Power Loss Minimization in the Distribution Network: Heuristic Approach for Capacitor Placement

[1]Ohanu, Chibuike Peter, [2*]Ohanu, Ifeanyi Benedict & [3]Uche C. Ogbuefi
[1]Department of Electrical Engineering Rivers State University, Port Harcourt
[2]Department of Industrial Technical Education University of Nigeria Nsukka.*
[3]Department of Electrical Engineering University of Nigeria Nsukka.
[1]chibuike.ohanu@unn.edu.ng [2*]Ifeanyi.ohanu@unn.edu.ng [3]uche.ogbuefi@unn.edu.ng
*Corresponding author

Abstract: This paper presents a new technique for power loss minimization in the distribution network. The research technique has been tested on a realistic network which is the Enugu State Thinkers Corner distribution network. The types, causes, and techniques for loss reduction in distribution networks have been presented. The heuristic technique for optimal capacitor location and sizing for the minimization of power or energy loss and voltage profile improvement has been adopted in our research due to its relatively high efficiency in loss reduction over other methods. This technique indicates the sizes and actual location of the capacitors to be placed at the network with less computational time. The Newton-Raphson's load flow technique has been applied in modeling the single line diagram of the distribution network in the power system toolbox (PSAT) enabled in MATLAB/Simulink software environment. The load variation and cost of installation of the capacitor as well as the economic power factor to achieve maximum energy savings were considered. The heuristic technique has been applied to the 30 bus, 11KV, 15MVA distribution networks having an initial power factor rating of 0.85. The analysis has been presented and it has shown that power losses are minimized from 0.556MW to 0.277MW on the application of maximum capacitor rating of 1200 (750 + 450) KVAR at a power factor of 0.96.

Keywords:- *active power, compensation, distribution network, loss reduction, power flow, PSAT*

1.0 INTRODUCTION

There has been an increase in the world's energy demand and the entire society will be standstill without access to the electricity supply. This increase in energy demand has led to an increase in the operation and planning of large interconnected power systems thereby making them more complex, prone to faults, and less security of power systems (Sun & Abe, 2018). (Rambabu et al, 2011) stated that electricity distribution involves primary and secondary voltage transformation into high, medium, and low voltage levels using appropriate transformation equipment. The distribution network is a part of the electricity supply chain that distributes power to the consumers at a lower voltage level (Mahdavian et al., 2017). It is pertinent to distribute power at a required voltage magnitude and angle for the reliability and sustainability of power supply. These constraints have resulted in poor power quality and interrupted power delivery to consumers. The actual sizing and placement of capacitors in the distribution system are a vital means of achieving an improved power delivery. A method of reconfiguration to reduce power losses in distribution system was considered by (Sudhakar et al., 2014). It asserts that by the proper selection of sectionalising and tie switches, the distribution system configuration will be varied to achieve its target. (Nahilia, 2016) proposed stochastic methods of optimization as a veritable tool for distributed generation placement on the network. The application of solid-state transfer switch (SSTS) which is a Custom Power (CP) device, dynamic voltage restorer (DVR), and the dynamic static compensator (D-STATCOM) have been reported by (Impact, 2014). The meta-heuristic optimization methods have been applied to solve the problem of low voltage profile and increased power loss in the distribution system as stipulated in (Kennedy & Eberhart, 1995; Gampa & Das, 2016; Neagu et al., 2016). These methods are powerful tools because of their abilities to carry out parallel searches in multidimensional spaces. Their limitation when applied with heuristic optimization methods is influenced by the starting point in the optimization process. Mostafa Sedighizadeh and Reza Bakhtiary reported a reconfiguration method as an efficient algorithm that is suitable for the optimization of unbalanced radial distribution networks was studied in (Mostafa & Reza, 2016). In a similar research, another effective technique to determine the optimal size and location of shunt capacitor has been reported by (Gnanasekaran et al., 2016). The aim of this approach is to minimize the cost of energy loss and reactive power compensation. (Ohanu et al., 2020) proposed a heuristic technique for shunt capacitor integration in a distribution network. This technique was used for the optimization of electricity supply to the Thinkers Corner area of Enugu State thereby achieving power loss reduction and improved voltage profile in the zone.

This paper presents a heuristic technique for capacitor bank location and sizing for power loss minimization and voltage profile improvement. This technique has been applied for the sizing and placement of shunt capacitor banks at 15 MVA, 11 kV, 30-bus, 3-phase, 50Hz, Nigeria Thinkers Corner distribution network.

2.0 REACTIVE POWER COMPENSATION WITH HEURISTIC APPROACH

The shunt capacitor banks are used as the most common compensator due to their high impact in transmission and distribution networks to improve power quality. To achieve this objective, the location and sizing of shunt capacitors are very important. Also, shunt capacitor placements increased the availability of feeders and the loading capacity of the distribution network (Soleymani & Soleymani, 2014). The procedure for the proposed technique is:

Step 1: perform power flow for the base case using Newton Raphson's (NR) technique.

Step 2: check the voltage magnitudes for all buses. Then, select the critically violated bus (bus with the minimum p.u. voltage amplitude) in the network to inject reactive power for power loss compensation and voltage profile improvement.

Step 3: place a sized shunt capacitor bank at the critically violated bus to improve the power quality.

Step 4: perform power flow again to ensure that voltage magnitude for all buses is within the voltage acceptable limit. If some buses are marginally violated, repeat step 3 by resizing or replacing a suitable sized shunt capacitor at the bus with minimum p.u. voltage amplitude until all bus voltage magnitudes are within the acceptable limits.

Step 5: finally, place the sized shunt capacitor at the appropriate location for reactive power compensation to achieve an improved voltage profile and minimal power loss in the network. Figure 1 depicts the procedure flow chart for the heuristic technique.

3.0 METHODOLOGY

The main objectives of this paper are to improve the voltage profile and minimize power losses along the distribution lines on this network using the heuristic technique. The heuristic approach was demonstrated using a Nigeria distribution network known as the Thinkers Corner distribution network. The base voltage of the network is 11 kV with an apparent power capacity of 15 MVA with the total real power loads and reactive loads as 2.802 MW and 1.617 MVAr respectively. The network's single line diagram of 30 buses has been modelled in the Power System Analysis Toolbox (PSAT) inside MATLAB/ Simulink software as shown in Figure 1. Voltage profile improvement can be achieved by minimizing the voltage deviation of load buses from their specified statutory limits. This is the first objective function. This can be mathematically represented as shown in (1).

$$F_V = \sum_{i=1}^{nbus} (V_i - 1) \quad (1)$$

where; $nbus$ is the number of load buses in the system, V_i is the voltage at the specific bus i. Our goal here is to keep the voltage profile for all buses within the acceptable limits. Therefore, the voltage constraint becomes,

$$V_{min} \leq V \leq V_{max} \quad (2)$$

In this paper, we considered the minimum voltage V_{min} = 0.95 p.u. while the maximum voltage V_{max} = 1.05 p.u To minimize the real power loss associated with the flow of branch current (both real and reactive) by optimal location and sizing of capacitor banks at weak buses is another objective of this paper.

$$F_p = P_{Loss} = \sum_{i=1}^{nbus} G_{ij} \left(V_i^2 + V_j^2 - 2V_iV_j \cos\delta_{ij} \right) \quad (3)$$

Where $nbus$ is the number of buses in the network, G_{ij} is the conductance of the distribution lines ij and δ_{ij} is the phase difference between voltages i, j. Equation (3) is subject to the constraints in (2) and the bus reactive capacity constraints in (4).

$$Qg_i^{min} \leq Qg_i \leq Qg_i^{max} \quad i \in nbus \quad (4)$$

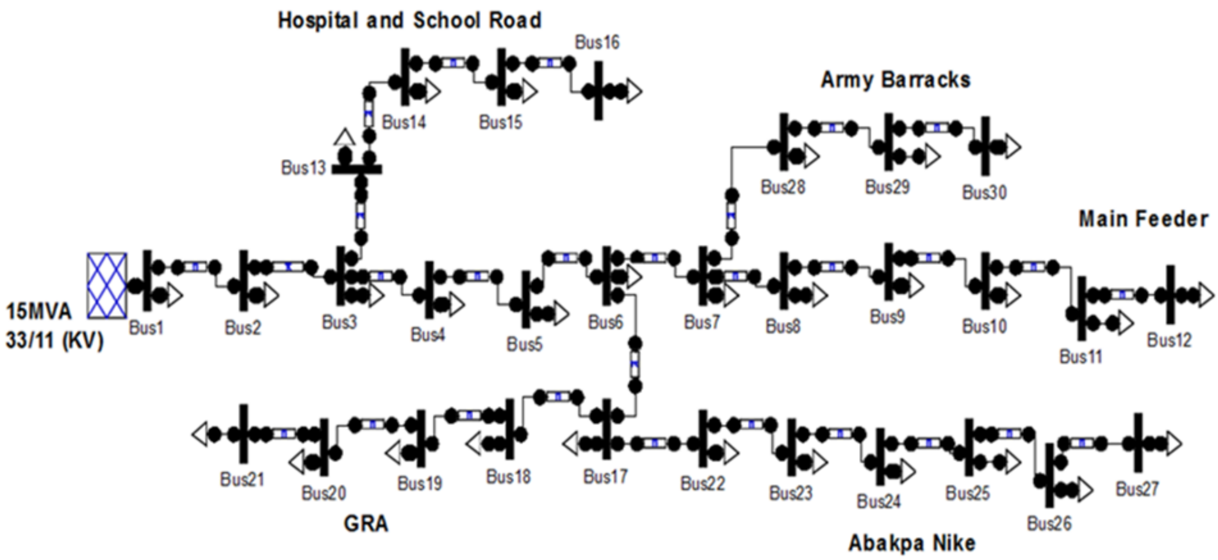

Fig. 1: Single line diagram of Thinker's Corner distribution feeder.

4.0 RESULTS AND DISCUSSION

4.1 Existing case of the network

Power flow studies were done on the network in Figure1 to determine the bus voltage magnitudes. The existing case minimum voltage magnitude in per unit was detected in buses 11 and 26 to be 0.7373 pu and 0.7769 pu respectively. The two buses are suitable locations for shunt capacitor placement.

4.2 Improved case of the network

The heuristic technique was initially applied to the considered network in PSAT then load flow analysis was done in MATLAB to determine the number of losses and to find the voltage profile. Shunt capacitors of 450KVAR and 750 KVAR are placed at the two buses 11 and 26, respectively. The sized capacitors are carefully placed at the specified locations and the effect on the network's voltage profile is compared with the existing state as shown in Figure 2.

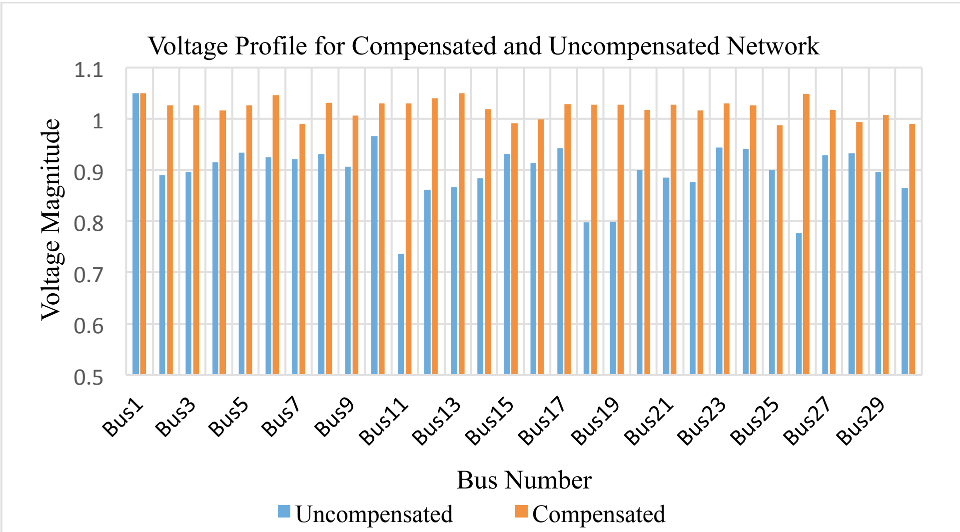

Fig.2. Voltage amplitude before and after compensation.

4.3 Impact on power loss

The existing state of the network has shown a high rate of power losses along the distribution lines, with the real and reactive power loss accounts for 0.55 MW and 0.89 MVAr respectively. When the full compensation of the network was done, shunt capacitors inject reactive power at critical buses to compensate for the amount of power lost due to the presence of reactive components in the system and the system performance significantly improved. This compensation minimized the system power losses, having the real power loss reduced to 0.277 MW (51% reduction from the former) and the reactive power loss reduced to 0.18 MVAr (78% reduction from the former). The power loss profile for the compensated state has been compared with that of the existing state as shown in Figure 3.

The heuristic approach used has minimized the network power loss to its sustainable magnitude. Furthermore, the introduced approach or technique is very cost effective to implement when compared with other techniques.

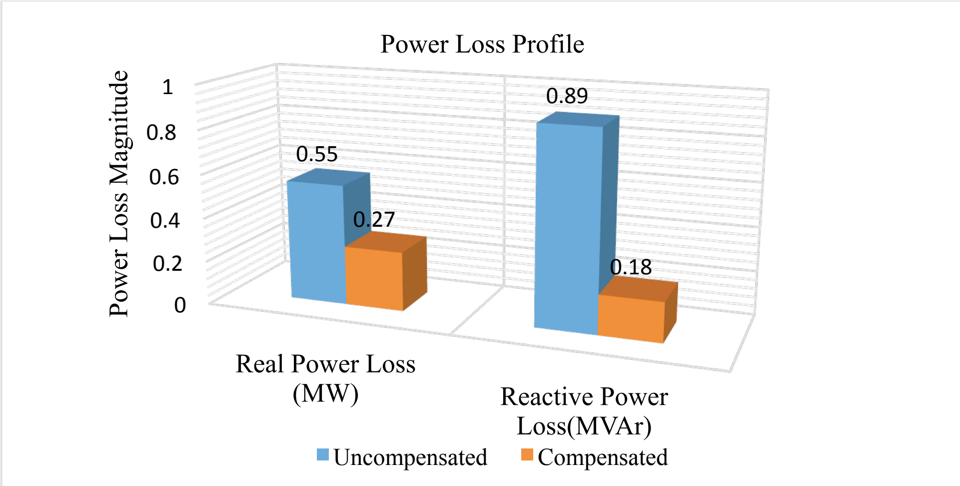

Figure 3: Power loss before and after compensation

5.0 CONCLUSION

In distribution network, shunt capacitors are placed to improve voltage profile and to minimize losses. Capacitor placement is complex, time consuming and introduces greater power loss when it is not optimally sized and located in the network. This drawback is surmounted with the application of heuristic technique for capacitor placement. The effectiveness of this proposed technique is tested on 30 bus, 11 kV, 50 Hz Thinker's Corner distribution network. The result shows significant power loss reduction and voltage profile improvement in the entire network in comparison with the existing state of the network and other methods. This has improved the electricity supply to this area and with the sustainable power supply, Internet and communication access has been enhanced. These service providers have the needed amount of power supply for constant service delivery. This work creates awareness on the benefits of improved power quality in a distribution network running along transmission lines for an improved power generation.

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