Building Integrated Hybrid PV-Battery-Diesel Generator Energy System for Oil Producing Communities in Niger-Delta Region of Nigeria

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Abstract- The potential of the use of hybrid PV-Battery-Diesel generator for household in the rural oil producing communities in the Niger Delta of Nigeria is presented. The analysis was done by the optimum configuration of the hybrid system through top-ranked system configuration, according to the Net Present Cost (NPC) in the HOMER platform. The optimal system delivers the best components alongside appropriate operating strategies to provide the most efficient, reliable cost-effective system possible. The system investigated reduces CO_2 emissions by 28.2%/year. The implementation of the hybrid RES will, therefore, reduce the emission level of the over-polluted Niger Delta region by the activities of oil producing companies and the use of standalone diesel generators. The system has a better potential for providing the energy needs of the households in the oil producing communities as compared to a standalone Diesel system as net present cost is reduced by 17%. However, reliability of power supply is assured with the hybrid RES.

Keywords- hybrid renewable energy; HOMER; Niger Delta region; oil producing communities.

1. Introduction

Economic viability and advancement of any nation is directly related to its energy generation capacity and sustainability. Nigeria is located in the western part of the Africa continent and is considered as the giant of Africa. The geographical area covered by the country is 923,770km^2 of which total land area is 910,770km^2; and the extensive coastline of Nigeria shares an approximate area of 853km^2. The South-South (the Niger-Delta region) geo-political zone, which is one of the six geo-political zones, produces 100% of the over 70% petroleum (oil and gas) revenue contribution of the Federal Government of Nigeria (FGN) revenue [1]. The petroleum continues to maintain its prominence as the single most important source of the FGN revenue and foreign exchange earner. However, despite the fortunes of the petroleum sector, other sectors of the FGN's economy are declining. For example production of electricity declined by 13.4% between 2002 and 2006 [1] and no significant improvement.

In Nigeria, there is a gross electric power poverty, which required about 90% of Nigerian businesses to own diesel generators for their daily energy demands [2]. The situation is worrisome for the remote villages, which are located far away from the national utility grid. In particular, the oil producing communities are absolutely located in the Niger-Delta region of Nigeria, which are largely in rugged terrains (see Fig. 1 for the Niger Delta map). Basically, the Niger-Deltan communities, outside the environmental and health concerns [3], lack in the supply of electricity, since it is impractical to extend the national grid to these dispersed populated areas. Meanwhile, electricity is required for such basic developmental services: pipe borne water, health care, telecommunications and quality education. Furthermore, the poverty eradication and Universal Basic Education programmes of the FGN, which are targeted on the rural communities, need electricity to be successful. The absence of electricity supply in the oil producing communities has not only left the dwellers of the communities socially backward, but has left their economic potentials untapped.

Fig. 1. The Niger Delta showing some of the Nigerians' oil producing communities [4]

Majority of the oil producing communities depend on diesel generators and firewood for their daily electricity and heating demands, respectively. Firewood is used by over 60% of the Niger-Deltans [5], which are dominantly oil producing communities' dwellers. Sourcing firewood for domestic usage, basically for heating, is attributed, in part, to the cause of erosion in the Niger-Delta region. The rate of deforestation is about 350,000 [hectares/year], which is equivalent to 3.6% of the present area of forests and woodlands; whereas, reforestation is only at about 10% of the deforestation rate [6]. It is worth noting that the average official pump price of diesel fuel in Nigeria is about $1.00/Liter since January 2012. However, this price is increased almost by 50% ($1.50/Liter) in the oil producing communities seemingly due to the rugged terrains and the wrong notion of high economic attachment to the oil producing communities.

Since the absolute majority of the oil producing communities totally depends on diesel generator and firewood for energy need, it implies that the combined effect of stringent Government's policy against indiscriminate deforestation and global hike in fuel prices would have undesirable impact on the social-economy of the communities – especially exacerbated crime rate.

Therefore, Renewable energy sources (RES) as alternative or complement energy sources in these oil producing communities would be of great benefits. The attendant concerns for global warming as a result of conventional energy conversion processes play important roles in the general acceptance of RES. Since the supply of RES is transient, the search to store the harnessed energy is paramount. Integrating hybrid RES into building would provide reliable and secured energy for the Niger-Delta communities. Hence, optimized building integrated hybrid PV-battery-diesel generator energy system for oil producing communities is long overdue.

Optimisation studies on hybrid PV/diesel systems size can be found in [2], [7]. An hourly solar energy series, a model of hybrid PV/diesel system and an hourly load profile are normally used in the optimisation of PV-battery-diesel generator. Therefore, this paper proposed an optimal building integrated hybrid PV-Battery-Diesel generator energy system for households in the oil producing communities of the Niger-Delta region, on the basis of average energy demand/household in the rural communities of the Niger-Delta region. The choice of complementing diesel generator with the PV energy is on the fact that: the area is located in abundant solar irradiation zone, 3.2 – 5.5 $kWh/m^2/day$ (see figures Fig. 2 and Fig. 4 for the solar insolation distributions); the established 7.5MW joint venture solar panel manufacturing plant in Nigeria by the National Agency for Science and Engineering Infrastructure Development Agency (NASEI); and ultimately, to reduce the pollutant emissions from the use of diesel generators.

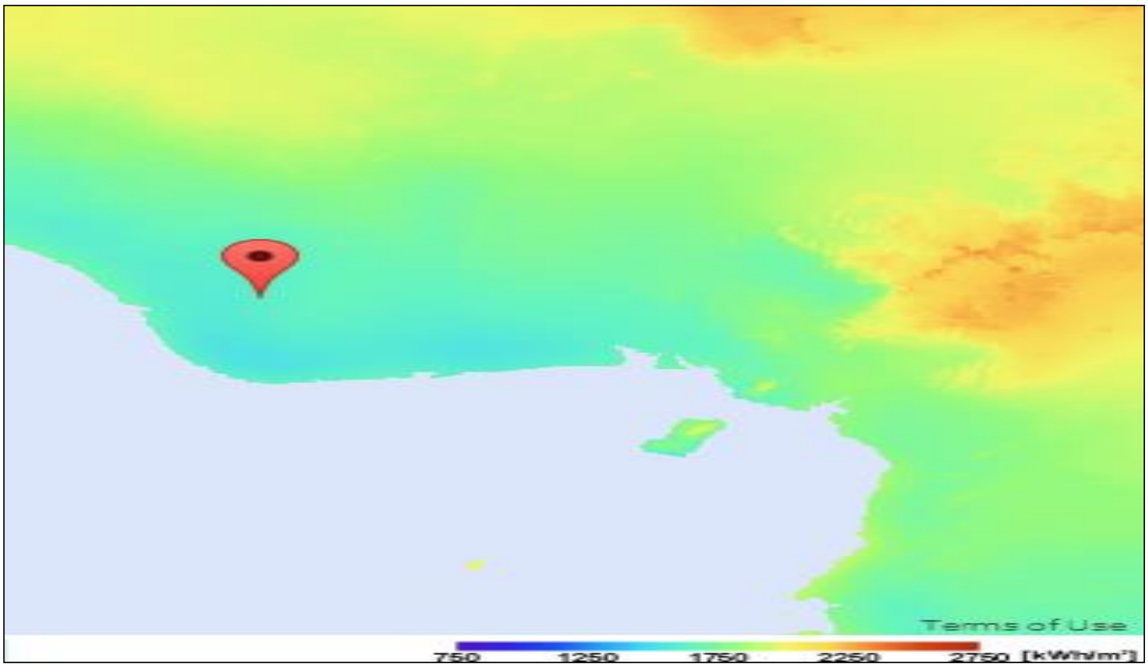

Fig. 2. Yearly solar irradiation on horizontal surface of Niger Delta, Nigeria [8]

The HOMER software is used to facilitate the hybrid RES configuration. The HOMER optimum system configuration is based on the top-ranked system configuration.

2. System description

The hybrid RES comprises solar PV panel, diesel generator, battery pack, charge controller and converter (inverter and rectifier), as depicted in Fig. 3. The solar PV panel produces Direct Current (DC), which is stored in the battery pack through the charge controller. The brown colour flow line, in Fig. 3, depicts the flow of DC current; whereas the red flow line depicts the flow of Alternating Current (AC). The diesel generator (DG) produces AC current, which is supplied directly to the household. However, the DG equally charges the battery pack when it runs at full power (cycle charging control strategy), via the rectifier. It should be noted that few houses in the oil producing communities have other appliances (e.g. refrigerator and water-pump), which are not considered in the daily power load profile presented in Fig. 4. Therefore, in such situation the DG will directly power such appliances. The electrical energy stored in the battery, in the form of chemical energy, is converted into AC power by the converter to meet the electrical load demand of the household.

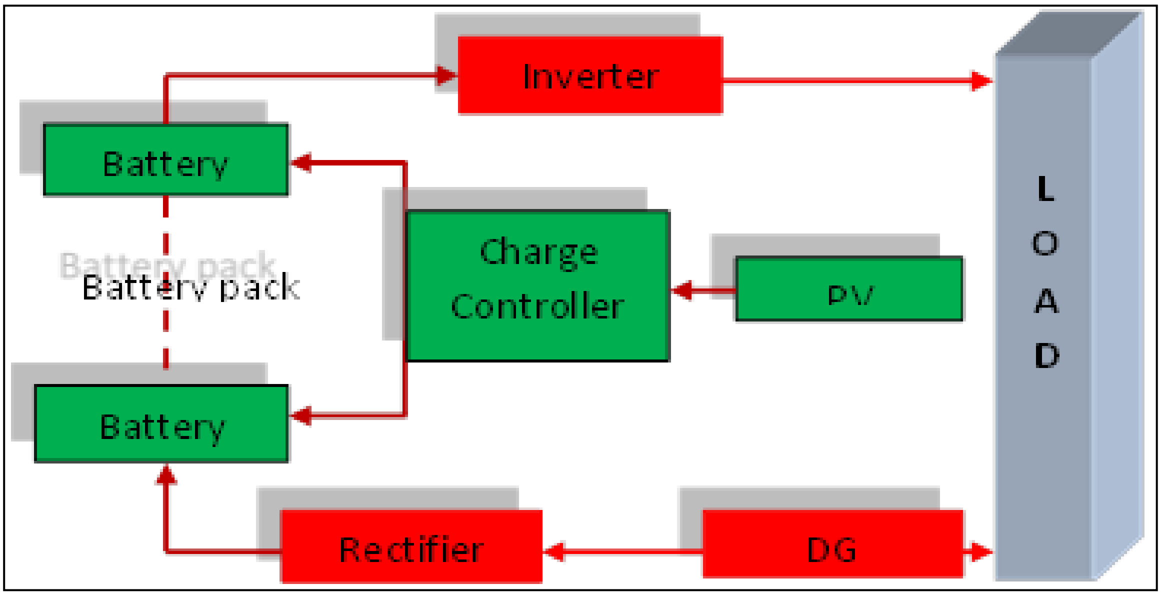

Fig. 3. Description of the Hybrid Energy Source

3. Data Collection

The Niger-Delta region of Nigeria is located in geographical coordinates of 5.3261°N, 6.4708°E; with Fig. 2 showing the region yearly solar irradiation on horizontal surface. Fig. 4 shows the Niger Delta region monthly solar irradiation on horizontal plane.

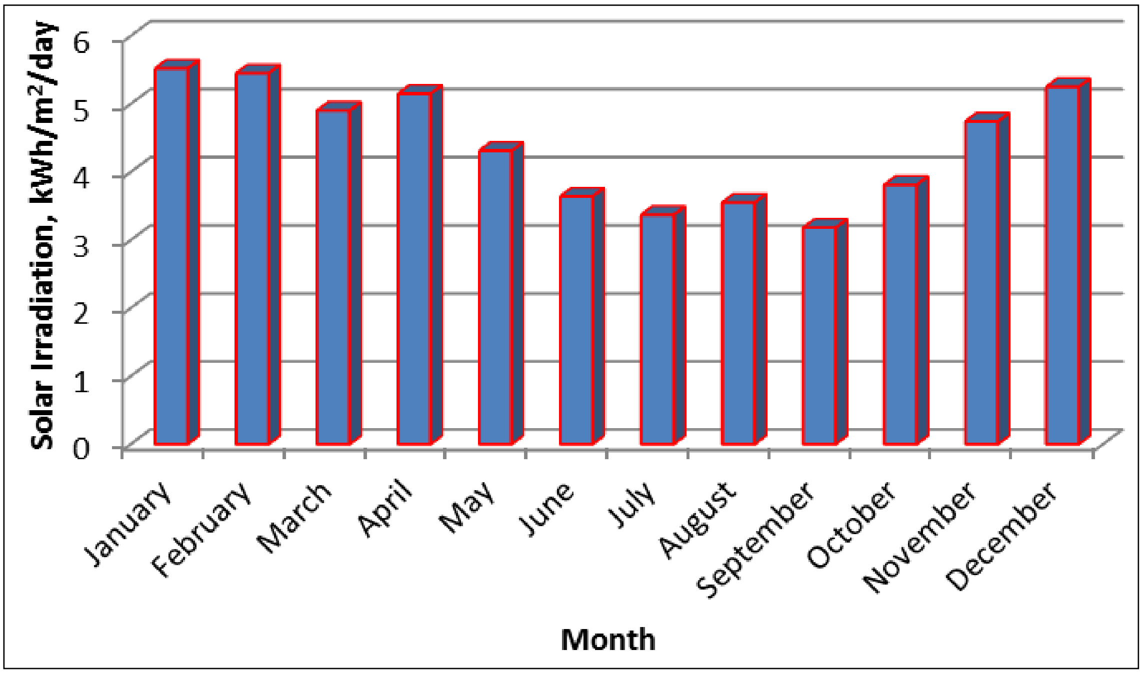

Fig. 4. The Niger-Delta monthly solar irradiation on horizontal plane [8]

The Load power profile shown in Fig. 5 represents a typical rural household in the oil producing communities of Nigeria. The profile was recorded on day to day basis and monitored over a period of one month to compute the average daily energy requirement of the household. It should be noted that few households in the oil producing communities have other appliances (e.g. refrigerator and water-pump), which are not considered in the recorded daily power load profile. However, the hybrid RES is flexible to account for such load by using the DG to directly power such appliances.

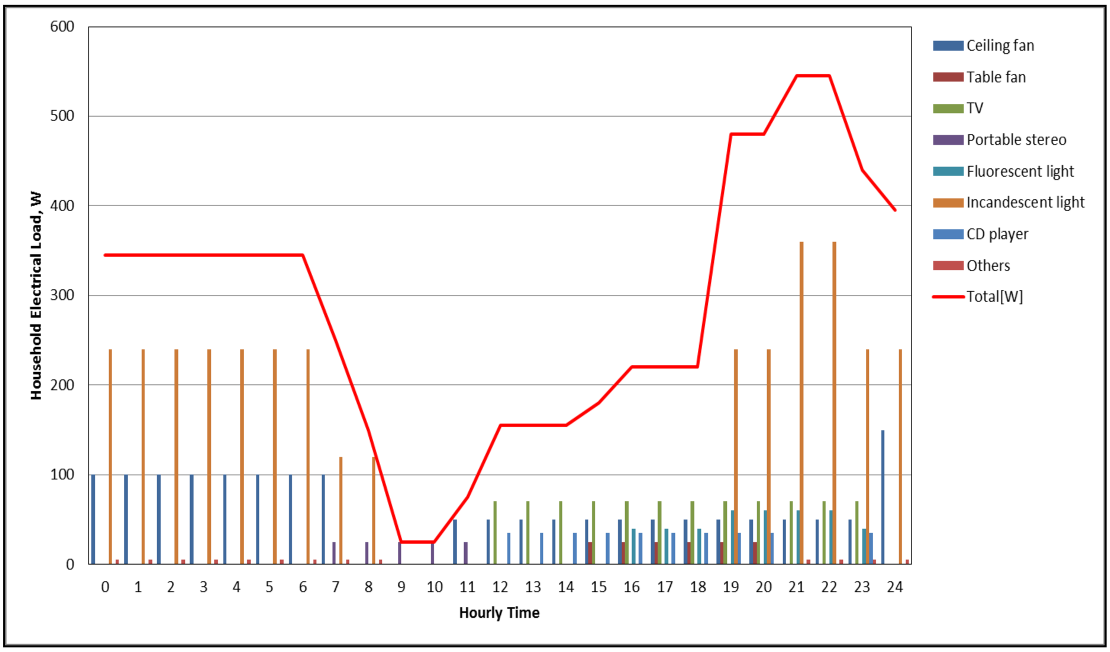

Fig. 5. Load power profile of a typical household in the oil producing communities on a typical day

4. System Specification

The technical and economic specifications presented in [2], with the modification to the fuel price to reflect the current reality, are adopted in the present analysis. Basically, the PV panel, diesel generator and battery type where chosen because of their technical and availability in the Nigerian market.

Table 1. Techno-economic specification

S/No	Description	Specification
1	*PV modules (DB F20)*	Polycrystalline
	Nominal power	20W
	Nominal load voltage	17.5V
	Short circuit current	5.03A
	Bus voltage	24V
	Nominal efficiency	12%
	Nominal operating temperature	47^{o}C
	Temperature coeff. of power	0.97%/^{o}C
	Capital cost	75US$
	Replacement cost	75US$
	Operating and maintenance cost	0*
	Life time	25yrs
	Slope	8.8125^o
	PV module floor area	0.32m^2
2.	*Diesel Generator*	Caterpiller
	Cost/kW	600US$/kW
	Replacement	600US$/kW
	Operation and Maintenance	0.15US$/hr
	Fuel cost	1.5US$/liter
	Minimum load factor	40%
3.	*Battery bank (Trojan T-105)*	
	Capital cost	90US$
	Replacement	90US$
	Operation and maintenance	2US$/yr
	Nominal voltage	6V
	Nominal capacity	225Ah
	Nominal energy capacity of each battery	1.35kWh
	Minimum battery life	5yr
	Minimum state of charge	30%
	Life time throughput	845kWh
4.	*Converter*	
	Maximum power	1kW

Capital cost	1000US$
Replacement	1000US$
Operation and maintenance	100US$/yr
Efficiency	98%
Life time	20yrs
Rectifier capacity relative to inverter	100%

*The operating and maintenance cost is taken to be zero since it is negligible for a distributed systems [9].

5. Analysis of the Hybrid RES

The analysis was done in the HOMER software platform. The HOMER software is based on top-ranked total NPC of the system configuration. Input information provided to HOMER includes: electrical loads, renewable resources (such as a typical yearly solar insolation data, see Fig. 4), component technical details/costs (Table 1), constraints, controls and type of dispatch strategy. HOMER uses the life cycle cost in its computational algorithms. HOMER's optimization and sensitivity analysis algorithms allowed the rapid techno-economic evaluation of a large number of technology options whilst accounting for variations in technology costs and energy resource availability.

5.1. Results and Discussion

The system calculation and simulation assumed a project's lifetime of 25 years and an annual real interest rate of 6% (the difference between the prevailing interest rate and inflation rate). The base case for the design uses the annual average global radiation of the Niger-Delta region of Nigeria as 4.40kWh/m^2/day, see Fig. 4. Results shown in Fig. 6 are the displayed top-ranked system configurations, which are listed according to their NPC for possible system configuration type.

The optimum system configuration of the hybrid RES, as shown in Fig. 6, indicates that an average household in the Niger-Delta region requires 0.6kW (i.e. 30 PV panels at 20W nominal power each); 1kW diesel generator, 0.5kW converter and twenty-five batteries with life span of ten years. The cost of energy (COE) of the optimum hybrid RES is 0.783US$/kWh and corresponding initial capital required, annual operating cost and NPC are 5,100US$, 1,525US$ and 24,591US$, respectively. The system has a better potential for providing the energy needs of the households in the oil producing communities as compared to a standalone Diesel system a net present cost is reduced by 17%, since the DG standalone NPC is 29,730 US$ (see Fig. 6). Though the COE of 0.783US$/kWh is not competitive with the current COE from the national utility grid. Nevertheless, this would be competitive considering the cost to extend the national grid to the rugged terrain of the rural oil producing communities.

PV (kW)	Gen_1 (kW)	T-105	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Diesel (L)	Gen_1 (hrs)	Batt. Lf. (yr)
0.6	1.0	25	0.50	CC	$ 5,100	1,525	$ 24,591	0.783	770	2,253	10.0
0.6	1.0	30	0.50	CC	$ 5,550	1,564	$ 25,538	0.813	772	2,258	10.0
0.6	1.0	25	0.40	CC	$ 5,010	1,630	$ 25,845	0.823	816	2,696	10.0
0.6	1.0	5	0.40	LF	$ 3,210	1,783	$ 26,008	0.828	900	4,442	7.2
0.6	1.0	5	0.50	LF	$ 3,300	1,785	$ 26,118	0.832	899	4,428	7.1
0.6	1.0	25	1.00	CC	$ 5,550	1,621	$ 26,277	0.837	823	2,318	10.0
0.6	1.0	5	1.00	LF	$ 3,750	1,790	$ 26,633	0.848	897	4,392	7.1
0.6	1.0	30	0.40	CC	$ 5,460	1,667	$ 26,773	0.853	816	2,694	10.0
0.6	1.0	30	1.00	CC	$ 6,000	1,652	$ 27,123	0.864	820	2,309	10.0
0.6	1.5	25	0.50	CC	$ 5,400	1,740	$ 27,644	0.880	865	2,152	10.0
0.6	1.0	5	0.25	LF	$ 3,075	1,942	$ 27,906	0.889	983	4,964	8.5
0.6	1.5	25	1.00	CC	$ 5,850	1,741	$ 28,106	0.895	888	1,813	10.0
0.6	1.5	5	0.40	LF	$ 3,510	1,954	$ 28,484	0.907	976	3,305	5.2
0.6	1.5	30	0.50	CC	$ 5,850	1,780	$ 28,602	0.911	866	2,159	10.0
0.6	1.5	30	1.00	CC	$ 6,300	1,758	$ 28,776	0.916	878	1,778	10.0
0.6	1.0	25	0.40	LF	$ 5,010	1,900	$ 29,299	0.933	893	4,414	10.0
0.6	1.0	25	0.50	LF	$ 5,100	1,901	$ 29,402	0.936	893	4,402	10.0
0.6	1.0	5	0.25	CC	$ 3,075	2,076	$ 29,608	0.943	1,080	4,924	10.0
	1.0	25	0.40	CC	$ 3,210	2,075	$ 29,730	0.947	1,074	3,341	10.0
	1.0	25	0.50	CC	$ 3,300	2,068	$ 29,734	0.947	1,076	3,205	10.0
0.6	1.0	25	1.00	LF	$ 5,550	1,904	$ 29,886	0.952	890	4,357	10.0
0.6	1.5	25	0.40	CC	$ 5,310	1,931	$ 29,993	0.955	944	2,707	10.0
	1.0	5	0.25	CC	$ 1,275	2,247	$ 30,001	0.955	1,181	4,939	7.1
0.6	1.0	30	0.40	LF	$ 5,460	1,936	$ 30,213	0.962	893	4,414	10.0
0.6	1.0	30	0.50	LF	$ 5,550	1,937	$ 30,313	0.965	893	4,401	10.0
	1.0	30	0.40	CC	$ 3,660	2,113	$ 30,673	0.977	1,075	3,345	10.0

Fig. 6. Hybrid RES System Configuration

The solar PV contributes 27%/year of the total electrical power output of the hybrid RES considered, see Fig. 7. This contribution is significant as the level of renewable energy penetration, deployed around the world, is around 11-25% [10].

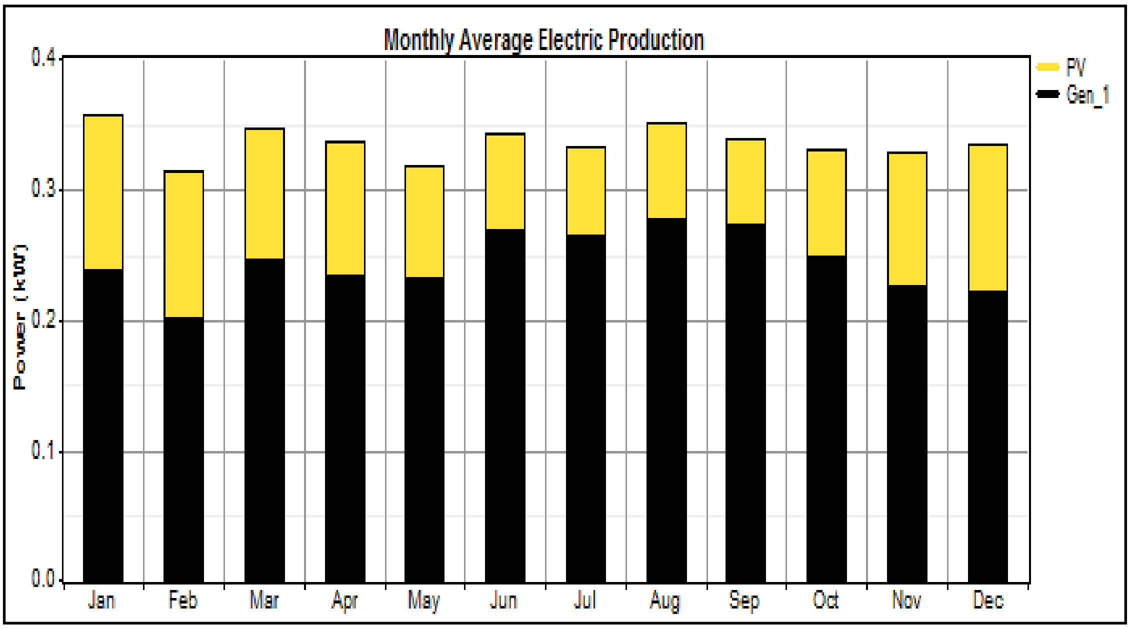

Fig. 7. Monthly Average Electrical Power Production

This hybrid RES will be a viable choice for implementation as the contribution made by the solar PV is quite significant. The hybrid RES compared fairly well with a similar system in the Malaysian's condition, which gives COE of 0.796$/kWh for a solar insolation and cost of fuel of 5.51kWh/m^2/h and 2.03$/L, respectively [10]. The difference in the COEs may be attributed to the cost of diesel fuel considered in [10], as solar insolation is higher than the Niger Delta region's insolation.

The CO_2 emission from a wholly DG energy system is 2,827kg/year; whereas it is 2,029kg/year for the optimum hybrid RES, which amounts to 28.2% yearly CO_2 emission reduction. This emission reduction is a significant achievement as it will reduce the over-polluted Niger-Delta region as a result of gas flaring and oil spillage resulting from crude oil production activities [3]. Furthermore, cost imposed on CO_2 emission by environmental legislations, which is the normal practice in most developed nations [11], will be averted. Although, there are currently no such environmental legislations in Nigeria, however, the 28.2% carbon reduction would make the environment friendlier.

6. Conclusion

In Nigeria, there is a gross electric power poverty, which required about 90% of Nigerian businesses to own diesel generators for their daily energy demands. The situation is worrisome for the remote villages, which are located far away from the national utility grid. In particular, the oil producing communities are absolutely located in the rugged terrains of the Niger-Delta region. Therefore, the potential of using a hybrid PV-Battery-Diesel generator as source of energy for buildings in the rural oil producing communities in the Niger-Delta region of Nigeria is presented; the analysis is based on the HOMER Software. From the HOMER software simulation, it has been demonstrated that the use of hybrid PV-battery-diesel system (COE of 0.783US$/kWh, one unit of 0.6 kW PV array, 1 kW diesel generator, 25 units of battery and 0.5 kW converter) will significantly reduce the dependence on diesel generator in the rural oil producing communities in the Niger-Delta region of Nigeria. The COE of 0.783US$/kWh may not be competitive with the current COE from the national utility grid. However, with positive FGN policy towards RES penetration and the support from oil producing companies toward their operational areas would see the COE being reduced. In addition to this, the Hybrid RES is able to reduce emission in the over-polluted Niger-Delta region to an appreciable level. Furthermore, cost imposed on CO_2 emission by environmental legislations, which is the normal practice in most developed nations [11], will be averted. The significant CO_2 emission reduction will make the Niger-Delta region environment friendlier.

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