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Power Loss Minimization For 11kv Radial Distribution System for Improved Power Quality

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Abstract- The distribution system can be seen as the networking line that interfaces between the large power generators and transmission lines on one hand and the electricity consumers on the other. The system can exist in different topologies among which, the radial form is popular because of its simplicity and comparative low cost of design. The problem of poor power quality and instability has been a major power system challenge especially in Nigeria. More reliable and stable power systems among other benefits can be enjoyed when system is optimized. In this research, active and reactive technical power loss was minimized by reactive power injection through placement of capacitor banks. The extent of power loss minimization was considered at different instances based on the absence and presence of capacitors at load buses. The fundamental capacitor sizing equation was deployed and result showed a minimum and maximum reactive power demand of $2100\ and\ 28800\ kVAr$ ***from*** $7\ and\ 96$ ***banks respectively. Upon application of adequate capacitor banks power loss minimization was achieved and valued between*** $169\ kW + j3385\ kVAr\ and\ 108\ kW + j2165\ kVAr$ ***against a default loss value of*** $180kW + j3593\ kVAr$***. Obviously, from the results obtained before and after capacitor placement shows achievement of the proposed aim.***

Indexed Terms- Power, Minimization, Radial Distribution, system design, modelling

I. INTRODUCTION

Electricity is an essential requirement for all areas of human endeavor. It has almost now been accepted as a basic human need and has been asserted to have the socio- economic development of any country depending on it. Electric power has become a fundamental part of the infrastructure of contemporary society, with most of today's daily activity based on the assumption that the desired electric power is readily available.

The power systems which provide this electricity are some of the largest and most complex systems in the world. They consist of three primary components: the generation system, the transmission system, and the distribution system. Each component is essential to the process of delivering power from the site where it is generated to the customer who uses it. There exist connecting joints in the system, which are known generically as the transmission lines and the distribution networks. Both the transmission and distribution system have prime task of delivering electrical power to customers at their place of consumption and in usable form. While performing this main task, the electric utility is interested in achieving certain sufficient levels of reliability, efficiency, peak load and costs (Kothari, 2013). The subject of distribution loss minimization has gained a great deal of attention due to high cost of electrical energy. This isso because, distribution systems can acquire longer life span and have greater reliability by reducing power losses unit (Kothari, 2013).

The focus of this report is on the application of a suitable solution of the power flow problem for the determination of technical losses and the feeder reconfiguration – an optimization technique for *distribution* systems which aims at minimizing technical losses already determined in the system. Typically, every distribution system originates at a substation where the electric power is converted from the high voltage transmission system to a lower voltage fordelivery to the customers. This work aims at implementing an optimization procedure using feeder reconfiguration for minimizing technical losses on the Rumuola Road 11kV power distribution feeder.

II. LITERATURE REVIEW

- Losses in Power Systems

Losses are inevitable in the provision of electrical energy; even technologically advanced countries cannot make all the electricity generated available for consumer use; some of it is lost just due to the natureof the business of generating, transmitting and distributing electricity.

Electric energy losses are broadly divided intotwo - technical and non-technical losses.

i. Technical Losses

Technical losses occur because the electrical equipment used in the power system, by nature, have losses associated with them which cannot be totally eliminated. Generators/transformers have losses in their windings (due to the winding resistance) as well as their core (due to eddy current and hysteresis).

ii. Non-Technical Losses

Non-technical losses (also called commercial losses) occur due to energy theft, poorly estimated billing, defective metering equipment (either deliberately tampered with or not), unpaid bills etc. They are generally caused by actions external to the power system and cannot be empirically computed like the technical losses. Energy theft can be done by tampering with meters to make them undercount, bypassing the meters, making illegal connections, colluding with utility company meter readers to falsify consumption data or billing department to alter the bill issued to the customer (Awosope, 2014)

- Unbalanced Loads

It is not uncommon to see all the four supply conductors (three phases and neutral) from the secondary distribution transformer connected to the single-phase consumer with wire connections to enable phase selection. Whenever there is loss of supply or excessively low voltage on one phase, consumers would then operate their fuse cut-out to transfer to any phase that is still energized. The realization that supply is still available on other phases usually occurs by observation of nearby houses or through indicators (usually light bulbs) installed at the premises (this in itself constitutes a waste of energy when it is left lit perpetually)

- Lack of Legislation on Electric Energy Theft

Electric energy theft is the illegal use of electricity with the objective of evading tariff payment. In Nigeriait is reported to be committed more by the wealthy and affluent with supposedly high social status (Okafor, 2019). Illegal use occurs when: consumption is done without an agreement, the metering equipment is circumvented, or the meter is interfered with to alter the readings; the main objective being to save money (Okafor, 2019). However, while the energy thieves are saving money, the utility company and even the honest customers are losing money. For example, the Port Harcourt Electricity Distribution company reported a monthly revenue loss of N233 million. Theft is made rather easy because of the physical access of the end users to the electricity infrastructure. Penaltiesimposed in other climes, e.g. in India where fines and imprisonment of up to five years is specified (Okafor, 2019), havenot completely eradicated energy theft. It is worse in Nigeria because there is no law on electrical energy theft (although disconnection and payment of a fee before reconnection is practiced). However, a bill seeking to criminalize and punish electricity theft with fines and jail terms has been submitted to the NationalAssembly by NERC (Smith, 2014).

The review of related literature suggest that a number of studies has been carried out to improve the energy distribution output for a given electrical energy and the losses which appear across the feeder will be used in eliminating or reducing the losses on the system for a maximum efficiency of its output.

Distribution System is an important system in power system. Distribution System can be seen as the networking line that interfaces between the large power generators and transmission lines on one hand and the electricity consumers on the other hand. Electricity utility is interested in achieving certain sufficient levels of reliability, efficiency, peak load and costs but sometimes the reverse becomes the case due to power loss. In developed countries, it isnot greater than 10%. However, in developing countries, thepercentage of active power losses is around 20%; therefore,utilities in the electric sector are currently interested inreducing it in order to be more competitive, since theelectricity prices in deregulated markets are related to the system losses, technical and non-technical losses are accounted as 23% of the total input energy. To manage a loss reduction program in a distribution system it is necessary to use effective and efficient computational tools that allow quantifying the loss in each different network element for system losses reduction. In order to increase the efficiency of the distribution electrical networks, a reconfiguration process was applied to improve the reliability indices. The main aim of this research work is to Minimized Power Loss on 11kv Radial Distribution System for Improving the Power Quality. Specifically, the study sought to:

i. Study and analyze existing systems,
ii. Collect network data for system design and modelling,
iii. Ascertain the present state of the system by subjecting it to load flow studies,
iv. Adopt a good power loss minimization approach for optimal loss reduction, and
v. Analyze and ensure that the adopted solution after implementation meets the aim of the project by improving the reliability and the efficiency of Rumuola distribution network.

III. MATERIALS AND METHODS

3.1 Simulation Data and Software

The data for simulation was collected from the PHEDC office rumuola branch comprising of 3 months data, June, July and August, from the data's available for the month with the highest peak load was selected to be used as load on that selected 11kV bus. And the Power system simulation software to be used is ETAP (Electrical transient analysis program) while excel is used for data visualization

3.2 Methods

Two methods of solution are deployed in this research; first a load flow is conducted to ascertain the steady state and transient behaviour of the system while a second method for capacitor placement will also be used to calculate reactive power demand as well as amount of capacitor bank needed based on the calculated values. Newton Raphson (NR) nonlinear approach will be used to solve the load flow power equations for appropriate values of real and reactive power flows and losses as well as voltage magnitude and angle. Based on the proceeds of the load flow calculations, further calculations will be made using the capacitor bank placement equation. Equation 3.1 is the fundamental equation for capacitor kVAr sizing for improved power supply through power factor and reactive power improvement.

$$kVAr = kW\ (tan\ \emptyset_1 - tan\emptyset_2) \quad (3.1)$$

Where $Cos\ \emptyset = Power\ factor$ (pf) (3.2)

$$\emptyset = Cos^{-1}(pf) \quad (3.3)$$

From equation 3.3 values of $\emptyset_1\ and\ \emptyset_2$ known as existing and expected angular values of the power factor will be deduced.

From equation (3.1), $KVAr = Capacitor\ rating\ value\ (minimum\ and\ maximum)$

$KW = Average\ and\ maximum\ active\ power$

Careful application of the above equations will reveal the effect of capacitor bank placement in the Rumuola distribution network be it positive or negative.

Total factor = 35.8MW ≡ $35800KW$

@ Minimum, power will used into average to form numbers of branches

∴ average power ≡ $\frac{Total\ power}{2} = \frac{35800}{2} = 17900KW$

For minimum placement

Given that,

$\cos\theta_1 = 0.76, \cos\theta_2 = 0.8,\ KW = 17900$

∴ $\theta_{1=}\cos^{-1}(0.76) = 40.54, \theta_{2=}\cos^{-1}(0.8) = 36.87$

Using capacitor bank sizing equation

KVAR = KW $[\tan\theta_1 - \tan\theta_2]$

KVAR = 17900 $[\tan 40.54 - \tan 36.87]$

KVAR = 17900 $[0.86 - 0.75]$

KVAR = 17900 x 0.11

KVAR = 1969

= 1969KVAR

How many 300KVAR banks required will be $\frac{1969}{300} = 6.56 \simeq 7$

i.e., 7 x 300KVAR banks of capacitor required for minimum banks

For maximum capacitor bank,

The desired power factor is taken as 99.9%

Given that,

$\cos\theta_1 = 0.76, \cos\theta_2 = 0.999,\ KW = 35800$

∴ $\theta_{1=}\cos^{-1}(0.76) = 40.54,$

Again $\theta_{2=}\cos^{-1}(0.999) = 2.56$

Using capacitor bank sizing equation

KVAR = KW $[\tan\theta_1 - \tan\theta_2]$

KVAR = 35800 [0.81]
KVAR = 28998
∴ total number of 300KVAR banks will be $\frac{28998}{300} = 96.06$
i.e., 96 x 300KVAR capacitor bank is required for maximum bank

IV. RESULTS

This section discusses the results obtained during the research work and the respective load behaviour in some specific areas as mentioned in the case study.

- Load Flow Network Bus Performance without System Modification

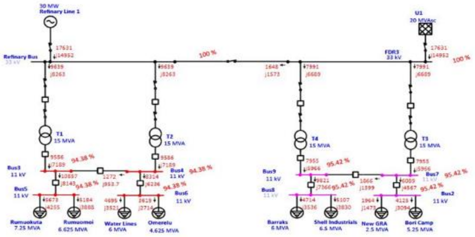

Figure 4.1: Pre-Capacitor Placement Load Flow Result

From the pictorial result displayed in Figure 4.1, out of ten bus bars, four namely buses 3, 4, 5 and 6 are critically overloaded while buses 2, 7, 8 and 9 are marginally overloaded with resultant effect of voltage drop beyond and within the IEEE prescribed limit of $\pm 5\%$. Detailed results as regards power loss minimization will be discussed based on the graphical results in the later figures.

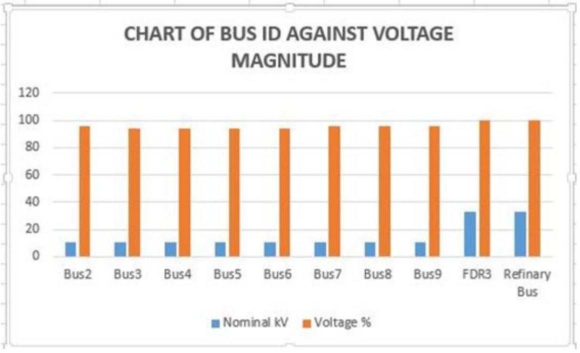

Figure 4.2: Pre-Modification Result for kV and % Voltage Magnitude

The above result from the chart in Figure 4.2 shows the difference between the nominal voltage magnitude and the existing voltage magnitude in terms of kV and % due to system voltage drop. Aside Feeder 3 and Refinery bus maintaining a voltage profile equal to the nominal voltage there is voltage sag in the remaining bus. Power factor, loading and voltage drops as well as real and reactive power flow results along the branches are displayed in Figures 4.3, 4.4 and 4.5.

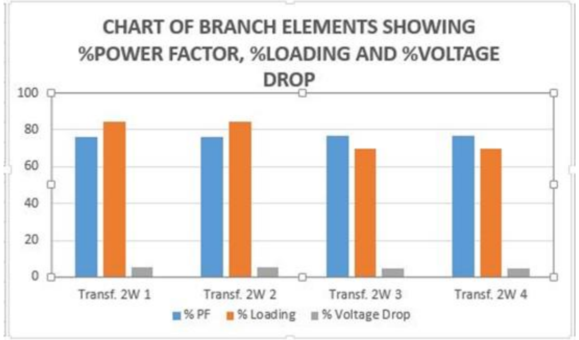

Figure 4.3: Percentage Pre-Modification Results for Branch Elements

From the results in Figure 4.3, transformers 1 and 2 had the highest loading and voltage drop as 84.6 and 5.62 in terms of percentage but has the least power factor as 75.92%.

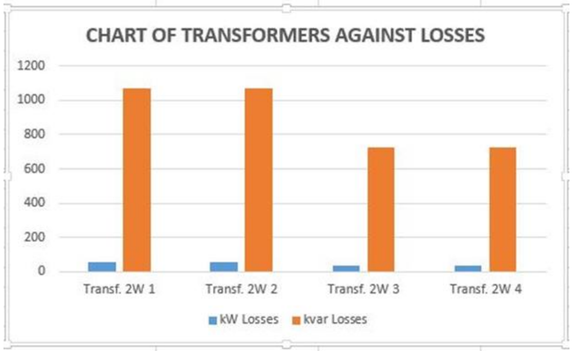

Figure 4.4: Pre-Modification Result of Branch Elements against Losses

Both real and reactive power loss results were produced from the pre-modification simulation based on the drops associated with the branch elements. From Figure 4.4, the least joint active and reactive power losses is valued at $36.16\ kW\ and\ 723.1\ kVAr$ due to transformer impedances.

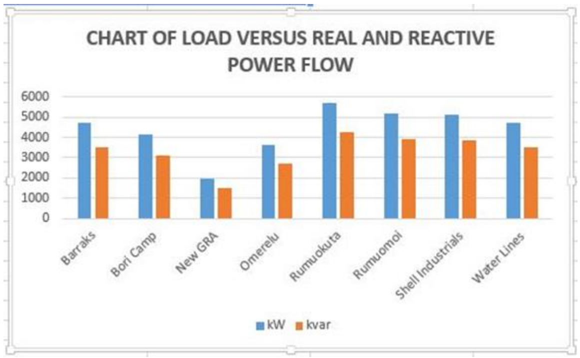

Figure 4.5: Pre-Modification Result for Feeder Power Flow

Active and reactive power flow results are displayed in figure 4.5, with the least and highest real and reactive power flow occurring at New GRA and Rumuokwuta feeders with numerical values of $1964.2\ kW + j1473.1\ kVAr\ and\ 5673.2\ kW + j4254.9\ kVAr$ respectively. From the pre-modification results so far, a total of $180kW\ and\ 3593kVAr$ are accounted for as real and reactive power losses awaiting minimization.

4.2 Minimum Modified Results

From the pre-modification result, with an average power of $17631kW$, existing branch power factor of 76% and a desired power factor of 80%, the minimum reactive power demand calculated using equation 3.1 is $1939.41kVAr$. If a capacitor of 300kVAr is to be used, then a minimum of $7 \times 300kVAr$ is being used to supply the total kVAr demand.

The effect of the capacitors placed at bus 5 as it improved the voltage profile of the four critically loaded buses to a marginal point with a minimal power loss reduction from $180kW + j3593kVAr\ to\ 169kW + j3385kVAr$. Pictorial results showing system improvement through power loss reduction upon $7 \times 300kVAr$ capacitor placement at bus 5 is contained in figure 4.6.

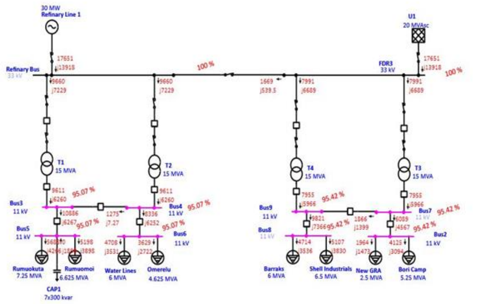

Figure 4.6: Post Capacitor Placement Load Flow Result with Minimum Banks

Aside the loss reduction, percentage voltage profile was also increased from 94.38% to 95.07% at buses 3, 4, 5 and 6.

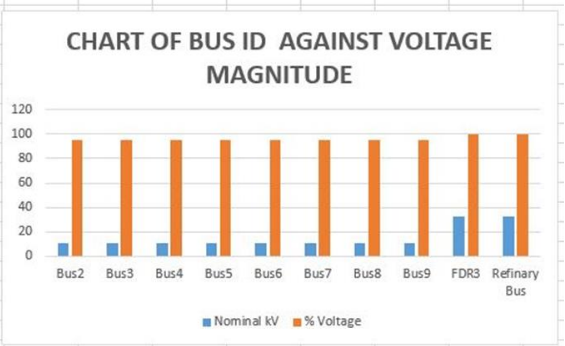

Figure 4.7: Post Modification Result for kV and % Voltage Magnitude with Minimum Banks

Figure 4.7 clearly shows that the voltage variation between the nominal and % voltage magnitude is slim and all buses operating within the prescribed voltage regulation with the least being at the marginal loadable region.

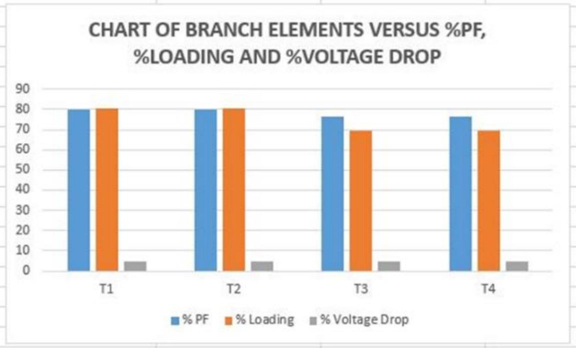

Figure 4.8: Percentage Post Modification Results for Branch Elements with Minimum Banks

Upon successful application of minimum capacitor banks, the percentage power factor, loading and voltage drop received appreciable boosting. The minimum and maximum percentage voltage drops was jointly recorded at transformers 3, 4 and 1, 2 as 4.58% and 4.93%. Evidently, the % voltage drop results obtained after minimum bank application showed compliance with the IEEE prescribed limit and a reduction as compared to the highest pre-modification drop result of 5.62%.

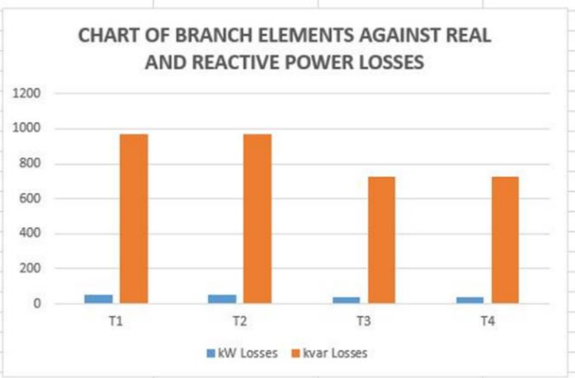

Figure 4.9: Post Modification Result of Branch Elements against Losses with Minimum Banks

Both real and reactive power loss results were produced from the post modification simulation based on the drops associated with the branch elements. From figure 4.9, the least joint active and reactive power losses is valued at $36.16\ kW\ and\ 723.1\ kVAr$ due to transformer impedances.

Though the least values were similarly to the pre-modification values, the maximum loss value experienced a drop from $56.66kW\ and\ 1073.3kVAr\ to\ 48.46kW\ and\ 969.2kVAr$.

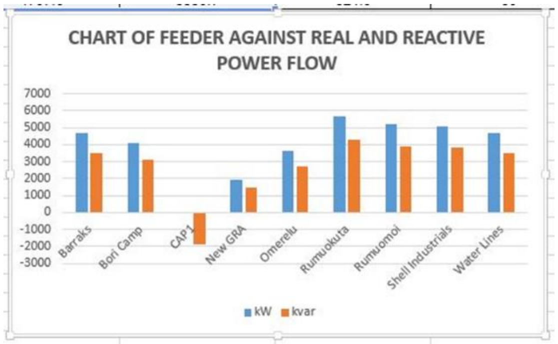

Figure 4.10: Post Modification Result for Feeder Power Flow with Minimum Banks

Active and reactive power flow results are displayed in figure 4.10, with the least and highest real and reactive power flow occurring at New GRA and Rumuokwuta feeders with numerical values of $1964.2\ kW + j1473.1\ kVAr\ and\ 5688.4\ kW + j4266.3\ kVAr$ respectively. This huge power flow increase was as a result of the presence of CAP 1 at bus 5 with injection capacity of $1897.9kVAr$.

The net power loss as per comparing the pre and post modification results in the absence and presence of minimum capacitor banks resulted in a 7% power loss reduction.

4.3 Maximum Modification Results

From the pre-modification result, with a total power of $35261kW$, existing branch power factor of 76% and a desired power factor of 99.9%, the maximum reactive power demand calculated using equation 3.1 is $28746.37kVAr$. If a capacitor of 300kVAr is to be used, then a maximum of $96 \times 300kVAr$ is being used to supply the total kVAr demand.

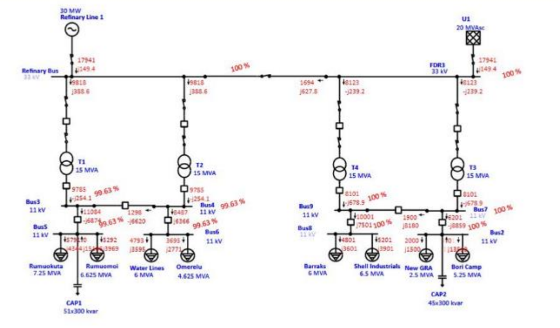

Figure 4.11: Post Capacitor Placement Load Flow Result with Maximum Banks

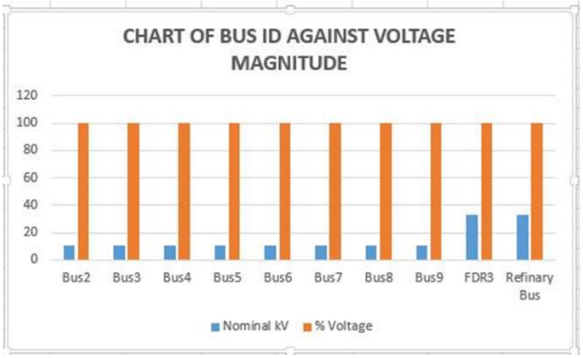

Figure 4.12: Post Modification Result for kV and % Voltage Magnitude with Maximum Banks

Figure 4.12 clearly shows that the voltage variation between the nominal and % voltage magnitude is negligible and all buses are operating within the prescribed voltage regulation without violation. Judging from the voltage profiles, there is a transition from marginal overloading to a point of best operation.

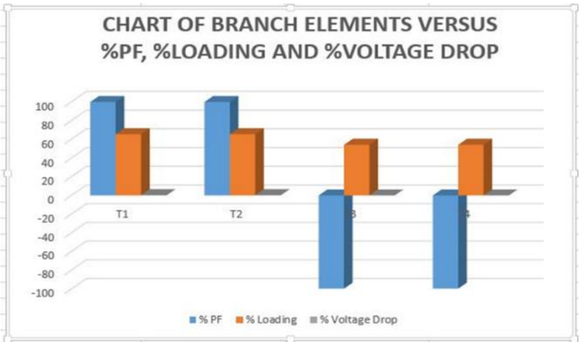

Figure 4.13: Percentage Post Modification Results for Branch Elements with Maximum Banks

Upon successful application of maximum capacitor banks, the percentage power factor, loading and voltage drop received huge boosting. The minimum and maximum percentage voltage drops was jointly recorded at transformers 3, 4 and 1, 2 as 0.04% and 0.37% which is less than unity. Evidently, the % voltage drop results obtained after minimum bank application showed compliance with the IEEE prescribed limit and a reduction as compared to the highest pre-modification and minimum post modification drop results. Comparatively, results from application of maximum number of capacitor banks showed 95.98% and 95.69% voltage drop optimization between the pre-modification and minimum post modification results. Also, optimal leading and lagging power factor was achieved with minimum percentage loading across all branch elements. From the results in figure 4.13, jointly the power factor of all branch elements is averagely 99.9%.

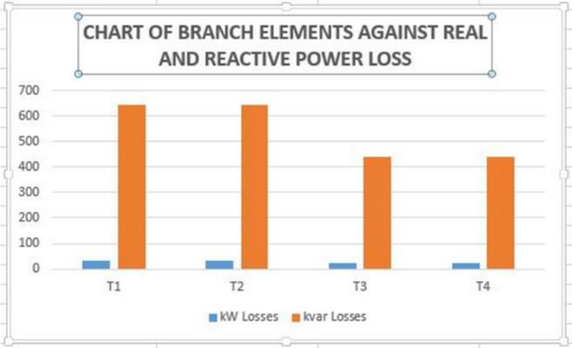

Figure 4.14: Post Modification Result of Branch Elements against Losses with Maximum Banks

Both real and reactive power loss results were produced from the maximum post modification simulation based on the drops associated with the branch elements. From figure 4.14, the least and maximum joint active and reactive power losses is valued as $21.99\ kW + j439.7\ kVAr$ and $32.14\ kW + j642.8\ kVAr$ due to transformer impedances.

When compared to the pre-modification and minimum post modification simulation results, a loss reduction in the tune of 60 and 64% active power loss minimization.

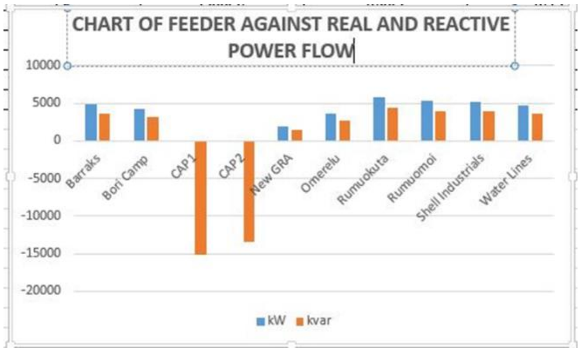

Figure 4.15: Post Modification Result for Feeder Power Flow

Active and reactive power flow results are displayed in figure 4.15, with the least and highest real and reactive power flow occurring at New GRA and Rumuokwuta feeders with numerical values of

$2000.3\,kW + j1500.2\,kVAr$ and $5791.4\,kW + j4343.5\,kVAr$ respectively. This huge power flow increase was as a result of the presence of CAP 1 and 2 at buses 5 and 8 with operating leading capacity of $28696kVAr$.

CONCLUSION

In this study, power loss reduction was successfully conducted in conformity with IEEE voltage regulation standard through voltage profile improvement by means of reactive power injection. Post simulation results clearly fulfils the aim of this research as optimal power loss minimization was achieved using maximum capacitor bank allocation as compared to the pre and post with minimal capacitor placement results. Apparently, results obtained after simulation proved positive as both aim and objectives of the research were fulfilled with violation of standards.

RECOMMENDATIONS

After considering effects of active power losses in distribution system on any nation's economy and cost of electricity, it is recommended that such feeder reconfiguration, capacitor placement among the many optimization techniques be performed on the system. Following the trends in power system technologies worldwide and recent research and development of smart grid technologies, it can be inferred that

i. Hardware application of the optimization technique implemented in this project
ii. A comparative review should be carried between the implemented method and introduction of relief transformers
iii. Smart grid technology should be adopted for lasting power systems solution

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