Journal of Electrical Engineering, Electronics, Control and Computer Science – JEEECCS, Volume 4, Issue 13, pages 1-8, 2018

Technical Loss Estimation and Reduction in a Typical Nigerian Distribution System: A Case Study

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***Abstract* - Nigeria's electric power distribution network is faced with high technical power losses arising mainly from the radial nature of distrib1ution systems, long length of feeders and poor voltage profile. This work estimates the financial implication of the technical losses in a typical Nigerian distribution network and proposes ways to reduce it.**

The existing Benin Electricity distribution company (BEDC) Asaba government core area injection substation distribution network comprising of a 15MVA 33/11KV power transformer and its two number radially connected 11KV feeders – SPC and Anwai road with their aggregate of ninety six (96) number secondary distribution 11/0.415KV transformers was modelled with ETAP 7.0.0 software, and a load flow analysis was carried on the modelled network using Newton-Raphson method deployed in the ETAP 7.0 software. This was done to determine bus voltages, real and reactive power losses in the network. Data used for the study were obtained from BEDC Asaba business district between June and August, 2017.

Analysis of the load flow results show that using the current multi-year tariff order (MYTO) for BEDC with the cost of a KWh of energy at ₦31.27 for residential customers as base, ₦1, 065,569,028.00 worth energy will be lost in the network within a ten-year period. Further analysis shows that a savings of ₦640,742,713.10 will be made within 10 years if the distribution network is compensated by optimally locating reactive power compensating devices.

Keywords- Compensating Devices, Financial Implication, Technical Losses, Financial Implication.

I. INTRODUCTION

Energy is defined as the capacity or ability for doing work. Therefore, any nation that seeks development must have serious business with energy development. Energy plays a major role in the economic, social and political development of any nation. Insufficient supply of energy limits economic growth, restricts socio-economic activities and adversely hinders the quality of life [1].

In spite of the enormous funds already committed by the federal government of Nigeria (FGN) into the power sector couple with the resultant deregulation and liberalization of the electricity industry commencing in 2005, Nigeria still has one of the lowest annual per capital energy consumption in Africa and the world at large as shown figure 1.
As shown in [3], poor return on investment also traceable to high energy losses in the network, has greatly hampered the development and growth of the energy sector in Nigeria. Hence this work focuses on estimating the energy losses in an electrical distribution network, using BEDC as a case study.

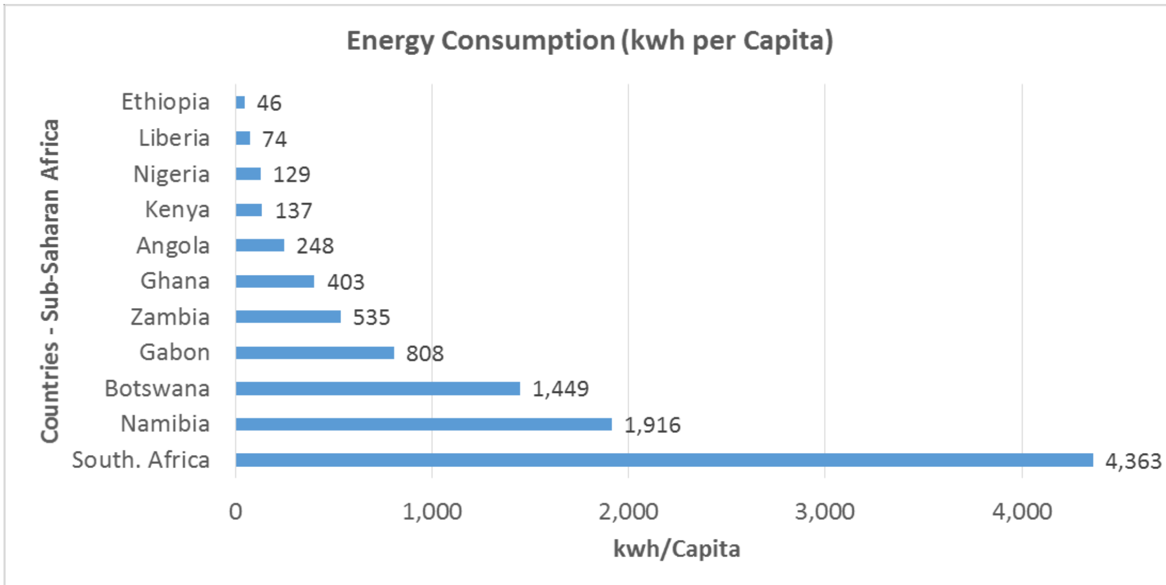

Figure 1. Energy Consumption per Capital for Selected African Countries [2].

II. Power Losses In A Distribution System

In [4]-[6], power losses refer to the amounts of electricity injected into the distribution grids that are not paid for by users. Total power losses have two components: Technical and Non-Technical power losses. Technical power losses (TL) are naturally occurring and consist mainly of power dissipated in the system components such as Distribution lines, transformers, power control equipment and measurement systems. Technical power losses are possible to compute and control, provided the power system network in question consists of known quantities of loads

Non-technical losses, on the other hand, are caused by actions external to the power system. Notable among these are electricity theft, non-payment of the energy used by the customer, use of substandard current transformer for industrial metering and industrial usage of electricity on low power factor amounting to undercharging and hence under billing by the utility company. Accurate reading of meters, poor customer billing, collection of billed amounts and proper accountability are functions that require specific management tactics. Non-Technical losses are more difficult to measure because these losses are often unaccounted for by the system operators and thus have no record information.

[7] acknowledged that various methods of loss minimization for distribution system are available in literature. But the basic methods are: (i) Distribution Network Reconfiguration, (ii) Optimal Capacitor placement, and (iii) Distributed Generations (DGs) allocation. Network reconfiguration methods presented in [8]-[10] are effective methods for reducing power losses mostly used in low voltage distribution systems.

In the Optimum Capacitor Placement (OCP) technique, shunt capacitors are generally placed near the main substation for power loss reduction, voltage profile improvement, compensation of reactive power and power factor correction [11].

It is the basic problem to determine the location and size of fixed shunt capacitor which is to be installed in the distribution system in such way that the total system power loss is minimized, voltage profile of the system is improved but net annual saving is reduced. Regarding investment

The overall cost function with capacitor placement and real power loss can be written by following equation (1) [12].

$$\text{Cost} = K_p\, P_{loss} + \sum_j^k k_j^c Q_j^c \qquad (1)$$

Where K_p is the annual cost for KW losses in $/KW and j = 1, 2… k are indices of selected buses for compensation, k^c is the corresponding capital investment per kVAr and represents the standard capacitor sizes with considering investment cost. The OCP technique will be deployed in the network under review.

III. Methodology

The existing Benin Electricity distribution company (BEDC) Asaba government core area injection substation distribution network comprising a one number 15MVA 33/11KV power transformer and its two number radially connected 11KV feeders – SPC and Anwai road with their aggregate of ninety six (96) number secondary distribution 11/0.415KV transformers was modelled with ETAP 7.0.0 software, and a load flow analysis was carried on the modelled network using Newton-Raphson method deployed in the ETAP 7.0 software. This was done to determine bus voltages, real and reactive power losses in the network. Data used for the study were obtained from BEDC Asaba business district between June and August, 2017.

Samples of data collected for the individual substation in the network under review is presented in table 5 of Appendix A. A section of the network modelled in the ETAP 7.0 environment is presented in Figure 2.

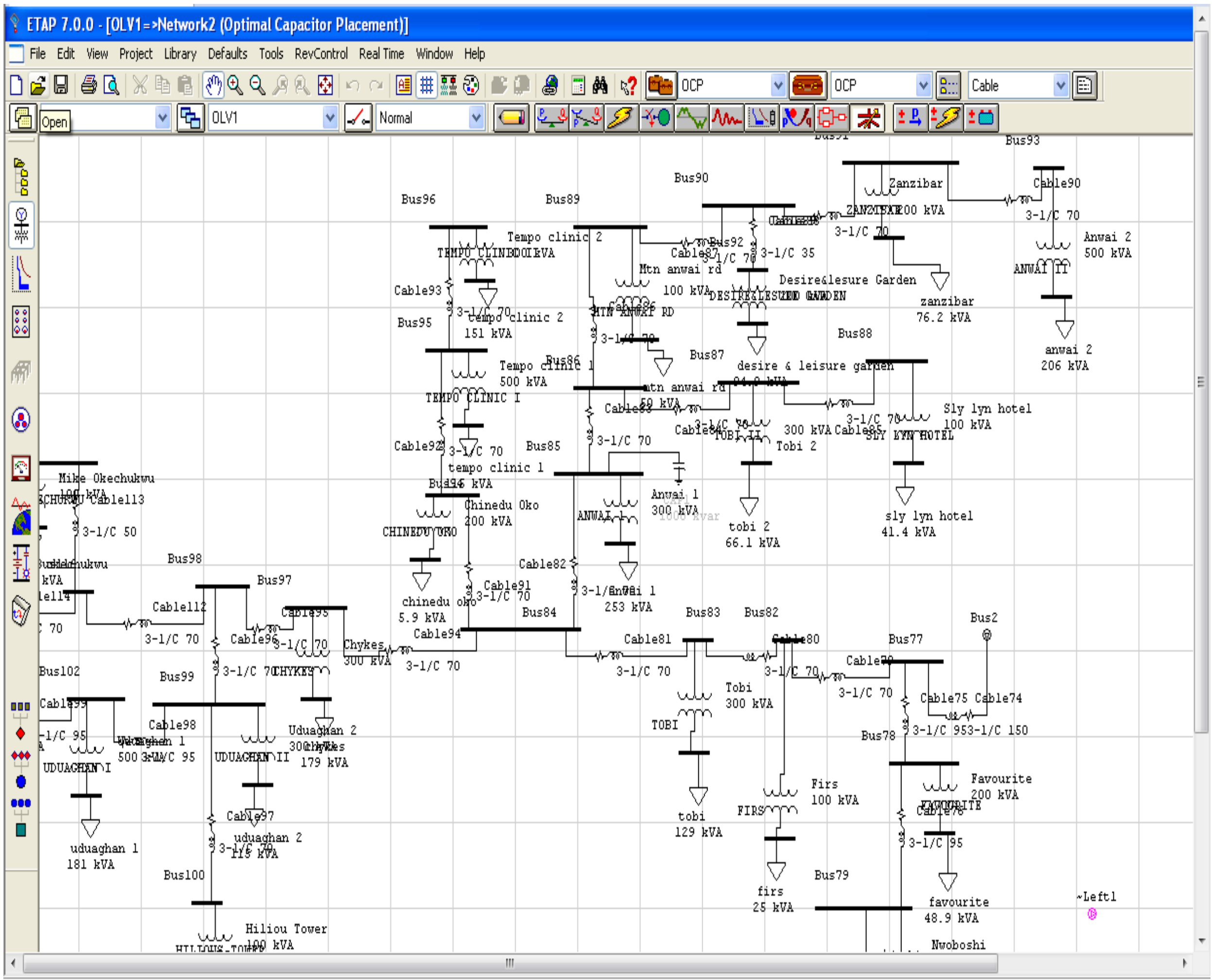

Figure 2. A Section of the Network Modelled in ETAP 7.0 Environment

Table 1 presents extracts from the load flow analysis carried out on 15MVA 33/11KV BEDC Asaba government core area injection substation and its associated feeders under review, while the graph of Figure 3 presents the variation of voltage profile for the 96 bus distribution system as extracted from the load flow result.

TABLE 1. EXTRACTS FROM LOAD FLOW ANALYSIS.

Study ID	Asaba transmission
Study Case ID	LF
Data Revision	Base
Configuration	Normal
Loading Cat	Design
Generation Cat	Design
Diversity Factor	Maximum Loading
Buses	232
Branches	231
Generators	0
Power Grids	1
Loads	96
Load-MW	10.675
Load-MVAr	5.455
Generation-MW	0
Generation-MVAr	0
Loss-MW	0.389
Loss-Mvar	0.818
Bus(es) with Voltage Violation	64

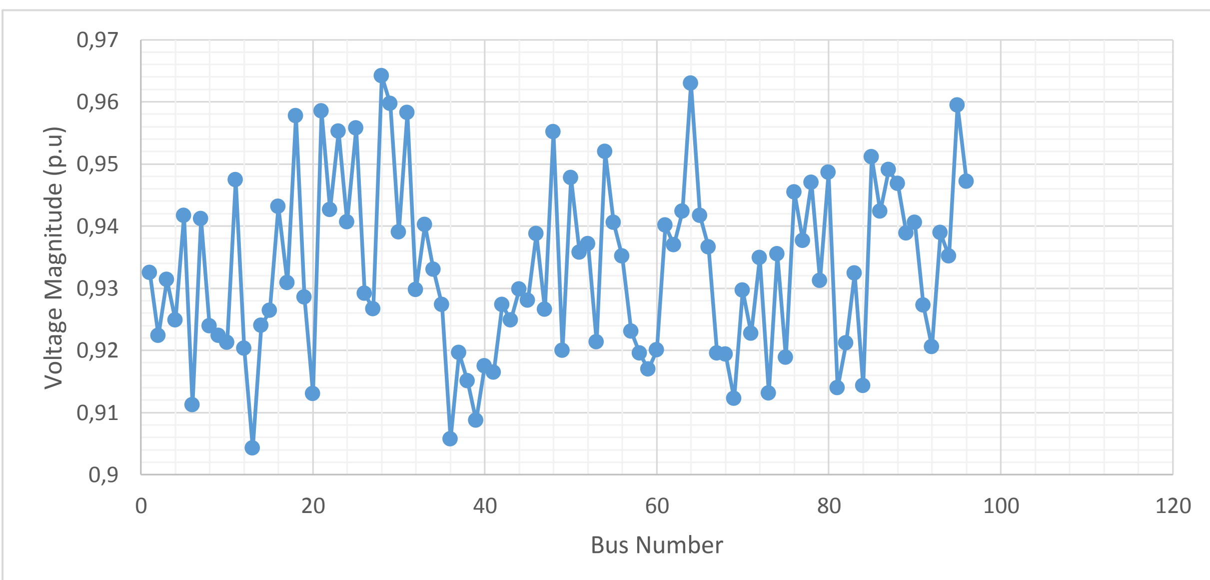

Figure 3. Variation of Voltage Profile for the 96 Bus Distribution System

IV. Deductions From The Load Flow Analysis

The result obtained from load flow analysis of the Asaba 15MVA 33/11kV injection substation and its associated feeders indicate the following:

(a) The load flow analysis carried on the network shows that out of a total of ninety six (96) load buses in the network, voltage violation occurs in sixty four (64) buses. (Buses with a voltage magnitude less than 0.94 p.u.)

(b) Total average active and reactive power loss of the system during peak period is 389KW, 818KVAr.

V. Power Loss Estimation / Costing In Asaba Government Core Area Injection Substation

The multi-year tariff order (MYTO) approved by the Nigerian Electricity Regulation Council (NERC) stipulates that the cost of a KWh of electrical energy for residential customers would be ₦31.27 for the year 2017. Using this as a base, the cost of 389kW technical power loss in the network under review for a day, a year, five years and for ten was determined, and they are presented in table 2.

TABLE 2. Cost Estimate Of The Energy Lost (Technical Loss) In The Network

Total Power Loss on the Network (KW)	**Total Energy Loss in the Network per Day(KWh)**	**Cost of Energy lost Per Day (Naira)**	**Cost of Energy Lost Per Year (Naira)**	**Cost of Energy Lost in 5 Years (Naira)**	**Cost of Energy Lost in 10 Years (Naira)**
389	9,336	291,936.72	106,556,902.8	532,784,514	1,065,569,028

Table 2 shows that over two hundred and ninety thousand Naira is lost in the network per day, and this would translate to a total of over one billion naira in ten years if the issue is not addressed.

VI. Determining Capacitor Sizes

Shunt capacitor banks are able to compensate for Var requirement, but bank size, location, cost considerations are important issues that need to be optimized during the design phase. An ideal solution would be a tool able to weigh these factors and consider load levels. The solution should be able to place capacitors for voltage support and power factor correction, while minimizing cost of operation. The problem of locating capacitors can be solved using a variety of techniques; however, the issue for determination here is the capacitor bank sizing.

The Optimal Capacitor Placement (OCP) module of the ETAP 7.0.0 software provides such an application

VII. Problem Formulation

Mathematically, the objective function of the problem is described as:

min f = min P_{Loss}; subject to:

$$V_{min} \leq |V_i| \leq V_{max} \quad (2)$$

For this study, the voltage constraint is given by :V_{min} = 0.94 pu and V_{max} = 1.06pu.

The capacitor banks are to be placed in the candidate buses already selected. The criterion for selection is simply buses with high reactive power loss. Other data input needed for the program to run are same with the load flow data input.

The OCP results are presented in table 3. The OCP module of the ETAP software, also gives the cost variables associated with the capacitors as shown in table 3.

TABLE 3. OCP Result

Candidate Bus(es) Data					**capacitor Bank Data**			**Cost (Dollars)**		
Bus No	**Volt (KV)**	**volt Mag (p.u)**	**Angle**	**power factor**	**Rated KVAr/Bank**	**No of Banks**	**Total KVAr**	**Installation**	**Purchase**	**Oper./Year**
85	11	0.9627	-3.2	0.98	300	5	1500	800	4500	1500

The OCP result (table 3) shows that to minimize power loss in the system and satisfy the voltage constraints as set out in equation (2), we will need to install the following:

(a) A bank comprising of five-number (5nos) 300KVAr capacitors at bus 85 (i.e. at Anwai I substation at the 11KV side)

(b) with the network duly compensated, (capacitor bank in place,) all bus voltages are within acceptable limit, active and reactive power loss has been reduced to 147.82Kw and 237.22 KVAr respectively.

The capacitance and reactance of the banks per phase are calculated below:

Line Voltage = 11 kV Phase Voltage = $\frac{11KV}{\sqrt{3}}$ = 6.35 kV

The rated reactive power of the capacitor bank is 300KVAr. Thus:

Q_c = 300KVar

Q per phase = Q_{cph} = 300/3 = 100 KVAr

Xcph = $\frac{V_{ph}^2}{Q_{cph}}$ = 6.35^2/100 = 403.225 Ω

$X_{cph} = 1/2\pi fc$; f = 50Hz,

C = $1/2\pi X_{cph} f$ = $394.7\mu F$

Hence, the 300KVAr banks should be of capacitance not less than $394.7\mu F$. These capacitor banks should be installed at location already stated.

VIII. Cost Of Installing Capacitor Banks At The Designated Bus

From table 3, the following information where extracted:

- Cost of procuring the capacitor required for compensation of the network = $**4500.00**
- Cost of Installation = **$800.00**
- Operating Cost in 10 year (i.e. $1500.00 per year) = $**15000.00**

If we assume it will cost 30% of the total cost of the capacitor banks to transport them to site, and another 20% of the cost of the banks as cost of procurement of other accessories, then the total cost of compensating the network to reduce power losses becomes:

$4500 + $800 + $15000 + $1350 +$900 = $22550.00

If we assume an exchange rate of 360 Naira to a U.S Dollar, the above amount translates to **8118000 Naira**. i.e. approximately 8.1 million Naira. Table 4 compare the cost of energy loss in the network before and after compensation.

TABLE 4. Cost Estimate of Energy lost in the Network before and after Compensation

	Total Power Loss on the Network (KW)	**Total Energy Loss in the Network per Day(KWh)**	**Cost of Energy lost Per Day (Naira)**	**Cost of Energy Lost Per Year (Naira)**	**Cost of Energy Lost in 5 Years (Naira)**	**Cost of Energy Lost in 10 Years (Naira)**
Before Compensation	389	9336	291936.72	103345598.9	516727994.4	1033455989
After Compensation	147.82	3547.68	110935.9536	**39271327**.57	196356637.9	392713275.7
SAVINGS	**241.18**	**5788.32**	**181000.7664**	**64074271.31**	**320371356.5**	**640742713.1**

IX. Conclusion

Within a period of 10 years, a savings of **₦640,742,713.10** (i.e. over 600 million Naira) would be made. If the cost of installing the capacitor banks and operating cost for a period of ten years is deducted from this amount, a total savings of over six hundred and thirty million Naira would be made within this period. Customers that hitherto experience low voltage will now enjoy better voltage levels at lower cost while the utility company will then be able to operate the Asaba government core area injection substation network at a lower cost.

Consequent upon the foregoing; it becomes reasonably necessary that the BEDC compensates the distribution network under review as it makes economic sense and doing so will ultimately serve the best interest of both BEDC and her numerous customers in the network.

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APPENDIX A

TABLE 5. SAMPLE OF SUBSTATION DATA USED FOR LOAD FLOW STUDY

S/N	Substaion Name and Rating (KVA)	Route Length (km)	Ave Power (Km)	Ave pf
1	ECOBANK 200	0.5	17.87	0.964
2	MTN I 100	1.35	57.5	0.967
3	JOBAS 300	1.38	216	0.973
4	WATER BOARD 300	0.95	210	0.971
5	DESIRE & LEASURE HOTEL 200	1.5	92.72	0.969
6	SPC 500	1.35	320.4	0.937
7	FMC ROUNDABOUT 500	1.7	304.4	0.953
8	BISHOP CHUKWUMA 500	1.93	310.6	0.961
9	MTN II 100	2.16	56.8	0.977
10	HELIUS TOWER 100	2.1	57.2	0.972
11	USONIA HOUSE 200	2.13	101.3	0.923
12	ONOCHIE 300	2.29	242.6	0.964
13	OKELUE 300	2.26	173	0.872
14	ODIACHI II 300	2.67	185.1	0.933
15	ODIACH I 500	2.31	187.6	0.968
16	NDDC 300	2.56	198.8	0.962
17	MTN III 50	2.51	27.6	0.96
18	UMUAGWU II 300	2.95	279.7	0.95
19	UMUAGWU I 300	3.03	237	0.939
20	BUDGET 500	2.63	295.4	0.977
21	ABBEY BANK 100	2.637	4.56	0.926
22	STARCOM OFFICE 200	2.65	4	0.921
23	FUNNAYA 300	2.92	217.6	0.953
24	OKECHUKWU OKAFOR 100	3.02	60.31	0.974
25	AIRTEL 100	2.89	67.8	0.967
26	STADIUM OFFICE 300	3.21	254.4	0.955
27	BENITA I 300	3.59	188.6	0.965
28	BENITA II 300	3.77	204.6	0.957
29	STADIUM 500	3.44	363.2	0.943
30	BENCLINTON 200	3.6	92.06	0.964
31	MTN IV 50	3.83	31.7	0.965
32	PARKINSON 500	3.86	281.8	0.963
33	ICON 300	3.69	246.9	0.926
34	ABUTA 300	3.99	239.3	0.963
35	MTN V 50	4.15	29,7	0.978
36	ENGR. ENENMOH 200	4.24	56.29	0.953