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Original Article

Modeling, Simulation and Design of Hydro-Solar Isolated Micro-grid without a Battery Storage System: A Case Study for Aba Business Cluster, Nigeria

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Abstract - *Unreliable power supply has made operating a business more challenging than usual in Sub-Saharan Africa. This research aims at comparative analysis of techno-economic feasibility of a sustainable hydro-solar energy system without battery storage, using a case study of Aba business cluster, Nigeria. The analysis aimed towards finding the optimum combination based on a compromise of the resources without battery storage. The result showed that photovoltaic/hydro/ battery was the least cost system with a life cycle cost of $380,075 and Cost of energy 0.13$/Kwh, which is slightly lower than photovoltaic/Hydro system without battery with a life cycle cost of $450,428 and Cost of energy 0.15$/Kwh. However, the configuration without battery storage is considered the best as its devoid of capacity loss due to corrosion and degradation of batteries. The study further demonstrated that the addition of solar photovoltaic generation capacity is more valuable than storage capacity, which increases the competitiveness of solar with overall operational sustainability, especially in a commercial application with adequate demand response to maintain the system operational reliability. The study has introduced a design technique in finding the optimal mix of hydro-solar energy resources without battery storage.*

Keywords — *Optimization, Hybrid Renewable energy system, HOMER; Hydro-solar, Optimization, Cost of energy.*

I. INTRODUCTION

The Cost of energy storage remains a great challenge in renewable energy development since their stochastic nature requires a stabilization mechanism provided by storage facilities. Even though renewable energy resource potentials are enormous have the potential to mitigate climate change and sustainably resolve the energy crisis in sub-Saharan Africa, their deployment is very slow. Over 60% of her population is currently with no access to electricity [1]. According to (Clean Technica., 2015), at least half of businesses in Sub-Saharan Africa perceive a lack of reliable electricity access as a major barrier to conducting business, and it is estimated that electricity shortages cost Sub-Saharan Africa nations between 1% and 2% of their GDP. Nigeria is the largest economy in Africa; however, unreliable power supply remains one of the major obstacles to doing business in the country. Only 60% of the population have access to electricity, and 80% of electricity generation comes from gas and oil-powered generators (about 14GW) [2, 3]. Lack of access to reliable electricity costs Nigeria approximately $29 billion annually. (International Monetary Fund - IMF, 2019). low energy access is a major factor in the social and economic poverty of any nation [4].

As in most Sub-Saharan African countries, Nigeria is endowed with enormous deposits of sustainable energy resources, mainly hydropower, wind, solar, and biomass. Nigeria has not been able to fully harness these renewable energy resources, despite the abundant potentials with 3.5–7.5 kW h/m^2/day of solar insolation, 2-4m/s at 10m height of wind speed and, over 286 dispersed small and micro-hydro sites capable of generating up to 734.2MW of electric power [3, 4]. Integration of renewable energy with storage systems and conventional generators has been the trend over the years in the microgrid energy system. Evidently, as a result of the intermittency of these resources, conventional energy sources continue to have a share in the so-called off-grid renewable energy system, which has made its operational sustainability, climate change mitigation and low operational costs an illusion [7]. Techno-economic analysis of wind/PV with hydrogen technology indicated that increasing annual energy generation decreases the life cycle cost and Cost of energy (COE) [8]. Again, optimum Photovoltaic system orientation is also related to a lower cost of energy [9]. HOMER Optimization modelling of a standalone renewable energy system for small and medium-scale tourist accommodation has demonstrated that a modification in the system configuration through selective addition of renewable energy

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sources reduces the NPC with significant increment in renewable energy fraction [10]. Solar photovoltaic ability to compensate for peak load in the mid-day has been demonstrated in a well-optimized hybrid renewable energy system [11]. An assessment of hybrid off-grid wind-PV and battery storage study done by the authors in [12] showed the configuration to be the optimum solution with minimum NPC, and the study suggested an optimization technique to tackle dynamic intermittency of the hybrid renewable energy resources.

The models used in previous works for hybrid renewable energy either comprises energy storage or diesel backup generator to mitigate the intermittency. Although battery-based energy storage can convert stochastic renewables to provide large energy value on-demand, regrettably, the Cost has been a key challenge over the years.

In [13], the study showed that one of the problems when dealing with stochastic renewable sources is adjusting its intermittent availability with the user's demand curve. The stability is usually maintained by energy storage. This section has provided an overview of previous studies done in hybrid renewable energy system optimization. However, the studies have all considered battery storage in the configurations. The merits of increasing generation capacity to storage capacity have not been studied.

Several state-of-the-art studies have been conducted on hybrid renewable energy system (HRES) optimization and design using hybrid optimization multiple energy resources (HOMER Pro) software. The utilization of these tools/methods in solving optimization problems with battery storage possesses operational constraints in actual application due to its preference in a ranking system with battery storage as the optimum since energy storage is the major cost component in the balance of system components. Models used in previous studies, as shown in Table 1, with HOMER software tool in off-grid renewable energy system configurations either comprises of battery storage system or Diesel backup generators. In this regard, this paper solves the optimization problem by a novel techno-economic approach without a battery.

The remaining part of this paper is arranged as follows. Section II is the methodology peculiar to the study, which consists of the site description, load demand assessment and site resource assessment. Section III discusses the mathematical modelling and the system constraints and cost components. Section IV shows the results and discussions, and Section V concludes the paper

II. METHODOLOGY

A. Site Description

Aba is situated in a tropical rain forest climate of Nigeria, with latitude $5^0 06'60.00''N$ and longitude $7^0 21'59.99''E$. Aba stream is a tributary of Imo River, recharged by precipitation with an average annual rainfall of 2285mm mostly between March and November (rainy season) and groundwater, and it's characterized by low terrain[14]

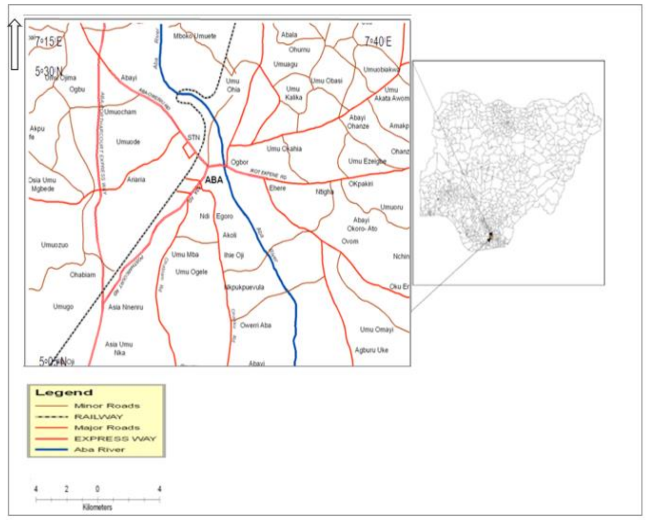

Fig. 1 Study Area Map

B. Load Assessment

The main requirement for micro-grid design is site-specific information such as load profile. The electrical loads are usually the most important factor in the Cost and size of HRES components. So, load determination is a crucial stage in the design of the HRES. The load profile was generated from a combination of on-site measured data and the historical load consumption of the shopping mall, which consist of about 1000 shops and is based on the users' energy behaviour from the grid (Enugu Electricity Distribution Company (EEDC). The grid supply is much unreliable with an average daily supply of 6hrs, hence, the combination of the data. An hourly load profile for a single day, as shown in Fig. 2, is fed into HOMER Pro for simulation. The hourly load data on Table 2 is the readings from an on-site measurement of the output load of a 100KvA generator with a power factor of 0.9 presently in the shopping complex, which will cover the demand for energy consumption in the shopping mall that consists mainly of light bulbs, Tvs, Radio and fans. HOMER software synthesizes hour-by-hour load demand input using the Graham algorithm to generate the peak load[15]. The load profile is a very important consideration in the design and optimization of the HRES for daily and seasonal micro-grid operational reliability.

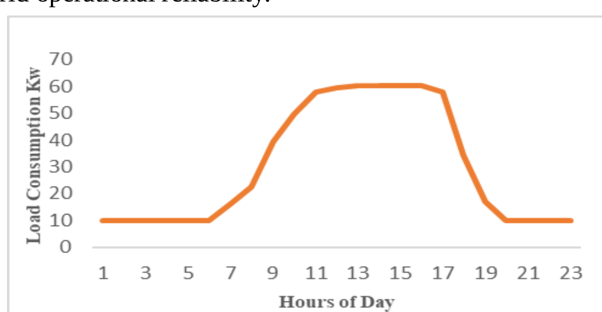

Fig. 2 Diurnal Load Curve of Aba Business Cluster

Table 1. Summary of off-grid Hybrid System Configurations and Cost of Energy at Various Locations

Study	System configuration	Tool/Methodology	Application	COE (USD/kWh)	Year	Reference Location
[16]	PV-wind-battery	HOMER	Off-grid	0.015	2018	Northern Cyprus Mediterranean Island
[17]	PV-battery/Generator	HOMER	Off-grid	0.106	2019	United States
[18]	Hydro/pumped storage-PV	Single & double objective optimization Genetic Algorithm	Off grid	0.289	2014	China
[19]	PV/Diesel Generator/Battery	HOMER	Off-grid	0.207		Benin
[20]	Wind-PV-battery storage	Dimentional Statistical variable (DSV)	Off-grid	0.22/0.25	2017	Maxico
[21]	Hydro-PV-Wind-battery	HOMER	Off-grid	0.16	2017	Ethiopia
[8]	Wind-PV-hydrogen storage & wind only	HOMER		0.83-1.016	2015	Turkey
[22]	PV-wind-Biomass & battery	RET screen & HOMER		0.381	2019	
[4]	PV-diesel-battery	HOMER	Off-grid	0.348	2014	Nigeria
[23]	PV-Wind-diesel-battery	HOMER	Off grid	0.288	2014	Somaliland

Table 2. Daily Load Consumption Measurement of Aba Business Cluster

TIME	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Daily Average Load (%)	Power in Kw **@0.9PF**
7	19%	17%	20%	15%	15%	21%	18%	16.05
8	28%	22%	23%	28%	23%	27%	25%	22.65
9	45%	40%	38%	44%	40%	55%	44%	39.3
10	53%	49%	50%	60%	61%	58%	55%	49.65
11	68%	66.50%	59.70%	65%	63%	64.50%	64%	58.005
12	68%	67.30%	63.70%	68%	63%	67%	66%	59.55
13	68%	67.20%	66.90%	68%	65%	67%	67%	60.315
14	68%	67.20%	67%	68%	65%	67%	67%	60.33
15	68%	67.40%	67%	68%	65%	67%	67%	60.36
16	68%	67.20%	67.10%	68%	65%	67%	67%	60.345
17	58%	67.20%	67.10%	65%	63%	66%	64%	57.945
18	35%	40%	39.10%	42%	33%	40%	38%	34.365
17	17%	20%	18%	21%	18%	19%	19%	16.95

A. *Solar Resource Assessment*

Solar resources assessment is another step in photovoltaic system design that requires proper evaluation, as the available solar resource quantifies the expected monthly or annual energy production, which directly influences the project feasibility or bankability. This study utilizes a microgrid design software (HOMER Pro) for solar resource assessment. The Global Horizontal Irradiation measured in kWh/m^2 (GHI) is used in HOMER software to calculate the output power for flat plate panel PV array, which is dependent on the quantity of GHI, hour-by-hour solar insolation data Meternorn/NASA shown in Fig. 3 will be used for simulation. The summation of beam radiation, diffuse irradiance, and ground-reflected radiation gives rise to the GHI. Nigeria is situated close to the equator in the Northern hemisphere at latitude 4-14^{0}N and longitude 2-15^{0}E with a total land area of 923 768km^2 and a global horizontal solar irradiance in the range of 3.5-7.5kWh/m^2/day.

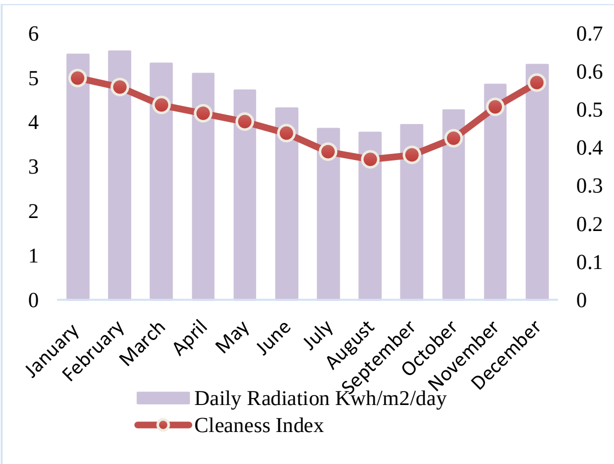

Fig. 3 Monthly Average Solar Global Horizontal Irradiance of Aba

B. Hydro Resources Assessment

Aba is situated in a tropical rainforest climate of Nigeria. Aba stream is a tributary of the Imo River, recharged by precipitation with an average annual rainfall of 2285mm mostly between March and November (rainy season) and groundwater, and it is characterized by relatively low altitude and geology. The hydrological data used in this study, as shown in Fig. 4, is from Anambra Imo River Basin Authority. The Flow varies from season to season, with the highest discharge occurring during the rainy season. On average, August to October has the highest discharge.

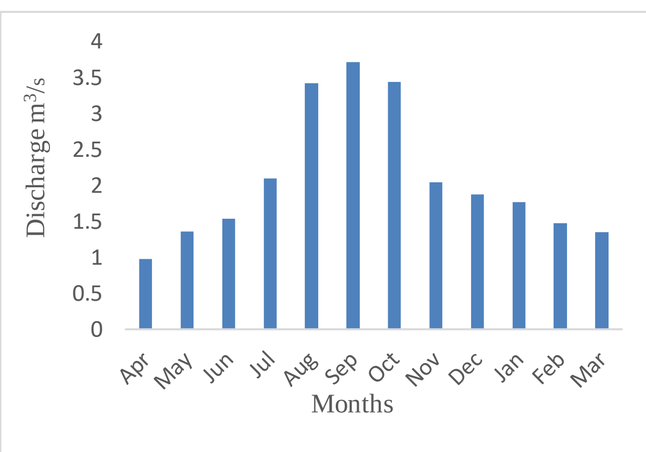

Fig. 4 A monthly Average River Flow Rate

III. SYSTEM MODELING AND CONSTRAINTS FORMULATION

A. Solar Photovoltaic Power Mathematical Modelling

Using the available historic solar insolation data for the optimum tilt surface and orientation, the hourly energy output of the photovoltaic array is given as;

$$P^t.PV \quad = f_{pv}.Y_{pv}\left(\frac{I_T}{I_S}\right) \tag{1}$$

$P^t.PV$
$= \quad Instanteneous\ ouput\ power\ of\ PV\ array\ [kWh]$
$f_{pv} = Derating\ Factor\ of\ PV[\%]$
$Y_{pv} = PV\ array\ rated\ capacity[kW]$
$I_T =$
$Globa\ solar\ radiation\ incident\ on\ the\ PV\ array\ [kW/$m^2]
I_S = the incident radiation at standard test condition [1kW/m^2]
Equation (1) determines the Photovoltaic output power at peak sun hours (PSH).
The total power output of the generic PV array in the HOMER model is given as;[24]

$$P_{P_V} = Y_{PV}.f_{PV}\left(\frac{GT}{GT,STC}\right)[1+\sigma_P(T_c - T_{C,STC})] \tag{2}$$

$GT = Global\ solar\ radiation\ (kWh/m^2)$
$GT_{STC} = Global\ inccident\ solar\ radiation$
$at\ standard\ test\ condition\ (1kW/m^2)$
$\sigma_P = Temperature\ coefficient$
T_c = the PV cell temperature in the current time step [^{0}C]
$T_{C,STC}$ = the PV cell temperature under standard test condition [25^{0}C]

B. Micro Hydropower Mathematical Modelling

The output power of a single micro-hydro turbine is given by; [25]

$$P_{MHP_{=1}(t)} = \cap_{turbine}\ X\ 9.81\ X\ Q\ X\ h \tag{3}$$

$P_{MHP=1(t)}$ = output power of the micro-hydro in the current time step [kW]

$\cap$ = Hydro turbine efficiency
Q = water flow rate [m^3/s]
h = Net available water head [m]

According to (Roy, 2019), the output power of run of the river that operates with low and medium heads can be calculated as;

$$P(h,q) = \cap(q).h.q \tag{4}$$

$P_{(h,q)}$ = Hydropower output with current head and flowrate[kW]

$\cap(q)$ = turbine efficiency at the current flowrate
Where $q = \sqrt{h}$ (5)

Equation (5) applies to ROR with a low head, and the head is the square of the flowrate

Where $h = q^2$ (6)

Equation (6) is very important since we only know the flow rate from the historical data to be provided by Anambra Imo River Basin.

Substituting equation (5) to equation (6)

$$P(h,q) = \cap (q).q^3 \quad (7)$$

$$P(h,q)_{(t)} = \cap (q).q^3.(t) \quad (8)$$

Modification of equation (7) gives rise to equation (8), which is the instantaneous output power (kWh) of the micro-hydro assuming no flow turbulence (with the use of penstock).

Assuming the hydro system will not meet the baseload during periods of low water inflows. The following equations give the water discharge needed to meet the peak load from hydro during the dry months of the, calculated as follows

Assuming negligible head (h = 1) for a run-of-river hydro,

$$Q = \frac{P}{h\ x\ \cap\ x\ 9.81} \quad (9)$$

The pondage capacity required to meet the daily peak load (if not met by PV),

C. System Reliability and Demand-Side Management Modelling

Calculates the probability of loss of Load in solar fraction as a function of the installed PV array.

$$LOLP = \frac{LOLH}{8760} \quad (10)$$

Loss of Load Probability (LOLP)= $\frac{LOLH}{8760}$

$LOLH = Loss\ of\ load\ hours,$

$8760 = is\ yearly\ operational\ hour\ of\ the\ plant$

Were, $LOLH =$

$$\sum ij \left\{ \begin{matrix} 0\ if\ peak\ load\ \leq (hydro\ power + solar\ pv\ power) \\ 1\ if\ peak\ load\ \geq (hydro\ power + solar\ ouput\ power) \end{matrix} \right\}$$

Therefore, the system reliability can be measured by equation (10).

If the LOLP from equation (10) is zero means the instantaneous power generated meets the required load demand (instantaneous load demand), and the LOLP value is 1, which means the required load demand is not met.

A machine learning model tool is used, which mimics human-level thinking and provides a common algorithm for making a decision. The decision tree algorithm used in this model determines the available energy production from the forecasted data in HOMER

D. The Hybrid System Model Analysis

The optimal hybrid system operation will be the summation of equations (1) and (8), given as;

$$P(h,q)_{(t)} + P_{PV_{(t)}} = P_G \quad (12)$$

therefore, if $P_D > P_G \xrightarrow{yields} Demand\ Respon$ (13).

$P_G = Total\ Energy\ Generated$

$P_D = Energy\ demand$

$P(h,q)_{(t)} = Instanteneous\ hydro\ power\ output$

$P_{PV_{(t)}}$
$= Instanteneous\ Solar\ Photovoltaic\ power\ output$

$P_G > P_D\ Then \int P_G(t) - P_D(t)dt \xrightarrow{yields} Energy\ supply\ to\ defferable\ Loads$

$P_G < P_D\ then \int P_{G(t)} - P_{D(t)}dt \xrightarrow{yields} Initiate\ demand\ response$

Equations (10) and (13) follows a machine learning model tool is used, which mimics human-level thinking and provides a common algorithm for making a decision by initiating demand response in the form of direct load control[26].

D. Hybrid System Model Constraints

The peak load of the system should always be met by total solar photovoltaic output

$P_{P_V} = Peak_{Load}$

Where, P_{P_V} is the total instantaneous PV output power, and Peak-load is the peak load of the system.

The baseload of the system should always be met by the total micro-hydropower output

$$P(h,q)_{(t)} = Base\ load$$

E. Cost Components of the System

The system cost components and performance characteristics are shown in Table 3 below. The key input cost to the HOMER model for the system includes the capital, O&M, replacement costs, and specifications (capacity and lifetime). The schematics of the hybrid system components, including PV, Electric Load, hydro converter and battery storage, is shown in Fig.5.

Table 3. System Cost Components

Description	Specifications	Reference
PV System	$/Kw	Emma, A. (2020, December 16). Personal interview
Capital ($/Kw)	1000	
Replacement ($)	1000	
O & M Cost	20	
Lifetime (years)	25	
Hydro	$/Kw	[27]
Capital ($/Kw)	1500	
Replacement ($)	1500	
O & M cost	1-2% of CAPEX	
Life time (years)	30years	
Inverter	$/Kw	Emma, A. (2020, December 16). Personal interview
Capital ($/Kw)	500	
Replacement ($)	500	
O & M Cost	400	
Lifetime (years)	15	
Battery Storage (Li-ion)	$/Kw	Emma, A. (2020, December 16). Personal interview
Capital ($)	1500	
Replacement ($)	1500	
O&M Cost		

IV. RESULTS AND DISCUSSIONS

A. System Simulation Output Results

Table 4 shows categorized optimization results for the hybrid system, and rank 1 presents the configuration with the least Cost with 56Kw PV, 24kWh battery energy storage, 26.8kW converter, and 2 units of 54kW hydro turbine. It followed by rank 2 with 38% and 12% increase in PV converter capacity respectively, however, with no storage capacity. The renewable penetration for both configurations is the same. The slight increase in the net present Cost and Cost of energy in rank 2 is a result of the increase in PV and converter capacity. It is to be noted that the COE from both configurations is not significant and has reached grid parity in Nigeria for the distribution company within the franchise of the study area (EEDC, Band A ₦58.22Kwh ≈ 0.15USD/Kwh). However, they are equally within the range of global tariff and much lower than what was previously studied for isolated microgrid systems without a hydro plant, as shown in Table 1.

Evidently, HOMER selection of the optimum system is based on the configuration with the lowest NPC and COE, which is hydro/PV and battery storage system. However, considering that HOMER's results in off-grid system simulation often gives a favourable outlook towards any configuration with battery storage as a result of assigning and using roundtrip efficiency throughout the battery life, which is not always realistic. This weakness is, however, reflected in the lower NPC and COE and shown in Table 2 and Table 4. Again, high maintenance and associated complicities discredit the merit of its application, as study has attributed battery storage as not clean [28], especially for rural electrification. The optimal system configuration of this simulation result is hydro and PV, without a battery storage system, thereby avoiding deep and extended discharges of the battery bank that may result, as shown in Fig. 6. This drastically shortens the battery life span since the battery autonomy is $<$ 1 hour.

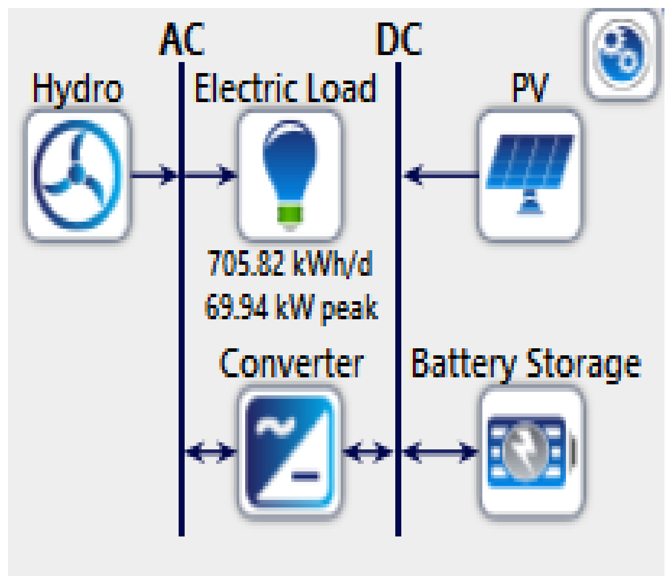

Fig. 5 Schematic Diagram of Hydro-solar and Battery System Design in Homer

Table 4. Categorized Optimization Results

Rank	PV (Kw)	Hydro (Kw)	Battery (Kwh)	Converter (Kw)	Dispatch	COE ($/Kwh)	NPC ($)	O&M ($/yr.)	RE Frac (%)	Autonomy (hr.)
1	56	2	24	26.8	CC	0.134	380,075	20,990	100	0.653
2	90.3	2	-	30.4	CC	0.15	450,428	25,349	100	-

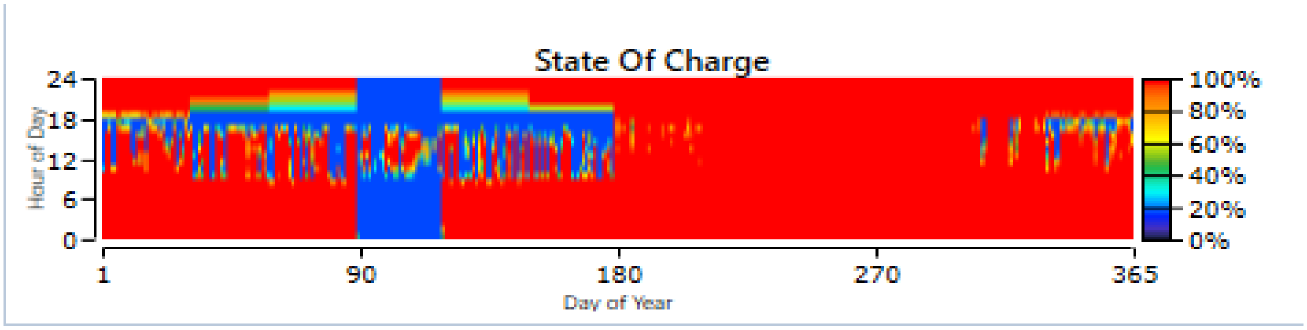

Fig. 6 Battery Storage Operational Time and State of Charge

B. Hybrid System Resource Optimization

Fig. 7 and Fig. 8 shows the electricity generation from solar and hydro generating units for optimal year-round configurations. It can be seen in the months with significant solar irradiation (October to May) that photovoltaic production plays a major role in the whole electricity production over the peak period. On the other hand, in the winter months, and particularly during the months of June to September, the PV production is quite low, and the corresponding low production from PV is compensated by the hydro system. Hydro and PV show complimentary electricity production patterns throughout the year to maintain supply to the base and peak load without a battery storage system. Again, this demonstrated that load profile is crucial in determining optimal complementary configurations for a renewable energy system design involving more than one variable renewable energy resource.

Hydropower is the ideal complimentary resource for PV power in nature, as a decrease in PV output power during the wet years will mean an increase in the hydropower output and vice versa.

The load profile used in this study could be likened to a parabolic load profile with a static relationship throughout the year. The power demand and supply profile demonstrated in Fig. 7 below has a parabolic solar insolation curve of 12 h with maximum solar insolation at midday in February. The energy consumption for the system is an 11 h trapezoidal load curve falling between 6 pm to 7 pm daily which ends the period of maximum demand, with a 13h constant baseload. Fig. 7 again shows the complimentary electricity generation of a solar array and hydro response to demand at any time of the day. Hence, the 11 h peak demand periods has no battery autonomy because the percentage of energy demand that coincides with solar power and hydro is higher. The load profile within the mid-day with a parabolic shaped curve (peak load) makes it ideal to almost match the peak production of the solar photovoltaic system during the midday with the peak demand, as the base plant (Hydro) is relatively constant throughout the day, which supplies the baseload. Fig. 7 equally shows a case of seemingly energy supply-demand mismatch. The PV system, under its current size and insolation, does not meet the Load at all times during the day. Whereas, Fig.8 shows a case where a very low solar insolation is complemented by high hydropower production. In any case, the system imbalance in demand supply could be managed with adequate demand response to maintain reliability.

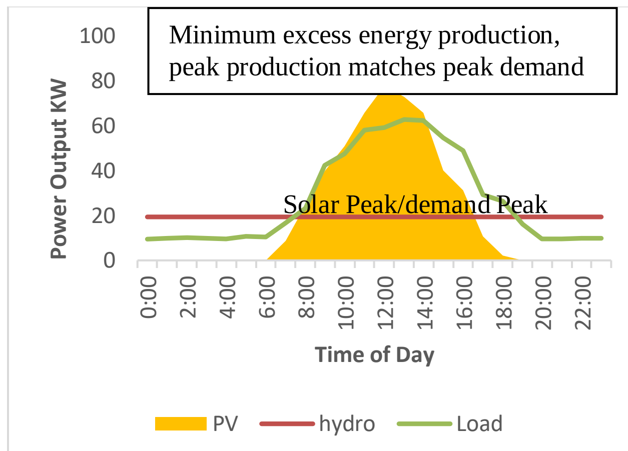

Fig. 7 Complimentary Energy Generation and Production for a Day in February

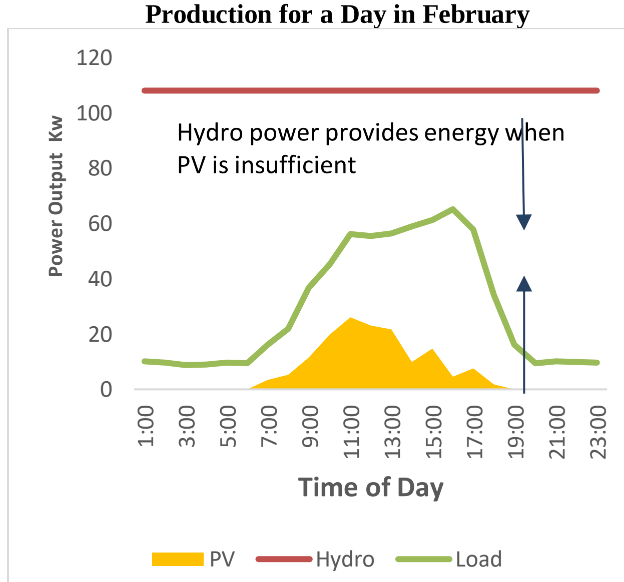

Fig. 8 Complimentary Energy Generation and Production for a Day In September

C. Hybrid System Cost Optimization

This configuration presents the basic system design that supplies electricity demand for the shopping mall. The basis of selecting the optimum HRES combination for a proposed site is based on the trade-off between reliability, NPC, Cost of energy, and system with no battery storage.

As shown in Fig.9, superimposing COE under the same cost rate, the effect of increasing battery storage cost on COE is greater than the Cost of a PV system, which shows that the costs of power generation are low when compared with the Cost of battery storage. Therefore, it is more beneficial to add PV generation capacity than battery-based storage capacity, especially for parabolic or trapezoidal shaped load profiles. Though battery-based energy storage can convert stochastic renewables to provide useful energy on demand, regrettably, Cost has been a key challenge over the years. Replacing the battery storage with a relatively stable hydro system reduces or eliminates the challenge.

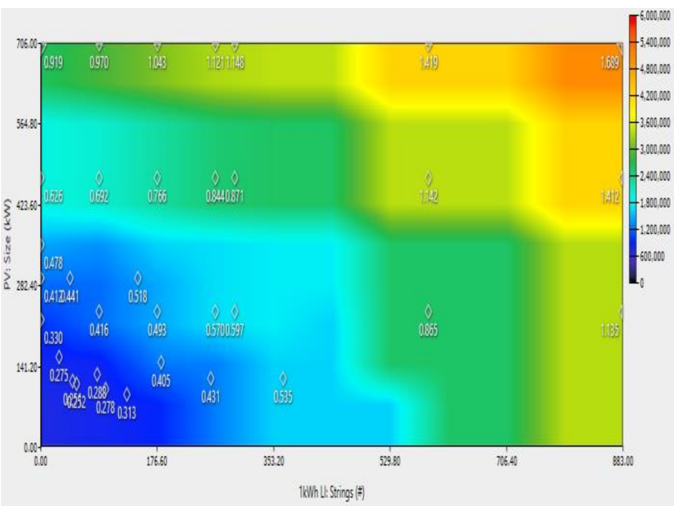

Fig. 9 Effects of PV and Battery Storage Capital cos on Cost of energy

D. System Demand-Side Management

Energy management schemes are often deployed in microgrids to alleviate any possible power fluctuations. The objective is to maximize Load with minimum operational Cost and keep a reliable power supply to uninterruptible loads while part of the loads (interruptible) could be cut off through the demand response mechanism via load shedding. The deferrable loads consider demand response to improve the utilization of variable renewable energy while reducing the Cost of energy storage which encourages more participation of system load

$P_D \; > \; P_G \xrightarrow{yields} Demand\ Response.$

System Reliability measure:

Loss of Load Probability (LOLP)= $\frac{LOLH}{8760}$

A decrease in LOLH increases the total NPC, while an increase in the renewable energy portion increases TNPC. However, a compromise needs to be reached on increasing or decreasing either LOLH and TNPC, respectively.

The decision tree determines the energy demand within the time period to make a decision(prediction) either to shed the loads (interruptible loads) or have a full supply, represented in the internal nodes of the tree branches as shown in Fig.10. however, full utilization of plant generation capacity is paramount. Priority will always be given to non-interruptible loads during supply. The demand response mechanism through load shedding is an essential means to deal with any sudden power deficit of the isolated microgrid energy system to maintain supply-demand balance in the system as illustrated in the root nodes and internal nodes of figure and figure, respectively. Demand response is essential in microgrid design due to uncertainties in supply and to maintain operational reliability, rather than attempting to match power generation with demand which will result in the system overcapacity and, as a result, increases plant capital cost of the project.

The capability to increase the energy production during the periods of low water inflow and peak demand with the use of small reservoirs (pondage), thereby balancing energy demand supply without the deployment of battery storage. The use of pondage as virtual batteries makes energy production predictable and available on-demand as it takes care of daily, month to month or seasonal changes in the flow pattern for temporarily storing water amid non-working hours, idle days, and low demand periods for use during hours of increased demand or low solar insolation (most dry month) using equation (9).

The pondage capacity required to meet the daily Load during a period of low inflows;

The total Load at 2hrs. intervals = 381.6KW

Average Load = $\frac{381.6\ kw\ x\ 2hrs}{24hrs}$

$\therefore The\ daily\ average\ load$ = 31.8Kw

The Flow (Q) required to develop the average daily Load assuming a negligible head (h = 1m), hydro turbine efficiency of 80% and $g = 9.81\frac{m}{s^2}$ from equation (9) is given as;

$$Q = \frac{\text{Daily average Load (Kw)}}{\cap \text{ x h x g}}$$

$$Q = \frac{31.8}{0.8\ x\ 1\ x\ 9.81} = 4.05\frac{m^3}{s}$$

The Flow required during the peak load periods from Table 4. Total shortage = Total Excess$(\frac{m^3}{s})$

$\therefore The\ Pondage\ Cpacity\ required\ to\ meet\ the\ daily\ peak$ $load\ demand = 16.91\frac{m^3}{s}\ for\ 2hrs.$

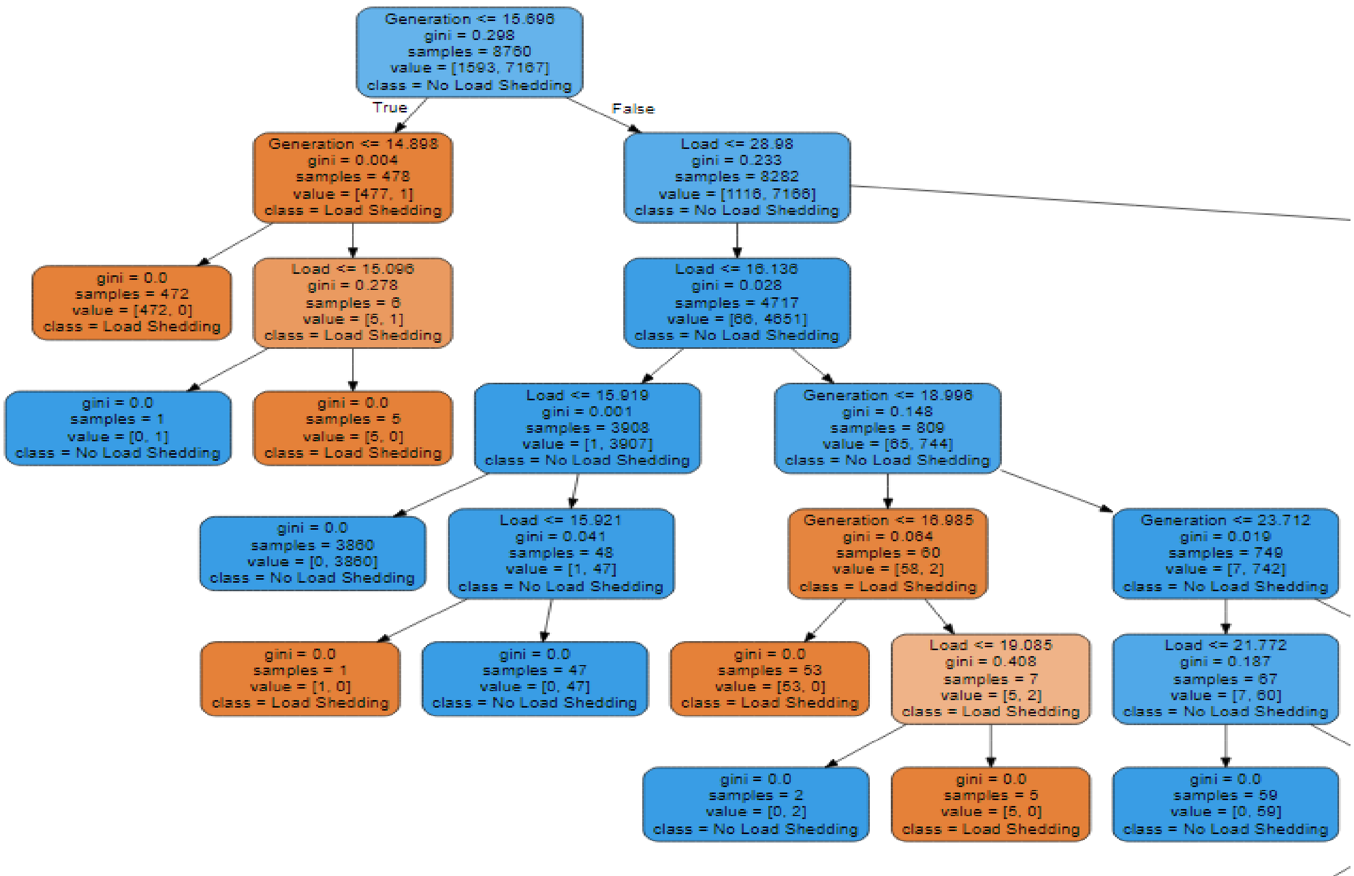

Fig. 10 Decision-based Demand Response

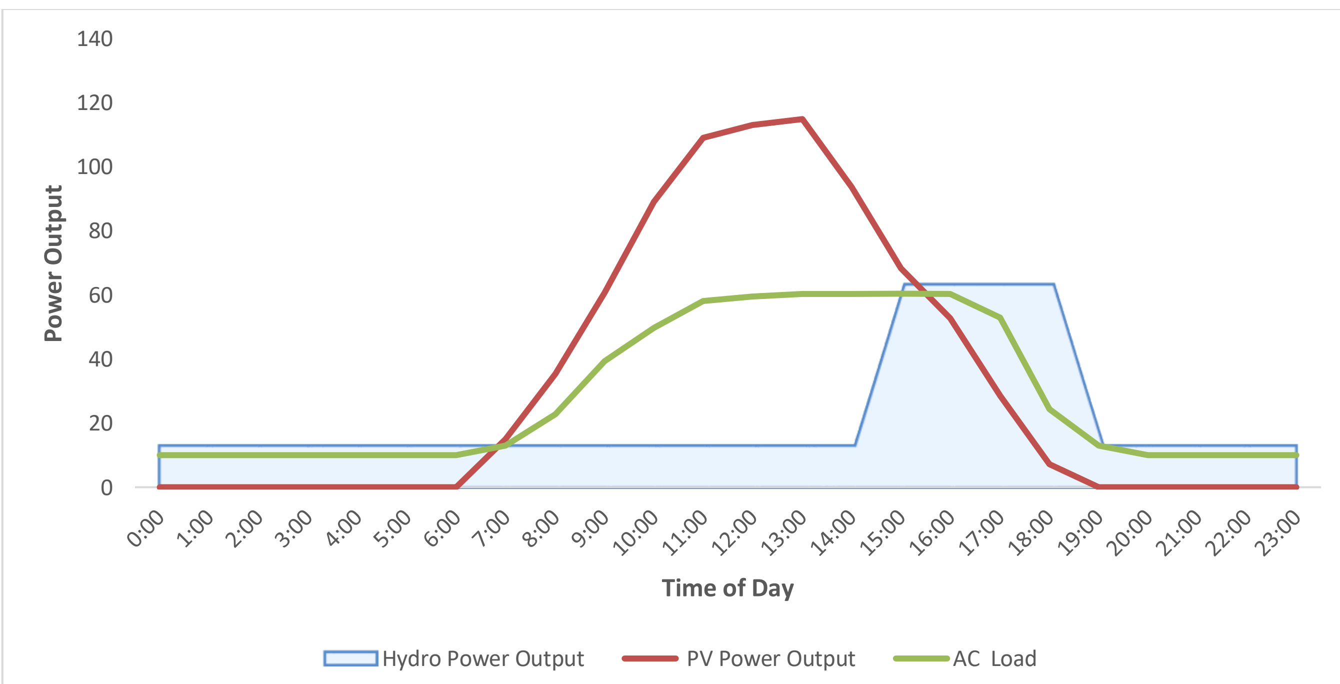

Fig. 11 Hydro Output Power Stability Using Pondage

Table 4. Pondage Capacity Required for Daily Variable Load

Time (hr.)	Daily Load Variation (KW)	Required Flow (m^3/s)	Deviation from Ave. flow of $4.05m^3/s$	
			Shortage	Excess
0-2	10	1.27	-	2.78
2-4	10	1.27	-	2.78
4-6	10	1.27	-	2.78
6-8	17.67	2.25	-	1.80
8-10	41.30	5.26	1.21	-
10-12	61.67	7.85	3.80	-
12-14	66.67	8.50	4.45	-
14-16	67	8.53	4.49	-
16-18	55	7.0	2.96	-
18-20	22.3	2.84	-	1.21
20-22	10	1.27	-	2.78
22-24	10	1.27	-	2.78
		Total =	**16.91**	**16.91**

E. Effect System Orientation and Tilt on the Overall Energy Production

The annual energy generation is greatest around 15^0 tilt and 0^0 Azimuth, south-facing orientation as shown in the figure below, which is modelled in PVsyst with varying latitudes. Comparing the energy production for 0^0 tilt with south-facing orientation, there is a slight increase of 0.02% (62Kwh/m^2/yr.) between 0^0 and 15^0 tilts. The slight increase may be as a result of relatively constant global incidence radiation throughout the year when compared with other latitudes with varying radiations. The figure further demonstrated a slight decrease in the global incidence radiation between May and August, which corresponds to the months with increased river flow for the optimum complimentary of the resources throughout the year. Evidently, optimization of the complementarity between solar PV and small hydropower systems compromises PV output energy which is related to installation orientation and tilt to improve synergy.

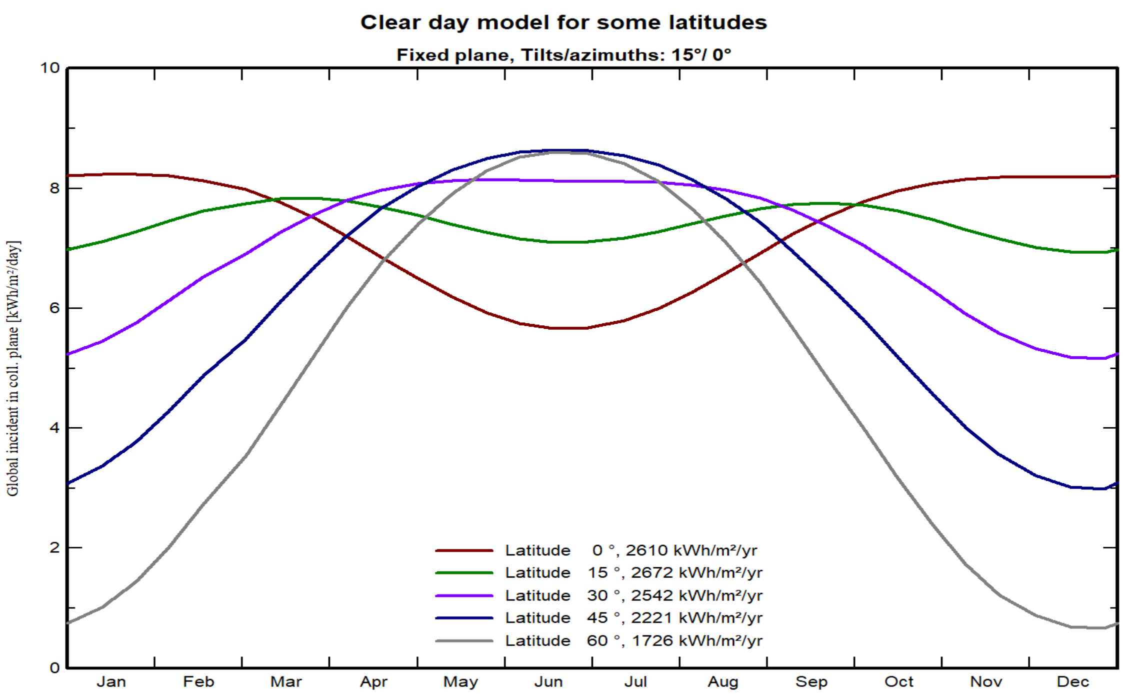

Fig. Annual Energy Generation at South-Facing Orientation with Different Tilt

V. CONCLUSION

Hybrid renewable energy systems are becoming the new normal to maintain system operational reliability. The study investigated and assessed the techno-economic performance of hybrid isolated microgrid energy without battery storage using HOMER. The study has demonstrated that a load profile with a parabolic or trapezoidal shape could operate with no battery energy storage in a hydro-solar renewable energy system. It is supposed that it will be helpful in balancing the energy supply-demand gap for communities with no or limited access to electricity as a result of low maintenance costs associated with the scheme. Instead of the sole renewable energy generation systems, which is common today, a solar photovoltaic system including hydro in the mix of the hybridization can produce reliable energy as the availability of these resources are complimentary.

The optimal operation of the scheme is dependent on the load curve. Therefore, the study is most viable for commercial loads. The consequent system designer needs to have a detailed energy demand situation for an off-grid hybrid energy system prior to implementation. Hence, system design optimal solution is always flexible, which is based on very specific regional, social and economic characteristics of electricity demand. Study of other hybrid renewable energy resources operational behaviour without battery storage at different load patterns is recommended

However, to provide more flexibility in the system operation, reserved power or an adequate energy management strategy is needed to meet short-term power shortages as a result of the stochastic behaviour of the resources. In this case, the virtual battery is considered for the suitable reserve with a pondage that will provide a more flexible power supply.

The clean and reliable supply of electricity through the use of the best technological fit of hybrid renewable energy systems can improve economic activities and wellbeing. In addition, using renewable energy systems can reduce greenhouse gas emissions, which is common with the current power generation dispensation across commercial cities in Nigeria and equally achieve grid parity, especially when there is synergy in the availability of the resources as the case of solar and hydro. Moreover, the findings in this work may be instrumental in solving erratic power supply facing businesses and can replicate in the design, execution, or development of techno-economic analysis of hybrid PV/hydro wherever the resources are available to provide a sustainable power system in Nigeria that will salvage our present predicament.

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