Sustainable Energy Growth In Nigeria: The Role Of Grid-Connected Hybrid Power System

O. D. Atoki, B. Adebanji, A. Adegbemile, E. T. Fasina and O. D. Akindele

Abstract: Fossil fuels, as of today, dominate power generation in Nigeria with its consequent environmental issues. The country is, however, blessed with immense Renewable Energy Sources (RES)-solar, hydro, biomass, and wind resources which can be effectively utilized for green power generation to bridge the wide power supply-demand gap. This paper reviewed the current status of renewable energy in Nigeria vis-à-vis global trends, identified the barriers to renewable energy penetration and recommended some measures in ensuring sustainable energy development for the nation. The paper also proposed the use of Grid-Connected (GC) Hybrid Power System (HPS) as a supplement to the power supply through the grid. To buttress the point, techno-economic evaluation of grid-connected Small hydropower-Solar PV-Diesel hybrid system in two selected villages in the southwestern states of Nigeria were carried out. Solar, hydro, and load demand data of selected towns were obtained National Aeronautics and Space Administration (NASA) website, River Basin Authorities (RBA), and Distribution Companies (DisCos) respectively. Sizing and costing of components were determined and analyzed for optimal economic and technical evaluation. The proposed work presented the best optimal hybrid system configurations for each selected location and comparisons were made with off-grid configuration of the same topology based on technical and economic considerations. The work will be useful for policymakers, investors and researchers in making unbiased decisions towards integration of renewable energy hybrid power generation into the national grid.

Index Terms: Grid-connected, hybrid system, renewable energy, south-western states, sustainable energy

1 INTRODUCTION

Power supply in Nigeria is inadequate, unreliable and unsustainable. This indeed has been a major obstacle in her economic and industrial development plans [1 et al], [2 et al]. The slow pace of economic development has increased the poverty level among her citizens. Almost half of the Nigerian populations are not connected to the grid (with most of them living in the rural areas), even those that are connected to the grid experienced perennial power outages, low voltages and load shedding [2 et al], [3]. The country's electricity per capita consumption is among the lowest in Africa despite its abundant fossil and Renewable Energy Sources (RES). Power generation in Nigeria relies mainly on two sources, non-renewable thermal (natural gas and coal), and renewable water or hydro [4]. The former has added to the effect of global warming and climate change on account of overextended dependency on the fossilised energy in Nigeria which is now a major concern in the world.Globally, generation of electricity through fossilised fuels has contributed to almost one-third of greenhouse gas emissions. It is therefore, expedient to improve the standard of living of the people by moving towards green economy [5 et al]. A projected survey carried out on medium and long-term electricity demand was put at 30,000 MW and 192,000 MW respectively [6 et al]. The total current installed generation capacity is 12,522 MW (with gas/thermal contributing 85% and hydro contributing the remaining 15%). The available generation capacity fluctuates between 3000 MW-5000 MW [1 et al], [3]. Hence, there is a need for significant improvement in electricity generation to meet this demand through alternative source-RES.

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Sustainable energy system is an essential ingredient for any meaningful development in any nation. In order for energy system to be sustainable, it must be cost-effective, reliable and environmentally benign. The use of renewable energy technologies will surely enhance sustainable development by ensuring reliable and affordable modern energy for the populace [6 et al], [7].

Electricity supply from Renewable Energy Sources (RES) alone cannot be said to be reliable due to its stochastic nature or randomness of weather [2 et al], [7]. Hence, the need to combine two or more renewable energy sources to form a hybrid system. Hybrid Power System (HPS) consisting of one or more renewables combined with/without conventional energy sources is better than a single system in technical and economic terms, for it has the lowest unit cost values and higher system reliability [8], [9 et al]. Investment in renewable energy Hybrid Power System (HPS) technologies are expected to create large number of employment opportunities for both skilled and unskilled people [9 et al], [10 et al]. Researches have been carried out by many scholars to offer solutions to the problems of power generation and environmental issues in Africa [4], [14 et al]. Shimaa et al [15] carried out techno-economic analysis on grid-connected PV-Wind-Biomass HPS for a small village in Egypt using HOMER. The optimal configuration resulted in reduced emissions and improved investment. The need for decentralised renewable energy system towards sustainable energy supply in Nigeria has been stressed several times in the past [6 et al]. Adepoju and Adebanji [16] implemented economic analysis of a grid-tied PV system using Khulna as a case study. Simulated results were able to meet the load demand of the village optimally. Amit et al [17] carried out feasibility study and optimal design of SHP-PV-DG hybrid power system for Itapaji-Ekiti, Nigeria which is also a related research to proffer solution to power problem in the village. It is a stand-alone HPS; however, this research is grid-connected which showed the technical and economic benefit of the advantage of grid-connected hybrid power system over off-grid power system. Some of the works carried out on renewable energy hybrid system utilization were majorly on stand-alone hybrid system and solar PV-Wind system; very few works have been done on grid-connected systems involving small hydropower (SHP). The paper proposed the use of Grid-Connected (GC) Hybrid Power System (HPS) as a supplement to the power supply through the grid. To buttress the point, a techno-economic evaluation of grid-connected Small hydropower-Solar PV-Diesel hybrid system in two selected villages in the south western states of Nigeria was carried out. The selected villages are Owena (Ondo State), and Itapaji-Ekiti (Ekiti State).

2 SUSTAINABLE ENERGY DEVELOPMENTS IN NIGERIA

An energy system is said to be sustainable if it can meet up with the present energy needs without jeopardizing the ability of the future generation in meeting up with their own demand [4]. Sustainable energy system is supposed to protect the natural resources and be environment-benign.

2.1 Renewable Energy Potentials in Nigeria

Renewable energy is the energy that is produced from natural resources-wind, hydro, tides, sunlight, geo-thermal, heat etc. It replenishes itself through natural process [2 et al], [7], [18]. Even up till now, fossil fuels remain the major part of the natural generation mix. RES are grossly underutilized [7]. There is urgent need to shift from the high cost-environmental unfriendly fuels to renewable energy hybrid technologies in order to achieve sustainable and prevent the adverse effects of climate change. This will enhance will enhance grassroots economic growth and a healthy ecosystem. The country is naturally blessed with abundant RES in almost every part of the nation. It has an estimated 11,250 MW and 3500 MW reserve for large and small hydropower (SHP) respectively. A total of 278 unexploited sites (with over 734.3 MW potentials) have been identified in the country [2 et al], [7], [19]. SHP technology is still at infant stage in Nigeria. The average annual daily radiation varies from 5.55 kW/m^2/day at the coastal region to about 7.0 kW/m^2/day at the northern region. It receives an average of 1.804×10^{15} kWh annually [19]. This value is enough to generate almost 117,000 times the generation capacity [20]. The wind speeds in the country are generally low in the southern region (1.4-3.0 m/s) and high (4.0-5.12 m/s) in the core part of the northern Nigeria. Some studies carried out on the energy potentials in Nigeria showed that the country has a total of exploitable reserve at 10 m height of between 8 MWh/yr to 51 MWh/yr in the peak of Jos Plateau and about 97 MWh/yr in Sokoto [2 et al], [4], [5 et al], [6 et al]. The available biomass resources include wood, grasses, residues, agricultural wastes, etc. It produces about 227,500 tons of fresh animal wastes daily [20].

2.2 Barriers and Future Prospects of RES

Some of the major barriers to RES penetration in the country are low level of awareness, defective energy policies, high capital cost, lack of standard quality control mechanism, low level of technology know-how and social/cultural environment constraints [20], [21], [22 et al]. The future is very bright for renewable energy technologies in the country. Some of the available research and development centres in the country are geared towards improving energy efficiency and integrating RES into the energy generation mix. Some of the available dams and rivers being used for water supply can be used for rural electrification as a standalone hybrid system or connected to the grid to cover the supply-demand deficit.

2.3 Way out?

Governments need to introduce policies that will attract investors into renewable energy industry through introduction of subsidies and grants, loans and other fiscal supports. Political supports are needed from federal, state and local governments in formulation of essential legal and regulatory framework towards creating enabling environment for renewable energy growth. In order to ensure rapid growth for renewable energy technologies, more application of renewable energy technologies (RET) for local adoption like solar cooker, water pumping, street lights should be encouraged. There is need to create more awareness about the benefits of RET, through campaign against deforestation and integration of environmental consideration into energy development plans. Renewable energy should be introduced in primary, secondary and tertiary institutions especially for science students. The available research and development centres should be well-equipped to support the global green economy drive. The existing energy policies should be modified for efficient utilization of RET.

2.4 Grid-connected HPS

Grid-connected HPS is a hybrid system that is connected or tied to the grid. It can also be referred to as on-grid. The excess power generated can be exported to the grid. It is less expensive and more economical than the off-grid system since it does not need any energy storage system. Grid-connection must be done with the approval of power utility companies in order to avoid total system collapse due to technical incompatibility. Off-grid or standalone (unlike on-grid) system is totally independent of the grid. It is especially useful for areas that are geographically and economically infeasible for grid extension. Hence, there is need for energy storage system.

3 GRID-CONNECTED HPS-A CASE STUDY OF SOUTH-WESTERN STATES OF NIGERIA

3.1 Data Acquisition

The hydro resources were gathered from the records of Benin-Owena River Basin Development Authority and solar resources were obtained from National Aeronautics and Space Administration (NASA) website [23], [24]. Load demand data were obtained from Benin Electricity Distribution Company (BEDC), Nigeria [25], [26].

3.2. Description of the Study Areas

The study areas covered two locations in the South-western states of Nigeria. The villages selected from each state are Owena (Ondo State), and Itapaji-Ekiti (Ekiti State). The study areas are shown in the Fig. 1

Fig. *1 Study Areas Map [21]*

3.2.1. Case Study area I-Owena (Ondo State)
Owena is located on latitude 7˚12'56"N and 5˚01'08"E. Global Positioning System (GPS) aerial view Owena River, Owena is shown in Fig. 2. The total load demand of Owena town is estimated to be 400 kW [26]. The village majorly relies on diesel and gasoline generators as supplement whenever there is power outage on the grid.

3.2.2. Case Study area II-Itapaji (Ekiti State)
Ele River is situated in Itapaji-Ekiti. It is located on latitude 7˚57'09"N, 5˚27'55"E. Global Positioning System (GPS) aerial view Ele River, Itapaji-Ekiti is shown in Fig. 3. The total load demand of Itapaji-Ekiti is estimated to be 50 kW [27]. The village majorly relies on diesel and gasoline generators as supplement whenever there is power outage on the grid.

Fig. 2 *GPS Aerial View of Owena River, Owena [29]*

Fig. 3 *GPS Aerial View of Ele River, Itapaji-Ekiti [29]*

3.3 Research Approach
The load, hydro and solar resources data were collected and analysed. Sizing and costing of components were determined to ensure best technical and economic evaluation. The modelling and simulation of the grid-connected Small hydropower-solar PV-diesel (SHP-Solar PV-Diesel) hybrid system for each selected village was done for the hybrid system components by feeding the collected data into HOMER software [28]. Simulation was run on the data fed into HOMER with and without grid in order to obtain the best configuration that would produce lowest levelised cost of energy (L.C.OE.) and net present cost (N.P.C.). The typical SHP-Solar PV-Diesel models for the two case studies are shown in Fig.4 and Fig.5.

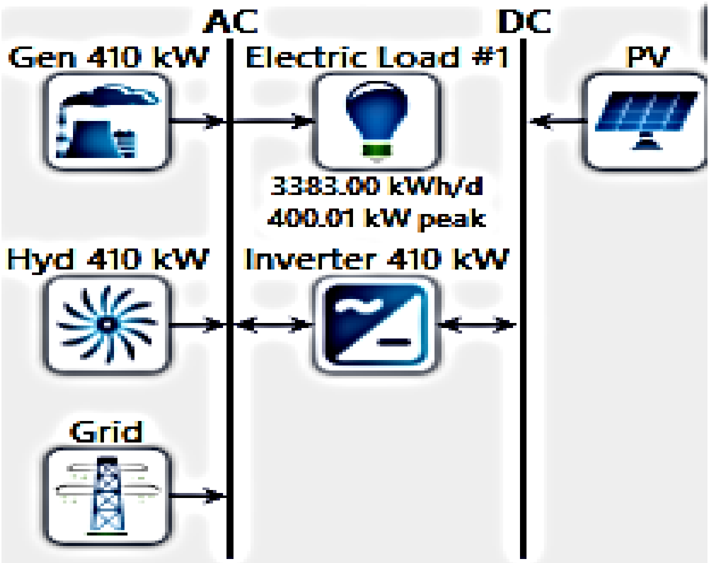

***Fig. 4** Owena Small hydropower-solar PV-diesel generator model*

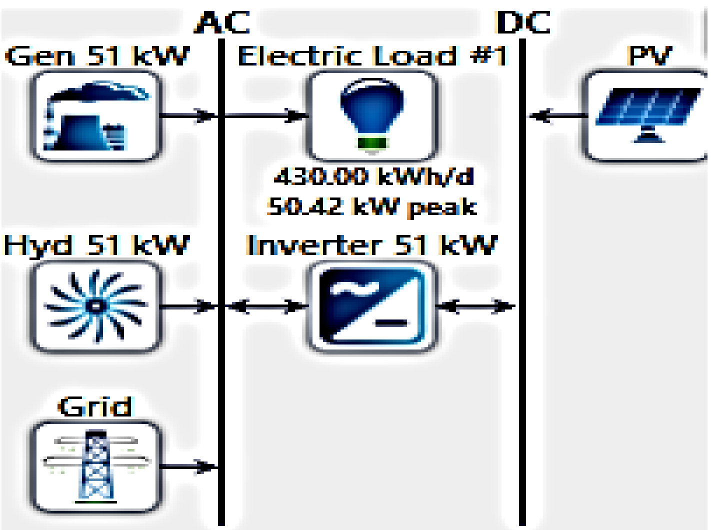

***Fig. 5** Itapaji-Ekiti Small hydropower-solar PV-diesel generator model*

3.4 Hydro, Solar Resources and Load demand of the Locations

The summary of hydro and the solar data collected for over the past twenty years in each location are shown in Tables 1 and 2 respectively. The daily load demand graphs are as shown in Fig.6 and Fig.7.

TABLE 1
SUMMARY OF OWENA RIVER MONTHLY AVERAGE HYDRO AND SOLAR RESOURCES DATA IN OWENA

MONTH	HEAD (m)	DISCHARGE (L/s)	PEAK SUN HOUR (kWh/m^2)	TEMPERATURE (°C)	CLEARNESS INDEX
JANUARY	0.87	4690	5.42	30.46	0.59
FEBRUARY	0.82	4030	5.39	31.08	0.55
MARCH	0.82	4000	5.41	30.65	0.53
APRIL	1.12	8220	5.35	29.96	0.51
MAY	1.61	17530	5.03	28.87	0.49
JUNE	2.01	26170	4.62	28.04	0.46
JULY	2.40	33690	4.16	27.53	0.41
AUGUST	2.56	37300	3.77	27.29	0.37
SEPTEMBER	2.33	32220	4.37	27.63	0.42
OCTOBER	2.05	23540	4.95	28.29	0.50
NOVEMBER	1.58	16130	5.47	29.29	0.59
DECEMBER	1.07	7620	5.44	29.88	0.61
ANNUAL AVERAGE	**1.06**	**17928**	**4.95**	**29.09**	**0.50**

[23, 24]

TABLE 2
SUMMARY OF ELE RIVER MONTHLY AVERAGE HYDRO AND SOLAR RESOURCES DATA ITAPAJI-EKITI

MONTH	HEAD (m)	DISCHARGE (L/s)	PEAK SUN HOUR (kWh/m^2)	TEMPERATURE (°C)	CLEARNESS INDEX
JANUARY	0.91	4380	5.42	30.46	0.56
FEBRUARY	0.85	3650	5.39	31.15	0.52
MARCH	0.82	3780	5.41	30.66	0.51
APRIL	1.02	8220	5.35	29.82	0.52
MAY	1.36	17530	5.03	28.78	0.52
JUNE	1.77	26170	4.62	27.96	0.50
JULY	2.11	33720	4.16	27.49	0.45
AUGUST	2.42	37300	3.77	27.34	0.40
SEPTEMBER	2.44	32220	4.37	27.64	0.42
OCTOBER	2.15	23520	4.95	28.34	0.49
NOVEMBER	1.81	16120	5.47	29.39	0.54
DECEMBER	1.20	7680	5.44	29.91	0.57
ANNUAL AVERAGE	**1.57**	**17861**	**4.95**	**29.08**	**0.50**

[23, 25]

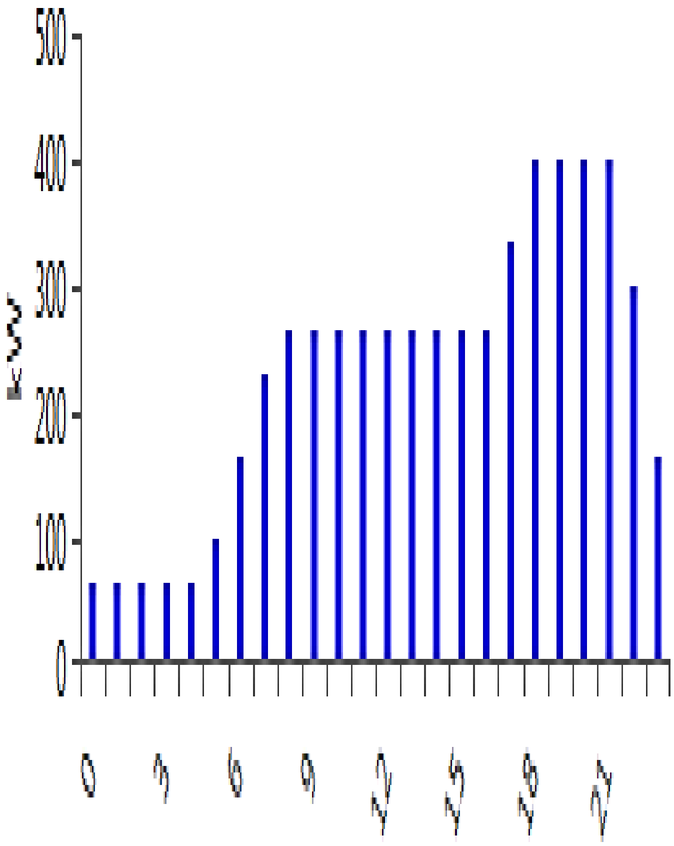

Fig. 6 *Daily Load Profile Chart of Owena*

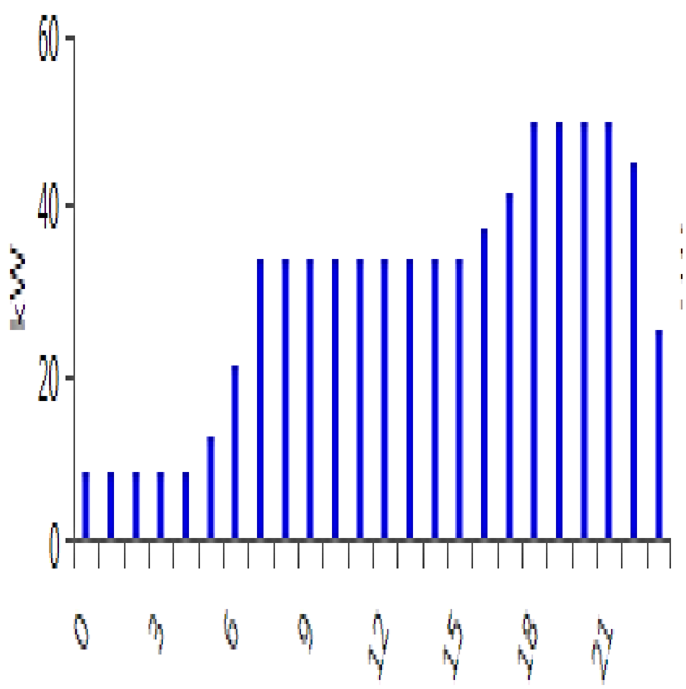

Fig. 7 *Daily Load Profile Chart of Itapaji-Ekiti*

TABLE 3
MATHEMATICAL EQUATION TERMS AND MEANINGS

Nomenclature	Meaning	Nomenclature	Meaning
A_p	Area of single PV panels	E_{DG},	Nominal power of diesel generators (kVA)
$P_{px}(t)$	Output power of solar PV	E_{ff}	total energy content of oil
N_{px}	Number of PV modules	η_{DG}	Efficiency of diesel generators
$E(t)$.	Insolation data	P_{in}	Inverting power
η	Energy conversion efficiency (%)	P_{ch}	Peak power demand
$P_{(W)}$	Out Power	η_{in}	Efficiency of the inverter
g	Acceleration due to gravity	ρ	Density of water
ηHG	Hydro Generator Efficiency	Q	Water flow rate (m^3/s)
H_n	Net Head (m)		

3.5 Hybrid Components Mathematical Model
The mathematical model of each component was presented in the following sections.

3.5.1 Mathematical model of small hydro generator
The power available from SHP generator can be calculated as in Eq. (1) [16]

$$P(W) = \eta HG\rho gQH_n \quad (1)$$

3.5.2 Solar PV Mathematical Model
The electric energy produced by a solar PV system is calculated as in Eq. (2) [18]

$$P_{PV}(t) = \eta A_p N_{PV} E(t) \quad (2)$$

3.5.3 Diesel Generator Mathematical Model
The capacity of Diesel Generator (DG) can be described as in Eq. (3) [22 et al]

$$E_{DG} = \eta_{DG} E_{ff} \quad (3)$$

3.5.4 Inverter Mathematical Model
Inverter power is shown in eq. (4) [22 et al].

$$P_{in} = {}^{Pch}/_{\eta_{in}} \quad (4)$$

3.6 Costing of Components and Assumption
A rule of thumb in costing of components was followed in estimating the initial capital (total installation cost of a component at the start of a project) and operating cost

(annualised value of operation and maintenance cost, fuel cost and replacement cost). The basis or premise for the costs of all components, Multi Year Tariff Order (MYTO), project lifetime and assumed rate were presented in the Appendix A.

3.7 Results and Discussion

3.7.1 Economic Comparison of Grid-Connected and Off-Grid Configurations

The best configuration is grid-connected SHP-PV-Diesel in Owena and Itapaji-Ekiti locations based on economic and technical considerations. Summary of economic comparison of each location is shown in Table 5. Negative Net Present Cost (N.P.C) means revenue is greater than cost while positive N.P.C. means cost is more than revenue. Negative Levelised Cost of Energy (L.C.O.E) indicates that power production is far more than demand. Return on Investment (R.O.I.) and Discounted Payback Period are also presented in Table 4. This shows that grid-connected configurations are better than off-grid configurations economically as R.O.I. of off-grid configurations show negative. Grid-connected SHP-PV-Diesel discounted payback period in Owena location is 6.7 years and that of Itapaji-Ekiti location is 1.82 years as off-grid SHP-PV-Diesel in both locations cannot break even.

TABLE 4

ECONOMIC COMPARISON OF THE LOCATIONS

LOCATION	TOPOLOGY	LCOE ($/kWh)	NPC ($)	ROI (%)	DISCOUNTED PAYBACK PERIOD (yr)
OWENA	GRID-CONNECTED SHP-PV-DIESEL	-0.0486	-3.39 M	15.5	6.70
	OFF-GRID SHP-PV-DIESEL	0.336	5.36 M	-6.9	N/A
ITAPAJI-EKITI	GRID-CONNECTED SHP-PV-DIESEL	-0.169	-3.57 M	56.8	1.82
	OFF-GRID SHP-PV-DIESEL	0.453	919,274	-4.4	N/A

3.7.2 Evaluation of Power Production of Grid-Connected and Off-Grid Configurations

The summary of the comparisons of power productions of best grid-connected topologies and off-grid configuration of the same topologies is shown in Table 5. The power production from each location was compared and it can be seen that grid-connected configurations are better than off-grid configurations of the same topology with the grid-connected. There were grid sales on the grid-connected as compared with the off-grid in which excess electricity could not be sold via it. It will only waste. Grid sales on grid-connected configuration made it better than off-grid configurations technically.

TABLE 5

COMPARISONS OF POWER PRODUCTIONS OF OPTIMAL GRID-CONNECTED AND OFF-GRID CONFIGURATIONS OF THE STUDY AREAS

LOCATION	TOPOLOGY	TOTAL POWER PRODUCTION (kWh/year)	GRID SALES (kWh/year)
OWENA	GRID-CONNECTED SHP-PV-DIESEL	6,023,756	4,164,938
	OFF-GRID SHP-PV-DIESEL	3,213,775	-
ITAPAJI-EKITI	GRID-CONNECTED SHP-PV-DIESEL	1,847,036	1,635,952
	OFF-GRID SHP-PV-DIESEL	1,494,820	-

3.7.3 Grid-Connected SPH-PV Configuration

Grid-connected SPH-PV Configuration cannot compete with grid-connected SHP-PV-Diesel as a result of not being able to deliver the total load demand all the time. Even though grid-connected SHP-PV has lower negative L.C.O.E. as compared with grid-connected SHP-PV-Diesel in Itapaji-Ekiti location, there are still unmet load. Grid-connected SHP-PV has higher negative L.C.O.E. as compared with grid-connected SHP-PV-Diesel in Owena location as shown in Table 6. This is as a result of the stochastic nature of weather affecting performance of solar PV and hydro. Therefore, it has to be complemented with diesel generator.

3.7.4 Pollution Emission Consideration

Evaluation of pollution emissions of DG in grid-connected configuration and grid-connected DG configuration of each location is shown in Table 7. The Table showed the emission saved as compared with when solely running diesel generator which means there is a pollution reduction with renewable hybrid configurations.

Table 6
Comparisons of Power Productions of Optimal Grid-Connected SHP-PV-DG and Off-grid SHP-PV Configurations of the study Areas

LOCATION	TOPOLOGY	TOTAL POWER PRODUCTION (kWh/year)	UNMET LOAD (kWh/year)	L.C.O.E. ($/kWh)
OWENA	GRID-CONNECTED SHP-PV-DIESEL	6,023,756	-	-0.0486
	GRID-CONNECTED SHP-PV	3,213,775	281,239	-0.0321
ITAPAJI-EKITI	GRID-CONNECTED SHP-PV-DIESEL	1,847,036	-	-0.169
	GRID-CONNECTED SHP-PV	1,451,769	34,191	-0.211

TABLE 7
EVALUATION OF EMISSIONS

LOCATION	TOPOLGY	TOTAL EMISSION (kg/yr)	EMISSION SAVED (kg/yr)
OWENA	GRID-CONNECTED SHP-PV-DIESEL	2,153,726.1	94,890.5
	GRID-CONNECTED DIESEL	2,248,616.6	
ITAPAJI-EKITI	GRID-CONNECTED SHP-PV-DIESEL	308,127.1	16,205
	GRID-CONNECTED DIESEL	324,332.1	

4 CONCLUSION AND RECOMMENDATIONS

This paper discussed the current status, barriers and future prospects of renewable energy in Nigeria. The need to use grid-connected hybrid system was also discussed. The work presented a model for implementation of grid-connected SHP-PV-Diesel hybrid system in two selected South-western states of Nigeria. This study explored optimal design and economic evaluation for grid-connected small hydropower (SHP) hybrid's installations where solar Photovoltaic (PV) system and Diesel Generator (DG) are integrated. The grid-connected hybrid systems with SHP-PV-Diesel generator were found to be better than any other hybrid combinations in terms of L.C.O.E., N.P.C., R.O.I. and Payback Period in Itapaji-Ekiti and Owena villages. Thus, this research revealed in details, by considering the value of R.O.I., and Payback Period, beyond existing studies that only revealed the L.C.O.E. and N.P.C. which are not enough to conclude economic evaluation for this kind of research. Besides, the meaning of negative L.C.O.E. and N.P.C. were clearly defined. Integration of other renewable energy sources in the country with small hydropower will ensure availability of power and reduction of emission that poses threat on ecosystem at affordable price. The private sectors, federal, state and local governments need to collaborate together in ensuring the growth of renewable energy technologies by creating more awareness on the benefits and prospects of renewable energy. The work will serve as an important tool for stakeholders in the power industry towards the use of renewable energy hybrid technology in energy generation.

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APPENDIX

Costing of Components and Assumption

COMPONENTS/COST	INITIAL CAPITAL ($)	REPLACEMENT COST ($)	OPERATION & MAINTENANCE ($)	FUEL PER LITRE ($)	MYTO ($)
Hydropower Plant/ 500 kW	4,180.8	60% of Initial Capital	2.5% of Initial Capital Per Year	-	-
Diesel Generator/ kW	1,200	80% of Initial Capital	0.020 Per kWh	0.6301	-
Solar PV/kW	1,000	70% of Initial Capital	22.22 Per kW per Year	-	-
PV Inverter/kW	417	80% of Initial Capital	-	-	-
Grid Sale/ kWh	-	-	-	-	0.2815

Assumed Rates

Metrics	Rate (%)	Project Lifetime
Discount	8	-
Inflation Rate	2	-
Annual Capacity Shortage	25	-
Year	-	25
Discount	8	-

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