Optimal Capacitor Placement Technique for Optimization of Power Distribution Networks in Nigeria

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Abstract - The protracted inability of Distribution Companies (DisCos) in Nigeria to optimally operate their distribution networks has given rise to the huge annual losses being currently experienced in the country. Thus, there is need to find a way of minimizing these losses. To address this problem, this paper proposes an optimum capacitor placement technique based on genetic algorithm (GA) which can be used to achieve improved reactive power compensation on distribution networks in Nigeria. Thus, using the Benin Electricity Distribution Company (BEDC) network as a case study, a load flow analysis was carried out on the existing Asaba Government Core Area injection substation distribution network comprising one 15MVA 33/11kV power transformer and its associated two radially connected 11kV feeders – Saint Patrick's College (SPC) and Anwai road feeder respectively with an aggregate of ninety six (96) secondary distribution 11/0.415kV transformers as load buses. Data used for the study were obtained from BEDC Asaba Business District between May and July, 2017. A simulation model of the network was built in ETAP 7.0.0 software environment. Using Newton-Raphson algorithm as available in ETAP, load flow analysis of the network indicated that the system requires reactive power compensation as total average active and reactive power losses of 389kW and 818kVAr respectively were incurred after the peak load network transient stability assessment of the 96 load buses was simulated. 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, the cost of energy lost in the network under review was estimated for a 10 year period at about ₦1, 065,569,028.00 if left uncompensated. When compensated by the optimal placement of shunt capacitor banks in the network, all bus voltages were found to be within acceptable limits as active and reactive power loses were reduced to 147.82kW and 237.22kVAr respectively. Cost benefit analysis carried out showed that this reduction in losses amounted to a savings of about ₦ 640,742,713.10 (60.13%) for the 10 years period after the network was optimized.

Indexed Terms- BEDC Plc. Distribution Network, Network Optimization, Optimal Capacitor Placement.

I. INTRODUCTION

Today, the optimization of power distribution systems through feasible loss minimization techniques has assumed greater significance owing to the fact that a substantial amount of generated power is being wasted as losses in the Nigerian electricity industry. In [1], 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 that is being considered consists of known quantities of loads [2]. 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 of the needed information. There is also the Aggregate Technical, Commercial and Collection (ATC & C) Losses. This is an index which indicates losses in the power system for both energy and revenue loss conditions [3]. This index is readily employed by the Nigerian Electricity Regulatory Commission (NERC) – an organ of the Federal Government Nigeria vested with state powers and saddled with the responsibility among others of enforcing operational efficiency from players within the national power industry. This is vital because studies have shown that 70% of the total system losses are occurring in the distribution systems, while transmission lines accounts for 30% of the total losses [4]. According to [5], one of the present challenges facing the Nigerian power sector is the high distribution losses incurred by the DisCos which they pledged to solve but have failed to solve. Furthermore, DisCos report of 2014 stated that the distribution networks suffered significant losses which approximately 46% of energy lost due through Technical losses (12%), Commercial losses (6%), and Collection losses (28%) [5]. this is as a result of the peculiar nature of distribution system networks which basically is connected to a large number of consumer loads. Majority of these loads are seen to be non-unity power factor loads which draw a reactive component of current together with the active component. Additionally, most of these loads are either non-linear loads or unbalanced loads, resulting into power quality issues such as voltage waveform distortions due to the injection of harmonics, flow of excessive currents in the neutral conductor, poor power factor, voltage fluctuations and increased power losses across the network. Consequently, electric utilities have to install compensation devices within their distribution networks that will ensure controlled flow of reactive power as well as achieve better power quality at minimal costs [6]. Thus, the pressure of improving the overall efficiency of power delivery has forced power utilities to reduce their losses especially at the distribution level. The Federal government of Nigeria through its regulatory organ – (NERC) duly accesses the performance of DisCos based on the reduction of their annual operational aggregate technical commercial and collection (ATC&C) losses. This paper proffers a way by which the Technical losses which is an integral part of the ATC&C losses arising from the operation of a typical radial distribution network of a DisCo – (BEDC Plc.) can be mitigated and the system optimized by the adoption of conventional optimal shunt capacitor placement technique.

II. OVERVIEW OF BENIN ELECTRICITY DISTRIBUTION COMPANY PLC

BEDC Electricity Plc. (BEDC) is one of the successor distribution companies (DisCos) created following the unbundling and privatization of the state-owned Power Utility, Power Holding Company of Nigeria Plc. BEDC is responsible for retail distribution of electricity in Delta, Edo, Ekiti, and Ondo States with geographical coverage of 55,770 square kilometers. The company operates from twenty seven (27) business districts with approximately 350 offices (business district, service units and services centers) located across the four (4) states with about 13 million people and about 4 million households [7]. BEDC is the 4th largest Disco in distribution capacity and 3rd largest in number of households among the Distribution Companies (DisCos) which was privatized. The company owns and maintains 39 number (No.) 33 kV and 200 number 11 kV circuits, covering 4,979. 391 and 5,708.5 kilometers respectively, It also operates 153 number 33/11kV injection substations and 124 number 6.6/0.415 kV distribution substations, It also owns and maintains 7 No. 6.6 kV circuit, 92.14 kilometers of 6.6 kV/3.3 kV. Customer Base: 529,341 (2008) [8].

BEDC operates its business from twelve (12) administrative business districts in Delta state namely: Agbor, Asaba, Koka, Ughelli, Isoko, Obiaruku, Udu, Sapele, Ogharra, Warri, PTI, and Effurun.

1. Asaba City 33kV Grid Source

Delta state capital – Asaba, receives its grid supply from the transmission company of Nigeria (TCN) 2 x 150MVA / 330 / 132kV transmission substation situated along Ibusa road in Asaba city. From the 2 x 60MVA 132 / 33kV injection substation inside the

(TCN) Asaba substation, six (6) numbers of 33kV feeders are issued forth for the powering of the growing Asaba metropolis as well as some other neighboring towns. Figure 1 illustrates the various 33kV feeders radiated from the (TCN) Asaba 2 x 60MVA 132 / 33kV injection substation.

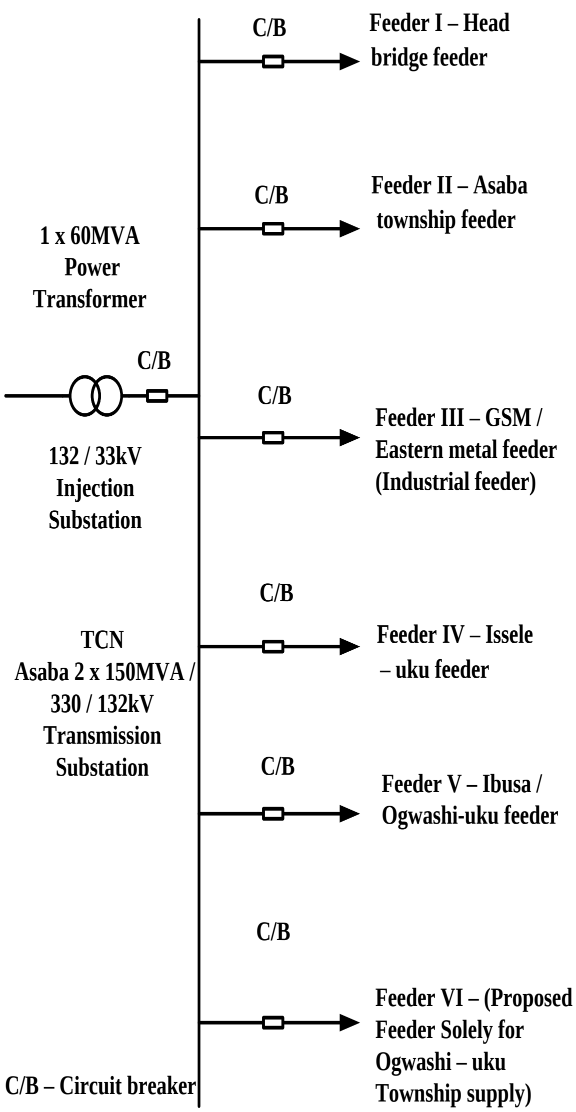
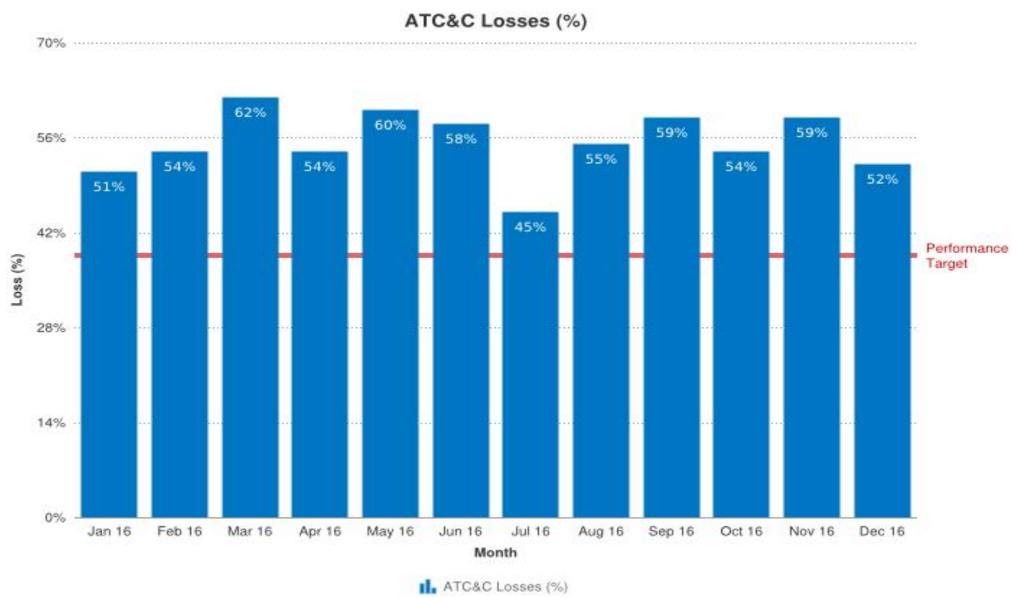


Figure 1: Single line diagram of TCN, Asaba 1 x 60MVA power transformer and its radiated 33kV feeders.

Table 1: BEDC business districts within Asaba and their service uints

s/n	Business District	Service Unit
1	Asaba	Nnebisi
		Cabinet
2	Koka	Ezenei
		Bonsac

NERC puts the ATC&C percentage monthly average losses of BEDC for the year of 2016 at 55.25%. This is as deduced from figure 2**.** It is equally noteworthy that the 55.25% is above the performance target set for the company in 2016 operational year. Thus, if the distribution systems of BEDC were to be eventually optimized, this will correspondingly decrease its monthly ATC&C losses.



Source: [9]

Figure 2: Benin Electricity Distribution Company (BEDC Plc.) 2016 ATC&C Losses

In this paper, a practical and easy to implement solution technique for the capacitor placement problem based on a Genetic Algorithm employed in ETAP 7.0.0 software is presented. The proposed algorithm determines the number, sizes, locations and value of capacitors to be placed on a distribution system in order to maximize savings due to reductions in peak power and energy losses. The solution method treats capacitor sizes as discrete variables and uses standard sizes in the optimal capacitor placement (OCP) module of the software.

2. Objective Function of OCP

The objective of optimal capacitor placement is to minimize the cost of the system. The cost includes four parts:

- Fixed capacitor installation cost
- Capacitor purchase cost
- Capacitor bank operating cost (maintenance and depreciation)
- Cost of real power losses

The cost i.e. minimum objective function (*Min.OF*) can be represented mathematically as [10]:

$$Min.\,OF = \sum_{i=1}^{N_{bus}} (x_i C_{oi} + Q_{ci} C_{1i} + B_i C_{2i} T) + C_2 \sum_{l=1}^{N_{load}} T_l P_L^l \quad (1)$$

$N_{bus} = Number\ of\ bus\ candidates$

x_i = *O/1, O means no capacitor installed at bus i*

C_{Oi} = *Installation cost*

C_{1i} = *Per KVar cost of capacitor cost*

Q_{li} = *Capacitor bank size in KVar*

B_i = *Number of capacitor banks*

C_{2i} = *Operating cost per bank, per year*

T = *Planning period (years)*

C_2 = *Cost of each KWh loss, in \$/KWh*

l = *Load levels, maximum, average and minimum*

T_l = *Time duration in hours, of load level l*

$P_L^l = Total\ system\ loss\ at\ load\ level\ l$

3. The Constraint

The main constraints for capacitor placement have to comply with the load flow constraints. In addition, all voltage magnitudes of load (PQ) buses should be within the lower and upper limits. Power Factor (PF) should be greater than the minimum. There may be a maximum power factor limit. The constraints can be represented mathematically as: Load Flow: F(x, u) = 0

$V_{min} \le V \le V_{max}$, $PF_{min} \le PF \le PF_{max}$ For all PQ buses.

The GA algorithm can handle large low voltage (LV) distribution networks and medium voltage (MV) networks. In case of significant variations in daily load curve, fixed and switched capacitors will be applied [11].

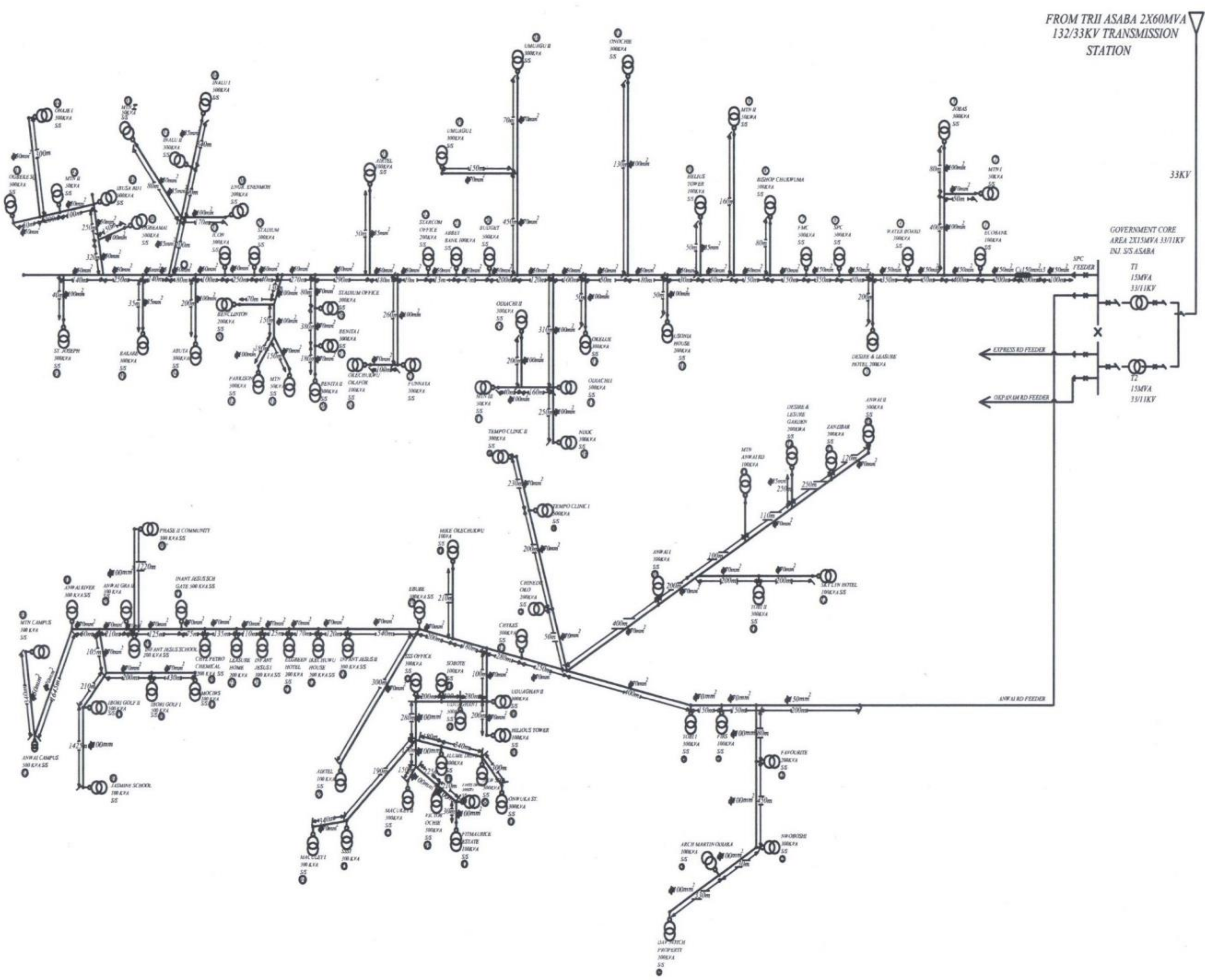


Figure 3: Single line diagram of BEDC Asaba government core area 2 x 15MVA 13/11kV injection substation showing power transformer T_1 (1 x 15MVA), SPC and Anwai road 11kV Feeders with their 96 nos. secondary distribution transformers.

Table 2: Sample of network parameters / peak load readings obtained from 19 number 11/0.415kV substations transformers from ANWAI ROAD 11kV Feeder of (BEDC) Asaba.

s/n	NAME OF SUBSTATION/ RATING (KVA)	ROUTE LENGTH (KM)	VOLTAGE (V)			POWER (KW)				POWER FACTOR (p.f)				REMARKS
			V_R	V_Y	V_B	P_R	P_Y	P_B	P (TOTAL)	R_{Pf}	Y_{Pf}	B_{Pf}	P.f (AVE.)	
1	FAVOURITE 200KVA	0.2800	230.6	231.2	233.4	26.82	19.96	29.17	75.95	0.968	0.972	0.958	0.966	
2	NWOBOSHI	0.7300	231.4	231.9	232.7	62.21	51.02	59.87	173.1	0.947	0.941	0.944	0.944	

	KVA300													
3	ARCH. MARTINS ODIAKA 100KVA	0.7600	231.7	233.4	230.6	20.63	32.18	30.15	82.96	0.877	0.922	0.912	0.904	
4	DAVNOTCH PROPERTY 300KVA	0.0900	230.9	232.7	231.8	72.26	52.97	63.94	189.2	0.961	0.952	0.957	0.957	
5	FIRS 100KVA	0.3500												NO ACCESS
6	TOBI I 300KVA	0.5000	230.4	230.8	229.7	57.24	73.13	66.29	196.7	0.944	0.981	0.953	0.959	
7	CHINEDU OKO 200KVA	0.9500	228.5	226.1	226.9	45.81	28.17	33.92	107.9	0.982	0.951	0.966	0.966	
8	TEMPO CLINIC I 500KVA	1.1500	227.1	224.8	227.7	83.15	44.32	62.77	190.2	0.987	0.964	0.967	0.973	
9	TEMPO CLINIC II 300KVA	1.3800	225.1	228.4	226.5	65.51	54.82	61.07	181.4	0.931	0.922	0.930	0.928	
10	ANWAI I 300KVA	1.3000	214.7	222.6	221.9	78.15	41.11	53.07	172.3	0.986	0.961	0.972	0.973	
11	TOBI II 300KVA	1.7000	215.8	219.7	222.6	71.64	45.51	66.87	184.0	0.931	0.929	0.925	0.928	
12	SLY LYN HOTEL 100KVA	1.9000	215.2	218.1	223.1	20.59	16.49	19.73	56.81	0.871	0.869	0.865	0.868	
13	MTN ANWAI RD. 100KVA	1.6000												NO ACCESS
14	DESIRE & LEASURE GARDEN 200KVA	1.7100	210.4	211.8	216.3	47.51	39.34	41.23	128.0	0.941	0.933	0.940	0.938	
15	ZANZIBAR 200KVA	1.9600	211.1	210.4	217.5	33.87	15.91	28.81	79.59	0.935	0.825	0.921	0.894	
16	ANWAI II 500KVA	2.0800	208.3	210.7	209.4	112.8	57.01	87.11	257.0	0.965	0.931	0.941	0.946	
17	CHYKES 300KVA	1.1500	220.7	221.4	225.1	114.8	63.07	52.64	230.5	0.975	0.947	0.941	0.954	
18	MIKE OKECHUKWU 100KVA	1.8200	220.4	221.7	221.9	22.14	11.78	15.06	48.98	0.891	0.843	0.887	0.874	
19	EBUBE 300KVA	1.8100	221.9	221.2	222.8	61.08	32.76	120.3	214.5	0.971	0.952	0.983	0.966	

Table 3: Sample of network parameters / peak load readings obtained from 11/0.415kV substations transformers from SPC 11kV Feeder of (BEDC) Asaba.

s/n	NAME OF SUBSTATION/ RATING (KVA)	ROUTE LENGTH (KM)	VOLTAGE (V)			POWER (KW)				POWER FACTOR (p.f)				REMARKS
			V_R	V_Y	V_B	P_R	P_Y	P_B	P (TOTAL)	R_{Pf}	Y_{Pf}	B_{Pf}	P.f (AVE.)	
1	ECOBANK 200KVA	0.5000	229.2	226.4	228.7	4.93	7.11	5.85	17.87	0.953	0.977	0.962	0.964	OFF-PEAK LOAD
2	MTN I 100KVA	1.3500												NO ACCESS
3	JOBAS 300KVA	1.3800	209.4	207.4	211.8	130.6	30.10	55.30	216.0	0.963	0.968	0.984	0.973	
4	WATER BOARD 300KVA	0.9500	214.5	215.8	214.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OFF-PEAK LOAD PERIOD
5	DESIRE & LEASURE HOTEL 200KVA	1.5000	213.9	213.4	219.2	35.14	25.96	31.63	92.72	0.966	0.972	0.968	0.969	
6	SPC 500KVA	1.3500	222.3	221.1	220.8	145.6	98.70	76.10	320.4	0.960	0.913	0.939	0.937	
7	FMC ROUNDABOUT 500KVA	1.7000	203.7	205.1	201.6	143.2	22.14	139.1	304.4	0.976	0.931	0.964	0.953	
8	BISHOP CHUKWUMA 500KVA	1.9300	201.8	208.6	204.3	102.4	110.5	97.70	310.6	0.966	0.967	0.951	0.961	
9	MTN II 100KVA	2.1600												NO ACCESS
10	HELIUS TOWER 100KVA	2.1000	205.6	204.1	206.1	20.46	17.51	19.22	57.20	0.971	0.989	0.957	0.972	
11	USONIA HOUSE 200KVA	2.1300	211.6	208.4	211.8	45.62	24.91	30.73	101.3	0.933	0.912	0.924	0.923	
12	OKELUE 300KVA	2.2900	182.3	189.3	185.4	88.98	67.88	85.70	242.6	0.941	0.969	0.981	0.964	
13	OKELUE 300KVA	2.2600	207.6	208.2	208.7	92.13	0.55	80.34	173.0	0.971	0.721	0.923	0.872	
14	ODIACHI II 300KVA	2.6700	205.8	209.1	211.8	78.52	45.24	61.33	185.1	0.945	0.941	0.912	0.933	
15	ODIACHI I 500KVA	2.3100	208.4	210.6	212.7	85.62	44.61	57.38	187.6	0.987	0.961	0.956	0.968	
16	NDDC 300KVA	2.5600	211.6	204.6	208.7	62.91	81.46	54.44	198.8	0.968	0.972	0.947	0.962	
17	MTN III 50KVA	2.5100												NO ACCESS
18	UMUAGWU II 300KVA	2.9500	204.5	201.3	203.1	103.7	89.60	86.40	279.7	0.945	0.949	0.956	0.950	
19	UMUAGWU I 300KVA	3.0300	200.8	207.3	209.8	95.11	72.81	69.11	237.0	0.904	0.947	0.965	0.939	

III. RESEARCH METHODOLOGY

Before proceeding with the task of optimizing 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 feeders respectively, with their aggregate of ninety six (96) number secondary distribution 11/0.415kV transformers. A detailed single line diagram of the entire network was first produced. This is as shown in figure 3. Thereafter, the network was modelled with ETAP 7.0.0 software, and a load flow analysis was carried out on the modelled network using Newton-Raphson method deployed in the ETAP 7.0.0 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 May and July, 2017 during peak load period. Samples of data collected for the individual substations in the network under review are presented in tables 2 and 3. A section of the network modelled in the ETAP 7.0.0 environment is presented in Figure 4. Table 4 presents extracts from the load flow analysis carried out on the 15MVA 33/11kV BEDC Asaba government core area injection substation and its associated feeders under review. The charts of Figures 5 and 6 respectively, represents the variation of voltage profile and voltage drop for the 96 bus distribution system as extracted from the load flow result.

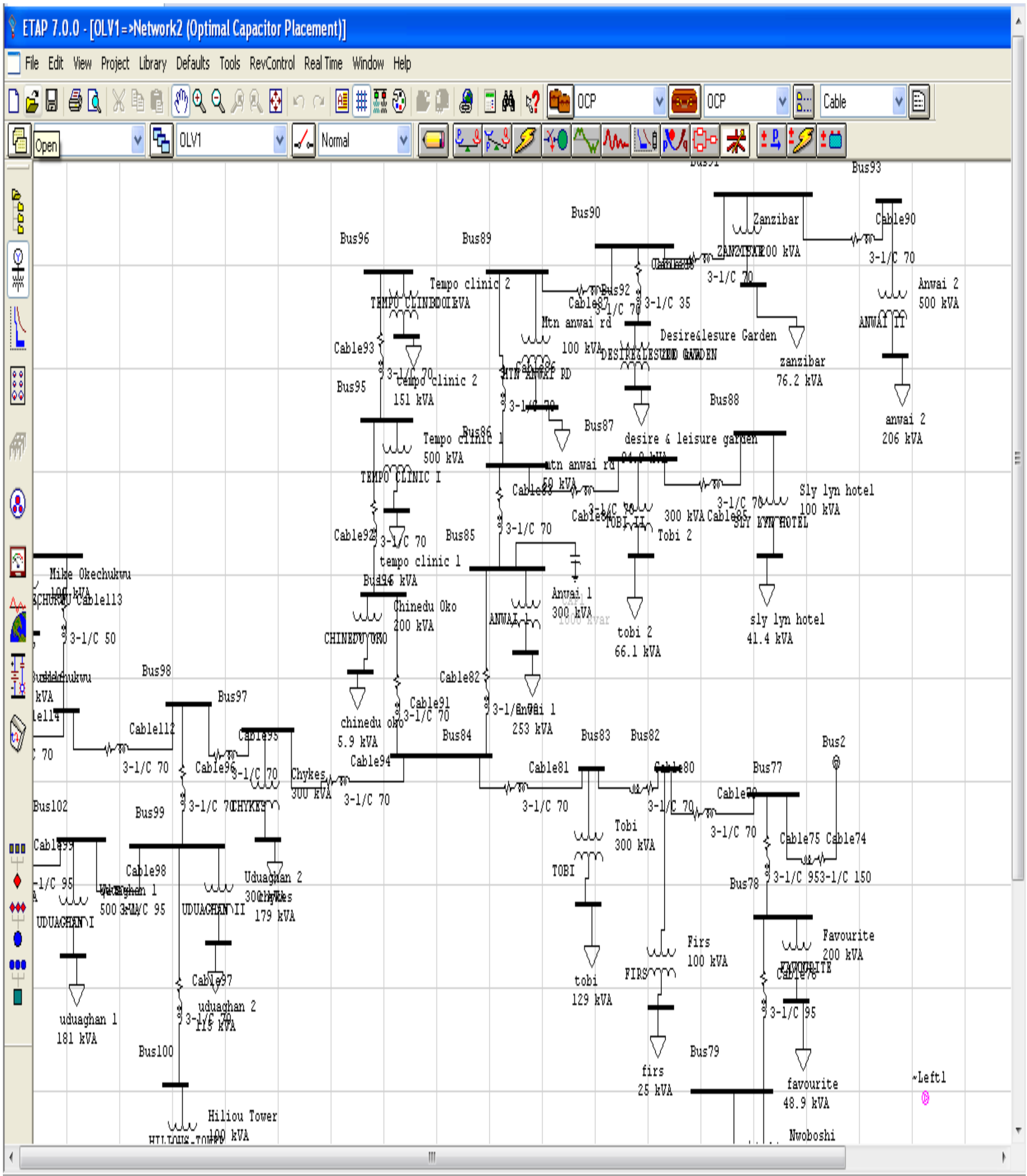


Figure 4. A section of the study case network modelled in ETAP 7.0.0 environment.

Table 4. Extracts from load flow analysis.

Study ID	**Asaba transmission**
Study Case ID	LF
Data Revision	Base
Configuration	Normal
Loading Category	Design
Generation Category	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
Mismatch-MW	0
Mismatch-Mvar	0
Number of Buses with Voltage Violation	64

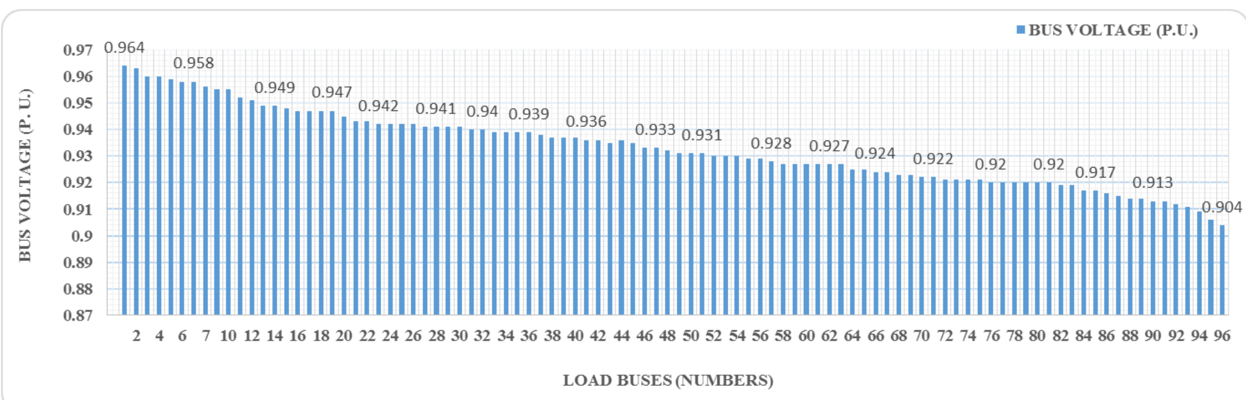


Figure 5: Chart of load flow result showing load bus numbers and bus voltage (p.u.) profile before OCP

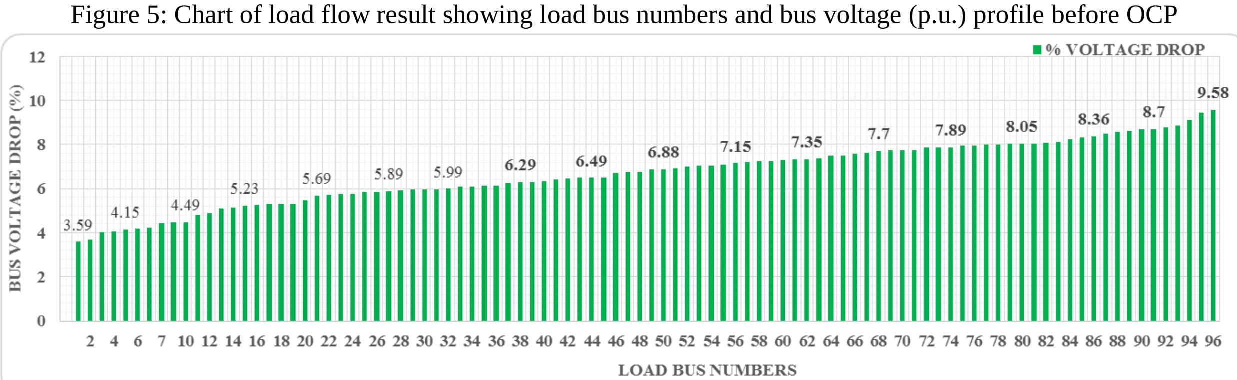


Figure 6: Chart of load flow result showing load bus numbers and bus (%) voltage drop profile before OCP

IV. LOAD FLOW ANALYSIS AND DEDUCTIONS

The results obtained from load flow analysis of the Asaba 15MVA 33/11kV injection substation and its associated feeders indicate the following: It is to be noted that a voltage of 220Volts single phase (i.e. 380Volts three phase) with maximum allowable drop of ± 6% is considered an acceptable voltage level in Nigeria. It is based on this premise that some deductions below were made.

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 occurred in sixty-four (64) buses – buses with a voltage magnitude less than 0.94 p.u. during peak load period.

b) Approximately 66.67% of the total load buses in the network require reactive power compensation. This implies that approximately 33.33% of the entire load buses in the network have their voltages within statutory limit. Hence, reactive power compensation will be required in order for the system to be optimized.

c) The highest bus voltage magnitude (0.964 p.u.) and the lowest percentage voltage drop (3.59%) occurred at **Load Bus 1** (Favourite substation) while the lowest bus voltage magnitude (0.904 p.u.) and the highest percentage voltage drop (9.58%) occurred at **Load Bus 96** (Benclinton substation).

d) Total average active and reactive power loss of the system during peak period is 389kW and 818kVAr respectively.

1. Power Loss Estimation / Costing in Asaba Government Core Area Injection Substation

The multi-year tariff order (MYTO) approved by the Nigerian Electricity Regulation Commission (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 value of 389kW technical power loss in the network under review for a day, a year, five years and for ten years was determined, and were presented in table 5.

Table 5. Cost estimate of the energy lost technical losses (TL) in the BEDC Plc. network under review.

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 5 shows that over two hundred and ninety thousand Naira is lost in the network per day, and this would correspond to a total of over one billion naira in ten years if the utility network under review remains uncompensated.

2. Capacitor Sizes Determination and Placement

Shunt capacitor banks are able to compensate Var requirement, but bank size, location and cost considerations are important issues that need to be optimized during the design phase. An ideal solution would 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

3. Problem Formulation

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

min f = min PLoss; subject to:

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

For this study, the voltage constraint is given by:

Vmin = 0.94 pu and Vmax = 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 figure 7. The OCP module of the ETAP software, also gives the cost variables associated with the capacitors as shown also in figure 7.

Project:	ETAP	Page:	1
Location:	7.0.0	Date:	09-02-2017
Contract:		SN:	12345678
Engineer:	Study Case: OCP	Revision:	Base
Filename: Asaba transmission station		Config.:	Normal

Optimal Capacitor Placement Results

Candidate Buses		Operating Voltage			Capacitor Information				Cost ($)		
ID	Nominal kV	% Mag.	Angle	% PF	Rated kvar/Bank	Rated kV	# of Banks	Total kvar	Installation	Purchase	Oper./Year
Bus85	11.000	96.627	-3.20	100.0	300.000	12.470	5	1500.000	800.00	45000.00	1500.00
Total							5	1500.000	800.00	45000.00	1500.00

Figure 7: ETAP 7.0.0 OCP Result for the Case Study Network Compensation.

The ETAP 7.0.0 OCP result (figure 7.) 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:

e) A bank comprising of five-number (5nos) 300kVAr capacitors at bus 85 (i.e. at Anwai 1-substation at the 11kV side).

f) With the network duly compensated also i.e. (capacitor bank in place) all load bus voltages are within acceptable limit, as active and reactive power loss has been reduced to **147.82**kW and **237.22** kVAr respectively.

The capacitance and reactance of the banks per phase are calculated as follows: Line Voltage = 11 kV

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

A Capacitor bank size 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,

$C = 1/2\pi X_{cph} f$ = 394.7μF

Hence, the 300kVAr banks should be of capacitance not less than 394.7μF.

These Capacitor banks should be installed at the location already stated i.e. bus 85.

3. Cost of Installing Capacitor Banks at the Designated Bus

From figure 7, 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.

Figures 8 and 9 represents the variation of voltage profile and voltage drop for the 96 bus distribution system as extracted from the load flow result after OCP was executed for the network under review.

Table 6 compares the cost of energy loss in the network under review before and after compensation.

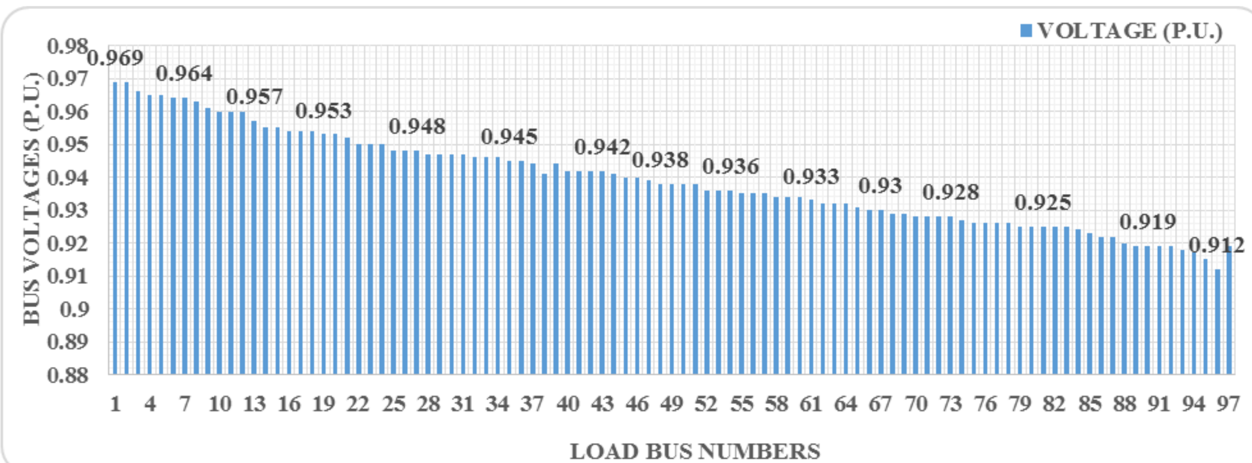


Figure 8: Chart of load flow result showing load bus numbers and bus voltage (p.u.) profile after OCP

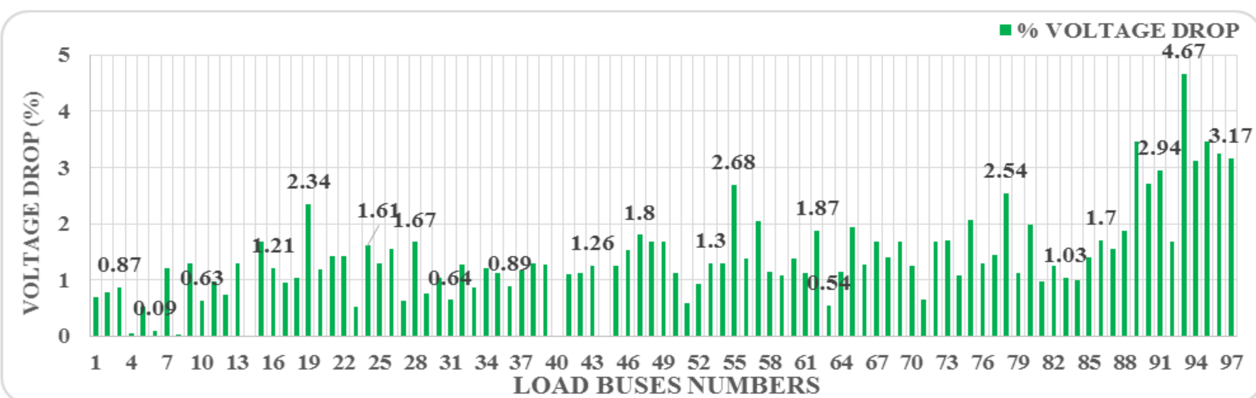


Figure 9: Chart of load flow result Showing load bus numbers and bus (%) voltage drop profile after OCP

Network Status	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	291,936.72	106,556,902.8	532,784,514	1,065,569,028
After Compensation	147.82	3547.68	110,935.9536	40,491,623.06	202,458,115.30	404,916,230.60
SAVINGS	**241.18**	**5788.32**	**181,000.7664**	**66,065,279.74**	**330,326,389.70**	**660,652,797.40**

Table 6. Cost estimate of energy lost in the network before and after compensation

V. CONCLUSION

This paper has shown that the actual estimated installation cost of the optimally sized and allocated capacitor banks at the designated bus for the optimization of BEDC Plc. network is valued at ₦ 8, 118,000.00. Furthermore, the estimated cost of energy lost in operating the network under review for a 10-year-period before and after network optimization was valued at ₦1, 065,569,028.00 (Over ₦ 1 Billion) and ₦ 404, 916, 230.00 respectively. Hence, a savings of ₦ 660, 652,797.40 (i.e. over ₦600 million) would be made within this period if the cost of installing the capacitor banks and operating cost incurred within the 10-years-period (i.e. ₦ 660, 652,797.40) is subtracted from (₦1, 065,569,028.00). Thus, customers that hitherto experience low voltage will finally be able to 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. Consequently, it becomes reasonably necessary that BEDC Plc. compensates the distribution network under review as it makes economic sense and doing so will ultimately serve the best interest of both BEDC Plc. and the numerous customers in the network. This work has presented a novel optimization approach for minimizing loses in power distribution networks in Nigeria.

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