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Determination of Electric Power Losses in Distribution Systems: Ekpoma, Edo State, Nigeria as a Case Study

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--ABSTRACT--

The purpose of distribution system is to take electric power from transmission system and deliver it to customers to serve their needs. However, a significant portion of the electric power that a utility generates is lost in the distribution process. Power losses in Ekpoma distribution network were computed from data obtained from Power Holding Company of Nigeria, Ekpoma for five years (January, 2008 to December, 2012). The results were shown graphically. The results reveal that distribution losses in Ekpoma are due to technical and non-technical losses. The technical losses are due to resistance and reactance of the conductors and faults. Several factors which includes unbalanced loading of transformers, transformer leakage current, aged transformer, damage accessories, inadequate size of conductors were discovered to have also attributed to power losses in Ekpoma. Suggestions were made in order to reduce power losses in Ekpoma distribution network.

Keywords: *Distribution Feeders, Non-Technical Power Losses, Power Losses, Technical Power Losses, Transformer Losses.*

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I. INTRODUCTION

Energy is the basic necessity for the economic development of a country. Many activities necessary for day to day living grind to halt when there is loss of energy, for this reason energy loss must be minimized. The availability of huge amount of energy in the modern times has resulted in shorter working hours with higher efficiency. Energy exists in various forms in nature but the most widely used among them is the electrical energy. The modern society is so much dependent upon the use of electrical energy that it has become part and parcel of our life. Electrical power system basically consists of generation, transmission and distribution, regulated either by single entity or by a number of entities. Electric power distribution is the application of scientific and technological knowledge to planning, design, construction, operation and maintenance of various electric supply schemes for the benefit of the society. Electric power when generated is sent through transmission lines to many distribution circuits that the utility operates. The purpose of distribution system is to take electric power from transmission system and deliver it to consumers to serve their needs, [5]. However, a significant portion of the electric 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. While each of these components may have relatively small losses, the large number of components involved makes it important to examine the losses in distribution system, [1]. Transformers and power lines are major sources of losses in power distribution systems. Core (iron) losses and copper (I^2R) losses occurs in transformers. As load increases, the copper losses become significant, until they are approximately equal to the core losses at peak load. It is very important for electric power suppliers to consider these losses and reduce them wherever practical. Losses are a function of the square of the current flow through the line. Transformer losses occur due to the current flow in the coils and alternating core magnetic field. Transformer losses can be broadly classified as No load losses and Load losses. No load loss is caused by hysteresis losses in core lamination, eddy current losses in core components and dielectric losses, [4]. Since load losses and no load losses occur concurrently on a transformer (transformer is considered to be on load), the structural modifications and measures taken to reduce load losses is similar to that of no load losses.

Load losses result from load currents flowing through the transformer. Winding losses are the power lost in the high and low voltage windings of the transformer due to winding's resistance present when the transformer is unloaded (load dependent). The three components of the load losses are copper or I^2R losses, eddy current losses and stray losses. Load losses can be reduced by increasing the conductor cross sectional area and complying with the manufacturer's guideline as regards temperature.

Hence, a total loss in a transformer is equal to iron loss or no load loss (P_1) plus effective copper loss or load loss (P_0). Reference [2] stated that many transformers work off constant-voltage mains, so P_0 is constant.

$$\text{Therefore, total loss} = \text{constant} + \text{effective resistance} \times I^2 \qquad (1)$$

Unbalanced loading is another factor which results to losses in electric distribution line. If one of the phases is loaded more than others, the loss will be more than it would have been when the load is balanced. As the current level has effect on electric line losses, the resistance of the line cannot be neglected. Technical losses mean losses that occur due to physical nature of the equipment and infrastructure of the power systems, that is, I^2R loss or copper loss in the conductor cables, transformers, switches and generators.

Non-technical losses are losses due to human errors and social issues. Non-technical losses are more difficult to measure because these losses are often unaccounted for by the operators and thus have no recorded information, [3]

II. METHODOLOGY

Data were collected on:

i. Monthly return on loading of 33kV and 11kV feeders.

ii. Feeder route length and distance between transformers.
   a) Iruekpen 11kV feeder (F I) route length 15km
   b) Express 11kV feeder (F II) route length 8km
   c) Irrua 11kV feeder (F III) route length 10km

Aluminium conductor (AAC) of size 150mm^2 with resistivity of $2.82\times 10^{-8}\,\Omega$m was used for both feeders and distributors.

The sample data collected are shown in Tables 1, 3 and 5 from which power losses were obtained from January, 2008 to December, 2012.

III. RESULT

The power losses on each of the 11kV feeders are obtained on the basis of the monthly maximum loading on the feeders, resistance, size of each feeder conductor, route length of each feeder and maximum current drawn from each feeder conductor are shown as follows:

(2) to (4) were used for computation.

Current drawn from feeder (I_L)

$$I_L = \frac{P}{\sqrt{3}\,V\,p.f} \qquad (2)$$

$$R = \frac{\ell L}{A} \qquad (3)$$

where P is Power in Mega Watts, V is voltage in Volts, ℓ is resistivity in Ω-m, R is resistance in Ω, A is cross sectional area in mm^2, L is route length of the feeder

$$\text{Power loss} = I_L^2 R \qquad (4)$$

Hence, power loss is power received less power consumed

Iruekpen Feeder (I)

Maximum loading = 4.5MW
Line voltage (V) = 11kV
Power factor (p.f) = 0.8
Cross sectional area of conductor =150mm^2
Route length (L) = 15km
Resistivity ℓ = 2.82 x $10^{-8}\,\Omega$m
Current drawn from feeder (I_L)

$$= \frac{4.5 \times 10^6}{\sqrt{3} \times 11 \times 10^3 \times 0.8} = 294\text{A}$$

$$R = \frac{2.82 \times 10^{-8} \times 15 \times 10^3}{150 \times 10^{-6}} = 2.82\Omega$$

$$\text{Power loss} = I_L^2 R = 294^2 \times 2.82 = 0.244\text{MW}$$

Express feeder (II)
Maximum loading = 3.6MW
Route length (L) = 8km
Current drawn from feeder (I_L)

$$= \frac{3.6 \times 10^6}{\sqrt{3} \times 11 \times 10^3 \times 0.8} = 237\text{A}$$

$$R = \frac{\ell L}{A} = \frac{2.82 \times 10^{-8} \times 8 \times 10^3}{150 \times 10^{-6}} = 1.5\Omega$$

$$\text{Power loss} = I_L^2 R = 237^2 \times 1.5 = 0.084\text{MW}$$

Irrua feeder (III)
Maximum loading = 1.9MW
Route length (L) = 10km
Current drawn from feeder (I_L)

$$= \frac{1.9 \times 10^6}{\sqrt{3} \times 11 \times 10^3 \times 0.8} = 129\text{A}$$

$$R = \frac{\ell L}{A} = \frac{2.82 \times 10^{-8} \times 10 \times 10^3}{150 \times 10^{-6}} = 1.9\Omega$$

$$\text{Power loss} = I_L^2 R = 129^2 \times 1.9 = 0.031\text{MW}$$

The loading on the three feeders from January, 2008 to December, 2012 is presented in Tables 1, 3 and 5 while the calculated monthly power losses on the feeders are presented in Tables 2, 4 and 6. The average maximum loading on the feeders, the average power losses and average power consumed on the feeders are presented in Tables 7, 8 and 9 respectively. The relationship between route length, average maximum loading and average power losses are shown in Table 10. The average feeders loading, average power losses and average power consumed from January, 2008 to December, 2012 are shown in Fig. 1, 2, and 3 respectively.

Table 1: Monthly Return Loading on Iruekpen 11kV Feeder (F I) from January, 2008 to December, 2012.

Months	Feeder Loading (M.W)				
	2008	2009	2010	2011	2012
Jan	4.5	3.9	4.5	4.5	5.8
Feb	4.5	4.1	4.5	4.3	5.8
Mar	4.6	4.3	4.6	4.7	5.6
Apr	4.5	4.4	4.5	4.7	5.5
May	4.5	4.4	4.4	4.9	5.8
Jun	4.6	4.2	4.4	5.2	5.8
Jul	4.5	4.6	4.6	5.1	5.8
Aug	4.5	4.5	4.3	4.0	5.6
Sept	4.3	4.3	4.4	5.7	5.8
Oct	4.3	4.7	4.5	5.6	5.6
Nov	4.1	4.6	4.4	5.7	5.7
Dec	4.1	4.4	4.4	5.8	5.8

Table 2: Calculated Power Losses from January, 2008 to December, 2012.

Months	Power Losses (M.W)				
	2008	2009	2010	2011	2012
Jan	0.244	0.192	0.250	0.249	0.403
Feb	0.243	0.206	0.249	0.227	0.402
Mar	0.264	0.229	0.264	0.269	0.378
Apr	0.247	0.239	0.244	0.275	0.365
May	0.244	0.234	0.234	0.289	0.403
Jun	0.259	0.210	0.234	0.329	0.416
Jul	0.254	0.254	0.254	0.318	0.403
Aug	0.244	0.249	0.224	0.197	0.378
Sept	0.227	0.224	0.234	0.390	0.403
Oct	0.229	0.264	0.244	0.378	0.378
Nov	0.206	0.254	0.234	0.390	0.390
Dec	0.206	0.239	0.234	0.416	0.403

Table 3: Monthly Return Loading on Express 11kV Feeder (F II) from January, 2008 to December, 2012.

Months	Feeder Loading (M.W)				
	2008	2009	2010	2011	2012
Jan	3.6	3.3	5.2	3.7	3.5
Feb	4.2	4.1	4.8	3.6	3.5
Mar	4.1	3.9	4.5	3.9	3.5
Apr	3.6	4.1	4.5	3.5	4.1
May	3.6	3.9	4.5	3.4	3.5
Jun	4.2	3.6	3.9	4.4	3.6
Jul	4.1	3.6	3.9	3.6	3.6
Aug	4.1	3.9	3.9	2.7	3.5
Sept	3.7	3.8	3.6	3.6	3.5
Oct	3.7	4.4	3.8	3.9	3.2
Nov	3.7	3.9	3.7	3.5	3.2
Dec	3.7	4.1	3.7	3.6	3.4

Table 4: Calculated Power Losses from January, 2008 to December, 2012.

Months	Power Losses (M.W)				
	2008	2009	2010	2011	2012
Jan	0.084	0.070	0.180	0.091	0.078
Feb	0.115	0.109	0.152	0.087	0.078
Mar	0.109	0.102	0.135	0.100	0.082
Apr	0.086	0.110	0.135	0.082	0.109
May	0.084	0.105	0.135	0.078	0.082
Jun	0.115	0.087	0.105	0.125	0.087
Jul	0.109	0.087	0.105	0.087	0.087
Aug	0.112	0.100	0.100	0.049	0.082
Sept	0.089	0.096	0.087	0.087	0.078
Oct	0.091	0.129	0.097	0.100	0.067
Nov	0.091	0.105	0.091	0.082	0.067
Dec	0.091	0.113	0.091	0.085	0.074

Table 5: Monthly Return Loading on Irrua 11kV Feeder (F III) from January, 2008 to December, 2012.

Months	Feeder Loading (M.W)				
	2008	2009	2010	2011	2012
Jan	1.9	2.4	2.5	2.4	2.5
Feb	1.9	2.4	2.5	2.4	2.5
Mar	1.9	2.4	4.1	2.4	2.5
Apr	1.9	2.4	2.5	2.5	2.5
May	1.9	2.5	2.8	2.4	2.7
Jun	1.9	2.5	2.9	2.4	2.8
Jul	2.1	2.4	2.7	2.4	2.5
Aug	1.9	2.4	2.5	1.9	2.5
Sept	1.9	2.7	2.5	2.4	2.4
Oct	1.8	2.4	2.4	2.5	2.5
Nov	1.9	2.5	2.5	2.5	2.5
Dec	1.9	2.5	2.5	2.5	2.5

Table 6: Calculated Power Losses from January, 2008 to December, 2012.

Months	Power Losses (M.W)				
	2008	2009	2010	2011	2012
Jan	0.031	0.046	0.053	0.048	0.049
Feb	0.029	0.048	0.053	0.047	0.049
Mar	0.029	0.044	0.137	0.048	0.049
Apr	0.029	0.046	0.053	0.046	0.049
May	0.030	0.049	0.065	0.048	0.060
Jun	0.031	0.053	0.067	0.046	0.065
Jul	0.039	0.048	0.060	0.048	0.049
Aug	0.031	0.048	0.049	0.029	0.049
Sept	0.029	0.061	0.049	0.047	0.048
Oct	0.028	0.047	0.048	0.052	0.049
Nov	0.029	0.049	0.049	0.051	0.049
Dec	0.029	0.049	0.049	0.049	0.049

Table 7: Average Maximum Loading of 11kV feeders from January, 2008 to December, 2012.

Feeder	Average Maximum Loading (M.W)				
	2008	2009	2010	2011	2012
I	4.4	4.3	4.5	5.0	5.6
II	3.8	3.9	4.2	3.6	3.5
III	1.9	2.4	2.6	2.4	2.5

Table 8: Average power losses from January, 2008 to December, 2012.

Feeder	Average Power Losses (M.W)				
	2008	2009	2010	2011	2012
I	0.23	0.23	0.24	0.31	0.39
II	0.09	0.10	0.11	0.08	0.08
III	0.03	0.04	0.06	0.04	0.05
Total	0.35	0.37	0.41	0.43	0.52

Table 9: Average Power Consumed from January, 2008 to December, 2012.

Feeder	Average Power Consumed (M.W)				
	2008	2009	2010	2011	2012
I	4.17	4.07	4.26	4.69	5.21
II	3.71	3.8	4.09	3.52	3.42
III	1.87	2.36	2.54	2.36	2.45

Table 10: Relationship between Length, Average Maximum Loading and Average Power Losses from January, 2008 to December, 2012.

Feeder	I	II	III
Route Length (km)	15	8	10
Average Maximum Loading (M.W)	4.76	3.80	2.35
Average Power Losses (M.W)	0.28	0.09	0.04

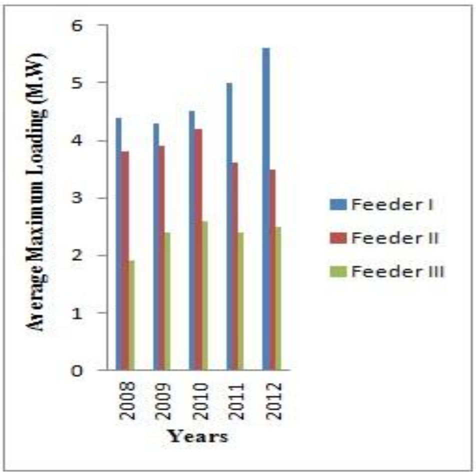

Figure 1: Average Feeders Loading Pattern from January, 2008 to December, 2012.

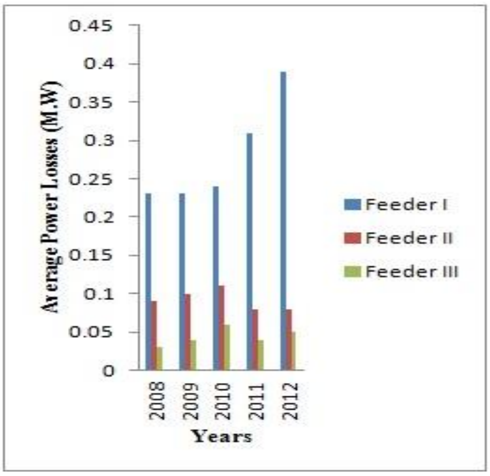

Figure 2: Average Power Losses from January, 2008 to December, 2012.

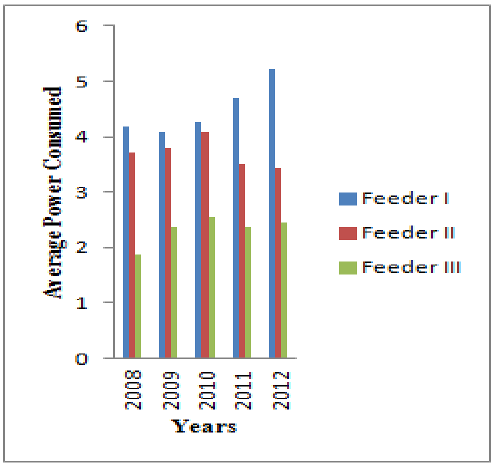

Figure 3: Average Power Consumed from January, 2008 to December, 2012.

IV. DISCUSSION

The power losses in Ekpoma distribution network through mathematical and graphical analysis reveals that the losses occurring on each feeders increases yearly. From January, 2008 to December, 2012, the average power losses on the three feeders for each year (2008 to 2012) were 0.35MW, 0.37MW, 0.41MW, 0.43MW, and 0.52MW respectively as shown in Table 8. The causes of power losses in the 11kV feeders were due to illegal connection resulting to overloading, route length of the feeders, transformer location too far from load centres, aged transformers, poor maintenance culture, use of wrong sizes of conductors and loads with poor power factor.

V. CONCLUSION

Preventive and corrective maintenance should be carried out to minimize power losses on the distribution network. In addition, aged and overloaded transformers should be replaced and upgraded respectively.
Effort should be made to complete the on-going installation of additional new distribution substation.

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