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Abstract. Accessibility to dependable energy resource is vital to the emerging economy to function appropriately in this contemporary world for both residential and commercial purposes. Technological advancement has opened avenues for more sophisticated technologies to combine multiple energy sources to generate affordable electricity for residential and industrial purposes. The study, therefore aims at analyzing the fiscal benefits of hybrid Solar PV and Diesel Generator (DG) (PV-DG) grid-connected system using RETSceen software. The study focused on a specific location, J. A. Plant Pool Ghana Limited, warehouse Department. The study recommended and proposed an effective design of a hybrid PV-DG grid connected electricity supply for the warehouse Department. The economic viability of the project and the payback period obtained through computation were very attractive. Also, the total revenue of electricity exported to the grid annually and GHG emission reduction were within the standard benchmark. The study finally concurred that renewable energy sources such as solar when hybridized with any other energy systems, lead to a noticeable electrical cost reduction. Therefore, this system design provides multiple benefits, including; improved reliability, reduced emission and significant cost reduction.

1. Introduction

Among extensive varieties of renewable energy, solar PV energy is exclusive and is commonly used in the residential and commercial sectors in Ghana. There are two categories of solar energy in relation to their mode of operation: active and passive solar energy. Active Solar energy are those that operates with other energy conversion measures often involving heating, cooling and advanced mechanical systems, while the passive mechanisms are those without the use of further mechanical energy conversion systems. The two types of active solar energy are the thermal energy and solar Photovoltaic (PV). Solar thermal energy often involves the conversion of heat energy from the sun and involved popularly known technologies such as concentrated solar power (CSP), water heating, etc. whiles the Solar PV converts the radiation from the sun to a useful electricity via photovoltaic cells

[1–3]. A hybrid solar system is an amalgamation of solar PV and other alternate energy resources such as fuel cells, diesel generators, grid, hydropower, wind and many others so as to supply a reliable, un-interrupted power to a load due the intermittency in the solar radiation and also to minimize cost. Most hybrid systems are standalone system operating as off-grid. Grid is a significant scale of power supply or macro-grid; both generate hundreds of Megawatts to hundreds of gigawatts (GW) with a centralized system for distribution and transmission across a country and even beyond.

Hybrid systems are either standalone system or grid connected systems that store and provide power through batteries or diesel generator (DG). Solar-diesel hybrid systems are seen as more reliable and a bit affordable compared to other renewables, especially in Ghana owing to the intense availability of the resource, the existing policy on cost reduction of system components[4–8]. Currently, hybrid systems are more grid connected in Ghana for economic reasons.

Hybrid PV-Diesel generators are becoming a widespread solution for continuous electricity[9,10]. It's therefore the aim of this research paper to analyze the economic gains of a grid-connected hybrid PVDG system using RETScreen software with a specific load: J. A. Plant Pool Ghana Limited, warehouse department so as to recommend the appropriate size of the PV-DG electricity plant for the Warehouse Department. Also, the relevance of this paper is due to the fact that the RETScreen software has really not been used for similar studies previously in Ghana though it seems to promise effective results from the literature. In a similar study, the Federal Government of Nigeria used the RETSceen Expert software from the Canadian government to attract international investors through economic analysis, technical analysis and sensitivity analysis [11].

RETScreen Expert software is a carbon free energy controlling, planning and simulation software for assessing the techno-socio-economic viability and ecological sustainability for the recommended Solar PV DG system for J. A. Plant Pool Ghana Limited. A solar PV and DG technologies were considered during the design stage in this study illustrated in the remaining paragraphs.

Given the capital cost per Watt peak (Wp) for PV compared to DG, the design consisted in ensuring an optimal balance between the PV and the DG, where the PV produced all the electricity that is consumed during the day and in the evening via the grid. The DG only produces electricity when both the grid and the PV are not available. Therefore, the DG served only critical load by day and all the evening load in the event when the PV and the grid are off.

The rest of the paper is structured as follows: section 2 deals with the materials and methods, section 4 presents the results and discusses them, section five presents the conclusion.

2. Materials and Methods

Solar PV is a recognized technology of electricity generation that minimizes CO2 emissions that subsequently lead to global warming and at the same time economic challenges [3,12–14]. The RETScreen software is used to execute environmental and socio-economic assessment of substituting grid with renewable resource for lesser infrastructure and have proven potent. Also, [15] presented the benefit and strengths of using the RetScreen Expert package to design a solar PV system for a specific load.

Pakistan's energy report using the RETScreen software indicates that implementing a 5-kW standalone solar PV system with 0.6–0.7 t_{CO2} falls in GHG emissions in diverse regions of Pakistan under usual climatic condition [10]. Their study established a new potential electricity price-tariff using the RETScreen.

RETScreen can also be used to determine a solar PV system's financial and environmental impact as well as handle other forms of renewables such us wind energy.

In Ghana, RETScreen software has not been used intensively among the available literature despite the promise of reliability and effectiveness. However, a few studies used it to assess the economic viability and potency of PV in Ghana [16]. The 5 MW of grid-connected PV of SPR-320E-WHTD PV module shows the government's contribution to providing incentives relieves and other subsidies to create the investment boost in the energy sector of Ghana to can help curb the recent load shedding and the power outages, thus increasing economic resilience of the energy sector.

2.1. RETScreen Overview

RETScreen is a unique, innovative renewable energy software for planning, education and capacity created to help and support decision making in the development and management of renewable energy by the Canadian Government [17]. The software is an intellectual property of 307 networks of experts and more, including academia, government, industry with partnerships from groups like the Renewable Energy and Energy Efficiency Partnership (REEEP), National Aeronautics and Space Administration (NASA), Global Environment Facility (GEF), United Nations Environment Program (UNEP), Leonardo Energy Initiative, Energy and Environment Foundation, World Bank's Prototype Carbon Fund (PCF). Aside the latest software version; RETScreen Expert is known only to be in a viewer mode for free [8]. The software is written in 36 dialects covering further than two-thirds of the world's populace in over 222 nations and terrains world wide. The uniqueness of the software meaningly reduce the time and cost related parameters when classifying and evaluating possible energy issues and developments that may rise at the planning, feasibility, implementation and engineering stages. The RETScreen PV project model is used universally to compute life-cycle costs, energy production and GHG reduction are the three elementary PV applications: water pumping, on-grid and off-grid. The Expert vision was used for this research.

2.2. *Computational Approach*

The study considered a specific location: the J. A. Plant Pool Ghana Limited (JAPP), on the Alajo link Rd, Accra, Ghana (5°36.3'N, 0°12.4'W) as illustrated in Figure one. The paper was mainly concerned with the design of a 90.2kWh electricity grid-connected hybrid solar PV and Diesel Generator (DG) system to power only the Warehouse Department of JAPP using the RETScreen software.

Figure 1. Google map view of site location

JAPP is a Jospong subsidiary, a leader in supply of luxurious buses, lubricants, heavy-duty trucks, earth moving equipment and tyres in Ghana and outside Ghana for over 12 years.

The vision of the company is to be the industry leader in sales, rental and repair of construction, mining and transport related machinery in Ghana and beyond by providing high quality construction and mining equipment, haulage and transport related services with excellent customer service to increase shareholder value.

The warehouse department is made of enclosed storage area with three offices on the J. A. Plant Pool premises at GA-090-0785, Dzorwulu, Accra. The Warehouse is the busiest place of the company since it houses all the company's stock valued as 2,475kUSD with 81% of availability, 144,743 pieces of Spare parts on 950m2 area. The offices are equipped with laptops, printers, refrigerators, air conditions, telephones and lights.

2.3. Energy Audit

Energy audit was conducted to run a summary on the load profile at the Department to determine the maximum, minimum and critical load for the grid connected solar PV and DG hybrid system using RETScreen software for the simulation and finally for the design. Although the main research study was conducted with the RETScreen software for the purposes of accuracy and efficiency, the design was transposed on the Homer software to conduct performance comparison and draw meaningful conclusions. For instance, the average annual solar radiation of 4.94kW/m2/day was used in the calculation of the inverter; the array area and capacity were obtained from Homer software. Homer software is another efficient energy software mostly used for energy optimalization and all other energy socio-economic analysis. The load profile of JAPP is presented in Table 1.

Table 1. Energy profile at JAPP Warehouse Department in Accra after the energy audit.

LOAD	Rate *(kW)*	Quantity	Usage	Hour *(h)*	Energy *(kWh)*
Laptop	0.02	5	08:00 - 17:00	9	0.9
Colour TV	0.045	1	08:00 - 17:00	9	0.405
Refrigerator	0.035	3	18:00 - 06:00	24	25.0
Light (Indoor)	0.015	6	08:00-17:00	9	0.81
Light (Warehouse)	0.04	12	08:00-17:00	9	4.32
Light (Outdoor)	0.04	4	18:00-06:00	13	2.08
AC	1.44	3	08:00 - 17:00	9	38.88
Telephone	0.002	4	08:00 - 17:00	9	0.072
Printer	0.03	1	08:00 - 17:00	9	0.27
UPS	0.42	1	00.00 - 24.00	24	10.08
TOTAL					**83.02**

2.4. Critical Loads

The design considered some loads to be critical based on their need to operate without interruption for effective running of business. These include laptops, indoor and outdoor lights, UPS, etc. as summarised in Table 2. They are therefore considered as critical loads and are connected directly to the Diesel Generator (DG) having a bypass to the Solar PV and the Grid; hence, in the absence of these two main sources that is the solar PV and the Grid, the DG will automatically supply the needed power to only the critical load to make the design more economical because the RETScreen simulation shows that DG is the more expensive comparing it to the Solar PV and the Grid. With this the electricity supply from the DG is at 10.5kWh.

Table 2. Critical Load

LOAD	Rate *(kW)*	Quantity	Usage	Hour *(h)*	Energy *(kWh)*
Laptop	0.02	5	08:00 - 17:00	9	0.9
Light (Indoor)	0.015	6	08:00-17:00	9	0.81
Light (Outdoor)	0.04	4	18:00-06:00	13	2.08
Telephone	0.002	4	08:00 - 17:00	9	0.072
Printer	0.03	1	08:00 - 17:00	9	0.27
UPS	0.42	1	00.00 - 24.00	24	10.08
TOTAL					**10.15**

2.5. Low Loads

These loads are considered as minimal load and for the purpose of this design they are mostly required in the evening. Generally, their power ratings are far lower than the critical load. Consequently, it is foreseen that the proposed PV-DG hybrid system will not fail because the capacity of the DG will be able to supply the needed load when the Solar PV and the Grid are off. A summary of the low loads is presented in Table 3.

Table 3. Low Load

LOAD	Rate *(kW)*	Quantity	Usage	Hour *(h)*	Energy *(kWh)*
Light (Outdoor)	0.04	4	18:00-06:00	13	2.08
UPS	0.42	1	00.00 - 24.00	24	10.08
TOTAL					**7.12**

2.6. *Design Profile with RETScreen software*

The location setting for the load profile using the RETScreen software has been stated in Figure two. The parameters and quantities have also been stated at Table 4 and 5 for the photovoltaic and the reciprocating engine (Diesel Generator) respectively. With the appropriate and successfully input of the parameters into the RETscreen Expert Software for the design proposed, run the simulation using the tools on the menu bar and generate the report for the design.

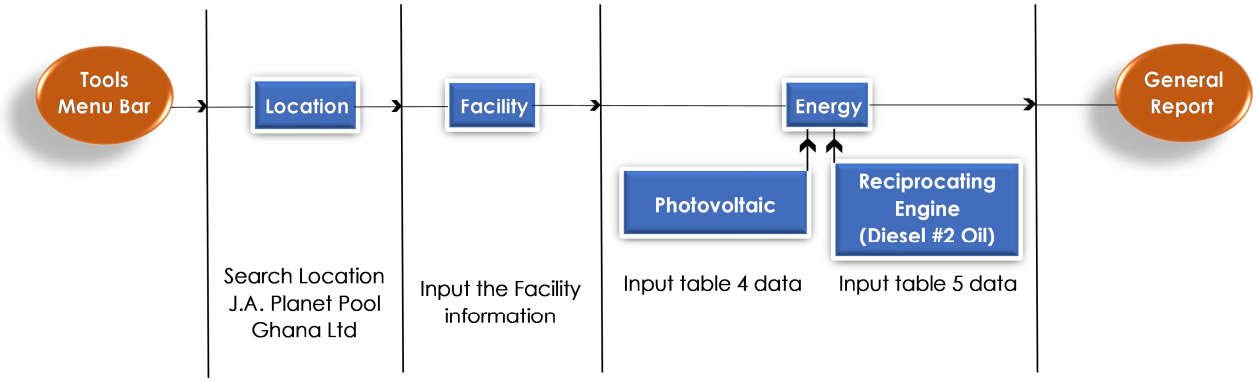

Figure 2. Breakdown of design procedure

Table 4. Solar Photovoltaic input parameters

Parameters	Values
Power capacity	0.01 kW
No. of units	500.00
Capacity factor	91.00%
Initial cost	2100.00$/kW-year
O&M cost (saving)	25.00$/kW
Electricity export rate	0.10$/kWh
Electricity exported to grid	0.08MWh
Electricity export revenue	7.97$

Table 5. Diesel Generator (DG) input parameters

Parameters	Values
Fuel type	Diesel (#2 oil) - L
Fuel rate	0.80$/L
Power capacity	0.004 kW
Availability	30%
Heat rate	13000.00kJ/kWh
Fuel requires	0.0001GJ/h
Initial cost	900.00$/kW
O&M cost (saving)	149.00$/kW-year
Fuel consumption	3.6L
Fuel cost	2.85$
Electricity export rate	0.10$/kWh
Electricity exported to grid	0.01MWh
Electricity export revenue	1.05$

3. Results and Discussion

The energy source from the PV panels is considered as the main electricity supply. The PV supply the power during the day and in the evenings or bad weather periods the electricity is supply by the grid, the diesel generator only supplies electricity in the absents of both the Solar PV and Grid.

3.1. Generation Summary

The RETScreen Expert Software is silent on inverter and its size to convert the DC supply from the Solar PV unlike the Homer software. It therefore important to calculate the inverter parameters, PV array area and the total capacity using the parameters from Homer software.

$$PAC = \frac{Daily\ Load\ \left(kW/d\right)}{RE\ Window\ \left(h/d\right)} \tag{1}$$

$$PAC = \frac{83.02}{10} = 8.302$$

The AC power is converted to DC by the interior with 90% efficiency. This implies the DC power obtained will be as shown below.

$$PDC = \frac{PAC}{Inv_{eff}} \tag{2}$$

$$PDC = \frac{8.302}{0.9} = 9.22\ kW$$

The DC power is not used due to system and other losses. Therefore, DC was adjusted to 40% as shown below.

$$PDC_{adjusted} = 40\%PDC + PDC \quad (3)$$

$$PDC_{adjusted} = 0.4 \times 9.22 + 9.22 = 12.91\ kW$$

Subsequently, the PV array area is determined as

$$A = \frac{PDC_{adjusted}}{1\left(kW/m^2\right) \times Eff_{PV}} \quad (4)$$

With the PV system's efficiency being 0.15, A is estimated as follows

$$A = \frac{12.91}{1 \times 0.15} = 84.067m^2$$

Estimating the PV area with the system total capacity give us

$$G = E_t \times A \quad (5)$$

Where G is the radiation from the sun and ET is the total energy. With $E_T = 4.94\ and\ G = 84.067m^2$:

$$G = 4.94 \times 84.067 = 415.28\ kWh$$

Therefore, the system's capacity is determined as follows

Table 6. shows, the energy summary show that the initial cost for this project is $24.60. The 9 units of electricity generated is sold to the grid and payback period is 4.6 years. The operation and the maintenance cost are only $0.85 which make it more economical.

$$C = \frac{G}{RE_{window}} \quad (6)$$

$$C = \frac{415.28}{10} = 41.528 \approx 42\ \text{kW}$$

Table 6. Energy summary

Electricity exported to grid	Capacity *(kW)*	Electricity *(kWh)*	Initial Cost *($)*	Electricity export revenue *($)*	Fuel Cost *($)*	O&M Cost (savings) *($)*	Single paybac *(yr)*
Photovoltaic	0.001	79.7	21	8	0	0.25	2.7
Reciprocating Engine (DG)	0.004	10.5	3.6	1.3	2.9	0.6	None
Total	**0.01**	**90.2**	**24.6**	**9.3**	**10.08**	**0.85**	**4.6**

3.2. Financial Analysis

The economic life span of the project is 20 years with a payback period is 4.6 years as shown in Figure three. The unit cost of electricity is $0.076kWh.

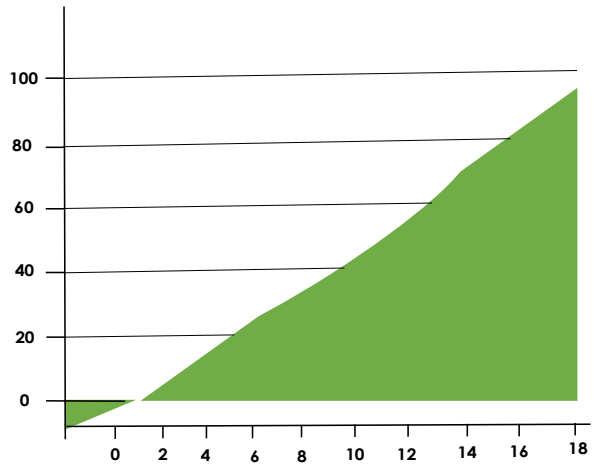

Figure 3. Payback period

3.3. GHG Emission

The gross annual GHG emission reduction is 78% against the standard as illustrated in Figure four. This supports the assertion that the proposed design is environmentally friendly and therefore more accepted.

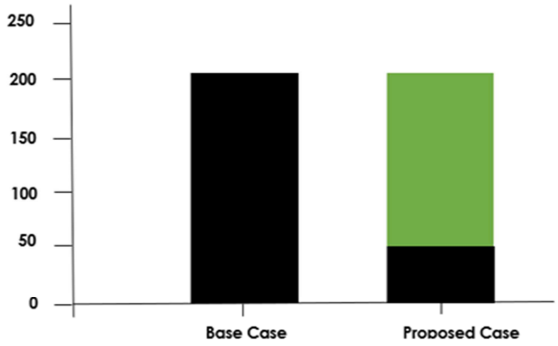

Figure 4. GHG Emission

4. Conclusion

The findings of the study corroborate previous studies regarding the benefits of the hybrid grid connected power systems with solar resources. A few of previous study supporting the assertion of immense benefits in terms of emission and cost reduction while hybridizing solar with other renewables, especially in West Africa are: [18–24]

A detail list of benefits suggested by most of these studies includes: cost reduction, a guarantee of continuous power supply, reduction of pollution and emissions.

The simulation of the load profile with RETScreen Expert software for the 90.5kWh grid-connected solar photovoltaic-diesel hybrid system with the constituent generating capacity of 79.7kWh from the solar PV and 10.5kWh from the Diesel Generator respectively shows that the supply efficiency and the reliability greatly improved. Also, an economic viability established with the fact that the project lifespan is 20 years with an approximate Four year and six months payback period.

The system is designed and sized to export the unused generated electricity to the grid. A total of 0.9 MWh is exported to the grid annually at a revenue of $9.02 with GHG emission reduction of 0.03 representing 78% per annum as against the global benchmark and standard.

The levelized cost of electricity per unit is $0.076 kWh, which is equivalent to Gh₵6.00 per unit cost of electricity in Ghana cedis. Comparatively is far cheaper than per unit cost of Gh₵24.2 for non-residential load [3] in Ghana.

Therefore, this study concurs that hybrid energy systems with renewable energy sources like solar, contribute to an obvious cost savings on electricity. It can therefore be concluded that the Grid Connected Solar PV/Diesel Hybrid system provides multiple benefits including; improved reliability, continuous power supply, reduced emissions and pollution, good operational life and reduced cost.

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