3 above. They are arranged from the highest energy generated by the renewable energy sources to the least energy generated by the renewable energy sources. For instance, PV/W+DG hybrid system type has the highest energy generated by the renewable energy [18/15/76 at Port Harcourt]. This is followed by PV/W+DG [16/12/83 at Emohua] and PV/W+DG [12/9/86 at Ogoni], while W+DG has the least energy generated by the renewable energy [8/98 at Ogoni], as shown in the table.

These results are further illustrated with bar charts and line graphs in Figures 3 for (NPC); Figure 4 for (environmental impact), and Figure 5 for (energy generated).

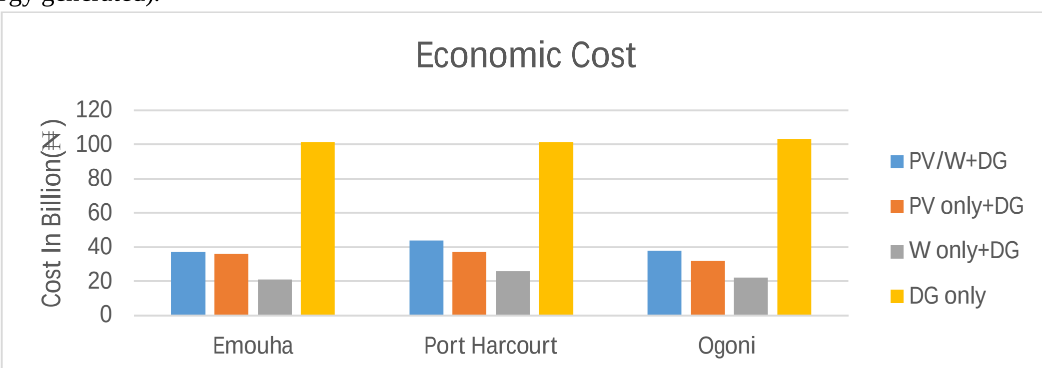

Figure 3a: Economic Costs Analysis Using Bar Chart

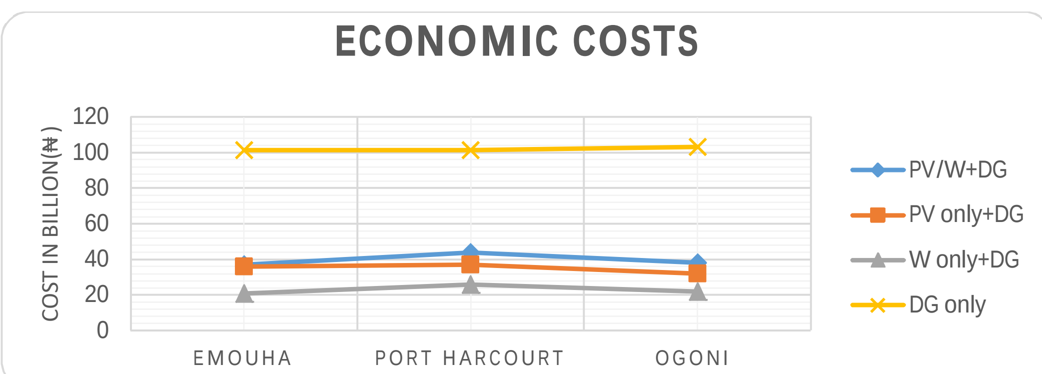

Figure 3b: Economic Costs Analysis Using Line Graph

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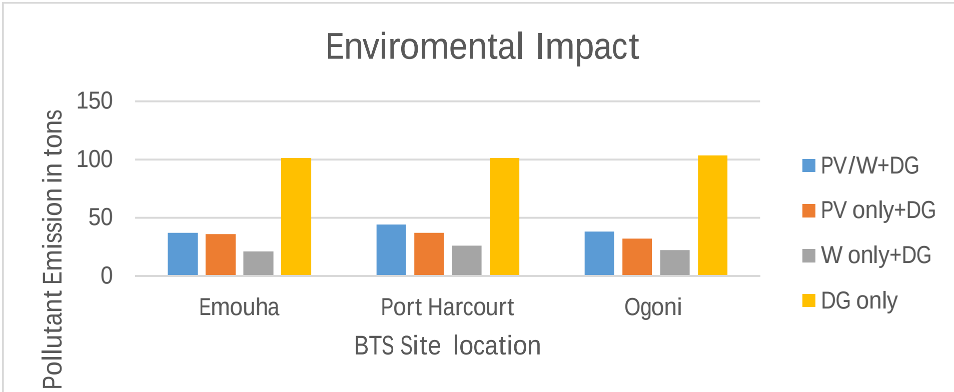

Figure 4a: Environmental Impact [emissions in tons of CO_2] Using Bar Chart

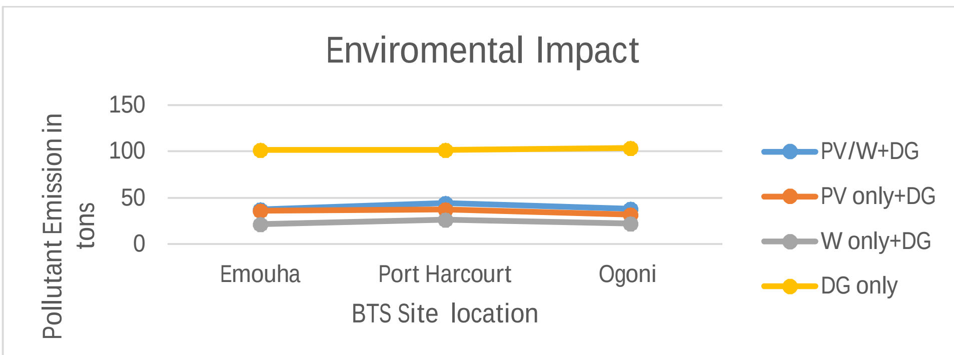

Figure 4b: Environmental Impact [emissions in tons of CO_2] Using Line Graph

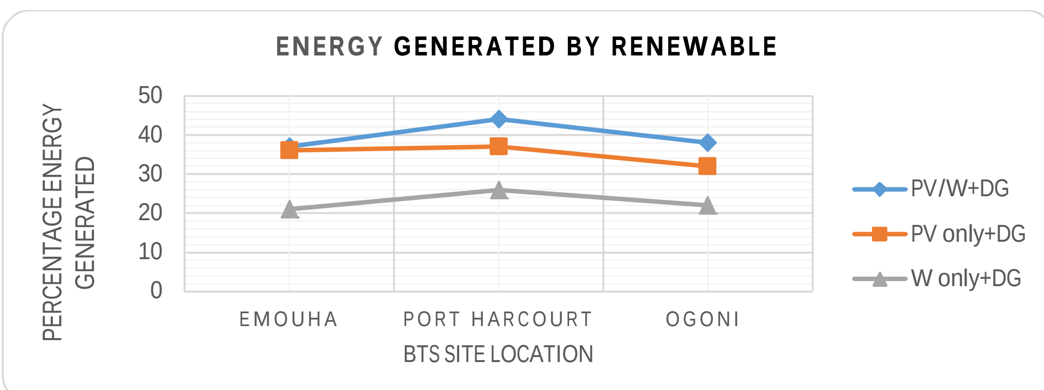

Figure 5: Percentage Energy Generated by PV per Renewable Energy Hybrid Type

Solar and wind energy systems are among the most developed renewable energy systems (RES), and these have found wide and popular applications. Among these applications are the hybrid renewable energy systems, which have been described as any combinations of one (or two or all) of the three systems (solar, hydro and wind) with a diesel generator and a battery. The popularity of both the individual renewable energy systems (oftentimes simply termed "the renewables") and their hybrid configurations stems from many inherent natural features and technological developments.

The features for "*the renewables*" are:

1) Inexhaustible and readily available natural resources, predominantly present in most parts of Africa;
2) Relatively environmentally friendly
3) Very scalable, from micro- to mega- solar/wind turbines, and from single-panel to multiple-panel PV (solar) systems; and
4) They have long lifetime (i.e. 20-50 years), and very low maintenance cost;

The features for "*the hybrid configuration system*" are:

a) Provide more reliable and higher quality energy at lower economic and environmental costs; and
b) More environmentally friendly than any of the conventional energy generators.

Unfortunately, despite these attractions and the abundance of these renewable energy resources, neither the individual renewables nor their hybrid configuration has found considerable applications in Nigeria. The telecommunications sector of the economy is a case in point. This study has demonstrated that the telecommunications industry is one of the areas where renewable energy systems could be deployed to maximize national, economic and environmental benefits, as obtains in many developed and developing countries, including a number of countries in Africa. (Setiawan, Ahmad , Yu , & Chem , 2009). As discussed in chapter 1, Section 1.1, more specifically, this study has shown that GSM Base Stations in different rural areas of the country could adequately be powered by renewable hybrid energy systems at less (minimum) economic and environmental costs than the use of conventional diesel generators only, as it is the case now.

From the Results and analysis, it can be shown that using renewable options which could run for approximately 12 hours a day would save Globacom telecommunication company about half the number of litres spent on diesel in a year.

The study also confirmed the significance of facilities' locations in the choice of renewable power options. A literature by Ashok, (2007) has it that the performance of solar and wind energy systems (singly or in combination) are strongly dependent on the climatic conditions at the location. This has been discussed extensively in Section above, and illustrated in the above Figures in the same section. Much ground was also covered in the literature review Section on economic costs; not only was it important to determine factors for the choice of renewable power options, but also pointing out relevant information for making critical decisions on systems design and economic investment. Many assertions (or observations) in the review were either confirmed numerically (as shown in the tables) or illustrated graphically by the simulation results presented here in the study. These include: i) that the more the renewable energy components in a hybrid system, the higher the initial capital cost [ICC], and this cost has no significant variation with the BTS sites. On the other hand, diesel only system has lower initial capital cost [ICC], but higher total net present cost [NPC]; ii) that the total net present cost (NPC) increases with the decrease of renewable energy components in the hybrid systems (see Figures), but decreases as the lifetime of the hybrid systems increases, and these differences vary significantly from one hybrid system type to another, but not with the BTS sites; and iii) that the hydro system appears to be the most cost effective renewable energy component that could be deployed for BTS sites in any rural area in Nigeria.

This study has also addressed the issue of pollution reduction as a major justification for alternative energy applications, as adequately reviewed in the literature review section and quantitatively demonstrated by the simulation results. Given that the major source of pollution in any alternative energy application, such as the hybrid system, is CO_2 emitted by the diesel generator component of the application, this study confirmed the observation that the more the number of the renewable energy components (in combination with a diesel generator (DG)) in any renewable energy hybrid system, the lower the CO_2 generated by the generator and hence the minimal is the pollution of the environment by the hybrid system. In other words, by increasing the renewable energy penetration in any alternative energy system, the power drawn from the diesel component of the system is minimized, thereby reducing the environmental pollution (the amount of CO_2 emitted) by the system. This study seems to have confirmed this observation with the comparison of pollutant emissions of CO_2 with renewable energy and without renewable energy as follows: PV/Wind/Diesel (7.460), Wind/Diesel (8.419), PV/Diesel (12.872), and Diesel only (13.799). Diesel only had the highest emission in all cases.

IV. RECOMMENDATIONS

A. For simulations using Solar and Wind, it is important to inspect the characteristics of each component thoroughly to aid selection for best performance. In addition, it is notable that when cascading was done with same products type and characteristics the optimization improved.

B. Since this study only looked at improving hybrid power supply systems for GSM operations in Nigeria, it is suggested that further studies look at formulating standards and policies that will define GSM base station siting in Nigeria with a view to reducing environmental pollution.

C. Since Hydro-turbine system appears to be the most cost effective renewable energy component and given that due to cost an actual prototype could not be used in this study, therefore it is recommended that a hybrid system prototype using Hydro- and Diesel- only be built and tested to power a GSM base station in a rural area during future research in order to corroborate the findings in this study.

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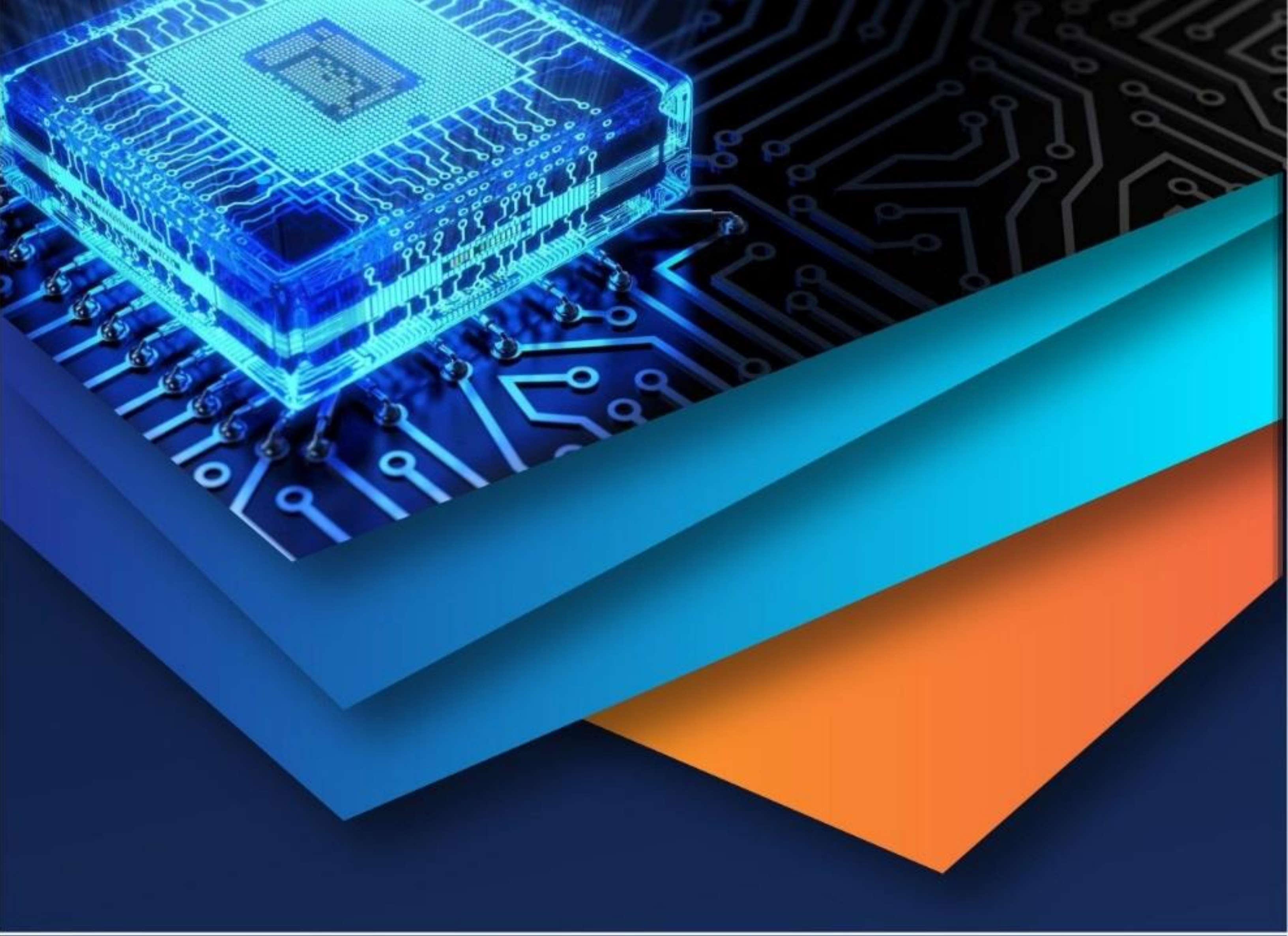

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