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LOADABILITY ANALYSIS OF THE EXISTING 330KV TRANSMISSION NETWORK OF THE NIGERIAN ELECTRICITY GRID

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ABSTRACT

The loadabilty analysis of the existing 330 kV Nigeria transmission network is presented in this paper. Newton-Raphson algorithm in Etap 12.6 was used to simulate and analyze the network. The parameters used for the study include bus data, transmission line power rating, generators active power, transformer rating and base load. The total installed capacity of the base case considered is 11,948MW out of which 4,420.4MW was available for load level of 3,633.6MW. Result obtained showed that the maximum load the existing 330kV network can accommodate and evacuate is 4,948.978MW and 1,448.721MVar when the buses were subjected to different percentage of the base case load and generation.

1. INTRODUCTION

Increase in economic activities resulting from increase in population and social advancement has led to increase in electrical energy demand. This has increased the burden on the existing transmission/distribution assets and in some cases, has caused the loading of the transmission assets beyond their design limits with consequent reduction in power quality and increased power outages in extreme cases (Oleka *et al.*, 2016).Power sources in Nigeria include hydro, gas, oil, and coal. Nigeria also has capacity for geothermal, wind, solar, tide and wave energy as well as combustible, renewable etc (Uujamhan, 2012). Electric power is the engine that drives industrialization, improves communication, helps innovation in science and technology, provides sound healthcare delivery system and improves citizen's standard of living (Oluwatoyin *et al.*, 2015). Hence, a stable electric power supply is the key for a nation to become one of the developed economy in the world.

As at 1992, the total installed generation capacity was about 5,900 MW. The total electricity available was 3,000 MW and the coincident maximum demand had reached 2,400MW (Uwaifo, 1994; Sule, 2010). In 2009, the electricity generating station installed capacity in Nigeria was 5000MW, but only 2900MW was generated as at November, 2009 (Babalola, 2009; Sule, 2010). The grid system is predominantly characterized by radial, fragile and very long transmission lines, some of which risk total or partial system collapse in the event of major fault occurrence and make voltage control difficult (Onohaebi and Igbinovia, 2008). In this paper the existing Nigeria 330kV network was simulated and analyzed to determine the system maximum load carrying capacity.

2. METHODOLOGY

Data was collected from the Transmission Company of Nigeria (TCN) for load flow analysis. The analysis of the data was done using Newton – Raphson algorithm in Etap 12.6 load flow analyzer which is a power system modeling, design, analysis, optimization, control, and automation software. Newton – Raphson method or techniques for load flow studies was used to simulate and investigate the generated power of the network. The load flow program calculates the magnitude and phase angle of the voltage at each bus, real and reactive power flowing in each line respectively. A number of methods for power flow calculation use equations in different forms considering sending end i^{th}end or receiving end j^{th}end. In this work, the method of Onah (2015) was adopted. The steady state real and reactive power supplied by a bus in a power network expressed in terms of nonlinear algebraic equations is given as:

$$\begin{pmatrix}\Delta P\\ \Delta Q\end{pmatrix} = \begin{pmatrix}J_1 & J_2\\ J_3 & J_4\end{pmatrix}\begin{pmatrix}\Delta\delta\\ \Delta V\end{pmatrix} \tag{1}$$

Table 1 shows the line length from one bus station to another while Figure 1 shows the transmission network modeled in Etap 12.6 edit mode. To ascertain the maximum loadability of the network, Etap 12.6 Load Flow Analyzer was used to simulate the 330kV consisting of fifty nine (59) buses, sixty seven (67) transmission lines and twenty (20) generating stations with (11,948MW installed generating capacity). Generating stations which has more than one stations in one place like Olorunsogo I and II were grouped together. The input data used in the simulation of the maximum load capacity are the various line loading and generation as obtained from Transmission Company of Nigeria (TCN) which represents the base case for the model. Electric power transfer were investigated by subjecting the base load and base generation to various percentage increase to ascertain the maximum load capacity of the network.

Table1: Existing 330kV transmission line network circuit

S/N	From Station Location	To Station Location	No of circuits	Length (km)
1	Afam G.S	Alaoji T.S	2	25
2	Afam G.S	PH main T.S	2	8
3	Ahoda T.S	Gbarian G.S	2	87.4
4	Aiyede T.S	Olorunsogo G.S	1	125
5	Ajah T.S	Lekki T.S	2	5.5
6	Ajah T.S	Alagbon T.S	2	21
7	Ajaokuta T.S	Geregu G.S	1	75
8	Aladja T.S	Sapele G.S	1	93
9	Alagbon T.S	Lekki T.S	2	24.5
10	Alaoji G.S	Alaoji T.S	2	50
11	Alaoji T.S	Owerri T.S	2	77.1

12	Asaba T.S	Onitsha T.S	2	65.8
13	Benin T.S	Ajaokuta T.S	2	195
14	Benin T.S	Delta G.S	1	107
15	Benin T.S	Sapela G.S	2	50
16	Benin T.S	Asaba T.S	2	153.9
17	Birnin – Kebbi T.S	Kainji T.S	1	310
18	Damaturu T.S	Maiduguri T.S	1	260
19	Delta G.S	Aladja T.S	1	30
20	Egbin G.S	Benin T.S	1	218
21	Egbin G.S	Aja T.S	2	14
22	Ganmo T.S	Osogbo T.S	1	87
23	Gbarian G.S	Yenegoa T.S	2	25
24	Gombe T.S	Damaturu T.S	1	160
25	Gombe T.S	Yola T.S	1	240
26	Gwagwalada	Shiroro G.S	1	144
27	Gwagwalada T.S	Lokoja T.S	1	135
28	Ihovbor G.S	Benin T.S	1	20
29	Ikeja west T.S	Akangba T.S	2	18
30	Ikeja west T.S	Omotosho T.S	1	160
31	Ikeja west T.S	Okearo T.S	2	32
32	Ikeja west T.S	Egbin T.S	1	62
33	Ikeja west T.S	Olorunsogo G.S	1	50
34	Ikot - Ekpene T.S	Ugwaji T.S	2	174
35	Ikot - Ekpene T.S	Alaoji T.S	2	57.9
36	Ikot - Ekpene T.S	Odukpani T.S	2	88.5
37	Jebba G.S	Jebba T.S	2	8
38	Jebba T.S	Ganmo T.S	1	70
39	Jebba T.S	Osogbo T.S	2	157
40	Jebba T.S	Shiroro G.S	2	244
41	Jos T.S	Makurdi T.S	1	285
42	Kaduna T.S	Shiroro G.S	2	95
43	Kaduna T.S	Kano T.S	1	230
44	Kaduna T.S	Jos T.S	1	197
45	Kainji T.S	Kainji G.S	2	0.47
46	Kainji T.S	Jebba T.S	2	81
47	Katampe T.S	Gwagwalada T.S	1	60
48	lokoja T.S	Ajaokuta T.S	1	215
49	New Haven T.S	Ugwaji T.S	2	65
50	New Haven T.S	Onitsha T.S	1	96
51	Odukpani T.S	Adiabor T.S	2	10
52	Okearo T.S	Egbin T.S	2	30
53	Omotosho G.S	Benin T.S	1	120
54	Onitsha T.S	Okpai G.S	2	56
55	Onitsha T.S	Alaoji T.S	1	138
56	Osogbo T.S	Aiyede T.S	1	119
57	Osogbo T.S	Ikeja west T.S	1	235
58	Osogbo T.S	Ihovbor G.S	1	251
59	Owerri T.S	Ahoda T.S	2	73.6
60	PH main T.S	Omoko T.S	2	83
61	Sapele G.S	Delta G.S	1	93
62	Shiroro G.S	Katampe T.S	1	144
63	Paras energy T.S	Sagamu T.S	2	4
64	Trans amadi G.S	PH main T.S	2	8
65	Egbin G.S	Ikorodu T.S	2	17
66	Ikorodu T.S	Sagamu T.S	2	34
67	Asco G.S	Ajaokuta T.S		50

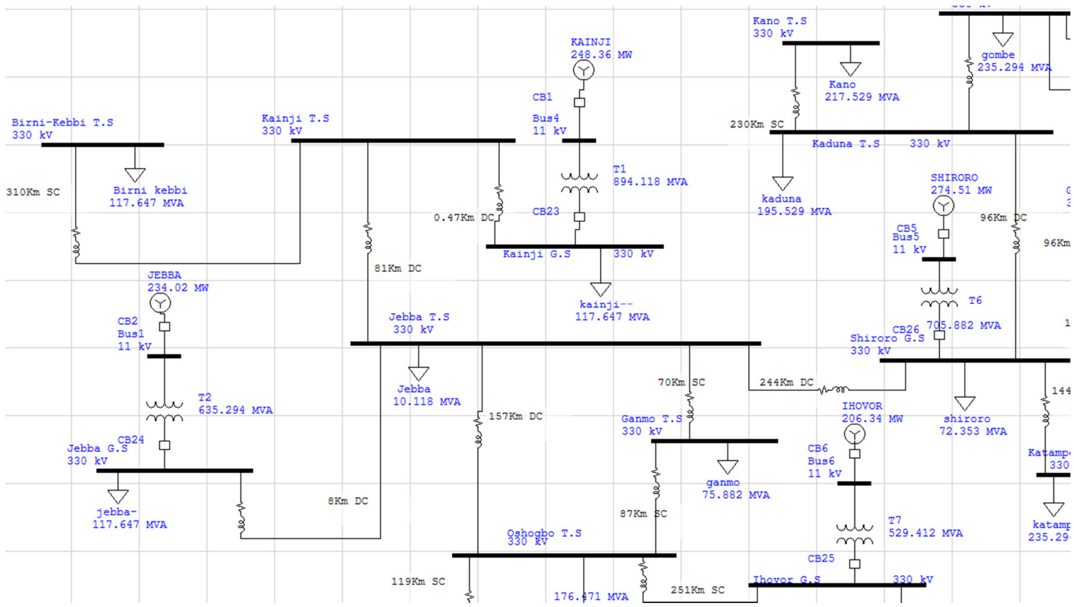

Figure1: Existing Nigeria transmission network diagram drawn in Etap 12.6 edit mode

3. RESULTS AND DISCUSSION

Results show that there was no convergence beyond 20% base load at twenty (20) iteration, even when the base generation was further increased beyond 2%. It was then ascertained that the maximum loadability of the existing network is 4,948.978MW and 1,448.72MVar with a loading of 4,702.727MW and 2,914.49MVar. However, Damaturu T.S (0.82.p.u), Gombe T.S (0.82p.u), Jos T.S (0.84p.u), Kaduna T.S (0.81p.u), Kano T.S (0.81p.u), Katempa T.S (0.82p.u) and Yola T.S (0.81p.u) violated the statutory set voltage limit of 0.85p.u – 1.05p.u. At each stage of percentage increase, it was observed that there were variations in the bus reactive power, bus voltages, real and reactive power from bus to bus and the real and reactive power losses from bus to bus as shown in Tables 2 and 3.

Table 2: Power flow results at 20% of base load and 2% of base generation increase

S/N	Bus ID	V(p.u)	Pgen (MW)	Qgen (Mvar)	Pload (MW)	Qload (Mvar)
1	Adiabor T.S	1.03	0	0	0	0
2	Aes G.S	0.95	229.6	153.1	0	0
3	Afam G.S	1.02	197.4	95.7	0	0
4	Ahoda T.S	1.03	0	0	0	0
5	Aiyede T.S	0.92	0	0	199.3	123.5
6	Aja T.S	0.95	0	0	0	0
7	Ajaokuta T.S	1.05	0	0	0	0
8	Akangba T.S	0.87	0	0	0	0
9	Aladja T.S	1.03	0	0	0	0
10	Alagbon T.S	0.95	0	0	0	0
11	Alaoji G.S	1.02	245.8	-23.2	0	0
12	Alaoji T.S	1.02	0	0	417.6	258.8
13	Asaba T.S	1.02	0	0	0	0
14	Asco G.S	1.05	39.6	-11.1	0	0

15	Benin T.S	1.01	0	0	292.7	181.4
16	Birni-Kebbi T.S	0.85	0	0	132.5	82.1
17	Damaturu T.S	0.82	0	0	0	0
18	Delta G.S	1.03	429.7	184.9	0	0
19	Egbin G.S	0.95	433.4	303	0	0
20	Ganmo T.S	0.97	0	0	57.5	35.6
21	Gbarain G.S	1.04	71.2	-37.2	0	0
22	Geregu G.S	1.05	144.4	-91.1	0	0
23	Gombe T.S	0.82	0	0	133.3	82.6
24	Gwagwalada T.S	0.89	0	0	0	0
25	Ihovor G.S	1.02	165.6	-4.9	0	0
26	Ikeja West T.S	0.87	0	0	1326.7	822.2
27	Ikorodu T.S	0.96	0	0	0	0
28	Ikot Epkene T.S	1.03	0	0	0	0
29	Jebba G.S	1.00	359.4	94.5	0	0
30	Jebba T.S	1.00	0	0	20.7	12.8
31	Jos T.S	0.84	0	0	246	152.4
32	Kaduna T.S	0.81	0	0	158.1	97.9
33	Kainji G.S	1.01	330.2	55.7	0	0
34	Kainji T.S	1.01	0	0	0	0
35	Kano T.S	0.81	0	0	135.4	83.9
36	Katampe T.S	0.82	0	0	429.9	266.4
37	Lekki T.S	0.95	0	0	0	0
38	Lokoja T.S	0.97	0	0	0	0
39	Maiduguri T.S	0.85	0	0	0	0
40	Makurdi T.S	0.97	0	0	0	0
41	New Haven T.S	1.00	0	0	183.6	113.8
42	Odupkani G.S	1.03	172.4	-45.2	0	0
43	Okaero T.S	0.91	0	0	0	0
44	Okpia G.S	1.02	250	-8.1	0	0
45	Olorunsogo G.S	0.99	344.6	174.1	0	0
46	Omoku G.S	1.03	118.9	-38.7	0	0
47	Omotosho G.S	0.96	271.9	178.4	0	0
48	Onitsha T.S	1.02	0	0	164	101.6
49	Oshogbo T.S	0.95	0	0	296.9	184
50	Owerri T.S	1.03	0	0	0	0
51	Paras energy G.S	0.96	136.3	84.5	0	0
52	PH main T.S	1.02	0	0	0	0
53	Sagamu T.S	0.96	0	0	0	0
54	Sapele G.S	1.02	509.8	22.9	147.9	91.7
55	Shiroro G.S	0.90	450.6	369.3	327.7	203.1
56	Trans amadi G.S	1.02	48.3	-4.7	0	0
57	Ugwuaji T.S	1.01	0	0	0	0
58	Yenegoa T.S	1.04	0	0	0	0
59	Yola T.S	0.81	0	0	33.1	20.5
	Total		4948.97	1448.8	4702.7	2914.5

Table 3: Line flow and power losses results at 20% of base load and 2% of base generation.

S/N	From Bus	To Bus	P Flow (MW)	Q Flow (MW)	P Loss (MW)	Q Loss (Mvar)
1	Adiabor T.S	Odupkani G.S	0.0	-7.3	0.0	-7.3
2	Afam G.S	PH main T.S	166.4	20.1	0.1	-5.2
3	Ahoda T.S	Gbarain G.S	71.0	41.5	0.2	-63.5
4	Aiyede T.S	Olorunsogo G.S	148.0	63.3	4.9	-25.6
5	Aja T.S	Alagbon T.S	0.0	-15.7	0.0	-12.9
6	Aja T.S	Lekki T.S	0.0	-15.7	0.0	-3.4
7	Ajaokuta T.S	Benin T.S	41.8	-150.6	0.9	-138.3
8	Ajaokuta T.S	Geregu G.S	144.2	-99.0	1.9	-123.1
9	Akangba T.S	Ikeja West T.S	0.0	-9.2	0.0	-9.3
10	Aladja T.S	Delta G.S	0.0	-10.4	0.0	-10.4
11	Alagbon T.S	Lekki T.S	0.0	-12.3	0.0	-15.1
12	Alaoji G.S	Alaoji T.S	245.7	-31.2	1.6	-28.9
13	Alaoji T.S	Owerri T.S	70.6	99.0	0.4	-53.9
14	Alaoji T.S	Onitsha T.S	54.0	-31.7	0.4	-44.9
15	Alaoji T.S	Afam G.S	263.7	9.8	0.9	-13.9
16	Asaba T.S	Benin T.S	51.6	-94.6	0.4	-108.1
17	Asaba T.S	Onitsha T.S	51.1	59.9	0.1	-46.4
18	Asco G.S	Ajaokuta T.S	39.5	22.4	0.0	-37.5
19	Benin T.S	Egbin G.S	51.6	78.7	1.3	-62.9
20	Benin T.S	Delta G.S	79.8	23.1	0.7	-33.2
21	Benin T.S	Omotosho G.S	66.0	91.0	1.4	-32.1
22	Benin T.S	Sapele G.S	360.7	-49.9	3.4	-20.4
23	Birni-Kebbi T.S	Kainji T.S	132.5	82.1	9.1	-47.4
24	Damaturu T.S	Maiduguri T.S	0.4	-57.1	0.4	-57.1
25	Egbin G.S	Ikorodu T.S	135.0	98.9	0.8	-29.1
26	Egbin G.S	Aes G.S	228.1	128.6	0.8	-8.8
27	Egbin G.S	Aja T.S	0.0	-40.0	0.0	-8.6
28	Ganmo T.S	Oshogbo T.S	65.5	39.1	0.5	-24.2
29	Gbarain G.S	Yenegoa T.S	0.0	-18.6	0.0	-18.6
30	Gombe T.S	Yola T.S	33.1	20.5	0.6	-39.0
31	Gombe T.S	Damaturu T.S	1.8	-81.5	1.5	-24.4
32	Gombe T.S	Kaduna T.S	184.3	5.2	15.5	22.6
33	Gwagwalada T.S	Lokoja T.S	209.3	206.3	6.7	-51.1
34	Gwagwalada T.S	Shiroro G.S	65.1	-20.5	0.8	-34.1
S/N	From Bus	To Bus	P Flow (MW)	Q Flow (MW)	P Loss (MW)	Q Loss (Mvar)
34	Gwagwalada T.S	Shiroro G.S	65.1	-20.5	0.8	-34.1
35	Gwagwalada T.S	Katampe T.S	273.6	219.9	10.4	33.6
36	Ihovor G.S	Benin T.S	69.3	17.3	0.4	-25.3
37	Ikeja West T.S	Olorunsogo G.S	191.2	110.3	9.1	-0.9
38	Ikeja West T.S	Egbin G.S	272.4	188.8	8.5	22.4
39	Ikeja West T.S	Okaero T.S	565.5	368.3	9.7	25.5
40	Ikeja West T.S	Omotosho G.S	337.2	232.1	12.2	39.4
41	Ikorodu T.S	Sagamu T.S	135.8	69.8	0.0	-0.9
42	Ikot Epkene T.S	Ugwuaji T.S	276.2	-54.9	6.6	-93.4
43	Ikot Epkene T.S	Alaoji T.S	105.8	-106.7	0.5	-39.1

44	Jebba G.S	Jebba T.S	358.8	64.2	0.6	-3.0
45	Jebba T.S	Shiroro G.S	197.3	165.1	7.9	-116.4
46	Jebba T.S	Oshogbo T.S	190.4	110.5	3.7	-86.3
47	Jebba T.S	Ganmo T.S	123.5	50.5	1.4	-16.1
48	Jos T.S	Makurdi T.S	245.9	152.4	14.6	-97.8
49	Kaduna T.S	Shiroro G.S	525.6	321.3	25.3	64.0
50	Kainji T.S	Jebba T.S	186.6	52.9	1.6	-49.2
51	Kainji T.S	Kainji G.S	329.8	38.2	0.0	-0.2
52	Kano T.S	Kaduna T.S	158.0	154.1	22.6	70.2
53	Lokoja T.S	Ajaokuta T.S	216.0	155.2	6.7	-121.2
54	Makurdi T.S	Ugwuaji T.S	271.0	-76.3	10.4	-130.9
55	New Haven T.S	Onitsha T.S	188.6	-21.0	3.6	-15.7
56	Odupkani G.S	Ikot Epkene T.S	172.3	-45.7	1.3	-58.4
57	Okaero T.S	Egbin G.S	574.3	389.6	8.9	21.3
58	Okpia G.S	Onitsha T.S	249.6	-24.5	1.8	-32.0
59	Omoku G.S	PH main T.S	118.8	-41.3	0.6	-57.2
60	Oshogbo T.S	Ihovor G.S	93.0	63.6	2.8	-67.7
61	Oshogbo T.S	Aiyede T.S	51.3	60.2	0.7	-31.1
62	Owerri T.S	Ahoda T.S	70.9	45.1	0.0	-3.6
63	Paras energy G.S	Sagamu T.S	135.8	68.9	0.1	-2.3
64	Sapele G.S	Delta G.S	0.9	-32.9	0.0	-31.8
65	Shiroro G.S	Katampe T.S	174.4	81.9	7.8	1.9
66	Trans amadi G.S	PH main T.S	48.3	-6.7	0.0	-5.7
67	Ugwuaji T.S	New Haven T.S	1.4	-119.0	0.1	-4.3

4. CONCLUSION

This work successfully presents an application of the Etap 12.6 software for the computation of power system transmission network parameters with fifty nine (59) buses, sixty seven (67) transmission lines and twenty (20) generating stations. The system profile analysis revealed that the maximum power the existing network can evacuate is 4,948.978MW and 1,448.72MVar but in practice, the Nigeria grid network can only evacuate between 1,000MW and 4,000MW due to inefficiency, unreliability, not properly ringed network, high losses and power station breakdown. More generating stations and transmission lines should be built and added to the network and the single circuit lines should be upgraded to double circuit to boost generation and transmission and control devices should be used in high voltage area.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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