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Power Quality Improvement for Evaluation (33KV) Garki Distribution Network Using Load Flow Method in Federal Capital Territory, Nigeria.

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ABSTRACT
The stability and control of the power system are essential for ensuring reliable operation of electricity supply from the grid to the end-users. The successful delivery of power to load centres necessitates the design and implementation of a functional and efficient distribution network. However, this remains a significant concern within the study area, particularly in the Garki area, where electric power distribution network frequently encounters low voltage distribution profile due to overload, harmonic distortion, and power losses within the system. Consequently, this research undertakes an evaluation of system overload, alongside associated harmonic distortion and power losses, to enhance the current state of system performance and ensure reliable power supply that sufficiently mitigates voltage drops following statutory nominal operating standard of ±5% in order to prevent violation of voltage regulations. To achieve this, this research utilizes the Fast Decoupled Load Flow method, embedded in Electrical Transient Analyzer Program (ETAP version 19.0.1) to model the existing case study: the Garki 33kV distribution network in the Federal Capital Territory (FCT) for simulation and evaluation. The specialized ETAP software is employed to ascertain system violations for enhancement. Results from simulated existing network indicate that voltage drop violations (Vd) were measured at 11.9, highlighting significant infractions within the network, while the Apparent Power (p) losses on the feeder amounted to 1825.2KVA, which represents a substantial deviation from the standard regulatory practice established by IEEE of ±5% for the declared operating conditions of reliable power quality. This study thus presents an optimal investigation utilizing series compensation within the ETAP software to determine the reactive power capacity (Q=kVAR/MVAR) to select appropriate capacitor locations and sizes, in the view to minimizing energy losses within the network to enhance performance. Following the installation of series capacitor compensation, with specified capacitor value of 0.6MVAR (600kVAR), the penetration of sized capacitor causes a significant improvement, decreasing from 1825.2KVA to 1327.3KVA, which constitutes a 28% enhancement. The voltage drop across the feeder and also reduced it to 7.93%. Furthermore, adjustments were made to the on-load tap changer (OLTC) setting of the primary winding in the 100MVA transformer feeding the Apo feeder, calibrated to -3.125%, thereby optimizing the voltage profile of the distribution network. This modification optimally improved the reliability of the 33kV feeder supplying the study zone (Apo line), hereby enhancing power quality, voltage sag, for the enhancement of daily macro-economic activities in the area.

Keywords: *Load Flow, Distribution Network, Power Quality, Overload, Reliability, Enhancement, Harmonic Distortion.*

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I. INTRODUCTION

1.1 Background of the Study

Electrical Power System consists of three major components, which are Generation, Transmission, and Distribution. The role of generation is to produce electric power to be able to meet the demands of consumers. The transmission system acts as a bridge to fulfil this significant role. Transmission system is the crux of a power system. It serves as a bridge between generation and distribution entities (Umair, 2021). Electrical power is transmitted via 330KV/132KV high voltage transmission lines from the generating substations to the distribution substations. At the distribution substations, the voltage is stepped down to a lower value (33kV or 11kV). The transmission system is further divided into primary and secondary transmission. Primary transmission is designed for the efficient long-distance transfer of electricity from power plants/generation to substations. Secondary transmission, however, is focused on delivering this power to the end users in a form that is safe and usable.

1.2 Statement of the Problem

Following the review of existing related study on the subject matter under research, the activities of power supply must be taken very seriously with the view to match power generation to the demand to avoid excessive power losses, voltage drop and harmonic distortion that may not conform to the declared nominal operating statutory regulatory framework of IEEE-standard (±5%).

Evidently, the case study (networks I, II, and III) of Garki area, Apo feeder (132/33kV) network in Federal Capital Territory (FCT), are regularly experiencing system overloads, as a result of people migrating from one location to another for economic activities. This has seriously led to:

(i) Overload/congestion
(ii) Power loss
(iii) Voltage drop and harmonic distortion and
(iv) Mismatches between power generation and load demand.

1.3 Aim of the Study

The aim of this study is to evaluate the load flow of 33KV Garki Distribution network for improved power quality in the Federal Capital Territory (FCT), Abuja, Nigeria.

1.4 Objectives of the Study

The objectives of the study are given as:

(i) To collate existing data for the network under investigation and implement collected data into governing equation.
(ii) To constitute governing equations for the load flow study and evaluation.
(iii) To model the existing case study, using ETAP version 19.0.1, as application tool for simulation.
(iv) To determine and verify the improvement of the case study before and after simulated results.

1.5 Scope of the Study

The scope of this research work shall be limited Garki area in Abuja.

1.6 Significance of the Study

This research work shall provide adequate information for future planning, expansion or upgrade of 33KV H31 Apo feeder network. It will also determine the steady state operational values as the losses along the branches of the network. Finally, the current findings regarding to the results are required to make recommendations on the solution for system improvement and expansion of the network configuration under investigation.

II. LITERATURE REVIEW

2.1 Extent of Past Works

Load flow analysis forms an essential pre-requisite for power system studies. Considerable research has already been carried out in the development of computer programs for load flow analysis of large power systems. There are many solution techniques for load flow analysis such as: Gauss Seidel, Newton-Raphson, Fast Decoupled algorithm etc. Power flow method is an essential tool in application software for the analysis of distribution systems.

III. MATERIALS AND METHODS

3.1 Materials Used

Materials needed for the actualization of this research required equipment data such as element nominal/rated KV, bus input data, and branch input data. The materials needed for the actualization of this research includes:

(i) The line and bus data under investigation.
(ii) The electrical tool ETAP version (19.0.1) for modelling.
(iii) The cross-sectional area of the conductor.
(iv) The impedance and reactance of the line under investigation

3.2 Method Used

Fast Decoupled Load Flow method embedded as a module in ETAP 19.0.1 will be used to analyse the H31 33KV Apo feeder to obtain its steady-state operational values. Series compensation shall be used for optimization strategy which shall be further improved by carrying out On-Load Tap Changing on the primary winding of the 100MVA power transformer feeding the Apo line network.

3.3 Load Flow Calculation (Non-Linear System)

Assume Load Voltage (V_R) (Initial Condition)

Calculate the current "I" given as:

$$I = \frac{S_{Load}}{V_R} \tag{3.1}$$

Based on current, calculate voltage drop "V_D" given as:

$$VD = I \cdot Z \tag{3.2}$$

Re-calculate load voltage "V_R" given as:

$$V_R = V_S - V_D \tag{3.3}$$

Re-use until results are within the specific precision

3.4 Load Calculation

The apparent power can be calculated as,

$$KVA = [(KW)^2 + (K_{var})^2]^{1/2} \tag{3.4}$$

$$\text{Power factor (P.F)} = \frac{KW}{KVA} \tag{3.5}$$

$$\text{Three phase power, } S_{3Q} = \sqrt{3}\, V_{L-L} I \tag{3.6}$$

or

$$I = \frac{KVA}{(\sqrt{3}KV)} \tag{3.7}$$

3.5 Power Transfer over a Non-Compensated Line (P_{T1})

$$P_{T1} = \frac{V_S V_R}{X_L} \cdot Sin\delta \tag{3.8}$$

Where:

V_S = Sending end-phase voltage

V_R = Receiving end-phase voltage

X_L =The series inductive reactance of the line

δ = Phase angle between V_S and V_R

3.6 Power Transfer over a Compensated Line

$$P_{T2} = \frac{V_S V_R}{X_L - X_C} \cdot Sin\delta \tag{3.9}$$

X_C = series capacitive reactance of the line

3.7 Compensation Factor (K)

The degree of compensation of the line is called the compensation factor.

$$\frac{P_{T1}}{P_{T1}} = \frac{1}{1-K} \tag{3.10}$$

Where, K is the compensation factor

Practically, the degree of compensation lies between 0.4 and 0.8. The power transferred increases, and K increases within the permissible limit.

3.8 Rating of Series Capacitor

$$Q_C = 3I^2 X_C \times 10^{-6} M_{var} \tag{3.11}$$

$$Q_C = 3I^2 X_C \mu M_{var} \tag{3.12}$$

I = the current through the compensated line in KAmps.

3.9 Per-Kilometre Active Resistance (R_o)

$$R_o = \frac{1000\ell}{A} (\Omega/km) \tag{3.11}$$

ℓ = The design resistivity of the conductor (Ωm)

A = The cross-sectional area of the conductor (m^2)

3.9.1 Per-Kilometre Inductive Reactance (X_o)

For a three-phase horizontal equally speed conductor with suitable transposed conductors, the line per kilometre inductance;

$$L_o = 2 \times 10^7 \left[Log_e \frac{d}{r^1} + \frac{1}{3} Log_e\, 2\right] \times 1000 \quad \left({}^{H}/_{Km}\right) \tag{3.12}$$

$$X_o = 2\pi f L_o \left({}^{\Omega}/_{Km}\right) \tag{3.13}$$

Where $r^1$is the Geometric Mean Ratio (GMR) $= re^{\frac{1}{4}} = 0.7788r$

r = is the radius of the conductor

d = the spacing between the phase conductors

3.9.2 Per-Kilometre Capacitive Susceptance (B_o)

For a three-phase system, the per-kilometre short capacitance

$$C_o = \frac{2\pi\varepsilon_0}{log_e\sqrt[3]{d_1 d_2 d_3}} \times 1000 \left({}^{F}/_{Km} \right) \quad (3.14)$$

$$B_0 = 2\pi f C_0 \left({}^{S}/_{Km} \right) \quad (3.15)$$

3.10 Voltage Drop (V_D)

Drop in voltage for a non-compensated line:

$$V_D = IRcos\theta + IX_L Sin\theta \quad (3.16)$$

Drop in voltage for a compensated line;

$$V_D = IRcos\theta + I(X_L - X_C)Sin\theta \quad (3.17)$$

Were, R = the resistance of feeder

X_L = the positive line inductance

X_C = The negative capacitive reactance of a series capacitor

$cos\theta$ is the receiving end power factor

$Sin\theta$ is the sine of the receiving end power factor angle

3.11 Transformer On-Load Tap Charger (OLTC)

Turns ratio $= \frac{N1}{N2}$

Where N_1 and N_2 are the number of turns on the primary and secondary sides of the transformer

From the transformer equation;

$$\frac{V1}{V2} = \frac{N1}{N2} \quad (3.18)$$

V_1 and V_2 are the voltages on the primary and secondary sides of the transformer. Thus;

$$V_2 = V_1 . \frac{N2}{N1} \quad (3.19)$$

$$V_2 = \frac{V1}{\left(\frac{N1}{N2}\right)} \quad (3.20)$$

To achieve an optimal voltage profile of the system, the tap position on the primary winding of the 100 MVA power transformer shall be entered in ETAP 19.0.1 software, thus, conducting an optimal OLTC/voltage Regulation study; with the tap position optimally set at -3.125% (-5% variation) for a 33 number of taps LTC.

3.12 Line Parameters for H31 33KV Apo Feeder

The 33KV H31 Apo line network is horizontally arranged overhead 120mm² ASCR cables, with equal spacing between adjacent conductors.

$$r = \sqrt{\frac{A}{\pi}} \quad (3.21)$$

$$r = \sqrt{\frac{120 \times 10^{-6}}{\pi}} = 0.00618\ m \quad (3.22)$$

From Pole specification, spacing between adjacent conductors, $d = 1.2\ m$

$$r^1 = 0.7788 \times 0.00618 = 0.004813\ m$$

3.12.1 Per-Kilometre Active Resistance of H31 33KV Apo Feeder

$$R_o = \frac{1000 \times 2.826 \times 10_{-8}}{120 \times 10^{-6}} = 0.29\ \Omega/km \quad (3.23)$$

3.12.2 Per-Kilometre Line Inductive Reactance of H31 33KV Apo Feeder

$$L_o = 2 \times 10^{\eta} \left[log_e \frac{1.2}{0.004813} + \frac{1}{3} log_e\ 2 \right] \times 1000 \quad (3.24)$$

$$L_o = 0.00115\ {}^{H}/_{km} \quad (3.25)$$

$$X_o = 2 \times \pi \times 50 \times 0.00115 = 0.36\ \Omega/km \quad (3.26)$$

3.13 Calculation for Size of Series Capacitor to be Installed

The line parameters of 33KV H31 Apo Feeder shall be obtained directly from ETAP 19.0.1 software.

Length of line = $16.7\ km$

Per km inductive reactance of the line = $0.36402\ \Omega/km$

Line inductive reactance of the line = 0.36402×16.7

$$= 6.07909\ \Omega \quad (3.27)$$

For 80% degree of compensation

$$K = \frac{X_C}{X_L} \quad (3.28)$$

$$X_c = KX_L = 0.8 \times 6.07909 = 4.863272\ \Omega \quad (3.29)$$

For a compensated line given as:

$Z = R + j\,(X_L - X_c)$ (3.30)
Per Km resistance of line, $R_o = 0.295\ \Omega/km$ (3.31)
Line resistance, $R = 0.295 \times 16.7 = 4.9265\ \Omega$ (3.32)
Thus, $Z = 4.9265 + j\,(6.07907 - 4.863272)$ (3.33)
$Z = 4.9265 + j\,1.215818$ (3.34)
$|Z| = [4.9265^2 + 1.215818^2]^{\frac{1}{2}}$ (3.35)
$|Z| = 5.07431\ \Omega$ (3.36)
Current through compensated line

$$I = \frac{\text{Operated Voltage of non} - \text{compensated line}}{\text{Impedence of Line}}$$

$I = \frac{31.94\ KV}{5.07431} = 6.2945\ KA$ (3.37)
Size of series capacitor
$Q_c = 3 \times 6.2945^2 \times 4.8632 \times 10^{-6}\ MVA\,r$ (3.38)
$Q_c = 0.000578\ MVA\,r$ (3.39)
$Q_c \simeq 0.0006\ MVA\,r$ (3.40)

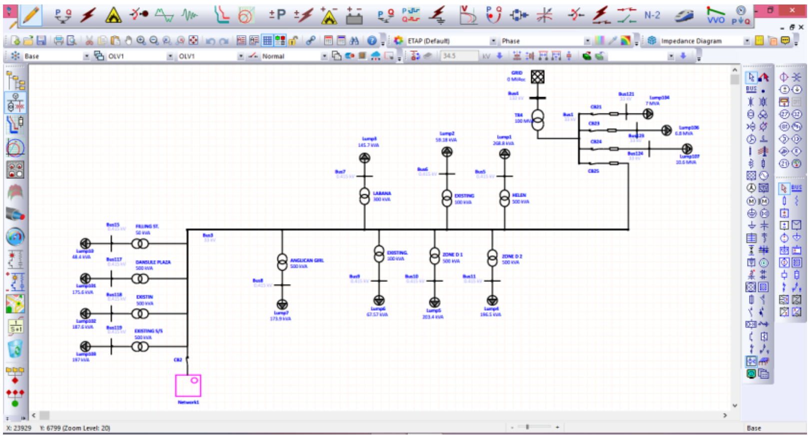

Fig. 3.1: Existing Network of H31 33 KV Apo Feeder Network I

The given figure 3.1 shows the existing network of H31 33Kv Apo feeder in FCT network -1, with supply voltage from 132/33kV. The system constitutes twelve (12) distribution transformers with 500kVA capacity for the study under investigation.

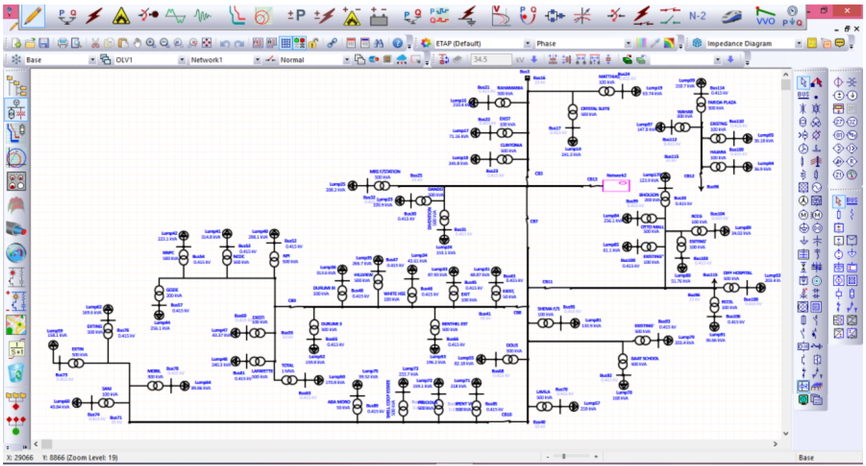

Fig. 3.2: Existing network of H31 33 KV Apo Feeder Network II

Similarly, the existing network of H31 33kV Apo feeder of network II takes grid supply from 132kV to 33kV for this study under investigation with its associated distribution transformers of forty-eight (48) attached to respective load or the transformer for purpose of verifying violation on the transformer when simulated according to IEEE regulations practice;

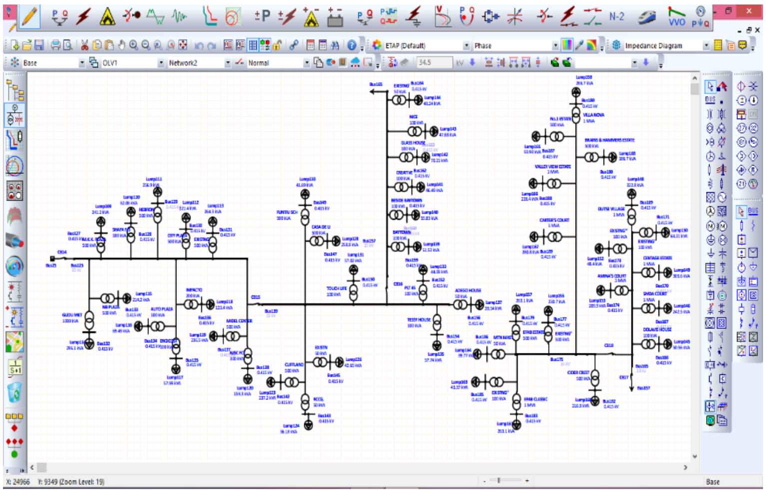

Fig. 3.3: Existing network of H31 33 KV Apo Feeder Network III

The existing system case of H31 33kV Apo feeder of network III shows the single line representation of the study case under investigation, modelled in electrical transient analyser (19.0.1). The study considered forty-five (45) distributed transformer with its associated load on the transformer with a view to model, simulation and verify system violation for improved network capacity using **Optimal Capacitor Placement** (OCP) and penetration of reactive power component.

IV. RESULTS AND DISCUSSION

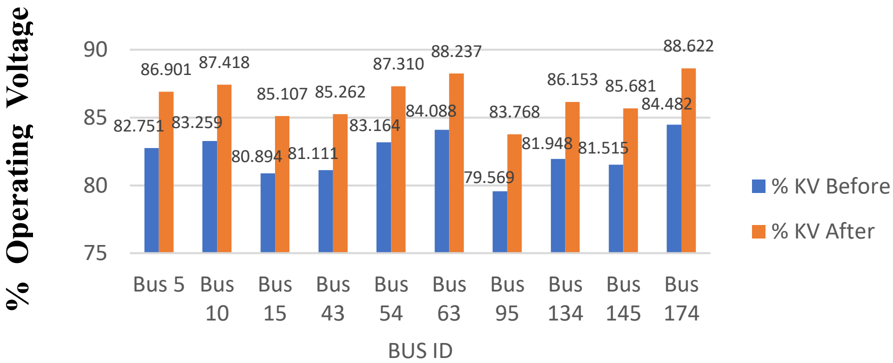

Figure 4.7: Operating Voltages of 0.145 KV for Before and After Compensation

Figure 4.7 is a graph that compares the percentage operating voltages of the same randomly selected 0.145 KV buses in the previous figures for before and after the installation of the appropriately sized series compensator of 0.0006MVAr. For instance, notice the increment of the percentage operating voltage of Bus 15, from 80.894% to 85.107% of the nominal rated value of the Bus.

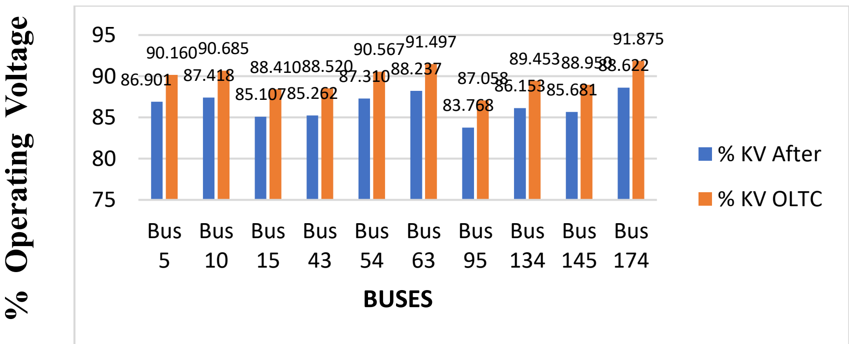

Figure 4.8: Operating Voltages of 0.145 KV Buses for after Compensation and after OLTC.

Figure 4.8 shows the comparisons of the percentage operating voltages of the randomly selected 0.415KV buses after the installation of 0.0006MVAr series capacitor and after On-Load tap changing is done on the 100MVA power transformer observe the noticeable improvements of the voltage profile experienced after OLTC.

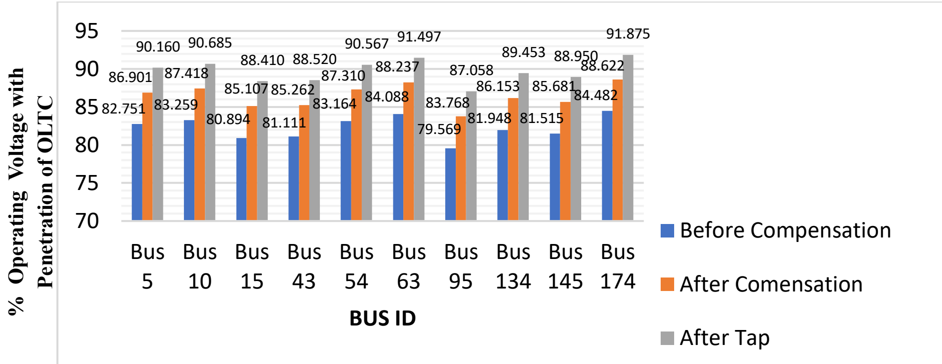

Figure 4.9: Operating Voltages of 0.145KV Buses Before Compensation, After Compensation, and After OTLC

Figure 4.9 is a graph that compares the percentage operating voltages of the randomly selected 0.415KV buses at their existing state and after the various stages of improvements. The present operating voltage of say, Bus 10 was 0.346KV. The installation of the fixed series compensator improved the operational voltage of Bus 10 to 0.363KV. This was then further improved to 0.376KV after OTLC was done at the primary winding of the 100 MVA power transformer by optionally placing the tap position at -3.125% setting.

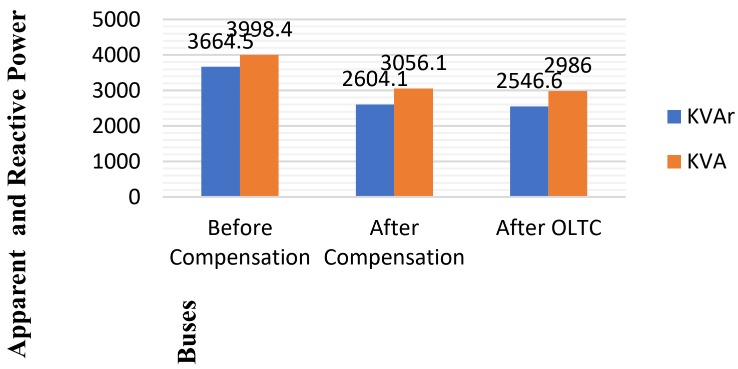

Figure 4.10: Total Reactive and Apparent Power for Existing and After the different Stages of Optimization

Figure 4.10 shows the comparison between reactive and apparent power loss for the existing network after the installation of the series compensation and after OLTC was performed on the power transformer. Observe the reduction of both the total reactive and apparent power losses as the network was improved using the various correction techniques. The reactive and apparent power loss from the entire system in the existing network is 3664.5KVAr and 3998.4KVA respectively.

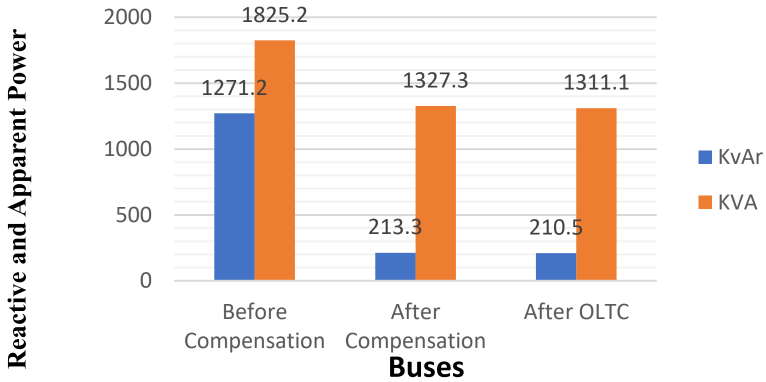

Figure 4.11: Apparent and Reactive H31 33KV Apo Line Losses Before Compensation, After Compensation, and After OLTC

Figure 4.11 is a graph that compares the reactive and apparent branch losses of the Apo feeder in its existing state and after the various cases of optimization of the network. Notice that the losses were reduced drastically after each case. The reactive and apparent losses for the line in its existing state are 1271.2 KVAr and 1825.2 KVA.

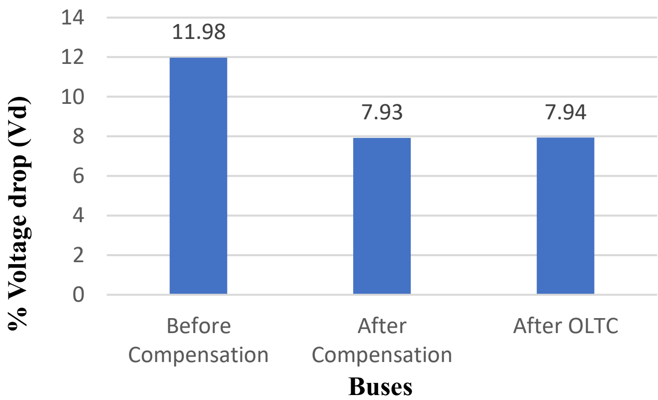

Figure 4.12: Percentage voltage drop from H31 33KV Apo line

Figure 4.12 is a graph that shows the drop in voltage from the H31 33KV Apo line before compensation, after compensation, and after OLTC was done. In the existing network, 11.98% of the line's nominal rated voltage was lost during operation. After the series compensation, the voltage drop was reduced to 7.93%. The figure was slightly increased by 0.01% after OLTC was conducted on the 100MVA power transformer.

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study determined the collated existing data under investigation on the view to analyse the Garki area, located at the major zone of the Federal Capital Territory (FCT), from the Apo feeder, from 132/33KV transmission network, the existing case study was modelled in electrical transient analyser (ETAP) tool and simulated, which shows violation on the Garki feeder. The research considered the application of reactive power injection using a series compensation technique to counteract 80% the line inductive reactance of the Apo 33KV line, reducing voltage drop and improving power transfer. The penetration of 0.0006MVar was appropriately sized and used for reactive power injection, enabling a reliable power supply.

Constituted governing equations were formulated, data was collected, and implemented using embedded fast decoupled load flow and its associated power system equations, which determined the existing study case violation in terms of critical and marginal overload. The reactive power was sized using an optimal search for the purpose of improved performance.

The system configuration of the existing case study, 33KV distribution network modelled in the electrical transient analysis program, version 19.01, with embedded Newton-Raphson and load flow as contained in figures 3.1, 3.2, and 3.3, respectively.

The results obtained from the load flow analysis are determined using a fast embedded decoupled load flow method with electrical transient analyzer software for simulation. However, the existing network violation shows 11.9 voltage drop (Vd) in the system while the apparent power (p) losses and the feeder were 1825.2KVA, which represent gross mismatches; following the given standard regulatory practice of IEEE with ±5% as declared operating condition for reliable power quality.

The study also presents an optimal search using a series compensation technique to determine reactive power capacity penetration for system enhancement, to select the most probable candidate for sizing and location. The technique determines 0.0006MVAR capacity to be optimally placed at bus 3 for network improvement. Installation of the series capacitor significantly improved the losses from 1825.2 kVA to 1327.3 kVA, which represents a 28% improvement, while the voltage drop (Vd) was also improved to 7.93%.
Consequently, the on-load tap charging transformer (OLTC) technique was also adjusted by using regulatory settings to -3.125% to improve voltage profile distribution.

5.2 Recommendations

Having noted the activities of the quality of power delivery to the end-user under this study and the mismatches between available power dispatched from the national grid to the transmission injection substitution are grossly inadequate, making the system experience excess power losses, voltage drop, harmonic distortion, congestion, etc. This means that injection substations must be given an optimal percentage loading of the available power supplied. Thus, the following recommendations are considered for future study:

(i) Fast decoupled load flow solutions should be implemented on the power workstation to analyse and identify the existing case study, enabling immediate action.

(ii) The case study should be reconfigured to conform to and adapt to the existing conditions of overload/congestion.

(iii) Real-time monitoring and control should serve as an essential platform for system planners and operators to continuously assess the conditions of the system.

(iv) The 33kV distribution network should further be expanded to accommodate more transformers, increasing conductor cross-sectional area and dimensions for system enhancement.

(v) An effective protective system with reactive power components must be sufficiently designed to respond to sudden changes in the system in the even if they are unlikely.

(vi) To achieve the purpose of future planning, operation, and improvement in the power distribution system, particularly in the case study, distributed generation (solar and wind hybrid) is strongly suggested to sustain power delivery always.

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