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The Study and Improvement of Electricity Power Distribution in Opolo Bayelsa State

S. O. Edward, D. C. Idoniboyeobu, C. O. Ahiakwo

Engr. Solomon Onovughe Edward is currently pursuing master's degree program in Power Engineering, Rivers State University, Port Harcourt, Nigeria. Email: onos2k16@gmail.com

D. C.Idoniboyeobu is a Professor of Electrical Engineering at the Department of Electrical Engineering, Rivers State University, Port Harcourt. He is a Professor of Electrical Engineering with specialty in Magnetics, Transmission and Distribution Systems.

C. O. Ahiakwois a Professor of Electrical Engineering at the Department of Electrical Engineering, Rivers State University, Port Harcourt. He is a Professor of Electrical Engineering with specialty in Power System and renewable Energy

ABSTRACT

This research, the study and improvement of electricity power distribution in Opolo community was carried out on a 33/0.415kv, thirty-four (34) distribution substations network in Opolo community using load flow based technique combined with network improving devices. The network was modelled and simulated using Newton Ralphson load flow method on ETAP 14.6 environment for the investigation and analysis. The results showed that there were violations, overloading and power losses in the distribution network. Total power losses of 79.6kw and 171.0kvar were observed in the network. Two transformers and about 34 buses had violations. Critical alert of overloading of 101.2% was observed at Udeme and 100.5% was experienced at Opuala Charles substations. The 34 buses were in overload condition.Shunt Capacitor Bank (SCB) and Static Var Compensator (SVC) were comparatively applied to improve the existing network by injecting active and reactive power where necessary. SCB reduced the losses in the networkfrom 79.6kw and 171.0kvar to 65.1kw and 151.0kvar while SVC did reduce them better to 57.8kw and 144.1kvar respectively. The results from the table, graphs and the calculations showed that SVC was more sensitive than SCB and had losses reduction performance efficiency of 27.6% and 18.1% for active and reactive power while SCB has 18.4% and 14.2% for active and reactive power. After improvement, the transformers and buses were operating at about 78% and the network was restored to normal. For improved and efficient power distribution,relief and higher capacity transformers are to be installed in the network with power compensating devices where necessary.

Keywords: Power Losses, Shunt Capacitor Banks, Static Var Compensator, Electrical Transient Analyser Program (ETAP), Newton Ralpson, Distrbution System, Load Flow.

1. INTRODUCTION

Power system across the world is established to meet the energy need of the modern man: the consumers, although, the profit comes along with creating value. The generation and transmission of power system are reliable as its distribution system[1].The analysis of the impact of electricity and customers' dissatisfaction proved that the distribution system is more important and deserved a serious attention because power generated and transmitted cannot be stored. That is, if the distribution system is not reliable, there will be poor power supply to customers [2].

Challenges such as losses, faults, lengthen distribution line, bad workmanship,poor voltage variation, inadequate conductors size, transformer size and selection, unequal load distribution, installation of distribution line away from load centres, overloading of the substations and feeders, abnormal condition of operation of transformers, low voltage at consumers' terminal causing higher drawn of current by the indicative loads experienced in power distribution network are responsible for poor power distribution, therefore, they are critical for reliable and efficient power distribution system[3].The measure of a reliable and efficient power supply system is one that seeks toovercome these shortcomings in the system and delivered quality power to end users irrespective of the odds in the system.

This paper, the study and improvement of electricity power distribution in Opolo, Bayelsa State, seeks to provide solution to the challenges of power distribution mentioned above that are reoccurring in Opolo by investigating and analysing the 33/0.415kv, thirty-four (34) distribution substations network in Opolo, using load flow based technique combined with network improving devices. The Newton Ralphson load flow method on ETAP 14.6 environment was used for the investigation and analysis while Shunt Capacitor Banks and Static Var Compensator were comparatively applied for the network improvement for reliable and efficient power supply.

Faults and losses are two reoccurring problem in power distribution network. Losses are traceable to technical and non-technical issues.Technical losses are due to deficiencies in operations arising from the physical properties of the components of the systems and occur naturally in the form of power dissipation in transformers, transmission and distribution lines. A technical loss could be calculated. Non-technical losses result from actions outside of the physical power system [4]. Faults are generally systemic in nature and can be prevented The distribution section accounts for 50% of all faults and losses in the power sector [5]. It is a known fact that the distribution system account for 75% to 80% of the unavailability and reliability problems of consumers [6]. Therefore, fixing the distribution challenges is solving 75% to 80% of the unavailable and unreliable electricity supply.

To improve the power distribution system, there is need to maintain the balance between production and consumption [7]. There must be an improvement in load distribution which translates to less breakdown, losses and fault elimination, availability of power to consumers. For an improved and satisfactory power supply, the distribution network operator must have an up till date load flow analysis of their network as operational and planning tool[8] The distribution system power supply adequacy, standardization and reliability is determined by load flow conformity of the network because over loading of the network leads to system breakdown.

2. MATERIALS AND METHODS

2.1 Materials

The necessary materials needed for this study are:Single line diagram of distribution network of Opolo community, load readings of distribution substations, total number and power rating of distribution transformers, Physical examination of Opolo community distribution network and feeder, installed capacity of injection substation feeding the community, Shunt Capacitor Banks (SCB), Static Var Compensator (SVC).
The Newton Ralphson method on ETAP environment was used for the network analysis.

2.2 Methods

The network was modelled and simulated using Newton Raphson load flow method to analysed the base 33/0.415kV Opolo community on Electrical Transient Analysis Program (ETAP 14.6 software) that provides a very high level of reliability, protection and security of critical applications. Violations, overloading and losses were identified. Thereafter, network improvement devices, Shunt Capacitor Banks (SCB) and Static Var Compensator (SVC) were applied to the existing network comparatively.The SBC and SVC improved the capability of the network by injecting active and reactive power to the network where necessary. The results of the simulation, analysis and comparativeof the system performance before and after improvement and other critical observations on the network were taken.

2.3 The Newton Ralphson Model of Load Flow Study

To apply Newton Ralphson model to the solution of power flow equations, we will express bus voltages and admittances in polar form. When n (i.e. no of buses) was set equal to 'I' and the corresponding terms were separated from the summations, we have

$$. P_i = |V_i|^2 G_{ii} + \sum_{\substack{K=1 \\ K\neq 1}}^{N} |V_i V_k V_{ik}| \cos(\theta_{ik} + \partial_k - \partial_1) \quad (3.1) \quad Q_i = -|V_i|^2 B_{ii} + \sum_{\substack{K=1 \\ K\neq 1}}^{N} |V_i V_k V_{ik}| \sin(\theta_{ik} + \partial_k - \partial_1)$$

(3.2)

P_i and Q_i are real and reactive power while B_{ii} and G_{ii} are the conductance and susceptance of a line joining two distribution stations. Since distribution lines connect bus (i) to another bus k which has its admittance expressed as Y_{ik}

$$Y_{ik} = |Y_{ik}| \angle \theta_{ik} = |Y_{ik}| (\cos\theta_{ik} + j\sin\theta_{ik}) \quad (3.3)$$

$$Y_{ik} = G_{ik} + JB_{ik} \quad (3.4)$$

This gives the voltage at a particular bus (k) to be

$$V_i = |V_i| \angle \partial_i = |V_i| (\cos\partial_1 + j\sin\partial_1) \quad (3.5)$$

So that

$$G_{ii} = |Y_{ii}|(\cos\theta_{ii}) \quad (3.6)$$

$$B_{ii} = |Y_{ii}|(\sin\theta_{ii}) \quad (3.7)$$

$$Y_{ii} = G_{ii} + jB_{ii} \quad (3.8)$$

$$\partial_k = \partial_i = 0 \quad (3.9)$$

For i=k

For a slack bus having specified values of V_i and δ_i, at each of the non-slack buses, the estimated values of V_i and δ_i corresponding to the estimate $\Delta x_1^{(0)}$ and $\Delta x_2^{(0)}$ in the proceeding section corresponds to the mismatch. The complex power mismatches for a typical bus (i) is giving thus;

$$\Delta P_i = P_{i,sch} - P_{i,calc} \quad (3.10) \qquad \Delta Q_i = Q_{i,sch} - Q_{i,calc} \quad (3.11)$$

For real power P, we have,

$$\Delta P_i = \frac{\partial P_i}{\partial \delta_2}\Delta\delta_2 + \frac{\partial P_i}{\partial \delta_3}\Delta\delta_3 + \frac{\partial P_i}{\partial \delta_4}\Delta\delta_4 + \frac{\partial P_i}{\partial |V_2|}\Delta|V_2| + \frac{\partial P_i}{\partial |V_3|}\Delta|V_3| + \frac{\partial P_i}{\partial |V_4|}\Delta|V_4| \quad (3.12)$$

$$where \quad P = j(\partial_2, \partial_3, \partial_4, V_2, V_3, V_4) \quad (3.13)$$

The last 3-terms can be multiplied and divided by their respective voltage magnitude without altering their values, and we obtain,

$$\Delta P_i = \frac{\partial P_i}{\partial \delta_2}\Delta\delta_2 + \frac{\partial P_i}{\partial \delta_3}\Delta\delta_3 + \frac{\partial P_i}{\partial \delta_4}\Delta\delta_4 + |V_2|\frac{\partial P_i}{\partial |V_2|}\frac{\Delta|V_2|}{|V_2|} + |V_3|\frac{\partial P_i}{\partial |V_3|}\frac{\Delta|V_3|}{|V_3|} + |V_4|\frac{\partial P_i}{\partial |V_4|}\frac{\Delta|V_4|}{|V_4|}$$

(3.14)

A similar mismatch equation can be written for reactive power Q,

$$\Delta Q_i = \frac{\partial Q_i}{\partial \delta_2}\Delta\delta_2 + \frac{\partial Q_i}{\partial \delta_3}\Delta\delta_3 + \frac{\partial Q_i}{\partial \delta_4}\Delta\delta_4 + |V_2|\frac{\partial Q_i}{\partial |V_2|}\frac{\Delta|V_2|}{|V_2|} + |V_3|\frac{\partial Q_i}{\partial |V_3|}\frac{\Delta|V_3|}{|V_3|} + |V_4|\frac{\partial Q_i}{\partial |V_4|}\frac{\Delta|V_4|}{|V_4|} \quad 3.15$$

Equationss (3.14) and (3.15) can be put into matrix form to produce the Jacobian matrix as seen in equation (3.16)

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_4 \\ \Delta Q_2 \\ \Delta Q_4 \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_4} & \frac{\partial P_2}{\partial |V_2|} & \frac{\partial P_2}{\partial |V_4|} \\ \frac{\partial P_4}{\partial \delta_2} & \frac{\partial P_4}{\partial \delta_4} & \frac{\partial P_4}{\partial |V_2|} & \frac{\partial P_4}{\partial |V_4|} \\ \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_4} & \frac{\partial Q_2}{\partial |V_2|} & \frac{\partial Q_2}{\partial |V_4|} \\ \frac{\partial Q_4}{\partial \delta_2} & \frac{\partial Q_4}{\partial \delta_4} & \frac{\partial Q_4}{\partial |V_2|} & \frac{\partial Q_4}{\partial |V_4|} \end{bmatrix} \begin{bmatrix} \partial \delta_2 \\ \partial \delta_4 \\ \Delta |V_2| \\ \Delta |V_4| \end{bmatrix} \quad (3.16)$$

In short form, equation 3.26 can be written as;

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta [V] \end{bmatrix} \quad (3.17)$$

The diagonal and the off-diagonal elements of J_{11} are

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{\substack{K=1 \\ K \neq 1}}^{N} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (3.18)$$

The diagonal and the off-diagonal elements of J_{12} are

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ii}| \cos \theta_{ii} \sum_{\substack{K=1 \\ K \neq 1}}^{N} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (3.19)$$

$$\frac{\partial P_i}{\partial |V_k|} = |V_i||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (3.20)$$

$$k \neq i$$

The diagonal and the off-diagonal elements of J_{21} are

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{\substack{K=1 \\ K \neq 1}}^{N} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (3.21)$$

$$\frac{\partial Q_i}{\partial \delta_k} = -|V_i||V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (3.22)$$

$$k \neq i$$

The diagonal and the off-diagonal elements of J_{22} are

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}|\sin\theta_{ii} \sum_{\substack{K=1 \\ K\neq 1}}^{N} |V_i||V_k||Y_{ik}|\sin(\theta_{ik} + \delta_k - \delta_i) \qquad (3.23)$$

$$\frac{\partial Q_i}{\partial |V_k|} = -|V_i||Y_{ik}|\sin(\theta_{ik} + \delta_k - \delta_i) \qquad (3.24$$

$$k \neq i$$

The term $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are the difference between the scheduled and the calculated values, known as the power mismatch (residuals), given by

$$\Delta P_i^{(k)} = P_{i,sch} - P_{i,calc} \qquad (3.25)$$

$$\Delta Q_i^{(k)} = Q_{i,sch} - Q_{i,calc} \qquad (3.26)$$

Then the new estimates for the bus voltages are

$$\delta_i^{(k=1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \qquad (3.27)$$

$$\left|V_i^{(k=1)}\right| = \left|V_i^{(D)}\right| + \Delta\left|V_i^{(k)}\right| \qquad (3.28)$$

3 RESULT AND DISCUSSION

The data below are the phase readings of the transformers/substations in Opolo 33/.415kv distribution network, as retrieved from PHEDCYenagoa Business Unit. It showed the three phase readings with the neutral in each substation/bus in the network as obtained from the field under steady state condition. It was also used to calculate the average current, apparent, active, reactive and complex power and percentage loading used in the load flow analysis simulation. There were thirty-four (34) transformer substations in the community which also depicted the number of buses in the network analysis. The substations were of various capacity rating; the highest rated transformers were 500kva

Table 3.1: The Location of Transformers, rating and load reading in Opolo Distribution Network

S/N	Location of transformer	Transformer rating Kva	Reading			
			R(A)	Y(A)	B(A)	N(A)
1	Nepa road	300	108	163	072	082
2	Back of market square	300	096	065	111	053
3	Mr. Biggs	300	096	117	106	039
4	Greater evangelica	300	056	034	095	050
5	Opolo market	300	145	154	215	062
6	JTF HQ	300	047	220	073	161
7	Opala secondary school	300	013	083	125	081
8	Community Estate 4	300	154	174	177	075
9	Community Estate 3	300	182	505	189	304
10	Community Estate 2	300	332	239	365	098
11	Community Estate 1	300	171	160	065	090
12	Opuala Charles	300	192	188	116	138
13	Senator Charles	300	130	187	133	047

14	Udeme hotel	300	052	066	047	025
15	Accountant general	300	028	124	078	084
16	Gloryland hospital	300	106	094	083	022
17	Federal poly, ekwe	300	322	213	077	198
18	Almiesiegha Road 1	300	196	197	130	082
19	Opala town hall	300	300	207	144	126
20	Pepperoni	300	295	269	184	093
21	Godday	300	058	032	090	055
22	Opposite Golden Gate	300	180	500	191	309
23	Golden Gate	300	032	120	080	082
24	Mtn Mast	200	189	189	178	105
25	Market Square	200	210	200	220	198
26	Diete spiff hospital	500	89	79	85	50
27	Pole mounted 8/s	100	75	75	80	40
28	Paulca	500	400	399	390	350
29	Mtn Mast	100	190	180	188	105
30	Igali	500	425	430	415	400
31	Alameiseigha road 2	200	200	198	198	196
32	Opposite community estate	500	470	430	320	280
33	Alameseigha	500	410	420	400	375
34	Famgbe	500	390	386	400	369

Figure 3.2. Is the ETAP simulation diagram of Opolo 33kv distribution network load flow in single line diagram. From the diagram, the transformers and buses in red colour meant violations. They were experiencing overloading and undervoltage, which translated to power losses. The transformer at Opuala Charles and Udeme hotel showed the alert report being critical. They were loaded at 100.5% and 101.2% operating capacity. The implication of the critical nature of the transformer was that they were in overloaded condition and can possibly breakdown any moment. It also showed that the 34 buses were in overload condition. Hence, there were losses in the network due to the overloading and voltage drop. Total losses of 79.8kw and179.0kvar were recorded in the network at no improvement.Total losses of 79.8kw and179.0kvar were recorded in the network at no improvement.

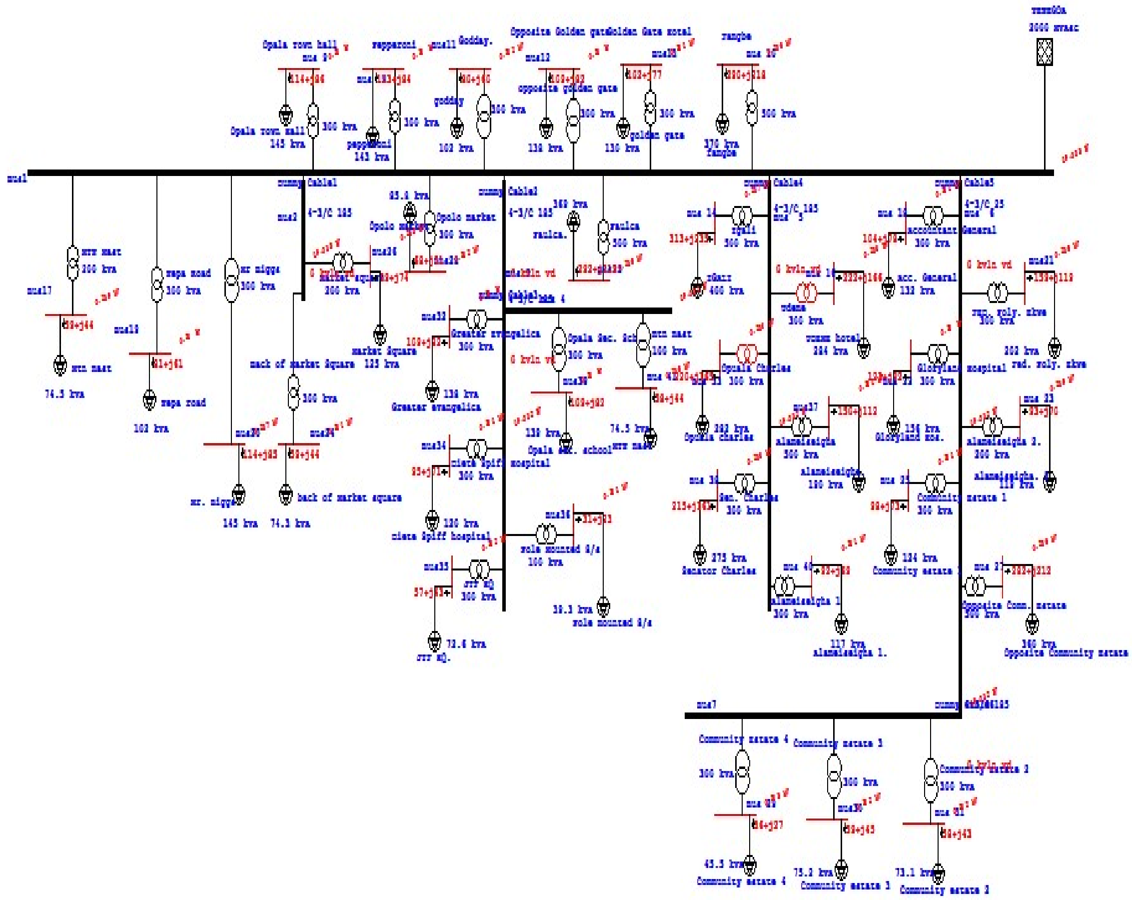

Figure 3.2: ETAP Single Line Simulation Diagram of Load Flow Analysis of Opolo 33kv Distribution Network Without Network Improvement

3.1 Improvement of Opolo 33/0.415kv Distribution Network with SCB

Fig 3.3 is the simulated single line diagram of Opolo 33kv distribution line with Shunt Capacitor Bank application for network improvement. The aim of the Shunt Capacitor Bank application was to improve the network by reducing the losses in the network and restoring the network to normalcy. The Shunt Capacitor Bank injected active and reactive power to the network where necessary and compensated for the losses in the affected buses. Hence, there were no alerts of red lines in the buses and transformers once the SCB was introduced. The two transformers that sounded the overload alert earlier, were now within normal operating capacity as can be seen from the network diagram.Total losses in the network were 79.6kw and 171.0kvar before the introduction of SCB. The losses were reduced to 65.1kw and 151.0kvar when the SCB was applied

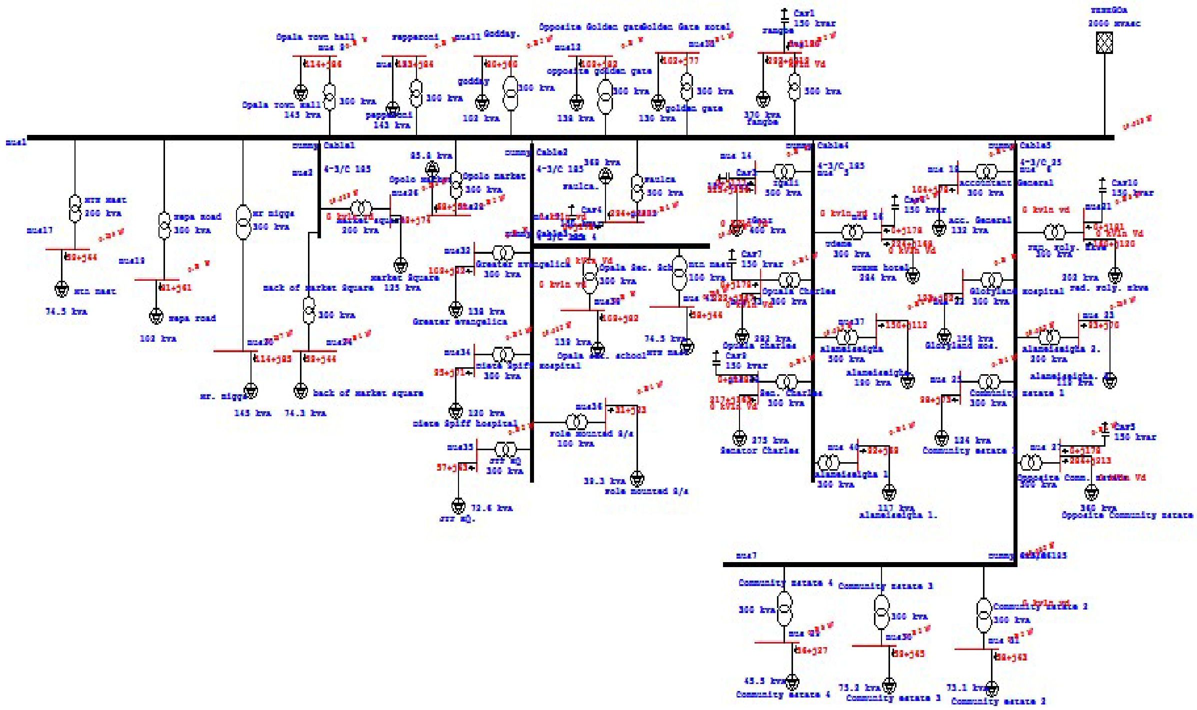

Figure 3.3: ETAP Simulation Diagram of Opolo Network Improvement with SCB**.**

3.2 Improvement of Opolo 33/0.415kv Distribution Network with SVC

Fig 3.4 is the single line diagram of Opolo 33kv distribution network in ETAP simulation when SVC was applied for improvement. Like the SCB, there was no alert of violations when the SVC was applied to the network because the active and reactive power losses at the buses/substations were duly compensated by the SVC, overloading andundervoltage were also handled. The two transformers at Opuala Charles, Udeme and the 34 buses in overloaded condition were all restored to normalcy. Total losses of 79.6kw and 171.0kvar observed in the network were reduced to 57.8kw and 144.1kvar with SVC application for improvement. SVC supplied the reactive power locally and can also consume the excess reactive power when necessary.

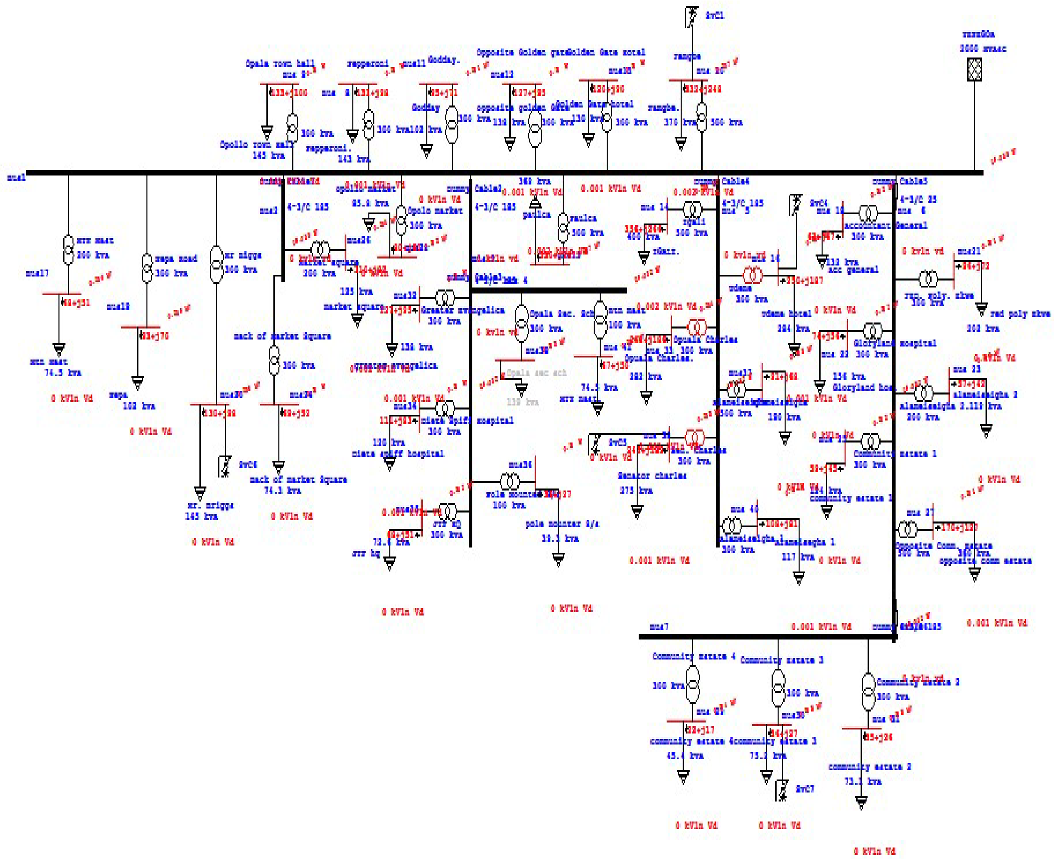

Figure 3.4: ETAP Simulation Diagram of Opolo 33/0.415kv Network improvement with SVC

3.3 Comparison of Opolo 33kv Network Improvement with Shunt Capacitor Bank (SCB) and Static Var Compensator (SVC)

Fig. 3.5 is the ETAP simulation diagram of Opolo 33kv distribution network fully compensated with either SCB or SVC and in normal working conditions. The two transformers and about 34 buses that had violations with critical alert of overloading of 101.2% at Opuala Charles and 100.5% at Udeme substations. The thirty-four (34) buses that were in over voltage condition and the two critically alerted transformers were all restored to normal after improvement with either of the compensating devices.

After compensation, the transformers and buses were operating at about 78% o. The drop in voltage magnitude (Vd%) of the network was also observed to be normal.

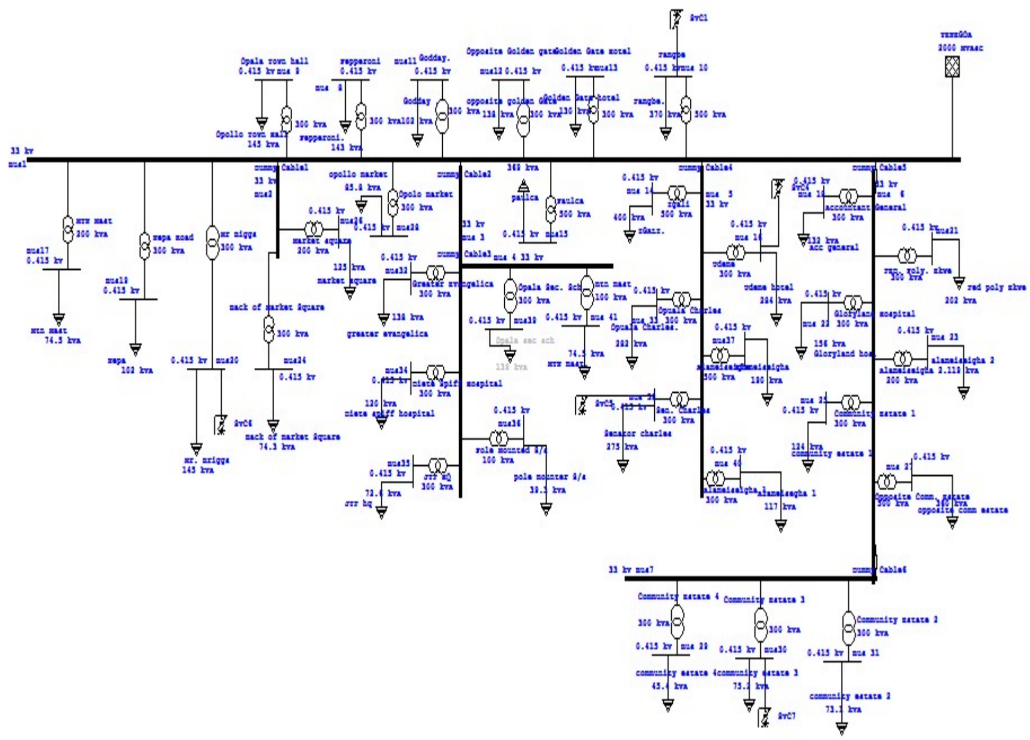

Fig. 3.5: ETAP Diagram of Opolo 33kv Network After Improvement with Either SCB or SVC

Fig. 3.6 and 3.7 are the comparisons of active and reactive power losses before improvement and after improvement with SCB and SVC at each bus in the network. The blue line graph represented network losses without improvement, the red line graphdenoted network losses improvement with SCB and the grey line graph depicted network losses improvement with SVC. Total losses in the network were observed to be 79.6kw and 171.0kvar before compensation. The losses were reduced to 65.1kw and 151.0kvar when compensated with SCB and to 57.8kw and 144.1kvar with SVC respectively. From the graphs, the highest point of losses occurred at Famgbe 1.1kw and 5.0kvar, Igali 2.4kw and 4.4kvar, Opposite Comm. Estate was 2.0kw and 3.7kvar, Opuala Charles was 2.1kw and 3.4kvar and Udeme recorded 2.1kw and 3.4kvar losses before the network was improved. With the application of SCB for improvement, the losses were reduced to 0.8kw and 3.6kvar at Famgbe, 1.6kw and 3.2kvar at Igali, 1.3kw and 2.7kvar at Opposite Comm. Estate, 1.3kw and 2.3kvar at Opuala Charles, 1.4kw and 2.4kvar at Udeme and then to 0.8kw and 3.4kvar at Famgbe, 1.1kw and 2.4kvar at Igali, 0.8kw and 1.9kvar at Opposite Comm. Estate, 1.3kw and 2.2kvar at Opuala Charles, 0.9kw and 1.9kvar at Udeme with SVC improvement

Comparing the two compensating devices performances graphically, there were significant differences, SVC had a higher losses reduction ability and sensitivity than SCB. Also, the results from the calculated values agreed with this fact. The calculated values showed that Static Var Compensator had losses reduction performance efficiency of 27.6% and 18.1% for active and reactive power while SCB has 18.4% and 14.2% for active and reactive power. Hence, it was established that SVChad a better overall performance efficiency than SCB

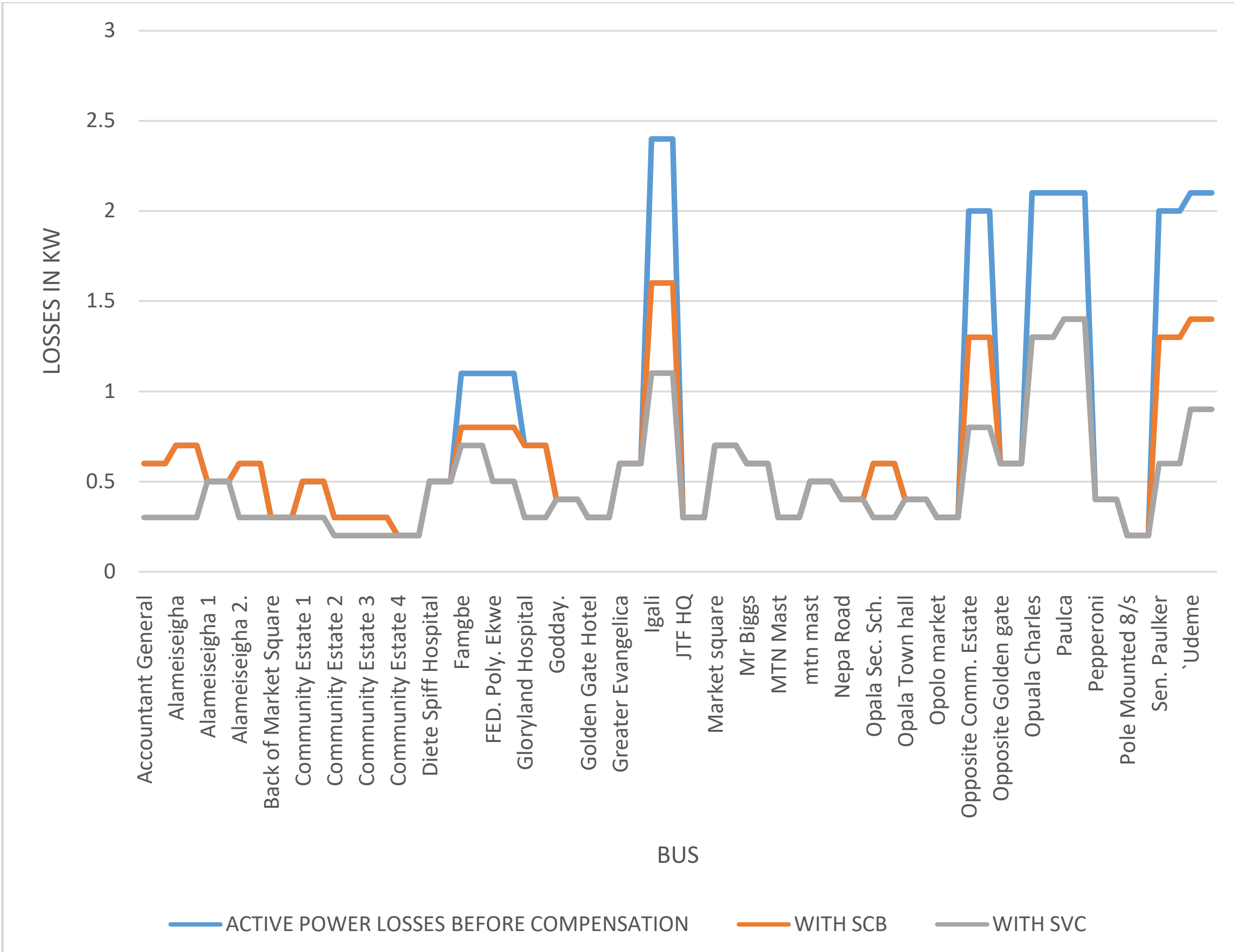

Fig. 3.6; Comparison of Active Power Losses Before and After Compensation with SCB and SVC

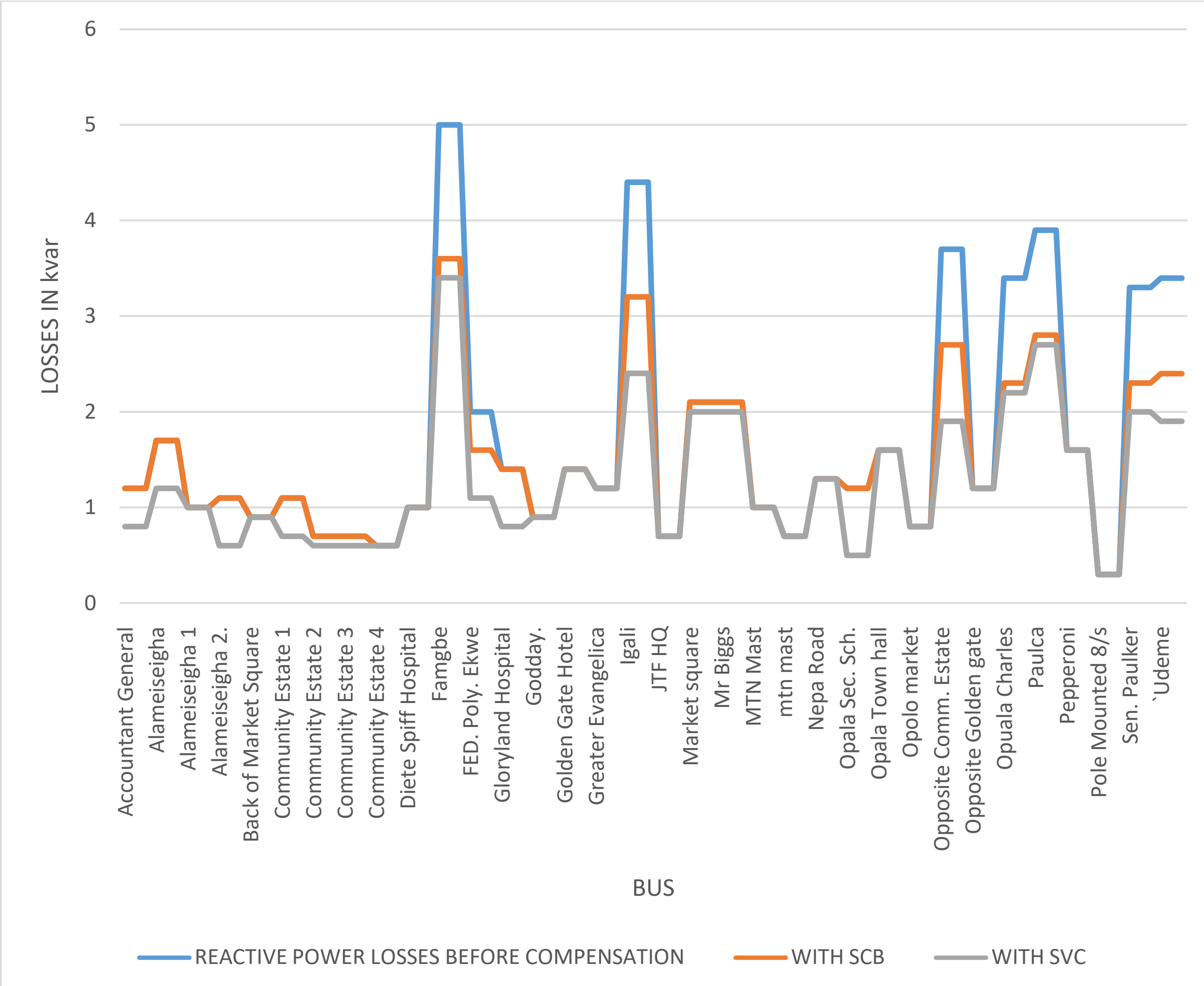

Figure 3.7: Comparison of Reactive Power Losses Before and After Compensation with SCB and SVC

4. CONCLUSION.

Load flow analysis using the Newton Ralphson method on ETAP software was used for the simulation and analysis while the network was improved with SCB and SVC comparatively. It was established that there were violations, overloading, critical challenges and losses of79.8kw and179.0kvar in the Opolo 33kv distribution network. The causes and sources of these violations were revealed by steady state investigation of the network, load flow analysis and technical observation of the network under consideration.Having established that there were losses and defects in the network, Shunt Capacitor Banks and Static Var Compensators compensated for the shortfalls and improve the magnitude of the losses to 65.1kw and 151.0kvar when compensated with SCB and to 57.8kw and 144.1kvar with SVC. The two transformers and the 34 buses that had violations of operating above 100% load input, resulting to overloading and undervoltage were restored to normal operating conditions.

Both devices adequately improved the network, SVC has a better sensitivity and overall performance efficiency than SCB. SCB responded to losses from 1.0kw and 2.0kvar above whereas SVC did respond to losses lesser than 0.5kw and 1kvar.SVC had 27.6% and 18.1% performance efficiency in losses reduction for active and reactive power, while SCB has 18.4% and 14.2% for the active and reactive power losses respectively. Thus, the Opolo Community 33kv network was adequately compensated, improved, steady and restored to normal working conditions.

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