International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611

On The Cost Implications of Technical Energy Losses on Nigerian 330-kV Transmission Grid System

Ademola Abdulkareem[1], Awosope Claudius[2], Ayokunle Awelewa[3]

[1,2,3] Electrical and Information Engineering Department, College of Engineering, Covenant University, Ota, Nigeria

Abstract: ***Base on the author's result of power line losses obtained for low, medium and high current levels as 146.73MW, 322.24MW and 738.28MW respectively, in his bid to evaluate the power line losses using symmetrical component theory of unbalanced fault, the annual energy (MWH) losses for year 2013 was calculated and validated in this study. The annual technical energy losses due to the low, medium and high power losses were respectively found to be 443.45GWH, 976.895GWH and 2231.230GWHbased on Load Factor and Load Loss Factor amounting to N8.4 billion, N18.6 billion and N42.4 billion respectively. The low power loss (steady-state) result of this work was validated by the result of load-flow obtained using the MATLAB and Power Word Simulator (PWS) while the annual MWH for the high power loss level compares favourably well with the normal practice of utility operator's monthly energy balance thereby closing the gap between the practical information and the theoretical one.***

Keywords: Power line losses, Current levels, Load Factor, Load Loss Factor, Load-Flow

1. Introduction

Power quality has become an important issue for maximum efficiency operation of energy that is delivered to transmission and distribution line. The more the power that flows through the network, the more the current and hence the voltage drop becomes more excessive and power quality declines. The global problem of the lower power availability to consumers is a consequence of power loss and no matter how carefully the power system network is designed, losses are inevitable. Loss of power on transmission lines is a global problem and it is necessary to state here that the losses on transmission lines can result into line outages in the electric power system. The existing transmission system in Nigeria is characterized by high line losses and several outages leading to interruption of systems and equipment. Nigerian electricity grid has a large proportion of transmission and distribution losses, and these amounts to a whopping 44.5% of generation [1]. Based on the Power Holding Company of Nigeria (PHCN) annual reports for the 2004 and 2005, the transmission line losses alone were estimated to be 9.2% [2]. Countries such as China that have attached importance to loss minimization to enhance efficiency have about 13% transmission and distribution losses with India having about 23% [3]. The losses in some other countries like Iraq, Moldova, Sudan, Venezuelan RB, Syria, Korea Republic, Yemen Republic, Pakistan, Tanzania, México, Taiwan, U.S.A, and Japan are 42, 40, 28, 27, 26, 25, 22, 20, 16, 9, 6 and 5% respectively [4].

However, going by the available data and tools needed for calculating technical losses in power system, current techniques have certain drawbacks regarding such calculations.Moreover, literature reveals different methods of loss estimation but the existing approaches focus mainly on theoretical calculation and probabilistic data that are based on simple model data, insufficient to give a correct evaluation assessment of losses [5]. Hence, there is still a clear gap between practical information and the theoretical one which tends to be poor and not precise [6] and the reduction of system losses is analyzed on the accuracy of the technical losses. To solve the challenging problems inherent in designing future power systems to deliver increasing amounts of electrical energy in a safe, clean and economical manner [7], a regular and fairly accurate description of power losses as a function of time to make a reliable prediction of energy losses is required. The objective of this study, therefore, is to evaluate the technical losses in and its cost implication on Nigeria 330-kV power transmission system.

2. Methodology

The methodology adopted for this study is the analysis of the disturbances brought about by the faults followed by the procedure for maximum line currents determination that is used to calculate the power losses and the values are used thereafter to evaluate the annual energy losses and its cost implications in the Nigeria 330-kV power transmission system. Results analysis of load-flows using the code-based MATLAB and Power World Simulation model-based software are presented and discussed.

2.1 Disturbances in Nigeria 330-kV Transmission System

Table 2.1 gives the summary of the yearly energy balance that reflects a total loss of 14204.74GWH from 2005 to 2011 as reported in the PHCN monthly energy balance summary.. These transmission losses - calculated to be approximately 10.05% of the energy fed into the grid [8], clearly show that majority of the outages in NESI are responsible for the problem in the transmission network.

Table, 2.1: (Yearly energy balance summary 2005-2011

Year	*Energy Delivered to Transmission Line (GWH)*	*Energy Available for Sale (GWH)*	*Transmission Line energy Losses (GWH)*	*Line Losses Percentage of Energy Delivered (%)*
2005	23,403.26	21,401.87	2,001.39	8.55
2006	22,576.02	21,024.39	1,551.63	6.87
2007	22,255.76	20,419.07	1,836.69	8.25
2008	20,765.71	18,885.51	1,880.19	9.05
2009	20,329.45	18,620.10	1,709.35	8.41
2010	24,362.42	2,1931.67	2,430.75	9.98
2011	26,999.35	24,,204.62	2,794.73	10.35
Total: 160,691.97			**14,204.74**	**8.84**

2.2. Overview of the Nigerian 330-kV Transmission Network

The Nigerian Transmission system is made up of interconnected network of 5,650km of 330kV that spans the country nationwide. The single-line diagram of the Nigerian 330-kV network currently consists of sixty 330-kV transmission line circuits, eight effective generating stations, twenty load stations, twenty-eight buses (sub-stations), and thirty-three transmission lines as shown in figure 2.1

The system may be divided into three geographical zones- North, South-East, and the South-West. The North is connected to the South through the one-triple circuit lines between Jebba and Oshogbo while the West is linked to the East through one transmission line from Oshogbo to Benin and one double line from Ikeja to Benin. The transmission grid is centrally controlled from the National Control centre (NCC) located at Oshogbo in Osun State, while there is a back-up or Supplementary National Control Centre (SNCC) at Shiroro in Niger State. In addition to these two centres are three Regional Control Centres (RCCs) located at Ikeja West (RCC1), Benin (RCC2) and Shiroro (RCC3) substations [9].

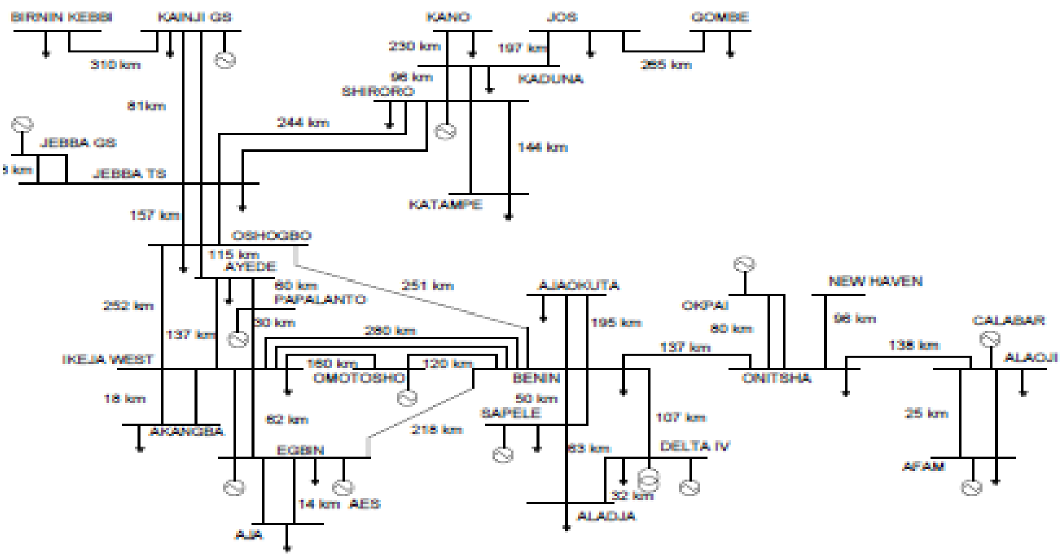

Figure 2.1: The Nigerian 330-kV Transmission System

3. Results and Discussion

3.1. Load-Flow Analysis of the Existing Nigerian 330-kV Transmission Network

In order to perform a power flow analysis using the Newton-Raphson (N-R) method program in the MATLAB environment, the one-line diagram of the existing Nigerian 330.kV network is redrawn using E-draw max as shown in figure 2.1 for clear identification of buses and branches in the network. This study is carried out majorly using statistical measures of central tendency to analyse data gotten from the nation's National Control Centre (NCC), Oshogbo and some of the generating stations in the country [10].

However, from the convergence of N.R load-flow results of table 3.1, a summarized result of active power, reactive power and complex power flow at each bus and the line flow is as presented in table 3.1.The total active power loss from the power flow program solutions by Newton-Raphson method is 203.620 MW and that of the reactive power loss is -1556.448 Mvar.

Table 3.1: Summary of load-flow results of N-R

From Bus	To Bus	Active Power flow (MW)	Reactive Power flow (Mvar)	Complex Power flow (MVA)	Active Power loss (MW)	Reactive Power loss (Mvar)
1	2	115.9879	-30.7254	119.9885	1.4879	-116.625
1	3	501.7121	-55.2062	504.7403	6.633	-11.5062
2	1	-114.5	-85.9	143.14	1.4879	-116.625
3	1	-495.079	43.7	497.0041	6.633	-11.5062
3	4	-494.329	-38.5246	495.8279	0.671	-2.3843
3	5	321.8366	13.46	322.1179	5.6016	-78.1002
3	23	656.5715	-26.8354	657.1197	26.6503	75.2551
4	3	495	36.1403	496.3176	0.671	-2.3843
5	3	-316.235	-91.5602	329.2231	5.6016	-78.1002
5	6	177.026	42.3656	182.0249	1.5765	-71.7504
5	8	128.921	11.3987	129.4239	1.0055	-93.4136
5	13	-190.912	-113.1042	221.9008	3.238	-172.5968
6	5	-175.4496	-114.116	209.2965	1.5765	-71.7504
6	7	-80.9763	-36.6775	88.8954	0.1617	-34.9959
6	8	-19.3741	-56.0066	59.2629	0.0222	-98.1078
7	6	81.138	1.6816	81.1554	0.1617	-34.9959
7	8	73.662	-1.6816	73.6812	0.0577	-17.1578
8	5	-127.9155	-104.8124	165.3723	1.0055	-93.4136
8	6	19.3963	-42.1012	46.3544	0.0222	-98.1078
8	7	-73.6044	-15.4763	75.2138	0.0577	-17.1578
8	9	247.6955	235.7035	341.9199	2.9955	-22.7965
8	10	-403.8922	-362.0502	542.4106	6.4373	2.3304
8	12	-44.8346	-59.1121	74.1915	1.2761	-96.9254
8	13	-250.0452	-126.1513	280.0656	6.7175	-147.3841
9	8	-244.7	-258.5	355.9499	2.9955	-22.7965
10	8	410.3295	364.3806	548.7654	6.4373	2.3304
10	11	276.706	169.1378	324.3051	2.306	-36.6622
10	13	-196.7158	18.1493	197.5513	2.8778	-27.954
11	10	-274.4	-205.8	343	2.306	-36.6622
12	8	46.1107	-37.8133	59.6326	1.2761	-96.9254
12	13	54.4893	37.8133	66.3244	0.3626	-83.348
13	5	194.15	-59.4926	203.0606	3.238	-172.5968
13	8	256.7627	-21.2328	257.6391	6.7175	-147.3841
13	10	199.5937	-46.1033	204.8491	2.8778	-27.954
13	12	-54.1266	-121.1613	132.7018	0.3626	-83.348
13	14	14.1681	-155.6499	156.2934	0.3681	-165.9499
13	15	-262.4152	-26.9578	263.7962	1.1368	-36.8382
13	16	-473.9006	20.0871	474.3261	4.7811	-12.9197
13	18	-257.5321	123.0107	285.4022	4.4327	-70.3566
14	13	-13.8	-10.3	17.22	0.3681	-165.9499
15	13	263.552	-9.8805	263.7372	1.1368	-36.8382
15	17	-93.852	3.7389	93.9265	0.2026	-50.8631
16	13	478.6817	-33.0068	479.8183	4.7811	-12.9197
16	17	191.3183	-28.4304	193.4192	0.7637	-46.2284
17	15	94.0547	-54.602	108.755	0.2026	-50.8631
17	16	-190.5547	-17.798	191.384	0.7637	-46.2284
18	13	261.9648	-193.3673	325.6017	4.4327	-70.3566
18	19	-703.8188	82.449	708.6316	46.1812	14.2387
18	20	178.7979	112.9396	211.4806	1.7979	-20.4604
18	22	78.4561	-140.4214	160.8525	7.0193	-97.1128
19	18	750	-68.2103	753.0954	46.1812	14.2387
20	18	-177	-133.4	221.6406	1.7979	-20.4604
21	22	378.5	359.6307	522.1077	22.9367	-3.8779
22	18	-71.4367	43.3086	83.5394	7.0193	-97.1128
22	21	-355.5633	-363.5086	508.4916	22.9367	-3.8779
23	3	-629.9212	102.0904	638.1404	26.6503	75.2551
23	24	294.9635	64.7522	301.9873	4.8635	-80.2478
23	25	653.5577	486.4913	814.7463	21.1085	145.1124
24	23	-290.1	-145	324.3193	4.8635	-80.2478
25	23	-632.4492	-341.3789	718.7013	21.1085	145.1124
25	26	230.5674	155.9158	278.3362	9.9674	13.0158
25	27	208.8818	40.7631	212.8221	4.8743	-25.2542
26	25	-220.6	-142.9	262.8398	9.9674	13.0158
27	25	-204.0075	-66.0173	214.4233	4.8743	-25.2542
Total **203.62 -1556.45**						

Another load-flow analysis was carried out on the same 330-kV transmission network (for the purpose of comparison) using the run mode of power world simulator [11]. The line flows and power losses are as presented in table 3.2. The load-flow is performed at a steady state and therefore these results are obtained under normal condition. The load-flow analysis was performed at a steady state; the power-flow solution results obtained for PWS and MATLAB software are compared with the results of low power obtained from LC that is likened to the current that flows under a steady-state condition for validation.

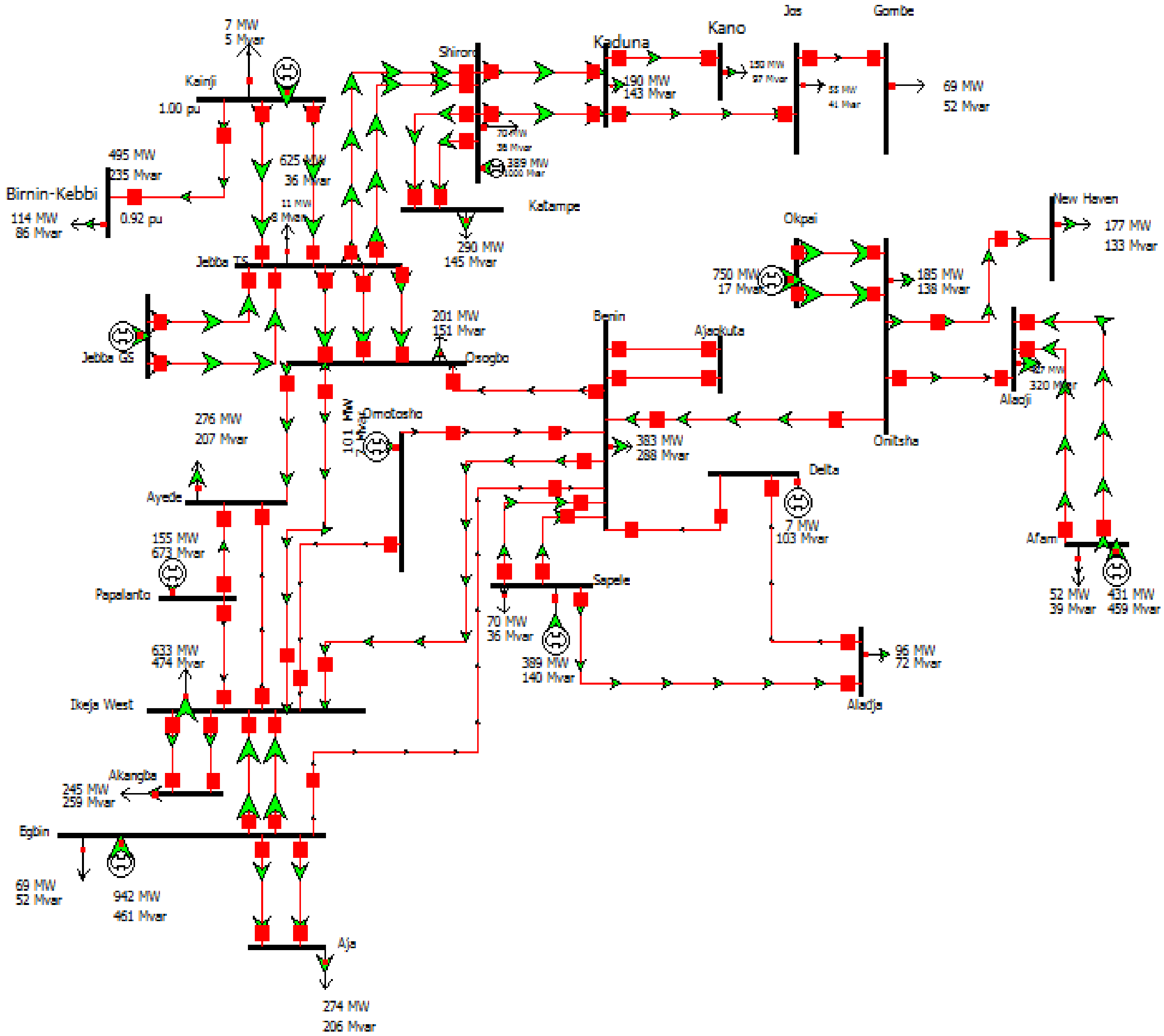

Figure 3.1: The Simulation run Mode of Existing Nigerian 330-kV Transmission Network

Table 3.2: Line-Flows and Power losses for PWS Model-Based Network

From Bus No	*From Name*	*To Bus No*	*To Name*	*Circuit*	*MW From*	*Mvar From*	*MVA From*	*MW Loss*	*Mvar Loss*
1	Kainji	2	Birnin-Kebbi	1	116.7	48.5	126.4	2.2	-37.42
1	Kainji	3	Jebba TS	1	250.5	-36.7	253.2	1.83	-15.25
1	Kainji	3	Jebba TS	2	250.5	-36.7	253.2	1.83	-15.25
3	Jebba TS	4	Jebba GS	1	-247.3	31.8	249.4	0.19	-2.07
3	Jebba TS	4	Jebba GS	2	-247.3	31.8	249.4	0.19	-2.07
3	Jebba TS	5	Oshogbo	1	116.7	-10.7	117.2	0.78	-52.18
3	Jebba TS	5	Oshogbo	2	116.7	-10.7	117.2	0.78	-52.18
3	Jebba TS	5	Oshogbo	3	116.7	-10.7	117.2	0.78	-52.18
3	Jebba TS	23	Shiroro	1	315.5	-41.3	318.1	6.67	-22.81
3	Jebba TS	23	Shiroro	2	315.5	-41.3	318.1	6.67	-22.81
5	Oshogbo	6	Ayede	1	192.3	3.5	192.3	1.59	-28.35
5	Oshogbo	8	Ikeja-West	1	130	-9.9	130.4	1	-48.67
5	Oshogbo	13	Benin	1	-175.8	-20	176.9	2.89	-68.38
6	Ayede	7	Papalanto	1	-70.7	-153.2	168.7	0.6	-13.71

6	Ayede	8	Ikeja-West	1	-14.4	-21.8	26.1	0.01	-49.07
7	Papalanto	8	Ikeja-West	1	83.5	303.9	315.1	1.02	0.24
8	Ikeja-West	9	Akangba	1	123.1	111.1	165.8	0.71	-18.1
8	Ikeja-West	9	Akangba	2	123.1	111.1	165.8	0.71	-18.1
8	Ikeja-West	10	Egbin	1	-195.9	-144.2	243.3	1.3	-14.55
8	Ikeja-West	10	Egbin	2	-195.9	-144.2	243.3	1.3	-14.55
12	Omotosho	8	Ikeja-West	1	44.5	-15.2	47	0.12	-39.71
8	Ikeja-West	13	Benin	1	-246	-13.8	246.4	6.53	-43.48
10	Egbin	11	Aja	1	137.6	82.5	160.5	0.62	-20.39
10	Egbin	11	Aja	2	137.6	82.5	160.5	0.62	-20.39
10	Egbin	13	Benin	1	-247.3	52.6	252.8	5.1	19.63
10	Egbin	29	AES	1	0	0	0	0	0
12	Omotosho	13	Benin	1	56.1	-0.6	56.1	0.15	-36.88
13	Benin	14	Ajaokuta	1	7	-68.7	69.1	0.08	-73.86
13	Benin	14	Ajaokuta	2	7	-68.7	69.1	0.08	-73.86
13	Benin	15	Sapele	1	-145.6	-54.3	155.4	0.42	-17.34
13	Benin	15	Sapele	2	-145.6	-54.3	155.4	0.42	-17.34
13	Benin	16	Delta	1	-445	14.4	445.3	4.65	14.76
13	Benin	18	Onitsha	1	-288.7	91.3	302.8	4.84	-8.72
15	Sapele	17	Aladja	1	-122.3	38	128.1	0.4	-20.43
16	Delta	17	Aladja	1	220.3	-0.5	220.3	1.12	-14.5
19	Okpai	18	Onitsha	1	375	23	375.7	12.73	-0.14
19	Okpai	18	Onitsha	2	375	23	375.7	12.73	-0.14
18	Onitsha	20	New Haven	1	178.6	116.6	213.3	1.6	-16.81
18	Onitsha	22	Alaoji	1	67.8	-108.8	128.2	6.17	-43.72
22	Alaoji	21	Afam	1	-182.7	-192.6	265.5	6.57	-4.98
22	Alaoji	21	Afam	2	-182.7	-192.6	265.5	6.57	-4.98
23	Shiroro	24	Katampe	1	146.3	27.5	148.9	1.27	-44.99
23	Shiroro	24	Katampe	2	146.3	27.5	148.9	1.27	-44.99
23	Shiroro	25	Kaduna	1	321.8	220.8	390.2	5.46	13.19
23	Shiroro	25	Kaduna	2	321.8	220.8	390.2	5.46	13.19
25	Kaduna	26	Kano	1	229.1	151.6	274.7	8.48	8.72
25	Kaduna	27	Jos	1	210.5	118.8	241.7	5.5	-9.88
27	Jos	28	Gombe	1	134.7	76	154.7	4.12	-21.87
								136.13	**-1057.4**

3.2. Procedure for Maximum Line Currents

Determination on the Test System

The results of all the line current magnitudes obtained in the simulation of various aspects of faults on the three-phase power line of the test system are analysed or streamlined in order to rigorously establish a categorical data of maximum line current magnitudes. The results of this analysis are generated for two scenarios: case 1 is when the fault impedance is 0.1 and case 2 when the fault impedance is set to zero.

The case 2 (i.e. $Z_f = 0$) is one extreme considered in the determination of maximum current on the test system and it forms the category that creates tremendous amount of current comparable to the maximum current of the fault impedance, $Z_f = 0.1$. A tabular summary and graphical representation of the results obtained for the two configurations are presented in tables3.3 and 3.4 for $Z_f = j0.1$ and for $Z_f = j0$ respectively for the line current magnitude to determine the available maximum current on each line for all the various types of asymmetrical fault considered. The faulted bus locations that cause the maximum current are also presented. Tables 3.3 and 3.4presentlocation and the corresponding maximum line current that is available on the three-phase line of the test system when SLG, LL and DLG faults are simulated with fault impedances of j0.1 and j0 respectively.

Table 3.3: Maximum line current caused by SLG, LL, DLG and Location when $Z_f = j0.1$

From - To bus	*SLG (pu)*	*Location*	*L - L (pu)*	*Location*	*DLG (pu)*	*Location*
1-2	**4.7596**	BirninKebbi	7.1658	BirninKebbi	8.973	BirninKebbi
3-1	8.5218	JebbaTs	**3.1828**	Kainji	9.3828	Kainji
4-3	16.4165	Oshogbo	**3.2043**	JebbaTs	5.615	JebbaTs
5-3	10.3361	JebbaTs	**3.7182**	Kainji	3.7935	JebbaTs
6-5	11.4695	Papalanta	**3.5445**	Ayede	5.831	Ayede
7-6	7.5392	Akangba	**1.4389**	Papalanto	3.2273	Ikeja West
8-6	12.0213	Papalanto	**3.5589**	Ayede	5.6907	Ayede
8-7	7.6034	Papalanto	**1.0787**	Osogbo	3.6238	Ayede
8-5	23.9129	Ikeja West	**6.2204**	Papalanto	10.541	Papalanto
8-9	12.4105	Egbin	**4.6204**	Akangba	7.3992	Akangba
10-8	11.3709	Akangba	**3.3964**	Ikeja West	5.3705	Ikeja West
10-11	14.2855	Omotosho	**4.7743**	Aja	7.8635	Aja
12-8	**2.1338**	Sapele	8.3932	Ajaokuta	8.3932	Benin
12-13	**4.3169**	Benin	4.4479	Omotosho	4.3787	Ajaokuta
13-10	9.7498	Aja	**7.7994**	Ajaokuta	7.7994	Benin
13-8	4.2561	Akangba	**1.0363**	Ikeja West	3.6871	Omotosho
13-5	**9.256**	Ayede	12.3477	Ajaokuta	12.3477	Benin
13-18	**9.8673**	Sapele	13.8204	Sapele	22.6256	Sapele
14-13	**7.1047**	Aja	10.776	Ajaokuta	10.7761	Benin
15-13	**2.6304**	Ajaokuta	8.2326	Ajaokuta	8.23255	Benin
15-17	5.4213	Aja	**3.4523**	Sapele	24.0364	Aladja
16-13	**4.6151**	Aladja	8.6404	Aladja	21.9803	Aladja
16-17	**1.5931**	Aja	7.9062	Aladja	5.8227	Benin
18-20	**7.0294**	New Haven	10.6699	New Heaven	15.7524	Okpai
19-18	**2.5873**	Benin	2.5873	Benin	4.1100	Alaoji
21-22	**3.8533**	Onitsha	5.7873	Ajaokuta	6.8982	Onitsha
22-18	**10.8159**	Alaoji	13.9714	Alaoji	25.4175	Alaoji
23-3	4.1506	JebbaTs	**2.496**	Shiroro	5.2994	Shiroro
23-24	**3.5248**	Katampe	5.5056	Katampe	7.45595	Katampe
23-25	**5.1388**	Kaduna	5.1385	Kaduna	9.67325	Kaduna
25-26	**4.8543**	Kano	6.7731	Kano	7.7021	Kano
25-27	**4.386**	Jos	6.3477	Jos	7.695	Jos
27-28	**2.9706**	Gombe	4.022	Gombe	4.552	Gombe

Note: Black = Low current (LC), Blue = Medium current (MC); Yellow = High Current (HC)

Table 3.4: Maximum line current caused by SLG, LL, DLG and Location when $Z_f = j0$

From - To bus	*SLG (pu)*	*Location*	*L - L (pu)*	*Location*	*DLG (pu)*	*Location*
1-2	5.7715	BirninKebbi	8.0049	BirninKebbi	8.521	BirninKebbi
3-1	7.638	Kainji	8.6994	Kainji	9.9115	Kainji
4-3	11.8103	JebbaTs	15.5621	JebbaTs	16.6508	JebbaTs
5-3	6.7635	Osogbo	9.876	Osogbo	10.3859	Osogbo
6-5	8.0217	Ayede	10.7309	Ayede	11.4168	Ayede
7-6	5.0456	Ikeja West	7.2605	Ikeja West	7.5195	Ikeja West
8-6	8.4356	Ayede	11.1363	Ayede	11.921	Ayede
8-7	4.6136	Ayede	7.2019	Ayede	7.4139	Ayede
8-5	16.4218	Papalanto	22.3493	Papalanto	23.6863	Papalanto
8-9	8.5826	Akangba	11.5117	Akangba	12.184	Akangba
10-8	8.4808	Ikeja West	10.8965	Ikeja West	11.4524	Ikeja West
10-11	9.4079	Aja	13.2802	Aja	13.962	Aja
12-8	6.5397	Omotosho	8.2427	Benin	8.5784	Benin
12-13	7.0578	Benin	5.981	Omotosho	6.5929	Omotosho
13-10	6.4179	Egbin	9.3047	Egbin	9.759	Egbin
13-8	2.9694	Ikeja West	4.0802	Ikeja West	4.270	Ikeja West
13-5	6.2546	Osogbo	8.7459	Osogbo	9.2419	Osogbo
13-18	16.4639	Sapele	24.5083	Sapele	25.4906	Sapele
14-13	7.2072	Benin	10.4319	Benin	10.8361	Benin
15-13	5.590	Benin	7.9602	Benin	8.2957	Benin
15-17	15.7491	Aladja	22.8129	Aladja	23.8742	Aladja

16-13	14.4491	Aladja	20.8551	Aladja	21.8356	Aladja
16-17	1.5684	Sapele	3.2814	Sapele	2.9961	Sapele
18-20	10.5221	Okpai	14.2337	Okpai	17.5902	Okpai
19-18	2.79635	Alaoji	3.83995	Alaoji	4.18085	Alaoji
21-22	5.362	Onitsha	6.6105	Onitsha	6.83945	Onitsha
22-18	17.3628	Alaoji	24.1392	Alaoji	23.7693	Alaoji
23-3	5.7098	JebbaTs	7.9588	JebbaTs	4.19125	JebbaTs
23-24	4.77465	Katampe	6.762	Katampe	7.10515	Katampe
23-25	7.0505	Kaduna	8.9056	Kaduna	9.29395	Kaduna
25-26	5.3429	Kano	7.1218	Kano	7.4349	Kano
25-27	5.1403	Jos	6.893	Jos	7.3189	Jos
27-28	3.2031	Gombe	4.1324	Gombe	4.386	Gombe

Red = Available maximum current (AMC)

3.3. Evaluation of Technical Power Loss on the Power Line Test System

Here, the calculation of technical power losses is carried out on the power line test system i.e the Nigerian 330-kV transmission system, using the results obtained in tables3.3 and based on the established peak line currents for both average (LC/MC) and maximum (HC/AMC) line current magnitudes.

Typical Base Values at 100MVA Base for the Nigerian 330-kV System

$$V_b = \frac{V_L}{\sqrt{3}} = \frac{330 \times 10^3}{\sqrt{3}} = 190.5255kV$$

$$I_b = \frac{MVA_b}{3V_b} = \frac{100 \times 10^6}{3 \times 190.5255 \times 10^3} = 174.9546A \text{ or } 0.175kA$$

$$R_b = \frac{V_b}{I_b} = \frac{190.5255 \times 10^3}{174.9546} = 1089\Omega$$

Using the above base values, the pu line current magnitude and line resistance are converted to their actual values. Thus, the power losses for LC, MC, HC and AMC are computed using equation 3.1.

$P = I^2R$………………. (3.1);

The power losses for the various categories are calculated. Therefore, these power losses in the power line test system for LC, MC, HC and AMC are presented as 146.73MW, 323.24MW, 737.79 and 738.77MW respectively. The graphical representations of the power losses calculated for LC, MC, HC and AMC are shown in figure 3.2.

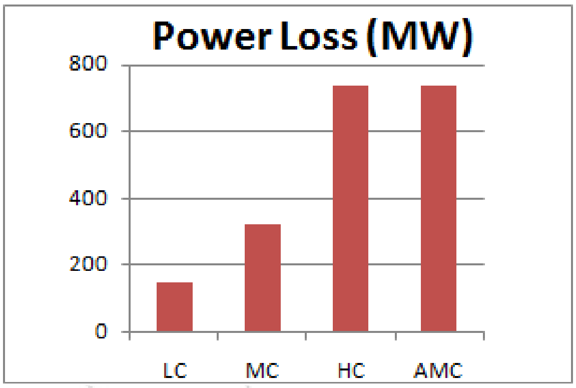

Figure 3.2: Power losses calculated for LC, MC, HC and AMC

It can be seen in figure 3.2, that the equality of HC and AMC is confirmed and that is a justifiable approximation of equality. Therefore, the average of the HC and AMC which is 738.28MW is considered as the possible available peak loss in the power line test system. Now for this study, there are three categories of power loss level determined to be associated with the power line test system. These are;

- Low power line loss is**146.73MW** obtained from LC
- Medium power line loss is**323.24MW** obtained from MC
- High power line loss is**738.28MW** obtained from HC/AMC

The three power loss level scenarios are likened to the trio of steady-state, sub transient and transient situation.stages of a fault.

3.4. Annual Loss Estimation of Low, Medium and High Power Line Losses

Estimation of annual power line losses of the test system is carried out based on the results of the three power loss levels shown in figure 3.2above. Since these results are obtained at their maximum peak current, there is the necessity to have the knowledge of the test system daily peak demand or peak load in order to determine the actual point of peak demand which is part of the parameter needed to calculate the annual power line losses. It should be noted that the maximum demand or peak demand dictates the size of transmission lines for utilities even if that amount lasts just one hour per year [12]. The peak load data for the period (January 2013 – December 2013) are tabulated as shown in table 3.5. The data are inputted into the HOMER simulation software [13]. Figure 3.4 shows the hourly average load variation for the Nigerian 330-kV transmission lines (test system). The peak load of 4950MW is as indicated in figure 3.3 and the daily average energy of 3754.69MW is computed from table 3.5.

Table 3.5: Daily peak demand of the test transmission system (January 2013–Dec. 2013)

Hour	1/1/2013	1/2/2013	1/3/2013	1/4/2013	1/5/2013	1/6/2013	1/7/2013	1/8/2013	1/9/2013	1/10/2013	1/11/2013	1/12/2013
0.00-1.00	4200.00	3900.00	4050.00	4200.00	4120.00	3700.00	3800.00	3700.00	3250.00	3425.00	3200.00	3450.00
1.00-2.00	4300.00	4350.00	4100.00	4350.00	3650.00	3600.00	3650.00	3450.00	3500.00	3200.00	3650.00	3650.00
2.00-3.00	4310.00	4200.00	4200.00	4170.00	3000.00	3700.00	3700.00	3250.00	3550.00	3275.00	3550.00	3500.00
3.00-4.00	4950.00	4150.00	4300.00	4100.00	2800.00	3775.00	3600.00	3500.00	3725.00	3175.00	3650.00	3400.00
4.00-5.00	3850.00	4250.00	4150.00	4050.00	3400.00	4100.00	3900.00	3575.00	3750.00	3400.00	3525.00	3500.00
5.00-6.00	3852.00	4170.00	4400.00	4100.00	3300.00	4025.00	4050.00	3600.00	3450.00	3500.00	3350.00	3450.00
6.00-7.00	4100.00	4120.00	4300.00	4070.00	3700.00	4025.00	3800.00	3900.00	3475.00	3400.00	3450.00	3300.00
7.00-8.00	4250.00	4200.00	4250.00	4250.00	4000.00	3850.00	3750.00	3800.00	3350.00	3600.00	3750.00	2900.00
8.00-9.00	3550.00	4150.00	4150.00	4350.00	4100.00	4100.00	3900.00	3800.00	3375.00	3700.00	3650.00	2875.00
9.0 - 10.0	4200.00	4290.00	4175.00	4100.00	4050.00	3700.00	3700.00	4025.00	2600.00	3800.00	3550.00	2900.00
10.00- 11.00	4300.00	4230.00	4275.00	4150.00	3700.00	3900.00	3600.00	3800.00	2700.00	3825.00	3450.00	2875.00
11.00-12.00	4450.00	4250.00	4250.00	3900.00	4050.00	3700.00	3500.00	3000.00	3000.00	3600.00	3750.00	3400.00
12.00-13.00	4500.00	4200.00	4400.00	4150.00	4075.00	4025.00	3100.00	3300.00	3300.00	3475.00	3500.00	3450.00
13.00-14.00	4517.60	4050.00	4200.00	4250.00	4200.00	3750.00	3725.00	3200.00	3550.00	3550.00	3850.00	3700.00
14.00-15.00	4517.00	4250.00	4300.00	4100.00	3850.00	4200.00	3500.00	3750.00	3450.00	3300.00	3650.00	3200.00
15.00-16.00	4250.00	4270.00	4100.00	3600.00	3800.00	3600.00	3700.00	3000.00	3500.00	3350.00	3825.00	3475.00
16.00-17.00	4300.00	4150.00	4350.00	4100.00	4000.00	3200.00	3750.00	3200.00	3325.00	3250.00	3650.00	3400.00
17.00-18.00	4250.00	4200.00	4275.00	4150.00	3700.00	3300.00	3675.00	3175.00	3275.00	3500.00	3700.00	3450.00
18.00-19.00	4220.00	4150.00	4250.00	3850.00	3900.00	3300.00	2500.00	3200.00	3500.00	3100.00	3450.00	3500.00
19.00-20.00	4150.00	4250.00	4250.00	3600.00	4000.00	3525.00	3600.00	3300.00	3400.00	3150.00	3750.00	3550.00
20.00-21.00	4300.00	4200.00	4300.00	4100.00	3750.00	3700.00	3525.00	3500.00	3375.00	3200.00	3900.00	3600.00
21.00-22.00	4125.00	4025.00	4225.00	4000.00	3800.00	3650.00	3600.00	3450.00	3350.00	3275.00	3600.00	3700.00
22.00-23.00	4100.00	4100.00	4275.00	4100.00	4050.00	3600.00	3675.00	3350.00	3375.00	3250.00	3350.00	3750.00
23.00-0.00	3900.00	4050.00	4200.00	4120.00	3700.00	3800.00	3700.00	3250.00	3425.00	3200.00	3450.00	3300.00

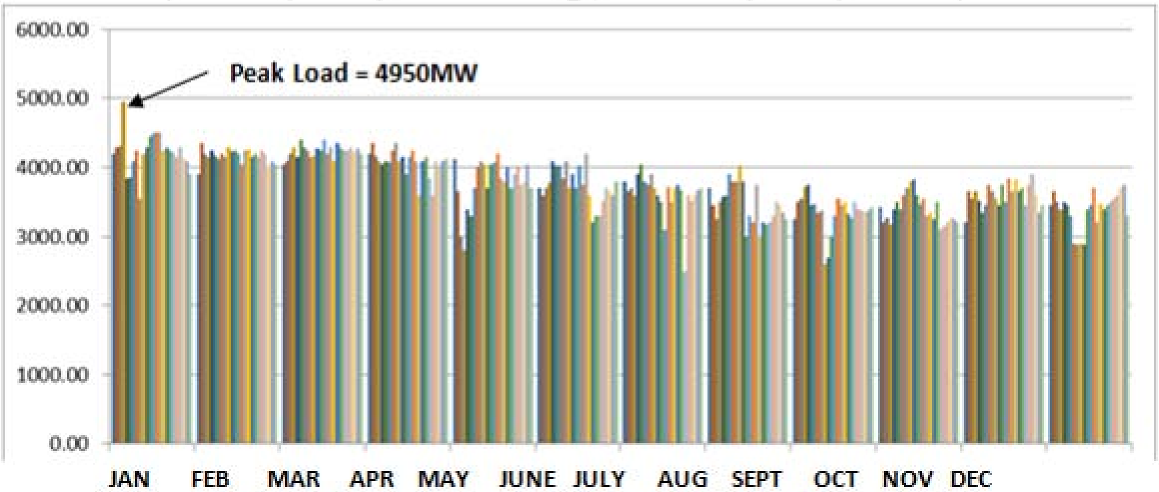

Figure 3.3: The daily peak demand load (January 2013 – December 2013)

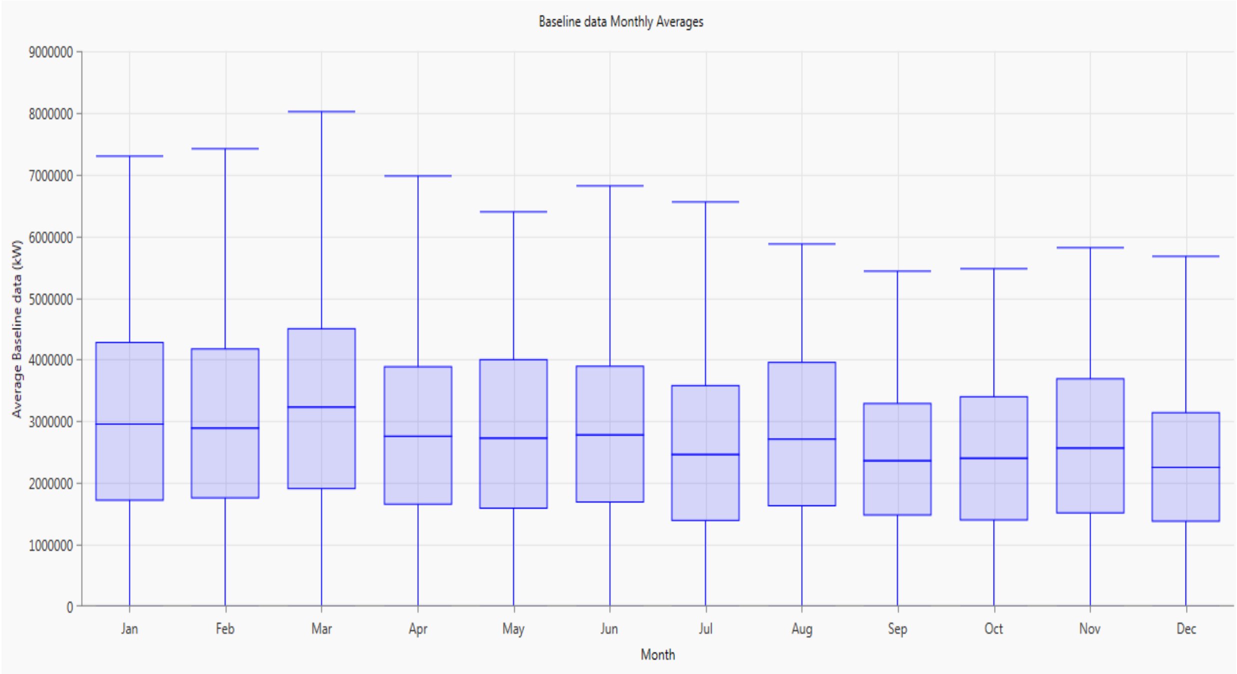

Figure 5: The monthly average load plot (January 2013 – December 2013)

From the result obtained in the simulation of peak load and average load under peak transmission line (test system) for January 2013 – December 2013, the total loss is obtained as follows: The daily load factor is given based on hourly load reading as

Daily load Factor (DLF) = $\frac{Average\ \ load\ \ in\ 24h}{Peak\ \ load\ \ in\ 24h}$ 3.2

Load factor may be given for a day, a month, or a year. The yearly or annual LF is the most useful since a year represents a full cycle of time. Thus, the annual LF is given as

Annual load Factor (ALF) = $\frac{total\ \ annual\ \ energy}{Peak\ \ load\ \ \times 8760\ hr}$ 3.3

In this study, the annual load factor (ALF) is estimated from the average load by using the hourly average load variation for January 2013 – December 2013.

Thus, the ALF is obtained as

ALF = DLF $\times$ R_{AD} $\times$ R_{AM} [14] 3.4 3.4

Where

ALF = Annual Load Factor

DLF = Daily load Factor

$R_{AD} = \frac{Average\ \ daily\ \ peak\ \ load}{Mont\ hly\ Peak\ load}$ 3.5

$R_{AM} = \frac{Average\ \ mont\ hly\ peak\ \ load}{Annual\ \ Peak\ \ load}$ 3.6

From the hourly readings of table 6, the peak load is 4950MW as indicated in figure 4 and daily average load is 3754.69 as calculated from table 3.5

Using equation 3.2 above, DLF is

DLF = $\frac{Average\ \ load\ \ in\ 24h}{Peak\ \ load\ \ in\ 24h} = \frac{3754.69}{4950} = 0.759$

The average daily peak load for January – December 2013 is 3812.08MW with monthly peak load of 4950MW in January.

Thus, using equation 3.5

R_{AD} = 3812.08/4950 = 0.770

Also from figure 3.4,

The average monthly peak load = 4400MW and the annual peak load = 4950MW.

Thus, using equation 6; R_{AM} = 4400/4950 = 0.889

Therefore, using equation 4.3, annual load factor (ALF) is given as

ALF = 0.759 × 0.770 × 0.889 = 0.52

The Load Loss Factor (LLF) required for annual energy calculation is given as

LLF = K $\times$ ALF + (1−K) $\times$ $(ALF)^2$ [15] 3. 7

where K means proportioning multiplier in the LLF equation 7;

where 0<K< 1 and K is normally 0.3 for transmission line.

Using equation 3.7;

$LLF = 0.3\ (0.52) + 0.7\ (0.52)^2 = 0.345$

Using the Loss Load Factor (LLF) of 0.345, the annual energy for the three categories of power loss evaluated in this study can be estimated as

- **Annual MWH Loss for 146.73MW (Low Power Loss Level):**

$= LLF \times (\text{peak loss in MW}) \times 8760.$ 3. 8

Using the maximum power loss of 146.73MW obtained in the course of this work; the total energy loss for year 2013 is estimated as

$= 0.345 \times 146.73 \times 8760$
= 443447.41MWH or 443.45GWH

- **Annual MWH Loss for 323.24MW (Medium Power Loss Level):**

Using equation 8 and the maximum power loss of 323.24MW obtained in the course of this work as medium power loss level; the total energy loss for the year 2013 is estimated as

$= 0.345 \times 323.24 \times 8760$
= 976895.93MWH or 976.895GWH

- **Annual MWH Loss for 738.28MW (High Power Loss Level):**

Using equation 8 and the maximum power loss of 738.28MW obtained in the course of this work as high power loss level; the total energy Loss for the year 2013 is estimated as

$= 0.345 \times 738.28 \times 8760$
= 2231229.82MWH or 2231.230GWH

3.5. Cost Implications

The total amount of financial loss in the estimated annual energy loss of section 3.4 is evaluated for each of the power loss levels – Low, Medium and High power losses. The cost evaluation is based on the Naira/KWH energy rates for Eko district, under the new power tariff MYTO 2 for 2013/2014 [16]. The cost of energy is rated at N19 per KWH or N19000/MWH, by taking the average of all the tariff class energy unit costs (N/KWH). Using the N19000/MWH, the annual financial loss due to each power loss level associated with the 330-kV power lines is estimated as follows:

- For the Low Power Line Loss with annual loss of 443447.41MWH, the annual financial loss for the year 2013 is 443447.41MWH $\times$ N19000/MWH

i.e. N8, 425,500,790; approximately amounted to **8.4 billion Naira**

- For the Medium Power Line Loss with annual loss of 976895.93MWH, the annual financial loss for the year 2013 is 976895.93MWH $\times$ N19000/MWH

i.e. N1.86 $\times 10^{10}$; approximately amounted to**18.6 billion Naira**

- For the Low power line loss with annual loss of 2231229.82MWH, the annual financial loss for the year 2013 is 2231229.82MWH $\times$ N19000MWH

i.e. N4.24 $\times$ 10^{10}; approximately amounted to **42.4 billion Naira**

4. Conclusion

In this study, the evaluation of technical losses-steady and transient phenomena was captured successfully on Nigeria 330-kV transmission network. Three levels (i.e low, medium and high) of maximum line current were determined and used accordingly to calculate the three categories of power loss level associated with the network which in turn was used to estimate the annual power line losses for the year 2013 using the peak load data for the period (January2013 – December2013). The annual loss energy for the year 2013 and the huge financial drain in the network were identified and quantified;the low, medium and high energy losses were respectively found to be 443.45GWH, 976.895GWH and 2231.230GWHamounting to financial losses of N8.4 billion, N18.6 billion and N42.4 billion respectively.

The results of the load-flow analysis that were performed using MATLAB and PWS compared favourably well with the 146.73MW power loss obtained at steady-state in this work. Also, it validated the results of 2231.23GWH losses obtained in the work with the normal practice of PHCN energy balance (as shown in table 2.1)thereby closing the gap between the practical information and the theoretical one and also it optimizes the loss level which results in a high degree of accuracy.

Acknowledgement

The author is highly indebted to Power Holding Company of Nigeria (PHCN) for providing relevant data necessary for power-flow study and the peak load demand data for the period (January 2013-December 2013.

References

[1] PHCH, 2003National Control Centre Oshogbo.(2004). Generation and Transmission GridOperations. AnnualTechnical Report for 2003.
[2] PHCN National Control Centre Oshogbo. (2005).Generation and Transmission Grid Operations.Annual Technical for Report 2004.
[3] Pabia, A. S., 2013. Electric Power Distribution (4th Edition), 6th; Reprint, Tata McGraw-Hill Publication Com. Ltd. New Delhi
[4] IEA (2013), *Key World Energy Statistics2013*[online] available:

http://www.iea.org/publications/freepublications/publication/KeyWorld2013.pdf{accessed 31/05/2014}
[5] Gaspar, Viera (2011). "Electrical Annual EnergyLosses Determination in Low Voltage - ACaseStudy". RevistaEletronica Sistemas & Gestao,91-116 vol. 6.
[6] Wadwah, C. (2006). Electric Power system.Chennai: New Age International Publisher Limited.
[7] Glover, J. D and Sarma, 2002. Power System Analysis and Design. (3rd Edition), Wadsworth Group, Brooks Cole,a division of Thomson Learning Centre
[8] ONEM. (2011). "The Electricity market Operations, January - December 2010" theMarketOperations report. Transmission Company of Nigeria.
[9] PHCN NCC ANNUAL REPORT. (2009). Generation, Transmission and Distribution Grid Operations. National Control Centre (NCC) Oshogbo.
[10] Power Holding Company of Nigeria (PHCN). (2013). "Network Data of the Nigerian 28-bus Power System; National Control Centre (NCC)". Oshogbo.
[11] Power World Co-operation. ((2014 Version)). Power World Simulator, Version 18 Glover/Sarma Build11/02/01, Licensed only forEvaluation and University Education use.
[12] Lowel. (2006). Energy Utility Rate Setting . Retrieved June 25th, 2013, from ulu.com.p.66.ISBN 1411689593 :
[13] HOMER Pro 3.1. (n.d.). National Renewable Energy Laboratory (NREL)Retrieved from617 Cole Boulevard Golden, CO 80401-3393: http:/www.nrel.gov/homer
[14] IEEE Standard Board. (1997). "IEEE RecommendedPractice for Industrial and Commercial Power SystemsAnalysis". Approved by American National Standard Institute, (IEEE Std 399-1991).
[15] Electricity Authority, Te Mana Hiko. (2013).Annual Energy Report .www.parliament.nz/.../electricity-authority-te-mana-hiko-annual-report-2...
[16] PHCN Eko Distribution Company. (2013/2014, February 3rd). 2013 New Energy Tariff &Cost for EkoDistrict. Retrieved February 16th, 2014, from Power Tariff under MYTO 2 for 2013/2014