

Estimation of Technical Losses in Generation and 330kv Transmission Network of Nigeria National Electric Power System

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Abstract: This research aimed at estimating technical losses in generation system and 330kV transmission network of Nigeria Electric Power System. B-coefficient approach, which expresses transmission losses as a function of the output of all generating plants was employed and Kron's formula was used to estimate transmission loss. Losses in generation subsystem has been calculated as the difference between the fuel input (\$/h) to and the power output (MW) from the generators. Hydrological unit data and thermal cost data were used to calculate generation loss. Transmission loss recorded was 5.424 per unit or 542.4MW while generation loss amounted to 25,411.62MW. Net technical loss in the system was 25,953.99MW. To mitigate real power losses and increase system stability, factors that contribute to losses should be eliminated. Also, loops should be created within the network to give room for flexibility.

Keywords: Technical losses; Generation; Transmission; Hydrological; Thermal

Date of Submission: 30-07-2019

Date of acceptance: 11-08-2019

I. Introduction

The economy of most societies or nations is driven by electrical power. Electricity being generated from the power stations needs to be transmitted to end users through transmission and distribution lines. A reliable development index of a nation is her per capita consumption of electricity [15]. In Nigeria this index being 14W per person is very low compared to those of other countries [6]. Table 1 shows the per capita consumption of electricity in some selected countries according to the International Energy Institute's comparative analysis of the per capita consumption of electricity worldwide [6].

Table 1: Per Capita Electricity Consumption of Selected Countries

Country	Per Capita Consumption per Person (in Watts)
United States of America	1,377
Cuba	68
United kingdom	547
Ukraine	369
Iraq	125
South Korea	1,109
Nigeria	14
Egypt	172
Ghana	39
Libya	162

Sources: Energy Information Administration

Economic growth in any country is a function of the quality and quantity of her electric power. In Nigeria, inadequacy, poor quality and inaccessibility to electricity services is a regular feature [9]. The Nigeria electric power system has been confronted with several problems such as inadequacy, instability and unreliability. As a result, electricity consumers have hardly enjoyed the supply of this commodity. The consequence is poverty due to the bad economy since the cost of doing business has become very high [8]. Previous administrations in Nigeria made promises to improve the quality of electricity supply to consumers. However, several years after those promises have been made no significant improvement has been achieved due to some planning and operational problems. One of such problems is lack of information on the losses inherent in the system.

It becomes very important, therefore to estimate the losses inherent in it. The Nigeria power system is predominantly dependent on hydro-thermal and gas plants and characterized by radial, fragile and very long transmission lines. Like any other power system that one can think of, Nigeria's electric power system is subjected to power losses. Energy loss constitutes any energy either wasted at the point of generation or sent out but cannot be sold or given out to consumers in exchange for money. In other words, it is a wasted or useless energy.

In generation, it may refer to energy that cannot be transmitted to the load center from the generation station. An example is the heat generated by the armature of a motor. In terms of transmission, losses constitute the energy transmitted from the power plant to the load center but cannot be distributed to consumers or converted to money.

Several studies have been carried out on estimation of losses in electrical power system of Nigeria. Work has been done on the 330kV network of the power system such as [2], [3], [19] and [13]. However, in all their studies, it was observed that there was no consideration of transmission losses as a function of the output of the generator, and this research work will address the issue.

System efficiency is related to system reliability, security and quality of the power to be delivered by the utilities to consumers in the right quantity and time. No doubt, the Nigeria electric power system is in a comatose state. Estimation of the losses will, therefore, enable engineers to ascertain the efficiency of our power system. This work is to estimate the loss in a more recent state of the power system using a more accurate procedure. It also estimates the loss in the generation subsystem of the power system.

The aim of this research is to determine the amount of power loss in generation and 330kV transmission network of the Nigeria National Electric Power System (NNEPS). For the loss in the transmission network, the Kron's loss formula is utilized and for the loss in generation, the power differential approach is used.

The objectives of the study are: To determine the Kron's loss coefficients namely; B_{ij} , B_{io} and B_{oo} and hence compute the loss in the transmission and generation subsystems. The study of the Nigeria power system with a view to estimating technical losses will allow industry participants devise means of mitigating losses and improve the system performance to boost economic activities.

II. Literature Review

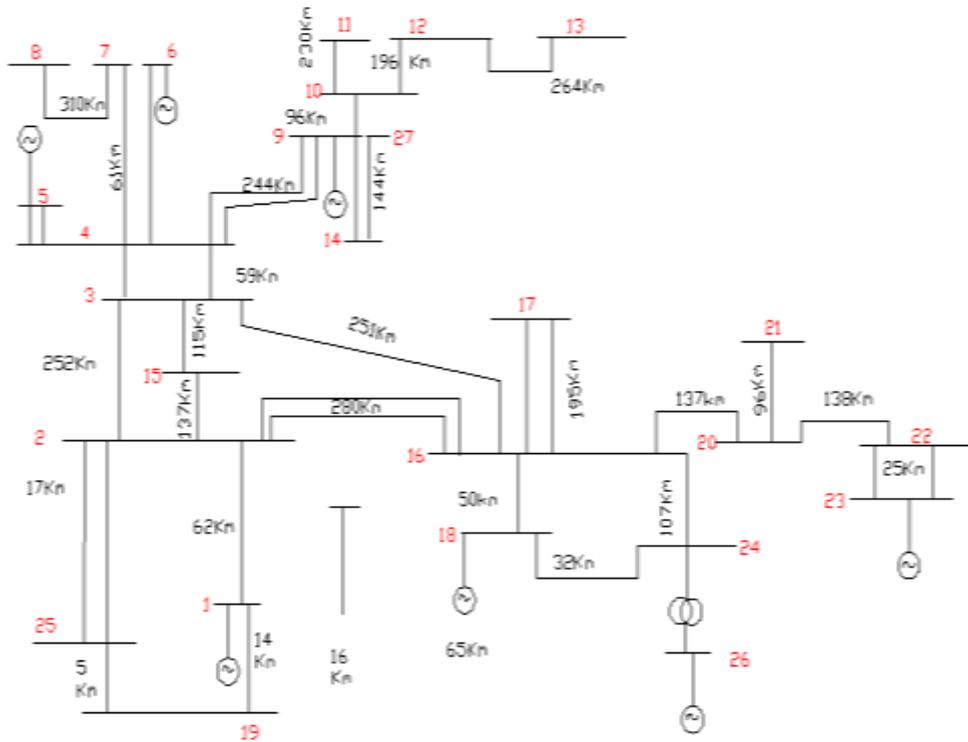
[12] Estimated technical losses in the Nigerian 330kV transmission network and pegged the losses in the Nigerian transmission and distribution systems at 44.5% of "sent out" generation. In their study, 9.2% of those losses were attributable to transmission lines alone. This study was silent on generation system.

[11], stated that electrical losses include field loss, armature winding loss and brush contact loss. The copper loss in the field circuit is obtained by adding I^2R , loss of field winding and the electrical loss of the field-rheostat or simply by multiplying the excitation voltage by the field current.

According to [11], the eddy current and hysteresis are caused by the flux resulting from the combined rotor and stator fields. These losses occur in pole faces and armature teeth and core. Core loss is independent of load, but rises with the excitation. If the excitation is to be varied with load and with the change in power factor, then there will be changes in this loss also. This is equal to the power required to drive the alternator with or without the field excited. Also loss between the bearing and brush is Friction and winding loss. The ions produced by the electric field result in space charges which move around the conductor. The energy required for the charges to remain in motion is derived from the supply system. The space surrounding the conductor is vulnerable to losses [4].

Differential power loss approach can be expressed as the difference between power input to the generation system and power sent out from the generation system. This constitutes the losses from generators [10].

Figure 1. Single Line Diagram with Buses Numbered



III. Thermal cost Data

Only the very early commissioned thermal plants, namely, Egbin ST2-5, Delta, Afam IV-V and Sapele (Steam) thermal plants have fully developed cost data. The cost characteristics are given as:

$$F_1 = 12787 + 13.1P_1 + 0.031P_1^2 \text{ \$/hr} \quad (1)$$

$$F_2 = 525.74 - 6.13P_2 + 1.2P_2^2 \text{ \$/hr} \quad (2)$$

$$F_3 = 1998 + 56P_3 + 0.092P_3^2 \text{ \$/hr} \quad (3)$$

$$F_4 = 6929 + 7.84P_4 + 0.13P_4^2 \text{ \$/hr.} \quad (4)$$

3.1 Hydro-generating unit data

Table 2 The unit Data of hydro-generating [5].

Table 2.: The Hydro-generating Unit Data.

Power Parameters	Stations	Kainji	Jebba	Shiroro
Head Water Elevation (Meters)		133.91	102.74	364.36
Tail Water Elevation (Meters)		104.68	74.00	271.00
Gross Operating Head (Meters)		29.23	28.74	93.36
Av. Turbine Discharge (M ³ /S)		663	1260	377
Average Spillage (M ³ /S)		0	0	0
Average Total Station Disc -harge (M ³ /S)		663	1260	377
Computed Inflow (M ³ /S)		1068	1191	481
Storage Differential		405	-69	104
Maximum Level for Spillage Commencement		141.73	103.3	359
Minimum Level below which No Generation		137	99	355

Source: TCN (2017)

3.2 Methods

The following steps were used in calculating losses in transmission and generation subsystems of the transmission and generation network:

3.3 Loss in transmission subsystem

The losses are first computed using power flow and loss approach before the use of Kron's loss formula. Following steps were followed in determining the power loss in transmission subsystem:

- i. Collection of some relevant information on the network such as Single Line Diagram (SLD) showing the line lengths. Resistance per unit length is thereby calculated.
- ii. Computation of losses based on power flow.
- iii. Calculation of the elements of the loss coefficients.
- iv. Calculation of transmission loss based on Kron's loss formula.

3.4 Calculation of B - coefficients

Current distribution factor and power factor which are very important variables to be used for calculating loss coefficients will be computed first.

The computation is as follows:

Peak load demand ($i_{k1}, i_{k2}, i_{k3}, \dots, i_{k8}$) on each element (generator bus) obtained from the system operator are; 500, 360A, 0, 0, 529A, 42.9A, 21A and 410A [17] respectively.

Therefore,

$$I_L = 1862.9A.$$

Hence, the distribution factors $d_{k1}, d_{k2}, d_{k3}, \dots, d_{k8}$ are given as:

$$d_{kn} = \frac{I_{kn}}{I_L} \quad (5)$$

It follows therefore, that

$$d_{k1} = \frac{500}{1862.9} = 0.27A$$

$$d_{k2} = \frac{360}{1862.9} = 0.19A$$

$$d_{k3} = \frac{0}{1862.9} = 0$$

$$d_{k4} = \frac{0}{1862.9} = 0$$

$$d_{k5} = \frac{529}{1862.9} = 0.28A$$

$$d_{k6} = \frac{42.9}{1862.9} = 0.02A$$

$$d_{k7} = \frac{21}{1862.9} = 0.01A$$

Phase angles $\phi_1, \phi_2, \phi_3, \dots, \phi_8$ are obtained as follows:

From

$$\cos\phi = \frac{P}{VI}$$

Where

P = real load from generator bus

Q = reactive load from generator bus.

3.5 Calculation of elements of loss coefficient matrices

The loss coefficient matrix B is symmetrical. Diagonal elements and off-diagonal elements of the matrix are obtained as follows [16]

Off - diagonal elements:

$$B_{mn} = \frac{\cos(\delta_m - \delta_n) \sum d_{km} d_{kn} R_k}{|V_m| |V_n| \cos \theta_m \cos \theta_n} \quad (6)$$

Diagonal elements:

$$d_{k8} = \frac{410}{1862.9} = 0.22A$$

$$B_{mm} = \frac{1}{|V_m|^2} \times \frac{1}{(\cos \theta_1)} \sum d_{km}^2 R_k \quad (7) \text{ Where}$$

R_k = resistance of the network element
(transmission line).

δ_n = voltage angle

d_k = distribution factor

$\cos\theta$ = generator bus power factor

$|V_m|$ = voltage magnitudes which are obtained from power flow.

Calculation of B_{io} and B_{oo}

The linear factor, B_o is given as [7].

$$B_o = \sum_{i=1}^n B_{oi} P_{gi} \quad (8)$$

$$P_{Gi} = P'_{gi}$$

$\therefore B_o = -0.2981$.

The constant factor, B_{oo} is given as [7]

$$B_{oo} = \sum_{i=1}^N P_{di} B_{ij} P_{dj}$$

$\therefore B_{oo} = 0.0043$.

Calculation of loss using George's formula

$P_{gi} = [5.85 \ 4.5 \ 3.12 \ 0.65 \ 0.00 \ 4.24 \ 2.9 \ 4.5]$;

$P_{gi} = P'_{gi}$

$$\begin{aligned} P_{L\text{George's}} &= P_{gi} \times B_{ij} \times P'_{gi} \\ &= 5.7175 \text{ per unit.} \end{aligned}$$

Therefore, the real power loss calculated using George's formula is equal to 5.7175 per unit.

3.6 Calculation of transmission loss using Kron's formula

The real power Loss, P_L calculated using Kron's Loss Formula is obtained as:

$$P_{L_{Kron's}} = P_G + B_O + B_{oo}$$

$$P_{L_{Kron's}} = 5.7175 - 0.2981 + 0.0043 \\ = 5.4237 \text{ per unit}$$

Where:

P_G = Real power loss using George's

loss formula

B_o = Linear coefficient factor

B_{oo} = Constant factor.

When multiplied by the base value, the power loss is obtained as:

$$P_{Kron's \text{ Loss}} = 5.4237 \times 100 \text{ MW} = 542.37 \text{ MW.}$$

3.7 Loss in Generation Subsystem

In the generation system, the losses are calculated as the difference between the power content of the fuel input to, and the power output from the generator.

Loss in thermal stations

In most practical cases, the utility operator maintains and updates one or more of four characteristic curves, namely; fuel input- power output curve with the input to the power plant expressed in Btu/h or Kcal/h and the output is in MW, Heat-rate curve, (ratio of the input fuel to the corresponding output power plotted against power output), the incremental heat rate characteristic which is simply a plot of dF/dP versus power output and the cost curve [14]. The cost curve is obtained by converting the coordinate of input-output curve from Btu/h to \$/h.

Most utility operators model the cost curve by a quadratic or cubic polynomial of the power output called cost function with the quadratic polynomial more frequently used [17] and [12]. The quadratic cost function is defined as;

$$C_F(P) = \alpha P^2 + \beta P + Y \text{ \$/h} \tag{9}$$

Where:

$C_F(P)$ is the cost function, P is the power output, α , β and Y are called cost coefficients.

The cost of electrical energy production is made up of the Operations and Maintenance costs and the fixed costs which include facility construction, salaries, taxes and insurance. The fixed costs are independent of the generator's MW output. For the quadratic cost model of equation (9), therefore, the 'Y' coefficient which is fuel costs independent represents the fixed cost and the 'α' and 'β' coefficients which are fuel cost dependent are the operating costs [1]. Fuel costs dominate the operating costs necessary to produce electrical energy from the plant so that the fuel costs (F_C) can be taken to be;

$$F_C(P) = \alpha P_g^2 + b P_g \text{ \$/h} \tag{10}$$

If the average price of fuel (natural gas) is, Say
 $F_p = X \text{ \$ per million British thermal units (mmBtu)}$

and the conversion rate is,

$$1\text{Btu/h} = R \text{ Watts} \tag{11}$$

Then the input power to a plant is,

$$P_{in} = \frac{F_C(P)}{X} R \text{ Watts} \tag{12}$$

The power loss in a power plant is

$$P_{Loss} = P_{in} - P_{out} \tag{13}$$

3.9 Loss in hydro plants

Before embarking on any hydro power generation project it is essential to survey the proposed site to calculate the amount of available hydro power. If there are no losses, the available hydro power is wholly

transformed into electrical power. The available power depends on two vital factors, the flow and the head of the stream or river or dam. The flow is the volume of water which can be captured and re-directed to turn the turbine generator, and the head is the distance the water will fall on its way to the generator.

The larger the flow, that is, the more water there is, and the higher the head, the more energy is available for conversion to electricity. The available energy for conversion is the potential energy contained in a volume of water suspended by the head. The potential energy per unit volume = ρgh

Where :

ρ is the density of the water (10^3 Kg/m^3),

g is the acceleration due to gravity (approximately 9.81 meters per second per second) and

h is the head of water.

P is the power available from a dam reservoir which is the power input to the plant [14] is given by:

$$P = \rho ghQ \quad (14)$$

Where:

Q is the water flow rate (volume of water flowing per second in m^3/second). The loss in hydro-plant is the difference between the available power from the dam reservoir and the power output from the plant.

3.10 Loss in the power system

Technical loss in the NNEPS is the sum of the loss in transmission network and generation subsystem.

IV. Results

4.1 Line flow and line losses

The computed line flow and line losses are shown on table 3.

Table 3: Line Flow and Losses

Line		Power at Bus and Line Flow		Line Loss	
From	To	P	Q	P	Q
1		5.850	-127.692		
	2	-3.650	121.542	2.200	-6.150
	19	2.200	-6.151	0.000	-7.801
2		4.500	0.000		
	1	-20.155	121.506	1.214	-0.036
	3	-2.446	-58.352	0.394	-0.479
	15	1.930	-4.365	0.000	-5.815
	16	25.171	-58.788	0.560	-2.835
	25	-6.026	13.090	0.132	-4.656
3		3.120	0.000		
	2	2.840	57.873	0.388	-0.479
	4	0.528	-67.574	0.335	-1.590
	15	1.556	7.221	0.007	-6.325
	16	-1.230	-0.092	0.045	-46.985
4		0.650	0.000		
	3	0.060	69.164	0.133	-1.590
	5	0.000	-10.075	0.000	-10.075
	7	2.900	0.000	0.004	-9.461
	9	-7.130	-17.992	0.006	-8.819
5		-6.210	0.000		

	4	0.000	-10.090	0.000	-10.090
7		2.900	0.000		
	4	2.900	0.000	0.004	-9.461
	8	2.900	0.000	0.004	-9.174
8		4.500	0.000		
	7	10.711	-28.661	0.024	-9.534
9		-1.781	-1.103		
	4	6.669	13.985	-0.007	3.254
	10	1.660	-1.555	0.000	-3.105
10		-1.660	-1.550		
	9	-1.660	1.553	0.000	3.101
	11	-1.661	-0.098	0.001	-3.260
	12	1.286	-3.162	0.001	-3.460
11		-5.100	-0.083		
	10	5.099	0.101	0.000	-4.881
12		-2.040	-1.480		
	10	-1.280	3.161	-0.001	-6.541
	13	2.005	14.021	0.001	6.254
13		-2.130	-0.439		
	12	2.015	-13.088	0.132	-5.589
14		-1.930	0.000		
	27	-1.930	1.930	0.001	-58.23
15		-3.690	-0.079		
	2	-25.010	80.850	0.276	-5.252
	3	-1.550	6.321	-0.006	4.567
16		-1.230	-0.360		
	2	-25.072	58.760	-0.560	-2.835
	3	-1.231	0.092	-0.046	-3.651
	17	1.275	-46.893	0.045	-46.985
	18	3.110	-3.165	0.000	-3.263
	20	7.054	-3.328	0.003	-0.440
	26	-5.668	2.447	0.021	31.257
17		-3.110	3.112		
	16	-1.270	46.893	-0.045	46.900
18		-2.200	-1.600		
	16	-3.100	3.164	0.000	7.082
	24	-2.200	1.600	0.001	-7.801
19		-3.580	-0.450		
	1	-2.200	6.151	0.000	7.800
	25	-0.124	0.001	0.013	-2.546
20		-1.250	-0.630		

16	-7.050	3.328	-0.003	3.338
21	-2.220	0.933	0.001	-2.100
22	1.820	-0.933	0.000	-0.933
21	-0.400	0.000		
20	2.221	-9.330	-0.000	-4.265
22	-1.820	0.000		
20	-1.832	1.004	0.000	-1.900
23	6.793	-23.118	0.211	-4.560
23	-2.760	0.000		
22	-6.780	23.118	0.210	4.561
24	-0.224	0.000		
18	2.200	1.600	0.000	7.801
25	0.123	-0.001		
2	6.025	13.090	-0.132	-4.656
19	-5.264	2.568	-0.000	-2.223
26	-1.228	-0.360		
16	5.600	2.447	-0.022	-33.257
27	-1.930	1.931		
14	1.932	1.931	0.000	58.23
Total			5.495	-121.535

4.2 Loss coefficient matrix

The computed loss coefficient matrix is shown on table 4.

Table 4: Loss Coefficient Matrix

0.0305	0.0214	0.0000	0.0000	0.0285	0.020	0.0010	0.0219
0.0214	0.0151	0.0000	0.0000	0.0200	0.0014	0.0007	0.0154
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0285	0.0200	0.0000	0.0000	0.0266	0.0045	0.0094	0.0205
0.0200	0.0014	0.0000	0.0000	0.0045	0.0001	0.0000	0.0007
0.0010	0.0007	0.0000	0.0000	0.0094	0.0000	0.0000	0.0007
0.0219	0.0154	0.0000	0.0000	0.2050	0.0007	0.0007	0.0158

4.3 Transmission loss using Kron's formula

The transmission loss recorded in the network in the period under review (2016) using Kron's loss formula was calculated to be equal to 5.4237 per unit or 542.37MW.

4.4 Power input to thermal plant

The computed power input to each thermal plant is shown on table 5.

Table 5: Power Input and Loss for Thermal Plants.

S/N	Power Station	Tur-bine Type	Installed Capacity (MW)	Power Generated P_g (MW)	Power Sent Out P_{out} (MW)	Input Fuel Cost $F_c = \alpha P_g^2$ (\$/h)	Input power = 0.293 (MW)	Power loss (MW)
1	Egbin ST2-5	Gas Fired Steam	1320	288.71	280.18	6,366.06	630.15	349.97
2	Sapele (Steam)	Gas Fired Steam	1020	35.08	33.42	435.01	43.06	9.64
3	Delta (Ughelli) Gas	Simple Cycle Gas	972	440.85	431.57	230,516.05	22,817.98	22,386.41
4	Afam IV-V	Open Cycle Gas	977	0.00	0.00	0	0	0
5	Okpai Gas/Steam NIPP	Combined Cycle Gas	480	277.25	270.63	-	-	-
	Total							22,746.02

4.5 Power loss from hydro plant

The computed power loss from each hydro plant is shown on table 6.

Table 6: Power Input and Loss from Hydro Plants

S/No	Power Station	Type	Installed Capacity (MW)	Head (m)	Discharge (m ³ /s)	Input power (MW)	Output power (P_{out}) (MW)	Power loss (MW)
1	Kainji Hydro	Hydro	760	133.91	663	871.0	184.91	686.0
2	Jebba Hydro	Hydro	576.8	102.74	1260	1269.9	326.99	942.9
3	Shiroro Hydro	Hydro	600	364.36	377	1347.5	310.81	1036.7
Total								2,665.7

4.6 Loss in the Nigeria National Electric Power System:

The loss in generation and 330kV transmission subsystems of the Nigeria National Electric Power System is: = 542.37MW+22,746.02MW+2,665.7MW = 25,953.99MW.

4.7 Discussion

The transmission loss recorded in the network using Kron’s loss formula was found to be about 542.37MW during the period under review. This value is higher than that discovered in previous works because despite the fact that more power now flows through the network there is inadequacy of evacuation due to the nature of the network. The generation subsystem is more worrisome. It was discovered that almost all the generating plants have very low efficiency. Among the thermal plants only Sapele thermal station could yield up to 81% of the power input to the plant. Egbin ST2-5, the largest plant in the network was only about 46% efficient. The worst cases in the thermal generation are the gas plants that can be said to be inefficient or redundant since they could not generate power when it is required. In the case of the hydro generation, all the three hydro plants yielded less 26% of their power input. The net electrical loss in the generation subsystem of the Nigeria power system was found to be 25,411.62MW. Losses account for about 70% of the fuel/power input to the plants. While [12] and [10] revealed that real power loss in the transmission network was found to be about 100MW and [1] found technical losses in the system to be 1,207.25MW, it has been discovered that the net technical loss in NNEPS is 25,953.99MW. This represents a huge economic loss to operators and the nation at large. It is advisable to use B-loss coefficients whenever it is necessary to calculate incremental losses and express transmission losses as a function of the output of all generating plants. The losses are a second order function of generation necessary to establish the effect of a second power generation supplying the load. These coefficients are not constant but vary with unit loading. Transmission losses are a crucial factor to be considered when energy has to be transmitted over long distances.

It is clearly observed from the results obtained that there are high technical losses existing in the electrical power system of Nigeria primary due to the absence of ring or loop system. Some causes of technical loss in the system include weak transmission lines and equipment and generators and turbines due to ageing,

overstretched transmission lines, load rejection by operators, failure of power equipment such as transformer and acts of vandalism. These losses can be mitigated in several ways.

V. Conclusions

The system cannot generate as much power compared to the generation capacity neither can it transmit power compared to the transmission capacity primarily due to the nature of the physical infrastructure of the network. It is important to know what quantity of generated power that can be delivered to consumers. To do so, knowledge of technical losses in the system is inevitable. The objectives of this study are to analyze the single-line diagram of the network and to estimate technical losses in it. With knowledge that a huge loss exist in the network system engineers, planners and operators can plan for expansion and improvement.

Loss coefficient approach was used to estimate the losses. This approach expresses transmission loss as a function of the output of all generating plants. This coefficient is not constant but varies with loading. The advantage of this approach over others which were used by other researchers is that transmission loss can be calculated at any instance of time provided the outputs of the generating plants are known.

The investigation carried out indicates that technical losses are inherent in the Nigeria National Electrical Power System. This is truly so for any power system no matter how small it may be Technical losses in 330kV transmission network and generation system of Nigeria National Electric Power System has been investigated.

Recommendations

In this research, the technical loss considered only dealt with the electrical loss in the Nigeria electric power system. It is an acceptable fact that mechanical losses also contribute to the abysmal performance or inefficiency of the system. It is, hereby recommended that the mechanical losses prevalent in the transmission and generation subsystems of the power system be investigated so as to identify the overall technical losses inherent in it.

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Peter Audu" Estimation of Technical Losses in Generation and 330kv Transmission Network of Nigeria National Electric Power System" *International Journal of Engineering Science Invention (IJESI)*, Vol. 08, No. 08, 2019, PP 23-33