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IMPROVED REACTIVE POWER COMPENSATION FOR 11KV DISTRIBUTION NETWORK: A CASE OF MARINE BASE PORT HARCOURT

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ABSTRACT

This research work focus on the distribution network (11/0.415KV), which is the power that supply the electricity to the end consumer at the receiving end for daily utilization. Thus, the distribution system is becoming too complex to solve mathematically due to the rise in Energy demand, load shedding, which Port Harcourt Electricity Distribution Company (PHED) is regularly being confronted with the supply of little available power to match the much-needed Energy (Power) demand. This research work adopted the application of voltage drop / voltage Regulation Technique for analysis and investigation using Marine Base Axis of Port Harcourt as case study. The work investigated the level of voltage drop on each section of the feeders (buses), with the view to determine where the voltage profile is critical. The critical voltage buses on the feeders are recommended with the integration of a static VAR Compensator, with the view to enhance performance in order to comply with the statutory limit of +- 10%. The deviation of voltage level, that is beyond the acceptable limit will seriously collapse or overstressed the existing operating condition of the distribution network. The capacity of the Marine Base Injection Sub-station (2x15 MVA), where (1x 15 MVA) is to supply two (2) outgoing feeders, which are Marine Base and Port Harcourt Flour Mill. Electrical Transient Analyzer Program (ETAP) was used in the analysis and simulation of load flow, voltage drop, mis-matches in active and reactive power are determined in order to investigate, identify the buses or feeder line that are critically overstressed or over loaded. The voltage drop/voltage regulation equations were formulated to measure the degree of over load/load shedding. The application of the software Electrical Transient Analyzer Program (ETAP version 12.6) requested the augmentation of static VAR compensator (size) to the distribution network help to enhance the power system quality performance, thereby making the distribution system to be more efficient.

Key word: Buses, Capacitor bank, Distribution network, Losses, Transformer, Voltage profile, Voltage drop

1.0 Introduction

Load flow examine in power system engineering, is a data analysis concern with the flow of electrical energy that is interconnected. It uses basic notations such as single line diagram and per-unit system, and involves determination of ac power parameters, such as bus voltages and angles, real power and reactive power. Its major emphasis is to determine the operating condition of the power network under steady state operation. (Navpreet and Sandeep, 2014).

Power flow study is very essential for future planning and enlargement of the system. Also, in knowing the operating condition of the existing system. The prime data gotten from the study are voltage magnitude and phase angle at each bus, and real and reactive power following in the branch. For a system that consist of more loads points such as shopping malls etc, power flow researched is significantly valued (Okwe and Akwukwaegbu, 2013).

Load-flow study provides insights and recommendation in the operational procedure of an existing system. In determination of total losses in the system, selection of transformer LTC setting, system optimization and generator unit commitment. (Nagrath and Kothari, 2016).

Due to their performance with respect to uncertainties, load flow studies can be categorised into deterministic and uncertainty. For deterministic, the study does not consider the uncertainties that may arises from both the system generation and load characteristics to account for the uncertainties, various methods such as probability theory, possibilities, information gap, decision theory, robust optimization and internal analysis were used. (Dorji, 2019).

The main function of an optimal load flow, is in planning of the system whereby the objective function is optimized for a set of non-linear constraints that are either equal or not. The power balance equations usually form the equality constraints, whereas the limit control or dependable variable forms the inequality constraints. (Dharanmjit and Tanti, 2012).

1.1 Statement of the Problem

There is a string decline in the distribution network in Port-Harcourt especially in marine base 11KV network which need improvement in the study cases. The activities of the power flow analysis the main pilar of power system analysis and design. This is because the power system future planning, and transfer of electrical power between utilities companies. The main reason for power flow analysis is to determine the voltage magnitude and phase angle on the various bus. Since reliability of electric power is absolutely important for modern society development to function optimally.

Evidently, inadequate electric power supply from generation stations to meet up energy demand requirement at the consumer ends results into:

i. Excessive losses on power line parameters
ii. Excessive losses voltage drop
iii. Power outage (black-out) in the study area.
iv. Over dependence of distribution feeder resulted into constant system collapse
v. Excessive current losses due to lower conductor size (cross sectional area).

1.2 Aim and Objectives of the Study

This paper is aimed at improving reactive power compensation for 11kv distribution network: a case of marine base Port Harcourt.

The objectives are:

i. Collect numerical data from PHEDC for the study case., for analysis
ii. Model the existing network using E-tap Environment
iii. Formulations of power flows equation, voltage equation/voltage drop and voltage regulation, for purpose of analysis
iv. To implement collected data into formulated equations
v. Conduct a simulation-test to establish violations of any component in the network.

2.0 Literature Review

Many countries, including Belgium, are facing serious electrical system challenges that have resulted in the collapse of three major reactive power sources. It was initiated by a planned failure of a large nuclear power plant during its commissioning test. In some station systems, their reactive power output is compensated and protected due to the limitation of the rotor current (Chakravorty and Das, 2012).

Although reactive power is required for most electrical equipment to operate properly, limiting it can adversely affect equipment. Normally the current flow in an electrical device is higher than the current required. However, excess power is dissipated in the form of heat when the reactive current flows through reactive components such as wires, switches and transformers, etc. (Yusuf and Muazu, 2013).

The reactive power support service plays an important role in the distribution network. Voltage regulation in any distribution network is very important for the satisfactory operation of electrical energy systems. The voltage control reduces losses in the system and also prevents a voltage breakdown. (Van, 2011)

Kapahi (2013) stated that the main cause of undervoltage in the distribution network is the lack of reactive power. He added that reactive power cannot be transmitted very far, especially when the load is high, and must therefore be generated close to the point of consumption. He further emphasized that the voltage in a power system is only / 5% of the nominal value and that this small voltage difference does not lead to significant reactive power flowing over long distances. However, he also suggested that reactive power must be available at the load centers so that the voltage level at the load centers does not drop.

In the same way, Guneet (2012) emphasized that system instability such as high transmission losses, voltage limit violations, cascade trips and high operating costs can be attributed to an unregulated flow of reactive power. However, they suggested that upgrading existing transmission and distribution lines with FACTs controllers is the solution to these problems.

According to Das (2016), it was highlighted in their paper that improving the voltage profile in the distribution system through the use of compensation devices such as capacitor banks and transformer on-load tap-changers is more effective.

3.0 Methodology

3.1 Description of Marine Base Distribution Network

The existing Marine Base distribution network consists of 2x15MVA 33/11kV injection substation with four (4) 11kV feeders. Power supply to the network is via a 33kV line duly linked to Port Harcourt Town (zone 4) Sub-Transmission Station. Table 1 and 2 shows the installed capacity of Marine base injection substation and 11kV feeder respectively.

Table 1: Installed capacity of Marine Base Injection Substation

Transformer		Rated Voltage KV	Out going Feeders
ID	MVA		
T1	15	33/11	2
T2	15	33/11	2

Table 2: Load Reading on Marine Base 11kV Feeder

Bus	Substation Information			I_R	I_Y	I_B	I_N
No	Bus ID	KVA	KV	(A)	(A)	(A)	(A)

1	Hospital Road	500	11	315	360	350	75
2	Pott Johnson	500	11	198	118	208	70
3	Barthus Street	500	11	265	252	214	88
4	Degema Street	500	11	250	208	200	40
5	Lagos Street	300	11	310	384	312	100
6	CPS	500	11	220	280	200	64
7	Police Workshop	500	11	322	313	340	106
8	Prime Rose 1	500	11	350	359	385	45
9	Prime Rose 2	500	11	350	345	380	65
10	Radio Rivers	300	11	100	110	125	45
11	St Cypran Church	300	11	110	184	112	50
12	Accra Street	500	11	310	264	296	90
13	Illorin Street	500	11	220	280	200	64
14	Ogu Street	500	11	265	200	250	60
15	Barrack Street	500	11	404	397	408	150
16	Eberi Street	500	11	290	280	275	55
17	King Ogan Street	500	11	270	285	265	50
18	Free Town	500	11	280	274	270	62

Source: Power Holding Electricity Distribution Company (PHEDC)

3.2 Load Determination

3.2.1 Average Load Current (I_L)

The average load current (I_L) of the distribution transformer is giving by

$$I_L = \frac{I_R + I_Y + I_B + I_N}{3} \quad (1)$$

Where

I_R is current in the red line

I_Y is current in yellow line

I_B is current in the blue line

I_N is neutral line

3.2.2 Transformer Rated Current (I_S)

The rated current (I_s) of a distribution transformer is giving by

$$I_S = \frac{KVA_{Rated}}{\sqrt{3} * V_s} \quad (2)$$

Where

KVA_{Rated} is the rated capacity of the transformer

Vs is the secondary voltage of the transformer

3.2.3 % Loading of Transformer (T_{FL})

The loading of a distribution transformer in percentage is giving by

$$T_{FL} = \frac{I_L}{I_S} * 100 \quad (3)$$

3.3 Moment Distribution Techniques

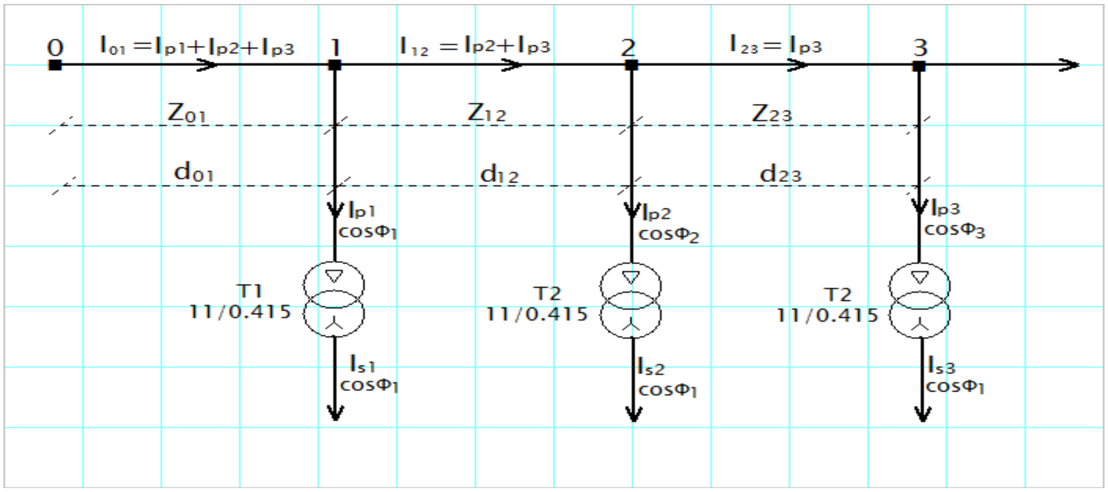

Figure 1: Current Flow in the Distribution Line

Figure 1 shows a distribution line supplied from one end with concentrated loads tapped at different points. The moment distribution of current about a node is the product of current and the total impedance through which it flows up to the point where it is tapped off.

3.3.1 Determination of Current Flowing along the Distribution Line

Complex power at the *ith* node on the distribution line is given by

$$S_i = V_i I_i^* = P_i + jQ_i \quad (4)$$

$$I_i = \left(\frac{S_i}{V_i}\right)^* = \frac{P_i - jQ_i}{V_i^*} \quad (5)$$

$$I_i = \frac{\sqrt{P_i^2 + Q_i^2}}{|V_i|} \frac{\angle \tan^{-1}\left(-\frac{Q_i}{P_i}\right)}{\angle - \delta_i} \quad (6)$$

$$|I_i| = \frac{\sqrt{P_i^2 + Q_i^2}}{|V_i|} \quad (7)$$

$$\phi_i = \delta - \tan^{-1}\left(\frac{Q_i}{P_i}\right) \quad (8)$$

$$I_i = |I_i| \angle - \phi_i \quad (9)$$

$$I_i = I_i(\cos\phi_i - j\sin\phi_i) \quad (3.10)$$

Where

P_i isActive power in the *i*th node

Q_i isline losses in the *i*th node

ϕ_i is power factor angle for the load current in the *i*th node

The load current tapped from respective nodes as shown in figure 3.1 above is giving by

$$I_{p1} = I_{p1}(\cos\phi_1 - j\sin\phi_1) \quad (3.11)$$

$$I_{p2} = I_{p2}(\cos\phi_2 - j\sin\phi_2) \quad (3.12)$$

$$I_{p3} = I_{p3}(\cos\phi_3 - j\sin\phi_3) \quad (3.13)$$

Similarly, the load current flowing on the distribution line to the point where it is tapped off at respective nodes is giving by

$I_{01} = I_{p1} + I_{p2} + I_{p3}$ (3.14)

$I_{12} = I_{p2} + I_{p3}$ (3.15)

$I_{23} = I_{p3}$ (3.16)

Therefore substituting I_{p1}, I_{p2}, I_{p3} in (3.11), (3.12), (3.13) into (3.14), (3.15), (3.16)

$I_{01} = I_{p1}(\cos\phi_1 - j\sin\phi_1) + I_{p2}(\cos\phi_2 - j\sin\phi_2) + I_{p3}(\cos\phi_3 - j\sin\phi_3)$ (3.17)

$I_{12} = I_{p2}(\cos\phi_2 - j\sin\phi_2) + I_{p3}(\cos\phi_3 - j\sin\phi_3)$ (3.18)

$I_{23} = I_{p3}(\cos\phi_3 - j\sin\phi_3)$ (3.19)

Where

I_{p1} is primary currents at node 1

I_{p2} is primary currents at node 2

I_{p3} is primary currents at node 3

3.3.2 Determination of Impedance per Section on the Distribution Line

$Z_{01} = z * d_{01}$ (3.20)

$Z_{12} = z * d_{12}$ (3.21)

$Z_{23} = z * d_{23}$ (3.22)

Where

z is impedance per unit length in Ω/km

d_{01}, is the distance up to node 1 in km

d_{12}, is the distance between node 1 and node 2 in km

d_{23} is the distance between node 2 and node 3 in km

3.3.3 Determination of Voltage Drop per Section on the Distribution Line

$V_{01} = I_{01} * Z_{01}$ (3.23)

$V_{12} = I_{12} * Z_{12}$ (3.24)

$V_{23} = I_{23} * Z_{23}$ (3.25)

Also, the total voltage drop on the distribution line is giving by

$V_{Tdrop} = V_{01} + V_{12} + V_{23}$……… (3.26)

$V_{Tdrop} = z[I_{p1}(d_1) + I_{p2}(d_1 + d_2) + I_{p3}(d_1 + d_2 + d_3)]$ (3.27)

Where

z is impedance per unit length in Ω/km

V_{01} is the voltage drop upto node 1

V_{12} is the voltage drop across node 1 and node 2

V_{23} is the voltage drop across node 2 and node 3

4.0 Result Presentation

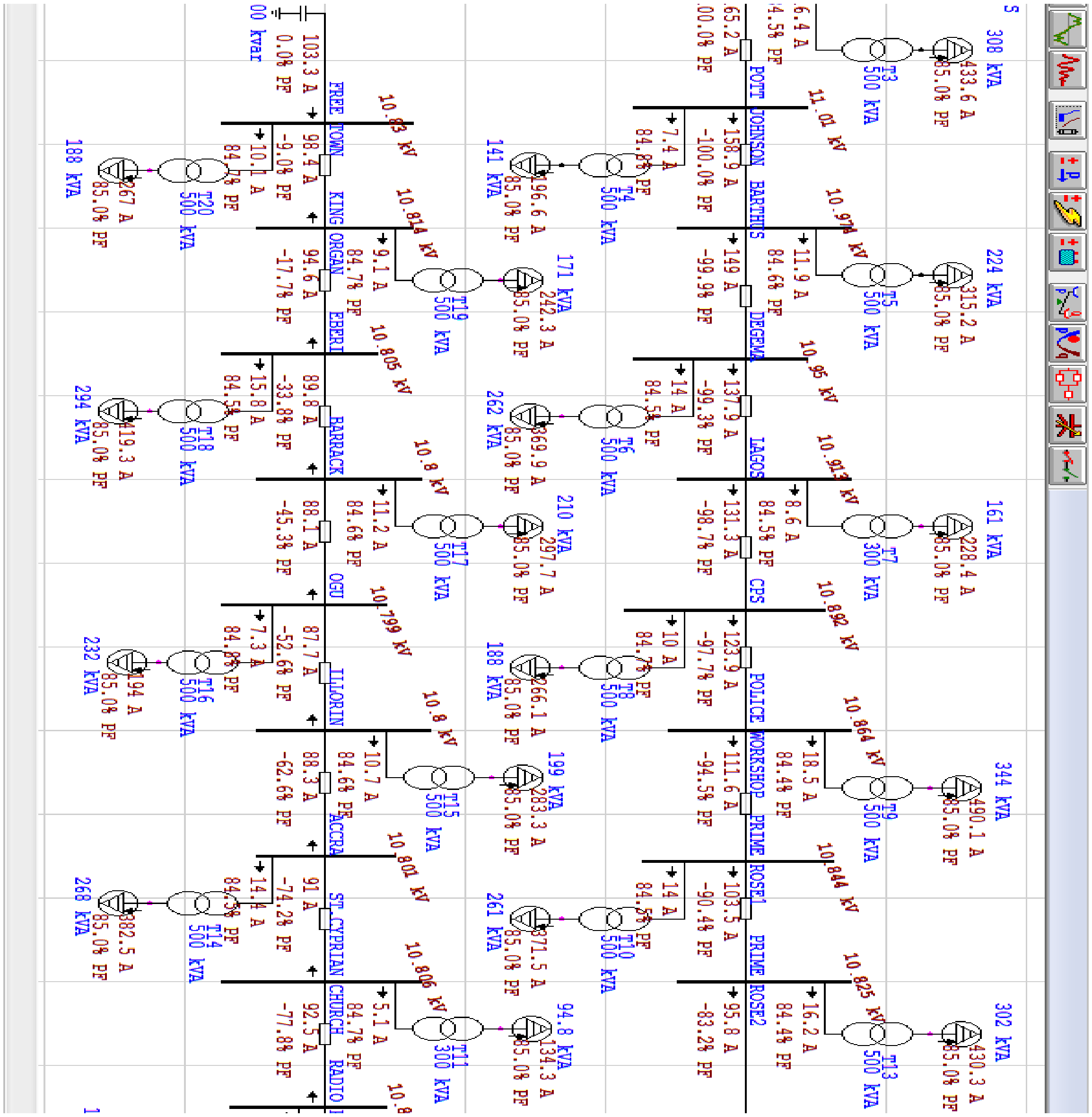

Figure 2: Etap simulation of Marine-Base 11kV Distribution Network

Table 3: Showing the Existing and Improved State of the Buses

Bus Information		Nominal Voltage	Operating Voltage			
			Existing State		Improved State	
ID	Name	(kV)	(kV)	%	(kV)	%
1	Hospital Road	11	10.722	97.47	11.039	100.35
2	Pott Johnson	11	10.684	97.13	11.011	100.1
3	Barthus Street	11	10.633	96.66	10.975	99.77
4	Degema Street	11	10.597	96.34	10.951	99.55
5	Lagos Street	11	10.541	95.83	10.914	99.22
6	Cps	11	10.511	95.55	10.893	99.03
7	Police Workshop	11	10.464	95.13	10.865	98.77
8	Prime Rose 1	11	10.430	94.82	10.846	98.60

9	Prime Rose 2	11	10.393	94.48	10.827	98.43
10	Radio Rivers	11	10.368	94.25	10.816	98.33
11	St Cypran Church	11	10.343	94.03	10.808	98.25
12	Accra Street	11	10.330	93.91	10.799	98.17
13	Illorin Street	11	10.320	93.82	10.793	98.12
14	Ogu Street	11	10.315	93.77	10.790	98.09
15	Barrack Street	11	10.309	93.72	10.788	98.07
16	Eberi Street	11	10.299	93.63	10.786	98.05
17	King Ogan Street	11	10.294	93.58	10.788	98.07
18	Free Town	11	10.291	93.55	10.793	98.12

Table4: Showing the Voltage Drop on the Line and the Distance Across the Various Buses

Line ID	From Bus	To Bus	Length (km)	%Voltage Drop in Line Section Existing State	Improved State
1	Marine Base S/S	Hospital Rd	0.95	3.75	2.8
2	Hospital Rd	Pott Johnson	0.47	1.7	1.25
3	Pott Johnson	Barthus	0.66	2.3	1.65
4	Barthus	Degema	0.49	1.6	1.1
5	Degema	Lagos	0.83	2.5	1.65
6	Lagos	Cps	0.50	1.45	0.9
7	Cps	Police Workshop	0.78	2.1	1.3
8	Police Workshop	Prime Rose1	0.67	1.55	0.9
9	Prime Rose1	Prime Rose2	0.82	1.7	0.85
10	Prime Rose2	Radio Rivers	0.65	1.15	0.5
11	Radio Rivers	St.Cyprian Church	0.68	1.1	0.4
12	St.Cyprian Church	Accra	0.43	0.65	0.4
13	Accra	Illorin	0.35	0.45	0.25
14	Illorin	Ogu	0.24	0.25	0.1
15	Ogu	Barrack	0.32	0.3	0.1
16	Barrack	Eberi	0.65	0.45	0.1
17	Eberi	King Organ	0.68	0.25	0.1
18	King Organ	Free Town	0.88	0.15	0.25
	Total		**11.05km**	**23.4%**	**14.6%**

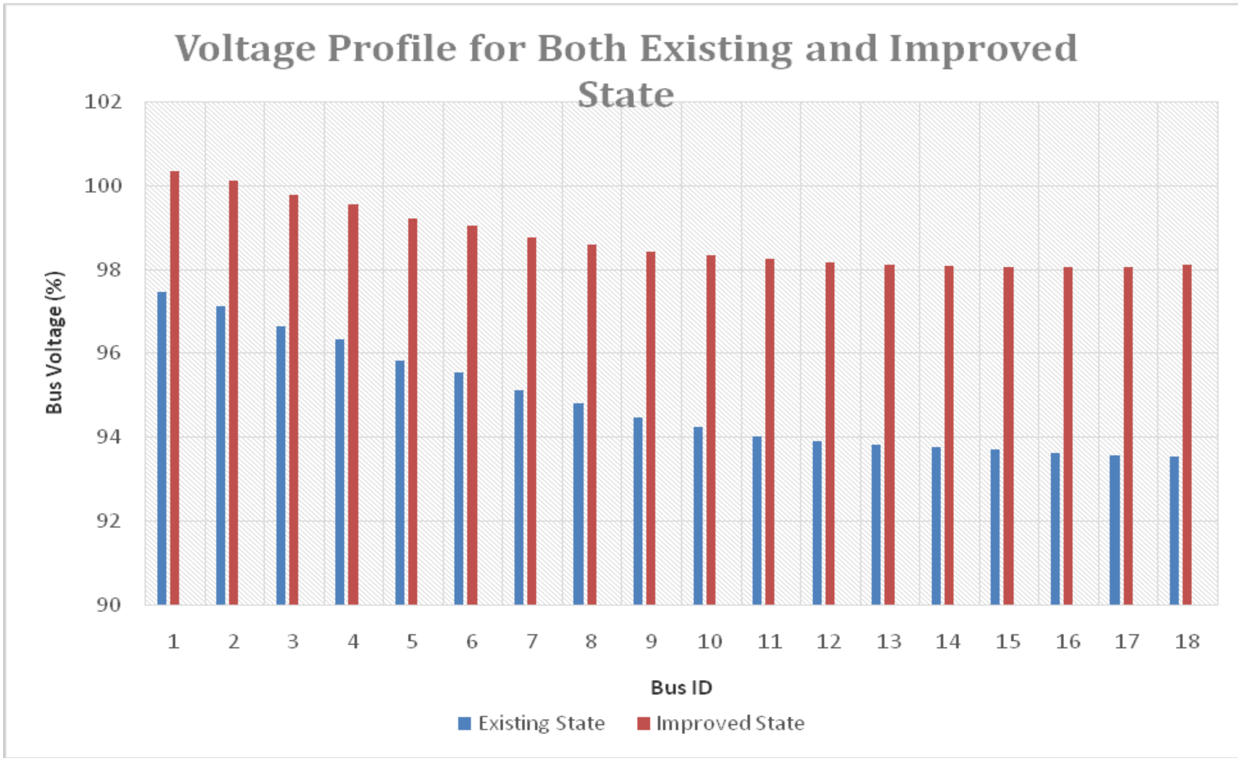

Figure 3: Voltage Profile of Marine Base 11kV Distribution Network

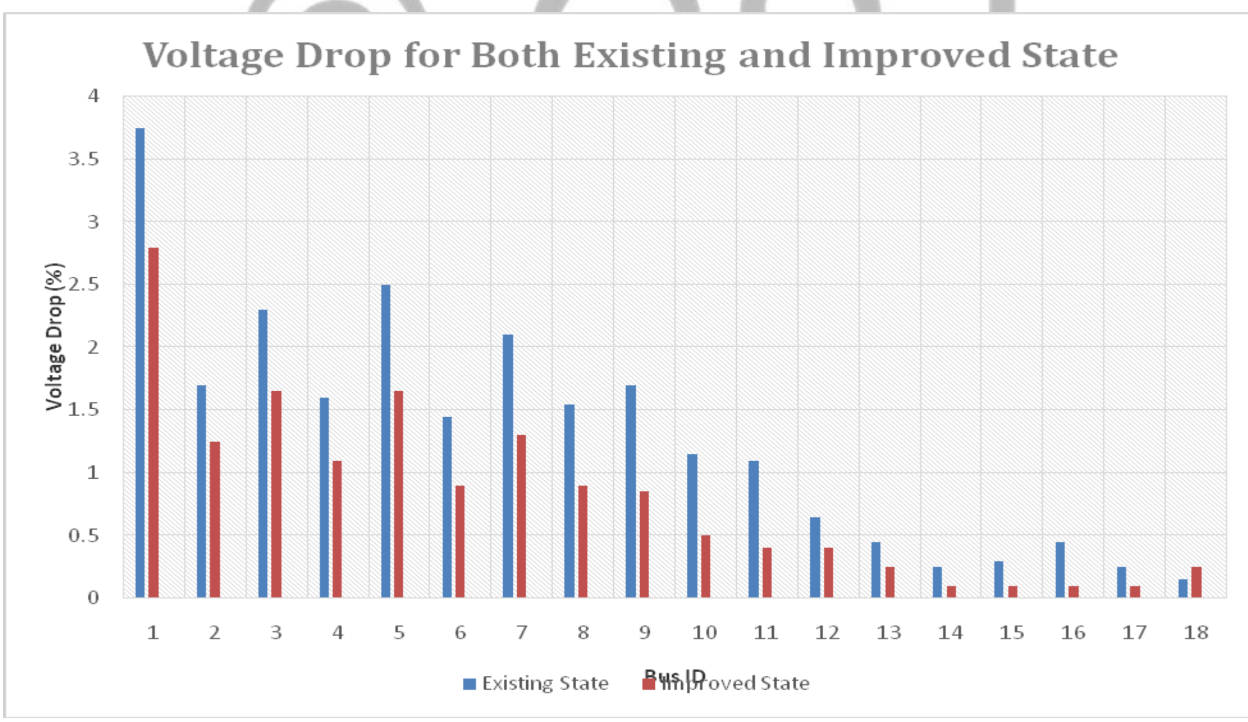

Figure 4: Voltage Drop in Marine Base 11kV Distribution Network

4.1 Result Discussion

Table 3 shows the nominal and operating values at each bus for both existing and improved state in the distribution network. A quick look at the voltage profile shows that violation of lower voltage statutory limit of 95% occurred at bus 10 (10.368kV), 11 (10.343kV), 12 (10.330kV), 13 (10.320kV), 14 (10.315kV), 15 (10.309kV), 16 (10.299kV), 17(10.294kV), and 18 (10.291kV) violated the lower voltage statutory limit of 95%. However, when static var compensation was added to the network the voltage profile improved as shown in table 4.1 bus 10 (10.368kV), 11 (10.343kV), 12 (10.330kV), 13 (10.320kV), 14 (10.315kV), 15 (10.309kV), 16 (10.299kV), 17(10.294kV), and 18 (10.291kV).

Table 4 shows the voltage drop along line section of the distribution network for both existing and improved state. For the existing state, the total voltage is 23.4% when no static var compensation is connected to the network while for the improved state, the total voltage is 14.6% when static var compensation is connected to the network. The voltage drop experienced in the distribution network is as a result of either increased in load demand by consumers, power theft or technical losses. A quick look at the table4.2 shows that the improvement in voltage at the buses is as a result of voltage drop reduction by 8.8% when static var compensation was connected to the system.

Figure3 shows the graph of voltage profile of Marine Base 11kV distribution network for both existing and improved state. The blue colour shows the existing state when no static var compensation is connected to the network. Similarly, the brown colours shows the improved state when static var compensation is connected to the network. A quick look at the figure 3 shows that the voltage profile of the network improved significantly when static var compensation was connected to the system.

Figure 4 shows the graph of voltage drop in the distribution system for both existing and improved network state. The voltage drop experienced in the distribution network is as a result of either increased in load demand by consumers on the network, power theft or technical losses. The blue color shows the existing state when no static VAR compensation is connected to the network. Buses with highest voltage drop are bus 1, bus 5, bus 3 and bus 7. Similarly, the brown color shows the improved state when static VAR compensation is connected to the network. A cursory look at the profile in figure 4 shows that there was significant reduction in voltage drop when static var compensation was connected to the network. Buses with lowest voltage drop are bus 15, bus 13, bus 18 and bus 16 respectively.

5.0 Conclusion

The existing Marine base distribution system was examined and modeled in Electrical Transient Analyzer Program (ETAP12.6) software. This research work strongly suggests the need for increasing the number of transformers at the Marine – Base Substation to enhance efficient and reliable power supply in the distribution network. Evidently, strategies are on the view to incorporate reactive power compensation devices, fast device, are suggested on the view to incorporate reactive power compensation device, fast devices, capacitors and capacitor bank.

5.1 Recommendations

The following recommendations are made which includes;

i. Provision of additional capacity for the marine-base sub-station to take care of the over stressed
ii. In co-operation of reactive power component devices, fact devices capacitor bank, thyristor in other to adjust voltage profile
iii. Need for expanding distribution network at Marine base

Reference

Chakravorty, M. & Das, D. (2012). Voltage stability analysis of radial distribution networks. *International Journal of Electrical Power & Energy Systems*, *23*(2), 129-135.

Das, D. (2016). *Electrical Power System*. New Delhi: New Age International (P) Ltd.

Dharanmjit and Tanti D.K. (2012). Load flow analysis on ieee 30 bus systems. *International Journal of Scientific and Research Publications*, 2, 1-6.

Dorji, U. (2019). A review on load flow studies. *Master's Seminar*, Kumamoto University, Japan. Retrieved from http://works.bepress.com

Guneet, K., Brar, G.S., Jaswant, I.D. (2012). Improvement of voltage profile by static var compensators in distribution substation. *International Journal of Instrumentation* Services, 2, 21-24.

Kapahi, R., (2013). Load flow analysis of 132kv substation using etap software. *International Journal of Scientific & Engineering Research*, 4, 25-30.

Nagrath, I. J. and Kothari, D.P. (2016). *Power System Engineering*. Tata, McGraw-Hill Publishing Company Limited.

Navpreet, S.T and Sandeep, C. (2014) Optimized power distribution planning: A review. *International Journal of Electronics and Electrical Engineering*, 2,

Okwe, G.I, Akwukwaegbu, I.O. (2013). Concept of reactive power control and voltage stability methods in Power System. IOSR *Journal of Computer Engineering*. 1, 15- 25.

Van C.T (2011) A method to compute reactive power margin with respect to voltage collapse", IEEE Transactions on power systems, Vol. 6, No. 1, Pp 145-156.

Yusuf, J. B. & Muazu, M. B. (2013). Regional grid system design result of Nigerian Electric Power System with the aid of Neplan.