Sensitivity Analysis of an Optimal PV-DG-BES for Sustainable Power System of a Technical Institution in Niger State

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Abstract- In this study, the different reactions of an ideal hybrid renewable energy system (HRES) to variations in the system input parameters of solar radiation was examined. HOMER software was used to conduct sensitivity analysis of the optimum system of the system under study. To allow for a broader examination, these parameters were changed by ±40%. The research work used sensitivity analysis to examine the impact of varying the hybrid system's input parameters on energy cost (COE), net present cost (NPC) and operational cost. The sensitivity analysis of the variation of solar radiation presented shows that as the solar radiation increases, there is a decrease in the NPC of the system and also a decrease in the levelized cost of energy of the hybrid system, although there is variation in the operating cost. The research work will serve as a means of sustainable energy development to be replicated in other region with similar solar radiation value of climatic condition in promoting energy access.

Indexed Terms- Sensitivity Analysis, Photovoltaic cell(PV), Disel Generator(DG), Battery energy system(BES), Sustainable Power System, Technical Institution.

I. INTRODUCTION

It is crucial to forecast an energy system's responses to changes in its input parameters, including the price of PV panels, batteries, solar radiation, wind speed, population consumption patterns and fuel prices, in order to prevent losses and subpar system performance. Among the benchmarks used to measure sustainability, energy production and system dependability are significantly impacted by changes in the modeler's selection of sensitivity parameters will indicate how responsive the power system is to changes in the objective functions, which include the total net present cost, cost of energy, renewable penetration factor and carbon dioxide emissions. For a technical institution, designing the best hybrid renewable energy system for a sustainable electrical power supply is not enough; one must also understand how the energy system reacts to changes in system input parameters and the technical and financial effects on energy producers, consumers, and other stakeholders. Sensitivity analysis of optimum hybrid renewable energy systems has been the subject of several studies, with a focus on the cost of sustainable renewable energy for household use, changes in specific system input parameters, and techno-economic analysis. Most of these works which include Bishnoi and Chaturvedi (2022), Singh and Rizwan (2022), Farh *et al.,* (2022) and Sandeep and Atul (2012). Detailed sensitivity analyses of the economic impact of solar radiation were not conducted in some of the available literature. This paper attempts to fill these research gaps by studying the effect of solar irradiation on an optimal PV-DG-BESS for sustainable power system to a technical institution in Niger state.

Methodology

The following criteria for analyses of the optimal hybrid renewable energy frameworks was employed in this study to achieve proper and accurate selection and optimization as shown in Figure 1.

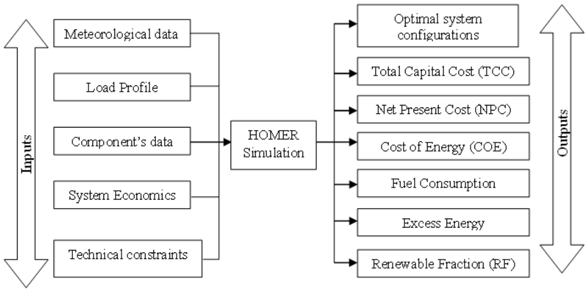

Figure 1.0 HOMER architecture

Study Location

Government Technical College, Eyagi, Bida is a technical and vocational training institution located in Nasarafu Banyagi in Bida local government area, Niger State. The power supply in this institution is challenge with inadequacy due to weak grid network, transformers and feeder faults as well as nonpayment of tariff and this as have far reaching implications in youth employment and the economy of the country. The background information of the study location is shown in Table 1 below

Table 1: Background information of the study location

Particulars	Detail
Country	Nigeria
State	Niger
Local government	Bida
Clan	Nupe
Community	Nasarafu
Longitude	9°3.8N
Latitude	6°1.4E.

Electrical Load Analysis

The presentation of load data in HOMER entailed specification of hourly electrical energy and the seasonal profile for the technical college is shown in Figure 2 below:

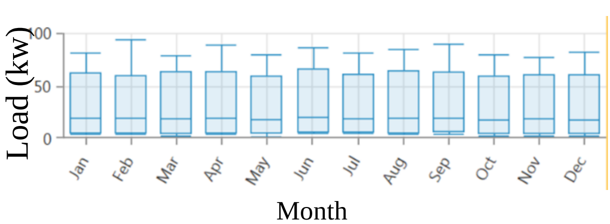

Figure 2: Seasonal Profile

It is observed that major load demand occurs during the daytime and this is due to the nature of setting of the institution where workshop activities are conducted in the morning. A day-to-day random variability of 10% and hour to hour random variability of 20% is specified in HOMER. This is done to check off the effect of the daily and hourly load variation on the hybrid system configuration to avoid under estimating the peak demand of the proposed system.

Solar Resources for Study Area

The availability of renewable resources at any particular place varies from one locality to another. This is important for the development of hybrid renewable energy system (Adaramola, 2012). The monthly solar radiation data, clearness index and temperature of the study area were obtained from National Aeronautics and Space Administration's (NASA) global satellite (NASA, 2023) as presented in Table 2 below.

Table 2: Mean monthly solar radiation clearness index and temperature of Government Technical College Bida.

Month	Clearness index	Solar radiation (kWh/m^2/day)	Temperature (°C)
January	0.635	5.720	24.340
February	0.622	6.010	26.500
March	0.610	6.260	28.390
April	0.583	6.120	28.720
May	0.533	5.730	27.730
June	0.507	5.170	26.590
July	0.453	4.640	25.590
August	0.420	4.360	25.310
September	0.468	4.820	25.820
October	0.554	5.420	26.320
November	0.641	5.850	25.660
December	0.654	5.730	24.220

Component data, System economic and technical constraint

HOMER is provided also with other Inputs that affect power system optimization so as to get the NPC of the system as shown in the Table below. The NPC is a composite of the system component, initial capital cost, replacement cost, annual operating and maintenance cost as well as fuel cost. Economic input parameters include annual real interest rate, project lifetime, fixed capital cost, capacity shortage penalty, system fixed operation and maintenance cost.

Table 3: Techno economic specification of PV

Parameters	Value
PV Type	Generic flat plate
Initial capital cost	\$2000/kw
Replacement cost	\$2000/kw
Operating and maintenance cost	\$5/year
Derating factor	80%
Lifetime	25years
Ground reflectance	20%
Tracking system	No tracking

(Muhammed *et al.*, 2022).

Table 4: Techno economic specification of battery system

Parameters	Value
Battery type	Lead acid
Nominal voltage	12v
Nominal capacity	1kwh
Initial capital cost	\$200/unit
Replacement cost	\$200/unit
Operating and maintenance cost	\$10/year
Lifetime	10years
Round trip efficiency	85%
Minimum state of charge	40%
Battery per string	10

(Dodo and Ashigwuke, 2023).

Table 5: Techno economic specification of converter

Parameters	Value
Initial capital cost	\$300/kw
Replacement cost	\$300/kw
Operating and maintenance cost	\$10/year
Lifetime	15years
Efficiency	95%

(Rashid *et al.*, 2023).

Table 6: Techno economic specification of Diesel Generator

Parameters	Value
Type	Auto size genset
Initial capital cost	\$300/kw
Replacement cost	\$300/kw
Operating and maintenance cost	\$0.036/hr
Lifetime (hr)	1500
Fuel price	\$1.0/L
Minimum load ratio	25%

Table 7: Techno economic specification of system economic, control and technical constraints

Parameters	Value
Simulation time step	60min
Project life time	25years
Inflation rate	12%
Discount rate	6%
Maximum renewable fraction	100%
Maximum unserved energy	0%
Maximum annual capacity shortage	0%

(Dodo *et al.*, 2022).

Sensitivity Variables

The modelling tool enables the consideration of future dynamic changes, such as variations in the availability of renewable and non-renewable resources and rising or falling demand. The modeler's selection of sensitivity parameters will indicate how responsive the power system is to changes in the input variables. To this aim global solar radiation on horizontal surface in HRES was selected as sensitivity variable. These parameters were varied by $\pm 40\%$ to give wider analysis as shown in Table 8.

Table 8: Sensitivity value of solar resources (kWh/m^2/day)

- 40%	- 30%	- 20%	- 10%	0%	10%	20%	30%	40%
3.29	3.84	4.39	4.94	5.49	6.04	6.59	7.14	7.69

Results and Discussion

The variation of the scaled radiation by percentage ±40%, ±30%, ±20%, ±10% also produced different system performance conditions. The NPC is $2,232,684.00, LCOE is $0.244/kWh, the operating cost is $26,010.11 per year when the scaled annual average irradiance is 3.29kWh/m^2/day and the PV capacity is 255kW, converter capacity is 88.6kW and the battery bank comprises 113 stings with load following as the operating strategy. The total annual electricity production of this system is 250,113kWh/yr and the share of power generation by the generic flat plate PV is 98.1% whereas the diesel generator produces 1.90%. The system has no unmet load and no capacity shortage with excess electricity production of 55,703 kWh/yr representing 22. 3% and the system emission of poisonous gases is 4,565kg/yr of carbon dioxide, 28.8kg/yr of carbon monoxide, 1.26kg/yr of unburned hydrocarbons, 0.174kg/yr of particulate matter, 11.2kg/yr of Sulphur dioxide and 27.0kg/yr of nitrogen oxides The optimal solution when the scaled annual average irradiance is 3.84kWh/m^2/day has an NPC of $2,150,580.00, the LCOE of $0.235/kWh, an operating cost of $25,682.70 per year and the optimal system comprises of 224kW of generic flat plate PV, 110kW of diesel generator, 112 strings of battery bank with load following as the operating strategy and 88.4kW of system converter. The system will produce annual electricity of 257,260kWh/yr with PV contributing 98.2% and diesel generator contributing 1.76% with excess electricity production of 62,867kWh/yr representing 24.4% with no capacity shortage and no unmet electric load. The system has emission of nitrogen dioxide of 25.67kg/yr, Sulphur dioxide of 10.6kg/yr, particulate matter of 0.166kg/yr, unburned hydro carbons of 1.19kg/yr, 27.4kg/yr of carbon monoxide and 4,339kg/yr of carbon dioxide.

When the scaled average solar radiation is increased to 4.39kWh/m^2/day, the winning system architecture has a PV capacity of 200kW, system converter of 89.2kW, diesel generator of 110kW which comprises of battery bank of 113 strings with load following as the operating strategy. The system has an NPC of $2,088,368.00, LCOE of $0.228/kWh and operating cost of $25,392.67 per year and the system has total electricity production of 263,006kWh/yr with PV contributing 98.4% and diesel generator contributing 1.60%, with an excess electricity production of 68,586kWhr/yr representing 26.1% of the total electricity production. The system has no capacity shortage and no unmet electric load. The environment will suffer pollution from carbon dioxide of 4,053kg/yr, carbon monoxide of 25.5hkg/yr, unburned hydrocarbon of 1.11kg/yr, 0.115kg/yr of particulate matter, 9.92kg/yr of Sulphur dioxide and 24.0kg/yr of nitrogen oxide.

When the scaled solar average radiation is set at 4.94kWh/m^2/day, the NPC is $2,037,882.00, LCOE is $0.223/kWh and the operating cost is $24,980.41 per year. The optimal system comprises of 187kW of generic flat plate PV, 110kW of diesel generator, 88.6kW of system converter and 112 stings of battery banks with load following as the operating strategy. The system produces 277,203kWh/yr of electricity with PV having 98.6% and diesel generator having 1.36% with an excess electricity production of 82,825kwh/yr representing 29.9% of the total electricity production and environmental pollution of 3,626kg/yr of carbon dioxide, 22.9kg/yr of carbon monoxide, 0.997kg/yr of unburned hydrocarbon. 0.139kg/yr of particulate matter, 8.88kg/yr of Sulphur dioxide and 21.5kg/yr of nitrogen oxide.

The optimal solution when the scaled annual radiation is 6.04kWh/m^2/day has an NPC of $1,960,540.00, the LCOE of $0.214/kWh and the operating cost of $25,296.68 per year. The optimal solution has system configuration of 170kW of PV, 110kW of diesel generator, 88.5kW of converter and 81 strings of battery banks with load following as the operating strategy. The system has total annual electricity production of 310,339kWh/yr with PV contributing 98.3% and diesel generator contributing 1.69kWh/yr with an excess electricity production of

116,429kWh/yr representing 37.5% of the total annual production. It has no capacity shortage and it has no unmet load with emission of 5,059kg/yr of carbon dioxide, 31.9kg/yr of carbon monoxide, 1.39kg/yr of un burned hydrocarbon, 0.193kg/yr of particulate matter, 12.4kg/yr of Sulphur dioxide and 30.0kg/yr of nitrogen oxide.

The winning system architecture when the solar radiation is set at 6.59kWh/m^2 /day uses a load following strategy and has component size capacity of 161kW of PV, 110kW of diesel generator, 91.6kW of converter and 81 stings of battery banks. It has an NPC of $1,928,368.00, LCOE of $0.211/kWh, operating cost of $25,040.58 per year and the system has no capacity shortage and no unmet load with total electricity production of 311,915kWh/yr with an excess of 117,969kWh/yr representing 37.8% with PV accounting for 98.9% and diesel generator accounting for 1.54%. The system has 4,634kg/yr of carbon dioxide, 29.2kg/yr of carbon monoxide, 1.27 kg/yr of unburned hydrocarbon, 0.117kg/yr of particulate matter, 11.3kg/yr of Sulphur dioxide and 27.4kg/yr of nitrogen oxide as harmful gas released into the atmosphere.

When the solar radiation is set at 7.14kWh/m^2/day, the operating strategy of the optimal system uses load following with PV capacity of 155kW, diesel generator of 110kW, converted of 88.8kW and comprises of 82 strings of battery banks. The total NPC is $1,899,267.00, LCOE of $0.207/kWh, an operating cost of $24,720.25 per year and the system has total electricity production of 306,120kWh/yr with PV having 98.6% and the remaining 1.43% for the diesel generator. The system has no unmet electric load and no capacity shortage with excess electricity production of 112,168kWh/yr representing 36.6% of the annual electricity production with 4,237kg/yr of carbon dioxide, 26.7kg/yr of carbon monoxide 1.17kg/yr of unburned hydrocarbon, 0.162kgh/yr of particulate matter, 10.4kg/yr of Sulphur dioxide and 25.1kg/yr of nitrogen oxide as poisonous gasses released into the environment.

Finally, when the solar radiation is 7.69kWh/m^2/day, the optimal system has component specification of 154kW of PV, 110kW of diesel generator, 89.8kW of system converter and 80 strings of battery banks which uses load following as the operating strategy. It has an NPC of $1,875,912.00, LCOE of $0.205/kWh, an operating cost of $24,401.81 per year and the system has excess electricity of 36.8% with total annual electricity production of 307,052kWh/yr with PV contributing 98.7% and diesel generator contributing 1.28%. The system has no unmet load and no capacity shortage with 3,806kg/yr of carbon dioxide, 24.0kg/yr of carbon monoxide, 1.05kg/yr of unburned hydrocarbon 0.145kg/yr of Sulphur dioxide and 22.5kg/yr of nitrogen oxide as harmful gases.

The result of the sensitivity analysis of the variation of solar radiation presented shows that as the solar radiation increases, there is a decrease in the net present cost of the system and also a decrease in the levelized cost of energy of the hybrid system, although there is variation in the operating cost, the capacities and sizes of the components, operating strategy and the annual power generation when the solar radiation is the sensitivity variable is shown in Table 5 and Figures 3 and 4 show the graph of the NPC, LCOE and the operating cost of the optimal system.

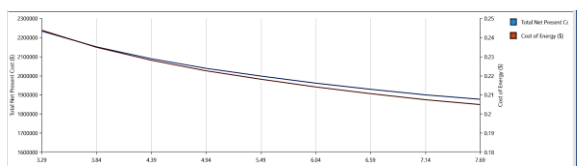

Figure 3: Economics of the NPC and LCOE of the optimal system with the variable solar radiation

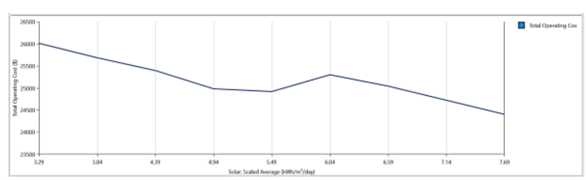

Figure 4: Economics of the operating system of the optimal system with the variable solar radiation

Table 9 : Summary of the component sizes, annual power generation and operating strategy of the optimal system with solar radiation as the sensitivity variable

Solar Radiation (kWh/m^2 per day)	3.29	3.84	4.39	4.94	6.04	6.55	7.14	7.69
PV Array (kW)	255	224	200	187	170	161	155	154
Diesel Generator (kW)	110	110	110	110	110	110	110	110
Wind Turbine (kW)	00	00	00	00	00	00	00	00
Converter (kW)	88.6	88.4	89.2	88.6	88.5	91.6	88.8	89.8
Battery (String)	113	112	113	112	81	81	82	80
Operating Strategy	LF	LF	LF	LF	LF	LF	LF	LF
Power generation (kWh/yr)	250,113	257,260	263,006	277,203	310,339	311,915	306,120	307,052

CONCLUSION

This study has highlighted the prospects of renewable energy sources for deployment in Nigeria technical institution as well as the economic impact of solar radiation on the hybrid renewable energy source based on the sensitivity value and techno-economics analyses presented due to the high solar radiation experienced in parts of the country. it is observed that as the solar radiation increased, the COE and NPC of the optimal system configuration decreases given more room to the adoption of renewable energy sources and the reliability of the hybrid system is found to be enhanced when solar radiation is high as the size of the battery storage and PV cell is reduced.

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