Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Load Flow Study of Nsukka Electricity Distribution Grid for Enhanced Performance

Okwe Gerald[1 *], Mustapha Abdullahi[2], Okebaram Protus[3], Onu Princeley[4], Elom Chidiebere[5], Akwukwaegbu Isdore[6], Ohiri Paschal[7], Obichere Jude Kennedy[8], Ezirim ThankGod[9]

[1,3,4,5] National Centre for Energy Research and development, University of Nigeria, Nsukka.
[2] Energy commission of Nigeria, Abuja
[6,7] Department of Elect/Elect, Federal University of Technology Owerri
[8,9] Department of Mechatronics, Federal University of Technology Owerri

ARTICLE INFO

Received: 15 Apr 2025

Revised: 19 May 2025

Accepted: 09 June 2025

ABSTRACT

For the past two decades, Nigerian electricity sector have continued to witness acute shortage. The situation is not only ascribed to widened discrepancy between energy demand and embarrassing population growth. The obsolete infrastructure without appropriate upgrading facilities to withstand the increasing loads makes the grid more susceptibility to collapse. The research is focused on load flow investigation of 30- bus, 33/11 kV Nsukka electricity distribution network. Simulation was performed using ETAP software. The voltage profile value of 90.012 % and -9.4380 phase angle obtained from initial results confirmed that the entire network is weakened thus, required reinforcement. The simulation was repeated when 12 MW solar power was integrated in the grid. The power losses reduced from 156.7 kW, 1544.9 kVar to 54.6 kW and 102.4 kVar, while the phase angle and voltage profile improved to 4.440 and 100.12 %, in line with the statutory voltage profile of 100±5%.

Keywords: Load Flow, Power Losses, Voltage Profile, PV System, Power System Security

INTRODUCTION

The economic progression of a nation depends majorly on her strength to generate affordable, clean electricity and efficiently distribute to consumers (Mutumba, et al., 2024). Unfortunately, Nigerian power industry is performing below expectation in spite huge budgetary allocation into the sector. Regrettably, the nation has not been able to explore renewable energy alternative upon the vast wealth of natural resources to drive the transition. The power generation in the country is highly dominated by conventional fossil fuel sources with 12,522 MW installed capacity but less than 5000MW is evacuated to the network. The availability is flagrantly inadequate and unhealthy for national industrial growth of the most populated nation with over 223.8 million individuals, which requires at least 180,000MW to meet the energy demand of consumers (Oladeji, et al., 2024). Load shedding has become a norm in Nigerian power industry especially at the distribution level other than exception just to prevent grid overload resulting to power outage (Mutambo et al., 2023). Virtually all the nations in Africa have made a remarkable improvement in their electricity sector while Nigerian power sector is still inundated with myriads of problem (Ibrahim, et al., 2021). There is urgent need to upgrade obsolete infrastructure and same time invest in renewable mix more especially photovoltaic technology to ease existing congested network in order to accommodate increasing loads.

This research is focused on load flow survey of 30- bus Nsukka 33/11 kV electricity distribution network incorporated with 12MW photovoltaic system. Load flow in power system is a technique adopted more especially, it is an essential part of power system design and operation (Sanjay Bhuriya, 2024; Ashokkumar et al , 2023).It offers insights into the steady-state behavior of electrical networks e.g like active, reactive power losses, voltage profile, phase angle (Ba Bahloul, et al, 2023). The load flow simulation will be achieved using dynamic software called ETAP. Incorporation of PV system will help to improve the voltage profile by injecting power locally, potentially reducing voltage drops in

Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

areas with high solar irradiance. It will equally help to mitigate losses and achieve system security inline with the sustainable development goal (Routray & Arya, 2020).

THEORETICAL ANALYSIS OF LOAD FLOW

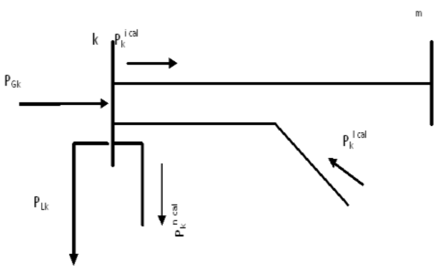

Figure 1.: Real power representation

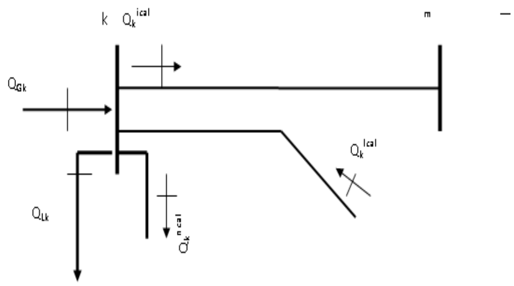

Figure 2.: Illustration of reactive power

Diagram of real and reactive power at bus k is displayed in figure 1.0 and 2.0. (Syafii, et al., 2019). Mathematical equations of the injected bus currents I_k and complex bus voltage E_k and E_m are expressed in equation 1.0 and 2.0:

$$I_k = y_{k0}E_k + y_{km}(E_k - E_m) = (y_{k0} + y_{km})E_k - y_{km}E_m = Y_{kk}E_k + Y_{km}E_m \quad 1.0$$

$$Y_{kk} = y_{ko} + y_{km} \quad 2.0$$

$$Y_{km} = -y_{km} \quad 3.0$$

Similarly, bus m

$$I_m = y_{mo}E_m + y_{mk}(E_m - E_k) = (y_{m0} + y_{mk})E_m - y_{mk}E_k = Y_{mm}E_m + Y_{mk}E_k \quad 4.0$$

$$Y_{mm} = y_{mo} + y_{mk} \text{ and } Y_{mk} = -y_{km} \quad 5.0$$

Equation 1.0 and 4.0 is transformed in matrix form of equation 6.0: (Aribi,et al,2015).

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} Y_{kk} & Y_{km} \\ Y_{mk} & Y_{mm} \end{bmatrix} \begin{bmatrix} E_k \\ E_m \end{bmatrix} \quad 6.0$$

Equation 7.0 is an explicit form derivation of bus admittances and voltage:

$$Y_{ij} = G_{ij} + jB_{ij} \quad 7.0$$

$$E_i = V_i e^{j\theta_i} = V_i(\cos\theta_i + j\sin\theta_i) \quad 8.0$$

Since i = k, m and j = k,m

The Complex power injected at bus k is given by :

$$S_k = P_k + jQ_k = E_k I_k^*$$
$$= E_k (Y_{kk}E_K + Y_{km}E_m)^* \quad 9.0$$

I_k^* = complex conjugate of I_k injected at bus k

Applying the value of Y_{ij} and E_i in S_k we get,

Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

$$S_k = V_k\left(\cos\theta_k + j\sin\theta_k\right)\left[\left(G_{kk} + jB_{kk}\right)V_k\left(\cos\theta_k + j\sin\theta_k\right) + \left(G_{km} + jB_{km}\right)V_m\left(\cos\theta_m + j\sin\theta_m\right)\right]^* \quad 10.0$$

Equation (10.0) can be expressed in real and imaginary form of power injected at k[th] bus into equation (11.0) and (12.0) respectively.

$$P_k^{cal} = V_k^2 G_{kk} + V_k V_m[G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)] \quad 11.0$$

$$Q_k^{cal} = -V_k^2 B_{kk} + V_k V_m[G_{km}\sin(\theta_k - \theta_m) - B_{km}\cos(\theta_k - \theta_m)] \quad 12.0$$

At bus k, the general net real and reactive powers that are injected are expressed in equation 13 and 14

$$P_k^{cal} = \sum_{i=1}^{n} P_k^{ical} \quad 13.0$$

$$Q_k^{cal} = \sum_{i=1}^{n} Q_k^{ical} \quad 14.0$$

P_k^{ical} and Q_k^{ical} are active and reactive power flows

Power Mismatch Equations

The power mismatch is normally applied in load flow analysis to ascertain the disparity between generated power and energy demand at bus k in order to guarantee power balance. The mathematically expression of real and reactive power mismatch is derived using complex power balance as shown in equation (15) and (16) (Muzzammel, et al, 2019). This computation is usually performed to verify status of electrical grid.

$$\Delta P_k = P_{Gk} - P_{Lk} - P_k^{cal} = P_k^{sch} - P_k^{cal} = 0 \quad 15.0$$

$$\Delta Q_k = Q_{Gk} - Q_{Lk} - Q_k^{cal} = Q_k^{sch} - Q_k^{cal} = 0 \quad 16.0$$

Where,

P_{Gk} , Q_{Gk} denotes real and reactive powers provided by the generator.

P_{Lk} and Q_{Lk} = Actual and reactive powers consumed.

The mathematical expression of power generation and load of equations (15) and (16) is transformed into equation (17) and (18):

$$\Delta P_k = P_{Gk} - P_{Lk} - \{V_k^2 G_{kk} + V_k V_m[G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)]\} = 0 \quad 17.0$$

$$\Delta Q_k = Q_{Gk} - Q_{Lk} - \{-V_k^2 B_{kk} + V_k V_m[G_{km}\sin(\theta_k - \theta_m) - B_{km}\cos(\theta_k - \theta_m)]\} = 0 \quad 18.0$$

The expression of power mismatch is found in equation (19) and (20):

$$\Delta P_k = P_{Gk} - P_{Lk} - \sum_{i=1}^{n} P_k^{i\,cal} = 0 \quad 19.0$$

$$\Delta Q_k = Q_{Gk} - Q_{Lk} - \sum_{i=1}^{n} Q_k^{ical} = 0 \quad 20.0$$

Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ Research Article

Net Active and Reactive Power

Net active power denotes actual power consumed while net reactive power, fluctuates between the source and the load and is necessary for the operation of inductive and capacitive loads, their net values termed scheduled active and reactive powers are expressed in equation (21) and (22)

$$P_k^{sch} = P_{Gk} - P_{Lk} \qquad 21.0$$

$$Q_k^{sch} = Q_{Gk} - Q_{Lk} \qquad 22.0$$

METHODOLOGY

There are numerous techniques adopted in load flow computation. The commonest among them are Fast Decoupled, Gauss-Seidel, Newton- Raphson method. This research utilizes ETAP software to simulate 30 bus, 33/11 kV Nsukka electricity distribution network. The evaluation was conducted using Newton Raphson technique (Rijal, et al, 2025). The flow chart for implementation of the method is shown in figure 3.0, while the oneline diagram of the distribution network designed with ETAP tool is equally shown in figure 4.0. The available data e.g transformer, loads line reactance and resistance obtained from local utility Enugu Electricity Distribution Company were specified and inserted to its positions in the diagram. The initial simulation will be performed to identify the critical buses, lines and power losses respectively (Winarta, & Rozzi, 2021). Similarly, the simulation will be repeated when a 12 MW solar power capacity was integrated into the network. PV system will help to improve the voltage profile by injecting power locally, potentially reducing voltage drops in areas with high solar irradiance. It will equally help to mitigate power losses in the network.

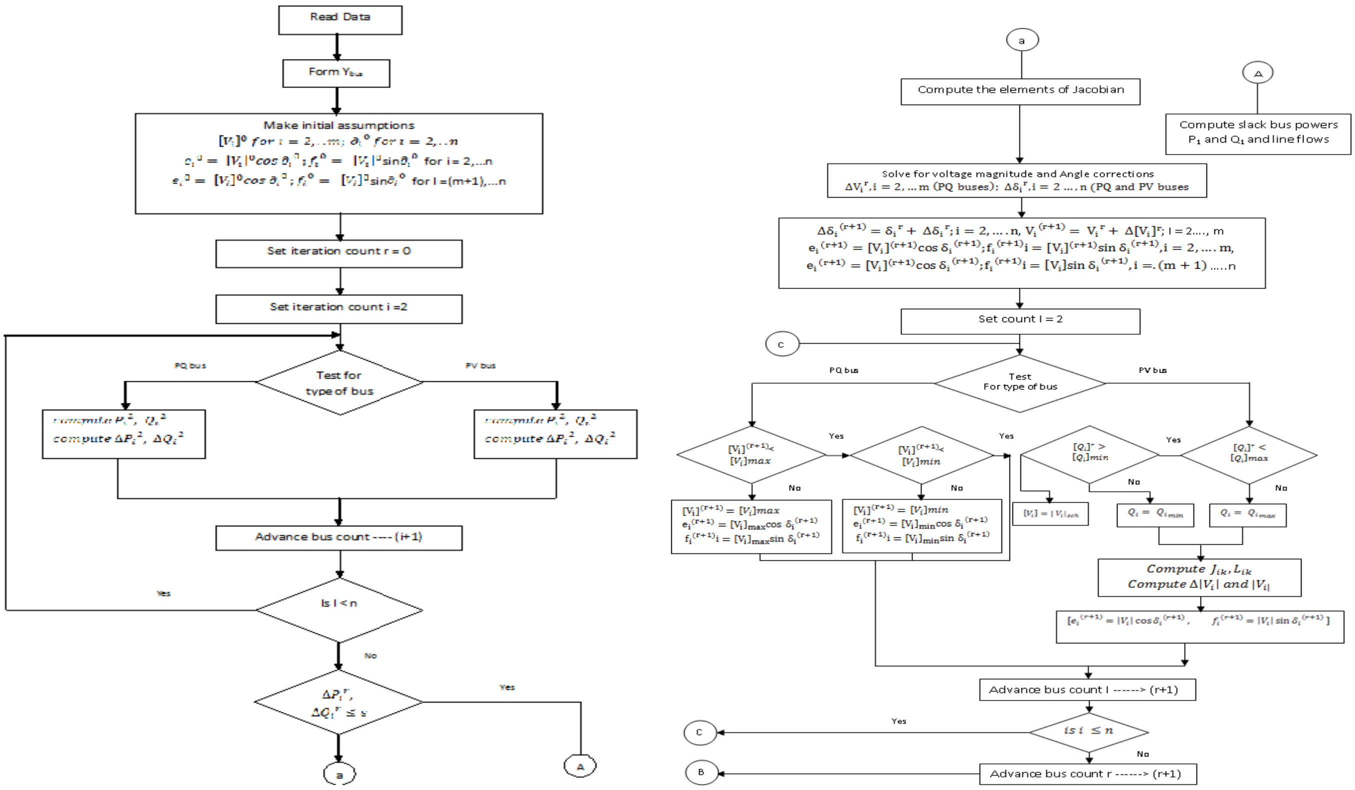

Figure 3. Newton Raphson Algorithm method for load flow (J. Nagrath, et al.,2012)

Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

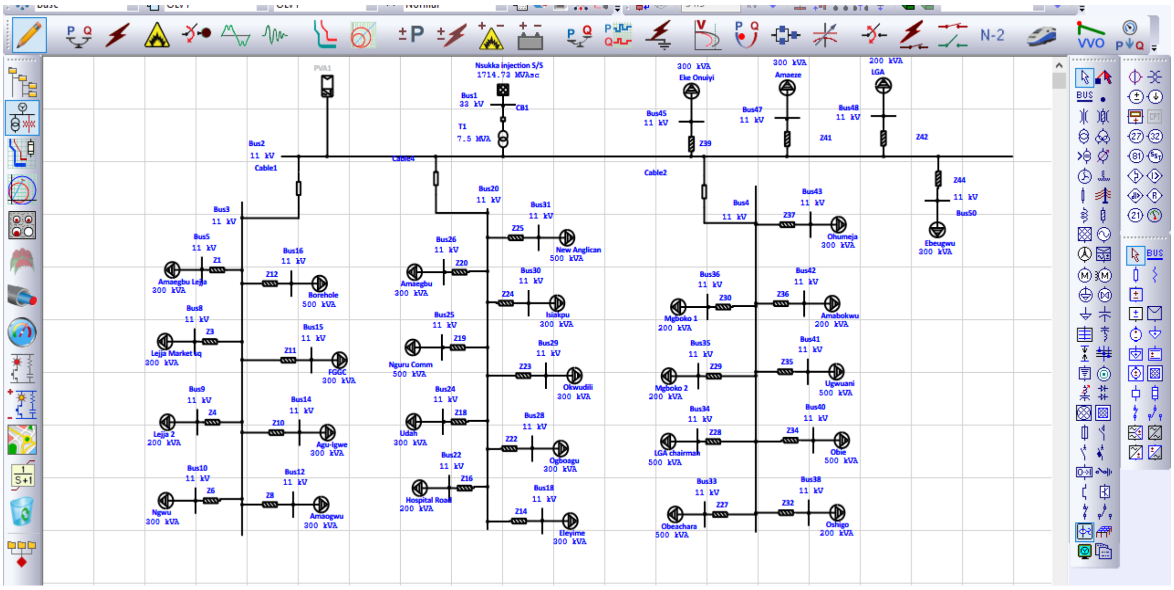

Figure 4. Oneline diagram of 33/11kV Nsukka distribution network integrated with PV system

RESULTS

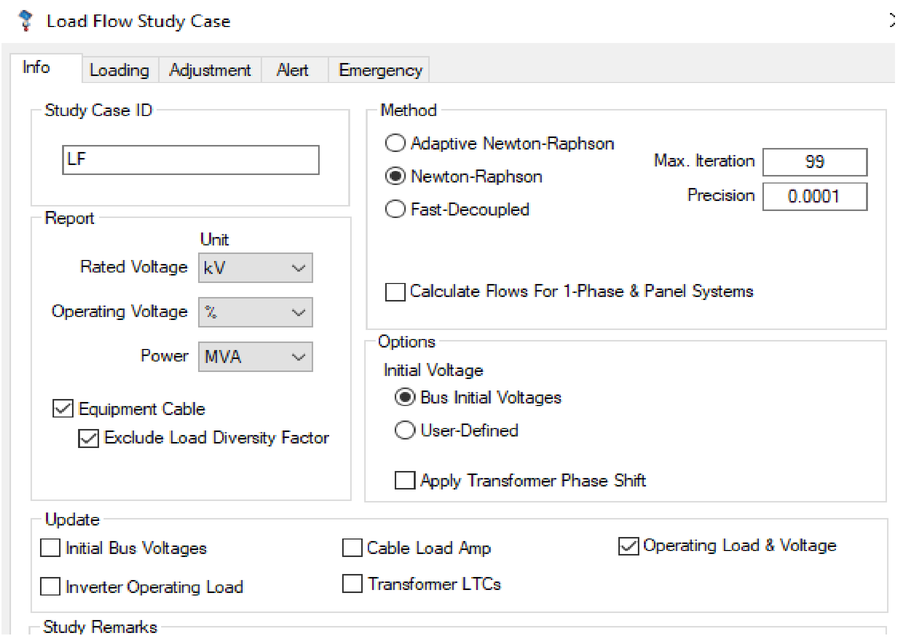

Plate 1. ETAP Load flow study case.

Table 1. Critical Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus10	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus12	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus14	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus15	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus16	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus18	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase

Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

Bus2	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus20	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus22	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus24	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus25	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus26	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus28	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus29	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus3	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus30	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus31	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus33	Bus	Under Voltage	11.000	kV	9.900	90.0	3-Phase
Bus34	Bus	Under Voltage	11.000	kV	9.900	90.0	3-Phase
Bus35	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus36	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus38	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus4	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus40	Bus	Under Voltage	11.000	kV	9.900	90.0	3-Phase
Bus41	Bus	Under Voltage	11.000	kV	9.900	90.0	3-Phase
Bus42	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus43	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus45	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus47	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus48	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus5	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus50	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus8	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
Bus9	Bus	Under Voltage	11.000	kV	9.901	90.0	3-Phase
T1	Transformer	Overload	7.500	MVA	10.352	138.0	3-Phase

Table 2. Summary of Branch losses without PV integration

	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
Branch ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
Cable1	2.044	1.137	-2.044	-1.137	0.1	-0.2	90.0	90.0	0.01
Cable2	2.535	1.425	-2.535	-1.425	0.2	-0.1	90.0	90.0	0.01
Cable4	2.453	1.374	-2.453	-1.375	0.2	-0.1	90.0	90.0	0.01
T1	8.089	6.461	-7.932	-4.429	156.3	2031.5	100.0	90.0	9.99
Z1	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z10	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z11	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z12	0.409	0.237	-0.409	-0.253	0.0	-16.2	90.0	90.0	0.00
Z14	-0.245	-0.152	0.245	0.136	0.0	-16.2	90.0	90.0	0.00
Z16	0.164	0.085	-0.164	-0.101	0.0	-16.2	90.0	90.0	0.00
Z18	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z19	0.409	0.237	-0.409	-0.253	0.0	-16.2	90.0	90.0	0.00
Z20	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z22	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z23	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00

Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

Z24	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z25	0.409	0.237	-0.409	-0.253	0.0	-16.2	90.0	90.0	0.00
Z27	0.409	0.237	-0.409	-0.253	0.0	-16.2	90.0	90.0	0.00
Z28	0.409	0.237	-0.409	-0.253	0.0	-16.2	90.0	90.0	0.00
Z29	0.164	0.085	-0.164	-0.101	0.0	-16.2	90.0	90.0	0.00
Z3	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z30	0.164	0.085	-0.164	-0.101	0.0	-16.2	90.0	90.0	0.00
Z32	0.164	0.085	-0.164	-0.101	0.0	-16.2	90.0	90.0	0.00
Z34	0.409	0.237	-0.409	-0.253	0.0	-16.2	90.0	90.0	0.00
Z35	0.409	0.237	-0.409	-0.253	0.0	-16.2	90.0	90.0	0.00
Z36	0.164	0.085	-0.164	-0.101	0.0	-16.2	90.0	90.0	0.00
Z37	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z39	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z4	0.164	0.085	-0.164	-0.101	0.0	-16.2	90.0	90.0	0.00
Z41	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z42	0.164	0.085	-0.164	-0.101	0.0	-16.2	90.0	90.0	0.00
Z44	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z6	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
Z8	0.245	0.136	-0.245	-0.152	0.0	-16.2	90.0	90.0	0.00
					156.7	1544.9			

Table 3. Branch Losses Summary Report with integration PV System

									Vd
	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		% Drop
Branch ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
Cable1	2.126	1.157	-2.126	-1.157	0.1	-0.3	100.1	100.1	0.00
Cable2	2.636	1.453	-2.636	-1.453	0.1	-0.2	100.1	100.1	0.01
Cable4	2.551	1.400	-2.551	-1.401	0.1	-0.2	100.1	100.1	0.01
T1	-3.830	5.215	3.884	-4.510	54.2	704.6	100.0	100.1	0.13
Z1	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z10	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z11	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z12	0.425	0.243	-0.425	-0.264	0.0	-20.0	100.1	100.1	0.00
Z14	-0.255	-0.158	0.255	0.138	0.0	-20.0	100.1	100.1	0.00
Z16	0.170	0.085	-0.170	-0.105	0.0	-20.0	100.1	100.1	0.00
Z18	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z19	0.425	0.243	-0.425	-0.264	0.0	-20.0	100.1	100.1	0.00
Z20	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z22	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z23	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z24	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z25	0.425	0.243	-0.425	-0.264	0.0	-20.0	100.1	100.1	0.00
Z27	0.425	0.243	-0.425	-0.264	0.0	-20.0	100.1	100.1	0.00
Z28	0.425	0.243	-0.425	-0.264	0.0	-20.0	100.1	100.1	0.00
Z29	0.170	0.085	-0.170	-0.105	0.0	-20.0	100.1	100.1	0.00
Z3	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z30	0.170	0.085	-0.170	-0.105	0.0	-20.0	100.1	100.1	0.00
Z32	0.170	0.085	-0.170	-0.105	0.0	-20.0	100.1	100.1	0.00
Z34	0.425	0.243	-0.425	-0.264	0.0	-20.0	100.1	100.1	0.00
Z35	0.425	0.243	-0.425	-0.264	0.0	-20.0	100.1	100.1	0.00
Z36	0.170	0.085	-0.170	-0.105	0.0	-20.0	100.1	100.1	0.00
Z37	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z39	0.255	0.138	-0.255	-0.158	0.0	-20.1	100.1	100.1	0.00

Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Z4	0.170	0.085	-0.170	-0.105	0.0	-20.0	100.1	100.1	0.00
Z41	0.255	0.138	-0.255	-0.158	0.0	-20.1	100.1	100.1	0.00
Z42	0.170	0.085	-0.170	-0.105	0.0	-20.1	100.1	100.1	0.00
Z44	0.255	0.138	-0.255	-0.158	0.0	-20.1	100.1	100.1	0.00
Z6	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
Z8	0.255	0.138	-0.255	-0.158	0.0	-20.0	100.1	100.1	0.00
					54.6	102.4			

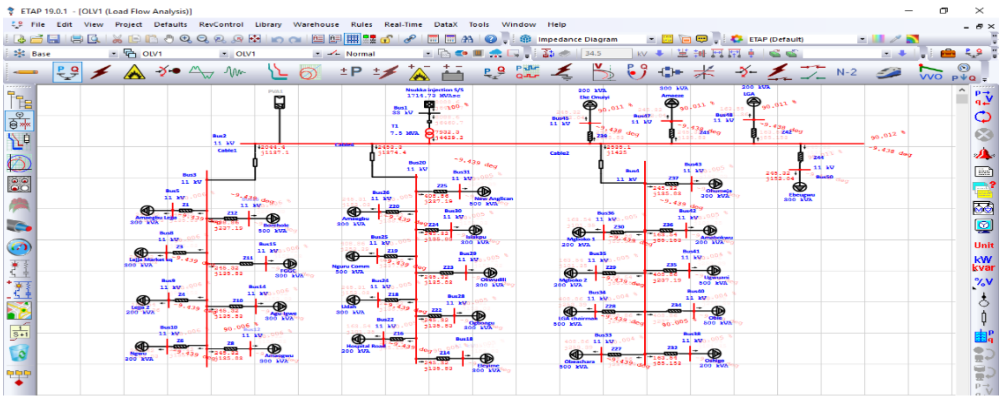

Figure 5. Outcome of power flow without incorporation of PV system

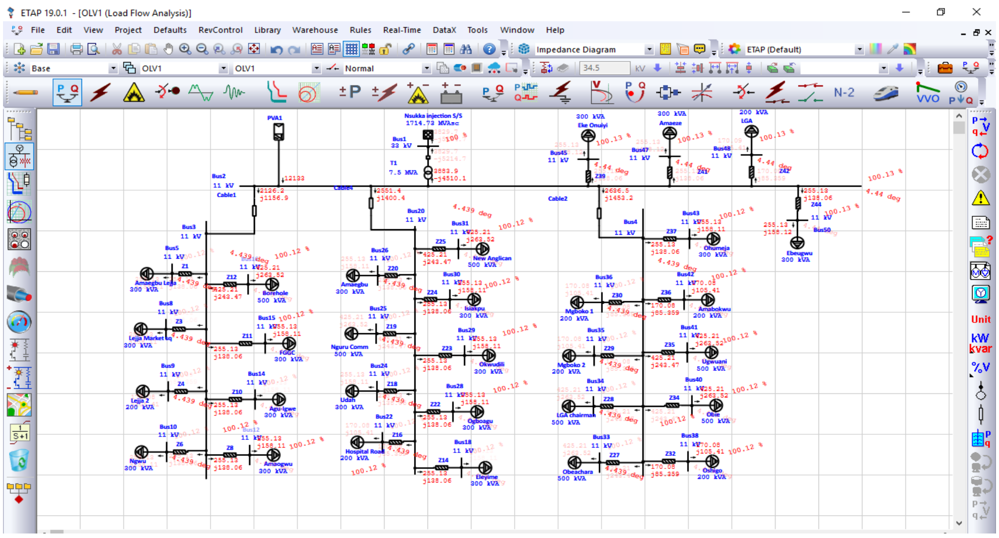

Figure 6. Result of power flow with PV integration

DISCUSSION

The simulation of the 30-bus Nsukka electricity distribution network was performed with ETAP tool in which Newton-Raphson technique was adopted. The base MVA, tolerance, and maximum numbers of iterations of 99 where specified ETAP load flow study case shown in plate 1.0. The simulation was initially performed without incorporation solar PV system to ascertain the actual state of the network as shown in figure 5.0. Table 1.0 contains the critical report buses in the network that are operating at an under voltage with voltage profile value of 90.012 % and -9.438° phase angle. Summary report of the power losses are contained in table 1. The simulation was repeated when 12 MW solar power was integrated into the network as shown in figure 6. The values of power losses reduced from 156.7 kW, 1544.9 kVar to 54.6 kW and 102.4 kVar, while the phase angle and voltage profile improved to 4.44° and 100.12 %, in line with the statutory voltage profile of 100±5%. The summary of branch losses report with integration PV System

Journal of Information Systems Engineering and Management
2025, 10(55s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

is shown in table 3.0. From the figure 6.0 and table 3, it can be observed the grid is operating in a stable condition. Integration of 12 MW PV system reduced losses and enhanced voltage profile of the critical buses in the grid.

CONCLUSION

The load flow investigation of 33/11 kV Nsukka electricity distribution network was performed with Newton Raphson technique and simulated using Electrical Transient Analyzer Program (ETAP). The voltage profile value of 90.012 % and -9.438° phase angle obtained from initial results confirmed that the entire network is in critical state thus, required reinforcement. The simulation was repeated when 12 MW solar power was integrated to the grid. Power losses values reduced from 156.7 kW, 1544.9 kVar to 54.6 kW and 102.4 kVar, while the phase angle and voltage profile improved to 4.44° and 100.12 %, in line with the statutory voltage profile of 100±5%. It can be inferred that incorporation of 12mw PV system into Nsukka electricity distribution network maintained statutory voltage profile of 100±5% and guaranteed power system security.

REFERENCES

[1] Aribi, F., Nwohu, M. N., Sadiq, A. A., & Ambafi, J. G. (2015). Voltage profile enhancement of the Nigerian North-East 330kV power network using STATCOM
[2] Ashokkumar N, kannusami G, prabakaran S, govindarajan R, (*April 2023)* Load Flow And Short Circuit Analysis Using Etap**,** International Journal of Innovation Scientific Research and Review,*Vol. 05, Issue, 04, pp.4319-4323,*
[3] Ba Bahloul, M., Horan, D., & Khadem, S. K. (2023). Energy storage sizing analysis and its viability for PV power plant clipping losses minimisation. Electric Power Systems Research, 225, 109837
[4] Barnawi, A. B. (2024). Development and analysis of AC optimal power flow optimization algorithms for minimization of cost and emissions with stochastic renewables. Energy Reports, 11, 2059-2076.
[5] Ibrahim, I. D., Hamam, Y., Alayli, Y., Jamiru, T., Sadiku, E. R., Kupolati, W. K., ... & Eze, A. A. (2021). A review on Africa energy supply through renewable energy production: Nigeria, Cameroon, Ghana and South Africa as a case study. *Energy Strategy Reviews*, *38*, 100740.
[6] J. Nagrath, D.P.Kothari, (2012) Modern Power System Analysis, Tata McGraw-Hill Publication.
[7] Mutambo, H., Kawimbe, S., Meki-Kombe, C., & Mwange, A. (2023). Impact of electricity load shedding on operations of small-scale enterprises in selected developing countries: A review of literature.
[8] Mutumba, G. S., Mubiinzi, G., & Amwonya, D. (2024). Electricity consumption and economic growth: Evidence from the East African community. *Energy Strategy Reviews*, *54*, 101431.
[9] Muzzammel, R., Khail, I., Tariq, M.H., Asghar, A.M. and Hassan, A. (2019) Design and Power Flow Analysis of Electrical System Using Electrical Transient and Program Software. Energy and Power Engineering, 11, 186-199.
[10] Oladeji, A. S., Atilola, O. F., & Olaniyi, J. I. (2024). Optimizing hybrid renewable energy systems for rural electrification: a case study of selected villages in Kwara State, Nigeria. *Nigerian Journal of Technological Development*, *21*(4), 1-12.
[11] Rijal, S., Acharya, S., Kande, D., Thapa, A., & Sharma, A. (2025). Load Flow and Short Circuit Analysis in Central Part of Nepal using ETAP. *OCEM Journal of Management, Technology & Social Sciences*, *4*(1), 81-93.
[12] Routray, A., Mistry, K. D., & Arya, S. R. (2020). Wake analysis on wind farm power generation for loss minimization in radial distribution system. Renewable Energy Focus, 34, 99-108
[13] Sanjay Bhuriya, 2024, Review on Load Flow Analysis and Power Loss Minimization in 33 Bus Power Distribution System, International Journal of Scientific Research & Engineering Trends Volume 10, Issue 1.
[14] Syafii, A. el Gazaly and A. Abadi, (2019)"Load Flow Analysis of PV System Integration in Universitas Andalas Distribution System," *2019 3rd International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM)*, Medan, Indonesia, pp. 17-20, doi: 10.1109/ELTICOM47379.2019.8943836
[15] Winarta, F. P., & Rozzi, Y. A. (2021). Load Flow Analysis and Short Circuit Faults with the Additional Distributed Generation Wind Turbine 300 kW at Andalas University. *Andalas Journal of Electrical and Electronic Engineering Technology*, *1*(1), 41-47.