Impact of Network Reconfiguration: A Case Study of Port-Harcourt Town 132/33kV Sub-Transmission Substation and Its 33/11kV Injection Substation Distribution Networks

Chinweike I. Amesi, Tekena K. Bala, and Anthony O. Ibe

***Abstract*— This paper examined the power flow status of the Port Harcourt Town (Zone 4) distribution networks to improve the performance. The network consists of 18 injection substations fed from 4 different sizes of transformers with a total power rating of 165 MVA, 132/33kV at the Port Harcourt Town sub-transmission substation. Gauss-Seidel power flow method was used to analyse the network in Electrical Transient Analyzer Program (ETAP 12.6) software to determine the various bus operating voltages, power flow, and over or under-loaded Transformers' units. The analysis presented both base-case and post-upgrade network state. From the base-case simulation results obtained, it shows that these injection distribution transformers at (PH Town 106.3%, RSU 90.5%, Marine Base 86.5%, UTC 87.9%, Nzimiro 89.5%, and Borokiri 88.7%) were overloaded on the network and the operating voltages observed for (PH Town 95.1%, RSU 83.0%, Marine Base 83.4%, UTC 82.8%, Nzimiro 85.2%, and Borokiri 82.1%) indicates low voltage profile. However, using network reconfiguration technique as proposed in this paper; there was reduction in the percentage loading of the said Transformers as it was upgraded to affect positively on its lifespan with (PH Town 44.1%, RSU 65.3%, Marine Base 60.7%, UTC 47.3%, Nzimiro 61.3%, and Borokiri 52.0%) loading, and the bus voltage profiles was improved for (PH Town 100%, RSU 98.4%, Marine Base 98.8%, UTC 98.2%, Nzimiro 98.6%, and Borokiri 99.1%) with additional facilities. It is recommended that the power infrastructure facilities in Port Harcourt Town distribution network be proactively upgraded to reduce losses and improve the electricity supply to consumers. Also, in regard to these analyses, the sub-transmission substation requires 240 MW of power for effective power delivery.**

***Index Terms*—Distribution Networks; ETAP Software; Gauss-Seidel Power Flow Method; Network Reconfiguration.**

I. INTRODUCTION

The primary function of an electric power system is to deliver energy with acceptable voltage and frequency, be clean, reliable and safe to consumers at a minimum cost [1]. Due to load growth and /or inappropriate size of distribution transformers, inadequate power injection, and frequent network expansion without corresponding increase in power supply; most injection substations transformers and feeders are overloaded and cannot effectively dispatch energy to meet the increasing load demand of the consumers. Consequently, consumers linked to the affected substations often time experiences under-voltage and epileptic power supply. Most feeders (distribution lines) are too lengthy in size especially the secondary distribution networks. In an attempt to meet the daily electricity demand, many households and commercial organizations now run their own independent power generator to complement their power needs [2]. The electricity distribution company in an attempt to mitigate these challenges resulted to an unplanned load-shedding, rationing the power supply as an alternative. However, to meet the ever-growing load demand of the distribution system; distribution system upgrade is required and this can be achieved by conducting a power flow study on the existing network to ascertain the various levels of the inadequacy of the power system networks [3].

The objectives of this research work are based on the setback suffered by distribution networks such as inadequate power injection into substations as compare with the net power delivered to load. We shall apply network reconfiguration techniques to upgrade the network under consideration for better performance as in improving the voltage profile of the distribution network within the acceptable limit; reduce network losses; reduces transformers working stress, and proffer proper accessibility of the power network as our main objectives.

However, it is imperative to apply necessary techniques to achieve the objective for a good power system network in order to reduce losses, improve voltage profile and reliability. A good and reliable distribution system is characterized by the followings attributes: has the maximum reliability of the power supply; minimum operation and maintenance cost; minimum duration of interruption; voltage drop at consumers end is within 5% of nominal magnitude; efficiency is not less than 90%.

II. PREVIOUS RELATED WORKS

In literature, voltage instability in distribution system was mentioned in [4] as an abnormal state in power system due to disturbance, increase in load demand, or change in system condition which causes a progressive decrease in voltage. According to [5] in their publication highlighted that the main cause of voltage instability in a typical distribution system may also be due to the failure of the system to adequately satisfy the demand for reactive power component occasioned by the limitation of generating power, transmission line, Transformers and increase in load demand. The effect of reactive power in distribution system

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was examined in [6] stating that the major cause of under voltage in the distribution system is the shortage of reactive power. It was added that reactive power cannot be transmitted very far especially under heavy loading conditions and so must be generated close to the point of consumption. According to [7] the performance of a power distribution system in terms of voltage and power at the load end can be improved by the addition of compensating devices such as static VAR and static synchronous compensator; and that, the compensating devices are more economical and convenient.

Again, according to [8] in their paper highlighted that improvement of voltage profile in the distribution system is more effective with the use of compensating devices such as capacitor bank and transformer load tap changer. In [9] a new and efficient way to derive the optimal position and size of capacitor banks so as to enhance the ultimate improvement of the voltage profile and reduction of line losses was presented. In [10] it was pointed out that the power loss in a distribution system is significantly high up to 13%. However, to improve line power transmission, we reduce losses and improve voltage margin; usually, shunt capacitor banks are widely used.

Network reconfiguration according to [11] is one of the methods for loss minimization in distribution systems. The techniques are employed by specifically opening or closing tie switches that are in normally-open conditions. It also involves sectionalizing of normally-closed switches, when this is done, power flow will be redirected.

According to [12] network reconfiguration in distribution systems is one of the effective techniques to achieve loss reduction and improve distribution system automation. The network can be reconfigured for two reasons: load balancing and power loss reduction in the distribution system. In view of [13], feeder reconfiguration is the process of closing and opening operation of switches in power distribution system in order to change network topology. Emphasizes were made on the importance and usefulness of feeder reconfiguration technique in reducing feeder loss, improve system security and reliability.

According to [14] optimal planning of distribution systems involves network reconfiguration for loss minimization, load balancing under normal operating conditions and fast service restoration. In spite of the various methods commonly practice in improving power distribution networks, the procedural steps of analysis must utilize power flow analysis to estimate the status of power penetration to various branch and loads. In literature, different methods of power or load flow study are mentioned.

According to [15] the Gauss-Seidel iterative method of carrying out load flow study is synonymous with doing a repeated simplification or solving equations with nonlinear characteristics. It is one of the most popularly used methods for solving power flow problems. The Gauss-Seidel method assumes an initial variable, and a set of new variables are then calculated from one of the equations. The solution is immediately updated with respect to the calculated variable. The process continues until the solution converges to a specified value.

In [16] highlighted the advantages of the Gauss-Seidel method as in terms of its simplicity. He further reiterated its merits such as its capacity to reduce the time – constraint associated with computations of this nature. On the hand, it also exhibits a fundamental demerit associated with its slow pace in achieving convergence and increased number of iterations due to the increased number of buses in a situation where there are several buses in the network considered.

III. Description of Existing Network

A. *Description of Port Harcourt Network*

As Port Harcourt is the capital city of Rivers State located in the south-south geopolitical zone of Nigeria. The city plays host to so many public and private organizations, including multinational oil companies, and is the sixth-most populous state in Nigeria with a growing population of 5.2 million people [17]. Port Harcourt receives power supply from Afam transmission station via a 132kV double circuit transmission line duly linked to the national grid at Alaoji-Afam transmission station.

Port Harcourt consists of two main transmission stations namely; Port Harcourt Mains (Zone 2) - having total installed transformers capacity of 180MVA, 132/33kV; and Port Harcourt Town (Zone 4) constitutes total transformers installed capacity of 165MVA, 132/33kV. Our focus here is the Port-Harcourt Town (Zone 4). Table I shows a detailed description of Port Harcourt 132/33kV substations and their installed capacities.

B. *Description of Port Harcourt Town (Zone 4) Distribution Network and transformers installed Capacity*

The Port Harcourt town (zone 4) distribution network consists of twelve 33/11kV and six 33/0.415kV injection substations duly linked to Port Harcourt Town (Zone 4) 132/33kV substation. Table II shows numbers of 33kV ‘feeders’ lines and their injection substations. Table III shows the recorded peak load data at the injection substation distribution network.

IV. Methodology

The test networks under analysis will require step by step approach of network reconfiguration. The network base-case data collected will be used to model the system using *Electrical Transient Analyzer Program (ETAP 12.6)* software to carry out the simulation using Gauss-Seidel (G-S) load flow algorithm to compute the unknown parameters of the network; thereafter, we shall examine and evaluate the various loading conditions using transformer load tap changer (LTC) technique, peak loading evaluation to check for overloaded transformer, determination of bus operating voltages, etc., to the base-case network under consideration.

The test networks, in reality, are exclusively depending on the available power from the grid supply. The application of these techniques for “network reconfiguration” is one of the techniques utilized to improve electric power system network to reduce the power losses , increase network performance with adequate power distribution, increase device lifespan, and increases the efficiency. However, the techniques in improving a power system network are not limited; power system networks require periodical assessment of its performance, therefore, the computational

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approach giving below proffer solution for network reconfiguration.

A. Data Collection and Analysis

The data used in this analysis were collected from the Public Utility Service Provider known as Port-Harcourt Electricity Distribution Company of Nigeria (PHEDC) during visitations to the injection substations. The Company provides power to some states in the country, Nigeria.

B. Mathematical Presentation of Gauss-Seidel Load Flow Analysis for Power System Network

The Gauss-Seidel method for power flow solution solves iteratively using the load flow equations. From Kirchhoff current law, the current entering the *ith* bus of an n bus system is given by

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + Y_{i3}V_3 + \dots + Y_{in}V_n \tag{1}$$

Also,

$$I_i = \sum_{k=1}^{n} Y_{ik}V_k \tag{2}$$

Complex power injected into the *ith* bus is given by

$$S_i = P_i + jQ_i = V_i I_i^* \tag{3}$$

or,

$$S_i^* = P_i - jQ_i = V_i^* I_i \tag{4}$$

Substituting I_i from (2) into (4), we have:

$$P_i - jQ_i = V_i^*\left(\sum_{k=1}^{n} Y_{ik}V_k\right) \tag{5}$$

Let $V_i^* = |V_i| \angle -\delta_i$, $V_k = |V_k| \angle \delta_k$ and $Y_{ik} = |Y_{ik}| \angle \theta_{ik}$ into (5), we have:

$$P_i - jQ_i = V_i^* \sum_{k=1}^{n} Y_{ik}V_k \angle(\delta_k + \theta_{ik} - \delta_i) \tag{6}$$

$$P_i - jQ_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k| \begin{bmatrix} \cos(\theta_{ik} + \delta_k - \delta_i) \\ + j\sin(\theta_{ik} + \delta_k - \delta_i) \end{bmatrix} \tag{7}$$

Separating the real and imaginary part, we get

Real power,

$$P_i = \sum_{k=1}^{n} |Y_{ik}V_iV_k| \cos(\theta_{ik} + \delta_k - \delta_i) \tag{8}$$

Reactive power,

$$Q_i = -\sum_{k=1}^{n} |Y_{ik}V_iV_k| \sin(\theta_{ik} + \delta_k - \delta_i) \tag{9}$$

For load buses,

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik}V_k\right] \tag{10}$$

For voltage control bus,

$$Q_i^{(k+1)} = -\operatorname{Im}\left[V_i^{*(k)}\left(V_i^{(k)}Y_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik}V_k^{(k)}\right)\right] \tag{11}$$

Where: V_i is the bus voltage at bus i; P_i is the real power injected into the *i*th bus; Q_i is the reactive power injected into the *i*th bus; Y_{ii} is the diagonal element (admittance) of the Y-bus matrix; Y_{ik} is the off-diagonal elements of the Y-bus matrix and V_k is the voltage at bus n. The solution computation is iterative, therefore, the number of iterations can be considerably reduced by using acceleration factor refer (12).

$$V_{iacc}^{(k+1)} = V_{iacc}^{(k)} + \alpha(V_i^{(k)} - V_{iacc}^{(k)}) \tag{12}$$

Where: V_{iacc} is the accelerate voltage; α is the acceleration factor. An acceleration factor of 1.6 is considered to be a good value for power flow studies. The choosing method of load analysis (G-S) is embedded in the ETAP software used for simulation.

C. Evaluation of Peak Loads for the Injection Substations

Using the Rivers State University (RSU) injection substation as an example; it is a substation under the Port-Harcourt Town (Zone 4). Thus, we shall compute the various distribution substations peak loads of the networks using (13)-(15). For RSU injection substation with four outgoing feeders, we have

$$Peak\ load\ (A)\ I_L = I_1 + I_2 + I_3 + \dots I_n \tag{13}$$

$$Peak\ load\ (A)\ I_L = 445 + 397 + 608 + 544 = 1994\ A$$

$$Peak\ load\ (MVA) = \sqrt{3} I_L V_L x\, 10^{-6} \tag{14}$$

$$Peak\ \ load\ (MW) = MVA \cos\theta \tag{15}$$

$$Peak\ \ load\ (MW) = 38 \times 0.8 = 30.4\ MW$$

Where: I_L is the total peak loads of respective outgoing feeders at the injection substation in (A); V_L is the line voltage of the feeder in (kV); cosθ is the power factor so that the peak load is in *MW*.

Refer (13), (14), (15), and the table of values of Table II (using the secondary voltage rating of the transformers) the

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various daily peak loads for all the injection substations are evaluated respectively as shown in Table III below.

D. Determination of Overloaded Transformer

The apparent power performance index is used to determine the percentage loading of the transformers in the network. Based on the principle of loading of distribution transformers, 70% of the design rating is considered. A transformer with loadings in excess of 70% is considered as overloaded; therefore, precautions should be taken to avoid overloading of a transformer on continuous operation. Refer (16), the percentage loading of each distribution transformers were calculated.

$$\%loading = \sum_{i=1}^{N_T}\left(\frac{S_{MVA}}{S_{MAX}}\right)x100 \qquad (16)$$

Where: S_{MAX} is the MVA rating of the transformer; S_{MVA} is the operating MVA from power flow calculation, and N_T is the number of transformers. For Example, T1A rated 30MVA, now operates at 35MVA. (See Table IV)

$$\%\ loading\ of\ T1A = \frac{35\ MVA}{30MVA}\ x100 = 116.7\%$$

E. Determination of Bus Operating Voltage

The bus voltage performance index is used to determine the percentage bus operating voltage. To be within limit bus voltages less than 95% are considered under voltage, whereas those above 105% are considered over voltage [18].

$$\%\ Operating\ Voltage = \sum_{i=1}^{N_B}\left(\frac{V_i}{V_i^{sp}}\right)\times 100 \qquad (17)$$

Where: V_i is the bus voltage magnitude at i^{th} bus; V_i^{sp} is the specified (rated) voltage magnitude at i^{th} bus; N_B is the number bus in the system. (See Table V, pre-upgrade voltage divided by base kV multiply by 100 is equal to the pre-upgrade % operating voltage)

F. Applying Transformers Load Tap Changer

i. For Example UST Feeder (line) at Port-Harcourt Town (Amadi Junction)

$$\frac{N_2}{N_1} = \frac{V_2}{V_1} = K \text{ (Turn ratio)} \qquad (18)$$

$$\%\ Tap\ setting = (K-1)\times 100 \qquad (19)$$

where: K= per unit turn ratio

The *sending end* and the *receiving end* operating voltage for UST feeder are 29.25kV and 27.39kV. The % tap setting of the transformer located at UST feeder is calculated using (18) and (19), thus:

$$K = \frac{27.39}{29.25} = 0.94$$

$$\%\ Tap\ setting = (0.94-1)\times 100 = -6.35\%$$

Selecting -6% tap setting on the primary winding, will reduce the primary turn N_1, by 6%, thereby increasing the secondary voltage output.

G. Upgrading of Existing Substation

$$New\ \%\ loading = \frac{\sum New\ Operating\ MVA}{\sum Transformer\ Capacity}\ x\ 100 \qquad (20)$$

Apply the new % loading (20) to evaluate the status of the loaded transformer after network reconfiguration and re-simulation of the network. Section D, E, and F must be applied first before section G, as a check. (See Table VI).

H. The Simulation of the Port Harcourt Town Distribution Network using ETAP 12.6

ETAP 12.6 is a fully graphical Electrical Transient Analyser Program that provides a very high level of reliability, protection and security of critical applications. ETAP 12.6 can be used to run analysis such as short circuit analysis, load flow analysis, motor starting, harmonic transient stability, generator start-up, etc., [18]. The input data for the power flow analysis includes Grid MVAsc, line parameters, bus parameters, transformer ratings and feeder loading, etc. Section V is the results obtained from the simulation analysis for both pre and post upgrade (with network reconfiguration).

V. Results

A. Data Collected

Tables I, II and III are data collected during the investigation at the injection substations. The data are factual from [19].

TABLE I: PORT HARCOURT 132/33KV SUBSTATION

Substations	*Rating*	*Total Capacity*	*Voltage*	*No of Feeder (Outgoing)*
Port Harcourt Mains (Zone 2)	3x60MVA	180 MVA	132/33kV	10
Port Harcourt Town (Zone 4)	2x30MVA 1x45MVA 1x60MVA	165 MVA	132/33kV	7

Source: *Port Harcourt Electricity Distribution Company, 2014*

TABLE II: THE 33KV FEEDERS LINES AND THEIR INJECTION SUBSTATIONS

From Port-Harcourt Town (Zone 4)			*To Injection Substations*	
Fdr ID	***Transformer Capacity***	***Feeder Line Name***	***Injection Substation Name***	***Capacity***
1	30 MVA	UST	RSU Agip NAOC	2x15 MVA,(33/11kV) 1x7.5 MVA,(33/11kV) 2x3 MVA,(33/0.415kV)
2	45 MVA	Secretariat	Secretariat Marine Base Juanuta	2x7.5 MVA,(33/11kV) 2x15 MVA,(33/11kV) 1x2.5 MVA,(33/0.415kV)
3		Borokiri	Borokiri Eastern Bypass	1x15 MVA,(33/11kV) 1x15 MVA,(33/11kV)
4	60 MVA	Silverbird	Silverbird Kidney Island	1x15 MVA,(33/11kV) 1x1.5 MVA,(33/0.415kV)
5		UTC	UTC Water Works	1x15 MVA,(33/11kV) 1x15 MVA,(33/11kV)

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6		Rumuolumeni	IA UOE RSS Nursing Akar base Naval Base Master Energy	1x7.5 MVA,(33/0.415kV) 1x15 MVA,(33/11kV) 1x7.5 MVA,(33/11kV) 2x2.5 MVA,(33/0.415kV) 1x1.5 MVA,(33/0.415kV)
7	30 MVA	Nzimiro	Nzimiro	2x15 MVA,(33/11kV)

Source: *Port Harcourt Electricity Distribution Company, 2014*

TABLE III: RECORDED PEAK LOAD DATA AT THE INJECTION SUBSTATIONS

Injection Substations			***Feeder load Current***					***Peak Load***	
S/No	***Name***	***Rating MVA***	***FDR 1 (A)***	***FDR 2 (A)***	***FDR 3 (A)***	***FDR 4 (A)***	***Total (A)***	***MVA***	***MW***
1	RSU	30	445	397	608	544	1994	**38.0**	**30.4**
2	Agip	7.5	171	171	-	-	342	**6.5**	**5.2**
3	NAOC	6	1252	1252	1252	1252	5008	**3.6**	**2.9**
4	Secretariat	15	157	157	157	157	628	**12.0**	**9.6**
5	Marine Base	30	424	385	403	483	1695	**32.3**	**25.8**
6	Juanuta	2.5	1391	1391	-	-	2782	**2.0**	**1.6**
7	Borokiri	15	493	462	-	-	955	**18.2**	**14.6**
8	Eastern Bypass	15	252	252	-	-	504	**9.6**	**7.7**
9	Silverbird	15	273	273	-	-	546	**10.4**	**8.3**
10	Kidney Island	1.5	765	765	-	-	1530	**1.1**	**0.9**
11	UTC	15	441	441	-	-	882	**16.8**	**13.4**
12	Water Works	15	278	278	-	-	556	**10.6**	**8.5**
13	IA UOE	7.5	1043	1043	-	-	2087	**1.5**	**1.2**
14	RSS Nursing	15	172	171	171	-	514	**9.8**	**7.8**
15	Akar Base	7.5	118	118	-	-	236	**4.5**	**3.6**
16	Naval Base	2.5	2087	2087	-	-	4174	**3.0**	**2.4**
17	Master Energy	1.5	696	696	-	-	1391	**1.0**	**0.8**
18	Nzimiro	30	483	420	488	540	1931	**36.8**	**29.4**
								217.7	**174.1**

Source: *Port-Harcourt Electricity Distribution Company, May 2015*

B. Results for Pre and Post Network Upgrade

The pre and post-upgrade results are presented below. Table IV is the pre-upgrade simulation results for substations with overloaded transformers including the primary distribution substation known as the Port-Harcourt Town (Zone 4) located at Amadi Junction, Old G RA, Port-Harcourt. Table V shows the results of the percentage bus voltage profile for pre and post-upgrade simulation (i.e. without and with network reconfiguration). Table VI presents the results of the present loading status of the post-upgrade Transformers after simulation for previously overloaded transformers in their various substations.

Fig. 1 shows the improved percentage voltage profile for both pre and post-upgrade states whereas Fig. 2 presents the substations loading (in operating MVA) for both pre and post-upgraded state of the affected substations. Fig. 3 presents the pre-upgrade simulation of the distribution network under consideration (base-case) whereas Fig. 4 presents the post-upgraded simulation of the distribution network reconfiguration state, with the addition of new 132/33kV Transformers at Port-Harcourt Town (Amadi Junction). The network reconfiguration for the 33/11 kV injection substations are presented below (See Fig. 3 and 4).

TABLE IV: PRE-UPGRADE SIMULATION RESULTS FOR THE AFFECTED OVERLOADED TRANSFORMERS IN THE SUBSTATIONS

Substation		***Device Id***	***Device Capacity***		***Operating Capacity***		***Loading***
S/N	***Name***	***Device Id***	***MVA***	***Total***	***MVA***	***% Substation Loading***	***Average % Substation Loading***
1	Port Harcourt Town (Amadi Junction)	T1A T1B TIC T1D	30 45 60 30	165	35.00 40.81 69.64 29.98	116.7 90.7 116.1 99.9	**106.3**
2	RSU	T2A T2B	15 15	30	13.58 13.58	90.5 90.5	**90.5**
3	Marine Base	T7A T7B	15 15	30	12.97 12.97	86.5 86.5	**86.5**
4	UTC	T14A	15	15	13.18	95.1	**87.9**
5	Nzimiro	T15A T15B	15 15	30	13.42 13.42	89.5 89.5	**89.5**
6	Borokiri	T16A	15	15	13.30	88.7	**88.7**

TABLE V: RESULTS OF % BUS VOLTAGE PROFILE FOR PRE AND POST-UPGRADE SIMULATION FOR SUBSTATIONS

Bus No	***Substation Name***	***Base (kV)***	***Operating Voltage in Magnitude (kV)***		***% Operating Voltage***	
			Pre-Upgrade	***Post-Upgrade***	***Pre-Upgrade***	***Post-Upgrade***
1	PHC Town	132	125.59	**132.0**	95.1	**100.0**
2	RSU	33	27.39	**32.48**	83.0	**98.4**
3	Agip	33	27.38	**32.47**	83.0	**98.4**
4	NAOC	33	27.38	**32.46**	83.0	**98.4**
5	Juanuta	33	28.15	**32.70**	85.3	**99.1**
6	Secretariat	33	27.83	**32.63**	84.3	**98.9**
7	Marine Base	33	27.58	**32.61**	83.4	**98.8**
8	RSS Nursing	33	27.19	**32.62**	82.4	**98.8**
9	Naval Base	33	27.30	**32.52**	82.7	**98.6**
10	Master Energy	33	27.33	**32.54**	82.8	**98.6**
11	Akar Road	33	27.31	**32.54**	82.7	**98.6**
12	IA UOE	33	27.33	**32.55**	82.8	**98.6**
13	Water Works	33	27.46	**32.54**	83.2	**98.3**
14	UTC	33	27.34	**32.42**	82.8	**98.2**
15	Nzimiro	33	28.11	**32.55**	85.2	**98.6**
16	Borokiri	33	27.09	**32.71**	82.1	**99.1**
17	Eastern Bypass	33	26.97	**32.56**	81.7	**98.7**
18	Silverbird	33	27.42	**32.76**	83.1	**99.3**
19	Kidney Island	33	27.41	**32.75**	83.1	**99.2**

TABLE VI: IMPROVED POST-UPGRADE SIMULATION RESULT FOR TRANSFORMERS LOADING IN SUBSTATIONS

Substation		***Device Capacity***			***Operating Capacity***		***% Substation Loading***
S/N	***Name***	***Device Id***	***MVA***	***Total***	***MVA***	***%***	
1	Port-Harcourt Town (Amadi junction)	T1A T1B TIC T1D T1E	60(New) 60(New) 60(Old) 60(New) 60(New)	300	31.2 34.7 37.5 28.8 37.3	**52.0** **57.8** **62.5** **48.0** **62.2**	**44.1**
2	RSU	T2A T2B T2C	15 15 15(New)	45	9.8 9.8 9.8	**65.3** **65.3** **65.3**	**65.3**
3	Marine Base	T7A T7B T7C	15 15 15(New)	45	9.1 9.1 9.1	**60.7** **60.7** **60.7**	**60.7**
4	UTC	T14A T14B	15 15(New)	30	7.1 7.1	**47.3** **47.3**	**47.3**

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5	Nzimiro	T15A T15B T15C	15 15 15(New)	45	9.2 9.2 9.2	**61.3** **61.3** **61.3**	**61.3**
6	Borokiri	T16A T16B	15 15(New)	30	7.8 7.8	**52.0** **52.0**	**52.0**

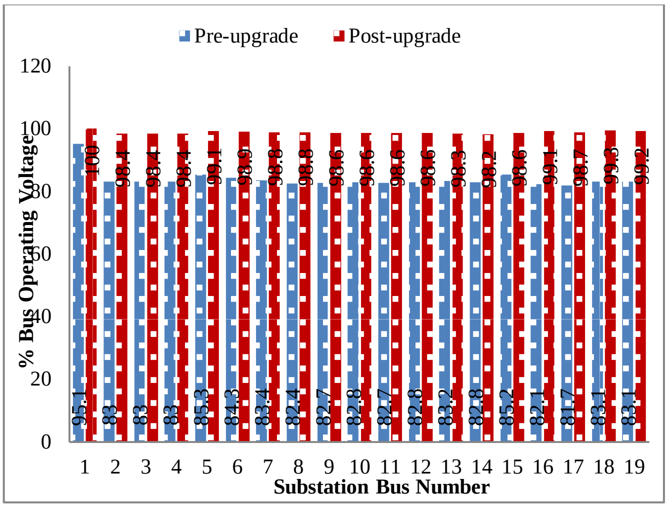

Fig. 1. Improved Percentage Voltage Profile for both Pre and Post-Upgrade State

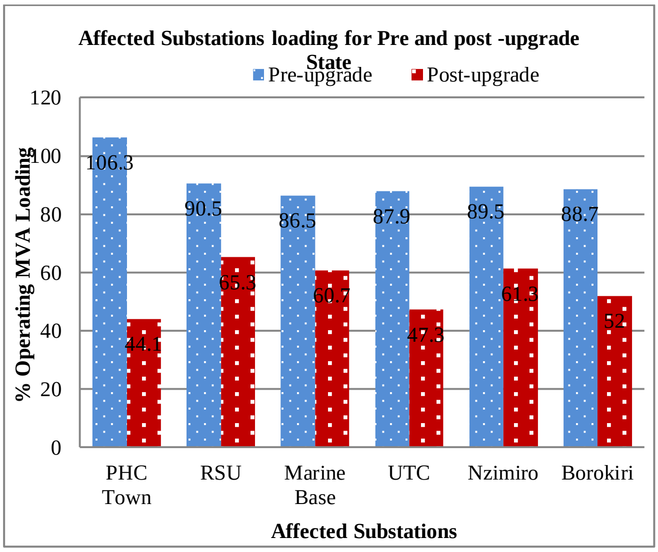

Fig. 2 Substations Loading (% Operating MVA) for both Pre and Post-Upgrade State

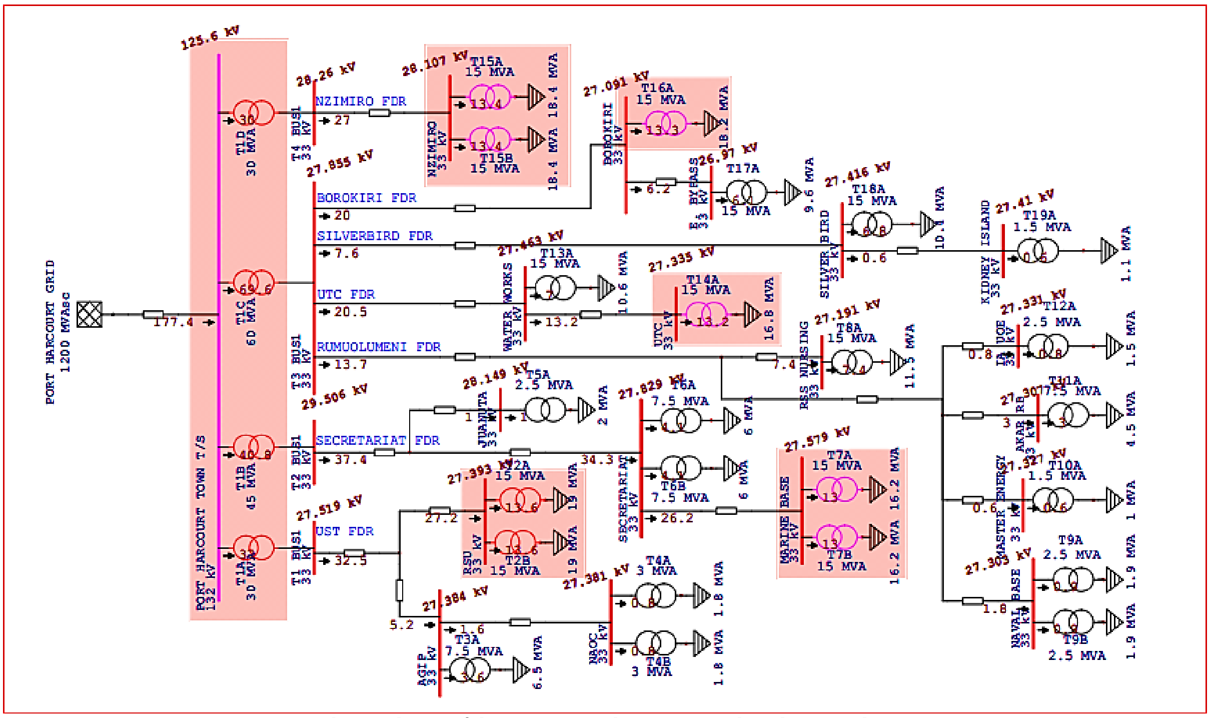

Fig. 3. Pre-Upgrade Simulation of the Power Distribution Network under Consideration (Base-case)

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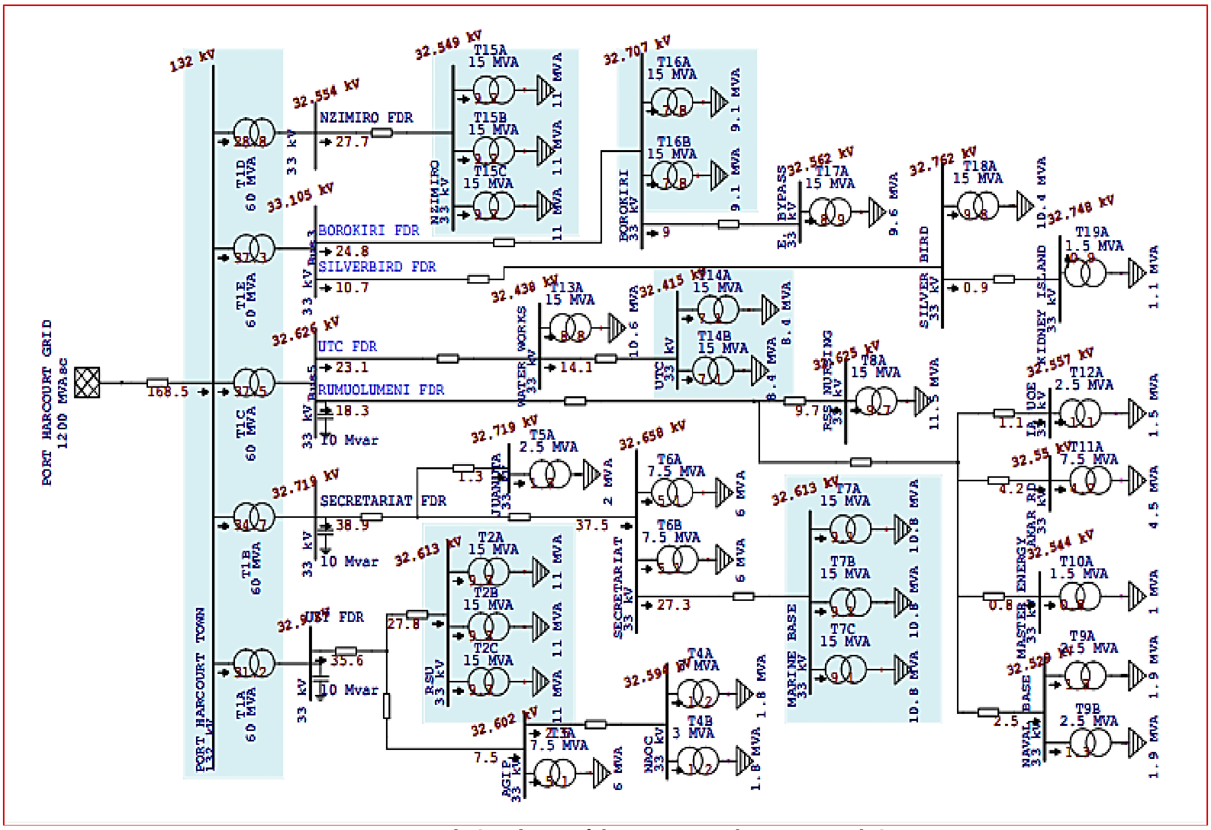

Fig. 4. Post-Upgrade Simulation of the Power Distribution Network State

VI. DISCUSSIONS

The Port-Harcourt Town (Zone4) operating at 132/33kV sub-transmission/primary distribution network with seven (7) 33kV feeders feeding eighteen (18) injection substations was taken as the reference bus. Fig. 3 shows the simulated base-case power system network of Port-Harcourt Town (Zone 4) region in Electrical Transient Analyzer Program (ETAP) for the pre-upgrade state; virtually all the buses are indicating critical state except the reference bus on the marginal state. The four (4) transformers at the reference bus were overloaded; RSU injection substation's transformer was also overloaded indicating critical alert (red colour) whereas Nzimiro, Borokiri, UTC and Marine-base indicates marginal alert (purple colour).

Fig.4 shows the post-upgraded simulation of the distribution networks with no critical or marginal alert on the loading state after network reconfiguration. The reference bus substation which is located at Amadi Junction is now incorporated with 5x 60MVA transformers; four (4) are new proposed upgraded transformers. The old 30, 30,45MVAs were upgraded to 60MVAs. Also, the proposed, reconfigured feeders are supported with five (5) additional numbers of 15MVA transformers to enhance the power delivery as indicated in Table VI. Note that, on Fig.4 the blue colour indicator shows the proposed injection substations with additional transformers to the existing network.

Table V shows the improved percentage bus operating voltage profile for both pre and post-upgrade network state with the least bus voltage magnitude of 32.42kV and a voltage drop of 0.58kV whereas Table IV and VI shows the percentage loading of the affected substations for both pre and post-upgrade network state. From the pre-upgrade network results, we have seen why consumers connected to these injection substations experiences under voltage, incessant load shedding and rationing syndrome. The results of the post-upgrade network show an improvement in the percentage bus voltage profile and the capacity of the substation margin respectively. We also noted that, in Fig.1, the bus operating voltages is within limit having a minimum value of 98.2% (in magnitude equals to 32.416 kV) and a maximum value of 99.3% (in magnitude 32.76kV).

The maximum allowable percentage voltage drop at a receiving-end shall not be more than 5% of the nominal terminal voltage (IEE Regulation). Hence, the minimum value, we recorded 0.7% drop while the maximum is 1.8% drop. Again, examining Fig. 2 we observed that, the initially overloaded substations MVA loading has also reduced meaning transformer losses due to over loading had also reduced thereby increasing the lifespan, efficiency and output of the substation transformers. These transformers are now saved.

VII. CONCLUSION

Power flow analysis is an important aspect of power system planning and operation. It is used for operational purposes to evaluate various operating conditions for both proposed power system network and an existing system as well as in planning stages to evaluate possible future expansion of the power system. Based on the results obtained, it is obvious that network reconfiguration pave way for network improvement by adding, and upgrading of

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the injection substation transformers, proper setting of the transformer load tap changer; carry out feeder bifurcation for cost-effective optimization to improve also, the bus voltage profile, adequate power delivery and eliminate overloading from the system.

We recommend that at the reference bus substation (*Port-Harcourt Town, zone 4)* located at Amadi Junction be restructured with 5x 60MVA transformers to replace the old 30, 30, and 45MVAs transformer on the ground. Also, reconfigured feeders and five (5) additional numbers of 15MVA transformers should be put in place to enhance the power delivery.

There is the likelihood of adding capacitor banks to some networks to further enhance the networks. The connected loads to Port-Harcourt Town (Zone 4) primary distribution substation have increased tremendously over the years, therefore, it required at least 240MW of power to effectively serve the connected load demand.

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REFERENCES

[1] R. Uhunmwangho, and E. K. Okedu, "Electrical power distribution upgrades: Case of towns in Akwa-Ibom State, Nigeria," International Journal of Applied Engineering Research, no. 3, pp. 1833- 1840, 2008.
[2] N.A. Hachimenum, "Power outages in Port Harcourt city: Problems and solutions," Journal of Electrical and Electronic Engineering, Vol. 10, no.2, pp.59-66, 2015.
[3] S. Apoorva, "Load-flow analysis of radial distribution network with reduced data preparation," Master Thesis, Thapar University, Patiala, 2008.
[4] M. Begovic, B. Milosevic, and D. Novosel, "A novel method for voltage instability protection," A paper presented at the 35th IEEE Annual International Conference on System Science, pp.802-811, Hawaii, 2002.
[5] R. S, Reddy and T. G. Manohar, "Review on voltage stability phenomenon and importance of FACT control in power system environment," Global Journal Researches in Engineering Electrical Electronics, Vol.12, 2012.
[6] R. Kapahi, "Load flow analysis of 132kV substation using etap software," International Journal of Scientific & Engineering Research, vol. 4, pp. 25-30, 2013.
[7] K, Porate, K. L. Thakre, and G.L. Bothe, "Voltage stability enhancement of low voltage radial distribution network using static VAR compensator," WSEAS Transaction on Power Systems, vol.4, pp.32-40, 2009.
[8] R. Vivek, and T. Sumit. (June 2012). "Modelling, simulation, analysis and optimization of a power system network: Case study," International Journal of Scientific & Engineering Research, [Online] 3(6), pp.1-9. Available: https://www.ijser.org/researchpaper/Modeling-Simulation-Analysis-and-Optimisation-of-a-Power-System-Network-Case-Study.pdf
[9] V. Srividya, "Optimum capacitor placement in radial distribution system using dijkstra algorithm methods," Enriching Power and Energy Development, pp.1-9, 2013.
[10] A. Hamouda, and K. Zehar, "Improvement of the power transmission of distribution feeders by fixed capacitor ban," Acta Polytechnica Hungarica, Vol. 4, pp.47-62, 2007.
[11] A. Metia and S. Ghosh, "A literature survey on different loss minimization techniques used in distribution network," International Journal of Scientific Research and Education, Vol.3, pp. 3861-3877, 2015.
[12] Z. Li, C. Wu, J. Chen, Y. Shi, J. Xwng and A.Y. Wang, "Power distribution network reconfiguration for bounded transient power loss," IEEE PES ISGT, Asia, 2012.
[13] N. Rugthaicharoencheep and S. Sirisumrannukul, "Feeder reconfigurations for loss reduction in three phase distribution system under unbalance loading condition," 2010.
[14] P.V. Rao and S. Sivangaraju, "Radial distribution network reconfiguration for loss reduction and load balancing using plant growth simulation algorithm," International Journal on Electrical Engineering and Informatics, Vol. 2, 2010.
[15] H. Saadat, Power system analysis, New York: Tata McGraw-Hill, 2006.
[16] B. R. Gupta, Power system analysis and design, Allahabard: Wheeler publishing, 2006.
[17] P. N. Ede, O.B. Owei, and C.I. Akarolo, "Does the greater Port Harcourt master plan meet aspirations for livable city? Greater Port Harcourt Master Plan," 47th ISOCARP Congress, 2008.
[18] ETAP 12.6, Electrical Transient Analyzer Program.
[19] PHEDC, "Daily substations report", Port-Harcourt Electricity Distribution Company Limited, unpublished, 2015.

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