Global Scientific JOURNALS

GSJ: Volume 9, Issue 3, March 2021, Online: ISSN 2320-9186
www.globalscientificjournal.com

JOURNAL OF NEWVIEWS IN ENGINEERING AND TECHNOLOGY (JNET
Vol 2 Issue 3, September 2020

Transient Stability Analysis of 132/33KV Transmission Network of Port Harcourt Town (Z4).

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ABSTRACT:
Transmission and distribution power systems are being operated under increasingly stressed condition as a result of the ongoing trend to make the most of existing age facilities increase demand and consumption of electricity in many countries of the world. The 132/33KV Network of Port Harcourt Town (Z4) in Nigeria was not exempted. The frequent outages of this network were due to instability of collapse voltage and overloading. The collected data (the bus, line input data, power transformed capacity and the loadings on the transformers) was modelled in E-TAP 16.00 software, Adaptive Newton-Raphson's method was used in analyzing the transient stability of the network, a detailed investigation shows that the steady state operational values of the network was achieved. While shunt capacitor placement method was used as the optimization technique for the improvement of the network, as such, the power factor of the network was improved from 0.8 to 0.95. The total branch losses before optimization was approximately 13.33MVA, with an average percentage voltage drop of 3.26%. The installation of appropriate size of shunt capacitors at strategic locations of the network, the total branch losses were reduced to 10.29MVA and the percentage voltage drop reduced to 2.06%. In conclusion, Proper inspection should be care out on transmission/distribution networks and feeders to correct weak insulators and terminations so as to enhance proper maintenance on the network.

KEYWORDS: Frequent Collapse, Overloading, Power Outages, Power Factor, Optimization, Shunt Capacitors and Transient stability.

1. INTRODUCTION

Power system stability is the ability of the system to return back to its steady state after the occurrence of a disturbance in the systems. The operation of an interconnected electrical power system provides different problems to the system operators, like in the aspect of planning, construction, operation and control [1]. Power system stability is the ability of the system to return back to its steady state after the occurrence of a disturbance in the systems. According to [2] Regardless of the huge spending on the power sector in Nigeria to actualise the required power supply suitable for their citizens and to the growth of the economy, which was paramount. The major challenge to steady and efficient electrical power supply to load center are Transient instability, owning to frequent switching and operation on the line [3]. The 132/33KV network feeding Port Harcourt Town was not exempted with power outages due to instability of collapse of voltage and overloading. The assessment of transient stability and prediction of system instability or collapse have become one of the most important analysis performed as part of system planning, operational planning and real-time operation.

1.1 Review of Related Work

Voltage unsteadiness in conveyance framework was referenced in [4] as a strange state in control framework because of unsettling influence, increment in load request, or change in framework condition which causes a dynamic decline in voltage. As indicated by [5] in their production featured that the fundamental driver of voltage insecurity in a run of the mill dissemination framework may likewise be because of the disappointment of the framework to enough fulfill the interest for responsive power part occasioned by the constraint of creating power, transmission line, Transformers and increment in load request. The impact of responsive power in dissemination framework was inspected in [6] expressing that the significant reason for under voltage in the dispersion framework is the deficiency of receptive power. It was included that receptive power can't be transmitted extremely far particularly under overwhelming stacking conditions thus should be created near the purpose of utilization. As per [7], the exhibition of a power appropriation framework as far as voltage and power at the heap end can be improved by the expansion of remunerating gadgets, for example, static VAR and static synchronous compensator; and that, the repaying gadgets are progressively affordable and helpful.

Once more, as per [8] in their paper featured that improvement of voltage profile in the dispersion framework is progressively powerful with the utilization of remunerating gadgets, for example, capacitor bank and transformer load tap changer. In [9] another and proficient approach to determine the ideal position and size of capacitor banks in order to upgrade a definitive improvement of the voltage profile and decrease of line misfortunes was exhibited. In [10] it was called attention to that the power misfortune in an appropriation framework is fundamentally high up to 13%. Be that as it may, to improve line control transmission, we decrease misfortunes and improve voltage edge; as a rule, shunt capacitor banks are broadly utilized.

System reconfiguration as per [11] is one of the strategies for misfortune minimization in dissemination frameworks. The methods are utilized by explicitly opening or shutting tie switches that are in typically open conditions. It additionally includes sectionalizing of ordinarily shut switches, when this is done, control stream will be diverted.

As indicated by [12], arrange reconfiguration in circulation frameworks is one of the powerful strategies to accomplish misfortune decrease and improve appropriation framework robotization. The system can be reconfigured for two reasons: load adjusting and control misfortune decrease in the conveyance framework. In the perspective of [13], feeder reconfiguration is the way toward shutting and opening activity of switches in control dissemination framework so as to change organize topology. Accentuates were made on the significance and convenience of feeder reconfiguration strategy in decreasing feeder misfortune, improve framework security and dependability.

As per [14], ideal arranging of conveyance frameworks includes organize reconfiguration for misfortune minimization, load adjusting under ordinary working conditions and quick help rebuilding. Regardless of the different strategies regularly practice in improving force appropriation organizes, the procedural strides of examination must use control stream investigation to evaluate the status of intensity entrance to different branch and loads. In writing, various techniques for power or burden stream study are referenced.

As per [15], the Gauss-Seidel iterative technique for doing stack stream study is synonymous with doing a rehashed improvement or comprehending conditions with nonlinear attributes. It is one of the most prevalently utilized strategies for taking care of intensity stream issues. The Gauss-Seidel strategy accept an underlying variable, and a lot of new factors are then determined from one of the conditions. The arrangement is quickly refreshed as for the determined variable. The procedure proceeds until the arrangement combines to a predetermined worth. [16], featured the benefits of the Gauss-Seidel technique as far as its straightforwardness. He further repeated its benefits, for example, its ability to lessen the time limitation related with calculations of this nature.

2.0 MATERIALS AND METHODS

The materials required for the analysis of this research are: the line and bus input data, the loadings of power transformers and it rating, the synchronous generators ratings, the voltage profiles, the power flows and losses in the network. It will also provide detailed information on the stability condition of the network. Electrical Transient Analyzer Program (ETAP) 16.00 software was used to model and simulate the network, while Adaptive Newton Raphson method was used to determine the load flow analysis.

A. Description of the Network

The data collected from Transmission Company of Nigeria (TCN) and the Port Harcourt Electricity Distribution Company (PHEDC) was purpose for the analysis and investigation of the power supply network from 132/33/11KV Transmission Network of Port Harcourt Town (Z4) located at Nzimiro by Amadi junction with an installed capacity of 165MVA, The substation receives its supply via double circuit transmission line from Afam 132kV switch yard duly linked to the 330kV national grid at Aloaji substation, as shown in figure 1.

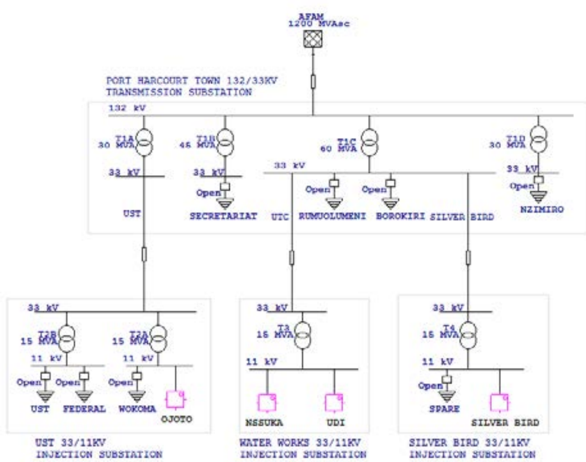

Figure 1: The Existing Network of 132/33KV Transmission Network of Port Harcourt Town (Z4) (Source: Port Harcourt Electricity Distribution Company (PHEDC)).

B. **Feeders Surveyed with transformers, Feeder route length, Conductor Size and Type.**

The load centers electricity distribution network within the Water Works, Silver Bird and UST 33/11KV Injection Substations respectively, Water Works delivered electricity supply through Udi with feeder route length of 3.61Km and Nssuka with feeder route length of 4.733Km that connect power Emenike Street, Lumumber and Iluabuchi road respectively. The 33/11KV Injection Substations of Silver Bird, takes electricity power to Ikwerre Road with feeder route length of 7.352Km along mile 2 Doibu Port Harcourt. the same rated Injection Substations of UST, transport electricity power to Ojoto with feeder route length of 6.19Km. table 3.1; shows the total numbers of transformers with their sizes on each route length, the conductor type and size, while table 3.2 shows the installed capacity at the transmission substation (Nzimiro), rated voltage and the number of feeders respectively.

Table 1a: Feeders Surveyed with transformers, Feeder Route Length, Conductor Size and Type.

Injection Substations	**Examined Feeders**	**Feeder Route Length**	**Conductor Size**	**Conductor Type**
Water Works	Udi	3.61Km	150mm^2	Aluminium
	Nssuka	4.733Km	150mm^2	Aluminium
Silver Bird	Ikwerre Road	7.352Km	150 mm^2	Aluminium
UST	Ojoto	6.19Km	150mm^2	Aluminium

Table 1b: Feeders Surveyed with transformers

Injection Substations	**Examined Feeders**	**No of Distribution Transformers in KVA**				
		500	300	200	100	50
Water Works	Udi	15	2	-	3	2
	Nssuka	6	-	-	1	-
Silver Bird	Ikwerre Road	7	-	3	1	1

UST	Ojoto	5	-	-	1	-

Source: Port Harcourt Electricity Distribution Company (PHEDC).

Determination of line per kilometer Resistance

Resistance, $R = \frac{\rho L}{A} \quad \Omega/km$ (1)

Where;

ℓ = Resistivity of Aluminum= $2.8\, X\, 10^{-8}$ Ohm/m

A = Area of conductor= $150mm^2$

L= Route length of the feeder (Km)

Determination of line per kilometer Reactance

$$GMD = \sqrt[3]{D_{ab} \times D_{ac} \times D_{ac}} = 1.26D \quad (2)$$

$$r = \sqrt{\frac{A}{\pi}} \quad (3)$$

$$X_0 = 0.1445 In\left(\frac{GMD}{r}\right) + 0.0157 \; \Omega/km \quad (4)$$

Determination of line per kilometer Impedance

$$Z_0 = R_0 + JX_0 \quad (5)$$

Determination of per kilometer Capacitive Susceptance

$$B = \frac{7.5}{\log_{10}\left(\frac{D_{GMD}}{r}\right)} \times 10^{-6} \quad (6)$$

Determination of line per kilometer Admittance

$$Y_0 = G_0 + JB_0 \quad (7)$$

Where:

D_{GMD} is the geometric mean distance of conductor

R is the radius of conductor

D is the distance between adjacent conductor (D=2m).

G is the conductance of the line

B is the susceptance of the line

Case 1: Water Works Injection Substations Parameters

a. Udi Feeder (line) Distribution Line Parameters:

Resistance, $R = \frac{\rho L}{A}$

A = $150mm^2 = 150 \times 10^{-6} m^2$

$\rho = 2.8 \times 10^{-8}$ohm/m

L = 3.61km = 3.61×10^3m

$\therefore$ The resistance of Udi feeder, R, was calculated using equation (1)

Per kilometer inductive reactance of the Udi feeder was calculated using equation (4).

$$X = 0.1445 \log_{10} \frac{1.108}{0.0069} + 0.0157$$

$$= 0.1445(2.205) + 0.0157\,; \; X = 0.3343 ohm/km$$

$\therefore$ The inductive reactance of the Udi feeder is

$$X = 0.3343 \times 3.61;\; X = 1.206 ohm$$

Applying equation 3.5, the impendence of the Udi feeder is

$$Z = R + JX \qquad = 0.674 + j1.206 ohm$$

Equation (6) was used in determining the Per kilometer capacitive B.

$$B = \frac{7.5}{\log_{10} \frac{1.108}{0.0069}} \times 10^{-6} \qquad = \frac{7.5}{2.205} \times 10^{-6}$$

$$B = 3.401 \times 10^{-6} ohm/km$$

$\therefore$ The capacitive susceptance of Udi feeder

$$B = 3.401 \times 10^{-6} \times 3.61$$

$$B = 1.227 \times 10^{-5}\, per ohm$$

Applying equation (7), the admittance of the Udi feeder is given below

$$Y = G + JB$$

$$Y = 1.483 + J1.227 \times 10^{-5}\, per ohm$$

Same mothed above was used in determining the examined feeder, feeder route length, the conductor size for each feeder and their injection substations with the use of the Parameters in table 1.1a and 1.1b.

Current Data Collected on 132/33 KV Primary and Secondary Transformer in Port Harcourt Town (Z4)

The collected data used in this research work were gotten from Port Harcourt Electricity Distribution Company (PHED), which includes; line impedance, bus voltage ratings, transformer data and transformer load readings:

Product of C. T=ABB

C.T Ratio=400:1

RHSV 36KV

Type =outdoor

Frequency =50 Hz

Burden =50VA core

Core 1=400/1A=10P10

Core 2=10P10 400-1A

Core 3=10P10 400-1A

Calculation of Load Current

Power Triangle was used in analyzing the reactive power, apparent power and power factor.

Transformer load in SVA= $\sqrt{3}IV$ (8)

Active power in watts or kW= $\sqrt{3}IV\cos\theta$ (9)

Reactive power in kVAR= $\sqrt{3}VI\sin\theta$ (10)

Apparent power in kVA= $\sqrt{\text{kW}^2+\text{kVAR}^2}$ (11)

Power factor, $\cos\theta = \frac{\text{Active power}}{\text{Apparent power}} = \frac{\text{kW}}{\text{kVA}}$ (12)

Complex power, S = P + JQ (13)

Current $I = \frac{P(KVA)}{\sqrt{3}IV}$ (14)

Where, I, represent Current. V, represent Voltage and $\cos\theta$ represent the power factor at primary and secondary of transformers respectively.

Using the above equation (11 - 14) in determining the transformer connection in Delta/Star since the system consists of different rout length which are as follows

Case 1: Water Works Injection Substations

The water works injection substations consist of two feeders namely (Nssuka and Udi) with installed transformer capacity rating of 45MVA and 60MVA respectively, while the rated voltage are 132/33 kV respectively, as shown in table 2 above, explaining the above formula deductions.

(1a) The Nssuka 45MVA, 132/33KV transformer was connected in Delta/Star,

Equation (12) above was used in determining the primary and secondary current of the 45MVA, 132/33KV transformer, we have

Power (P) in KVA $= \sqrt{3}IV$; Hence, $I = \frac{P(KVA)}{\sqrt{3}IV}$

Primary Load current $I_p = \frac{P(KVA)}{\sqrt{3}IV} = \frac{45*10^{\wedge 6}}{\sqrt{3}*132*10^{\wedge 3}} =$ 196.82A

While,

Secondary load current $I_s = \frac{P(KVA)}{\sqrt{3}IV} = \frac{45*10^{\wedge 6}}{\sqrt{3}*33*10^{\wedge 3}} =$ 787.3A

Same mothed above was used in determining the transformer load current rating in the primary and secondary transformer for each Injection Substation and feeders as represented in table 2: shows the determined data 30MVA, 33/0.415KV transformer load current rating in the primary and the load current rating on 200KVA, 33/0.415KV secondary transformer connected in Delta/Star in UST Substation.

Table 2: The Transformer Load Current Rating in the Primary and Secondary Transformer for each Injection Substation and feeders.

Injection Substations	Feeders Name	Primary Load Current	Secondary Load Current
Water Works	Nssuka	196.82	787.3
	Nssuka	8.75	695.6
	Udi	2624.32	10497.28
	Udi	8.75	695.6
Silver Bird	Ikwerre Road	131.22	524.86
	Ikwerre Road	8.75	695.6
UST	Ojoto Road	131.22	524.86
	Ojoto Road	8.75	695.6

Capacitor Bank Calculation

For optimal results, capacitor banks shall be installed near load terminals, so as to provide leading voltage-Ampere reactive (VAR) and thus improve power factor of systems to 0.95 (desire).

Bus 27:

Total KW load = 20500KW

Existing pf = 0.8

Desired pf = 0.95

$\theta_1 = \cos^{-1} 0.8 = 36.87^0$

$\theta_2 = \cos^{-1} 0.95 = 18.19^0$

Size of capacitor needed to be installed on Bus 27;

cKvar = 20500 (tan 36.87^0 – tan 18.19^0)

cKvar = 8638.96

Bus 14:

Total KW on bus 14 = 12500KW

Capacitor needed to be installed on Bus 14;

cKvar = 20500 (tan 36.87^0 – tan 18.19^0)

cKvar = 12500 x 0.4214 = 5267.5 Kvar

Bus 15:

Total KW on bus 15 = 13100KW
Capacitor needed to be installed on bus 15;
cKvar = 13100 x 0.4214 = 5520.34Kvar

Bus 16:
Total KW on bus 16 = 10500KW
Capacitor needed to be installed on bus 16
cKvar = 10500 x 0.4214 = 4424.7 Kvar

Bus 17:
Total KW on bus 17 = 7400KW
Capacitor needed to be installed on bus 17
cKvar = 7400 x 0.4214 = 3118.36 Kvar

Bus 18:
Total KW on bus 18 = 12300KW
Capacitor needed to be installed on bus 18
cKvar = 12300 x 0.4214 = 5183.22 Kvar

Bus 19:
Total KW on bus 19 = 12200KW
Capacitor needed to be installed on bus 19
cKvar = 12300 x 0.4214 = 5141.08 Kvar

The preferred size of capacitor rating for this research work shall be 800Kvar per unit. Hence, size of capacitor bank that shall be installed on the buses will be:

Bus 27 = 11 x 800Kvar
Bus 14 = 7 x 800Kvar
Bus 15 = 7 x 800Kvar
Bus 16 = 6 x 800Kvar
Bus 17 = 4 x 800Kvar
Bus 18 = 7 x 800Kvar
Bus 19 = 7 x 800Kvar
Total size of capacitor installed = 48 x 800Kvar = 38,400Kvar

3.0 RESULTS AND DISCUSSION

The results in figure 2, shows that the one-line diagram of the network using transient stability analysis.

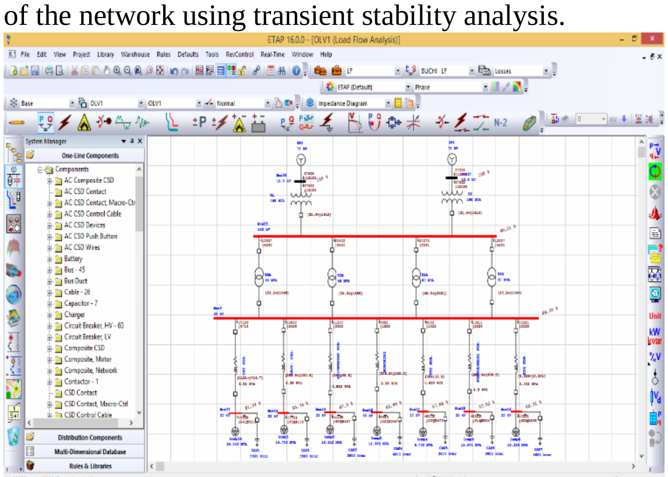

Figure 2: Load Flow Result of 132/33KV Transmission Network of Port Harcourt MainTown before Optimization

Figure 3, shows the power flow result of the resisting network. All the buses aside from the generation buses are seen to be flagged critically low. The power losses from Borokiri, K24, Rumuolumeni, Secretariat, Silverbird, UST and UTC feeder are (281.7j84.7)KVA, (0.7+j0.4)KVA, (637.0+j402.4)KVA, (371.2+j234.5)KVA, (124.7+j78.5)KVA and (1451.9 + j917.1)KVA respectively, with their drop in voltage seen to be 2.83%, 0.01%, 5.44, 3.13%, 0.99% and 7.54%, 0.55% respectively. From the result, it is clear that the existing network was operated on a pf of 0.8.

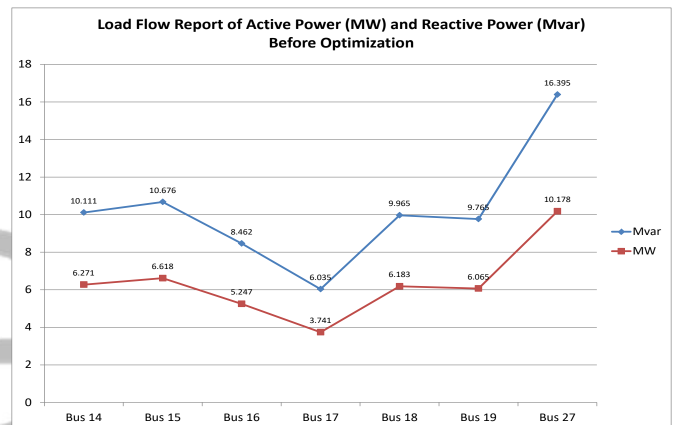

Figure 3: Load Flow Report of Power Injected into Buses before Optimization.

The result in figure 4, shows the power losses along the 33KV feeders of the network. The blue curve gives the real power losses, while the red curve shows the reactive losses along the feeders.

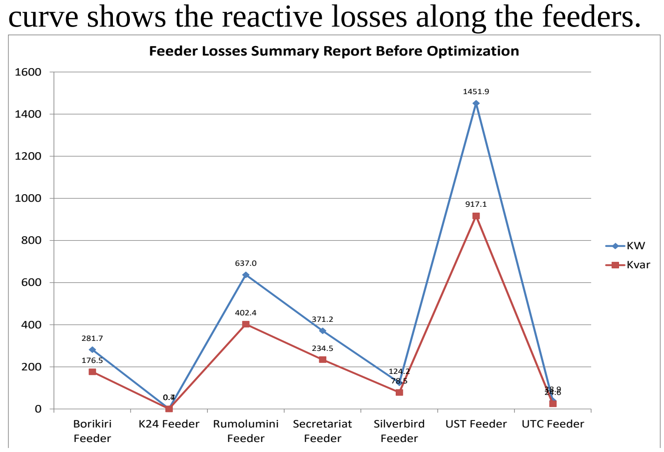

Figure 4: Feeder Losses Summary Report before Optimization

The result in figure 5, shows that the percentages operating voltages of the buses under study, as well as the current injected into them. The red curve gives the percentage voltage at which the buses are operated, while the blue curve is for the amount current flow into the buses.

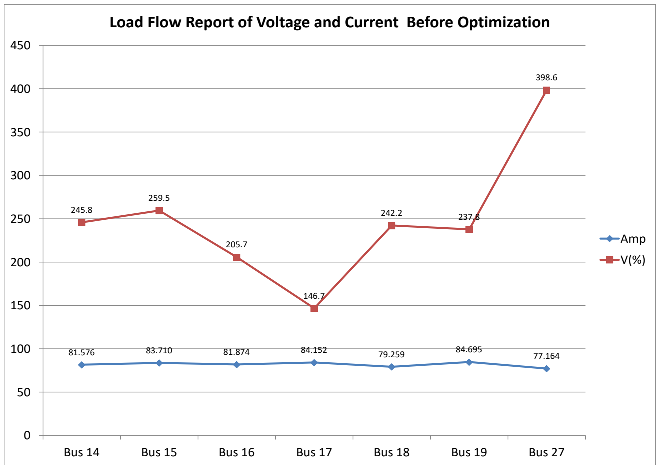

Figure 5: Load Flow Report of Voltage and Current Flow before Optimization

The result in figure 6, shows the Adaptive Newton-Raphson method used in ETAP 16.00 software, capacitor placement was used as the optimization technique in improving the network.

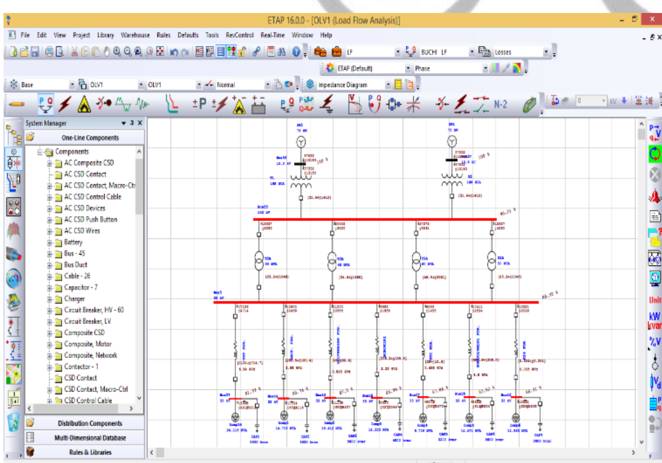

Figure 6: Load Flow Result of 132/33KV Transmission Network after Optimization

4.0 CONCLUSION:

The 132/33KV Afam transmission line network was analyzed in ETAP 16.00 using the adaptive Newton Raphson method from which the steady state operational values and losses were obtained. From analysis, it was seen that the network is overloaded with a considerable amount of energy lost via losses. The amount of current flow from supply to the buses was high due to the increase in the reactive part of it. As a result of this, the losses along branches and conductor were high. Results showed that the present network was operated on a power factor of 0.8.

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