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POWER LOSS REDUCTION IN ELECTRICAL DISTRIBUTION SYSTEMS USING CAPACITOR PLACEMENT

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Abstract- As power factor falls below unity the current in the system increases with the following effects: I^2R power loss increases in cables and windings leading to overheating and consequent reduction in equipment life; cost incurred by power company increases and efficiency as a whole suffers because more of the input is absorbed in meeting losses. Distribution losses cost the utilities a very big amount of profit and reduce life of equipment. The system is considered as efficient when the loss level is low. So, attempts at power loss minimization in order to reduce electricity cost, and improve the efficiency of distribution systems are continuously made. This paper investigates the losses in a 34-bus distribution system and how the installation of capacitors at some points in the system can significantly reduce losses in circuits and cables, ensure that the rated voltage is applied to motors, lamps, etc, to obtain optimum performance, ensure maximum power output of transformers is utilized and not used in making-up losses, enables existing transformers to carry additional load without overheating or the necessity of capital cost of new transformers, and achieve the financial benefits which will result from lower maximum demand charges.

Keywords: Losses, Power factor, Reactive power, Capacitor, Distribution system, Loss reduction.

I. INTRODUCTION

The Enugu distribution system is the case study. The type of losses, the causes of losses and methods of loss reduction in distribution system are presented. A method based on a heuristic technique for reactive loss reduction in distribution system is applied in this work because it provides realistic sizes and locations for shunt capacitors on primary feeder at a low computational burden. The variation of the load during the year is considered. The capital and installation cost of the capacitors are also taken into account. The economical power factor is also determined so as to achieve maximum savings. This method is applied to a 34 bus, 11KV, 6MVA distribution system with original power factor of 0.85.

A. Losses In Distribution Lines

A significant portion of the power that a utility generates is lost in the distribution process. These losses occur in numerous small components in the distribution system, such as transformers and distribution lines. Due to the lower power level of these components, the losses inherent in each component are lower than those in comparable components of the transmission system. While each of these components may have relatively small losses, the large number of components involved makes it important to examine the losses in the distribution system [1]. One of the major sources of losses in the distribution system is the power lines which connect the substation to the loads. Virtually all real power that is lost in the distribution system is due to copper losses. Since these losses are a function of the square of the current flow through the line, it should be obvious that the losses in distribution lines are larger at high power levels than they are at lower levels. Power loss in the distribution lines can be considered to be entirely due to copper losses given as:

$$P_L = I^2R \qquad (1)$$

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$$\rho_1 = \rho_2 \frac{T_2 - T_o}{T_1 - T_o} \qquad (2)$$

The letter rho (ρ) is the resistivity at a specific temperature. It is equal to 2.83×10^{-8} ohm meters for aluminum and 1.77×10^{-8} ohm meters for copper at a temperature of 20°C. T_0 is a reference temperature and is equal to 228°C for aluminum and 241°C for copper. ρ_1 and ρ_2 are the resistivity at temperature T_1 and T_2 respectively [2].

B. Losses In Distribution Transformers

While losses in distribution lines are virtually all due to copper losses, transformer losses occur due to both copper and core losses. The core losses are made up of eddy current and hysteresis losses. The copper losses in transformers are essentially the same as those in the power distribution lines. The copper losses in a transformer are smaller in magnitude than the core losses. These losses occur in the form of heat produced by the current, both primary and secondary, through the windings of the transformer. Like the copper loss in the distribution line, it is calculated using the I^2R relationship of Equation 2.1. Any factor which affects either current or winding resistance will also affect the amount of copper loss in the transformer. An increase in loading, either real or reactive, will result in an increase in current flow and a correspondingly greater amount of loss in the transformer. Additionally, an unbalanced system load will increase transformer loss due to the squared current relationship. The winding resistance also has an effect on the amount of copper loss and is mainly determined by the total length of the wire used, as well as the size of the wire. Temperature of the winding will affect the resistivity of the wire, therefore affecting the overall resistance and the copper loss. Since all but the smallest distribution transformers have some type of cooling system, such as immersion in oil, the temperature effect on losses is usually minimal.

The core loss in a transformer is usually larger in magnitude than the copper loss. It is made up of eddy current losses, which are due to magnetically induced currents in the core, and hysteresis losses, which occur because of the less than perfect permeability of the core material. These losses are relatively constant for an energized transformer and can be considered to be independent of the transformer load. Transformer core losses have been modeled in various ways, usually as a resistance in parallel with the transformer's magnetizing reactance [2], [3], [4]. Since the core loss is relatively independent of loading, the most important factor when considering core loss is the manufacture of the core. The physical construction of the core has serious consequences on the amount of core loss occurring in the transformer. For instance, eddy currents are greatly reduced by using laminated pieces to construct the core. These thin sheets are oriented along the path of travel of the magnetic flux and restrict the amount of reduced currents that occur. [4] The hysteresis loss occurs in the transformer core due to the energy required to provide the magnetic filed in the core as the direction of magnetic flux alternates with the alternating current wave form. This energy is transformed into heat. Hysteresis loss can be reduced by the use of higher quality materials in the core which have better magnetic permeability [5] [6]. A final aspect of the distribution system that increases losses in the transformers is the presence of harmonics in the system. The harmonic currents only cause a small increase in copper losses throughout the system. However, the high frequency harmonic voltages can cause large core losses in the transformer. Frequently, utilities are forced to use an oversized transformer to compensate when a large harmonic presence is indicated. The increased skin effect of larger conductors combined with the high frequency harmonics can result in even greater losses [7].

II. DEFINITION OF TERMS

Power factor is the ratio of Active Power (P) to the Apparent Power (S) as shown in Fig. 1

$$Power\ \ factor = \frac{Active\ power\,(W)}{Apparent\ power(KVA)} = \frac{P}{S} = \frac{S\cos\theta}{S} = \cos\theta \quad (3)$$

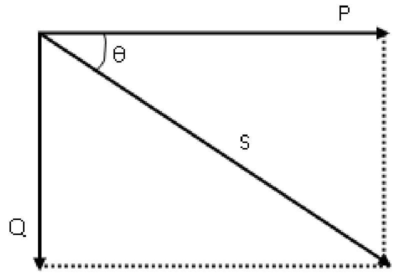


Fig. 1 Power diagram

Inductive components, such as ballasts, draw reactive power, Q (Var) from the mains. It lags behind the Active Power, P (W) by 90º (Figure 2.1). A capacitor, if connected across the mains, will also draw reactive power, but it leads the active power by 90º. The direction of the capacitive reactive power
(Q_C) is opposite to the direction of the inductive reactive power (Q_L) (Figures 2 and 3)

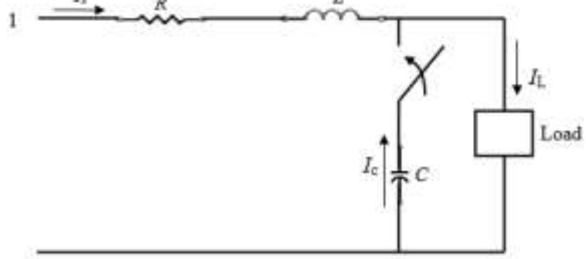


Fig. 2 Capacitive power loss reduction

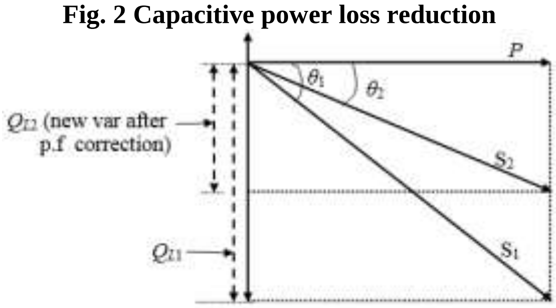


Fig. 3 Phasor diagram for Fig. 2

If a capacitor is connected in parallel with an inductive load, it will draw capacitive leading reactive power. The effective reactive power drawn by the circuit will reduce to the extent of the capacitive reactive power, resulting in reduction of apparent power from S_1 to S_2. The phase angle between the active power and the new apparent power S_2 will also reduce from θ_1 to θ_2 (Fig. 2). Thus the power factor will increase from cos θ_1 to cos θ_2. The reactive power supplied by the capacitor is thus given by:

$$Q_C = Q_{L1} - Q_{L2} = P\left(\tan\theta_1 - \tan\theta_2\right) \quad (4)$$

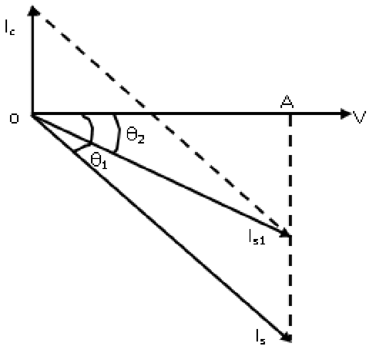


Fig. 4 Current Phasor diagram for Fig. 2

After compensation (capacitor is switched on) I_s decreases to I_{s1} i.e., reactive component of I_s decreases from $I_s \sin\theta_1$ to $I_{s1}\sin\theta_2$

$$I_c = I_s \sin\theta_1 - I_{s1}\sin\theta_2 \qquad (5)$$

As shown in Fig. 4

$$KVA_1 = \frac{W}{COS\theta_1} \qquad (6)$$

$$KVAr_1 = \frac{W}{\tan\theta_1} \qquad (7)$$

Suppose by installing capacitors he power factor rises to $\cos\theta_2$ (his power consumption P remaining the same), then

$$KVA_2 = \frac{W}{COS\theta_2} \qquad (8)$$

$$KVAr_2 = \frac{W}{\tan\theta_2} \qquad (9)$$

Reduction in KVA maximum demand is

$$\left(KVA_1 - KVA_2\right) = \left(\frac{W}{COS\theta_1} - \frac{W}{COS\theta_2}\right) \qquad (10)$$

If charge is ₦A per KVA maximum demand, annual saving on account is:

$$A\left(\frac{W}{COS\theta_1} - \frac{W}{COS\theta_2}\right)$$

KVAr is reduced from $KVAr_1$ to $KVAr_2$, the difference $KVAr_1$ - $KVAr_2$ = W $\tan\theta_1$ - $W\tan\theta_2$ being neutralized by the leading KVAr supplied by the capacitors. The cost of power factor improvement equipment is taken into account by way of interest on capital required to install it plus depreciation and maintenance expenses. Thus, the greater the KVAr reduction, the more costly the P.F improvement capacitor and hence greater the charge on interest on capital outlay and depreciation. A point is reached in practice when any further improvement in power factor, cost more than saving in the bill. Hence it is necessary for the consumer to find out the value of power factor at which his net savings will be maximum. The value can be found if:

(i) Annual charge per KVA maximum demand and
(ii) The cost per KVAR rating of capacitor are known.

If the cost per KVAR of capacitor is ₦B and the rate of interest and depreciation is U percent per year, then its cost per annum is

If the cost per KVAR of capacitor is ₦B and the rate of interest and depreciation is U percent per year, then its cost per annum is

$$\frac{B*U}{100}\left(P\tan\theta_1 - P\tan\theta_2\right)$$

Assuming $C = \frac{B*U}{100A}$ (11)

Cost per annum $= C\left(P\tan\theta_1 - P\tan\theta_2\right)$ (12)

Net annual saving S is

$$S = A\left(\frac{P}{COS\theta_1} - \frac{P}{COS\theta_2}\right) - C\left(P\tan\theta_1 - P\tan\theta_2\right) \qquad (13)$$

This net savings is maximum when $\frac{dS}{d\theta_2} = 0$

(14)

Therefore

$$\frac{dS}{d\theta_2} = \frac{d}{d\theta_2}[A\left(\frac{P}{\cos\theta_1} - \frac{P}{\cos\theta_2}\right) - C\left(P\tan\theta 1 - P\tan\theta 2\right) \qquad (15)$$

$$\frac{dS}{d\theta_2} = \frac{d}{d\theta_2}\left[AP\left(\sec\theta_1 - \sec\theta_2\right) - CP\left(\tan\theta_1 - \tan\theta_2\right)\right] = 0 \qquad (16)$$

$$= -AP\left(\sec\theta_2 \tan\theta_2\right) + CP\left(\sec^2\theta_2\right) = 0$$

$$AP \sec\theta_2 \tan\theta_2 = CP\sec^2\theta_2$$

$$A \sec\theta_2 \tan\theta_2 = C\sec^2\theta_2$$

$$A\tan\theta_2 = C\sec\theta_2$$

$$\frac{\tan\theta_2}{\sec\theta_2}$$

$$= \frac{\frac{\sin\theta_2}{\cos\theta_2}}{\sec\theta_2} = \frac{\sin\theta_2}{\cos\theta_2} * \frac{1}{\sec\theta_2} = \frac{\sin\theta_2}{\cos\theta_2} * \cos\theta_2 = \sin\theta_2 = \frac{C}{A} \qquad (17)$$

Recall that

$$\sin^2\theta + \cos^2\theta = 1$$

Therefore

$$\cos\theta_2 = \sqrt{1 - \sin^2\theta} = \sqrt{1 - \left(\frac{C}{A}\right)^2} = \sqrt{1 - \left(\frac{B*U}{100A}\right)}$$

(18)

From this expression θ_2 and hence $\cos\theta_2$ can be found. Investigation shows that the current charge per KVA by PHCN is two hundred and fifty Naira (₦250.00). As for compensating capacitors, the cost per KVAR is about seven hundred Naira (₦700.00) and interest on the capital plus depreciation and maintenance expenses is taken as 10%. From the above expressions, the economical power factor for this project can be found as follows: Let the charge per KVA maximum demand be ₦250.00 =A. The cost per KVAR rating be ₦700.00 = B

Rate of interest plus depreciation and maintenance expenses is:

U =10%

$$C = \frac{B*U}{100} = \frac{700x10}{100} = 70$$

$$\frac{C}{A} = \frac{70}{250} = \frac{7}{25} = Sin\theta_2$$

$$Cos\theta_2 = \sqrt{1-\left(\frac{7}{25}\right)^2} = 0.96$$

$$\theta_2 = \cos^{-1} 0.96 = 16.3^o$$

Therefore, the optimal economical power factor for this project is $\cos\theta_2$ = 0.96.

Net savings = cost of KVA before compensation – (cost of KVA after compensation + cost of capacitor)

Time required to save the initial cost of capacitor is

$$T = \frac{Y*Z}{N} \text{ years}$$

(19)

Where

Y = Value of capacitor in Kvar

Z = Cost of capacitor per Kvar in Naira

Y*Z = Total cost of installed capacitor in Naira

N = Net saving in Naira

Net savings is the amount that is saved by reducing losses after discounting the investment in equipment acquisition and its installation.

III. LOSS CALCULATION IN A 34-BUS DISTRIBUTION SYSTEM

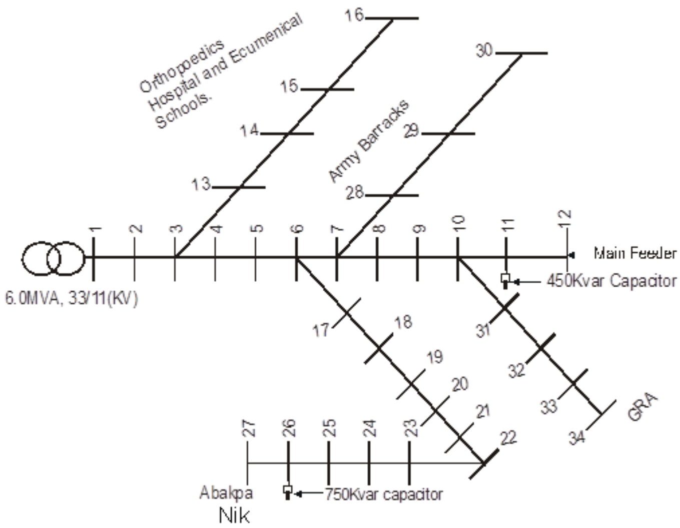


Fig. 4 34-bus distribution network

Table 1 Bus Data

Bus No	Load	
	P(Kw)	Q(Kvar)
1	0	0
2	230	142.5
3.	0	0
4	230	142.5
5	230	142.5
6	0	0
7	0	0
8	230	1425
9	230	142.5
10	0	0
11	230	142.5
12	137	84
13	72	45
14	72	45
15	72	45
16	13.5	7.5
17	230	142.5
18	230	142.5
19	230	142.5
20.	230	142.5
21	230	142.5
22	230	142.5
23	230	142.5
24	230	142.5
25	230	142.5
26	230	142.5
27	137	85
28	75	48
29.	75	48
30	75	48
31	57	34.5
32	57	34.5
33	57	34.5
34	57	34.5

Table 2 Line Data

Line No	Line Impedance		Length (Km)	Impedance
	$r(\Omega/Km)$	$x(\Omega/Km)$		r +jX (Ω)
1-2	0.195	0.080	0.60	0.117 + j0.048
2-3	0.195	0.080	0.55	0.10725 + j0.044
3-4	0.299	0.083	0.55	0.16445+ j0.04565
4-5	0.299	0.083	0.50	0.1495 + j0.0415
5-6	0.299	0.083	0.50	0.1495 + j0.0415
6-7	0.524	0.090	0.60	0.3144+j0.054
7-8	0.524	0.090	0.40	0.2096+j0.036
8-9	0.524	0.090	0.60	0.3144+j0.054
9-10	0.524	0.090	0.40	0.2096+j0.036
10-11	0.524	0.090	0.25	0.131+ j0.0225
11-12	0.524	0.090	0.20	0.1048 + j0.018
3-13	0.524	0.090	0.30	0.1572+j0.027
13-14	0.524	0.090	0.40	0.2096 + j0.036
14-15	0.524	0.090	0.20	0.1048 + j0.018
15-16	0.524	0.090	0.10	0.0524 + j0.009
6-17	0.299	0.083	0.60	0.1794 + j0.0498
17-18	0.299	0.083	0.55	0.16445 + j0.04565
18-19	0.378	0.086	0.55	0.2079 + j0.0473
19-20	0.378	0.086	0.50	0.189 + j0.043
20-21	0.378	0.086	0.50	0.189+j0.043
21-22	0.524	0.090	0.50	0.262 + j0.045
22-23	0.524	0.090	0.50	0.262 + j0.045
23-24	0.524	0.090	0.60	0.3144 + j0.054
24-25	0.524	0.090	0.40	0.2096+ j0.036

25-26	0.524	0.090	0.25	0.131+j0.0225
26-27	0.524	0.090	0.20	0.1048 + j0.018
27-28	0.524	0.090	0.30	0.1572 + j0.027
28-29	0.524	0.090	0.30	0.1572 + j0.027
29-30	0.524	0.090	0.30	0.1572 + j0.027
10-31	0.524	0.090	0.30	0.1572 + j0.027
31-32	0.524	0.090	0.40	0.2096 + j0.036
32-33	0.524	0.090	0.30	0.1572 + j0.027
33-34	0.524	0.090	0.20	0.1048 + j0.018

The admittance to a bus, $Y = \dfrac{I}{V}$ (20)

The distribution system is characterized by a system of n nonlinear equations of the form in (24). Therefore (24) can be written as

$[I_{bus}] = [Y_{bus}]\,[V_{bus}]$ (21)

Where: n is the number of buses in the system.

I_{bus} is the bus current vector

V_{bus} is the bus voltage vector

Y_{bus} is the bus admittance

Thus, from Fig.4 the net current injected into the network at bus 3, for instance is:

$$I_3 = (V_3 - V_4)Y_{34} + (V_3 - V_{13})Y_{3-13} = Y_{33}V_3 - Y_{3-4}V_4 - Y_{3-13}V_{13} \quad (22)$$

Where $Y_{33} = Y_{3-4} + Y_{3-13}$

Hence if 3 is denoted by *i* the current into bus 3 is given as:

$$I_i = Y_{i-3}V_3 - Y_{i-4}V_4 - Y_{i-13}V_{13} = \sum_{n=3}^{N} Y_{i-n}V_n \quad (23)$$

$$I_i = \left(\frac{S_i}{V_i}\right)^* = \frac{P_i - jQ_i}{V_i^*} \quad (24)$$

$$P_i - jQ_i = V_i^* \sum_{n=3}^{N} Y_{i-n}V_n \quad (25)$$

$$V_3 = = \frac{1}{Y_{i-3}}\left[\frac{P_i - jQ_i}{V_i^*} + Y_{i-4}V_4 + Y_{i-13}V_{13}\right] \quad (26)$$

Applying the Gauss-Seidel iterative method [8], equation (26) can be used to determine all the bus voltages and thereafter, equation (22) is applied to solve for the line currents. The results of these computations are shown in table 3

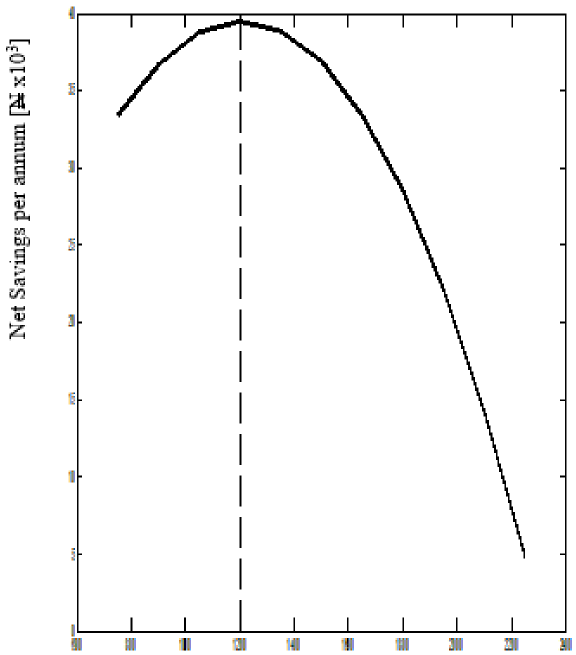
LOAD FLOW RESULTS

Table 3 Voltages and Currents in the Distribution System

Bus Voltages (per Unit)	**Line Currents (Per Unit)**	**Line Currents (A)**	**Load Currents (Per Unit)**	**Load Currents (A)**
V1 = 1.00		**Ib = 5248.6**		
V2 = 0.9941 + 0.0009i	i2 = 0.0486 – 0.0294i	**I2 = 2.5498e+002 - 1.5424e+002i**	il2 = - 0.0023 + 0.0014i	il2 = - 12.1500 + 7.5122i
V3 = 0.9890 + 0.0017i	i3 = 0.0463 – 0.0280i	**I3 = 2.4283e+002 - 1.4673e+-002i**	il3 = - 0.0000 + 0.0000i	il3 = - 0.0000 + 0.0000i
V4 = 0.9820 + 0.0037i	i4 = 0.0439 – 0.0265i	**i4 = 2.3063e+002 – 1.3918e+002i**	il4 = - 0.0023 + 0.0014i	il4 = - 12.3207 + 7.5702i
V5 = 0.9761 + 0.0053i	i5 = 0.0416 – 0.0251i	**i5 = 2.1831e+002 – 1.2402e+002i**	il5 = - 0.0024 + 0.0014i	il5 = - 12.4096 + 7.5951i
V6 = 0.9704 + 0.0069i	i6 = 0.0392 – 0.02361i	**i6 = 2.0590e+002 – 1.2402e+002i**	il6 = - 0.0000 + 0.0000i	il6 = - 0.0000 + 0.0000i
V7 = 0.9666 + 0.0084i	i7 = 0.0134 – 0.0081i	**i7 = 70.2534 – 42.5449i**	il7 = - 0.0000 + 0.0000i	il7 = - 0.0000 + 0.0000i
V8 = 0.9644 + 0.0092i	i8 = 0.0110 – 0.0066i	**i8 = 57.9617 – 34.8303i**	il8 = - 0.0024 + 0.0014i	il8 = - 12.4096. + 7.5951i
V9 = 0.9620 + 0.0102i	i9 = 0.0086 – 0.0052i	**i9 = 45.3718 – 27.1957i**	il9 = - 0.0024 + 0.0014i	il9 = - 12.4096 + 7.5122i
V10 = 0.9608 + 0.0107i	i10 = 0.0062 – 0.0037i	**i10 = 32.7424 – 19.5543i**	il10 = - 0.0000 + 0.0000i	il10 = - 0.0000 + 0.0000i
V11 = 0.9603 + 0.0108i	i11 = 0.0038 – 0.0023i	**i11 = 20.1972 – 12.1519i**	il11 = - 0.0024 + 0.0014i	il11 = - 12.4096 + 7.5122i
V12 = 0.9602 + 0.0109i	i12 = 0.0014 – 0.0009i	**i12 = 7.5412 – 4.5060i**	il12 = - 0.0014 - 0.0009i	il12 = - 7.5400 – 4.5063i
V13 = 0.9887 + 0.0018i	i13 = 0.0023 – 0.0014i	**i13 = 12.2007 – 7.5430i**	il13 = - 7.2909e - 004 +4.5379e-004i	il13 = - 3.8267 + 2.3818i
V14 = 0.9884 + 0.0020i	i14 = 0.0016 – 0.0010i	**i14 = 8.3741 – 5.1612i**	i114 = - 7.2909e - 004 + 4.5379e-004i	il14 = - 3.8267 + 2.3818i
V15 = 0.9883 + 0.0020i	i15 = 8.6615e-004- 5.2947e-004i	**i15 = 4.5463 – 2.7790i**	il15 = - 7.2909e-004+4.5379e-004i	il15 = - 3.8267 + 2.3818i
V16 = 0.9883 + 0.0020i	i16 = 1.3704e-004 - 7.5561e-005i	**i16 = 0.7184 – 0.3966i**	il16 = - 1.3675e-004+7.56lle-005i	il16 = - 0.7178 + 0.3969i
V17 = 0.9659 + 0.0081i	i17 = 0.0258 – 0.0155i	**i17 = 1.3565e+002-8.1474e+001i**	il17 = - 0.0024 + 0.0014i	il17 = - 12.4096 + 7.5951i
V18 = 0.9622 + 0.0092i	i18 = 0.0234 – 0.0141i	**i18 = 1.2308e+002 – 7.3836e+001i**	il18 = - 0.0024 + 0.0014i	il18 = - 12.4096 + 7.5951i
V19 = 0.9581 + 0.0105i	i19 = 0.0210 – 0.0126i	**i19 = 1.1046e+002 – 6.6183e+001i**	il19 = - 0.0024 + 0.0014i	il19 = - 12.4096 + 7.5951i
V20 = 0.9548 + 0.0116i	i20 = 0.0186 – 0.0111i	**i20 = 97.7813 – 58.5160i**	il20 = - 0.0024 + 0.0014i	il20 = - 12.4096 + 7.5951i
V21 = 0.9519 + 0.0125i	i21 = 0.0162 – 0.0097i	**i21 = 85.0451 – 50.8370i**	il21 = - 0.0024 + 0.0014i	i121 = - 12.4096 + 7.5951i
V22 = 0.9486 + 0.0138i	i22 = 0.0138 – 0.0082i	**i22 = 72.2624 – 43.1480i**	il22 = - 0.0024 + 0.0014i	i122 = - 12.4096 + 7.5951i
V23 = 0.9459 + 0.0148i	i23 = 0.0113 – 0.0068i	**i23 = 59.4251 – 35.4503i**	il23 = - 0.0024 + 0.0014i	i123 = - 12.4096 + 7.5951i
V24 = 0.9434 + 0.0158i	i24 = 0.0089 – 0.0053i	**i24 = 46.5425 – 27.7454i**	il24 = - 0.0024 + 0.0014i	i124 = - 12.4096 + 7.5951i
V25 = 0.9422 + 0.0163i	i25 = 0.0064 – 0.0038i	**i25 = 33.6175 – 20.0337i**	il25 = - 0.0024 + 0.0014i	i125 = - 12.4096 + 7.5951i
V26 = 0.9417 + 0.0165i	i26 = 0.0040 – 0.0023i	**i26 = 20.6723 – 12.3188i**	il26 = - .00024 + 0.0014i	i126 = - 12.4096 + 7.5951i
V27 = 0.9416 + 0.0165i	i27 = 0.0014 – 0.0009i	**i27 = 7.7190 – 4.6026i**	il27 = - 0.0014 – 0.0009i	i127 = - 7.5400 – 4.5063i
V28 = 0.9664 + 0.0085i	i28 = 0.0023 – 0.0015i	**i28 = 12.2934 – 7.7141i**	il28 = - 7.8056e – 004 + 4.8988e-004i	i128 = - 4.0969 + 2.5712i
V29 = 0.9662 + 0.0085i	i29 = 0.0016 – 0.0010i	**i29 = 8.1970 – 5.1428i**	il29 = - 7.8056e – 004 + 4.8988e-004i	i129 = - 4.0969 + 2.5712i
V30 = 0.9661 + 0.0086i	i30 = 7.8099e-004 – 4.8990e-004i	**i30 = 4.0993 – 2.5713i**	il30 = - 7.8056e – 004 + 4.8988e-004i	i130 = - 4.0969 + 2.5712i
V31 = 0.9604 + 0.0108i	i31 = 0.0024 -0.0014i	**i31 = 12.5477 – 7.4019i**	il31 = - 5.9744e-004 + 3.5251e-004i	i131 = - 3.1358 + 1.8502i
V32 = 0.9601 + 0.01090i	i32 = 0.0018 – 0.0011i	**i32 = 9.4122 – 5.5516i**	il32 = - 5.9744e-004 + 3.5251e-004i	i132 = - 3.1358 + 1.8502i
V33 = 0.9599 + 0.0110i	i33 = 0.0012 – 0.0007i	**i33 = 6.2759 – 3.7011i**	il33 = - 5.9744e-004 + 3.5251e-004i	i133 = - 3.1358 + 1.8502i
V34 = 0.9599 + 0.0110i	i34 = -5.9844e-004 – 3.5254e-004i	**i34 = 3.1393 – 1.8502i**	il34 = - 5.9744e-004 + 3.5251e-004i	i134 = - 3.1358 + 1.8502i

Capacitor banks on nodes 26 & 11	Power factor	Power Loss (KW)	Power Loss reduction (KW)	Net Savings (₦) x 10^3
750 + 0	0.92	182.6	39.1	33.4
750 + 150	0.94	176.9	44.8	36.7
750 + 300	0.95	173.5	48.2	38.8
750 + 450	0.96	172.3	49.4	39.5
750 + 600	0.97	173.4	48.3	38.9
750 + 750	0.98	176.8	44.9	36.9
750 + 900	0.98	182.4	39.3	33.4
750 + 1050	0.99	190.2	31.5	28.5
750 + 1200	0.99	200.3	21.4	22.1
750 + 1350	1.0	212.7	9	14.2
750 + 1500	1.0	227.4	-5.7	4.8

Table 4 Power Factor and Savings due to the addition of capacitor banks on nodes 11 and 26



Size of capacitor bank [kVAr]

Fig. 5 Net Savings per annum versus total Size of capacitor banks on nodes 11 and 26 of Fig. 5

IV. CONCLUSION

The ability of utility to reduce technical losses in its operation will provide enough revenue for future expansion, upgrades and modernization. This will improve on reliability and security of supply. Many utilities are faced with the crippling effect of power losses (Technical) and are putting in place various measures to reduce these losses. This project therefore presents a technique for reducing the power losses arising from the flow of reactive power in a distribution system by placing compensating capacitors at a few specific locations in the network termed “sensitive nodes” to achieve a maximum loss reduction and maximum annual naira savings. This method is applied to a 3-phase, 11kv, and 50Hz distribution network in Enugu. It can be observed that capacitor bank 1200kVAr was required to provide an optimum net saving of ₦ 39,500.00 (thirty-nine thousand, five-hundred naira).

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