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VOLTAGE VIOLATION ON THE 330KV POWER NETWORK OF NIGERIA WITHOUT FLEXIBLE ALTERNATING CURRENT TRANSMISSION DEVICE.

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Abstract:
This paper on Identification of voltage violations on the power network of Nigeria without flexible alternating current transmission device investigates the 58 buses, 330Kv Nigeria transmission Lines. The work was on 58 buses, 330kv Nigeria transmission line network. It examined some major voltage control methods which are necessary and vital in controlling voltage violations on the network. The specific objectives are : To characterize the 58 Bus Nigeria interconnected power network, To model the 58 Bus 330Kv Nigeria Transmission Network, To Simulate the 58 Bus Nigeria 330kv Transmission Network and to identify the voltage violations from the simulation results. To identify the voltage violations on the transmission lines of 58 Buses, 330kv Nigeria network was modelled and load flow simulation was done using PSAT in MATLAB environment just to initialise the dynamic simulation of the System and also the violated buses were noted. The methods used in achieving the specific objectives were properly explained. The result obtained shows thatsix buses that had violated voltages were Kano-0.936895pu, Gombe-0.908595pu, Damaturu-0.906397pu, Maiduguri-0.897593pu, Yola – 0.9012pu, Jos -0.93719pu. This was done using a Test case one, which contains no FACTS device inserted in the study system.

Keywords: Voltage control, Characterization, Modeling, Simulation, FACTS,

1.1. Introduction

Voltage violations and power losses in power systems are caused by insulation breakdown or collapse, long length of transmission lines, interconnected grid, changing system loads and other unforeseen disturbances in the system. These instabilities result in reduced line flows or even line trip.

As the years goes by, there an unending demand for power and ensuring development of the modern power system. This has led to an increasing complexity in the study of power systems thereby presenting new challenges to power system stability in particular (Kumar and Dubey, 2015). This research was inspired by difficulties in power transfer capabilities due to outages, blackouts and system faults that occur due to dynamics in long transmission lines of interconnected systems and distance between load and generation points. Since, Electrical power system in general is a complex interconnected network which comprises of numerous generators, transmission lines, variety of loads and transformers at the distribution/transmission level, there is every need to study the changes and causes of the changes on the power network. This led to the quest of this work. In Nigeria Power network, power generated is usuallytransmitted over the existing lines to meet the increasing demand. Many factors affect the transmitted power over the transmission lines resulting in power losses at the expected destinations. Therefore, to study properly those variations on the complex network, an advanced tool is employed for a best analysis. Before identifying the violations on the Nigeria Network, various voltage control methods are discussed in the following sections.

1.2. Voltage Control Methods in Power System

Voltage ratings of the various buses in the power system which includes generating station buses, switching substation buses, receiving substation buses and distribution substation buses should be within the permissible limits for satisfactory operation of all electrical equipments (Paserba, 2017). The task of voltage control is closely associated with fluctuating load conditions and corresponding requirements of reactive power compensation. Therefore several voltage control methods are employed in power system to keep the voltage levels within the desirable limits. In this article some of the voltage control methods in power system are discussed (Emmanuel et al, 2016).

- Excitation control and voltage regulators at the generating stations:
- Use of tap changing transformers at sending end and receiving end of the transmission lines

- Switching in shunt reactors during low loads or while energizing long EHV lines
- Switching in shunt capacitors during high loads or low power factor loads
- use of series capacitors in long EHV transmission lines and distribution lines in case of load fluctuations
- Use of tap changing transformers in industries, substations, distribution substations
- use of static shunt compensation having shunt capacitors and thyristorized control for step-less control of reactive power
- Use of synchronous condensers in receiving end substations for reactive power compensation
- Voltage Control by Flexible AC transmission (FACT) devices

All the above methods are suitably applied at different parts of the power system to maintain the voltage levels within the limits (Huang et al, 2017).

1.3. Specific objectives

The specific objectives of this work are:

i. To characterize the 58 Bus Nigeria interconnected power network
ii. To model the 58 Bus 330Kv Nigeria Transmission Network
iii. To Simulate the 58 Bus Nigeria 330kv Transmission Network.
iv. To identify the voltage violations from the simulation results

2.1. Methodology for Achieving the Objectives

The methodology for achieving the objective of this research is explained in the following sections.

2.1.1. Characterization ofthe 58 Bus Nigeria 330kv Network

The Nigeria 330kV transmission network was obtained from Transmission Company of Nigeria, TCN (master plan data, 2014) and was characterized in p.u values using 100 MVA as the base power and 330kV as the rated and the base voltage. This network is shown in fig 3.1 below.

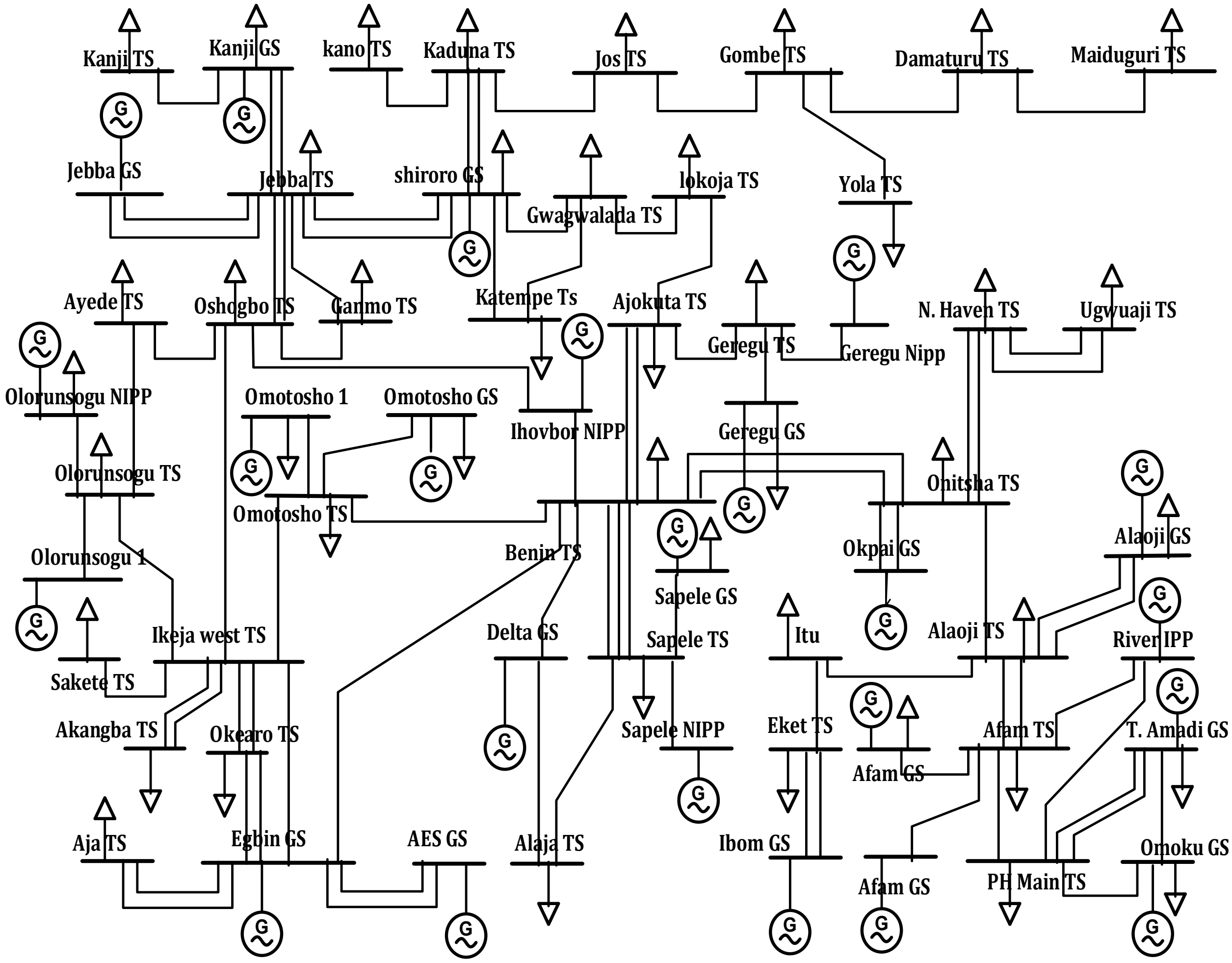

Figure 1:58 Buses Nigeria 330 kV Transmission Line

From the figure above , it shows that the Nigerian Transmission grid is made up of interconnected network of 6702 km of 330-kV that spans the country nationwide. The single-line diagram of the Nigerian 330-kV network currently consists of eighty–seven (87) 330-kV transmission line circuits, twenty– three (23) generating stations, forty – three (43) load stations, and fifty-eight (58) buses (sub-stations) fig 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 the following substations: Ikeja West (RCC1), Benin (RCC2) and Shiroro (RCC3)(Ogbuefi and Madueme,2016) from (PHCN Annual Report, 2009).

2.1.2. Modeling of 58 Bus 330Kv Nigeria Transmission Network

The 58 bus Nigeria 330kV transmission line network was modeled in PSAT 2.1.8. Before the development, other parameters to be used during the process are determined and explained below.

2.1.3. Development of Simulation Model and the Simulation of 58 Bus Nigeria 330kv Transmission Network.

The 58 bus Nigeria 330 kV transmission line network was modeled in PSAT 2.1.8 and simulated in matlab 2013b environment. The PSAT model for the research is shown in fig 1. The simulations of Nigeria 330kV was solved using the power flow equation which is using Newton – Raphson method of load flow solution. Egbin substation was chosen as the slack bus. The solution to the load flow calculation give the output as the bus voltage and phase angle, real reactive power (both sides of each line), line active and reactive loss, and slack power. The voltage violated buses will be sorted from the result of the load flow analysis using the permissive voltage bus limit criteria of 0.95 to 1.05 pu or $\pm 5\%$ of the rated bus voltage. The PSAT uses a subroutine program to solve the problems.

3.1. Test case 1 (no FACTS device inserted in the study system)

In this case no facts device is inserted in 58 bus Nigeria 330 kV transmission line fig 2. This test case circuit of fig 1 was configured in PSAT and simulated. The configured test circuit is shown in fig 2.

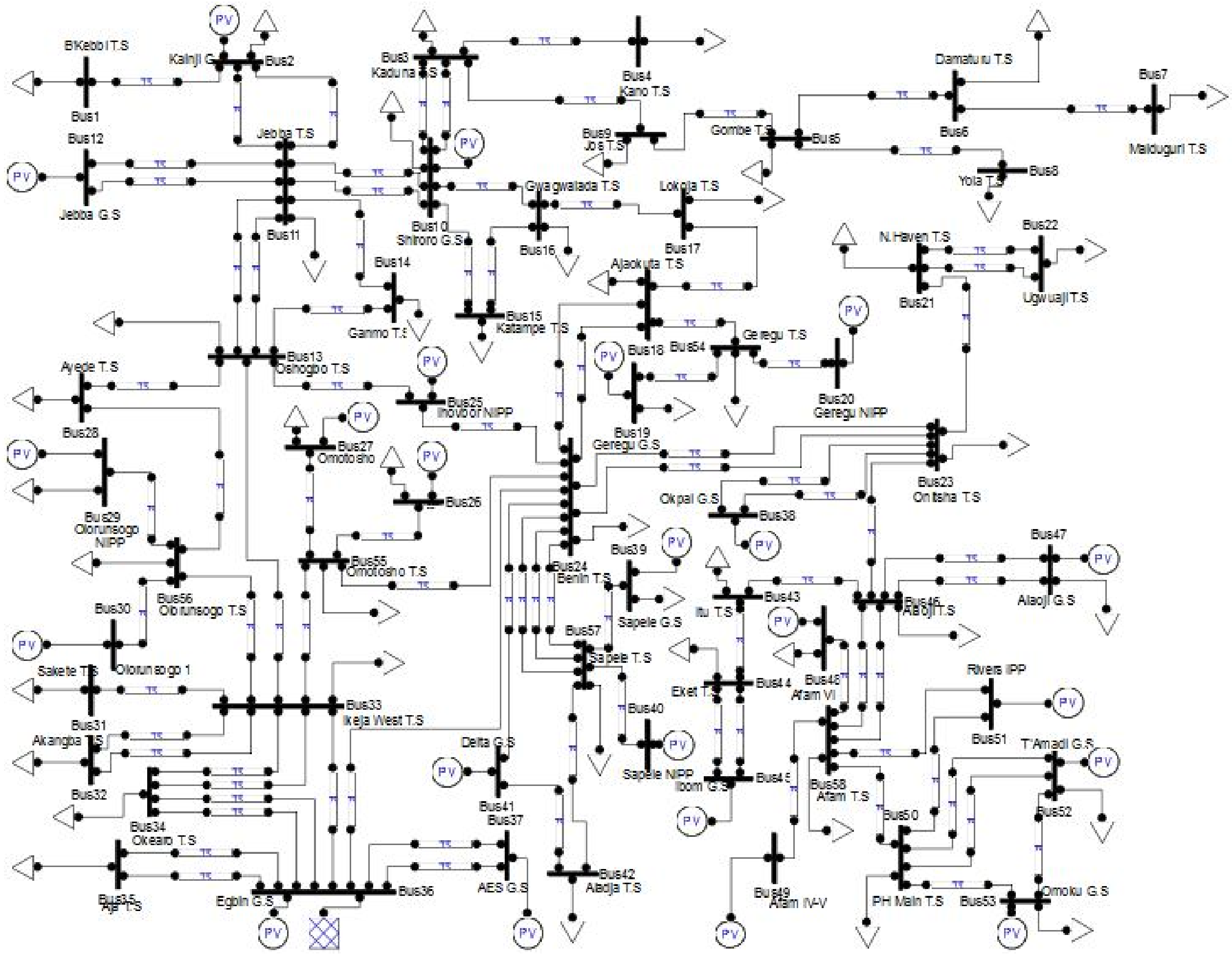

Figure 2: PSAT Model for 58 Bus Nigeria 330 kV Network without FACTS Device

4. Results and Discussion

4.1 Simulation Result Presentation

The presentation of the research simulation is as follows. The simulation of 58 buses, 330kV Nigeria transmission line network was simulated; Bus numbers assigned to the buses were tabulated in Table 1. Also the simulation transmission line numbers and its bounded buses and corresponding bounded bus names were shown in Table 2. The network statistics which showed that the simulated 330 kV transmission network consisted of 58 buses, 87 transmission lines, 23 generators and 46 load centers were shown in table 3. Table 4 showed the solution statistics during simulations.

Simulation results of 58 buses, 330 kV Nigeria transmission line network to study the bus voltage status during no facts and when SSSC, UPFC, and STATCOM were inserted were shown in table 5.

Table1: Simulation Bus Numbers and Names

BUS NUMBER	BUS NAME	BUS NUMBER	BUS NAME
1	BIRNIN KEBBI	30	OLORUNSOGO I
2	KAINJI	31	SAKETE
3	KADUNA	32	AKANGBA
4	KANO	33	IKEJA WEST
5	GOMBE	34	OKEARO
6	DAMATURU	35	AJA
7	MAIDUGURI	36	EGBIN
8	YOLA	37	AES
9	JOS	38	OKPAI
10	SHIRORO	39	SAPELE G/S
11	JEBBA T/S	40	SAPELE (NIPP)
12	JEBBA G/S	41	DELTA
13	OSHOGBO	42	ALADJA
14	GANMO	43	ITU
15	KATAMPE	44	EKET
16	GWAGWALADA	45	IBOM
17	LOKOJA	46	ALAOJI T/S
18	AJAOKUTA	47	ALAOJI G/S
19	GEREGU G/S	48	AFAM VI
20	GEREGU (NIPP)	49	AFAM IV-V
21	NEW HAVEN	50	PH MAIN
22	UGWAJI	51	RIVERS (IPP)
23	ONITSHA	52	TRANS AMADI
24	BENIN	53	OMOKU
25	IHOVBOR (NIPP)	54	GEREGU T/S
26	OMOTOSHO (NIPP)	55	OMOTOSHO T/S
27	OMOTOSHO I	56	OLORUNSOGO T/S
28	AYEDE	57	SAPELE T/S
29	OLORUNSOGO (NIPP)	58	AFAM T/S

Table 2: Simulation Transmission Line Numbers and Their Bounded Buses

LINE NO	BUS - BUS	TRANSMISSION LINE	LINE NO	BUS - BUS	TRANSMISSION LINE
1	1 - 2	Birnin Kebbi - Kainji	45	34 - 33	Okearo - Ikeja West
2	3 - 4	Kaduna - Kano	46	2 - 11	Kainji – Jebba TS
3	10 - 11	Shiroro – Jebba TS	47	34 - 33	Okearo - Ikeja West
4	10 - 11	Shiroro – Jebba TS	48	35 – 36	Aja - Egbin
5	3 - 10	Kaduna - Shiroro	49	35 – 36	Aja - Egbin
6	10 - 16	Shiroro –Gwagwalada	50	34 - 36	Okearo - Egbin
7	3 - 9	Kaduna - Jos	51	34 - 36	Okearo - Egbin
8	9 - 5	Jos –Gombe	52	33 - 36	Ikeja West - Egbin
9	16 - 17	Gwagwalada - lokoja	53	24 - 36	Benin – Egbin
10	11 - 14	Jebba TS –Ganmo	54	36 - 37	Egbin - Aes
11	13 - 14	Oshogbo – Ganmo	55	36 - 37	Egbin - Aes
12	11 - 13	Jebba TS –Oshogbo	56	24 - 23	Benin – Onitsha
13	5 - 8	Gombe –Yola	57	12 - 11	Jebba GS - Jebba TS
14	11 - 13	Jebba TS –Oshogbo	58	24 - 23	Benin – Onitsha
15	1 6- 15	Gwagwalada - Katampe	59	23 - 38	Opkai – Onitsha
16	10 - 15	Shiroro – Katampe	60	23 - 38	Opkai – Onitsha
17	18 - 17	Ajaokute –Lokoja	61	24 - 57	Benin – Sapele T/S
18	53 - 50	Omoku –PH Main	62	24 - 57	Benin – Sapele T/S
19	58 - 51	Afam T/S - Rivers IPP	63	24 - 57	Benin – Sapele T/S
20	19 - 54	Geregu G/S - Geregu T/S	64	39 - 57	Sapele G/S – Sapele T/S
21	54 - 20	Geregu T/S - Geregu (NIPP)	65	57 - 40	Sapele T/S – Sapele (NIPP)
22	18 - 54	Ajaokute – Geregu T/S	66	24 - 41	Benin – Delta
23	21 - 23	New Heaven - Onitsha	67	41 - 42	Delta - Aladja
24	5 - 6	Gombe – Damaturu	68	12 - 11	Jebba GS - Jebba TS
25	21 - 22	New Heaven - Ugwaji	69	57 - 42	Sapele T/S – Aladja
26	21 - 22	New Heaven - Ugwaji	70	43 - 44	Itu - Eket

LINE NO	BUS - BUS	TRANSMISSION LINE	LINE NO	BUS - BUS	TRANSMISSION LINE
27	18 - 24	Ajaokute – Benin	71	44 - 45	Eket - Ibom
28	18 - 24	Ajaokute – Benin	72	44 - 45	Eket - Ibom
29	25 - 24	Ihovbor(NIPP) - Benin	73	43 - 46	Itu – Alaoji T/S
30	13 - 25	Oshogbo – Ihovbor(NIPP)	74	23 - 46	Onitsha – Alaoji T/S
31	55 - 26	Omotosho T/S - Omotosho (NIPP)	75	46 - 47	Alaoji T/S - Alaoji G/S
32	27 - 55	Omotosho 1 - Omotosho T/S	76	46 - 47	Alaoji T/S - Alaoji G/S
33	55 - 24	Omotosho T/S – Benin	77	58 - 49	Afam T/S - Afam IV–V
34	28 - 13	Ayede – Oshogbo	78	52 - 50	Trans Amadi – PH Main
35	6 - 7	Damaturu - Maiduguri	79	2 - 11	Kainji – Jebba TS
36	29 - 56	Olorunsogo(NIPP) – Olorunsogo T/S	80	46 - 58	Alaoji T/S – Afam T/S
37	56 - 30	Olorunsogo T/S - Olorunsogo 1	81	46 - 58	Alaoji T/S – Afam T/S
38	28 - 56	Ayede – Olorunsogo T/S	82	58 - 50	Afam T/S – PH Main
39	31 - 33	Sakete - Ikeja West	83	51 - 50	Rivers IPP – PH Main
40	56 - 33	Olorunsogo T/S - Ikeja West	84	52 - 50	Trans Amadi – PH Main
41	13 - 33	Oshogbo –Ikeja West	85	52 - 53	Trans Amadi - Omoku
42	55 - 33	Omotosho T/S - Ikeja West	86	48 - 58	Afam IV - Afam T/S
43	32 - 33	Akangba - Ikeja West	87	3 - 10	Kaduna - Shiroro
44	32 - 33	Akangba - Ikeja West			

Table 3: Network Statistics

	NETWORK STATISTICS			
Network condition	**SSSC**	**UPFC**	**STATCOM**	**No FACTS**
Buses	58	58	58	58
Lines	87	87	87	87
Generators	23	23	23	23
Loads	46	46	46	46

Table 4: Solution Statistics

	SOLUTION STATISTICS			
Power Flow Solution Type	**Newton - Raphson**			
Simulation Condition	SSSSC	UPFC	STATCOM	No FACTS
Number of Iterations:	5	5	5	5
Maximum P mismatch [p.u.]	41.17842	41.17645	41.22503	9.28E-12
Maximum Q mismatch [p.u.]	10.01818	10.01743	10.03604	0.197854
Power rate [MVA]	100	100	100	100

Table 5: Bus Voltages without FACTS Insertion

Bus Number	**Bus Name**	**V [p.u.]**	**phase [rad]**	**P gen [p.u.]**	**Q gen [p.u.]**	**P load [p.u.]**	**Q load [p.u.]**
Bus 1	BIRNIN KEBBI	0.979671	-0.67098	8.88E-16	-6.7E-16	1.62	1.22
Bus 2	KAINJI	0.97	-0.50455	2.92	-4.49602	0.89	0.67
Bus 3	KADUNA	0.989272	-0.86088	-2E-12	1.78E-13	1.43	0.98
Bus 4	**KANO**	**0.936896**	**-1.00471**	**2.75E-13**	**8.24E-14**	**1.94**	**1.46**
Bus 5	**GOMBE**	**0.908595**	**-1.14256**	**-2.5E-12**	**4.15E-12**	**0.68**	**0.51**
Bus 6	**DAMATURU**	**0.906397**	**-1.17949**	**2.8E-12**	**1.17E-12**	**0.24**	**0.18**
Bus 7	**MAIDUGURI**	**0.897593**	**-1.20893**	**7.61E-12**	**5.93E-13**	**0.31**	**0.2**
Bus 8	**YOLA**	**0.9012**	**-1.16512**	**4.58E-12**	**4.62E-13**	**0.26**	**0.2**
Bus 9	**JOS**	**0.938719**	**-1.00219**	**-9.3E-12**	**2.22E-12**	**0.72**	**0.54**

Bus Number	Bus Name	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
Bus 10	SHIRORO	1	-0.77658	3	-2.26389	1.7	0.98
Bus 11	JEBBA T/S	1.0016	-0.51444	-1.4E-13	-1.2E-13	2.6	1.95
Bus 12	JEBBA G/S	1	-0.50967	4.03	-2.04678	0	0
Bus 13	OSHOGBO	1.021973	-0.4437	7.55E-15	2.23E-14	1.27	0.95
Bus 14	GANMO	1.013572	-0.48713	2.18E-14	9.44E-15	1	0.75
Bus 15	KATAMPE	0.968761	-0.8546	7.99E-15	-8E-15	3.03	2.27
Bus 16	GWAGWALADA	0.981015	-0.81865	0	8.66E-15	2.2	1.65
Bus 17	LOKOJA	0.983658	-0.66839	-2.2E-16	7.88E-15	1.2	0.9
Bus 18	AJAOKUTA	0.985653	-0.61087	-3.6E-13	1.34E-13	1.2	0.9
Bus 19	GEREGU G/S	0.985	-0.60912	3.85	1.455111	2	1.5
Bus 20	GEREGU (NIPP)	0.985	-0.60933	1.46	-0.00394	0	0
Bus 21	NEW HAVEN	0.971998	-0.93997	-4.9E-15	-3.3E-14	1.96	1.47
Bus 22	UGWAJI	0.971496	-0.94174	8.08E-14	2.33E-14	1.75	1.31
Bus 23	ONITSHA	0.973807	-0.82315	3.5E-14	1.24E-13	1	0.75
Bus 24	BENIN	0.995828	-0.49639	2.98E-14	-5.4E-14	1.44	1.08
Bus 25	IHOVBOR (NIPP)	1	-0.4835	1.166	-1.38708	0	0
Bus 26	OMOTOSHO (NIPP)	1.006	-0.33761	1.147	0.512867	0.9	0.44
Bus 27	OMOTOSHO I	1	-0.33783	0.508	-0.02731	0.3	0.14
Bus 28	AYEDE	0.980821	-0.30971	-4.4E-15	-2.9E-15	1.74	1.31
Bus 29	OLORUNSOGO (NIPP)	0.973	-0.19955	0.93	-0.14974	0.71	0.58
Bus 30	OLORUNSOGO I	0.97	-0.18351	1.027	-0.97025	0	0
Bus 31	SAKETE	0.97798	-0.12887	-4.4E-16	9.77E-15	2.05	1.1
Bus 32	AKANGBA	0.99619	-0.09054	9.33E-15	1.16E-13	2.03	1.52
Bus 33	IKEJA WEST	0.999964	-0.08613	2.13E-14	-7.8E-14	8.47	6.35
Bus 34	OKEARO	1.01469	-0.04388	-6.7E-15	3.72E-14	1.2	0.9

Bus Number	Bus Name	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
Bus 35	AJA	1.031295	-0.00213	-7.1E-15	-5E-14	1.15	0.86
Bus 36	EGBIN	1.033	0	41.23471	10.03976	0	0
Bus 37	AES	1	0.076642	2.452	-3.49485	0	0
Bus 38	OKPAI	1	-0.78611	4.66	1.692064	0	0
Bus 39	SAPELE G/S	0.985	-0.48992	0.67	-0.95668	0.4	0.18
Bus 40	SAPELE (NIPP)	1	-0.48001	1.111	-0.18175	0	0
Bus 41	DELTA	1.003	-0.4791	3.41	0.905989	0	0
Bus 42	ALADJA	0.992198	-0.49737	7.99E-15	-1E-14	2.1	1.58
Bus 43	ITU	0.97848	-1.53205	3.55E-15	-8.1E-15	1.99	0.91
Bus 44	EKET	0.988548	-1.56369	-1.1E-14	-9.8E-15	2	1.47
Bus 45	IBOM	1	-1.56214	0.305	1.496835	0	0
Bus 46	ALAOJI T/S	0.981995	-1.48959	1.33E-15	6.13E-14	2.4	1
Bus 47	ALAOJI G/S	1	-1.49044	2.5	9.415142	2.27	1.7
Bus 48	AFAM VI	1	-1.51254	6.46	8.916558	5.34	4.01
Bus 49	AFAM IV-V	0.956	-1.51175	0.54	-4.4108	0	0
Bus 50	PH MAIN	0.998574	-1.53855	-8.9E-14	5.84E-14	2.8	1.4
Bus 51	RIVERS (IPP)	1	-1.53337	0.8	1.498423	0	0
Bus 52	TRANS AMADI	1	-1.53852	1	1.70441	0.8	0.24
Bus 53	OMOKU	1	-1.53867	0.448	0.208557	0.5	0.1
Bus 54	GEREGU T/S	0.984922	-0.6101	8.33E-13	1.02E-13	2	1.5
Bus 55	OMOTOSHO T/S	0.992783	-0.34213	-1.8E-15	2.61E-14	0.8	0.5
Bus 56	OLORUNSOGO T/S	0.980349	-0.2047	-8.9E-15	-2.7E-14	0.71	0.58
Bus 57	SAPELE T/S	0.996462	-0.4953	-5.9E-14	-2.7E-14	1	0.77
Bus 58	AFAM T/S	0.976824	-1.51604	-6.2E-15	1.47E-13	7.2	4.12

Table 6:Line Flow without FACTS Device Insertion

LINE FLOWS

Line	Bus to Bus (Number)	Bus to Bus (Name)	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
1	1 - 2	Birnin Kebbi - Kainji	-1.62	-1.22	0.032504	-2.99326
2	3 - 4	Kaduna - Kano	1.976379	-0.60748	0.036379	-2.06748
3	10 - 11	Shiroro – Jebba TS	3.508108	-1.28468	0.10724	-1.79416
4	10 - 11	Shiroro – Jebba TS	3.508108	-1.28468	0.10724	-1.79416
5	3 - 1 0	Kaduna-Shiroro	-2.84369	-0.42697	0.028438	-0.80733
6	10 - 16	Shiroro –Gwagwalada	1.061306	-0.53927	0.006599	-1.69578
7	3 - 9	Kaduna - Jos	2.28101	0.481425	0.041099	-0.11615
8	9 - 5	Jos –Gombe	1.519911	0.057573	0.025614	-0.20929
9	16 - 17	Gwagwalada - lokoja	-2.9024	-0.47224	0.057264	-1.60539
10	11 - 14	Jebba TS –Ganmo	-2.14766	-0.84828	0.01833	-1.17653
11	13 - 14	Oshogbo – Ganmo	3.182456	0.022805	0.016464	-0.39894
12	11 - 13	Jebba TS –Oshogbo	-1.53884	-1.06545	0.01348	-1.66703
13	5 - 8	Gombe –Yola	0.260751	-0.08023	0.000751	-0.28023
14	11 - 13	Jebba TS –Oshogbo	-1.53884	-1.06545	0.01348	-1.66703
15	1 6- 15	Gwagwalada - Katampe	1.757111	-0.02125	0.008795	-0.76875
16	10 - 15	Shiroro – Katampe	1.296166	-0.92494	0.014482	-2.44745
17	18 - 17	Ajaokute –Lokoja	4.190804	-0.55609	0.031136	-0.32294
18	53 - 50	Omoku –PH Main	-0.00068	0.134661	2.23E-05	-0.1435
19	58 - 51	Afam T/S - Rivers IPP	0.822646	-1.46796	0.003403	-0.33032
20	19 - 54	Geregu G/S - Geregu T/S	1.85	-0.04489	0.000191	0.00083
21	54 - 20	Geregu T/S - Geregu (NIPP)	-1.45988	0.004088	0.000119	0.00015
22	18 - 54	Ajaokute – Geregu T/S	-1.30946	1.551	0.000229	0.001193
23	21 - 23	New Heaven - Onitsha	-3.71042	-0.7058	0.051399	-2.17621
24	5 - 6	Gombe – Damaturu	0.553546	-0.16291	0.002395	-0.26791
25	21 - 22	New Heaven - Ugwaji	0.87521	-0.3821	0.00021	-1.0371
26	21 - 22	New Heaven - Ugwaji	0.87521	-0.3821	0.00021	-1.0371
27	18 - 24	Ajaokute – Benin	-2.04067	-0.94745	0.030529	-2.08178
28	18 - 24	Ajaokute – Benin	-2.04067	-0.94745	0.030529	-2.08178
29	25 - 24	Ihovbor(NIPP) - Benin	1.723991	0.214585	0.002785	-0.2552
30	13 - 25	Oshogbo –Ihovbor(NIPP)	0.561192	-1.21292	0.003201	-2.81459

Line	Bus to Bus (Number)	Bus to Bus (Name)	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
31	55 - 26	Omotosho T/S - Omotosho	-0.24607	-0.94392	0.000932	-0.87105
32	27 - 55	Omotosho 1 - Omotosho T/S	0.208	-0.16731	0.000337	-0.87081
33	55 - 24	Omotosho T/S – Benin	9.730415	-0.86011	0.176081	0.940829
34	28 - 13	Ayede – Oshogbo	3.674223	-1.94631	0.065375	-0.72928
35	6 - 7	Damaturu - Maiduguri	0.311151	-0.075	0.001151	-0.275
36	29 - 56	Olorunsogo(NIPP) –	0.22	-0.72974	0.000505	-0.62529
37	56 - 30	Olorunsogo T/S - Olorunsogo	-1.0236	0.371473	0.003403	-0.59877
38	28 - 56	Ayede – Olorunsogo T/S	-5.41422	0.636308	0.067509	-0.06167
39	31 - 33	Sakete - Ikeja West	-2.05	-1.1	0.0124	-0.65774
40	56 - 33	Olorunsogo T/S - Ikeja West	-4.94864	-0.35794	0.070249	-0.24684
41	13 - 33	Oshogbo –Ikeja West	-4.50944	0.226245	0.198456	-1.15733
42	55 - 33	Omotosho T/S - Ikeja West	-10.0767	2.007535	0.30943	2.190202
43	32 - 33	Akangba - Ikeja West	-1.015	-0.76	0.000909	-0.19224
44	32 - 33	Akangba - Ikeja West	-1.015	-0.76	0.000909	-0.19224
45	34 - 33	Okearo - Ikeja West	8.062141	1.843209	0.043091	0.162556
46	2 - 11	Kainji – Jebba TS	0.188748	-1.69638	0.006866	-0.83151
47	34 - 33	Okearo - Ikeja West	8.062141	1.843209	0.043091	0.162556
48	35 – 36	Aja - Egbin	-0.575	-0.43	0.000212	-0.16865
49	35 – 36	Aja - Egbin	-0.575	-0.43	0.000212	-0.16865
50	34 - 36	Okearo - Egbin	-8.66214	-2.29321	0.05001	0.214526
51	34 - 36	Okearo - Egbin	-8.66214	-2.29321	0.05001	0.214526
52	33 - 36	Ikeja West - Egbin	-16.639	-3.47666	0.18594	1.370476
53	24 - 36	Benin – Egbin	-7.78233	1.249642	0.477338	1.766043
54	36 - 37	Egbin - Aes	-1.21232	-0.43097	0.013676	-2.1784
55	36 - 37	Egbin - Aes	-1.21232	-0.43097	0.013676	-2.1784
56	24 - 23	Benin – Onitsha	7.576969	0.112432	0.287749	0.967823
57	12 - 11	Jebba GS - Jebba TS	2.015	-1.02339	0.001447	-0.08899
58	24 - 23	Benin – Onitsha	7.576969	0.112432	0.287749	0.967823
59	23 - 38	Opkai – Onitsha	2.33	0.846032	0.015488	-0.77711
60	23 - 38	Opkai – Onitsha	2.33	0.846032	0.015488	-0.77711
61	24 - 57	Benin – Sapele T/S	-0.08213	-0.33217	1.45E-05	-0.59527

Line	Bus to Bus (Number)	Bus to Bus (Name)	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
62	24 - 57	Benin – Sapele T/S	-0.08213	-0.33217	1.45E-05	-0.59527
63	24 - 57	Benin – Sapele T/S	-0.08213	-0.33217	1.45E-05	-0.59527
64	39 - 57	Sapele G/S – Sapele T/S	0.27	-1.13668	0.001469	-0.57765
65	57 - 40	Sapele T/S – Sapele (NIPP)	-1.10874	-0.39876	0.002258	-0.58051
66	24 - 41	Benin – Delta	-1.43208	-0.62051	0.003265	-0.43176
67	41 - 42	Delta - Aladja	1.974658	0.717241	0.005361	-0.31278
68	12 - 11	Jebba GS - Jebba TS	2.015	-1.02339	0.001447	-0.08899
69	57 - 42	Sapele T/S – Aladja	0.130839	-0.14096	0.000136	-0.69093
70	43 - 44	Itu - Eket	1.700399	-0.84671	0.004614	-0.30673
71	44 - 45	Eket - Ibom	-0.15211	-1.00499	0.000392	-0.25657
72	44 - 45	Eket - Ibom	-0.15211	-1.00499	0.000392	-0.25657
73	43 - 46	Itu – Alaoji T/S	-3.6904	-0.06329	0.011911	-0.06393
74	23 - 46	Onitsha – Alaoji T/S	14.44564	2.255919	1.134019	8.151814
75	46 - 47	Alaoji T/S - Alaoji G/S	-0.10967	-3.88163	0.005325	-0.02406
76	46 - 47	Alaoji T/S - Alaoji G/S	-0.10967	-3.88163	0.005325	-0.02406
77	58 - 49	Afam T/S - Afam IV–V	-0.53261	4.418576	0.007389	0.007781
78	52 - 50	Trans Amadi – PH Main	0.074337	0.749149	8.33E-05	-0.03884
79	2 - 11	Kainji – Jebba TS	0.188748	-1.69638	0.006866	-0.83151
80	46 - 58	Alaoji T/S – Afam T/S	3.714332	0.434006	0.007605	-0.0376
81	46 - 58	Alaoji T/S – Afam T/S	3.714332	0.434006	0.007605	-0.0376
82	58 - 50	Afam T/S – PH Main	1.034418	-1.24573	0.00118	-0.37283
83	51 - 50	Rivers IPP – PH Main	1.619243	0.360785	0.000291	-0.05796
84	52 - 50	Trans Amadi – PH Main	0.074337	0.749149	8.33E-05	-0.03884
85	52 - 53	Trans Amadi - Omoku	0.051325	-0.03389	5.55E-07	-0.05999
86	48 - 58	Afam IV - Afam T/S	1.12	4.906558	0.009	0.024888
87	3 - 10	Kaduna - Shiroro	-2.84369	-0.42697	0.028438	-0.80733

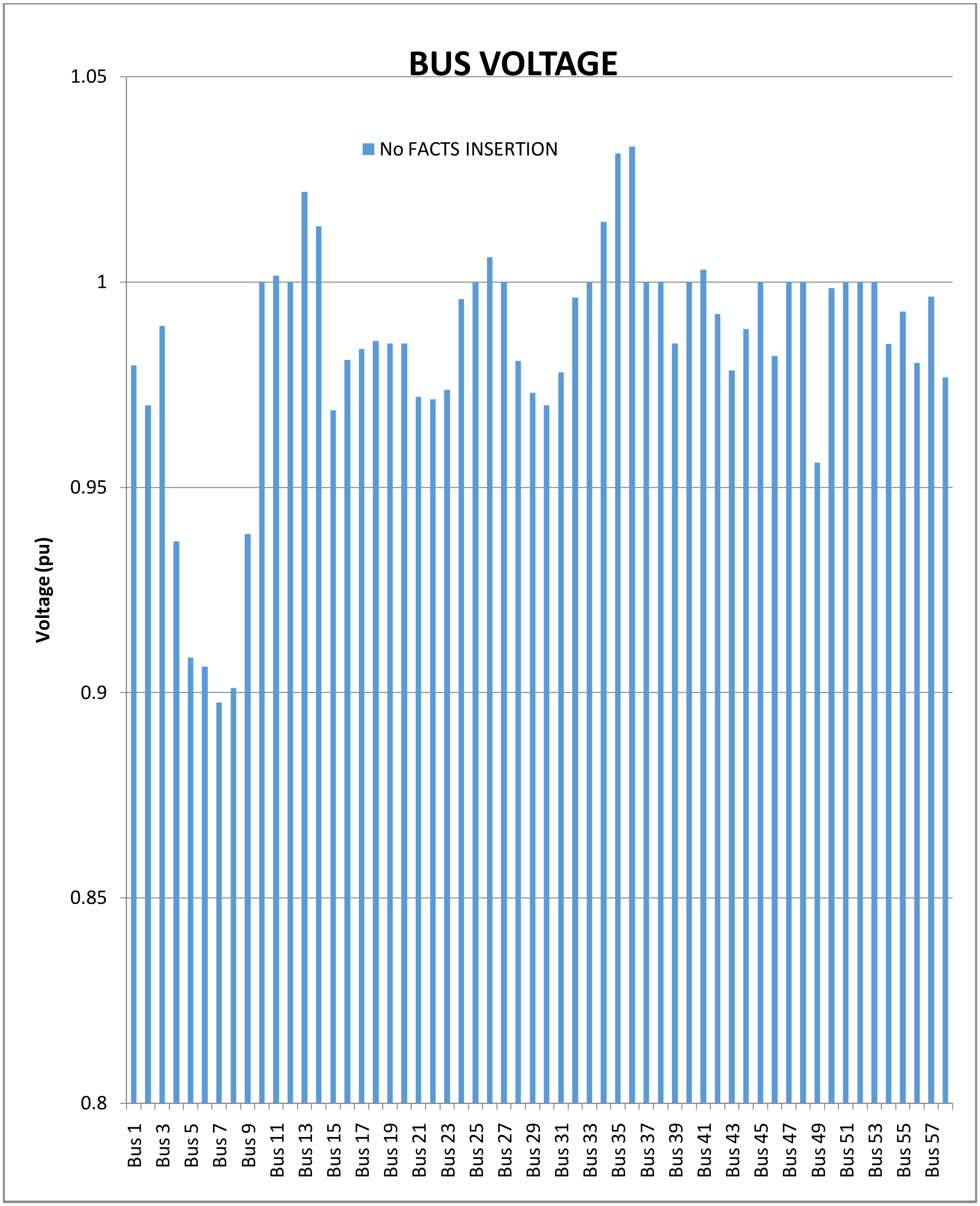

Figure 3: Bus voltages without FACTS insertion

4.2. Discussion and Analysis of Test Case 1 Result (Simulation without Facts Device)

The simulation of 58 buses, 330kV Nigeria transmission line system without facts devices was done and result recorded in table 5 and table 6. Table 5, column 3 and 2 recorded the simulated buses voltages and phase angles at these buses respectively. The buses voltages were shown graphically in figure 3.

The system generated line active and reactive power flow was shown by the PSAT analysis tool as the simulation parameters was recorded in table 5, column 4 and 5 respectively. The demanded active and reactive power in the buses were shown in table 5, column 6 and 7 respectively. Table 5, column 1 actually showed the bus numbers while the names of the substations represented by these bus numbers were listed in table 1.

Table 6 showed the result of line power flows and line losses. The active and reactive power flows were shown in table 6, column3 and 4 respectively .while the active and reactive line power loss were shown in table 6, column 5 and 6 respectively. Table 6, column 2 showed the corresponding bound buses for these lines that were shown in table 6, column 1. The bus to bus name representation of these lines could be read off in table 2.

The simulation of 58 buses, 330 kV Nigeria transmission line network without compensation has shown that six (6) buses had voltage violation see table 5 and figure 3 and these buses were bus 4 (Kano), bus 5 (Gombe), bus 6 (Damaturu) bus 7 (Maiduguri), bus 8 (Yola) and bus 9 (Jos). These voltages violation had occurred majorly on the radial line serving Kaduna to Maiduguri with a single transmission line feeding all the violated busses from Kaduna substation. Violation in Kano was a case of high active and reactive power demand 1.94 pu and 1.46 pu respectively. The major cause of this voltage violation in Kano substation was of course reactive power demand. The cause of violations on buses along Kaduna – Maiduguri line was mostly due to drops along the long line. The total power demand along this line from Kaduna – Maiduguri and tee connected line from Gombe to Yola was 2.21pu and 1.63pu, active and reactive power respectively. Maiduguri substation experienced the highest voltage violation because it had longest measured distance from Kaduna 795 km and power demand of 1.95 + j1.43

pu. Compare with Kaduna to Yola, and which had second highest voltage violation of 0.9012 but had distance of 615 km from Kaduna and total power demand of 1.64 + j1.23 pu.

5.1 Conclusion

The 58 buses, 330 kV Nigeria transmission line network as shown by this research has 7 voltage violated buses. These buses are Kano (0.9180 pu), Gombe (0.7890 pu), Damaturu ().7634 pu), Maiduguri (0.7613 pu), Yola (0.7769 pu) and Jos (0.8756 pu). When these voltage violated buses where enhanced with SSSC and UPFC inserted in the line between Kaduna – Jos buses and STATCOM inserted in Jos substation bus, the bus enhancement capabilities of UPFC was the greatest while STATCOM was better than SSSC.

References

Acha, E., Fuerte-Esquivel, C.R and Ambriz-Perez., H (2014), FACTS: Modeling and Simulation in Power Networks, Wiley, London, U.K.

Aggarwal, G., Pablo,H and Justine,O (2014), “MATLAB/Simulink Based Simulation of a Hybrid Power Flow Controller”, Advanced Computing & Communication Technologies (ACCT), Fourth International Conference

Emmanuel U. Oleka, Samuel N. Ndubisi, Gerald K. Ijemaru(2016) Electric Power Transmission Enhancement: A Case of Nigerian Electric Power Grid*American Journal of Electrical and Electronic Engineering*, 4(1), 33-39 doi:10.12691/ajeee-4-1-5

Folorunso Oladipo, Olowu Temitayo . O(2015),The Nigerian Power System till date: A review; *International Journal of Advance Foundation and Research in Science & Engineering (IJAFRSE)Volume 1, Issue 5, pp20-33*

Kumar, A and Dubey, S.B (2015), “Enhancement of Transient Stability in Transmission Line Using SVC Facts Controller”, International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-2, Issue-2, May 15.

Paserba, J.(2017), “Recent Power Electronics/FACTS Installations to Improve Power System Dynamic Performance”, Power Engineering Society General Meeting,. IEEE

Ogbuefi U. C. and Madueme T.C (2015). ‘A Power Flow Analysis of the Nigerian 33oKV electric power system’. IOSR *Journal of Electrical and Electronics engineering (iosr-jeee)* vol. 10, pp 46 – 57

Huang, A.Q., O’brien S.C and Hulart,M(2017), “Active Power Management of Electric Power System Using Emerging Power Electronics Technology”, Power Engineering Society General Meeting, . IEEE

Math Works, (2017) "Three-Phase 48-Pulse GTO Converter," [Online]. Available: http://www.mathworks.com/help/physmod/sps/examples/three-phase-48-pulse-gtoconverter.html. [Accessed 20- 07 -21].