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Evolutionary Algorithm based Approach for Power Quality Enhancement

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Abstract: *Power quality enhancement analysis was conducted in this research to have knowledgeable insight on the Egbema 33/11kV and 11/0.415kV distribution feeders responsible for conveying supply to Mgbede, Aggah, Okwuzi, Etekwuru 1 and 2. Load flow analysis was conducted using Newton Raphson (NR) on the network and emanating results revealed that 37 out of 41 buses were heavily loaded resulting to poor voltage profile below the 95% IEEE approved lower limit voltage regulation margin. In a bid to improve the system for optimal power distribution, appropriate sizes of capacitor banks were deployed at precisely 27 bus bars using a biological inspired artificial intelligent system in ETAP called genetic algorithm (GA). Results after deployment of adequate and appropriate capacitor banks produced an improved load flow solution with the least bus bar operating at 95% voltage profile which lies within the IEEE* $\pm 5\%$ *voltage regulation standard. Loss results for both real and reactive power before and after optimal capacitor bank placement is recorded as* $517KW + j1473\ KVAR$ *and* $330KW + j913\ KVAR$ *with the latter reflecting about 40% loss reduction compared to the former. From the voltage profile and power loss results, it is evident that the solution algorithm deployed was capable of improving power supply to the five Egbema communities under investigation.*

Background**: **Electricity is a vital element in any modern economy. Reliable access to affordable electricity is essential for economic growth and development in the country. Therefore, global energy services, striving to meet the needs of customers as economically as possible through efficient service [1]. In order to meet customer needs, service must be developed progressively, and effective maintenance of system infrastructure. Global analysis shows that about 90 percent of all customer development problems are due to a problem in the distribution system, which is why, improving distribution development is key to improving customer development. The mandate of the Power Holding Company of Nigeria (PHCN) to transmit, distribute, and supply sufficient electricity in a safe, reliable, and efficient manner and this must be achieved. In contrast, the occasional supply of electricity to customers through the Nigerian electricity system has become a source of concern for the aid company. Many power system engineers have conducted various development studies using heuristic, network configuration, integration of renewable energy resources, and distributed production communications aimed at improving system performance. This study proposes a genetic algorithm to measure the appropriate size and location of the capacitor banks of the electrical profile and to reduce power losses. The proposed study will look at the state of the system using Newton Raphson before and after the installation of the capacitor bank of the 33kV distribution feeder under investigation.

***Materials and Methods**: In this research. Power system network data was gathered and modeled using ETAP 19.0 software as materials while Newton Raphson (NR) and genetic algorithm (GA) were deployed for load flow and optimal capacitor placement and sizing.*

***Results**: Load flow results before improvement reveals the present state of the Egbema network with 37 out of 40 buses suffering from under voltage issues. The state of under voltage is critical and below the -5% IEEE voltage regulation with real and reactive loss indexed at* $517\ kW$ *and* $1473\ kvar$. *The employed algorithm after simulation was able to appropriately size and place capacitors for an optimal electricity distribution. The optimal location and sizing algorithm was able to place a total of 61 capacitor banks across 27 out of the 41 buses. Results after capacitor placement was able to adequately improve bus voltage profile, reduce branch percentage voltage drop and power losses in the real and reactive domain.*

***Conclusion:** Evolutionary algorithm based approach upon implementation was able to fulfil the aim of the research with a huge improvement in voltage profile and optimal loss margin reduction in the network under investigation*

Key Word**: **Genetic-Algorithm; Optimal; Capacitor; Load; Flow; Newton-Raphson; Real; Reactive; Power; Voltage; Drop; Power Loss.

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I. Introduction

This section introduces thought-provoking and related texts from a variety of companies on which research is focused to provide evidence and critical reviews of a topic based on current research. The relevance and consistency of these revised texts are reflected in the applicable studies.

Genetic-based algorithm (GA) to properly detect FACTS devices - Unified Power Flow Controllers (UPFC) and Thyristor Controlled Series Controllers (TCSC) devices in the power network. Combined 330kV increase and loss of power transmission. Reduction in separate active and efficient loading. The result showed that there was a reduction in transmission line losses in both active and active power, after the full installation of TCSC and UPFC devices in the network [2].

The Particle swarm optimization (PSO) method was used to fine-tune the DG in the distribution network of 33 and 69 bus systems. This work introduces different types of DGs using the PSO method of active and efficient energy compensation to minimize real power losses on basic distribution networks [3]. Genetic Algorithm based on the correct size and placement of the DG in the distribution network is proposed. GA methods are used to determine the correct size and location of the DG bus deployment using power losses and to reduce power losses in a network system based on bus entry, establishment information, and system load distribution [4].

The problem of network restructuring to minimize real power loss in power system in [5]. They used a meta-heuristic approach to achieving the goal. The enhanced algorithm predicts a reversal pattern that provides minimal losses and minimal power outages. It also reduces the number of shift jobs and at the same time satisfactory barriers.

Plant growth simulation algorithm (PGSA) was deployed for the redesigning of a radial distribution network. The effectiveness of this proposal was tested in a 69-node radial distribution system. The result, when compared to the development of a genetic algorithm, showed that the PGSA was successful in finding a global solution with a high probability of a limited solution [6].

Network configuration based on genetic algorithm using the graphical user interface (GUI) of MATLAB software was proposed in [7]. Experiments conducted on 6 buses, IEEE 14-bus, IEEE 30-bus, and IEEE 57 bus testing programs have been successful but the work is a theoretical guess.

Static var compensators (SVC) was deployed on Nigeria's 330kV transmission network with a focus on developing indicators to improve temporary stability using the appropriate size to detect SVC within the network [8]. The result showed an improved electrical profile and network stability but the authors considered only the appropriate size of the DG. The objective function in [9] was to determine the ideal location and size of the DG in order to minimize the deviation from the pre-determined profile but the method did not meet the stiffness requirement.

In [10] a research was conducted to develop Nigeria’s 330kV grid network using compliant compensation (STATCOM). In their work, the impact of the use of static synchronous compensator, FACTS control was tested on performance in Nigeria 330kV, a 28-bus power system. Newton-Raphson-based and flow-based power flow statistics describing the stability situation before and after compensation were analyzed by the system. Results from the analysis showed that 5 out of 28 samples of the sample system with voltage magnitudes falling outside the legal limits of $0.95 \leq Vi \leq 1.05$, were improved, and the number of system power losses was reduced by 5.88%.

II. Material And Methods

Materials used comprises of both software and hardware inclusive of network data for the system under investigation while all solutions are software based. Network data for the system under investigation was collected from First Independent Power Limited. As per the data collected, Egbema communities are interconnected through a distribution link with total route length of 55km through an $1 \times 15MVA$ injection sub-station located at Ebocha. All relevant network data is contained and represented in Table 1.

Table 1: Transformer and Load Data for Egbema Communities at 0.8 Power Factor

S/N	COMMUNITY	TRANSFORMER (MVA)	UNIT	LOAD (MW)
1	MGBEDE	1	1	2.31
2	AGGAH	0.75	1	1.89
3	OKWUZI	1	1	2.10
		0.75	1	
		0.5	6	
4	ETEKWURU 1	0.5	1	0.35
		0.3	1	
5	ETEKWURU 2	0.3	2	0.35

Source First Independent Power Limited (2021)

The system under consideration is a distribution system with one power grid, forty branches, forty-one transformers and forty lumped loads. Electrical Transient Analyzer Program (ETAP) 19.0 was used for designing of the network single line diagram as shown in Figure 1.

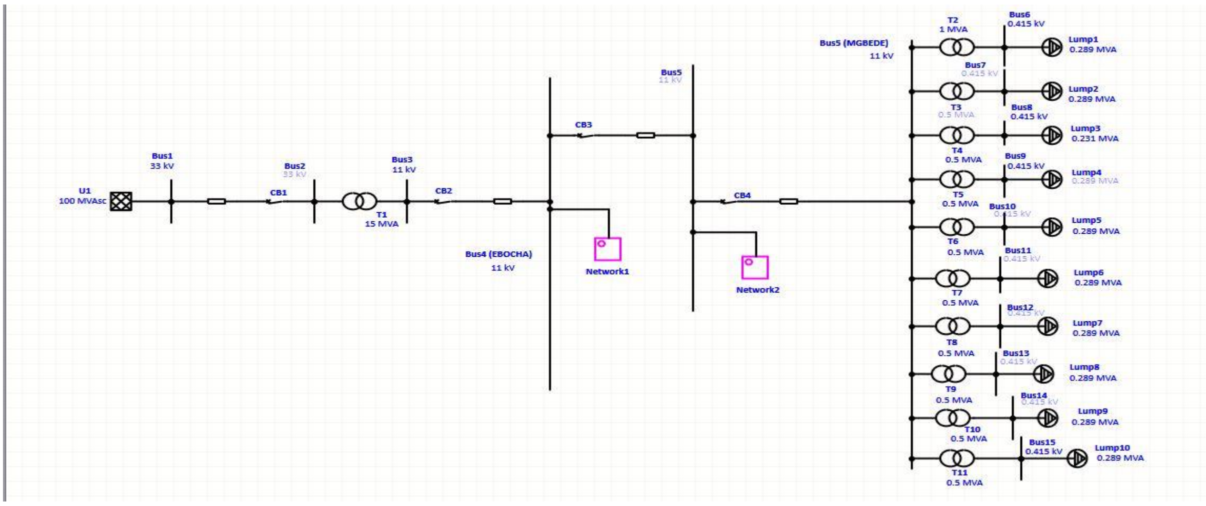

Figure 1: Single Line Diagram of Egbema Communities using ETAP 19.0

Network 1 is a subset of the single line diagram in Figure 1 which houses Okwuzi community. This network comprises of 11 buses, 7 distribution transformers and 7 lumped loads with a total consumption of 2.1MW. Network 2 is a subset of the single line diagram in Figure 3.1 which emanates from bus 5 and houses Aggah, Etekwuru 1 and Etekwuru 2 communities. This network comprises of 14 buses, 11 distribution transformers and 11 lumped loads with a total consumption of 2.59MW. In addition to the enlisted software, Microsoft word and excel was deployed for typing and representation of data and results.

Procedure Methodology

The Newton-Raphson method holds and repeatedly solves the following flow rate:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \qquad (1)$$

Where ΔP and ΔQ are the actual bus power and the operating force do not exactly match the vectors between the stated value and the calculated value, respectively; ΔV and Δδ represent the maximum power of the bus and angles in the form of additions; and J1 to J4 are called Jacobean matrices.

After a successful load flow studies and identification of normal or abnormal buses using Newton Raphson, GA will be employed for optimal sizing and placement of capacitor banks for voltage profile improvement and system upgrade.

Genetic Algorithm (GA) is a method of optimization based on the theory of natural selection. The genetic algorithm starts with the generation of solutions with a wide variety to represent the features of every search space. By mutation and crossover, good characteristics are selected and carried to the next generation. The optimal solution can be reached through repeated generations. Optimal capacitor placement (OCP) uses the present worth method to perform alternative comparisons. It considers initial installation and operating costs, which include maintenance, depreciation, and loss reduction savings.

The objective of optimal capacitor placement is to minimize the operational cost of the system and it is implemented using equation 2.

$$\sum_{i=1}^{N_{bus}} (x_i C_{0i} + Q_{ci} C_{1i} + B_i C_{2i} T) + C_2 \sum_{l=1}^{N_{load}} T_l P_L^l \qquad (2)$$

Where;

N_{bus}- Number of bus candidates

x_i – 0/1, 0 means no capacitor at bus i

C_{0i} – Installation cost

C_{1i} – Per $kVar$ cost of capacitor banks

Q_{ci} – Capacitor bank size in $kVar$

B_i – Number of capacitor banks

C_{2i} – Operation cost of per bank yearly

T – Planning period

C_2 – cost of each KWh in \$/ KWh

l – load levels

T_i – Time duration
P_L^l – Total system loss at load level

III. Result

Pre-improvement Analysis:

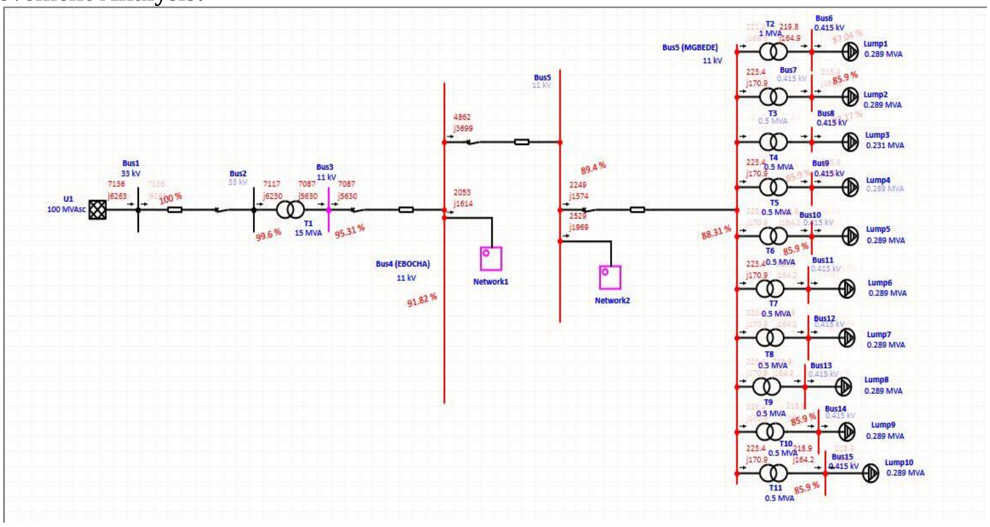

Figure 2: Load Flow Simulation Result before Capacitor Placement

Results from Figure 2 clearly reveals the present state of the Egbema network with 37 out of 40 buses suffering from under voltage issues. The state of under voltage is critical and below the -5% IEEE voltage regulation. From figure 2, 37 buses are flagged red while one bus is flagged pink. The red and pink colors are indicators of how critically and marginal the issues surrounded the buses are with reference to the IEEE $\pm 5\%$ voltage regulation.

From the above results, it is pertinent to proffer quick solution to the network to enhance improved electricity supply for economic and social development without limitation to the people of Egbema clan but the country at large. From the pre-OCP load flow result, it is obviously seen that real and reactive power losses to the tune of 517 kW and 1473 $kvar$ is inherent in the system. Pre – OCP findings after simulation with Newton-Raphson (NR) is pictorially represented using histograms in the figures 3, 4 and 5.

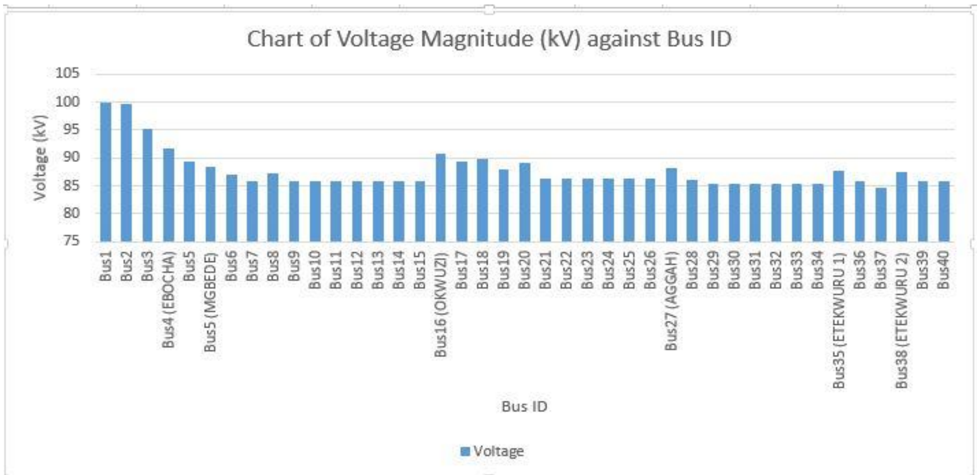

Figure 3: Bus Voltage Profile before OCP

Figure 3 explains in details the voltage level at all buses during the pre-improvement phase of the network. As earlier stated, excluding buses 1, 2 and 3 all other buses are unhealthy based on the load flow result.

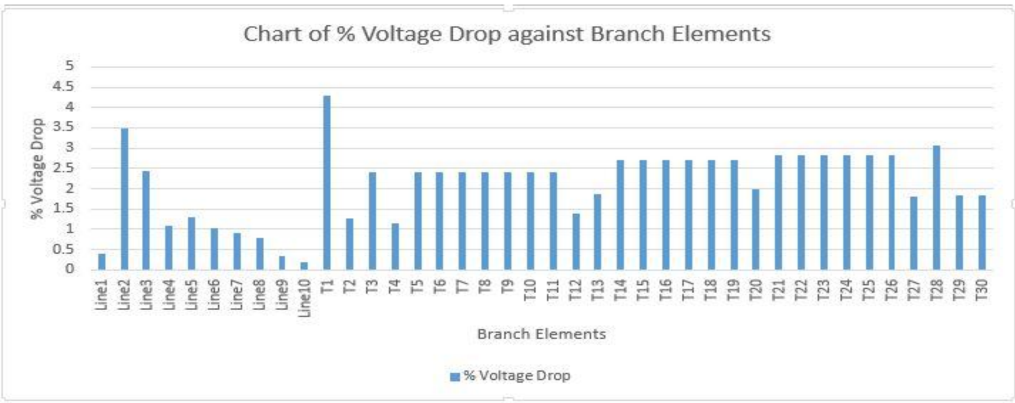

Figure 4: Branch Elements % Voltage Drop before OCP

From Figure 4, the percentage voltage drop of branch elements are within the permissible limits but requires further reduction for improved power supply. With 4.29 and 0.18 being the highest and least percentage drop values recorded at transformer 1 (T1) and line 10, there is need for collective and individual branch voltage drop remediation. Haven exhaustively looked at the power flow results using NR prior to improvement, careful steps will be taken to strengthen the network performance by flattening the voltage drop and loss magnitude curve.

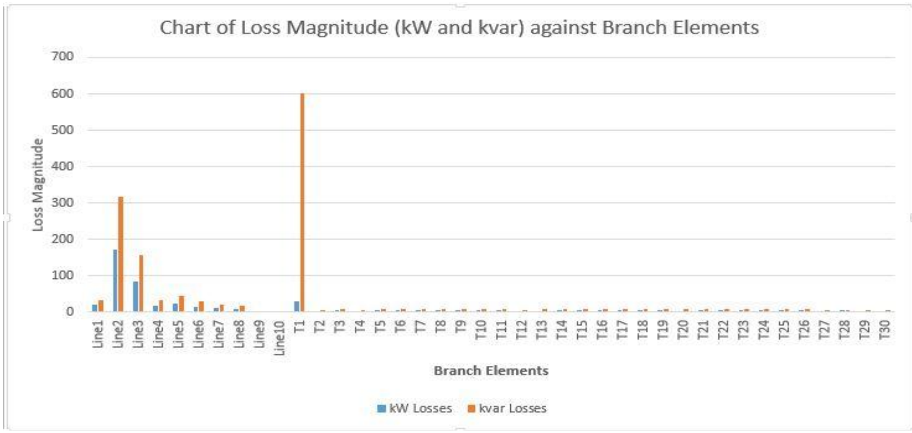

Figure 5: Load Flow Result of Power loss against Branch Elements

From the loss magnitude and branch element chart, the losses appear to be minimal as a result of the extent of percentage voltage drop recorded in Figure 4. Though kW and $kvar$ losses are minimal, it adversely affects the overall system performance.

Post-improvement Analysis:

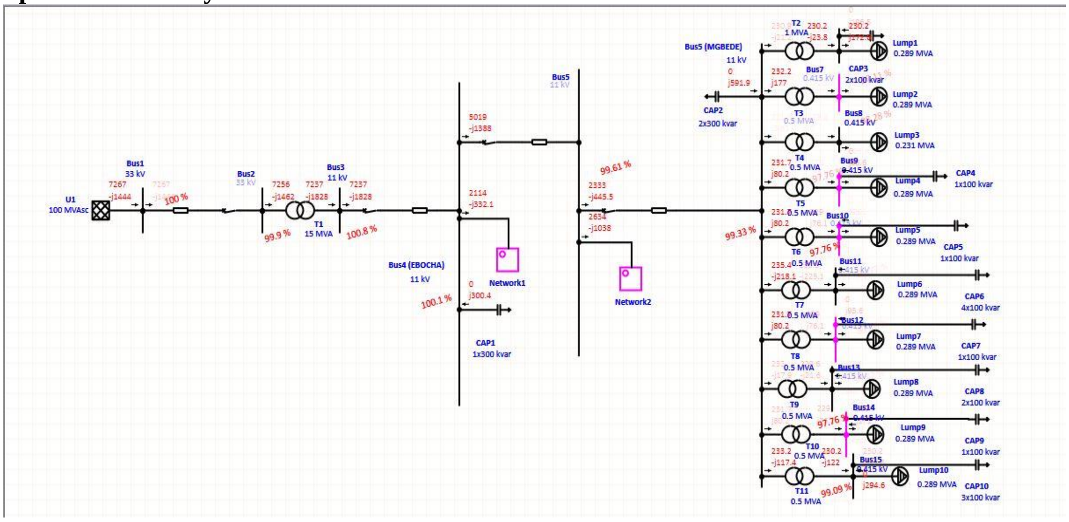

Figure 6: Load Flow Simulation Result after Capacitor Placement

Figure 6 shows the post improvement state of the network upon application of GA for capacitor placement. Evidently, all critical loaded elements (buses and transformers) changed status to marginal and normal loading upon capacitor placement. Not only was sick buses made healthy, effect of overloaded transformers, kW and $kvar$ losses are drastically minimized. The other part of the as contained in network 1 and 2 is contained in Appendix 1. Outcomes after improvement is presented in the figures below.

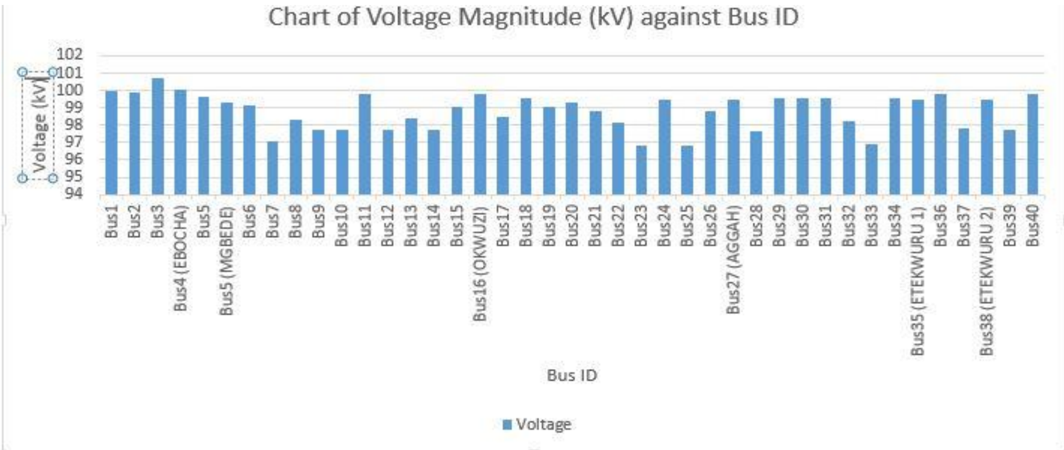

Figure 7: Bus Voltage Profile after OCP

From the chart in Figure 7, after fusing appropriate capacitor bank, the system voltage profiles for all 41 buses were adequately improved within the prescribed limit of $\pm 5\%$ with the least and maximum bus values recorded as 96.8 and 100.75 kV respectively. The least voltage magnitude was jointly produced by buses 23 and 25, while the maximum voltage magnitude was produced by bus 3.

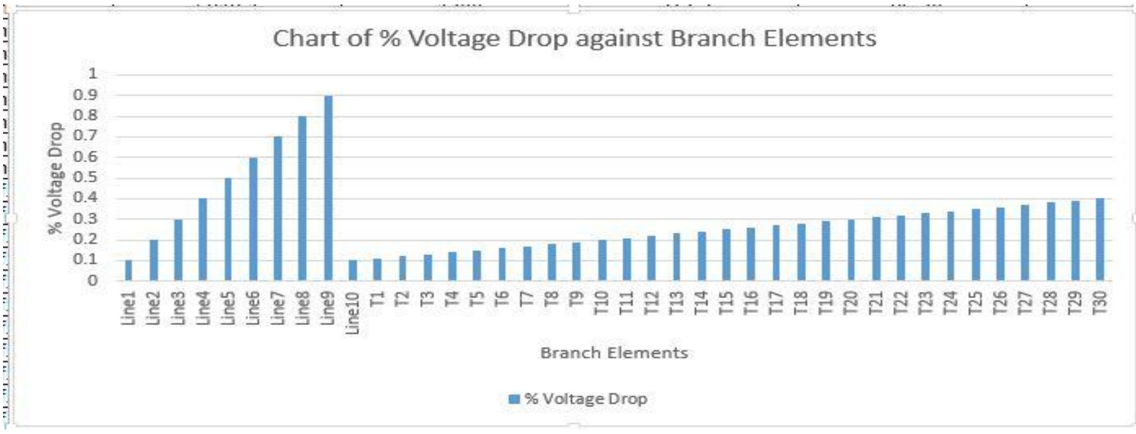

Figure 8: Branch Elements % Voltage Drop after OCP

Result as contained in Figure 4.8 show drastic percentage voltage drop minimization as compared to the pre-OCP chart in Figure 4.
The least percentage drop is jointly produced by lines 1, 10 and 11 as 0.1% whereas the highest percentage drop is produced by line 9 with a numerical value 0.9%.

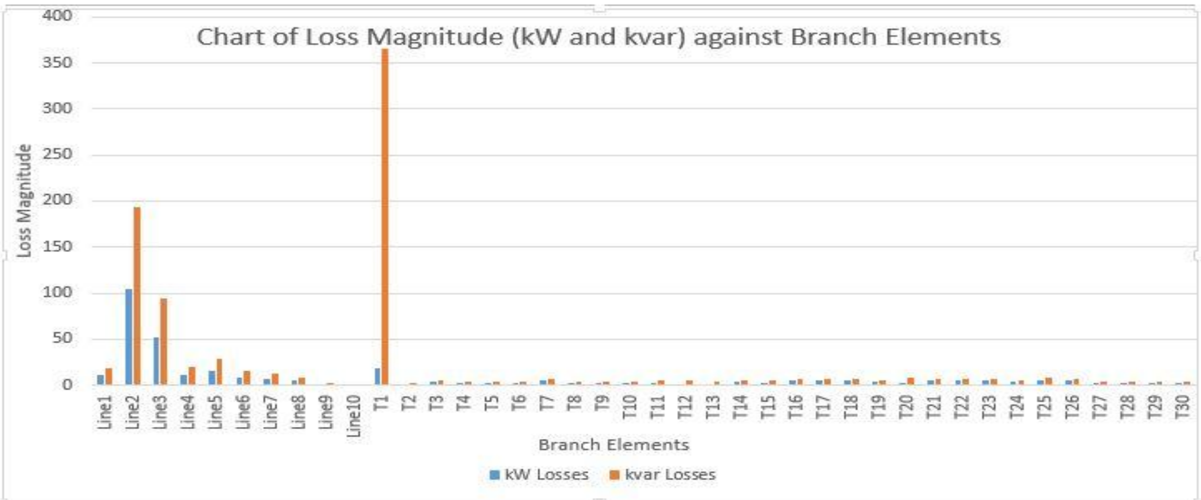

Figure 4.8: Load Flow Result of Power loss against Branch Elements after OCP

The post improvement loss magnitude chart clearly reveals the extent of active and reactive power loss minimization amongst the branch elements (lines and transformers). The least active and reactive power loss values as contained in Figure 4.8 emanates from line 10 with numerical values of $0.242\ kW\ and\ 0.127\ kvar$. Similarly, the highest $kW\ and\ kvar$ losses deduced from the chart in figure 4.8 is valued 104.8 and 192.7 respectively.

IV. Discussion

The status of the 41-bus system investigated was found to be unhealthy as diagnostic report after simulation with valid solution methodology showed high level of voltage profile defect beyond the permissible limit of $\pm 5\%$. Transformer overloading and branch losses were also pertinent issues discovered to be inherent in the system from the simulation report.

Deficiency identification without mitigation or enacting adequate and appropriate control measures will further encumber the minds of the consumers and subject the system to further deterioration. For this singular reason, genetic algorithm (GA) was deployed for remediation of real and reactive power losses as well as mitigation of under voltage issues rocking the network of Egbema communities. The developed algorithm after application was able to successfully improve electricity distribution to the five communities under x-ray thereby alleviating all under voltage buses to conform to the IEEE prescribed voltage limit.
The overall system real and reactive power loss was drastically reduced after optimal capacitor placement to $330\ kW\ and\ 913\ kvar$ against the pre-OCP loss values of $517\ kW\ and\ 1473\ kvar$.

V. Conclusion

From the results achieved after post improvement simulation using the biologically inspired solution method, faster computational time was offered against the traditional method of trial and error for optimal capacitor placement.

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