NIPES

Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

Analysis and Improvement of Voltage Profile Magnitude in Power Distribution Networks

Edohen, O.M.*, Ike, S.A. and Agbontaen F.O.
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Benin, PMB 1154, Benin City, Nigeria.
*Corresponding Author: osarodion.edohen@uniben.edu

Article information

Article History
Received 18 September 2022
Revised 10 October 2022
Accepted 13 October 2022
Available online 16 December 2022

Keywords:
Voltage profile, Power flow analysis ETAP 19, Optimum capacitor placement, Raphson-Newton.

https://doi.org/10.5281/zenodo.7445219
https://nipesjournals.org.ng

Abstract

The Electric power system is the main energy source for industrial, commercial, and domestic activities hence its importance cannot be neglected across the world. However, the reverse is the case in the Nigerian power sector where there is inadequate power generation, transmission and distribution networks thereby creating huge economic loss by deploying alternative sources of power. These inadequacies of power systems in Nigeria has been linked to poor voltage profile magnitude in the distribution systems thereby impeding the continuous control and operation of the power distribution networks within the allowable limits that will mitigate burden on the power installation equipment and redue the cost of running the networks. This research therefore seeks to investigate the voltage profile magnitudes in power distribution network of eleven selected distribution networks in GRA 11/0.415 kV, Benin City, Nigeria using the ETAP 19 analytical software. The load flow result using the Newton-Raphson method in ETAP 19 shows that out of a total of eleven (11) load buses being investigated, only two (2) load buses met the voltage magnitude profile limit criteria of between 95% and 105% set for this study, the voltage profile magnitude for police Comms bus and Folake Oke bus are 97.2% and 95.5% respectively representing 18.2% of the investigated network which shows that the two buses were in good operating mode while a total of Nine (9) load buses representing 81.8% of the network violated the voltage constraint limits which prompted the network to behave abnormally. It is worthy of note that all the 11kV buses were all within the voltage limit. The introduction of compensating devices using the optimal capacitor placement brought the network under control where all the load buses were in good operating mode and within the voltage limit set for this study.

1. Introduction

The importance of electric power in today's world cannot be overemphasized; it is the main energy source for industrial, commercial, and domestic activities. Its availability in the right quantity and quality is essential to the advancement of civilization [1].

Electrical energy is supplied to the end users through an interconnected system; this interconnection is made up of generation, transmission and distribution network. The final load is connected through a distribution system. This implies that the quality of service is based on the continuity of power and maintaining the supply voltage within certain limits with specified frequency [2]. Voltage Unbalance (VU) is one of the main power quality problems in distribution networks which can be very high in these networks if the loads are distributed unequally among the three phases [3]. It is important to state that voltage instability in distribution network is an abnormal state in power system due to disturbance, increase in load demand, or change in system condition which causes a progressive decrease in voltage [4]. This voltage magnitude profile can be maintained within its' allowable limits through an installation of shunt capacitors which relies on the proper locations and size of capacitors within the distribution networks [5].

Electric distribution systems are becoming large and complex leading to higher system losses and poor voltage regulation. Shunt capacitors in distribution networks are used not only for power loss reduction but also for other purposes such as voltage profile improvement and maximize transmitted power in cables and transformers [6]. [7] clearly stated that in order to avoid the collapse of power network, there is need to finding solution for restoring voltage stability, hence the compensation measures or at worst the shedding of certain loads. Voltage collapse is a system instability that involves several power system components failure simultaneously which occurs on power systems that are heavily loaded, faulted and/or have reactive power shortages [8].

To enable the continuous control and operation of the power distribution networks within the allowable limits that will maximize profit thereby reducing the cost of running the networks, it is worthy to deploy compensation scheme. The deployment of optimal capacitor placement has been established to be one of the most effective and useful methods in reducing the power losses of distribution networks. In using shunt capacitors, the reactive power needed for loads is provided so that besides the reduction of losses, the voltage profile of nodes is also improved. However, the most important issues in the placement of capacitors are considering the load variations of the network since the distribution network is characterized by large single phase loads which are unbalance; it is useful to investigate the optimum capacitor placement for unbalanced distribution networks [9]. Therefore, the aim of the research is to evaluate the effects of voltage profile magnitude in power distribution networks using Newton-Raphson load flow method and it’s enhancement using optimal capacitor placement. However, the Newton-Raphson load flow method has faster convergence ability compared to other conventional methods of load flow analysis. It requires less computer memory for a large power system and also increases linearly with the network size. One of its disadvantages is that it suffers a flat start, since the solution at the beginning can oscillate without converging towards the solution.

The Newton-Raphson method is more accepted and widely used in solving power system load flow problem due to its faster convergence adaptability which makes it more superior to the other method [10]. The Newton-Raphson method is a very powerful load flow solution technique that incorporates first-derivative information when computing voltage updates.

2. Methodology

The substation data which include average unbalanced loading current, transformer capacity, length of the distribution lines and resistances were used to model the networks under investigation using ETAP 19.0.1. Load flow study was carried out to determine the voltage profile magnitude level in all the connected substations under investigation. The network being investigated was modeled using ETAP 19.0.1 software as shown in Figure 1 (before compensation) and Figure 2 (after compensation).

After modeling the network, all the network parameters were assigned while limit of voltage magnitude was set on study case section of ETAP 19.0.1. Load flow study was carried out using the Newton-Raphson method embedded in ETAP 19.0.1 software. The load flow iteration result shows that the weak buses were marked with red colours which informed us to further carry out compensation study to see if the performance of the network could be improved upon. System design was done to select capacitors that best fit each candidate bus to be compensated by using the optimum capacitor placement in the study case of ETAP 19.0.1.

Finally, the iteration was repeated using the Newton-Raphson method and the result shows that the entire network was being enhanced as shown in Figure 2 as compared to the original network of Figure 1.

2.1 Study Location

This study was carried out in Eleven (11) selected 11/0.415kV distribution substations emanating from the GRA 11/0.415kV feeder in Benin City, Edo State, Nigeria.

2.2 Data Collection and Processing

Data were collected from the 11/0.415kV load side of the distribution substations under investigation for a period of one year (January to December 2019).

2.3 Constraints

The main constraints for optimal capacitor placement are to meet the load flow constraints. In addition, all voltage magnitude of load (PQ) buses should be within the allowable limit. The constraint considered for all load (PQ) buses in this work is given below:

Load Flow: $F(x, u) = 0$
$\mathrm{V_{min}} \leq \mathrm{V} \leq \mathrm{V_{max}}$
The voltage magnitude at each bus must be maintained within limits as described by the constraints above.
Where;
$\mathrm{V_{min}}$= 95 % (minimum voltage limit)
$\mathrm{V_{max}}$= 105% (maximum voltage limit),

The bus voltage performance index is used to control the percentage bus operating voltage. To be within allowable limit, bus voltages that are less than 95% are considered under voltage, while bus voltages that are above 105% are considered over voltage [11].

3. Results and Discussion

The Newton-Raphson method was used to carry out load flow of the investigated section of the distribution network with the aid of ETAP 19 analyzer software. Figure 1 and Table 1 shows the load flow result of the network and the voltage profile results for the original network. The load flow result using ETAP 19 shows that out of a total of eleven (11) load buses being investigated, only Two (2) load buses met the voltage magnitude profile limit criteria of between 95% and 105% set for this study, they include police Comms and Folake Oke buses with 97.2% and 95.5%

respectively representing 18.2% of the investigated network while a total of Nine (9) load buses representing 81.8% of the network violated the voltage constraint limits which prompted the network to behave abnormally. The load flow result further shows that Five (5) load buses which includes Crown Estat, Alonge, CEO, SCID2 and Owena River Basin had marginal values of 94.5%, 94.1%, 94.2%, 94.9% and 94.9% respectively showing close proximity to the minimum limit while Four (4) load buses which includes SSS, SCID1, A&K and Deputy Governor buses did not show any form of closeness with voltage profile magnitude limit.

The analysis revealed that the sectional network being studied need urgent compensation. For this case, shunt capacitor module was deployed to help enhance the network as shown in Figure 2 while Table 3 shows the result of the voltage profile magnitude after compensation was applied to the network for enhancement purposes. The load flow critical report in Table 2 shows that a total of eight (8) transformers were overloaded which includes A&K, Alonge, CEO, Crown Estat, Deputy Governor, Owena River Basin, SCID1 and SSS substations. However, after the enhancement of the network, only CEO substation was within the limit of the applied load while others remained overloaded.

A total of Twelve (12) capacitor banks with 100 KVARs rating each were installed at the load buses that required to be compensated for optimum performance. Following the installation of the optimal capacitor placement (OCP), it was revealed that the network performance increased appreciably by having all the load buses satisfied the voltage profile magnitude constraints set out for this study.

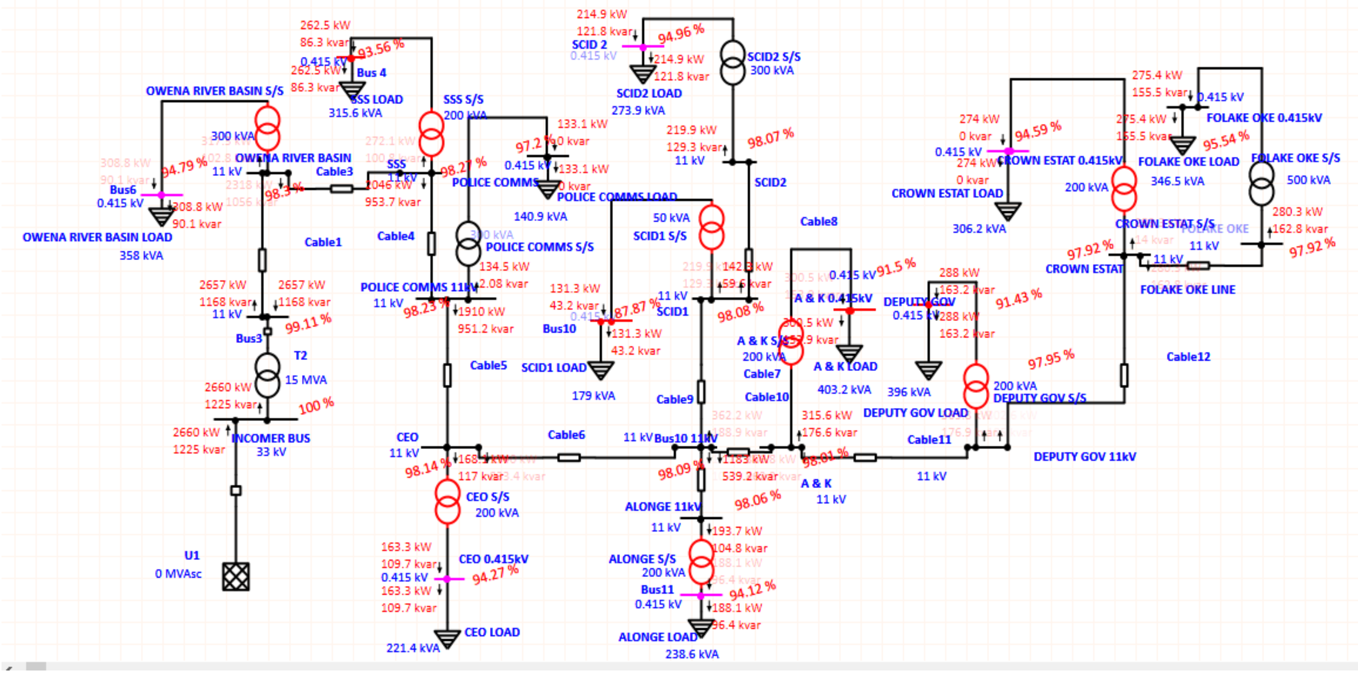

Figure 1: Run mode before optimal capacitor placement.

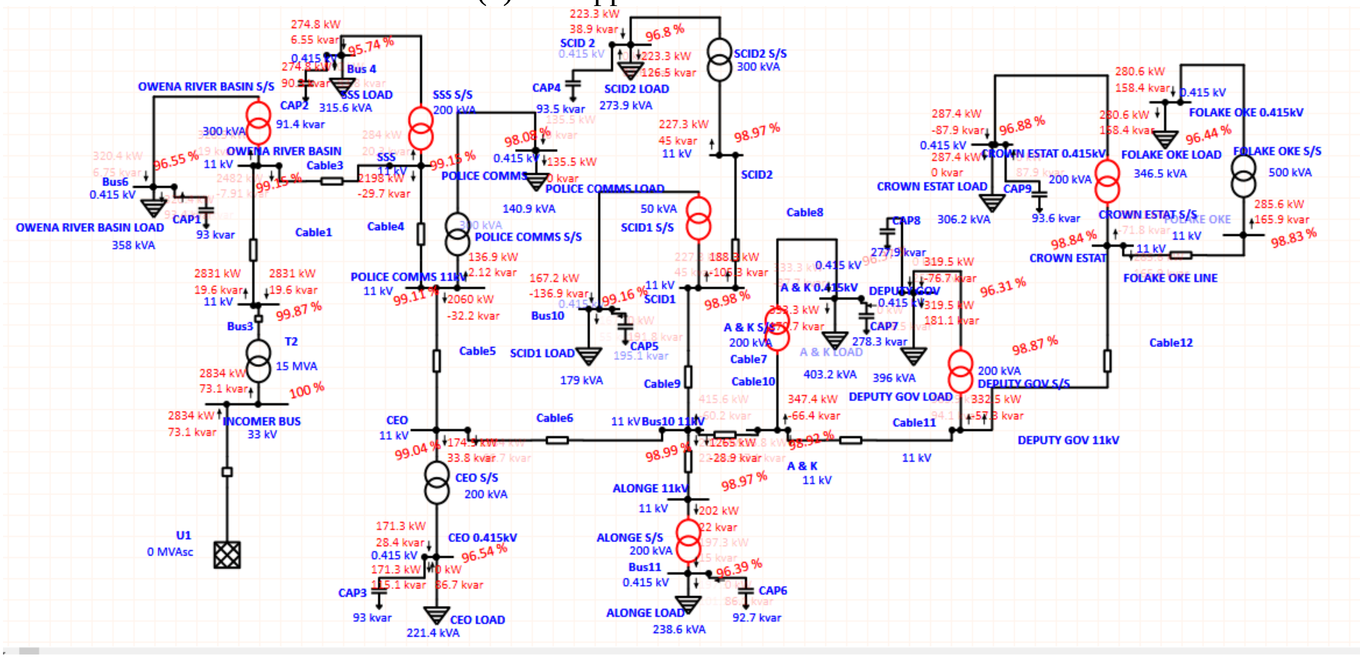

Figure 2: Run mode after optimal capacitor placement.

Table 1: Load flow report before compensation.

Bus		Voltage		Generation		Load	
ID	KV	%Mag.	Angle	KW	KVAR	KW	KVAR
A & K	0.415	91.503	-3.1	0.0	0.0	300.5	153.9
SSS	0.415	93.561	-3.1	0.0	0.0	262.5	86.3
OWENA RIVER BASIN	0.415	94.793	-2.7	0.0	0.0	308.8	90.1
SCID1	0.415	87.872	-5.6	0.0	0.0	131.3	43.2
ALONGE	0.415	94.119	-2.3	0.0	0.0	188.1	96.4
CEO	0.415	94.273	-2.0	0.0	0.0	163.3	109.7
SCID2	0.415	94.962	-1.9	0.0	0.0	214.9	121.8
POLICE COMMS	0.415	97.205	-1.9	0.0	0.0	133.1	0.0
CROWN ESTATE	0.415	94.591	-3.8	0.0	0.0	274.0	0.0
DEPUTY GOV	0.415	91.434	-2.9	0.0	0.0	288.0	163.2
FOLAKE OKE	0.415	95.545	-1.7	0.0	0.0	275.4	155.5

Table 2: Load flow critical report.

Device ID	Type	Condition	Rating/Limit	Unit
A & K	Bus	Under Voltage	0.415	kV
A & K S/S	Transformer	Overload	200.000	kVA
ALONGE S/S	Transformer	Overload	200.000	kVA
SSS	Bus	Under Voltage	0.415	kV
SCID1	Bus	Under Voltage	0.415	kV
CEO S/S	Transformer	Overload	200.000	kVA
CROWN ESTAT S/S	Transformer	Overload	200.000	kVA
DEPUTY GOV	Bus	Under Voltage	0.415	kV
DEPUTY GOV S/S	Transformer	Overload	200.000	kVA
OWENA RIVER BASIN S/S	Transformer	Overload	300.000	kVA
SCID1 S/S	Transformer	Overload	50.000	kVA
SSS S/S	Transformer	Overload	200.000	kVA

Table 3: Load flow report after compensation.

Bus		**Voltage**		**Generation**		**Load**	
ID	KV	%Mag.	Angle	KW	KVAR	KW	KVAR
A & K	0.415	96.36	-5.3	0.0	0.0	333.3	-87.7
SSS	0.415	95.73	-4.0	0.0	0.0	274.8	6.5
OWENA RIVER BASIN	0.415	96.55	-3.3	0.0	0.0	320.4	6.7
SCID1	0.415	99.15	-11.4	0.0	0.0	167.2	-136.9
ALONGE	0.415	96.38	-3.2	0.0	0.0	197.3	15.0
CEO	0.415	96.54	-2.8	0.0	0.0	171.3	-28.4
SCID2	0.415	96.8	0	0.0	0.0	-223.3	38.9
POLICE COMMS	0.415	98.08	0	0.0	0.0	136.9	2.1
CROWN ESTATE	0.415	96.88	-4.8	0.0	0.0	287.4	-87.9
DEPUTY GOV	0.415	96.30	-5.1	0.0	0.0	319.5	-76.7
FOLAKE OKE	0.415	96.44	-2.1	0.0	0.0	280.6	158.4

4. Conclusion

This work investigated the voltage profile magnitude in power distribution networks using some selected substations as case study. This research investigated the voltage profile magnitudes in power distribution network of Eleven selected distribution networks in GRA 11/0.415 kV, Benin City, Nigeria using the ETAP 19.0.1 analytical software.

The load flow result using the Newton-Raphson method in ETAP 19.0.1 shows that out of a total of eleven (11) load buses being investigated, only Two (2) load buses met the voltage magnitude profile limit criteria of between 95% and 105% set for this study, they include police Comms and Folake Oke buses with 97.2% and 95.5% respectively representing 18.2% of the investigated network while a total of Nine (9) load buses representing 81.8% of the network violated the voltage constraint limits which prompted the network to behave abnormally. It is worthy of note that all the 11kV buses were all within the voltage limit. Following the result of Table 2, we therefore recommend that additional substations being installed to cater for the ever growing population so as to avoid overloading of the transformers.

The introduction of compensating devices using the optimal capacitor placement brought the network under control where all the load buses fell within the voltage limit set for this study. The results of this study have clearly revealed that unbalanced loading in power distribution networks may lead to unhealthy network.

References

[1] Bamigbola O. M., Ali M. M. and Awodele K. O. (2014): "Predictive Models of Current, Voltage, and Power Losses on Electric Transmission Lines", Journal of Applied Mathematics Volume 2014, Article ID 146937, 5 pages.

[2] Adel Ali Abou El-Ela, Ragab A. El-Sehiemy, Abdel-Mohsen Kinawy and Mohamed Taha Mouwafi (2016): "Optimal capacitor placement in distribution systems for power loss reduction and voltage profile improvement", Journal of The Institution of Engineering and Technology, IET Generation, Transmission, Distribution, 2016, Vol. 10, Iss. 5, pp. 1209–1221.

[3] Farhad Shahnia, Peter Wolfs and Arindam Ghosh (2014): "Voltage Unbalance Reduction in Low Voltage Feeders by Dynamic Switching of Residential Customers among Three Phases", https://www.researchgate.net/publication/261309701.

[4] Chinweike I. Amesi, Tekena K. Bala, and Anthony O. Ibe (2017): "Impact of Network Reconfiguration: A Case Study of Port-Harcourt Town 132/33kV Sub-Transmission Substation and Its 33/11kV Injection Substation Distribution Networks", EJECE, European Journal of Electrical and Computer Engineering Vol. 1, No. 1, October 2017.

[5] Essam A. Al-Ammar, Ghazi A. Ghazi, and Wonsuk Ko (2018): "New Technique for Optimal Capacitor Placement and Sizing in Radial Distribution Systems", 2018 10th International Conference on Computational Intelligence and Communication Networks.

[6] Sirjani Reza, Azah Mohamed and Hussain Shareef (2011): "Optimal Capacitor Placement in a Distribution Network with Nonlinear Loads Using Harmony Search Algorithm", Australian Journal of Basic and Applied Sciences, 5(6): 461-474, 2011, ISSN 1991-8178.

[7] Yao Bokovi, Comlanvi Adjamagbo, Adekunle Akim Salami, Ayite Sena Akoda Ajavon (2020): "Comparative Study of the Voltage Stability of an Hight Voltage Power Grid: Case of the Power Grid of the Electric Community of Benin". Science Journal of Energy Engineering. Vol. 8, No. 2, 2020, pp. 15-24.

[8] Amit Kumar Chowdhury, Surajit Mondal, S. K. Mehboob Alam, Jagadish Pal (2015**):** "Voltage Security Assessment of Power System", A journal of World Scient i f ic News 21 (2015) Pages 36-50.

[9] Hooshmand Rahmat-Allah and Ataei Mohammad (2007): "Optimal Capacitor Placement in Actual Configuration and Operational Conditions of Distribution Systems Using RCGA", Journal of Electrical Engineering, Volume 58, No 4, pages 189 – 199.

[10] Idoniboyeobu, D.C. and Ibeni C. (2017): Analysis for Electrical Load Flow Studies in Port Harcourt Nigeria,Using Newton Raphson Fast Decoupled Techniques, American Journal of Engineering Research (AJER) e-ISSN: 2320-0847 p-ISSN : 2320-0936 Volume-6, Issue-12, pp-230-240, www.ajer.org.

[11] Amesi Chinweike I., Tekena K. Bala, and Anthony O. Ibe (2017): "Impact of Network Reconfiguration: A Case Study of Port-Harcourt Town 132/33kV Sub-Transmission Substation and Its 33/11kV Injection Substation Distribution Networks" EJECE, European Journal of Electrical and Computer Engineering Vol. 1, No. 1, October 2017.