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MODELING AND SIMULATION OF SMALL HYDRO-SOLAR PV HYBRID GENERATING SYSTEM FOR COMPLEMENTARY POWER SUPPLY IN A METROPOLITAN CITY

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Abstract:
In this work, a grid-connected small hydro-solar PV hybrid power system (HPS) was modeled to complement electricity supply in Ado-Ekiti metropolis in Nigeria, and hence, investigated the steady state stability of the distribution networks with and without HPS integration. Consumers' load audit was carried out through measurement of apparent load at peak periods on each outgoing cable riser from the low voltage circuit of the distribution transformer using clamp-on ammeter which represents loads on respective 11 kV feeders. The solar PV system employed the use of JAP6-72-30/4BB solar PV module and average solar radiation intensity of 4.95 w/m^2 was considered when sizing the solar PV power system. The designed and modeled HPS was integrated into the grid through a hydro inverter and five numbers of parallel-connected 2000 kVA grid-tie solar PV inverters. Simulation analysis of the distribution networks with and without renewable energy integration was carried out using DigSILENT power factory. This work analyzed two scenarios for each of the distribution networks. Simulation results indicated that the networks were stable as evident in the analyses of the renewable grid integration and notable improvement on profile voltage (pu) of all the 11 kV distribution networks were observed.

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1. INTRODUCTION

Steady growth of energy sector in any nation is an essential ingredient for economic and technological advancement. This massively reduces rural-urban migration, depletion of conventional energy resources, deforestation and harmful gaseous emission to the environment [1-3]. Restricted access to reliable and sustainable energy for developing nations could have significant negative impact on their citizens' standard of living especially in semi-urban cities and other rural areas [4]. Such energy is needed to deliver services for health centers, businesses, schools, offices, home services, transportation systems, food production, and mining industries, to lighten the environment and most importantly for industrialization [5-6]. Power supply in the country is absolutely unreliable, insufficient and not sustainable [7].

Oyedepo et al. [8], in a projected electricity demand survey carried out for the country, estimated the medium and long-term electricity demand to be at 30,000 MW and 192,000 MW respectively. The total installed generation capacity for the country is 12,500 MW and largely depend on fossil fuel resources (i.e. thermal/gas power and hydro power sources representing 87.5% and 12.5% respectively). The available power generation in Nigeria (about 3,800 MW-4,500 MW) cannot match up with demand [9, 10]. Hence, the need for

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significant electricity generation through sustainable and environment-friendly source.

Renewable energy has demonstrated to be a very good alternative source of energy generation to fossil fuel resources. Unlike fossil fuel resources that may not be available for a very long time due to daily depletion, renewable energy resources replenish faster as human consumes them due to its natural existence, long life cycle and with almost free maintenance cost [10-12]. Renewable energy sources (RES) are more profitable, reliable, efficient and stable when connected to the grid [3, 13-14]. Some of the available RES in Nigeria are solar, wave power, tidal, wind, biomass, hydropower, geothermal resources, biofuels and solar thermal etc. Any of the above highlighted resources can be developed and explored based on geographical availability and suitability with the purpose of eliminating challenges of increasing power demand [15-17].

However, one renewable energy system cannot satisfy the power need alone as it is irregular in nature, hence the need to form a hybrid energy system [18, 19]. A hybrid power system (HPS) can be described as a combination of unrelated, but complementary energy generation systems based on renewable energy or conventional energy sources. It captures the top qualities of each energy source [20, 21].

Several works have been carried out on feasibility of renewable energy sources for rural electrification [7, 10, 13, 15, 20-24], off-grid HPS [7, 9, 10, 13, 16, 20, 21, 23, 24], and grid-connected HPS using HOMER software [3, 9, 11, 22, 23]. Olabode et al. [16] carried out a comprehensive review of methods, designs and techniques being adopted by different authors on HPS for rural areas. The review was necessitated due to the several cases of unreliable or non-functional HPS projects that is so prevalent in Sub-Saharan Africa. The work identified some of the major causes of unreliable HPS and made some useful recommendations for future research purposes.

Almukhtar et al. [22) worked on a HPS utilizing renewable energy sources and grid electricity to supply electric power to a rural primary school in Unm Qasr primary school, Iraq. Adepoju and Adebanji [13] conducted a feasibility study of a hybrid system on an existing water supply dam of a rural village-Itapaji, Nigeria. The work explored the optimal combination of small hydro, solar PV, battery and diesel hybrid system. The results showed that small hydro-solar PV-battery-Diesel hybrid system is the optimal combination for the village. In a related work, Adebanji et al [10] developed an optimal sizing model consisting of Solar PV, Small hydro (SHP), diesel and batteries for the same village-Itapaji-Ekiti, Nigeria using Genetic Algorithm (GA). The optimized results when compared with HOMER's simulation results showed improved correlation coefficient of 0.88 and the root mean square error of 0.001.

Syahputra and Soesanti [21] researched on planning of hybrid micro-hydro and solar photo voltaic system for rural areas of central Java, Indonesia. The research work proposed an optimal placement of grid-connected micro-hydro and solar photovoltaic HPS using direct measurement method of data gathering to determine ideal capacity of solar, micro-hydro plants and electricity load analysis of central Java, Indonesia. However, recognized optimization and sensitive power analyzing tool should have been adopted.

Jibrin [25] carried out a related work on modeling and simulation of grid-connected Small hydro-solar HPS to supplement power supply in Kaduna, Nigeria using Artificial Neural Network for the load profiling. The developed HPS was implemented in MATLAB/SIMULINK environment. The developed model was able to supplement the power deficit from the grid. However, the stability of the distribution network after the HPS integration was not investigated.

All the above researchers presented different research works on hybrid generation systems suitable to their areas of study, very few of them especially in Nigeria have worked on modeling and simulation for complementary power supply and at the same time investigated the steady state stability of the distribution network with and without solar PV hybrid integration using the same methodology. In this work, a grid-connected small hydro-solar PV hybrid power system was modeled to complement electricity supply of Ado-Ekiti metropolis and hence, investigated the steady state stability of the distribution networks with and without HPS integration.

2. METHODOLOGY

2.1 Description of Ado-Ekiti 11 kV distribution networks

The single line diagram of Ado-Ekiti mains 33 kV line is as shown in Fig.1.

The main injection substation is connected to two steps down, 15 MVA, 33/11 kV variable transformers located at Ado mains injection substation at Basiri-Ado-Ekiti. It is stepped down to four 11 kV township feeders' namely; Ajilosun, Okesha, Adebayo and Basiri.

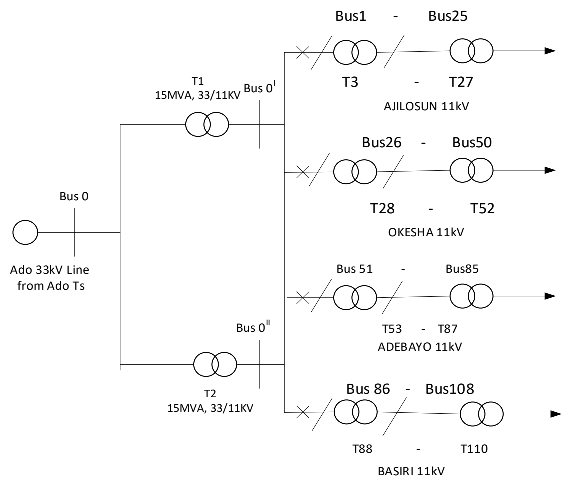

Fig. 1. Single line diagram of 2x15 MVA, 33/11 kV

2.2 Daily power allocation and consumers' load profile assessment

Power allocation to any part of the state by the electricity utility company-Benin Electricity Distribution Company, (BEDC) depends on available power generation from the nation's generating stations (GENCOs). The average daily power allocation to Ado-Ekiti metropolis is 14.9 MW and this occurs when power generated by the GENCOs hit all-time highest record of about 8000 MW. The total maximum load demand from consumers' load profile assessment of all the 11 kV feeders is 23.88 MW, which represents what the metropolis actually needs at peak periods.

It is evident that the metropolis has power allocation deficit of 8.9 MW. The daily consumers' load demand profile chart is as shown in Fig. 2. The data was obtained through the use of questionnaires (on the number of appliances used by each consumer) and the daily loading log books from BEDC.

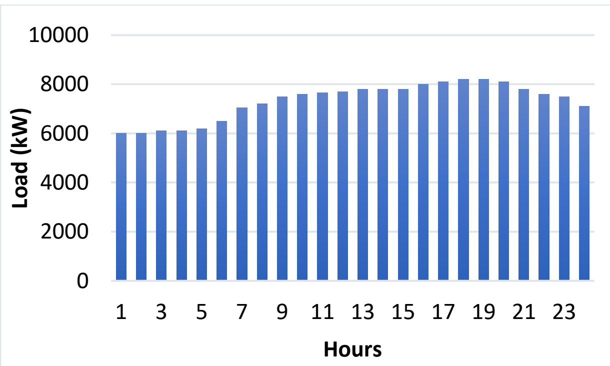

Fig.2. Daily consumers' load demand profile for Ado-Ekiti

2.3 Small hydro power resources assessment of the study area

The hydro resource available is from Elemi River. It is a main tributary of Ogbese River. The catchment elevation ranges from 550 msl. near the source-Igede-Ekiti (7°46'00.67" N; 5°16'00.50" E) to 356 msl at gauge station-Erinfun (7°36'56.04"N; 5°17'51.54"E) [26]. A feasibility study carried out on the river (with hydrological data of the river collected for a period of 11 years) showed that the average annual derivable head and stream flow discharge are 8 m and 45,900 l/s respectively [26]. Fig. 3 presents the mean annual flow rate of Elemi River, Ado-Ekiti.

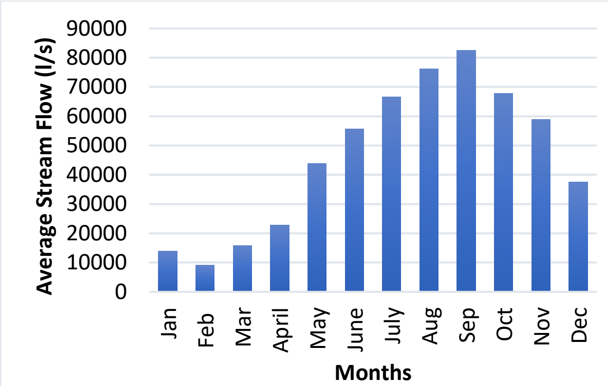

Fig. 3. Mean annual flow rate curve of Elemi River, Ado-Ekiti

2.4 Solar energy resources assessment of the study area

Solar irradiance and radiation of the study area were obtained from National Aeronautics and Space Administration (NASA) on 20th of December, 2021. The annual average solar irradiation and temperature are 4.95 kWh/m^2 and 28.78 °C respectively. Fig. 4 and Fig. 5 presents the monthly average solar irradiance and clearance index for Ado-Ekiti as executed using HOMER software.

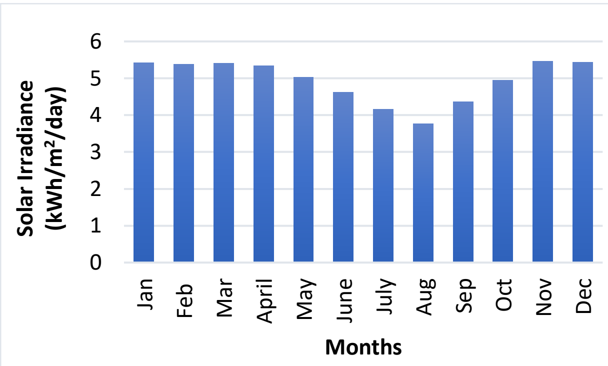

Fig. 4. Monthly solar irradiance and clearness index of Ado-Ekiti

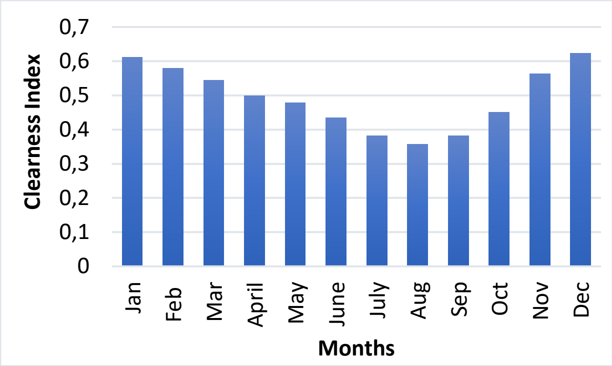

Fig. 5. Monthly clearness index of Ado-Ekiti

2.5 Research approach

The research work was executed in sequential order through collection of relevant data inputs like consumers' load profile, Elemi River hydrological data, solar irradiance and radiation data from BEDC, Federal Ministry of Water resources and irrigation, National Aeronautics and Space Administration (NASA) and Nigeria Meteorological Agency (NiMET) respectively.

Quarterly load reading of each distribution transformer (11/0.415 kV) at peak periods of 5:30 am - 9:30 am and 5:30 pm - 9:30 pm respectively were taken on the 11 kV power distribution network using Clamp-on Ammeter. These were used in determining the percentage loading and load demand on the distribution transformers. It was assumed that the customer load remains static and the system frequency is constant**.** Each of the 11 kV distribution network was modeled as π-network, with each feeder having power factor (p.f.) of 0.94 and frequency of 50 Hz. The transformers and the bus bars were modeled as a 3-phase tap changer. Single phase voltage level was taken to be 240 V from the Low Voltage circuit.

The power generated from small hydro and solar energy resources were connected as a HPS due to the stochastic nature of renewable energy resources. This allowed each resource to capture the best features of each other. The grid-connected small hydro-solar HPS data input was optimized using HOMER software. The hydropower system uses a salient pole synchronous generator type with rated output power of 2.21 MW. The Solar PV system adopted a single diode model generating output power of 6.69 MW.

The Small hydro-solar PV HPS were both connected to the weakest nodes on the distribution networks based on the load flow analysis of the base cases that reveals them. The single line diagrams of the networks were modeled with and without renewable resources integration and afterwards, steady state stability of the networks were carried out via simulation using Dig SILENT power factory.

3. POWER FLOW EQUATIONS

The actual and reactive power at any node p is as expressed as in equation (1)

$$P_p - JQ_p = E_p^* Ip \qquad (1)$$

Current flowing in any node $P$is as expressed in equation (2)

$$\mathrm{I}_p = \frac{P_p - JQ_p}{E_{p^*}} \qquad (2)$$

where P_p (W) and Q_p(VAR) are the overall active and reactive power attainable at node P and I_p (A) is an electric current flowing in any node P. The above expression is the total electric current of a node if the shunt constituents are grounded. If the shunt constituents are not involved, the total current at the node P is as expressed in equation (3).

$$Ip = \frac{P_p - JQ_p}{E_{p^*}} - Y_p E_p \qquad (3)$$

where Y_p (S) is the total shunt admittance at the node and $Y_P E_p$is an electric current flowing from node P to ground. The effecting expression in the admittance configuration is as in equation (4),

$$\mathrm{I_{Bus}} = [Y_{BUS}] E_{BUS} \qquad (4)$$

Enlarged form of above expression is demonstrated as in equation (5).

At any node P, the effecting admittance expression is as given in equations (6) and (7):

$$\begin{bmatrix} I_1 \\ I_2 \\ \dots \\ I_p \\ \dots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11}\, Y_{12} \dots Y_{1p} \dots Y_{1n} \\ Y_{21}\, Y_{22} \dots Y_{2p} \dots Y_{2n} \\ \dots \\ Y_{p1}\, Y_{p2} \dots Y_{pp} \dots Y_{pn} \\ \dots \\ Y_{n1}\, Y_{n2} \dots Y_{np} \dots Y_{nn} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ \dots \\ E_p \\ \dots \\ E_n \end{bmatrix} \qquad (5)$$

$$I_p = Y_{p1}E_1 + Y_{p2}E_2 + - - Y_{pp}E_p + - - Y_{pn}E_n \qquad (6)$$

$$I_p = \sum_{q=1}^{n} Y_{pp}E_q = Y_{pp}E_p + \sum_{q=1}^{n} Y_{pq}E_q \qquad (7)$$

$$Y_{pp}E_p = I_p - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq}E_q \qquad (8)$$

$$E_p = \frac{1}{Y_{pp}}\left[I_p - \sum_{\substack{q=1\\q\neq p}}^{n} Y_{pq}E_q\right] \quad (9)$$

Replace Ip from Expression (3) in expression (4), E_p (V) is as expressed in equation (10):

$$E_p = \frac{1}{Y_{pp}}\left[\frac{P_p - JQ_p}{E_{p*}} - \sum_{\substack{q-1\\q\neq p}}^{n} Y_{pq}E_q\right] \quad (10)$$

4. RESULTS AND DISCUSSION

4.1 Hybrid power system (HPS) power Production

A feasibility study carried out on the river (with hydrological data of the river collected for a period of 11 years) shows that the total power that can be extracted from the hydrological data inputs as modeled using HOMER software is 2.21 MW. The extractable power from the solar energy resources was appropriately sized to generate 6.69 MW. The complementary operation of the grid-connected small hydro-solar PV HPS is as shown in Fig.6.

The power need of the metropolis is met and sustained by the Grid and Solar PV systems from the month of January through April. Obviously it is a dry season period and is characterized with shortage of water resulting to insufficient hydro power production. The small hydro power resource has no contribution to the power sustainability of the study area throughout these periods. However, from the month of May through October, the power needs of the study area is provided and sustained by the Grid, small hydro and solar PV systems. Clearly, raining season is characterized with more water for stream flow and low solar irradiation and temperature due to frequent down pour resulting to sufficient hydro power production. Furthermore, from the month of November to December, the power demand of the metropolis will be taken care of by the Small hydro, Solar PV and the Grid Systems. In the period, both the Solar PV and Small hydro will provide and sustain power adequacy within the metropolis.

At these periods the output power production efficiency of the solar PV resources is at maximum and thereby contributing massively to the power sustainability of the metropolis.

4.2 Steady state analysis of Ajilosun 11 kV distribution network with small hydro-solar PV HPS integration

The load flow analysis of Ajilosun distribution network without HPS integration is shown in Table 1. All parts of the distribution network showed no indication of overloading. Load requirement on the generator was stabilized while result of the load flow algorithm of the network shows convergence. The power load flow report of 11 kV Ajilosun distribution network with small hydro-solar PV HPS integration is as shown in Table 2. The power load flow assisted in the steady state analysis of the network.

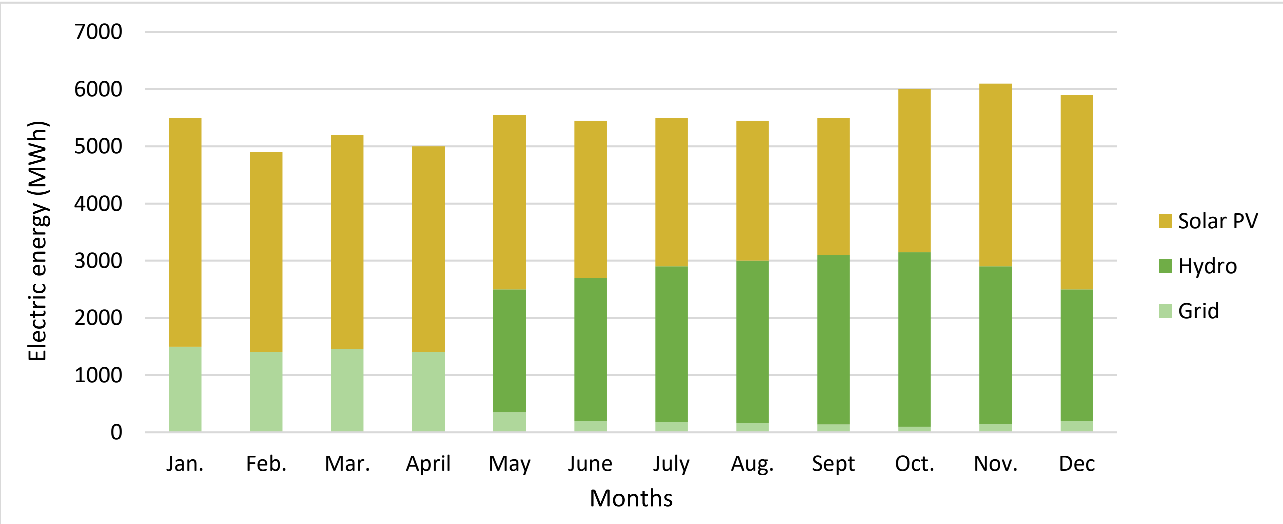

Fig.6. Complementary operation of Ado-Ekiti Grid connected small hydro-solar PV Hybrid Power System

Table 1. Load flow report of 11 kV Ajilosun distribution network without the HPS integration

Bus No	Voltage (pu)	Active power (MW)	Reactive power (Mvar)	Current (kA)	Loading (%)
bk_1	1	1.47	2.08	0.13	12.75
bk_2	1	-0.06	-0.08	0.01	0.53
bk_3	1	-0.03	-0.04	0.01	0.28
bk_4	0.99	-1.37	-1.92	0.12	12.43
bk_5	0.99	0.04	0.05	0.01	0.35
bk_6	0.99	-0.04	-0.05	0.01	0.35
bk_7	0.99	-0.06	-0.08	0.01	0.54
bk_8	0.99	-1.12	-1.59	0.01	10.30
bk_9	0.99	0.09	0.27	0.02	10.77
bk_{10}	0.99	-0.44	-0.63	0.04	4.09
bk_{11}	0.99	-0.41	-0.59	0.04	3.83
bk_{12}	0.99	-0.32	-0.46	0.03	3.01
bk_{13}	0.99	-0.17	-0.24	0.02	1.59
bk_{14}	0.99	-0.09	-0.13	0.01	0.86
bk_{15}	0.99	-0.1	-0.14	0.01	0.93
bk_{16}	0.99	-0.06	-0.08	0.01	0.52
bk_{17}	0.99	0.09	0.12	0.01	0.80
bk_{18}	0.99	-0.09	-0.12	0.01	0.80
bk_{19}	0.98	-0.39	-0.55	0.04	0.56
bk_{20}	0.98	-0.33	-0.47	0.03	3.60
bk_{21}	0.98	-0.33	-0.47	0.03	3.04
bk_{22}	0.98	-0.22	-0.31	0.02	2.05
bk_{23}	0.98	-0.19	-0.23	0.02	1.53
bk_{24}	0.98	-0.07	-0.1	0.01	0.63
bk_{25}	0.98	-0.03	-0.05	0.01	0.30

Table 2. Load flow report of 11 kV Ajilosun distribution network with small hydro-Solar PV HPS Integration

Bus No	Voltage (pu)	Active power (MW)	Reactive power (Mvar)	Current (kA)	Loading (%)
bk_1	1	-2.47	4.13	0.25	78.93
bk_2	1	-0.06	-0.08	0.01	0.53
bk_3	1	-0.03	-0.04	0.00	0.28
bk_4	1	2.61	-3.95	0.25	24.90
bk_5	1	0.04	0.05	0.00	0.34
bk_6	1	-0.04	-0.05	0.00	0.34
bk_7	1	-0.06	-0.08	0.01	0.54
bk_8	0.99	-1.12	-1.59	0.10	10.28
bk_9	0.99	0.19	0.27	0.02	1.76
bk_{10}	0.99	-0.99	-0.63	0.04	4.09
bk_{11}	0.99	-0.41	-0.59	0.04	3.82
bk_{12}	0.99	-0.33	-0.46	0.03	3.01
bk_{13}	0.98	-0.17	-0.24	0.02	1.59
bk_{14}	0.98	-0.09	-0.13	0.01	0.85
bk_{15}	0.97	-0.10	-0.14	0.01	0.94
bk_{16}	0.97	-0.06	-0.08	0.01	0.52
bk_{17}	0.99	0.09	0.12	0.01	0.79
bk_{18}	0.99	-0.09	-0.09	0.01	0.79
bk_{19}	0.99	-0.06	-0.09	0.01	0.56
bk_{20}	0.99	-0.39	-0.55	0.04	3.59
bk_{21}	0.99	-0.33	-0.47	0.03	3.03
bk_{22}	0.99	-0.22	-0.31	0.02	2.04
bk_{23}	0.99	-0.17	-0.23	0.02	1.52
bk_{24}	0.99	-0.07	-0.10	0.01	0.63
bk_{25}	0.99	-0.03	-0.05	0.00	0.29

4.3. Steady state analysis of Okesha 11 kV distribution network with small hydro-solar PV HPS integration

The load flow analysis of Okesha distribution network without HPS integration is as shown in Table 3. There is no indication of overloading on the network. Load requirement on the generator was stabilized and power load flow algorithm of the network converges. The power load flow report of 11 kV Okesha distribution network with small hydro-solar PV HPS integration is as shown in Table 4. Some parts of the distribution networks experienced overloading especially at the point of renewable integration. Buses on the network closer to the point of integration enjoy maximum load ability and exhibited distributed generation (DG) features. The power load flow algorithm of the network converges and the load requirement on the generator with small hydro-solar PV integration was stabilized. The results of the simulation reveals that the distribution network system is working to perfection but nearing voltage tolerance limit while some buses indicates overloading tendencies with integration of HPS as compared with the base case. So it is obvious from the simulation reports that the voltage stability of the network system nears NEC tolerance voltage stability limit of (0.95 to 1.05 pu) at steady state as shown in Figure 7. The quality of power supplied to various locations within the metropolis significantly improved with integration of HPS thereby eliminated scheduled load shedding operations for some areas within the metropolis.

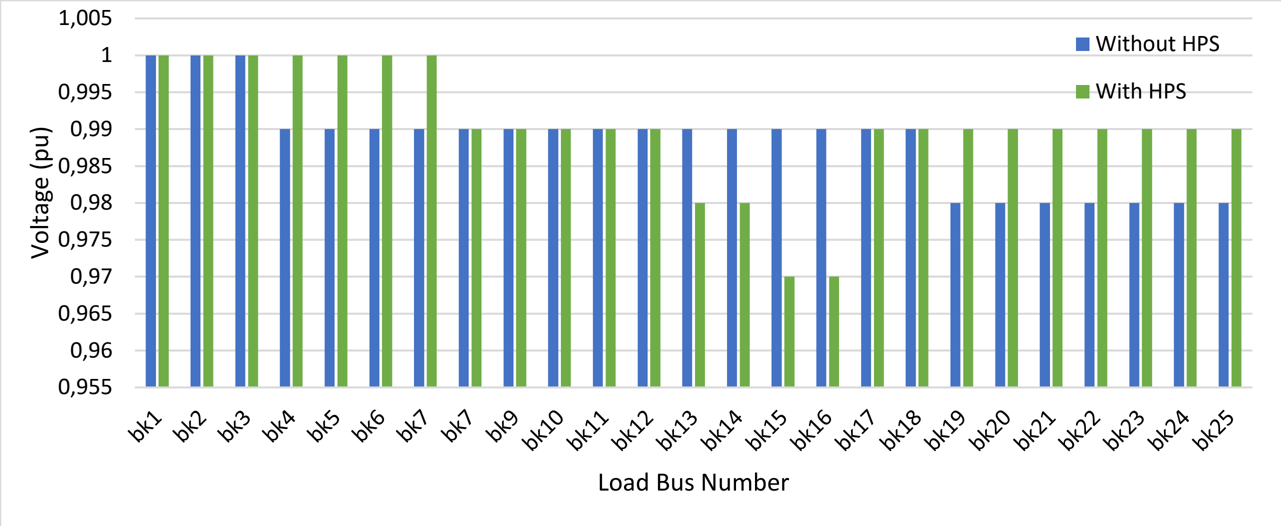

Fig.7. Bus voltages on 11 kV Okesha distribution network with and without small hydro-solar PV HPS integration

Table 3. Load flow report of 11 kV Okesha distribution network without HPS integration

Bus No	Voltage (pu)	Active power (MW)	Reactive power (Mvar)	Current (kA)	Loading (%)
Kh_1	1	1.89	2.5	0.17	15.97
Kh_2	1	0.15	0.21	0.01	52.59
Kh_3	0.99	-1.62	-2.2	0.14	14.43
Kh_4	0.99	0.11	0.15	0.01	60.39
Kh_5	0.99	0.18	0.24	0.02	1.59
Kh_6	0.99	0.12	0.17	0.01	1.10
Kh_7	0.99	0.12	0.17	0.01	41.95
Kh_8	0.99	1.03	1.4	0.09	9.21
Kh_9	0.98	0.91	1.24	0.08	8.20
Kh_{10}	0.98	0.85	1.16	0.08	7.69
Kh_{11}	0.98	0.78	1.06	0.07	7.02
Kh_{12}	0.98	0.07	0.06	0.01	7.06
Kh_{13}	0.98	0.03	0.04	0.01	0.28
Kh_{14}	0.97	0.03	0.04	0.01	17.59
Kh_{15}	0.97	-0.61	-0.82	0.06	5.50
Kh_{16}	0.97	0.09	0.12	0.01	0.80
Kh_{17}	0.97	0.07	0.09	0.01	22.71
Kh_{18}	0.97	0.05	0.07	0.01	0.49
Kh_{19}	0.97	0.05	0.07	0.01	31.32
Kh_{20}	0.97	0.17	0.23	0.02	1.51
Kh_{21}	0.97	0.17	0.23	0.02	1.51
Kh_{22}	0.97	0.12	0.16	0.01	1.08
Kh_{23}	0.97	0.07	0.09	0.09	0.61
Kh_{24}	0.97	0.02	0.03	0.01	0.19
Kh_{25}	0.97	0.02	0.03	0.01	12.02

Table 4. Load flow report of 11kV Okesha distribution network with small hydro-solar PV integration

Bus No	Voltage (pu)	Active power (MW)	Reactive power (Mvar)	Current (kA)	Loading (%)
Kh_1	1	-5.44	6.50	0.25	42.40
Kh_2	1	0.16	0.21	0.01	52.59
Kh_3	1	6.12	-6.0	0.45	11.99
Kh_4	1	0.11	0.15	0.01	60.25
Kh_5	1	0.18	0.24	0.02	1.58
Kh_6	1	0.12	0.17	0.01	1.10
Kh_7	1	0.12	0.17	0.01	41.85
Kh_8	1	-6.81	5.09	0.45	8.11
Kh_9	1	-7.01	4.89	0.45	7.55
Kh_{10}	1.01	-7.16	4.66	0.45	7.30
Kh_{11}	1.01	-7.33	4.45	0.45	7.03
Kh_{12}	1.01	0.07	0.09	0.01	0.59
Kh_{13}	1.01	0.03	0.04	0.01	0.27
Kh_{14}	1.01	0.03	0.04	0.01	17.40
Kh_{15}	1.01	7.71	-3.98	0.45	6.62
Kh_{16}	1.01	0.09	0.12	0.01	0.79
Kh_{17}	1.01	0.07	0.09	0.01	22.39
Kh_{18}	1.01	0.05	0.07	0.01	0.49
Kh_{19}	1.02	0.05	0.07	0.01	30.87
Kh_{20}	1.02	-0.03	0.16	0.01	1.49
Kh_{21}	1.02	-0.03	0.16	0.01	1.49
Kh_{22}	1.02	-0.02	0.07	0.01	1.06
Kh_{23}	1.02	0.07	0.09	0.01	0.60
Kh_{24}	1.02	0.02	0.03	0.01	0.19
Kh_{25}	1.02	0.02	0.03	0.01	11.84

5. CONCLUSION

The research work modeled a grid-connected small hydro-solar PV HPS to complement inadequate power supply to Ado-Ekiti metropolis, Nigeria and also investigated the steady state response of the distribution network with and without HPS integration. The daily power demand of the study area is 23.8 MW as obtained from Benin Electricity Distribution Company (BEDC) central load dispatch. Hence, the metropolis has power allocation shortage of 8.90 MW due to insufficient power allocation of 14.9 MW from Transmission Company of Nigeria (TCN). This gap was identified and this research work proffered solution through well designed grid-connected small hydro-solar PV HPS.

The designed and modeled HPS was integrated into the grid through a hydro inverter and five numbers of parallel-connected 2000 kVA grid-tied solar PV inverters. Result obtained from the hybrid power system model shows that small hydropower system generated 2.21 MW and solar PV power system produced 6.69 MW. The modeled HPS was able to inject 8.90 MW into the 11 kV distribution networks, thereby increasing and improving power supply quantity and quality in the metropolis.

The results of the steady state power load flow analysis show that the 11 kV distribution networks are working perfectly but nears steady state stability limit while some buses are slightly overloaded with integration of HPS as juxtaposed to their base cases except for 11 kV Adebayo network that has majority of its buses still operating below tolerance voltage level due to long route length, and overloading of the distribution network. The work will be of assistance to all the stakeholders in the power sector in making informed decisions that will enhance rapid growth of HPS technology for complementary power supply in cities.

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