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Determination of Power System Losses in Nigerian Electricity Distribution Networks

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ABSTRACT

Nigerian Electric Power Utilities face epileptic power supply due to poor generation level. The available power is characterised with high losses of Aggregate Technical and Commercial (ATC) or Total network losses. These losses have serious effects on the quality of power delivered to customers and adverse effect in meeting the expected revenue targets. Technical losses are caused by network impedance due to current flowing in the network and auxiliary supplies. Whereas, non-technical losses are caused by several factors which include, energy theft, unbilled accounts, non-payment of customers, estimated customer accounts etc. This paper presents analysis of some selected power system network for estimation of total network or ATC losses and determination of network technical losses (TL) using power flow analysis. From the results of ATC losses and TL calculations, a total network non-technical loss (NTL) is determined.

Keywords: *Aggregate Commercial and Technical Losses, Non-Technical Loss, Power Utilities*

1. INTRODUCTION

The process of making electricity available to the user starts from the power generating station, where energy is being generated from available sources like gas, oil, hydro, coal, thermal, bio-waste, etc. at a reasonable voltage level that is further stepped up for onward transmission. It is eventually transformed into power at a voltage level compatible with customer or consumer requirements via the distribution substations that receive the energy from transmission stations. During the process, power losses are experienced at the following different stages.

- ➢ In transmission of energy from the generating station to the transmission station at a high voltage.
- ➢ In transportation of energy from the transmission station to distribution substations (Injection substations) at medium voltage level, in Nigeria network, it is 33kV.
- ➢ In distribution of energy from an injection substation to various distribution transformers on the 11kV feeders. In practice, there are three 11kV feeders per 15MVA, 33/11kV power transformer.
- ➢ In servicing customers at the Point of Customer Connection (PCC) as well in customer's premises.

2. AGGREGATE TECHNICAL AND COMMERCIAL LOSSES (ATC)

Generally, power losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users [1, 2]. 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 Transmission and 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 [1].

Technical powers losses occur during transmission and distribution processes and also involve station transformers and line related losses. These losses include resistive losses of the primary feeders, distribution transformer losses (resistive losses in windings and the core losses), resistive losses in the secondary network (in Nigeria, typically 33kV & 11kV networks), resistive losses in service drops to customers and losses in kwh Meter (most especially at the inductive load customers). Technical power losses are classified as copper losses (I^2R), Dielectric losses and induction & radiation losses. However, the occurring technical power losses known in power systems have different causes and these include harmonic distortion, improper earthing of electrical equipment at various injection substations, unbalanced loading of distribution transformer and substandard equipment such as Aluminium conductor, cable etc [1, 2, 4],

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 energy used by the customers, 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 customers billing, collection of billed amounts and proper accountability are functions that required 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 [1,2,3].

The relationship between power system networks aggregate technical and commercial loss (P_{ATC}), Technical loss ($P_{TL\ losses}$) and Non-Technical losses ($P_{NTL\ losses}$) is illustrated as follows,

$$P_{ATC\ Losses} = P_{TL\ losses} + P_{NTL\ losses} \qquad (1)$$

From equation (1), the absolute value of $P_{NTL\ losses}$

$$P_{NTL\ losses} = P_{ATC\ Losses} - P_{TL\ losses} \qquad (2)$$

The estimated input power $P_{estimated}$ using power flow analysis and the algebraic summation of bus bars output power P_{output} are used to calculate the Aggregate Technical Losses (ATC) of the power system network P_{ATC} is given as,

$$P_{ATC} = P_{estimated} - P_{output} \qquad (3)$$

3. POWER FLOW SOLUTION

The power flow solution is an important tool involving numerical studies applied to a power system. Power flow solution uses simplified notation such as a one-line diagram and per unit system, and focuses on various forms of AC power (i.e reactive, real and apparent) rather than voltage and current [3,5]. It analyses the power system in normal steady operation [3]. In the process of power flow solution, investigation is required in regard to bus voltages and amount of power flow through the Transmission/Distribution lines. Power flow study aims at reaching the steady state solution of complete power system networks. Power flow equations represent a set of non-linear simultaneous algebraic equations [3,4]

The solution to the power flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of Bus. A Bus without any generator connected to it is called a load Bus. While a Bus with at least a generator connected to it is called a Generator Bus [1, 7]. However, one of the generator buses is often selected as slack bus on generator bus, while the source of supply bus is normally used as slack bus on Load Bus [7].

In power flow problem, it is assumed that the real power (P) and reactive power (Q) at each load bus are known. Hence, load buses are referred to as PQ Buses. For Generator Buses, it is assumed that the real power (P) generated and the voltage magnitude |V| are known. For the slack Bus, the voltage magnitude |V| and phase angle θ are specified. This implies therefore, that for the load bus, the voltage magnitude and angle θ are unknown and need to be calculated in the process. For the generator Bus, the voltage angle θ is the unknown and need to be calculated in the process. For the Slack Bus, there are no variables to be calculated in the process. But where technical losses in the system are required, overall power from the Slack Bus may be determined in the power flow process [3]. Then, in a system with N buses and R generators, there are 2(N-1) – (R-1) unknowns [1]. Thus, in order to solve for the 2(N-1) – (R-1) unknowns, there must be 2(N-1) – (R-1) equations that do not introduce any unknown variables [1]. The possible equations to use are power balance equations, which can be written for real and reactive power for each bus. Equations included are the real and reactive power balance equations for each Load Bus and the real power balance equations for each Generator Bus. Only the power balance equation is written for a Generator Bus because the net reactive power injected is not assumed to be known and therefore including the reactive power balance equation would result in some additional unknown variables.

4. NEWTON-RAPHSON POWER FLOW SOLUTION

In this paper, technical losses would be first computed using power flow method. Non-technical losses cannot be computed and measured easily, but it can be estimated by subtracting technical losses from the total network losses.

Table 1: Network Bus Loading in MW

S/N	NAME OF BUS	BUSBAR LOADINGS	
		P(MW)	Q(MVAR)
1	ALAGBON	-	-
2	ANIFOWOSHE	11.7	7
3	BANANA ISLAND	3	1.5
4	FOWLER	9.6	5.5
5	ALAGBON LOCAL	3.6	2.1
6	ADEMOLA	10.6	6.5

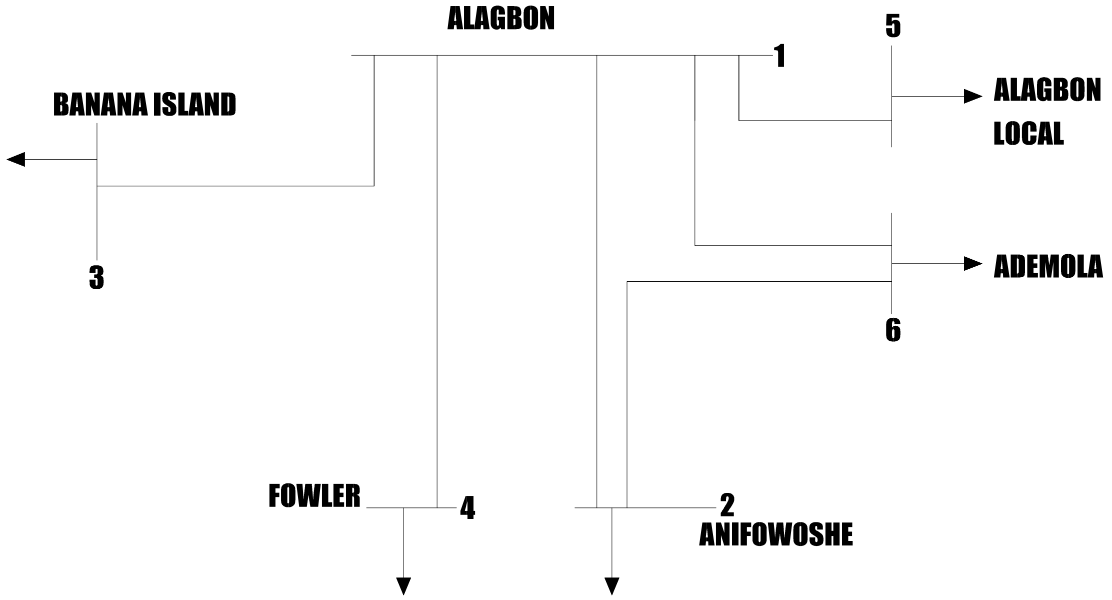

Figure 1 : 33KV NETWORK OF ISLAND DISTRICT,EKEDP

The network of Figure 1 is modelled to suit the application of the NEPLAN software [8]. It involves opening of dialog boxes and inputting all the necessary parameters.

Contents of Tables 2a and 2b were used in power flow analysis using the Algorithm in 4.1 [8]. Power flow was carried out and the process converged at iteration K=3. The results of the power flow analysis are shown in Table 3a to 3c.

4.1. Newton-Raphson Power Flow Algorithms

1. Input Network Parameters
    - Line Resistance (R)
    - Line Reactance (X)
    - Line Susceptance (B)
    - Bus bar scheduled active power (P_s)
    - bus bar scheduled reactive power (Q_s)
2. With bus 1 chosen as a slack bus and the only source of supply to the network;

    Assumptions:

    - Initial Bus voltage (E) = 33kV
    - Power mismatch Tolerance, $\in = 0.001$
    - Initialize iteration count, k
3. Compute Shunt Admittance (Y_{sh})
4. Calculate Power P_k and Q_k
5. Calculate all ΔP, ΔQ and save ΔP_{max} and ΔQ_{max}
6. Obtain Jacobian matrix
7. Solve for $\Delta|E_p|$ and $\Delta\theta_p$ by triangular factorisation

    If yes, go to step 13
8. Compare: is $\Delta P_{max} \leq \in$ and $\Delta Q_{max} \leq \in$
9. Update all bus voltages

    $$|E^k| = |E^{k-1}| + \Delta E$$

    $$\theta^k = \theta^{k-1} + \Delta\theta$$
10. Increase iteration k = k+1
11. Go to step 4
12. Calculate line flow losses and slack bus power
13. Print Results
14. End.

Table 2a: Distribution Lines and Their Distances

S/N	BUS	BUS	LINE DISTANCE (KM)
1	ALG	ALG - BAN/I	5.00
2	ANF	ALG – FOW	3.00
3	BAN/I	ALG – ANF	6.84
4	FOW	ALG – ALG/L	0.15
5	ALG/L	ALG - ADM	10.6
6	ADM	ADM – ANF	2.4

Table 2b: Line Parameters and their Values

S/N	Name of Parameters	Parameters Value
1	Reactance (X)	0.093 Ω/km
2	Susceptance (B)	0.37 μ/km
3	Resistance (R)	0.098 Ω /km
4	Impedance (Z)	0.135 Ω /km

4.3. Power Flow Results

Table 3a: Busbar Power Flow Results

S/N	NAME OF BUS	VOLTAGE (kV)	% VOLTAGE	VOLTAGE ANGLE (Deg.)	P (MW)	Q (MVar)	INPUT P (MW)	INPUT Q (MVar)
1	Ademola	32.711	99.12	-0.1	10.6	6.569	0	0
2	Alagbon	33	100	0	0	0	38.725	18.658
3	Alagbon-Local	32.997	99.99	0	3.6	2.231	0	0
4	Anifowoshe	32.645	98.93	-0.2	11.7	7.251	0	0
5	Banana-Island	32.942	99.83	0	3	1.859	0	0
6	Fowler	32.868	99.6	-0.1	9.6	5.95	0	0

Table 3b: Power Flow Results Showing Network Loading

S/N	SUBSTATION/BUSBAR	ACTIVE POWER (MW)	REACTIVE POWER (MVar)	CURRENT (kA)	CURRENT ANGLE (Degree)
1	Ademola	10.6	6.569	0.225	-32.2
2	Alagbon-Local	3.6	2.231	0.074	-31.8
3	Anifowoshe	11.7	7.251	0.246	-32.1
4	Banana Island	3	1.859	0.062	-31.8
5	Fowler	9.6	5.95	0.198	-31.8
		38.5	**23.86**		

Table 3c: Lines Power Flow Results

S/N	SB	RB	LENGTH (KM)	P (MW)	Q (MVar)	CURRENT (kA	CURRENT ANGLE (Deg.)	% LOADING	P LOSS (MW)	Q LOSS (Mvar)
1	ALG	BAN-I	5.00	-3	-1.228	0.057	157.7	13.18	0.0044	-0.6276
2	ALG	BAN-I	5.00	0	-0.631	0.011	89.9	2.56	0	-0.6307
3	ALG	FOW	3.00	0	-0.377	0.007	89.9	1.54	0	-0.3767
4	ALG	FOW	3.00	-9.6	-5.573	0.195	149.8	45.24	0.033	-0.3469
5	ALG	ANI	6.84	-11.7	-6.28	0.235	151.6	54.49	0.1077	-0.7544
6	ALG	ANI	6.84	0	-0.847	0.015	89.8	3.48	0.0001	-0.8474
7	ALG	ADM	6.13	10.68	5.113	0.207	-25.6	48.06	0.0796	-0.6936
8	ALG	ADM	6.13	0	0	0	90	0	0.0001	-0.7625
9	ALG	ALG-L	0.15	-3.6	-2.212	0.074	148.4	17.15	0.0002	-0.0187
10	ALG	ALG-L	0.15	0	-0.019	0	90	0.08	0	-0.019
11	ADM	ANI	2.40	0	-0.124	0.002	89.8	0.51	0	-0.1239
				-17.22	**-12.178**				**0.2251**	**-5.2014**

5. DISCUSSION OF RESULTS

Power flow analysis results in Table 3a shows that the input power at Busbar 1 (Slack Bus) is estimated to be 38.725MW. Also, Table 3c shows that the estimated technical losses (P_{TL}) in the power system network of figure 1 is 0.2251MW. Furthermore, the algebraic sum of power system network output powers (i.e load on the bus bars) of the buses in Figure 1 is 38.5MW. Consequently, the subtraction of the absolute values of these powers (i.e estimated input power and summation results of Bus bar powers) give the power system networks Aggregate Technical and Commercial Losses (ATC). From equation (3), ATC losses is 0.725MW. Also from equation (2), P_{NTL} becomes 0.5MW. The result of P_{NTL} greater than P_{TL} (i.e $P_{NTL} > P_{TL}$) equal 0.225MW shows the common situation in developing countries where non-compliance to engineering standards are rampant. Whereas, in developed countries where situations are the reverse, $P_{NTL} < P_{TL}$. Thus, such ideal power system networks are almost perfect and the supply availability is 24/7.

6. CONCLUSION

The power system network aggregate losses, technical losses and non-technical losses (commercial and collection losses) have been fully described. Various causes of technical as well as non-technical losses including their effects are clearly presented. Details of Newton-Raphson power flow method to determine the technical losses as well as other parameters are stated. The results of this power flow study are presented and discussed. The result obtained for non-technical losses reflect the true situation of Nigeria power system network, & typically, network of a developing countries, where non-technical losses are greatly affected by poor revenue collection of the utility companies. The main scope of future work is through the use of newer technologies, such as the implementation of a Supervisory Control and Data Acquisition (SCADA) System to increase measurement capabilities, with the existing methods, favoured by the utilities in most developing countries. Non-technical losses in all forms are very real and also pose significant problems for utilities companies.

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