International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 21, Issue 4 (April 2025), PP 171-177

Feasibility Study and Comparative Analysis of Grid-connected Solar PV-Diesel Hybrid System for a University Campus

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ABSTRACT: *Reliable and efficient electric power is essential for rapid social, economic and technological growth of any nation. It dictates the quality of life and convenience of her citizens. This work considered the technical and economic feasibility study of an hybrid system consisting grid, Solar PV and Diesel for Ekiti State University campus, Ado-Ekiti, Nigeria. The estimated load demand, solar radiation data, diesel (DG), design details e.t.c were collected and analyzed. Accurate components selection and system oprations were done to ensure its cost-effectiveness. Solar PV generator and DG were modeled with grid using HOMER software. The results showed that grid-connected Solar PV-Diesel hybrid system is the most optimal configuration with least Cost of Energy, COE, of $0.106/kWhr and least operating cost of $307,758 as no fuel cost is incurred. It can be deduced that it is economically advisable for the university management to invest in Solar PV operating as a hybrid electric power supply system with the existing diesel generator and grid electric power supply. This will definitely lead to reduced energy cost, less greenhouse gas emission and reliable electric power supply in the campus.*

Date of Submission: 08-04-2025 Date of acceptance: 19-04-2025

I. INTRODUCTION

Reliable and efficient electric power is essential for rapid social, economic and technological growth of any nation. It dictates the quality of life and convenience of her citizens. Being without sufficient and reliable energy could be one of the barriers to socioeconomic growth of any nation.An efficient and reliable electric power supply system will lead to low cost of production, enhance storage system in preservation of perishable goods, promote improved educational quality and improve citizens's standard of living (Olabode et al, 2021).

The country, Nigeria is faced with diverse issues and challenges hindering easy access to reliable and sustainable electric power supply (Adebanji, Fasina & Akinyede, 2024). The present energy infrastructures is insufficient, inefficient and unsustainable (Abe, Adebanji & Fasina, 2024). It is inadequate, unreliable and unsustainable Millions of Nigerians struggle to access consistent electric power supply for their daily needs, while some areas are facing complete blackouts. Almost 45% of the populace, lack access to grid electricity. Even those connected to the grid experience highly unreliable power supply(Adebanji et al., 2020).

People living in the rural areas of the country, have limited access to electricity because of their distant locations, which makes connecting them to the grid both unrealistic and economically not feasible. It is of utmost importance to enhance the living standards of the rural dwellers in meeting the basic energy needs like communication, education, healthcare, businesses, lighting, agriculture and water supply (Olabode et al, 2021). However, agricultural activities, businesses, lighting, water supply, education, and healthcare needs energy for their smooth running. This lack of electricity doesn't just affect businesses-it has a ripple effect on education, healthcare, and overall quality of life. Efforts are underway to increase power generation capacity to meet current and future demands, but a clear sustainable electricity generation vision aligned with the country's development, industrialization, and climate goals is still lacking(Usman et al, 2017).

Nigeria has a variety of power plant types, with gas-fired power plants accounting for 88% of all power plants and hydropower plants making up the remaining 12%. Given that hydropower facilities do not contaminate the environment, however gas-fired plants do, this demonstrates how power plants significantly contribute to the problems associated with environmental pollution. The adverse effect of climate change and global warming caused by heavy dependence on fossil fuels is currently a global challenge (Kdair Abd, 2020).

The increasing environmental concerns and the need to reduce its impact on climate change has indeed intensified renewable energy technology explorations (Adeleye, Adebanji & Awogbemi, 2024). Due to the increasing demand for energy, depletion nature of conventional energy reserves and its detrimental environmental effects, Renewable Energy Sources (RES) is now being promoted globally (Adebanji, Fasina & Akinyede, 2024). It is reliable, effective and sustainable (Hasan, 2019).

The country is richly blessed with RES like biomass, wind, solar, geothermal, biogas, hydro e.t.c. But less than 25% have been utilized (Oyedokun et al, 2022). High investment in renewable energies will not only solve perpetual electric power issues but will go a long way in achieving and building an environmentally friendly energy system (Adebanji et al, 2020). Succintly put, RES adoption is of numerous benefits and tends towards improved environmental quality (Ugwu et al, 2022; Zhang, 2020). With no doubt, RES will significantly promote future energy generation and enhance the progress of the country.

The fluctuating nature of RES like Solar PV and wing energy, however. pose another serious challenge. This challenge can easily be overcome by using two or more RES (that are complementary in nature) to form a hybrid system (Adebanji et al, 2020). Sustainable energy system is an indispensable tool in enhancing appreciable socio-economic growth in any society (Osalade, Adebanji & Fasina, 2022). It preserves the existing natural endowments and avoid detrimental environmental impacts to the ecosystem in the present and in the future (Adebanji, Fasina & Akinyede, 2024).

So many authors have worked on the feasibility of Solar PV-Diesel-Grid hybrid system (Usman et al, 2017; Hasan et al, 2019; Adebanji et al, 2020; Olabode et al, 2021; Miravet-Sanchez et al, 2022; Oyedokun, Fasina and Adebanji, 2023). Hasan et al (2019) coducted a feasibility analysis on usage of a Solar PV system for street lighting in a university campus, Syllet, Bangladesh. The work was done using RETScreen software for a project lifetime of 25 years. The simulation results showed that the project is economically viable for the case study area. The Solar PV was reported to have saved 11827 tonnes of CO_2..Olabode et al (2021) also carried out a review of hybrid system design applications technologies, and future trends especially for rural areas where it is seemly uneconomical for distribution companies to reach. Miravet-Sanchez et al (2022) worked on Solar PV technology development in Latin American and Caribbean countries (LAC). The study assesed its impacts on homes, schools and health institution particularly in isolated or very difficult communities to access. The authors also presented and recommended the need to replace the use of firewood and kerosine with RES in order to reduce its detrimental effects on the environments.

Oyedokun, Fasina and Adebanji (2023) designed a 2 MW grid-Solar PV hybrid system using Idofian, Kwara State, Nigeria as a case study. The authors used RETScreen software. The simulated results confirmed the feasibility of the project. Adeleye, Adebanji & Awogbemi (2024) conducted RES acceptability assessment across the six states in Southwest, Nigeria. The work reviewed the available RES in the country, highlited the challenges and recommended the use of decentralized enery system using RES.

The purpose of this research is to carry out a comparative analysis and feasibility assessment of a solar PV-diesel generator hybrid power system at Ekiti State University, Ado-Ekiti, Nigeria. It compares the economics of various hybrid power system configurations by examining how to meet its load demand using Grid-Solar PV and diesel generator hybrid systems.

II. MATERIAL AND METHODS

This work considered the technical and economic feasibility study of an hybrid system consisting grid, Solar PV and Diesel for Ekiti State University campus, Ado-Ekiti, Nigeria. The estimated load demand, solar radiation data, diesel (DG), design details e.t.c were collected and analyzed. Accurate components selection and system operations were done to ensure its cost-effectiveness. Solar PV generator and DG were modeled with grid using HOMER software

2.1 Study Area Description

Ekiti State University campus, Ado-Ekiti, Nigeria (7.712° N, 5.251° E) is chosen as the study area. The average monthly solar radiation of Ekiti State University is given in Figure 1

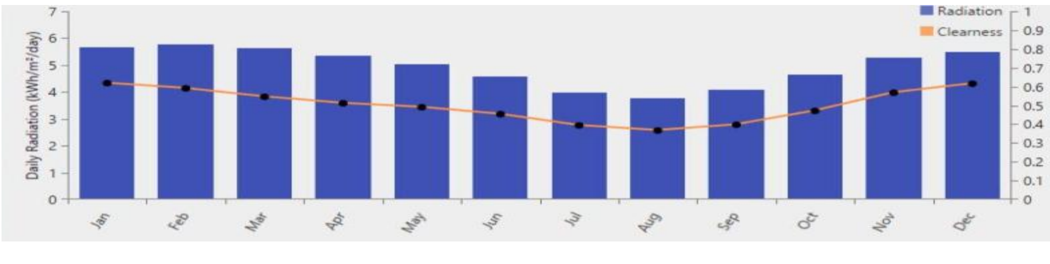


Figure 1: Monthly Solar Radiation and Clearness Index (Average)

2.2 The Existing Power Distribution Network

The single line diagram of the current power network of Ekiti State University (EKSU), Ado-Ekiti is presented in Figure 2 . The network consists of one 2.5 MVA; 33/11kV power transformer and fourteen distribution transformers

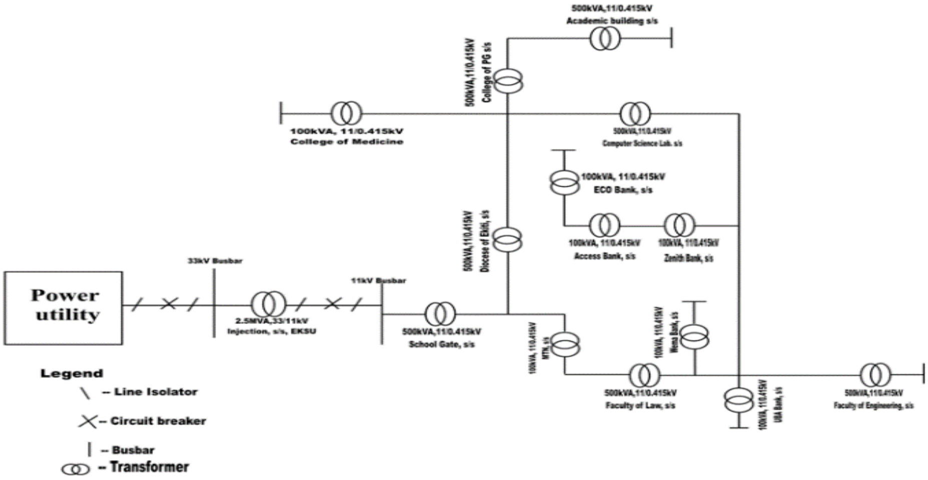


Figure 2 : Single line diagram of EKSU, Ado-Ekiti, Electrical Distribution Power Network.

2.3 Hybrid Power System Components Modelling

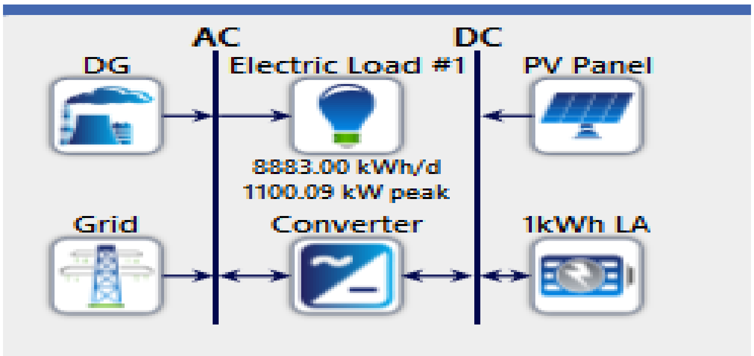


Figure 3: Schematic diagram of Solar PV-DG on-grid hybrid power system

2.3.1 Solar PV

$P_{PV} = Y_{PV} f_{PV} (\frac{\overline{G}_T}{\overline{G}_{T,STC}})[1 + \alpha_P(T_c - T_c, STc)]$ (1)

$Y_{PV} =$ *the rated* capacity of the PV array,]$f_{PV} =$ *the PV derating factor*[%],
$\overline{G}_T =$ *the solar radiation* incident],$\overline{G}_{T,STC} =$ *the incident radiation* at standard test conditions [1 kW/m²] , $\alpha_p =$ *the temperature coeficient* power [%/℃], $T_c =$ *the PVcell temperature* in the current time step [℃] , $T_{c,sTC} =$ *the PV cell* temperature under standard test conditions [25℃]

2.3.2 Battery Charge Power

The maximum amount of power that can be absorbed by the system is given by equation 2:

$$P_{batt,cmax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \quad (2)$$

The storage charge power corresponding to this maximum charge rate is given by equation 3

$$P_{bat,cmax,mor} = \frac{(1-e^{-\alpha_c \Delta t})(Q_{max} - Q)}{\Delta t} \quad (3)$$

α_c = the storage's maximum charge rate [A/Ah]

Q_{max} = the total capacity of the storage bank [kWh]

$$E_{DG} = \eta DGEff \quad (4)$$

A linear model assumed for the fuel consumption rate (F) in liters/hour of operation by the DG, given in equation 5.

$$F = (0.246 * P_{out})(0.08415 * P_{Ngen})\text{Litres/hour.} \quad (5)$$

The fuel cost, C_{fuel} can be calculated using the formula as in equation 6.

$$C_{fuel} = C_{diesel}\, F(R_s) \quad (6)$$

III. RESULTS AND DISCUSSION

3.1 Load Profile of EKSU, Ado-Ekiti.

The peak load of EKSU is 1,100 kW, this value was gotten from BEDC metering for the month of May, 2024. Figure 4 shows the plot of the hourly load of the school for a period of 24 hours.

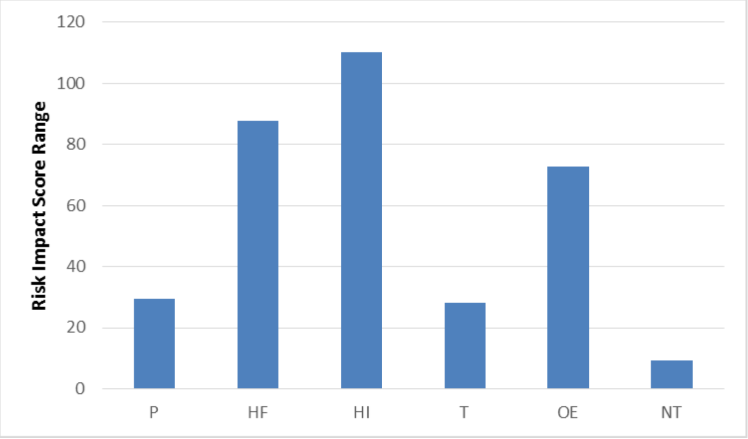
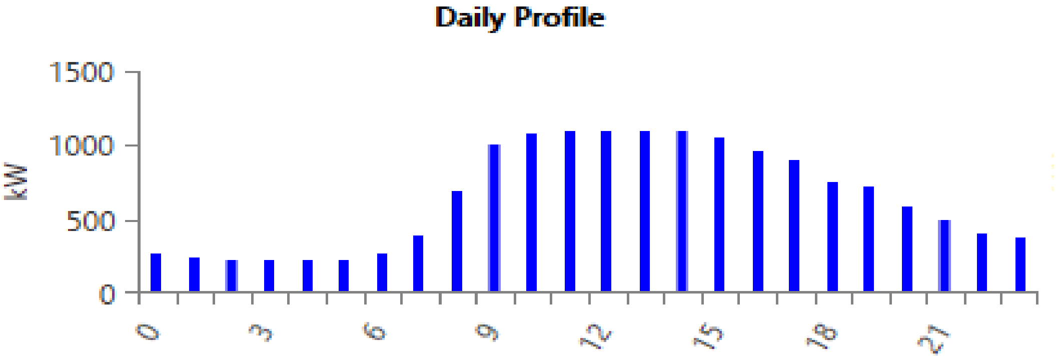


Figure3: Daily Load profile of Ekiti State University, which has a peak load of 1,100 kW



3.2 Simulation Results

Table 1 shows the economics of the hybrid system of Ekiti State University from the software (HOMER).

Table 1: Economics of the hybrid system for different configurations.

Configuration	NPC(S)	COE($/kWh)	Operating cost ($/yr)	Initial cost ($)	Total Fuel (L/yr)	Fuel cost ($/yr)
DG-BAT- CONVERTER	26.4M	0.631	1.96M	1.06M	995,827	587,538
SOLAR PV- DG-BAT-CONVERTER	26.5M	0.633	1.96M	1.23M	987.342	582,532

DG	30.4M	0.725	2.33M	348,688	1,197,402	706,467
SOLAR PV- DG-BAT-GRID- CONV	4.42M	0.106	307,758	445,142	-	-

Table 2 shows the optimal Sizing of the different components for each configuration of Ekiti State University from the software (HOMER).

Table 2: Optimal Sizing result for different configurations

Configuration	DG-BAT-CONV	SOLAR PV-DG-BAT-CONV	DG	SOLAR PV-DG-BAT-GRID-CONV
Solar PV(kW/yr)	-	35,576	-	35,576
DG(kWh)	3,359,811	3,323,863	3,980,711	
Battery (kWh/yr)	263,560	268,447		
Grid (kW/yr)				3,228,201

Table 3 showed the environmental effect of the hybrid system for different configurations, the configuration with the least gas emission is the one which is more environmental friendly while the one with the highest gas emission is the least environmental friendly.

Table 3: Emission of gases for Ekiti State University, Ado- Ekiti, Nigeria.

Gases	DG-BAT-CONV	SOLAR PV-DG-BAT-CONV	DG	SOLARPV-DG-BAT-GRID-CONV
CO (kg/yr)	1,105.367	1,095.949	1,329.116	-
Unburned HC (kg/yr)	358.497	355.443	431.064	-
NO_x(kg/yr)	23,650.891	23,449.372	28,438.297	4,345
CO_2 (kg/yr)	2,609,066	2,586,836.04	3,137,193.24	2,049,130
SO_2(kg/yr)	3,983.308	3,949.368	4,789.608	8,884

DG-BAT-CONV Configuration

In this configuration the diesel generator operated for 6,986 hours and produced 3,359,811 kWh of electricity, the battery stored 263,560kWh of energy per year , solar and the grid has no contribution in this configuration as it does not include both, the NPC is $26.4 M , cost of energy per kWh is $0.631, the operating cost is $1.96 M per year, initial cost of the system is $1.06 M, total Fuel consumed by this system is 995,827 liters per year and the fuel cost per year is $587,538,emission of gases per year; 1,105.367 kg of carbon monoxide, 2,609,066 kg of CO_2, 3,983.308 kg of SO_2, 358.497 kg of unburned hydrocarbon and 23,650.891 kg of oxides of nitrogen per year.

SOLAR PV-DG-BAT-CONV Configuration

The energy produced by the Solar panel is 35,576 kWh per annum, the diesel generator operates for 6,971 hours and produces 3,323,863 kWh of electricity and the battery stored 268,447 kWh of energy per year, grid power has no contribution to this configuration as it is not connected to the grid. The NPC of this system is $26.5 M, the COE per kWh is 0.633, the operating cost per year is $1.96 M, initial cost is $1.23 M, the system consumes 987,342 liters of fuel per year at a cost of $582,532, emission of gases by this system; 1,095.949 kg of carbon monoxide, 2,586,836.04 kg of CO_2, 3,949.368 kg of SO_2, 355.443 kg of unburned hydrocarbon and 23,449.372 kg of oxides of nitrogen per annum. The presence of PV panel reduced the amount of fuel used which led to the reduction emission as compared to the previous one, hence this system is more environmental friendly than the previous configuration.

DG Configuration

The generator operates for 8,760 hours and produces 3,980,778 kWh of electricity. solar, grid and battery has no contribution in this configuration as it does not include them, it has the highest NPC of $30.4 M , highest COE of $0.725 per kWh, highest operating cost of $2.33 M, it has the least initial cost of $348,688, however, it has the highest fuel consumption of 1,197,402 liters per annum at a cost of $706,467, the system has the highest emission of gases; 1,329.116 kg of carbon monoxide, 3,137,193.24 kg of CO_2, 4,789.608 kg of SO_2, 431.064 kg of unburned hydrocarbon and 28,438.297 kg of oxides of nitrogen .The system is the least environmental friendly and the most expensive of all configurations as it has the highest cost of energy per kW and the highest net present cost even though it has the least initial cost.

SOLAR PV-DG-BAT-GRID-CONV Configuration

The Solar PV panel produced 35,576 kWh of electricity, the grid produced 3,228,201 kWh of electricity, the battery and DG does not contribute to this configuration as the software replaces them with the grid during simulation. This system has the least NPC of $4.42 M, the least COE per kW of $0.106, the least operating cost of $307,758 as no fuel cost is incurred, the second to the least initial cost of $445,142 because the grid power has zero initial cost, the system consumes zero liters of fuel per annum; this is because the software replaces the diesel generator with grid. Since there is no fuel consumption, the gases emitted are from the grid; 2,049,130 kg of carbon dioxide per year, 8,884 kg per year of SO_2 and 4,345 kg of NO_2. It is the best of all the configurations.

IV. CONCLUSION

This work considered the technical and economic feasibility study of an hybrid system consisting grid, Solar PV and Diesel for Ekiti State University campus, Ado-Ekiti, Nigeria. Using HOMER software, the hybrid system was meticulously modeled and simulated. The simulations scrutinized various configurations to ascertain the most cost-effective and environmentally friendly option. It compares the economics of various hybrid power system configurations by examining how to meet its load demand using Grid-Solar PV and diesel generator hybrid systems.

It is showned that grid-connected Solar PV-Diesel hybrid system is the most optimal configuration. It is therefore, economically advisable for the university management to invest in Solar PV operating as a hybrid electric power supply system with the existing diesel generator and grid electric power supply. This will definitely lead to reduced energy cost, less greenhouse gas emission and reliable electric power supply in the campus.

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APPENDICES

Appendix I

Detailed parameters of the components

Solar PV Specification		**Battery Specifications**	
Model name	CL 25000E	Minimum lifetime	5 years
Panel type	Flat panel	Initial state of charge (%)	100

Rated Capacity (kW)	25	Depth of discharge (%)	80
Temperature coefficient (°C)	-0.4100	Voltage	12
Operating temperature (°C)	45	Efficiency (%)	80
Efficiency (%)	17.3		
Lifetime	25 years		

Converter Details		**Fuel properties**	
Size (kW)	6	Density (kg/m^3)	820
Lifetime	10 years	Low heating value (m/kg)	43.2
Inverter efficiency (%)	93	Carbon content (%)	88
Rectifier efficiency (%)	93	Sulphur content (%)	0.4
		Fuel price ($/L)	0.59

DG parameters

School DG	
Size (kW)	1,400
Quantity	1
Lifetime (hrs)	90,000
Fuel curve intercept	36.3L/hr
Fuel curve slope	0.22/L/hr/kW
Emission	
CO (g/l fuel)	1.11
Unburned HC (g/l fuel)	0.36
Particulates (g/l fuel)	0.15
NO_x(g/l fuel)	23.75
CO_2 (kg/l)	2.62

Appendix II

Detailed cost parameters of the components (initial, replacement and maintenance costs)

Component	Initial cost ($)	Replacement cost ($)	O& M Cost ($)
PV module	3,000/kW	3,000/kW	10/kW
School diesel generator	348,688	348,688	182.546
Battery	1710/kAh	1710/kAh	76/kAh
Converter	2,600/kW	3,100/kW	0