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Techno-economic optimization of a hybrid power system for Azari farm

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Abstract
The increasing demand for reliable and cost-effective electricity supply, particularly in regions with unstable grid infrastructure, has intensified the need for optimized hybrid energy systems. This study investigates the techno-economic performance and optimal configuration of a hybrid power system consisting of photovoltaic (PV), grid and diesel generator components. The system was modeled and simulated using Hybrid Optimization of Multiple Energy Resources (HOMER) Pro to determine the most economically viable and technically reliable energy configuration for the Azari Farm. Techno-economic analysis was carried out in Hybrid Optimization of Multiple Energy Resources (HOMER) to evaluate multiple system configuration. The evaluation was based on key performance indicators such as Net Present Cost (NPC). Return on Investment (ROI), Internal Rate of Return (IRR), and discounted payback period. The result indicate that the hybrid PV /Grid /Generator provided the most economically viable solution with a discounted payback period of 8.19 years, a Return on Investment of 11.5%, an Internal Rate of Return of 15% and NPC value of about ₦212.63 million while the Grid-only and Generator-only gave a zero discounted payback period, a zero Internal Rate of Return indicating that these systems are unable to recover their investment costs due to higher operational expenses and lack of renewable energy integration. This study therefore highlights the importance of integrating renewable energy resources into conventional power system for the Azari Farm and provides useful insights for energy planners, policymakers and investors seeking cost-effective and reliable energy solutions.

Keywords: Renewable Energy, Net Present Cost, Return on Investment, Discounted Payback Period and Hybrid Energy System

1. Introduction

Agricultural productivity increasingly depends on reliable electricity for activities such as irrigation pumping, crop processing, storage, and farm mechanization. However, in many rural areas the electricity supply from the utility grid is either unreliable or completely unavailable. Farmers often rely on diesel generators to meet their energy demands, but this solution is associated with high fuel costs, frequent maintenance and environmental pollution. These limitations highlight the need for alternative solutions that can provide reliable and cost-effective power for agricultural operations. Hybrid renewable energy systems have emerged as a promising approach for addressing these challenges. By integrating solar photovoltaic (PV) systems with conventional energy grid electricity and diesel generators, hybrid systems can improve energy reliability while reducing operational costs and dependence on fossil fuels. Simulation and optimization tools such as Hybrid Optimization of Multiple Energy Resources (HOMER) enable researchers to analyze different system configurations and determine the most economically feasible energy solution for specific applications.

This study focuses on a case study of Azari Farm, where reliable electricity is required to support agricultural activities such as irrigation, farm processing equipment, and other energy dependent operations. Due to the challenges associated with grid reliability and the high cost of diesel generation, it is necessary to investigate alternative energy solution that can ensure stable and affordable power supply for the farm. Although several studies have explored hybrid renewable energy systems for rural electrification, limited research has focused specifically on farm-level agricultural power systems using hybrid PV/Grid/Generator configurations. In addition, few studies have provided a comparative techno-economic evaluation of hybrid systems relative to conventional grid-only and generator-only power supply options in agricultural settings.

Therefore, the research gap addressed in this study is the limited techno-economic comparison of hybrid renewable energy systems for farm level power supply. This research evaluates the performance of three energy system configurations namely PV/Grid/Generator, Grid-only system, and Generator-only system for the case study of Azari farm using HOMER Pro. The objective is to identify the most reliable and economically viable power supply solution for sustainable agricultural operations.

Several researchers have investigated the design and optimization of hybrid energy system. According to a similar study by Alsharifet al. (2017), which examined the optimization of energy in the telecommunications sector for base stations using integrated energy systems, they were able to achieve an OPEX savings of 43% to 47% while taking Malaysia's solar radiation into account. In many developing countries, the CO_2 gas pollution from fuel burned by terrestrial base station providers for their base stations constitute a significant contributor to greenhouse gas (GHG) emissions into the atmosphere. According to Alsharif et al. (2017), mobile telecommunications accounts for 51% of the Telecommunication and digital Technology sector’s overall carbon footprint. By integrating hybrid systems, this percentage would be greatly decreased.

In their study of hybrid micro-grid modeling, Moradi, Esfahanian, Abtahi, and Zilouchian (2017) came to the conclusion that a significant impact on grid functioning in terms of emissions requires a large penetration of renewable energy. For effective energy management and strategies to reduce reliance on CO2-emitting diesel generators on a university campus, Sanni, Olajude, Abdulkarea, and Alabi (2019) investigated the potential for integrating PV arrays, fossil fuel generators, and battery storage systems. Numerous writers have worked on integrated renewable energy system optimization, using a variety of methods and goals. Sanni et al (2019) analyzed the techno=economic feasibility of PV-diesel hybrid systems for agricultural applications in Nigeria. According to Al Garni and Awasthi (2017), solar photovoltaic systems can significantly reduce the cost of irrigation energy in agricultural applications

An efficiency maximization framework for an integrated renewable energy system for electrifying a confined space in Kerman, Iran, was presented by Askarzadeh and Dos Santos (2015). To determine the ideal life cycle cost (LCC) values, they used various Particle Swarm Optimization (PSO) variations in their investigation. They outperformed others in their results while using adaptive inertia weight-based PSO algorithms. Shariffi and Elmekkawy (2017) developed the E-constraint method, which was used to reduce the overall cost of an integrated renewable energy system, CO_2 emissions, and the likelihood of a load loss. To solve the optimization problem, they suggested a PSO simulation approach in their study. On the basis of economic and environmental impacts, they compared a grid-tied Hybrid Renewable Energy System (HRES) with a typical grid operation. Relative to the conventional grid power system, their study's findings shown a decrease in energy costs as well as emissions of CO_2, SO_2, and NO_2 gas emitted compared to the standard grid power system. Integrating many energy sources into a unified platform enables a flexible setup and seamless evolution and simple extension in the hybrid system (Khan, Yadav, & Mathew, 2017). The hybrid solution can accomplish the following:

- With the solar hybrid system, the Diesel Generator's (DG) fuel consumption can be reduced by 40% to 90%. It is also possible to cut the operational expenditure cost (OPEX) by 90%. locations with DG power alone have a higher OPEX than locations with mixed power. It was possible to reduce the carbon footprint by 30 to 75 percent by reducing the use of fossil fuels.
- A 50% decrease in the OPEC of conventional energy sources
- As a result of integrating additional energy sources to fulfill load demand, a 50% reduction in the DG set run hour would result in a 50% reduction in generator time of operation. The life cycle of DG would be extended with the ensuing decrease in the lower run hour. A generator's lifespan is extended by reducing the number of hours it is operated.
- Keeping the temperature of the equipment within a reasonable range so that heating won't damage it.

To enable speedy installation in remote areas, a whole hybrid system might be placed in an energy container. The cycling battery needs to be able to withstand high temperatures, have low maintenance, support rapid charging, and provide a high number of cycles of charge and discharge. While the controller should have specialized and effective software that can enable module enhancement and provide the least cost of operation, the rectifier should be able to offer a greater efficiency. Utilizing renewable energy sources will allow for longer cycling times, which will prolong the battery and generator's lifespan and lessen their impact on the environment. The following are some of the difficulties telecom carriers encounter while trying to power their base transceiver stations:

- High Mean Time to Repair (MTTR)
- Increase fuel consumption and CO_2 emission
- Increased cost of operation
- Fuel theft, increase load cooling load, and ecological contamination (noise, carbon emissions, and oil spills).

Maleki and Rosen (2017) investigated the efficiency of a fuel cell and wind turbine hybrid energy system for an Iranian residential structure. Their study's conclusions demonstrated that using fuel cell waste heat enhances system performance and boosts its dependability and economic rationale. The viability of boosting solar photovoltaic (PV) resources in the existing diesel-based systems was investigated by Peerapong and Limmeechokchai (2017), who found that the hybrid PV/diesel system reduced the cost of electricity generation while also reducing the harmful emissions from fossil fuels. The lifetime analysis and energy modeling of a typical hybrid energy system constructed on the Greek island of Crete were investigated by Arnaoutakis, Kanellos, and Papaefthimiou (2018). Their research system consisted of a cogeneration system, photovoltaics, and wind turbines. Fan, Li, Dong, and Jermsittiparsert (2021), presented a system integrating wind, hydropower, and photovoltaic systems. Maximizing power generation and minimizing energy fluctuations in electricity generation were the goals of their study. In order to tackle the optimization challenge, they used three applications in their investigation.

In order to sustainably operate a remote cold storage facility for underdeveloped nations, Kanti and Ganguly (2021) investigated a hybrid power system based on solar and hydrogen. The proposed system includes a stack of proton exchange membrane fuel cells, an array of solar photovoltaic modules, an electrolyzer bank, compressed hydrogen storage, and an array of parabolic trough collectors with short-term thermal storage to meet the thermal and electrical needs of a standalone multi-commodity cold storage. De Campose et al. (2021) evaluated the impact of installing floating PV electricity in the massive Sobradinho hydrogen plant reservoir in Brazil, which is situated in the Sao Francisco River, between 2009 and 2018. From 50 to 1000MW, the installed PV power capacity was modified in the simulated scenarios. A number of these investigations were carried out with software for hybrid system design, sizing, optimization, and functional control. The ozone layer is being destroyed as a result of excessive fossil fuel use, which has caused environmental crises. Adoption of hybrid energy sources that are renewable is therefore crucial. But because of their sporadic nature, these energy sources struggle to supply the system's long-term energy requirements. They recommended using a hybrid energy system in their conclusion. To lower the energy consumption of the terrestrial cellular hybrid energy system, several authors have used a variety of techniques.

The hybrid system components of the Azari Farm comprise of the PV panels, The Diesel Generators (DG), Converters, Charge Controllers and Batteries. The PV panels, Batteries and DG were combined to provide the output system. The Panel capacity is 400W and the site has 438 panels. The Battery capacity is 200AH, 12V. The load requirement of the BTS is 968.80KWh/day, giving a total of 353,612KWh/yr. The total number of batteries in the site is 160 while the Generator is a 180KVA Mikano sound proof Generator. The Converter is a 25KW, 240Vdc bi-directional converter. Table1 depicts the yearly load profile data of the Azari farm hybrid station while table2 shows the cost assumption of the Azari farm system component.

2.0 Materials and methods

2.1 Economic analysis

In a hybrid energy system, the cost of each component varies. These expenses are classified as cost fall into Capital cost (Cap Ex), Operational Cost (OP Ex), and Replacement Cost (RC).

2.1.1 Total Life Time Cost of the PV System (TLC_{solar})

The solar system capital cost is given as

$$CapEx_{solar} = C_{solar}\ x\ P_{solar} + I_{solar} \tag{1}$$

Where
C_{solar} = Cost per watt peak of solar PV (₦/kW)

P_{solar} = Installed capacity of the solar system (kW)
I_{solar} = Installation and Infrastructure cost for solar
The operational cost of the solar system is given as

$$OPEx_{solar} = M_{solar} \times P_{solar} \quad (2)$$

Where
M_{solar} = Annual Maintenance cost per kW of installed capacity (₦/kW/yr)
P_{solar} = Installed capacity of the solar system (kW)
Since solar panels typically last 20 to 25 years, replacement could not be possible within the system's lifetime. Inverters and other electronics, however, can require replacing. Consequently, the inverters' replacement cost is provided as

$$\text{Replacement Cost}_{solar} = R_{inverter}\ x\ (1 + r)^{-t} \quad (3)$$

Where
$R_{inverter}$ = Replacement cost of inverter
t = Year in which replacement is required

2.1.2 Total Life Time Cost of the Battery System ($TLC_{battery}$)

The battery system capital cost is given as

$$CapEx_{batt} = C_{batt}\ x\ E_{batt} + I_{batt} \quad (4)$$

Where
C_{batt} = Cost per kwh of battery storage (₦/kWh)
E_{batt} = Energy storage capacity of battery (kWh)
I_{batt} = Installation and infrastructure cost for battery system
The operational cost of the battery system is given as

$$OPEx_{batt} = M_{batt}\ x\ E_{batt} \quad (5)$$

Where
M_{batt} = Maintenance cost/kwh of storage capacity (₦/kWh/yr)
E_{batt} = Energy storage capacity of battery (kWh)

Batteries generally require replacement every 5-10 years due to capacity degradation. Hence the replacement cost is given as

$$Replacement\ cost_{batt} = R_{batt} \times (1 + r)^{-t} \quad (6)$$

Where
R_{batt} = Replacement cost per kWh for battery ((₦/kWh)
t = Replacement year

2.1.3 Total Life Time Cost of the Diesel Generator System (TLC_{Gen})

The diesel Generator capital cost is given as

$$CapEx_{Gen} = C_{Gen} \times P_{Gen} + I_{Gen} \quad (7)$$

Where
C_{Gen} = Cost per kW of diesel generator capacity (₦/kW)
P_{Gen} = Diesel generator rated capacity (kW)
I_{Gen} = Generator installation cost
The operational cost of diesel generators are significant along with maintenance cost and is given as

$$OPEx_{Gen} = (F_{Gen}\ x\ fuel\ price) + (M_{Gen}\ x\ P_{Gen}) \quad (8)$$

Where
F_{Gen} = Annual fuel consumption (Liters)
Fuel Price = Cost per liter of diesel (₦/ liter)
M_{Gen} = Maintenance cost per kw (₦/kW /yr.)

P_{Gen} = Rated capacity of the diesel generator (kW)
Since diesel generators may require complete replacement, their replacement cost is given as

$$Replacement\ Cost_{Gen} = R_{Gen}\ x\ (1+r)^{-t} \quad (9)$$

Where
R_{Gen} = Replacement cost for generator parts
t = Replacement year

2.1.4 Total Life Time Cost of the Converter System (TLC$_{conv}$)
The converter capital cost is given as

$$CapEx_{conv} = C_{conv}\ x\ P_{conv} + I_{conv} \quad (10)$$

Where
C_{conv} = Cost per kW of converter (₦/kW)
P_{conv} = Capacity rating of converter (kW)
I_{conv} = Installation cost for converter
The operational cost of the converter is given as

$$OPEx_{conv} = M_{conv}\ x\ P_{conv} \quad (11)$$

Where
M_{conv} = Maintenance cost per kW of converter (₦/kW/yr)
P_{conv} = Capacity rating of converter (kW)
The converter may need replacement every 10 to 15 years. Hence the converter replacement cost is given as

$$Replacement\ cost_{conv} = R_{conv}\ x\ (1+r)^{-t} \quad (12)$$

Where
R_{conv} = Replacement cost per kW for converter (₦/kW)
t = Replacement year
Therefore, the total lifetime cost of the (TLC) of the hybrid energy system is given by

TLC = Total Capex + Total OPEx + Total Replacement cost
$$TLC_{sys=} \sum_{j=1}^{j}(CE_j + OE_j + RC_j) \quad (13)$$
Where
CE =Capital expenditure
OE = Operational expenditure
RC = Replacement cost
J are the constituent units of the suggested power system which denotes the PV system, the diesel generator, the battery and the converter system.

2.2 Optimization Algorithms
2.2.1 Objective Function
The objective function aims to minimize the total Cost of Energy generation while meeting total Energy requirements and constraints.

Minimize
$$\text{Cost}=\sum_i TLC_{PV_i}N_{PV_i} + \sum_k TLC_{B_k}N_{B_k} + \sum_j TLC_{C_j}N_{C_j} + \sum_n TLC_{DG_n}N_{DG_n} + \sum_m TLC_{G_m} \quad (14)$$
Subject to:
- Energy balance constraints.
- Battery SOC constraints.
- Generator operational constraints.
- Renewable energy availability constraints

Where
TLC_{PV_i} = Total life time cost of the PV system
N_{PV_i} = Number of PV panels

TLC_{B_k}= Total lifetime cost of the battery system
N_{B_k} = Number of batteries
TLC_{C_j} = Total life time cost of the converter
N_{C_j} = Number of converters
TLC_{DG_n} = Total life time cost of the diesel generator
N_{DG_n} = Number of diesel generators
TLC_{G_m}= Total cost of grid purchases

2.2.2 Constraints

- Energy balance constraints.

$$E_{total}(t) = E_{grid}(t) + E_{gen}(t) + E_{solar}(t) + E_{battery}(t) \quad (15)$$

- Battery SOC constraints.

$$SoC_{min} \leq SoC(t) \leq SoC_{max}$$

- Generator operational constraints.

$$E_{gen}(t) \leq E_{gen}^{max}$$

- Renewable energy availability constraints.

$$E_{solar}(t) \leq E_{solar}^{max} \quad (t)$$

2.2.3 Cost of Energy Generation

The total energy generation cost considers the costs associated with each energy source.

$$C_{total} = C_{grid} + C_{gen} + C_{solar} + C_{battery} \quad (16)$$

Where
C_{total} = the total cost of energy generation
C_{grid} = the cost of grid energy
C_{gen}= the cost of generator energy, which includes fuel and maintenance costs.
C_{solar} = the cost of solar energy, including installation and maintenance.
$C_{battery}$ = the cost associated with battery usage, including charging and discharging cycles.

2.3 Carbon Emissions

The ecological footprint of the hybrid energy system is evaluated by calculating the carbon emissions associated with each energy source.

$$CO_2\ Emissions = Egen(t) \times CO_2\ Emissions\ Factor \quad (17)$$

Where:

- Emission Factor = emission rate per unit of energy generated by the fossil fuel generator.

The mass of CO_2 emission is calculate using CO_2 emission rate of 2.68 Kg/KWh of Electrical power generated by the Generator and 0.5Kg/KWh of Energy generated by the utility grid. (Oti and Lewachi, 2017)
Where the mass of CO_2 emitted is given by

Mass of CO_2 emitted = 2.68 x KWh of E_{gen} + 0.5 x KWh of E_{grid} (18)
The diesel cost is calculated based on the unit cost of a liter of diesel as #1,300.
Where the cost of diesel consumed is given by
Cost of diesel l Consumption = Liters of diesel Consumed x #1,300 (19)

2.4 Levelized Cost of Energy (LCOE)

Several cost objective functions, including Levelized Cost of Energy (LCOE), Lifecycle or Net Present Cost, and the Annualized Cost, have been established in the past to be minimized. The Levelized Cost of Energy is the price of solar-generated electricity over the lifespan of the PV system; it is the present value of the entire cost of building and operating a power plant over an estimated lifetime; it allows for the comparison of various technologies (such as wind, solar, and natural gas) with varying lifespan and project sizes. The goal of optimizing hybrid energy systems is to minimize costs while taking into account a number of constraints in order to meet energy demand.
The levelized Cost of Energy is essentially the Cost of Energy and is expressed as

LCOE = $\frac{Total\ annualize\ cost}{Total\ Energy\ served} = \frac{Totalnetpresentcost}{\sum_{t=1}^{T} P_{Load(t)}}$ X CRF (20)

Where

Annualize cost = Total cost x CRF

CRF = the total recovery factor which is given by

CRF = $\frac{i(1+i)^N}{i(1+i)^N - 1}$

Where

i = the interest rate (Discount rate = 7.88%)

N = System life period =25 Years. (Oti and Lewachi, 2017)

2.4.1 Net Present Cost (NPC)

The net present cost (NPC) which is referred to as the life-cycle cost. It is computed by deducting the present value of all installation and operating costs from the present value of all revenues the component is expected to generate over its lifetime. It is expressed as

$$NPC = C_{investment} + OM_{npv} + R_{npv} - S_{npv} \quad (21)$$

Where

$C_{investment}$ = the capital cost of investment

OM_{npv} = the operation and maintenance cost

R_{npv} = the replacement cost

S_{npv} = the salvage value

The OM_{npv} is modeled using the formula

$$OM_{npv} = F_I \times OC \times \left[\left(\frac{1+F_e}{d-F_e}\right) \times \left(1 - \left(\frac{1+F_e}{1+d}\right)^N\right)\right] \quad (22)$$

F_I = percentage of Initial Cost (5%)

F_e = rate of cost increase assumed to be 5%

D = Discount rate, assumed to be 7.88%

N = Number of years (25 years)

OC = Capital Cost of Investment

The replacement cost is given by

$$R_{npv} = P \times (1 + i)^N \quad (23)$$

Where

P = Initial Capital Cost for replaced Component

i = Rate of interest assumed as 7.88%

N = System life period =25 Years.

Table 1 depicts the yearly load profile data of the Azari farm hybrid station while Table 2 of the shows the cost assumption of the Azari farm system component. Table 3 shows the monthly average data of solar irradiance for the Azari farm station, which is situated on $(4^0 59' 50.11^0 N,\ 8^0 20' 37.58^0 E)$ This is important so as to ascertain if the amount of renewable energy source that is currently available will be sufficient to meet the station's load requirements. Determining the amount of sunshine that can reach a specific region at any given time is therefore essential.

2.5 Modeling of the Hybrid System in HOMER.

Figure 1 shows the schematic diagram of the hybrid energy system. The system is a grid-connected system that manages the diesel generator, photovoltaic panels, batteries, converter and grid. An AC bus connects the grid with the diesel generator, while a DC bus connects the PV and batteries. The AC and DC buses are connected to the converter. The load is connected to the AC output. The diesel generator, photovoltaic panels, batteries, converter, and grid are all part of the system, which is grid-connected. The batteries are attached to the PV panels

Table 1 Monthly Load Profile of Azari

MONTH	ENERGY (KWh)
January	30032.8
February	27126.4
March	30032.8
April	29064
May	30032.8
June	29064
July	30032.8
August	30032.8
September	29064
October	30032.8
November	29064
December	30032.8

Table 2 Cost Assumptions for Azari System Components

COMPONENT	CAPITAL COST (₦)	REPLACEMENT COST (₦)	MAINTENANCE& OPERATION COST (₦/Yr.)
SOLAR PV	73,584,000.00	58,900,000.00	1,051,200
INVERTER	27,000,000.00	19,800,000.00	270,000.00
GENERATOR	13,200,000.00	9,000,000.00	300
GRID			75

Table 3 Monthly Average Solar Global Horizontal Irradiance (GHI) for Azari Farm

Month	Clearness Index	Daily Radiation ($KWh/m^2/Day$)
January	0.579	5.500
February	0.569	5.700
March	0.478	4.970
April	0.444	4.620
May	0.429	4.320
June	0.367	3.600
July	0.322	3.190
August	0.305	3.110
September	0.315	3.260
October	0.360	3.630
November	0.448	4.290
December	0.553	5.140

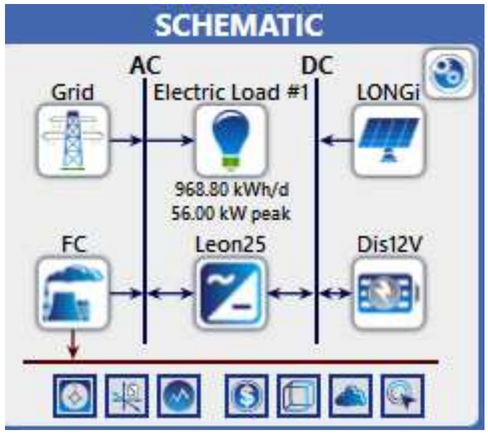


Figure 1 Schematic Diagram of the Hybrid Energy

3.0 Result and Discussion

Production	kWh/yr	%
LONGi LR6-72HV-350M	336,754	85.7
Generic Fuel Cell (size-your-own)	0	0
Grid Purchases	56,396	14.3
Total	393,150	100

Consumption	kWh/yr	%
AC Primary Load	353,612	100
DC Primary Load	0	0
Total	353,612	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	84.1
Max. Renew. Penetration	446

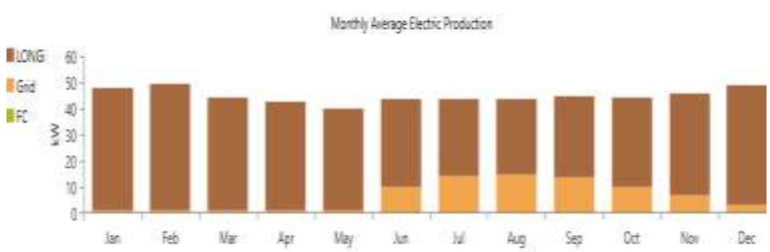


Figure 2 Monthly Electric Productions of the PV /Grid

From figure 2, it was observed that the PV panels had a total of 336,754KWh/yr., representing 85.7% of the total electric productions while the grid had a total electric production of 56,396KWh/yr. representing 14.3% of the total electric productions. The total electric production for the optimized hybrid system was 393,150KWh/yr. indicating an increment of 39,538Whr/yr. from the initial value of 353,612KWh/yr. giving a percentage increase of 11 .18% depicts the Grid rate schedule of the optimized system. This shows that the optimized system performance improved tremendously.

Figure 3 Cost Analysis of the Optimized Hybrid Energy System

The total cost analysis of the optimized hybrid energy system is depicted in figure 3. From the optimized result, the Net Present Cost was ₦212,633,900.00, the Operating Cost was ₦6,368,056. while the Levelized Cost of Energy was measured as ₦46.51/KWh. This shows that the cost of running the PV/Grid/Generator system throughout its lifetime period is very low as well as the operation and maintenance cost thereby making the system economically viable The total salvage value of the system stood at ₦1,562,942.07.

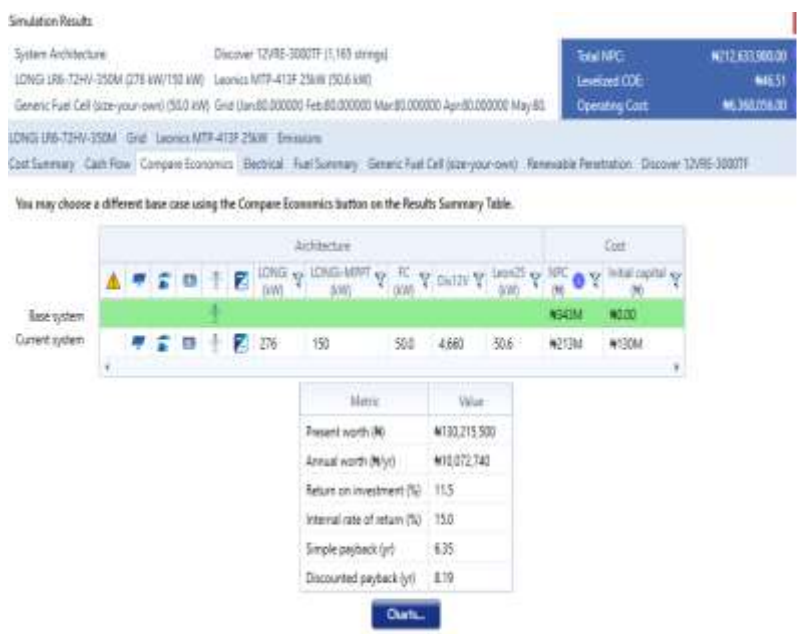
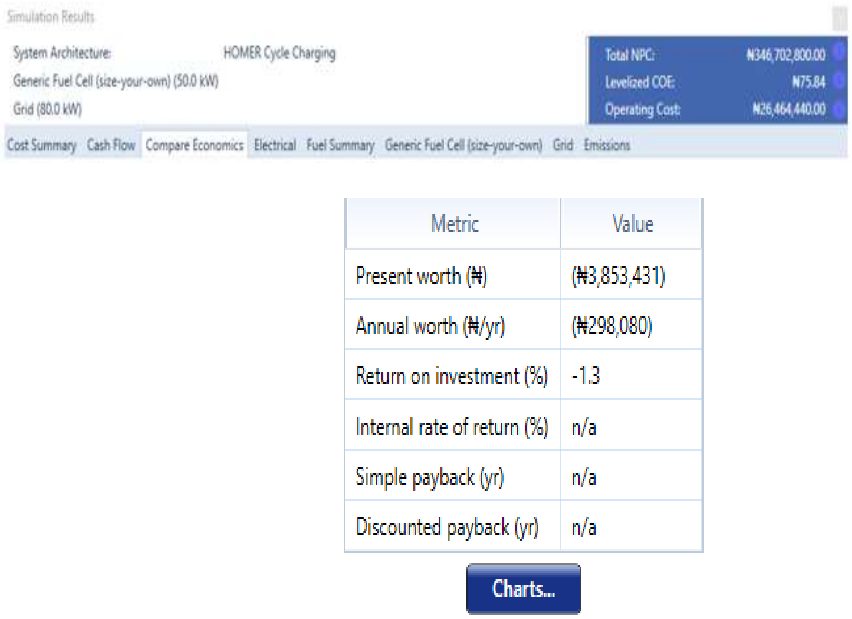


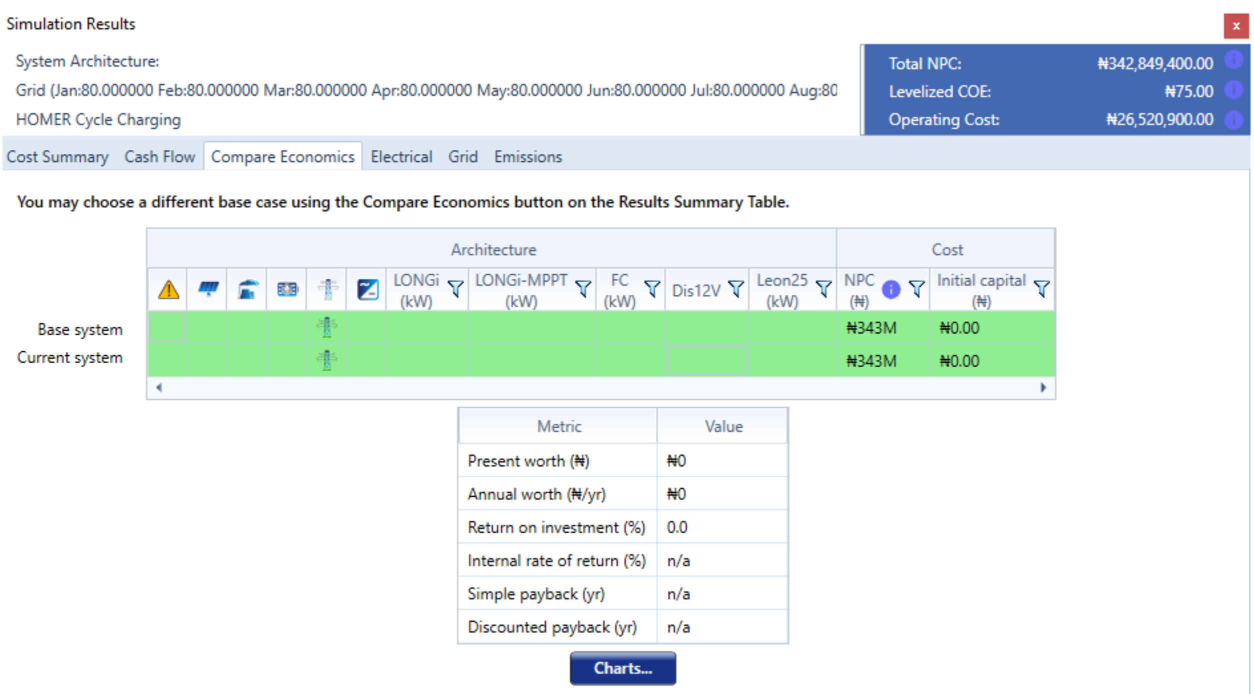
Figure 4 Economic Performance of the Optimized Hybrid System

Figure 4 depicts the economic performance of the PV /Grid / Generator configuration. From the result, the total Net Present Cost was ₦212,633,900.00, the Operation and Maintenance Cost ₦6,368,056.00 while the Levelized Cost of Energy stood at ₦46.51. Also the return on investment was 11.5%, the internal rate of return gave 15% while the simple payback years and the discounted payback years stood at 6.35 years and 8.19 years respectively.



Metric	Value
Present worth (₦)	(₦3,853,431)
Annual worth (₦/yr)	(₦298,080)
Return on investment (%)	-1.3
Internal rate of return (%)	n/a
Simple payback (yr)	n/a
Discounted payback (yr)	n/a

Figure 5 Economic Performance of the Generator-only Configuration



Metric	Value
Present worth (₦)	₦0
Annual worth (₦/yr)	₦0
Return on investment (%)	0.0
Internal rate of return (%)	n/a
Simple payback (yr)	n/a
Discounted payback (yr)	n/a

Figure 6 Economic Performance of the Grid-only Configuration

3.1 Validation of the Hybrid System Using Comparative Economic Analysis

This section presents the validation of the proposed hybrid energy system using HOMER Pro by comparing its performance with two alternative configurations: Grid-only and Generator-only systems. The objective is to verify that the optimized hybrid system offers superior techno-economic benefits over conventional supply options. By comparing key economic indicators, the effectiveness of the hybrid system can be objectively assessed. Three system configurations were analyzed. Grid /PV / Generator, Grid-only and Generator-only. Each configuration was simulated under identical load and environmental conditions.
The validation was performed using the following economic indicators.

- Net Present Cost (NPC)
- Annual Operating Cost
- Levelised Cost of Energy (LCOE)
- Return on Investment (ROI)
- Internal Rate of Return (IRR)
- Simple Payback Period
- Discounted payback Period

Table 4. Comparative Economic Performance of System Configuration

PARAMETER	HYBRID (Grid /PV /Gen)	Grid Only	Generator Only
NPC (₦)	212,633,900.00	342,849,400.00	346,702,800.00
LCOE (₦/KWh)	46.51	75.00	75.84
Operating Cost (₦)	6,368,056.00	26,520,900.00	26,464,440.00
ROI (%)	11.5	n/a	-1.3
IRR (%)	15	n/a	n/a
Simple Payback (Yr)	6.35	n/a	n/a
Discounted Payback(Yr)	8.19	n/a	n/a

Table 4 depicts the simulation result of the techno-economic performance of the three different configuration that was proposed namely the PV /Grid /Generator configuration, the Grid-only configuration and the Generator-only configuration.

3.1.1 Net Present Cost (NPC)

The hybrid system recorded the lowest NPC of ₦212.63 million compared to ₦342.85 million for Grid only and ₦346.70 million for Generator only. This indicates that the hybrid system has the lowest lifetime cost, reduces dependence on grid tariffs, reduces long-term expenses and minimizes diesel fuel. This is followed by the Grid-only configuration while the Generator-only configuration recorded the highest value of NPC. Thus the hybrid configuration is economically superior over the project lifespan,

3.1.2 Operating Cost

The annual operating cost of the hybrid system (₦6.37 million/year) is substantially lower than that of the Grid-only which stood at ₦26.52 million while the generator-only has an operating cost of ₦26.46 million. This reduction in the operating cost of the hybrid system is mainly due to

- Free solar energy contribution
- Reduced diesel fuel consumption and
- Lower generator running hours.

Lower operating cost improves system sustainability and affordability

3.1.3 Levelized Cost of Energy (LCOE)

The hybrid system achieved the lowest LCOE of (₦46.51/Kwh) while the grid-only had an LCOE of (₦75/KWh) and generator-only had an LCOE of (₦75.84/KWh). This shows that the energy from the hybrid system is cheaper per unit, and that solar integration improves cost efficiency. Hence the hybrid system provides the most economical electricity supply.

3.1.4 Return on Investment (ROI)

Table 5 Standard Return on Investment (ROI)

RETURN ON INVESTMENT (ROI)	Financial Implication
< 8%	Weak
8-12%	Fair
➢ 12%	Good
➢ 15^%	Very Good

Table 5 depicts the standard return on investment (ROI) values. This standard is used as a yardstick to ascertain the profitability of various hybrid configurations. The Return on Investment values of the different configurations are compared with this standard values to evaluate the economic feasibility of the configuration. The hybrid system recorded an ROI of 11.5%. This implies that the project generates reasonable financial returns and the system can recover its cost while generating surplus value thereby making the system profitable. The Return on Investment for the Grid-only recorded n /a while the Generator-only recorded an ROI of -1.3% indicating a negative return on investment. This indicates that the system does not generate profits or cost savings relative to its initial cost savings relative to its initial cost. Instead it results in a net financial loss over the projected lifetime. This outcome suggests that the total operating and energy purchase costs of the Grid-only system exceed any potential economic gains associated with its implementation. Since operating a generator involves continuous spending without producing financial gains, there is no basis for calculating investment return. The Generator-only and the Grid-only system is characterized by

- High long-term operating costs
- Dependence on fuel price fluctuation
- Low economic sustainability
- High environmental emissions.

Although they may provide short-term reliability, it is economically unattractive for long-term energy planning.

3.1.5 Internal Rate of Return

The IRR for the Grid-only system and the Generator-only system was reported as n/a because the system does not generate economic returns. Their configuration operates as a consumption based model, where electricity is purchased continuously without producing revenue or savings However for the hybrid system, the IRR of 15% indicates strong financial performance. Since this value is higher than typical discount rates of 8-12% it implies that the project is financially attractive, which implies that the risk level is low and investors are likely to benefit.

3.1.6 Simple Payback

Table 6 Standard Simple Payback Period Values

Payback PERIOD	Financial Implication
< 5 YEARS	Excellent
5-8 years	Good
10years	Poor

Table 6 also depicts the standard simple payback values. This standard is used as a yardstick to ascertain the profitability of various hybrid configurations. The simple payback values of the different configurations are compared with this standard values to evaluate the economic feasibility of the configuration. The simple payback period of 6.35 years for the hybrid system indicates that the initial investment is recovered in about 6 years and that the remaining system lifetime represents profit. The Grid-only system and the Generator-only system recorded a payback period of n /a. This is because the Grid relies solely on utility power supply and does not involve substantial capital investment that can generate cost savings. The generator also does not involve in cost saving investment hat can be recovered over time. Instead it operates mainly on recurring expenses associated with continuous diesel consumption, regular maintenance and frequent replacement of generator components. Since there is no significant capital investment aimed at reducing operating costs, HOMER Pro is unable to determine any period within which the system can recover its expenditure. Consequently, the payback period for the Grid only and Generator only is not applicable.

3.1.6 Discounted Payback

From the simulation result, the PV /Grid /Generator configuration recorded a discounted payback of 8.96years. This result indicates that the initial investment cost associated with the hybrid system will be recovered after approximately 8.19 years of operation, taking into account the discount rate and the operational savings generated by the system. The relatively moderate payback period suggests that the hybrid system is economically viable over its project lifetime and can provide long-term financial benefits.In contrast, the grid-only and generator-only configuration recorded a discounted payback period of n/a (not available). This indicates that the system does not recover its initial investment cost within the project lifetime. This usually occurs when the operational cost of the system is too high. For the generator-only, this can be attributed to the high cost of fuel consumption and maintenance associated with diesel generator which prevents the system from achieving sufficient financial savings to offset the initial investment cost.

Similarly, for the Grid-only, this could be attributed to the reliance on electricity purchase from the utility grid since no additional cost-saving sources such as the renewable generation are integrated into the system, there is no financial recovery of investment that would produce a defined payback period. Therefore, the result demonstrates that the PV /Grid /Generator hybrid configuration provides a more economically attractive solution compared to the Grid-inly and Generator-only configuration. The validation results therefore confirm that the hybrid Grid /PV /Generator system outperforms the Grid-only and Generator-only systems in all major economic indicators.
Key observations include

i. Lowest lifecycle cost (NPC)
ii. Lowest operating and maintenance cost as well as lowest Levelised Cost of Energy (LCOE)
iii. Acceptable investment returns (ROI AND IRR)
iv. Reasonable payback period.

These results validate the effectiveness of the proposed hybrid system. Therefore, the proposed hybrid system is suitable for deployment in farms powered by hybrid system like the Azari farm as well as in GSM base stations and similar critical load applications

4.0. Conclusion

The simulation result shows that the PV/Grid/Generator configuration is the most economically viable and technically reliable option for agricultural electricity supply. The hybrid system achieved the lowest lifecycle cost and demonstrated a discounted payback period of 8.19 years indicating favorable investment potential. In contrast, the grid-only and generator-only were found to be economically unattractive due to their high operational costs and lack of financial returns. Therefore, the integration of photovoltaic technology significantly reduced reliance on fossil fuel-based generation while improving system reliability and long-term economic performance

5.0 Recommendation

Based on the findings of this study, the adoption of hybrid renewable energy is recommended for agricultural power supply at Azari Farm and similar facilities. Integrating solar photovoltaic technology with grid supply and back-up generators can improve power reliability while introducing long-term energy costs and dependence on fossil fuels. energy system planning for agricultural operations should also utilize optimization tools such as HOMER Pro to identify the most economically viable configuration before implementation. In addition, policymakers should encourage the use of renewable energy in agriculture through supportive policies and incentives to promote sustainable and cost-effective farm energy systems.

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