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Revenue Loss Analysis due to Unbalanced Loading in Power Distribution Network

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ABSTRACT

Unbalance loading in power distribution network has continued to pose a great threat to the electricity grid system due to phase load inequality, especially where large single–phase loads are used. The network configuration and length also have effects on the voltage unbalance in the feeder. In low voltage residential feeders, majority of the houses have single–phase power supply. This research focused on finding the revenue loss on JBS 1 Estate 11/0.415kV sub-station. Using direct calculation on established formulas, the values of the unbalance voltages and current were calculated using the real time field data obtained during the period under investigation. It was observed that the highest voltage unbalance of 4.13% was recorded in the month of May while low voltage unbalance figure of 1.05% was recorded in the month of January as depicted in Table 2 and Figure 1 respectively. The research further revealed that the annual revenue loss on JBS 1 Sub-station is quite high during the period under investigation which amounted to ₦4,688,759.90 (four million, six hundred and eighty-eight thousand, seven hundred and fifty-nine naira, ninety kobo) which is predicted to be a high revenue loss to the utility company.

1. Introduction

Energy is a basic necessity for the economic development of any country. Electrical energy is one of the forms of energy and its importance cannot be over-emphasized worldwide. Electrical power has proven its importance beyond human imagination due to its constant availability in developed world. The availability of huge amount of electrical energy in present days has resulted in higher industrial output, a healthier environment and better transportation facilities. Electricity demand has increased drastically due to growing population and industrialization in developing countries and therefore it has become important to operate power plant that deliver energy to transmission and distribution lines at maximum efficiency. The present situation of losses in the power sectors is worrisome and that on the average, power losses ranges between 25% and 40%, in some developed and developing countries, these are indeed high. For instance, [1] informed that the Nigerian electricity grid has a large proportion of transmission and distribution losses, and this amount to a whopping 40%. [2] describe unbalance as a serious power quality problem which mainly affects low voltage distribution network, overheating of rotating machines, increasing system losses which also interfere with neighboring communication systems and causes malfunctioning or breakdown of protection relays and measuring instruments.

[3] further asserted that electricity plays a vital role in modern society which is about the greatest invention of man and further said that a country becomes a 24hours society if there is an

uninterrupted supply of electricity. [4] stated that since power system losses represent a substantial cost for distribution companies, end users and host country, the evaluation and its reduction have been a concerned for researchers. [5] affirmed that distribution networks are operated in an unbalanced configuration which affects the efficiency and effectiveness of services to consumers. The unbalance load and excessive current in neutral wire is one of the issues in three phase four-wire distribution systems that causes voltage drop through neutral wire and create problems for users. [6] opined that electricity plays a critical role in the advancement of any nation and thereby serves as a major means for industrialization. The electrical power system is an inter-link of networks from the generation stations through the transmission, distribution and finally to the consumers via a sub-distribution station. These installations are set of conductors which run from one place to another and supported on transmission towers. [7] also explained that the unbalanced loading level at sub-transmission network and established that unbalanced loading increases power losses and reduce transmission capacity. [8] revealed that the problem of energy losses is badly affecting performance of Pakistan's power sector in general and further stressed that different transformer circuits had different level of unbalance in loads. It is observed through simulation results that load balancing of the selected feeder reduces technical power losses of 62.8 kW accounting to an annual savings of Rs. 2.68 Million. Hence, it is concluded that energy efficiency is increased by load balancing, which is achievable by monitoring and load shifting by dedicated manpower.

1.1 Technical and Non-Technical Losses

Technical losses are naturally occurring losses (caused by actions internal to the power network) and consist mainly of power dissipation in electrical system components such as transmission lines, power transformers, measurement systems etc. Technical losses are possible to compute and control, provided the power system in question consists of known quantities of loads. Non-technical losses (NTL), on the order hand, are caused by actions external to the power system, or are caused by loads and conditions that the technical losses computation failed to take into account. Non-technical losses are more difficult to measure because these losses are often unaccounted for by the system operators, and thus have no recorded information [9].

1.1.1 Line Losses

The power line loss is proportional to resistance and square of current (i.e. $P_{loss}=I^2R$) while the current level has the biggest effect online loss, the resistance of the line cannot be neglected. The line resistance depends on many factors, including the length of the line, the effective cross-sectional area and the resistivity of the metal of which the line is made. The resistance is inversely proportional to the cross-sectional area and directly proportional to both the length and resistivity. This is shown in Equation 1, where R is the resistance, ρ is the resistivity, L is the length of the line and A is the effect cross-sectional area.

$$R = \rho \frac{L}{A} \tag{1}$$

Therefore, a long line will have a higher resistance and large losses than a short line with the same current flow. In addition, a larger conductor size results in a smaller resistance and lower losses than a smaller conductor. The resistivity is determined by the material of which the line is constructed and the temperature for the material. A better conducting material will result in lower resistivity and lower losses. The resistivity of the metal of the line will be affected by temperature. As the temperature of the metal increases, the line resistance will also increase, causing higher copper losses in the distribution lines. Copper and aluminium are materials commonly used for transmission and distribution cables and wires. The resistivity of copper and aluminium can be calculated from Equation 2.

$$\ell_1 = \ell_2 \frac{T_2 - T_o}{T_1 - T_o} \quad (2)$$

The letter rho, ℓ, is the resistivity at a specific temperature. It is equal to 2.83 x 10^{-8} ohm meter for aluminium and 1.77x10^{-8} ohm meters for copper at a temperature of 20^{o}C. T_o is a reference temperature and is equal to 228^{o}C for aluminium and 241^{o}C for copper. ℓ_1 and ℓ_2 are the resistivities at temperatures T_1 and T_2 respectively [10].

2. Methodology

The sub-station under investigation is JBS1 Estate 11/0.415kV, this sub-station is a sub-distribution network which emanate from the 11kV GRA feeder. The sub-station was visited; relevant information including the geographical information system mapping, nameplate of transformer and the single line diagram of the sub-station was collected. Also, the load readings (red, yellow and blue phase) for the 11/0.415kV transformer in the network were captured between January 2019 to December 2019. Using direct calculation on established formulas depicted in Equations (3) - (11). The values of the unbalance voltages and current were calculated using the real time field data obtained.

$$\sum V = V_{RN} + V_{YN} + V_{BN} \quad (3)$$

The average voltage $V_{avg} = \sum V / 3$ (4)

$$\text{Voltage unbalance (\%)} = 100\text{x}\frac{\max\{|V_{I,rms} - V_{avg}|\}}{V_{avg}} \quad (5)$$

Where,
Voltage unbalance% = voltage unbalance index in percent,
V_{irms} = rms single-phase voltage, and
V_{avg} = average among the three single-phase voltages.
This method is also recommended in the case of availability of voltage rms measurements and its values must be within the range of 0% - 2%.

Average load on each phase (Amps) $I_{PH} = \frac{(I_R + I_Y + I_B)A}{3}$ (6)

Balanced load loss (kW) $= \frac{(I_{PH}^2 R_R) + (I_{PH}^2 R_Y) + (I_{PH}^2 R_B)}{1000} kW$ (7)

Unbalanced load loss (kW) $= \frac{(I^2{}_R R_R + I^2{}_Y R_Y + I^2{}_B R_B)}{1000} kW$ (8)

Applying the Equations 6 and 7 above, the copper losses for each phase in the transformer was calculated. In doing this the winding resistance R per phase is assumed to be unity since this value is the same and constant for all phases of the transformer irrespective of loading.

From Table 1,
The average load current for the period under review are as follows;
I_R = 576.2A

I_Y = 533.9A
I_B = 497.5A
Using Equation 6, the average load on each phase (Amps),
I_{ph} = 535.86A

Recall that the resistance R is unity and Equation 7 gives;

Balanced load loss (kW) = 861.45kW

Again Equation 8 gives;

Unbalanced load loss = 864.5619kW

Saving in losses (kW) = unbalanced load loss – balanced load loss (9)

Saving in losses (kW) = 864.5619 – 861.45 = 3.1119kW

Average availability of power per day = 10 hours

Energy loss per annum = saving in losses (kW) x Average Availability x 365 days (10)

Energy Losses per annum = 3.1119 x 10 x 356 = 11,358.43kWHr

Billing tariff of BEDC as approved by NERC MYTO 2019 = ₦34.40 per kWHr

Energy loss in naira per annum = Energy loss per annum x Billing tariff x 12months (11)

Energy loss in naira per annum = 11358.43 x 34.4 x 12 = ₦4,688,759.90k

4. Results and Discussion

Table 1: JBS1 Sub-Station Monthly Average Load Profile Survey Results for 2019

Months	R Ph Voltage (V)	Y Ph Voltage (V)	B Ph Voltage (V)	R Ph Current (A)	Y Ph Current (A)	B Ph Current (A)
January	224.4	228.8	227.2	527.1	519.9	514.0
February	234.3	228.6	232.6	609.6	509.5	429.6
March	238.1	232.2	243.1	579.6	562.4	432.4
April	227.4	236.0	235.9	517.6	460.9	441.0
May	215.0	225.7	232.1	538.6	449.6	364.9
June	229.0	237.7	240.2	610.0	603.3	410.6
July	239.7	229.0	228.3	569.7	498.2	512.7
August	228.6	222.7	224.2	632.4	610.7	590.9
September	222.9	228.7	233.1	636.2	630	563.4
October	220.4	233.9	231.3	521.3	472.2	604.9
November	223.5	227.6	221.7	542.6	532.7	571.8
December	226.6	240.0	238.1	630.6	558.1	534.5
Overall average	**227.4**	**230.9**	**232.3**	**576.2**	**533.9**	**497.5**

Table 2: Voltage Unbalance figures for the period under review

Months	Voltage Unbalance	Voltage Unbalance in percentage (%)
January	0.0105	1.05

February	0.0139	1.39
March	0.0235	2.35
April	0.0244	2.44
May	0.0413	4.13
June	0.0280	2.80
July	0.0174	1.74
August	0.0109	1.09
September	0.0233	2.33
October	0.0355	3.55
November	0.0114	1.14
December	0.0353	3.53

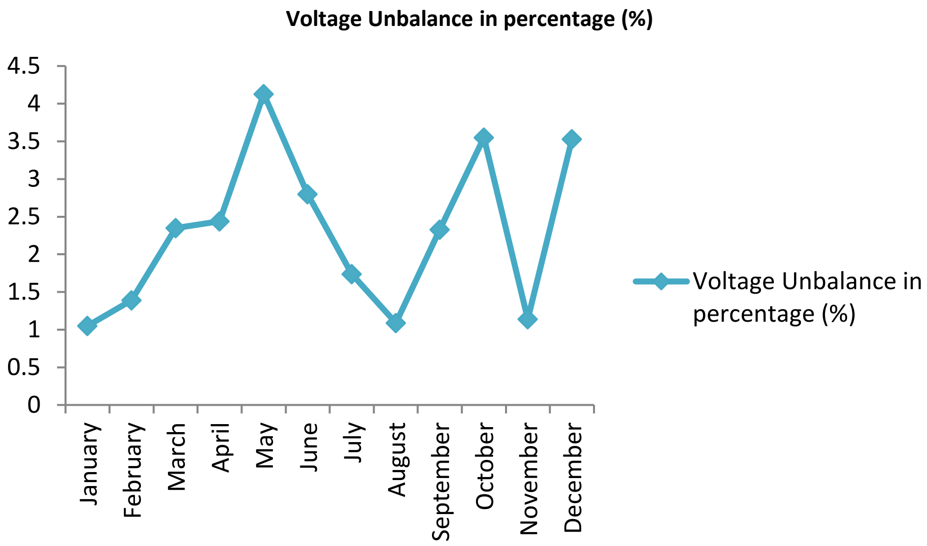

Figure 1 Graphical representation of percentage voltage unbalance

From the analysis of the investigation of unbalance loading in JBS1 sub-station, it was observed that the highest voltage unbalance of 4.13% was recorded in the month of May while low voltage unbalance figure of 1.05% was recorded in the month of January as shown in Table 2 and Figure 1. It was further revealed that the annum revenue loss resulting from unbalanced loading in low power distribution network using JBS 1 Sub-station as case study is quite high which amounted to ₦4,688,759.90 (Four million, six hundred and eighty-eight thousand, seven hundred and fifty-nine naira, ninety kobo).

5. Conclusion

The research revealed that high level of unbalanced loading is responsible for the continued hike in electricity tariff which means that when the network is fairly balanced, there would be lesser losses along the lines which in turn allow for lower tariff by electricity distribution companies. The reason for the high tariff is simply a compensation scheme put in place by the regulating agencies which is bore by the consumers and the providers.

Nomenclature

NERC	Nigeria Electircity Regulatory Commission
MYTO	Multi Year Tariff Order
BEDC	Benin Electricity Distribution Company
I_R	Red phase Load in Amps (A)
I_Y	Yellow phase Load in Amps (A)
I_B	Blue phase Load in Amps (A)
I_{PH}	Average phase Load in Amps (A)
V_R	Red phase Voltage in volts (V)
V_Y	Yellow phase Voltage in volts (V)
V_B	Blue phase Voltage in volts (V)
R_R	Red phase Resistance in ohms (Ω)
R_Y	Yellow phase Resistance in ohms (Ω)
R_B	Blue phase Resistance in ohms (Ω)

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