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Performance Evaluation of the 132KV Sub-Transmission Lines in the Nigeria Power Network: A Case Study of Port Harcourt Sub-Region, Rivers State

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Abstract: *Efficient electric power transmission is a major concern in Nigeria. Electric power transmission is the link between power generation and power distribution network. The performance evaluation of the 132KV Sub-transmission lines is a research work carried out to ascertain the status of the networks for better performance. The data used in the research work were obtained from the Transmission Company of Nigeria (TCN) substations and the networks under consideration constitute five generating stations which are Afam 4 & 5, Afam 6 (Shell), Omoku, Trans-Amadi and Independent Power Project (IPP) at Afam. The 132KV networks of the Port-Harcourt Sub-region under analysis constitute 9 numbers of 132KV active networks and 8 numbers of 33KV active networks and the total active loads connected to the 33KV buses were 443.617MVA. Electrical Transient Analyzer Program (ETAP 12.6) was used to model the network and to perform simulation using Newton-Raphson techniques to solve the static load flow problems and to obtain the real and reactive power flow; determine the various bus voltages, and to investigate the power losses in the networks. During simulation, it was found that the majority of the network's apparatus such as transformers, buses, transmission lines and generators were overloaded beyond their capacities. From the results of the base-case simulation, two capacitor banks (60Mvar and 90MVar) were introduced to enhance the voltage margin and 160MWof power was added to the networks to provide adequate power supply to reduce the total power loss from (10.540MW +j 28.119MVar) to (3.8170MW+j0.8616MVar) thereby improving the performance of the networks.*

Keywords: *Adequate Power Supply, ETAP Software, Loss Reduction, Newton-Raphson Method, Voltage Profile improvement.*

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I. INTRODUCTION

Electrical power is an essential requirement for the development of any nation, economically or industrially. Imagine a country without electricity, life would be boring. Therefore, availability of this electric power brings about a positive change in all aspect which calls for investment. It is of good benefits to rejuvenate the electric power systems to increase productivity in industries, agriculture, raising the standard of the people's livelihood, because there is an adequate supply of electrical energy. There is a connection between the standard of living of the people and the existing power supply in a nation [1]. The demand for this essential utility is directly proportional to population size. As the population size increases the demand also increases resulting in a corresponding increase in the burden of existing transmission systems. That is, increase in the population size over time will affect the existing transmission lines to be overloaded beyond their designed ratings with a consequent reduction in electrical power transmission quality and in extreme cases; there is a total power outage. We are familiar that engineering electricity to the final consumable point requires generation, transmission and distribution, of course, these stages are very important and the performance of any stages indicates how adequate the power supply, its reliability and security is. Therefore, subsequent maintenance of these sections or stages proactively or periodically will aid adequate power supply in any power system or networks [2].

Transmission lines are the link or connection between generating stations and distribution systems. In most part of the world, bulk electric power is transmitted through overhead lines at a very high voltage low current due to conductor size, weight and cost whereas a distribution system links the total load in a particular area to the transmission line as seen in [3],[4]. The network of transmission lines in a state of a country is known as a grid and the different grids connected through tie lines formed a regional grid while these different regional grids further interconnected to form a national grid. Currently, in Nigeria, the primary transmission lines voltage is 330KV (i.e. national grid voltage) whereas the secondary transmission lines voltage is 132KV (regional grid voltage – Sub-transmission). The operation and control of these lines or networks depend on available power generating stations and control centres. Power transformers are actively transforming the power from one level to another level. The focus of this research work is the evaluation of the performance of the 132KV Sub-transmission lines in the Nigeria power network.

1.1 Problem Statement

The major challenges in the power system industry in Nigeria is the inability of the transmission companies to effectively manage the reactive power flow problem, inadequate power generation resulting to low voltage profile and load shedding operation; operating transmission lines beyond its limit could result to voltage collapse. Because the demand for power continues to increase steadily whereas the expansion of power generation and transmission has been grossly stunted due to inadequate resources, many uncompleted transmission line projects, poor network configuration, overloading of in-service transformers, and incessant vandalism of the 132KV Sub-transmission lines in the various regions of the country. The networks are associated with inadequate power dispatch and under-available generation capacity, poor control infrastructure, inadequate or complete absence of reserve.

1.2 Aim and Objectives of this Research Work

The aim of this research work is to evaluate and improve the performance of the 132KV Sub-transmission lines in the Nigeria power network: A case study of Port Harcourt Sub-region, Rivers State. It will provide a medium-term operation of the network. The objectives are as follows: (i) using collected data from field survey i.e. from Port-Harcourt Electricity Distribution Company of Nigeria (PHEDC) and Transmission Company of Nigeria (TCN)) to evaluate the current status of the transmission lines; (ii) model, reconfigure and simulate the network using Newton-Raphson load flow based technique in Electrical Transient Analyzer Program (ETAP) environment; (iii) utilizing the results of the base-case simulation to improve the overall real and reactive power flow and ensuring there is reduction in power loss on the 132kV Sub-transmission network; (iv) possibly integration of active (generator) and passive (capacitor banks) components to further enhance the networks.

1.3 Scope and Significance of this Research Work

The Nigeria 132KV Sub-transmission networks are very large network; therefore, it is regionalized for better identification and service delivery. The scope of this research work is on the Port-Harcourt region having six (6) sub-regions consists of (i) Port Harcourt Mains, (ii) Port Harcourt Town, (iii) Ahaoda, (iv) Yenegoa, (v) Rumuosi, and (vi) Elelenwo for improved performance of service delivery. Significances of this research work are that the study will proffer solutions to effectively reduce real and reactive power losses, optimally inject active and reactive power into the networks with a quest to improve the performance and better service delivery. Again, the evaluation results shall provide useful information for future expansion.

II. LITERATURE REVIEW

2.1 Nigeria Power Transmission Industry

For several years the electric power transmission section in the Nigerian power sector has been saddled in the government established organization. Time to time the government would restructure the organization to perform the task for power delivery. Several reforms have been made to better the service delivery but to no avail in terms of adequate power generation, transmission and distributions to the end users. Currently, the different sections in the power sector are managed by companies as the names imply, Genco for Generation section, Transco for transmission section and Discos for distribution section. The reform paves way for the Transmission Company of Nigeria (TCN) to take over from Power Holding Company of Nigeria (PHCN). It was incorporated in November 2005 and was licensed to transmit power in July 2006. The license involves activities such as electric power transmission, the operation of the power system and trading of electricity [5].

Presently, the transmission capacity of the Nigerian Electricity Transmission System is composed of about 5,523.8 km of 330 KV lines and 6, 801.9 Km of 132 KV lines. The grid power network in the power transmission sector is made up of generators, transformers, transmission lines, capacitor banks, switchgear, steel towers, protection system, etc., [6].

2.2 Power Transmission Network Regions in Nigeria

The power transmission networks in Nigeria are divided into eight (8) regions namely: (1) Port Harcourt region, (2) Enugu region, (3) Benin region, (4) Lagos region, (5) Oshogbo region, (6) Ibadan region, (7) Kano region, and (8) Kaduna region. However, Port Harcourt region is further divided into five (5) sub-regions: (i) Aba sub-region, (ii) Afam sub-region, (iii) Calabar sub-region, (iv) Owerri work centre and (v) Port Harcourt sub-region. Presently, Port Harcourt sub-region controls six transmission sub-stations namely: (1) Port Harcourt Mains, (2) Port Harcourt Town, (3) Ahaoda, (4) Yenegoa, (5) Rumuosi, and (6) Elelenwo [6].

2.3 Power Distribution Section

The power distribution system is made up of medium voltages classified as primary and secondary distribution voltage. The primary distribution voltage is 33KV whereas the secondary distribution (feeder) voltage is rated 11KV. The distribution sector is composed of distribution substations, distribution transformers, distribution lines or feeders, sub-feeders, etc. Both 33KV and 11KV are 3-phase, 3-wire system (for balanced load). The tertiary distribution section constitutes 3-phase, 4-wire system (for unbalanced load) [7], [8].

2.4 Transmission and Distribution System Losses

According to [9] when a distribution system is energized, at the connection of a load, losses take place due to the resistance of all connecting conductors and load. When current passes through cables and other electrical devices (e.g. transformer,) there is bound to be a power loss represented as I^2R; thus, this power loss is known as technical loss and the losses that do not involve the physical power system but rather related to electric theft and errors due to billing and metering system are counted as non-technical losses. According to a report published in [10] declared that 26 - 30% of power losses took place in T & D system with a voltage variation up to 10% of the rated value. However, in their report, they opined that non- technical losses are due to the aging of equipment of power system; also human errors in measurements of KWh on energy meters and the theft of electricity are classified as non-technical losses.

In view of [11], the losses mentioned above will results in the reduction of efficiency of the overall system thereby increasing the operational cost of service delivery resulting in high cost of electricity to end users. According to [12] transmission and distribution losses account for a good portion of the power losses in any power system. If the real power losses are greater than demand, the distribution companies will be adversely affected. Hence, it is very important for the system engineers to put in place the necessary mechanism.

2.5 Improving Transmission Networks

As seen in [13] there are many ways which can be implemented to improve the power transfer capability of transmission lines such as: (a) new transmission line installation – here the new transmission lines are built or constructed to help reduce the challenges posed by overloading by providing more paths or route for power flow. This option tends to increase the reliability of the power transmission system (less prone to faults due to overheating, overcurrent, overvoltage, etc.). (b) transmission line upgrade/ replacement of terminal equipment - As long as the transmission poles or towers do not need a major change to support the much heavier conductor, previously installed inadequate size of conductors can be replaced with a conductor of higher cross-sectional area based on its current carrying capacity to transport power effectively. (c) increase in the high voltage system - upgrading the operating voltage of the conductor or transmission line from one lower level to higher level may affect the current carrying capacity of the conductor also new clearance levels, higher capacity equipment is required thus uneconomical. (d) phase shifting/ transposition of conductors – is due to unequal line impedances found in a double circuit transmission line, imbalance in the sharing of the load between the circuits of the line occurs. These conditions will results into overload of one circuit while the other is under loaded. To battle this, the addition of phase shifting device in the line helps to regulate and to conduct the power flow on the system in a better way and also to optimize the existing transmission capability by evenly distributing the power flow across the transmission lines.

According to [14], the installation of series compensation capacitors on power transmission lines lowers the impedance of the line, thereby increasing the transmission capability. The application of series capacitors is advantageous because of its simplicity and its installation cost. It provides increased system stability, reduced system losses, and better voltage regulation. We noted in [15] that, increase in the number of transmission circuit improve transmission capability; it is a method whereby existing transmission towers are been modified to accommodate a second transmission line onto the structure. It enables addition of a new line to a single circuit to form double circuit thereby reducing the line impedance while the current carrying capacity of the line is increased and hence, the power transmission capacity of the line is also increased.

In view of [15], introduction of flexible alternating current transmission systems (FACTS) devices will enhance the performance of a transmission network such that reactive power loss could be compensated. The device is formed to provide series compensation, shunt compensation or the combination of both. The application of these compensators depends upon the characteristic of the line and the identified deficiency and need. On application of the device, power flow is increased through the transmission line. FACTS devices are a good enhancer for voltage margin improvement in the power transmission system [15].

According to [4] the use of shunt compensation-static var systems (SVS) in high voltage transmission, when the voltage at a bus is less than the reference value, capacitive reactive volt-amperes (VARs) are to be injected and when the bus voltage exceeds the reference value, inductive VARs are to be introduced to lower the bus voltage. It can be used to maintain a constant voltage. The concept uses capacitor banks for the static var compensation. A capacitor bank is an energy storing device made up of a collection or a group of two or more capacitors of the same rating which are connected serially, parallel or in serial-parallel connection to improve the reactive power losses. The usefulness of static VAR compensator (SVC) in power transmission system was also mentioned in [16]. The device is used to counteract the effect of a power factor lag or phase shift in an alternating current (AC) power supply. It is basically a passive element that injects reactive power into a network. It improves the bus voltage profile of a power system.

A network reconfiguration technique was applied in [17] to power systems network; it was stated that, the technique applied is one of the operative practices to achieve networks loss reduction, increase network power supply and improve network performance. The network under consideration in practice will be reconfigured by upgrading overloaded transformers, adjustment of transformer tap changers, opening, and closing of some feeder lines, etc., to boost power supply. According to [18] a combination of network reconfiguration and installation of synchronous generators or distributed generators (DGs) along the network as mentioned in [19] directly or indirectly to utility's power transmission or distribution network can enhance and reduce power losses and to provide adequate power supply to end users.

III. MATERIALS AND METHODS

3.1Description of the Existing 132KV Sub-transmission Networks

The networks under consideration are categorised as Port-Harcourt sub-region which controls six transmission sub-stations, namely: (i) Port Harcourt Town, (ii) Port Harcourt Mains, (iii) Ahaoda, (iv) Yenegoa (v) Rumuosi, and (vi) Elelenwo as mentioned earlier. Table I shows the Port Harcourt sub-region substations and their various load and transformer capacities before improvement. Table II presents the Load Legend for the 132KV Sub-transmission networks of the Port Harcourt Sub-region and their load capacity for analysis.

3.2 Materials Utilized

During the simulation period, the following materials shall be used to actively reconfigure and upgrade for better performance of the 132KV Sub-transmission network within the Port-Harcourt Sub-regions.

i. Transmission line conductors are kept overhead and vertically arranged using Aluminum conductor steel reinforced with galvanised (ACSR/GZ of 182mm^2) on steel tower supports
ii. Transformers voltage rating (132/33kV) and Power rating: 30 - 150MVA
iii. Revamping already installed synchronous generators to installed capacities
iv. Adding power generation or distributed generation (DG), if necessary
v. Adding FACTS devices (i.e., using sizable capacitors banks, etc.)[16- 19]

3.3 Methods Adopted to Improve the 132KV Sub-transmission Networks

In view of the above materials stated and the existing networks layout, a load flow based technique combine with network improving techniques will be applied to the 132KV base-case networks. The networks will be modelled and reconfigured for simulation using Newton Raphson load flow method to analyse the base-case 132KV Sub-transmission networks being considered with a full graphical Electrical Transient Analyzer Program (ETAP 12.6 software) that provides a very high level of reliability, protection and security of critical applications [20]. Thereafter, network reconfiguration techniques will be applied to the existing network by injecting active and reactive power where necessary using synchronous generators and FACTS devices such as shunt capacitor banks or shunt reactors to improve the transmission capability. It is a load flow based technique. The above software can be used to run analysis such as short circuit analysis, load flow analysis, motor starting, harmonic transient stability, generator start-up, etc. using input data for the power flow analysis such as Grid MVAsc, line parameters, bus parameters, generators parameters; capacitors bank rating, transformers ratings and feeder loading, etc. From the simulation results, the existing synchronous generators will be revamped to installed capacities to improve the networks. Thus, the results of the simulated 132KV Sub-transmission network before and after improvement of the network are presented herein.

Table I: Sub-transmission Network of Port Harcourt Sub-region Substations before Improvement

Port –Harcourt Sub-region						
S/N	**Transmission substation**	**Transmission Substation Location**	**Areas Connected**	**Load (MW)**	**Transformer Location Name**	**Transformer Size (MVA)**
1	Port Harcourt Town	Nzimiro street/Amadi Junction	Silver Bird UTC Secretariat Borokiri Rumuolumini UST	8 8 22 13 22 22	T_1A T_1B T_2A T_2B	60 30 30 45
			RSPUB 1	8.2		

2	Port Harcourt Mains	Rumuobioakani	Abuloma Uniport Ref 1 RSPUB Rainbow Ref 2 FDR 1 FDR 2 FDR 3	8.5 17.6 1.8 14.3 12.1 5.8 17.8 13.8 16.4	T_1A T_2A T_3A	60 60 60
3	Ahoada	Ahoada	Ahoada Isiokpo Choba Abonnema 1 Abonnema 2	15 15 3 2.5 4.5	T_1 T_2	40 40
4	Yenegoa	Yenegoa	Imiringi 1 Imiringi 2 Opolo	19 20 8	T_1 T_2	40 40
5	Rumuosi	Rumuosi	Airport Rukpoku NTA UPTH	Nil 4 10 13	T_1 T_2	40 40
6	Elelenwo	Elelenwo	Bori Elelenwo Bristle Eleme Igbo-Etche Iriebe	16 17.6 7.5 6.8 7.5 8.4	$T0_1$ $T0_2$	60 60
(**Source:** Transmission Company of Nigeria, Rumuobioakani) [21]						

Table II: Load Legend for 132KV Sub-transmission Network for Port Harcourt Sub-region and their Load Capacity before Improvement

Load Legend for 132kV Sub-transmission Networks					
Legend	**Name**	**Power (MW)**	**Legend**	**Name**	**Power (MW)**
L1	Bori	16	L2	Elelenwo	17.6
L3	Bristle	7.5	L4	Eleme	6.8
L5	Igbo-Eche	7.5	L6	Iriebe	8.4
L7	Silverbird	8	L8	UTC	8
L9	Secretariat	22	L10	Borokiri	13
L11	Rumuolumini	22	L12	UST	22
L13	Fdr	17.8	L14	Fdr2	13.8
L15	Fdr3	16.4	L16	RSPUB	14.3
L17	Rainbow	12.1	L18	Ref2	5.8
L19	Rspub1	8.2	L20	Abuloma	8.5
L21	Uniport	17.6	L22	Ref1	18
L23	Ahoada	15	L24	Isiokpo	15
L25	Choba	3	L26	Abonnema1	2.5
L27	Abonnema2	4.5	L28	Imiringi2	19
L29	Imiringi1	20	L30	Opolo	8
L31	Airport	Nil	L32	Rukpoku	4
L33	NTA	10	L34	UPTH	13

(**Source:** Transmission Company of Nigeria, Rumuobioakani) [21]

IV. RESULTS AND DISCUSSION

4.1 Simulation Results

The results obtained for the 132KV Sub-transmission networks analysed using Newton-Raphson loads flow based technique in ETAP 12.6 environment for various bus voltage levels, power losses and power flow before and after network improvement are presented below. The impacts of upgrading both existing transformers and revamping of the existing synchronous generators to their installed capacities yield positive results on the networks. However, integration of capacitor banks and a new generator at a strategic location also aids for adequate power supply to enhance the voltage profile.

4.1.1 Branch Power loss

Table III and Table IV show the summary results of the branch power losses before and after networks improvement. The losses are arithmetically obtained between "from-to bus flow" and the "to- from bus flow" of the various circuit components/lines. Table V presents the comparative results of the branch power losses before and after improvement of the 132KV Sub-transmission networks. Fig.1 is the graphical representation of the branch active power losses before and after networks improvement.

4.1.2 Voltage Profile

On Table III and IV, the % bus voltages of the respective circuit components before and after improvement are present. Also, Table VI shows the comparative results of the % voltage drop and Fig.2 shows the graphical representation of the percentage voltage drop before and after networks improvement.

4.1.3 Network simulations

Table VII presents the three-phase power transformers upgraded. The base-case networks of the 132 KV Sub-transmission lines for Port Harcourt Sub-region and their load capacities are shown in Fig. 3. However, Fig.4 shows the base-case load flow results of the 132 KV sub-transmission lines with critical buses (in red) and marginal buses (in purple colour). Fig.5 is the voltage drop results of the base-case simulated 132 KV sub-transmission networks. Fig. 6 indicates the branch power losses of the 132 KV sub-transmission networks for Port- Harcourt sub-region before the networks improvement whereas Fig.7 is the improved power flow results of the 132 KV sub-transmission networks for Port Harcourt sub-region with the integration of capacitor banks and additional power generation.

Table III: Summary Results of the Branch Power Losses before Networks Improvement

Branch	**From – to Bus Flow**		**To - From Bus Flow**		**Losses**		**% Bus Voltage.**		**%**
ID	**MW**	**MVar**	**MW**	**MVar**	**KW**	**KVar**	**From**	**To**	**Vd**
T1	-3.494	2.133	3.494	-2.125	**0.1**	**8.0**	100.0	99.9	0.10
Elelenwo	32.067	20.920	-31.649	-21.237	**417.9**	**-317.2**	99.8	97.9	1.88
Line 1	30.600	-53.667	-30.515	53.725	**84.9**	**58.1**	99.8	99.9	0.13
Line 2	30.600	-53.667	-30.515	53.725	**84.9**	**58.1**	99.8	99.9	0.13
Line 5	7.333	32.747	-6.828	-33.437	**505.3**	**-690.2**	99.8	97.1	2.66
Line 6	7.333	32.747	-6.828	-33.437	**505.3**	**-690.2**	99.8	97.1	2.66
T1-T59	32.067	20.920	-31.649	-21.237	**417.9**	**-317.2**	99.8	97.9	1.88
Line 18	22.050	-40.380	-22.003	40.376	**46.9**	**-4.3**	99.9	100.0	0.10
Line 19	35.486	-64.945	-35.411	65.019	**75.5**	**73.3**	99.9	100.0	0.10
Ahoada T/S	-41.596	-27.831	44.754	29.534	**3158.2**	**1703.4**	89.8	99.8	10.04
T1-T140	22.541	14.891	-22.188	-15.413	**353.1**	**-521.7**	89.8	87.7	2.03
T1-T219	-41.596	-27.831	44.754	29.534	**3158.2**	**1703.4**	89.8	99.8	10.04
Yenegoa T/S	22.541	14.891	-22.188	-15.413	**353.1**	**-521.7**	89.8	87.7	2.03
T11	19.055	12.939	-19.025	-11.664	**30.4**	**1275.5**	89.8	87.0	2.80
T12	19.055	12.939	-19.025	-11.664	**30.4**	**1275.5**	89.8	87.0	2.80
Line 16	44.818	29.558	-44.754	-29.534	**63.9**	**23.7**	100.0	99.8	0.21
Line 17	44.818	29.558	-44.754	-29.534	**63.9**	**23.7**	100.0	99.8	0.21
T2	31.649	21.237	-31.605	-19.377	**44.3**	**1860.7**	97.9	97.7	0.24
T3	31.649	21.237	-31.605	-19.377	**44.3**	**1860.7**	97.9	97.7	0.24
Line 8	22.298	16.791	-22.280	-16.837	**18.3**	**-46.5**	97.1	97.0	0.11
T1-T106	-15.470	16.647	15.472	-16.654	**1.5**	**-7.1**	97.1	97.1	0.00
Line 7	22.298	16.791	-22.280	-16.837	**18.3**	**-46.5**	97.1	97.0	0.11
Port Harcourt T/S	-15.470	16.647	15.472	-16.654	**1.5**	**-7.1**	97.1	97.1	0.00
Line 9	46.479	31.606	-46.433	-31.578	**46.3**	**28.4**	97.0	96.9	0.14
Line 13	-24.199	-14.769	24.218	14.723	**18.9**	**-45.6**	97.0	97.1	0.11
Line 10	46.479	31.606	-46.433	-31.578	**46.3**	**28.4**	97.0	96.9	0.14
Line 14	-24.199	-14.769	24.218	14.723	**18.9**	**-45.6**	97.0	97.1	0.11
T4	-33.715	-20.670	33.769	22.966	**54.7**	**2295.5**	93.8	96.9	3.06
T5	-16.857	-10.335	16.885	11.483	**27.3**	**1147.8**	93.8	96.9	3.06
T6	-16.857	-10.335	16.885	11.483	**27.3**	**1147.8**	93.8	96.9	3.06
T7	-25.286	-15.503	25.327	17.224	**41.0**	**1721.6**	93.8	96.9	3.06
T8	46.768	33.092	-46.661	-28.597	**107.0**	**4494.5**	97.1	92.8	4.35
T9	-31.483	-19.302	31.530	21.283	**47.2**	**1981.6**	94.3	97.1	2.84
T10	-35.270	-21.635	35.329	24.134	**59.5**	**2498.8**	94.1	97.3	3.20
Line 3	124.670	-24.134	-124.22	25.213	**447.7**	**1078.5**	97.3	97.1	0.15
T15	-13.260	-8.129	13.272	8.645	**12.3**	**515.3**	95.4	97.1	1.75
T16	-13.444	-8.242	13.452	8.571	**7.8**	**328.5**	98.9	98.5	1.13
T13	-22.144	-13.576	22.188	15.413	**43.7**	**1836.7**	98.9	97.0	1.19
T14	-13.260	-8.129	13.272	8.645	**12.3**	**515.3**	95.4	97.1	1.75
T1-T43	-22.144	-13.576	22.188	15.413	**43.7**	**1836.7**	84.3	87.7	3.38
Total					**10540.2**	**28118.9**			

Table IV: Summary Results of the Branch Power Losses after Network Improvement

Branch	From - to Bus Flow		To - From Bus Flow		Losses		% Bus Voltage.		%
Id	MW	MVar	MW	MVar	kW	kVar	From	To	Vd
T1	-1.645	-2.101	1.645	2.105	**0.0**	**3.4**	100.0	100.1	0.10
Elelenwo	32.185	-24.719	-31.733	24.427	**451.5**	**-292.2**	100.2	100.4	0.23
Line 1	28.693	12.195	-28.671	-12.242	**21.5**	**-46.4**	100.2	100.1	0.11
Line 2	28.693	12.195	-28.671	-12.242	**21.5**	**-46.4**	100.2	100.1	0.11
Line 5	9.126	12.521	-9.015	-13.892	**110.7**	**-1371**	100.2	98.9	1.32
Line 6	9.126	12.521	-9.015	-13.892	**110.7**	**-1371**	100.2	98.9	1.32
T1-T59	32.178	-24.714	-31.726	24.422	**451.4**	**-292.6**	100.2	100.4	0.23
Line 18	27.849	11.190	-27.829	-11.238	**19.9**	**-48.7**	100.1	100.0	0.10
Line 19	27.849	11.190	-27.829	-11.283	**19.9**	**-48.7**	100.1	100.0	0.10
Ahoada T/S	0.000	-1.968	0.000	-1.887	**0.0**	**-3855**	100.0	100.0	0.01
T1-T140	23.669	-15.773	-23.369	14.867	**299.9**	**-906.2**	100.0	100.1	0.06
T1-T219	0.000	-1.968	0.000	-1.887	**0.0**	**-3855**	100.0	100.0	0.01
Yenegoa T/S	23.664	-15.770	-23.364	14.863	**299.8**	**-906.6**	100.0	100.1	0.06
T11	19.883	12.905	-19.866	-12.179	**17.3**	**725.5**	100.0	98.3	1.70
T12	19.883	12.905	-19.866	-12.179	**17.3**	**725.5**	100.0	98.3	1.70
Line 16	0.000	-1.968	0.000	1.887	**0.1**	**-81.2**	100.0	100.0	0.01
Line 17	0.000	-9.168	0.000	1.887	**0.1**	**-81.2**	100.0	100.0	0.01
T2	31.730	20.974	-31.697	-19.585	**33.1**	**1388.8**	100.4	98.4	2.05
T3	31.730	20.974	-31.697	-19.585	**33.1**	**1388.8**	98.9	98.4	2.05
Line 8	27.968	18.078	-27.884	-18.203	**83.9**	**-125.7**	98.9	98.5	0.43
T1-T106	-18.953	-4.185	18.954	4.177	**1.1**	**-8.1**	98.9	98.9	0.01
Line 7	27.966	18.076	-27.882	-18.202	**83.9**	**-125.7**	98.9	98.5	0.43
Port Harcourt T/S	-18.951	-4.184	18.952	4.176	**1.1**	**-8.1**	98.9	98.9	0.01
Line 9	47.000	30.586	-46.911	-30.537	**89.4**	**48.9**	98.5	98.2	0.27
Line 13	-19.118	-12.384	19.176	12.086	**58.4**	**-297.9**	98.5	98.9	0.44
Line 10	47.004	30.588	-46.914	-30.539	**89.4**	**48.9**	98.5	98.2	0.27
Line 14	-19.120	-12.385	19.178	12.087	**58.4**	**-297.9**	98.5	98.2	0.44
T4	-23.438	-14.482	23.456	15.269	**18.7**	**786.9**	96.7	98.2	1.53
T5	-23.438	-14.482	23.456	15.269	**18.7**	**786.9**	96.7	98.2	1.53
T6	-23.438	-14.482	23.456	15.269	**18.7**	**786.9**	96.7	98.2	1.53
T7	-23.438	-14.482	23.456	15.269	**18.7**	**786.9**	96.7	98.2	1.53
T8	47.478	31.187	-47.431	-29.220	**46.8**	**1966.2**	98.9	97.0	1.91
T9	-32.212	-19.749	32.234	20.669	**21.9**	**920.1**	100.1	98.9	1.19
T10	-35.881	-21.998	35.910	23.178	**28.1**	**1179.4**	98.5	100.0	1.53
Line 3	124.090	73.982	-123.14	-72.633	**955.0**	**1349.0**	100.0	98.9	1.10
T15	-13.444	-8.242	13.452	8.571	**7.8**	**328.5**	98.9	100.0	1.13
T16	-13.444	-8.242	13.452	8.571	**7.8**	**328.5**	98.9	100.0	1.13
T13	-20.011	-12.269	20.029	13.004	**17.5**	**735.5**	98.4	100.1	1.71
T14	-26.682	-16.358	26.705	17.339	**23.3**	**980.7**	98.4	100.1	1.71
T1-T43	-32.836	-11.748	33.097	11.410	**260.2**	**-338.2**	98.9	100.0	1.10
Total					**3817.0**	**861.6**			

Table V: Comparative Results of the Branch Power Losses before and after Improvement

Branch Power Losses					
	Branch	Losses Before		Losses After	
S/No.	Id	KW	KVar	KW	KVar
1	T1	0.2	8	0.1	3.4
2	Elelenwo	417.9	-317.2	451.5	-292.2
3	Line 1	84.9	58.1	21.5	-46.4
4	Line 2	84.9	58.1	21.5	-46.4
5	Line 5	505.3	-690.2	110.7	-1371
6	Line 6	505.3	-690.2	110.7	-1371
7	T1-T59	417.9	-317.2	451.4	-292.6
8	Line 18	46.9	-4.3	19.9	-48.7
9	Line 19	75.5	73.3	19.9	-48.7
10	Ahoada T/S	3158.2	1703.4	0	-3854.9
11	T1-T140	353.1	-521.7	299.9	-906.2
12	T1-T219	3158.2	1703.4	0	-3854.9
13	Yenegoa T/S	353.1	-521.7	299.8	-906.6
14	T11	30.4	1275.5	17.3	725.5
15	T12	30.4	1275.5	17.3	725.5
16	Line 16	63.9	23.7	0.1	-81.2
17	Line 17	63.9	23.7	0.1	-81.2

18	T2	44.3	1860.7	33.1	1388.8
19	T3	44.3	1860.7	33.1	1388.8
20	Line 8	18.3	-46.5	83.9	-125.7
21	T1-T106	1.5	-7.1	1.1	-8.1
22	Line 7	18.3	-46.5	83.9	-125.7
23	Port Harcourt T/S	1.5	-7.1	1.1	-8.1
24	Line 9	46.3	28.4	89.4	48.9
25	Line 13	18.9	-45.6	58.4	-297.9
26	Line 10	46.3	28.4	89.4	48.9
27	Line 14	18.9	-45.6	58.4	-297.9
28	T4	54.7	2295.5	18.7	786.9
29	T5	27.3	1147.8	18.7	786.9
30	T6	27.3	1147.8	18.7	786.9
31	T7	41	1721.6	18.7	786.9
32	T8	107	4494.5	46.8	1966.2
33	T9	47.2	1981.6	21.9	920.1
34	T10	59.5	2498.8	28.1	1179.4
35	Line 3	447.7	1078.5	955	1349
36	T15	12.3	515.3	7.8	328.5
37	T16	7.8	328.5	7.8	328.5
38	T13	43.7	1836.7	17.5	735.5
39	T14	12.3	515.3	23.3	980.7
40	T1-T43	43.7	1836.7	260.2	-338.2
	Total	**10540.2**	**28118.9**	**3817**	**861.6**

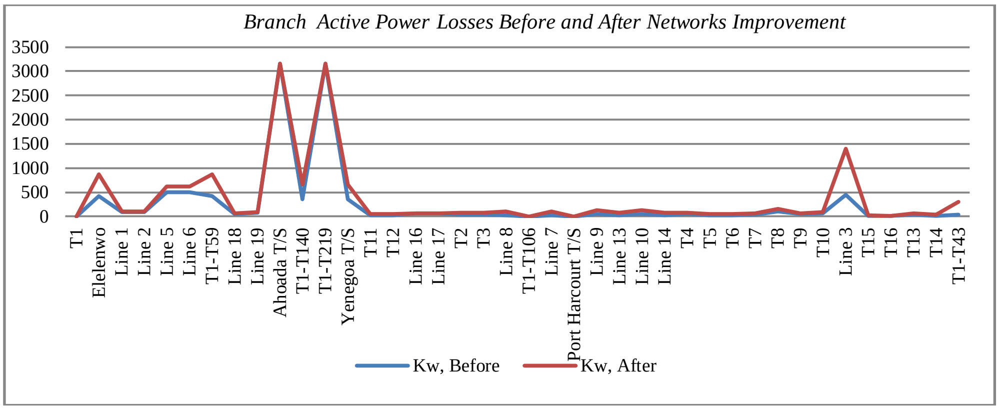

Fig.1: The Branch Active Power Losses before and after Networks Improvement

Table VI: Comparative Results of % Voltage Drops before and after Network Improvement

% Voltage Drop					
Branch Id	**% Vd (Before)**	**% Vd (After)**	**Branch Id**	**% Vd (Before)**	**% Vd (After)**
T1	0.1	0.1	Elelenwo	1.88	0.23
Line 1	0.13	0.11	Line 2	0.13	0.11
Line 5	2.66	1.32	Line 6	2.66	1.32
T1-T59	1.88	0.23	Line 18	0.1	0.1
Line 19	0.1	0.1	Ahoada T/S	10.04	0.01
T1-T140	2.03	0.06	T1-T219	10.04	0.01
Yenegoa T/S	2.03	0.06	T11	2.8	1.7
T12	2.8	1.7	Line 16	0.21	0.01
Line 17	0.21	0.01	T2	0.24	2.05
T3	0.24	2.05	Line 8	0.11	0.43
T1-T106	0	0.01	Line 7	0.11	0.43
Port Harcourt T/S	0	0.01	Line 9	0.14	0.27
Line 13	0.11	0.44	Line 10	0.14	0.27
Line 14	0.11	0.44	T4	3.06	1.53
T5	3.06	1.53	T6	3.06	1.53
T7	3.06	1.53	T8	4.35	1.91
T9	2.84	1.19	T10	3.2	1.53
Line 3	0.15	1.1	T15	1.75	1.13
T16	1.13	1.13	T13	1.19	1.71
T14	1.75	1.71	T1-T43	3.38	1.1

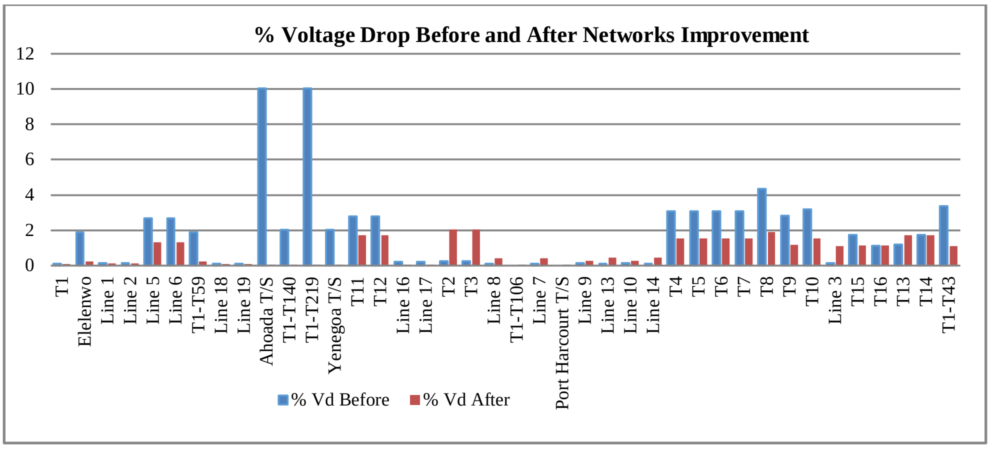

Fig.2: Percentage Voltage Drop before and after Networks Improvement

Table VII: Three-phase Power Transformers Upgrade before and after Networks Improvement

Id	Phase	MVA Rating (before)	MVA Rating (after)	Id	Phase	MVA Rating (before)	MVA Rating (after)
T1	3 Phase	162	162	T2	3 Phase	60	80
T3	3Phase	60	80	T4	3Phase	60	80
T5	3Phase	30	80	T6	3Phase	30	80
T7	3Phase	45	80	T8	3Phase	60	130
T9	3Phase	60	120	T10	3Phase	60	120
T11	3Phase	40	60	T12	3Phase	40	60
T13	3Phase	40	60	T14	3Phase	40	80
T15	3Phase	40	60	T16	3Phase	40	60

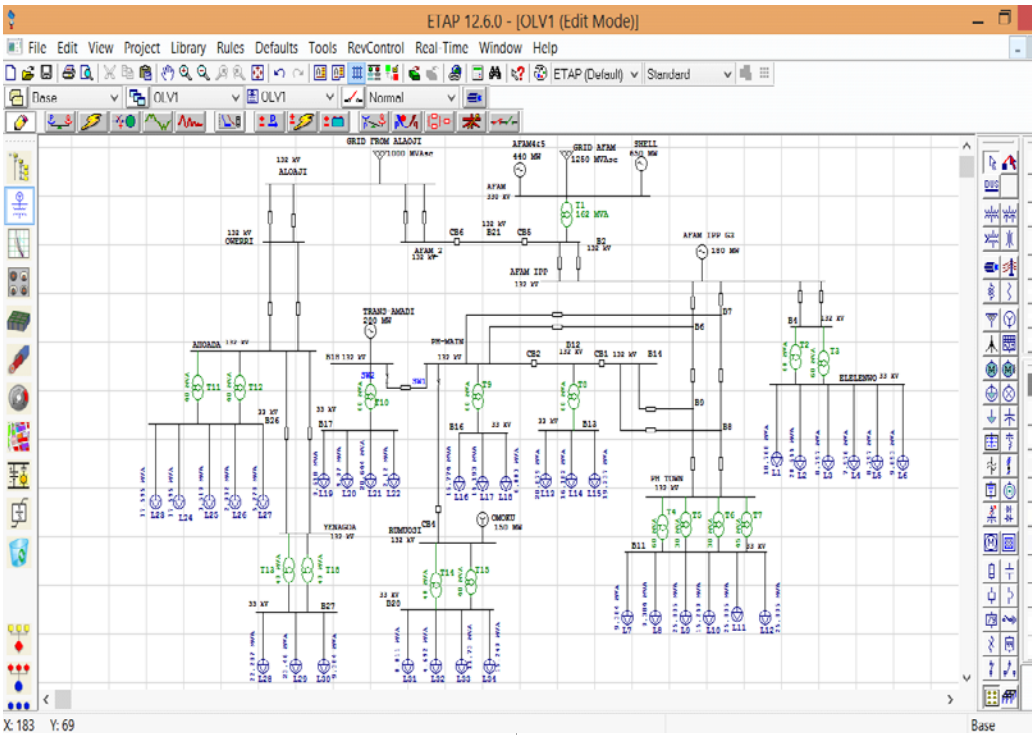

Fig.3: The Base-case Network of the 132 KV Sub-transmission Lines for Port Harcourt Sub-region and their Load Capacities

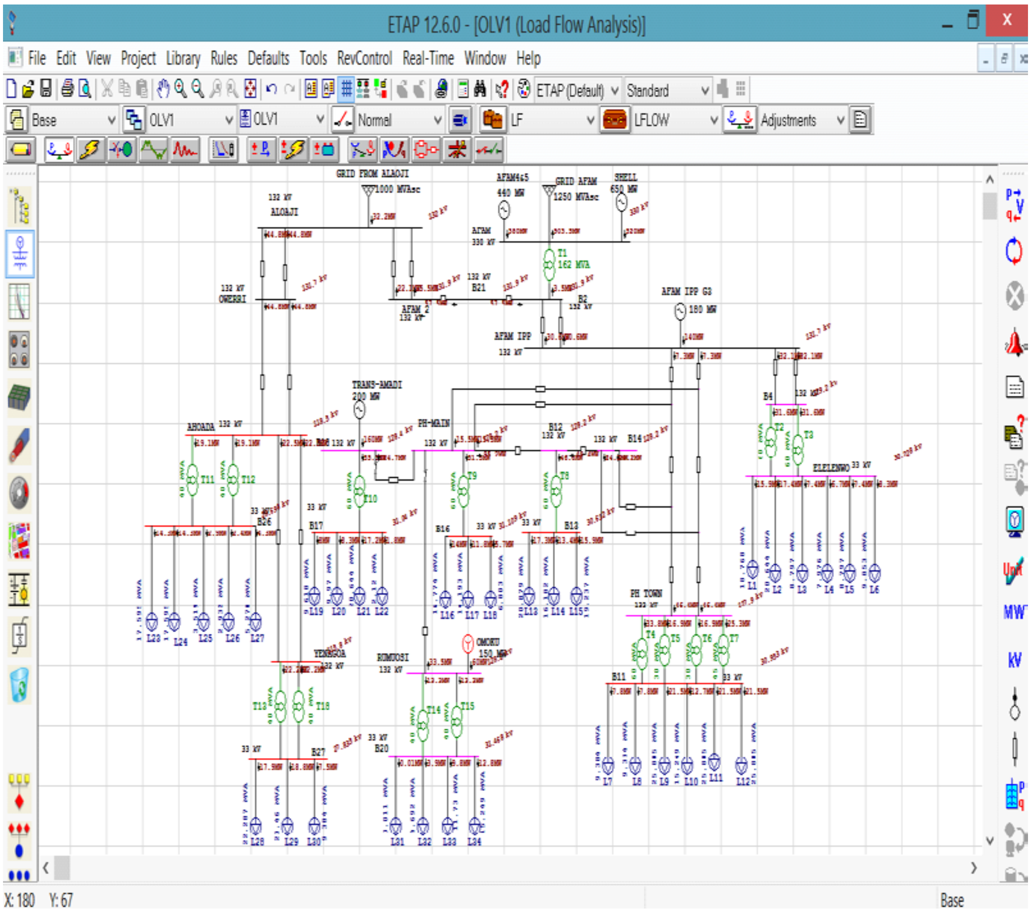

Fig.4: The Base-case Power Flow Results of the 132 KV Sub-transmission Lines for Port Harcourt Sub-region, Power Generation and Load Capacities showing Critical and Marginal Buses

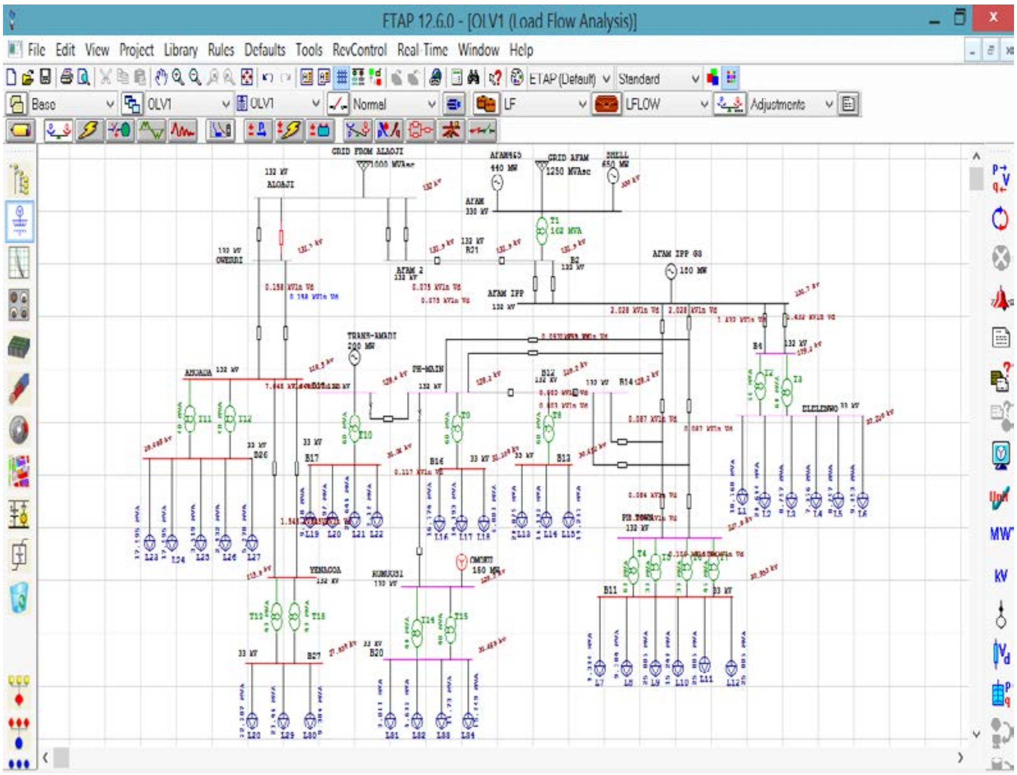

Fig.5: Voltage Drop Results of the Base-case Simulated 132 KV Sub-transmission Networks for Port Harcourt Sub-region.

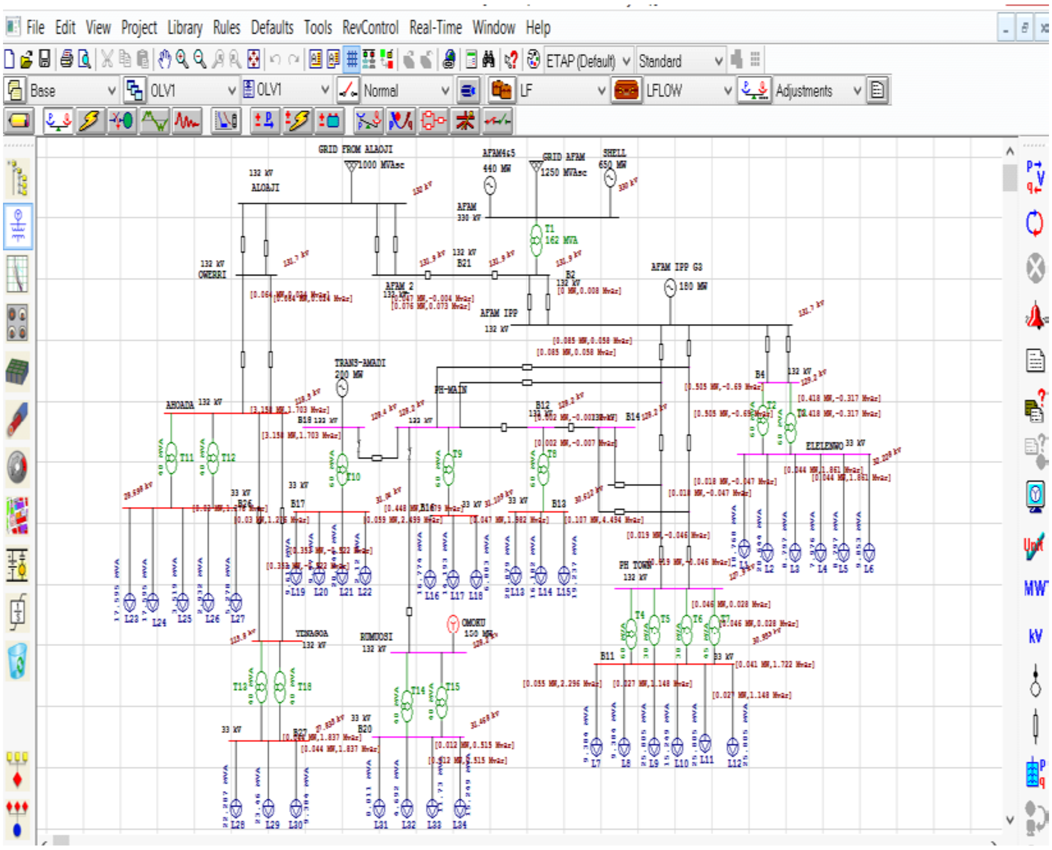

Fig. 6: Results of the Branch Power Losses of the 132 KV Sub-transmission Networks for Port- Harcourt Sub-region before Networks Improvement.

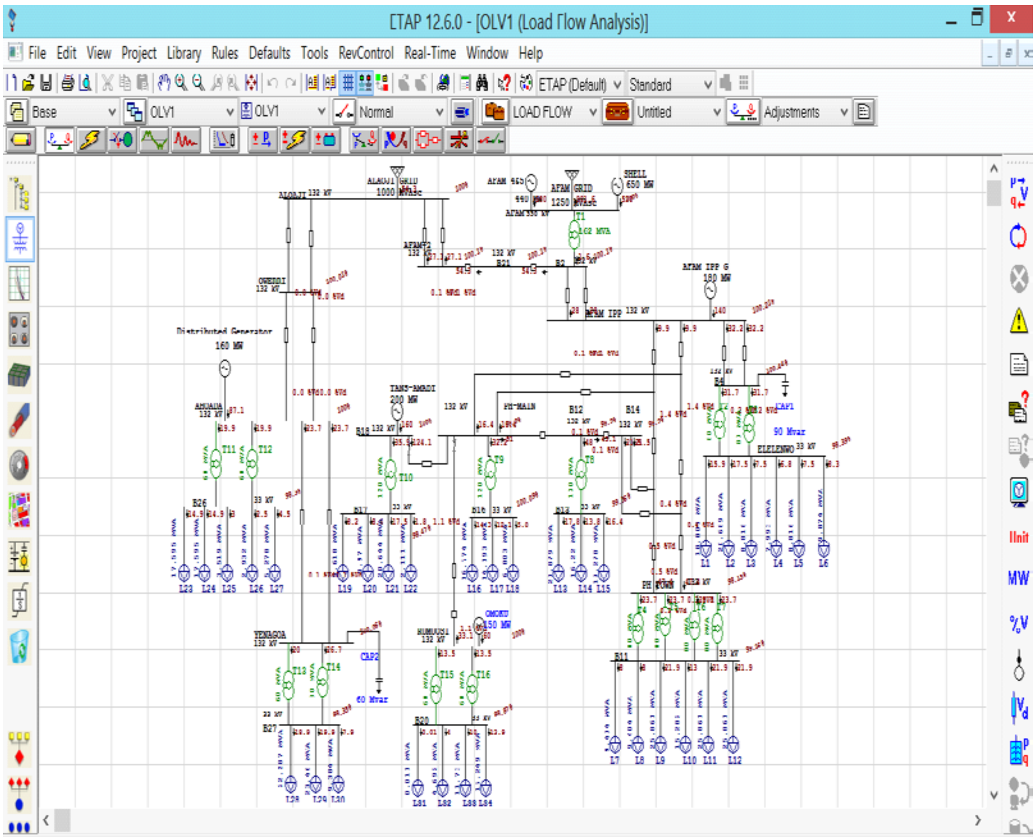

Fig.7: Improved Power Flow Results of the 132 KV Sub-transmission Networks for Port Harcourt Sub-region with Capacitor Banks and additional Power Generation.

4.2 Discussion

Having simulated the base-case networks to ascertain the status of power flow; it was found that 9 buses were operating at the critical point of 84.3% while 13 buses were operating at the marginal point of 96.9%. The marginal bus voltage areas were within acceptable limit but any change in load demand will put these buses to a critical point, hence, efforts were made to improve the networks' power delivery.

4.2.1 Branch Power loss Reduction

From the networks analysed, the total power loss was reduced from (10.5402MW +j 28.118MVar = 30.028∠69.5°MVA) to (3.8170MW +j0.8616MVar = 3.913∠12.7° MVA). A total power loss reduction of 87% of the base-case results was recorded. The overloaded transformers on the networks were upgraded in rating; also 160MW of power was installed at Ahaoda axis. The generation of active power close to load centres improved the power service in other branches of the networks thereby reducing active power losses.

4.2.2 Voltage Profile Improvement

The introduction of the two capacitor banks (60MVar at bus B4, Elelenwo Networks and 90MVar at Yenegoa bus, Yenegoa Networks) improve the network voltage profile. The injection of reactive power by these capacitor banks directly compensates the line losses to some extent as seen in Table VI, the maximum % voltage drops recorded were at Ahoada T/S and Transmission line T1 – T219 with 10.04% drop, which violates the acceptable voltage drop limit of 5%. However, when the networks were injected with reactive power through the capacitor banks, the voltage profile was enhanced thereby reducing the voltage drop of these transmission lines to 0.01%.

V. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

The 132KV Sub-transmission networks of the Port-Harcourt Sub-region analyzed constitute 9 numbers of 132KV active routes/buses and 8 numbers of 33KV active routes/buses. The network is characterized by 132/33KV lines /feeders. The total loads connected to the secondary buses (33KV feeders) were 443.617MVA. The networks also constitute five (5) power generating stations previously and later one (1) proposed power generating station with an installed capacity of 160MW was added at Ahoada substation to provide active power in the networks. In practice power supplies come from Alaoji-Afam lines, Owerri - Ahoada lines, Afam-Port-Harcourt to Port-Harcourt Sub-regions. However, Port Harcourt Mains and Port-Harcourt Town sub-transmission sub-stations received power from Afam-Port-Harcourt on line 1&2 (a double circuit sub-transmission), and Power generated from the Trans-Amadi power station is injected to Port-Harcourt Mains on the 132KV bus.

Obviously, part of the system that needs urgent attention was clearly seen during the simulation. Thus, using Newton-Raphson power techniques embedded in the ETAP software, with the application of network optimization techniques mentioned earlier. Buses such as (Ahaoda, B11, B13, B16, B17, B26, B27and Yenegoa bus) and the generator at Omoku on the simulated networks were in critical condition with undesirable voltage limit whereas buses (B12, B14, B18, B20, B4, B6, B7, B8, B9, Elelenwo, PH Town, PH Main and Rumuosi) were within margin limit. With the addition of two (2) numbers of capacitors banks and a proposed power generating station at Ahoada sub-station aid adequate power flow to the load centres. Of course, without power generation there will be no development of a country. In a nut shell, there was a power loss reduction of 87% of the base-case.

5.2 Recommendations

Having evaluated the performance of the 132KV Sub-transmission network Port-Harcourt Sub-region, Rivers State, as a case study, we recommend that:

- Most old 132KV Sub-transmission networks should be upgraded for better power capacity.
- There should be continuing investment in the power sector especially introduction of distributed generation and more 132KV Sub-transmission networks.
- Very aged power transformers should be replaced with greater MVA capacity for future growth.
- Utilize the benefits of capacitor banks in power transmission system.
- There should be a proper calibrated energy meter (pre-paid meters to all consumers) to avoid non- technical losses. This will assist the service providers to generate more funds for operation and maintenance of the system infrastructures, etc.

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REFERENCES

[1]. O. F. Akpojedje, E. M. Onogbotsere, C.E. Mormah, and E. P. Onogbotsere, A comprehensive review of Nigeria electric power transmission issues and rural electrification challenges. International Journal of Engineering Trends and Technology, 31(1),2016
[2]. N. Vijaysimha, and CH. Chengaiah, Evaluation of fault analysis in transmission lines using relay settings, Journal of Theoretical and Applied Information Technology,14(2), 2005,126-143.
[3]. J. D. Glover, M. S. Sarma, and T. J. Overbye, Power system analysis and design, 2008
[4]. J. B. Gupta, Transmission and distribution of electrical power (New Delhi: S. K. Kataria & Son, 2012)
[5]. U.C. Ogbuefi, and T.C. Madueme, (2015), A power flow analysis of the Nigerian 330kV electric power system, IOSR Journal of Electric and Electronics Engineering,10(1),2015, 46-57.
[6]. O. Eyekpimi, Electricity tariff structure in Nigeria, 2016. Available [online] from: https://infoguidenigeria.com/electricity-tariff-structure/
[7]. Federal Ministry of power, Works and Housing, Overview of Nigeria's power sector, 2013. Available [online] from http://www.power.gov.ng/
[8]. A. Dembra, and A.K. Sharma, Improvement in voltage profile and loss minimization using high voltage distribution system, International Journal of Electrical and Electronics Research,(2)3,2014,11-20
[9]. S. S. Mustafa, M. H. Yasen, and H. H. Abdullah, Evaluation of electric energy losses in kirkuk distribution electric system area, Iraq J. Electrical and Electronic Engineering, 7(2), 2011, 144-150.
[10]. O. S. Adeoye, and C. O. Ekejuiba, Assessment of line losses and methods of reduction on selected power transmission lines in Nigeria, International Journal of Novel Research in Engineering and Applied Science (1)3, 2014, 54-63.
[11]. M. C. Anumaka, Analysis of technical losses in electrical power system (Nigerian 330kV network as a case study), International Journal of Recent Research and Applied Studies, 12 (2), 2012, 320-327.
[12]. J. Jayaprakash, P.M. Angelin, L.R. Jothi, and P. J, Juanola, Planning and coordination of relay in distribution system using ETAP, Pakistan Journal of Biotechnology,13(Special),2016,252-256.
[13]. E.U. Oleka, S.N. Ndubisi, and G.K. Ijemaru, Electric power transmission enhancement: a case of Nigerian electric power rrid, American Journal of Electrical and Electronic Engineering,4(1),2016, 33-39.
[14]. C.T.Summers, Distance protection aspects of transmission lines equipped with series compensation capacitors, master thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, 1999.
[15]. SSR Engineers, Transmission Enhancement Technology Report: transmission system planning, Western Area Power Administration Upper Great Plains Region, 2002, 1-19.
[16]. Md. M. Biswas, and K. D, Kamol, Voltage level improving by using static var compensator (svc), Global Journal of Researches in Engineering: J General Engineering,11(5), 2011.
[17]. C. I. Amesi, T. K. Bala, and A.O. Ibe, Impact of network reconfiguration: a case study of port-harcourt town 132/33KV sub-transmission substation and its 33/11KV injection substation distribution networks, European Journal of Electrical and Computer Engineering, 1(1), 2017, 1-8.
[18]. F.C. Okereafor, D.C. Idoniboyeobu, and T. K. Bala, Analysis of 33/11KV RSU injection substation for improved performance with distributed generation (DG) unit, American Journal of Engineering Research, 6(9), 2017, 301–316.
[19]. G. Nibedita, S. Sharmistha and B. Subhadeep, A load flow based approach for optimum allocation of distributed generation units in the distribution network for voltage improvement and loss minimization, International Journal of Computer Applications,50(15),2012,15-22.
[20]. ETAP 12.6, Electrical Transient Analyzer Program
[21]. Transmission Company of Nigeria, Single line diagram of port-harcourt work centre stations and their load capacity, Rumuobioakani, Nigeria, Unpublished, 2017.

D. C. Idoniboyeobu, T. K. Bala, K. I. Blue-Jack. "Performance Evaluation of the 132KV Sub-Transmission Lines in the Nigeria Power Network: A Case Study of Port Harcourt Sub-Region, Rivers State." International Journal of Research in Engineering and Science (IJRES), vol. 05, no. 12, 2017, pp. 28–40.