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Modelling A Series Compensator to Minimize Losses on The Bus Impedance Matrix of A Power System Network

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Abstract:

Modelling a series compensator to minimize losses on the bus impedance matrix of a power system network was carried out on 26 (twenty six) buses, of Nigeria 330kV power system network using a tolerant voltage of ±5% which resulted in 0.95pu (313.5kV) equivalent to lower limit and 1.05pu (346.5kV) as upper limit representing under voltage and over voltage respectively. The network system stated had a total of eight (8) generating stations and eighteen (18) load buses (transmission station) with 29 (twenty nine) interconnectivity. However, due to the generalized nature of Newton Raphson Iteration technique to solving non-linear equation with less number of times of iteration and its convergence ability these data were inputted to run a load flow analysis on our sample network. Further studies to vary the behaviour of the system when loss or addition of a circuit occurred showed insignificant change in the bus impedance matrix. Hence from the result of the analysis it could be said that the program which was written in Matlab code was able to solve the problem of under voltage, over voltage and identify best link position for compensator installation to achieve optimal result. However this solved the problem of proper placement and optimal compensator position with the emphasis on the program being able to analyse virgin network with the parameters of such network provided it could run a load flow on the system and the result will identify places of voltage violation and buses that may need compensation for easy system stability, load balance and efficiency of the power

System network and minimize losses.

Keywords — **Transmission System, Generating Station, Tawal Dimension, Impedance Matrix**

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I. INTRODUCTION

Electricity being the basic life wire of any developed and developing nation, should be efficient, reliable and stable in other to achieve the set desired goal of industrialization, economic breakthrough, food security, quality and affordable utility services and independence on other foreign countries, it is therefore pertinent to meet the citizen growing demand for steady electricity supply. These aspirations of growth and development cannot be achieved without an efficient and reliable power system network that will be able to transmit bulk power from the generation station through the transmitting station and then to the end users at most affordable rate. However it will be of great benefit to the companies generating, transmitting and distributing power to do these at the barest minimum loss to enhance their profit margin and meet obligations. Hence the need to have an in depth study of the power system network arises for a recommendation of the best appropriate technique to achieve efficient and reliable power supply to consumers and in turn ensure power network reliability and stability. This entails more growth and demand of power supply by the companies and consumers respectively.

One major method that has been used in the past to tackle the power efficiency of transmission network is fast responding system known as flexible alternating Current Transmission System (FACTS) devices. This system has ability to control and increase power transfer capability using an electronic based and static controller to enhance performance. Hence the need arise for a way out of this hook posed by incessant breakdown, under voltage and power losses on the power system network.

However my desire to delve into this research work was necessitated by the instability, voltage drop and power losses associated with our power system network. It is on this ground I want to model a series compensator to minimize losses on the network bus impedance matrix for online application as a clue to solving the problem of inappropriate positioning, seizing and installation of compensation capacitors on our model network using Newton Raphson Iterative technique with computer Matlab written code for load flow analysis and data simulation respectively.

Motivation

The need to resolve the challenge associated with lack of model for installation of line compensator along power system network and inability to analyze a virgin network with load flow analysis on estimated line properties and have a clue of voltage violation and best busses for compensation while checking under/over voltage led to the development of the program to reduce losses due to line impedances.

Statement of the Problem

The power system network is obviously bedevilled with issues of power losses resulting in voltage drop due to long distance transmission of bulk power. These losses are mainly caused by line resistance to the flow of power and it has consequences on electrical appliance that need power for its operation leading to damages and inefficiency of electrical equipment. Against this backdrop, there is need to fashion the best way of minimizing this loss to ensure better power delivery to end user and in turn improve on the efficiency of service

The need for line compensation therefore arise in other to minimize losses witnessed along transmission lines and improve on system loadability, steady state stability and reduce voltage drop in load areas.

This work tends to use a computer aided simulation program to resolve issue of size and position of capacitor compensators along transmission line network to reduce voltage drop, power loss and disturbances.

Aims and Objectives Of Study

The major aim of this project work is to reduce problems associated with power losses, voltage drop and disturbances experienced on power system transmission network to the barest minimum.

Objective of the study

1. To take sample of a 26 buses, 330kv Nigerian power system network and characterize to compute line parameters.
2. Develop an algorithm for network Bus impedance matrix computation and perform load flow analysis on our sample network
3. Develop an algorithm for proper sizing and positioning of series compensator on our model network using Newton Raphson iterative technique at places of voltage violation

Significant of study

1. This project tends to ensure proper planning, seizing and positioning of appropriate compensator on a power system network impedance bus.
2. It will enhances minimal loss and wastage along power system network
3. These will ensure future forecasting of any sample network Viz-viza the appropriate, size, position and capacitors needed for compensation through the computer aided program at points of voltage violation.

Scope of the Study

This work will have an in-depth study of the 26 buses, 330kv Nigerian power system network with load flow analysis to identify the necessary areas of voltage violation and need for compensation along the value network value chain with emphases on solving problem of proper placement and installation of capacitors in between the bus bars of transmission or load buses to enhance efficiency, steady and reliable electricity power supply and minimize losses.

II. RESEARCH METHODOLOGY

Material

The materials used for this project include;

i. Computer System
ii. MATLAB & Simulink software
iii. Transmission line Parameters
iv. Generating Station
v. Tawel Dimension
vi. Impedance Matrix

Objective 1: Takea sample of a 26 busses, 330kv Nigerian power system network and characterize it.

Methodology for Realization of Objective 1

To realize the number one objective of this research is the under listed steps were taken

1. Data on the sample of Nigerian 330kv power system studied was sourced from National Control Centre Oshogbo primarily through correspondence. The data collected included station's generation and/or load, both real and reactive; transmission line length between buses (stations); conductor size and conductor material type; tower dimensions
2. Manufacturer's data sheet was used to obtain technical specification of the conductor material.
3. The transmission line were represented using π model
4. To obtain the parameters of the π models of the lines, codes written in Matlab were used. The codes which are saved function file in Matlab when called prompt the user to supply it with the necessary input data. Such input data included sub conductor geometric mean radius (readily obtained from manufacturer data sheet), conductor spacing on tower number of circuits on tower; circuit configuration (horizontal or vertical), conductor diameter, units of measurement (cm, in, m) etc. with these information supplied to our user interactive property, the geometric mean distance (GMD) for computation of line charging susceptance and inductance and the geometric mean radius of equivalent conductor were computed and returned by our program.
5. The complete transmission lines parameters were then obtained by multiplying the per unit length parameters by the line length.
6. To obtain the per unit values of the parameter, a base MVA of 1320MVA was chosen (this corresponds to the generation of highest station in our study network through correspondent.

Objective 2: Develop an algorithm for network Bus impedance matrix formation and perform load flow analysis on our network sample.

Methodology leading to Objective 2 Realization

1. Prepare network data and save them in Matlab files named as 'linedata, gendata, and yload'.
2. Call the function Zbuild pi with data files so it can build the network n x n square impedance matrix.
3. Call the function Lf newton so it can perform load flow analysis on the network.
4. Display results using the functions Busout and Line flow.

All Matlab programs used are appended.

Objective 3: Develop an algorithm for proper sizing and positioning of series compensator on our model network

Methodology for Realization of Objective 3

The following steps were taken for realization of objective 3

1. Declare voltage constraint on our network
2. Use load flow result obtained in objective 2 to identify bus that violated the declared voltage constraint
3. For such bus(es) identified in step 2 above read their connecting line parameters such as r, l, c, g, f, and length and also note their V_R, P_R, Q_R

4. Obtain for such line(s) the transmission line constants ABCD and Z and Y. Also state degree of compensation desired.
5. Perform series compensation.
6. If no bus voltage constraint violation is observed during step 2, note total system loss from power flow result and compensate to minimize loss.
7. Read out the MVAR of the specified series capacitor needed to achieve the stated degree of compensation and V_s, P_s, Q_s, line losses, voltage regulation, and transmission efficiency for the compensated line.

Objective 4: Develop an algorithm for network bus impedance matrix modification following additional or removal of a circuit

Methodology for realization of objective 4

The methodologies for realization of objective are given in steps as under;

Step 1: Read in original network data, zdata

Step 2: Specify the kind/type of modification to make type 1 – type 4 according to Rule 1 – Rule 4 in section 3.4.3 above

Step 3: Call the function zbuild to form the original network bus Impedance matrix, zbus

Step 4: Modify Zdata to suit change needed to make on the network, Zdatam

Step 5: Call Zbuild again using Zdatam to form the new bus Impedance matrix $[Zbus]_{new}$ using any of the equations corresponding to the rule of modification specified in step 2 here

Step 6: End and print result

III. RESULTS AND DISCUSSION

We present here the results of our work for each of the objectives. A brief discussion follows each result.

Objective 1 Results: Take a sample of a power system and characterize it.

As stated before, our work was based on a sample of Nigeria power system. The network studied was 26 (twenty-six) bus, 330kv interconnected transmission network typical of Nigeria for case of reference, the stations (buses) are classified as either load or generating bus. Table 1 show the generating stations in our model network with their various generations for the day or data was collected. Also, table 2 shows the load stations and the corresponding loads on the stations both real and reactive. Table 3 shows our bus numbering and the corresponding stations.

The transmission line parameters were calculated and tabulated in table 4 with the aid of the information contained in line property as tabulated in table 5. All line parameters, that is, resistance, inductive reactance and shunt capacitive reactance are expressed in per unit with base value as 82.5ohms.

Table 1: Generating Stations Bus

Name of Gen Station	bus no	S (MVA)	P(MW)	Q(MVAR)
Egbin GS	1	1474.8	1320	657.75
Kainji GS	15	800	760	249.8
Jebba GS	12	680	578.4	357.6
Shiroro	13	705	600	370.17
Delta 3 GS	21	267.52	214.02	160
Afam GS	25	877.5	702	526.59
Sapele GS	9	1275	1020	765
Okpai	22	630	480	408

Table 2: Load Buses on Our Model Network

		Load	
Station Name	bus no	MW	MVAR
Ikeja West TS	3	943	40
Akangba	4	25	5
Ayede	5	152	10
Benin	6	109.9	8
Osogno	7	104.4	4
Onitsha	8	98	12
New Haven	23	72	4
Aladja	10	40.4	2
Ajaokuta	11	60	12
Jebba TS	14	10.3	0.5
BirninKebbi	16	205	26
Kumbotso TS	17	286	38
Mando	26	233	185

Jos	18	161	27
Gombe	19	101	9
Katampe	20	319	12
Alaoji	24	289.4	40

Table 3: Stations and their Conventional Bus Numbers

bus name	bus no
Egbin GS	1
Aja TS	2
Ikeja West	3
Akangba TS	4
Ayede	5
Benin TS	6
Osogbo	7
Onitsha TS	8
Sapele NIPP	9
Aladja TS	10
Ajaokuta	11
Jebba GS	12
Shiroro GS	13
Jebba TS	14
Kainji GS	15
BirninKebbi TS	16
Kumbotso TS	17
Jos TS	18
Gombe	19
Katampe	20
Delta GS	21
Okpai PS	22
New Haven	23
Alaoji TS	24
Afam Vi	25
Mando TS	26

Table 4: Line Parameters in Per Unit for Our Model Network

from bus	to bus	R (PU)	XL (PU)	Ysh/2(PU)
16	15	0.1486	1.2053	0.0449
15	14	0.0194	0.1521	0.0244
14	12	0.0019	0.015	0.0024
14	13	0.0585	0.4581	0.0734
13	26	0.023	0.1802	0.0289
13	20	0.069	0.5599	0.0208
26	17	0.1103	0.8943	0.0333
26	18	0.0944	0.766	0.0285
18	19	0.127	1.0303	0.0384
14	7	0.0376	0.2948	0.0472
7	5	0.057	0.4627	0.0172
7	6	0.1203	0.9759	0.0363
5	3	0.0657	0.5327	0.0198
3	4	0.0043	0.0338	0.0054
3	7	0.1208	0.9798	0.0365
3	1	0.0149	0.1164	0.0187
1	2	0.0034	0.0263	0.0042
3	6	0.0671	0.5257	0.0842
6	11	0.0935	0.7582	0.0282
6	9	0.012	0.0939	0.015
6	21	0.0513	0.416	0.0155
21	10	0.0153	0.1244	0.0046
6	8	0.0328	0.2572	0.0412
8	22	0.0192	0.1502	0.0241
8	23	0.046	0.3733	0.0139
8	24	0.0662	0.5366	0.02
24	25	0.006	0.0469	0.0075
9	10	0.0302	0.2449	0.0091

Table 5: Line Properties of our model network

16	15	310	1
15	14	81	2
14	12	8	2
14	13	244	2
13	26	96	2
13	20	144	1
26	17	230	1
26	18	197	1
18	19	265	1
14	7	157	2
7	5	119	1
7	6	251	1
5	3	137	1
3	4	18	2
3	7	252	1

3	1	62	2
1	2	14	2
3	6	280	2
6	11	195	1
6	9	50	2
6	21	107	1
21	10	32	1
6	8	137	2
8	22	80	2
8	23	96	1
8	24	138	1
24	25	25	2
9	10	63	1

Objective 2 Results: Develop an algorithm for network bus impedance matrix formation and perform load flow analysis on our network sample.

When our algorithm was applied to the network, a bus impedance matrix of 26 rows x 26 columns was obtained and as presented in table 5 below. The bus impedance matrix which is a square matrix has no zero elements as against admittance matrix which is usually sparse.

The results of the load flow which was based on Newton Raphson load flow technique are presented in tables 7 – 8. From the load flow result, it was observed that a total system loss of 241.583MW was recorded on our sample network under its given generation and loading conditions. The losses were usually due to line resistance which appeared to be appreciable as most of the lines are long lines or medium ones.

Also, given the voltage regulation in the Nigerian power system (transmission) at 330kv level, a tolerance of ±5% is usually allowed. This translated to minimum and maximum values of 313.5kv and 346.5kv respectively. In per unit, with 330kv as base voltage, the limits correspond to 0.95pu and 1.05pu for minimum and maximum respectively. A look at column 2 of table 8 shows that the voltage constraint imposed on the network was violated at bus 17 which corresponds to Kumbotso (Kano) transmission system. A stem plot of the system voltage profile is as shown in figure 1. Both figure 1 and table 5 depict clearly the under voltage problem emanating at kumbotso transmission station (bus 17). Need for series compensation therefore arose from the foregoing. It is equally observed from the load flow result that highest real power loss occurred along the 280km, double circuit lines connecting Ikeja West transmission station to Benin, that is, between buses 3 and 6.

Table 7: Power Flow Solution by Newton-Raphson Method

Maximum Power Mismatch = 2.01535e-07; No. of Iterations = 10

Bus No	Voltage Mag.	Voltage Angle (deg)	Load		Generation		Injected Mvar
			MW	Mvar	MW	Mvar	
1	1.020	0.000	0.000	0.000	-878.415	478.819	0.000
2	1.020	-0.028	25.000	2.000	0.000	0.000	0.000
3	0.989	4.859	943.000	40.000	0.000	0.000	0.000
4	0.989	4.821	25.000	5.000	0.000	0.000	0.000
5	0.995	11.653	152.000	10.000	0.000	0.000	0.000
6	1.003	36.455	109.900	8.000	0.000	0.000	0.000
7	1.011	20.581	104.400	4.000	0.000	0.000	0.000
8	1.023	44.112	98.000	12.000	0.000	0.000	0.000
9	1.010	40.423	0.000	0.000	1020.000	-72.784	0.000
10	1.017	40.019	40.400	2.000	0.000	0.000	0.000
11	1.013	34.408	60.000	12.000	0.000	0.000	0.000
12	1.030	27.863	0.000	0.000	578.400	-164.846	0.000
13	1.000	17.100	0.000	0.000	600.000	83.998	0.000
14	1.031	27.495	10.300	0.500	0.000	0.000	0.000
15	1.050	30.761	0.000	0.000	760.000	4.005	0.000
16	1.055	20.741	205.000	16.000	0.000	0.000	0.000
17	0.916	-1.905	286.000	38.000	0.000	0.000	0.000
18	0.988	1.130	161.000	27.000	0.000	0.000	0.000
19	1.008	-3.649	101.000	9.000	0.000	0.000	0.000
20	0.980	9.115	319.000	12.000	0.000	0.000	0.000
21	1.020	40.037	0.000	0.000	214.020	35.149	0.000
22	1.030	47.071	0.000	0.000	480.000	-16.820	0.000
23	1.024	42.970	72.000	4.000	0.000	0.000	0.000
24	1.027	53.275	289.400	40.000	0.000	0.000	0.000
25	1.030	54.625	0.000	0.000	702.000	0.391	0.000
26	0.966	10.739	233.000	185.000	0.000	0.000	0.000
Total			3234.400	426.500	476.005	347.912	0.000

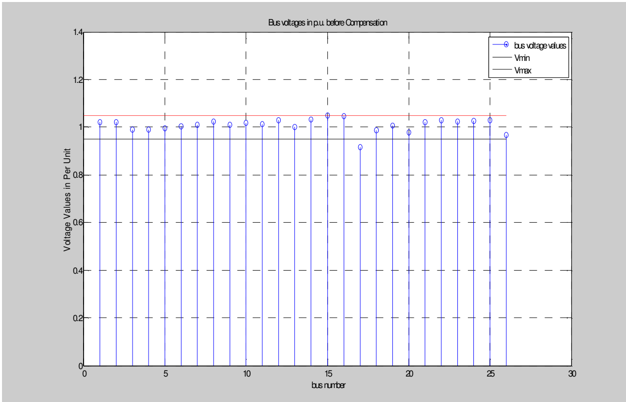

Figure 1: Voltage Profile of Our Model Network Before Compensation

Table 8 Line Flow and Losses

--Line--		Power at bus & line flow			--Line loss--	
from bus	To bus	MW	Mvar	MVA	MW	Mvar
1		-878.415	478.819	1000.440		
	3	-903.417	488.376	1026.973	11.691	41.861
	2	25.002	-9.557	26.766	0.002	-11.557
2		-25.000	-2.000	25.080		
	1	-25.000	-2.000	25.080	0.002	-11.557
3		-943.000	-40.000	943.848		
	5	-283.625	13.003	283.923	4.167	-17.708
	4	25.002	-8.970	26.563	0.002	-13.970
	7	-356.875	18.463	357.352	12.317	3.597
	1	915.108	-446.515	1018.233	11.691	41.861
	6	-1242.610	384.019	1300.596	92.872	506.695
4		-25.000	-5.000	25.495		
	3	-25.000	-5.000	25.495	0.002	-13.970
5		-152.000	-10.000	152.329		
	7	-439.792	20.711	440.280	8.532	23.476
	3	287.792	-30.711	289.426	4.167	-17.708
6		-109.900	-8.000	110.191		
	7	374.653	-52.274	378.283	12.713	5.841
	3	1335.482	122.677	1341.104	92.872	506.695
	11	60.296	-61.365	86.031	0.296	-73.365
	9	-977.736	44.088	978.730	8.660	27.586
	21	-205.497	-42.147	209.775	1.648	-28.483
	8	-697.098	-18.979	697.356	12.042	-17.357
7		-104.400	-4.000	104.477		
	14	-559.976	-50.014	562.205	8.756	-61.388
	5	448.324	2.765	448.333	8.532	23.476
	6	-361.940	58.115	366.576	12.713	5.841
	3	369.191	-14.866	369.491	12.317	3.597
8		-98.000	-12.000	98.732		
	6	709.140	1.621	709.141	12.042	-17.357
	22	-476.841	-25.378	477.516	3.159	-42.198
	23	72.180	-32.972	79.354	0.180	-36.972
	24	-402.478	44.729	404.956	8.012	9.600
9		1020.000	-72.784	1022.594		
	6	986.396	-16.502	986.534	8.660	27.586
	10	33.604	-56.282	65.550	0.069	-24.182
10		-40.400	-2.000	40.449		
	21	-6.865	-34.100	34.784	0.009	-12.616
	9	-33.535	32.100	46.422	0.069	-24.182
11		-60.000	-12.000	61.188		
	6	-60.000	-12.000	61.188	0.296	-73.365
12		578.400	-164.846	601.432		
	14	578.400	-164.846	601.432	0.494	-2.880
13		600.000	83.998	605.851		
	14	-532.545	-69.446	537.054	12.599	-101.223
	26	807.987	150.280	821.843	11.999	20.272
	20	324.558	3.164	324.574	5.558	-8.836
14		-10.300	-0.500	10.312		
	15	-546.270	-119.314	559.148	4.230	-36.531
	12	-577.906	161.966	600.174	0.494	-2.880
	13	545.144	-31.777	546.069	12.599	-101.223
	7	568.732	-11.374	568.846	8.756	-61.388
15		760.000	4.005	760.011		
	14	550.499	82.783	556.689	4.230	-36.531
16		-205.000	-16.000	205.623		
	15	-205.000	-16.000	205.623	4.501	-94.778
17		-286.000	-38.000	288.513		
	26	-286.000	-38.000	288.513	8.147	-11.803
18		-161.000	-27.000	163.248		
	26	-263.138	55.575	268.942	5.702	-25.614
	19	102.138	-82.575	131.342	1.138	-91.575
19		-101.000	-9.000	101.400		
	18	-101.000	-9.000	101.400	1.138	-91.575
20		-319.000	-12.000	319.226		
	13	-319.000	-12.000	319.226	5.558	-8.836
21		214.020	35.149	216.887		
	6	207.146	13.665	207.596	1.648	-28.483
	10	6.874	21.485	22.558	0.009	-12.616
22		480.000	-16.820	480.295		
	8	480.000	-16.820	480.295	3.159	-42.198
23		-72.000	-4.000	72.111		
	8	-72.000	-4.000	72.111	0.180	-36.972
24		-289.400	-40.000	292.151		
	8	410.491	-35.128	411.991	8.012	9.600
	25	-699.891	-4.872	699.908	2.109	-4.481
25		702.000	0.391	702.000		
	24	702.000	0.391	702.000	2.109	-4.481
26		-233.000	-185.000	297.513		
	13	-795.987	-130.008	806.534	11.999	20.272
	17	294.147	26.197	295.311	8.147	-11.803
	18	268.840	-81.189	280.832	5.702	-25.614

Total loss: 241.583MW; -76.940MVAR

Table 9: Bus voltages for initial network setting

Bus no.	Voltages in Per Unit
1	1.0200
2	1.0200
3	0.9891
4	0.9891
5	0.9946
6	1.0033
7	1.0107
8	1.0227
9	1.0100
10	1.0173
11	1.0133
12	1.0300
13	1.0000
14	1.0310
15	1.0500
16	1.0457
17	0.9158
18	0.9879

19	1.0077
20	0.9795
21	1.0200
22	1.0300
23	1.0243
24	1.0268
25	1.0300
26	0.9662

Objective 3 Results: Develop and algorithm for proper positioning and sizing of a series compensator on our model network

Following the problem of under voltage recoded at bus 17, an algorithm was developed for proper positioning and sizing of a series compensator suitable for solving our model network problem.
Different positions were tried for a fixed level of percentage compensation, 25% in our work. The experience gained showed good results could only be obtained when the compensation inserted between bus (es) tied/linked to the affected bus or to remote buses connected to such bus which themselves were connected to the affected bus. At 25% degree of compensation, lines 26 – 17, 26 – 18 and 13 – 26 were evaluated for optimal result, having tried and eliminated the other links. The voltage profile and their various stem plots are depicted in table 10 and figure 2 (a – c).
It was hence observed that series compensator inserted mid-way on the line linking bus 13 and 26 showed best promise in addressing the under voltage problem emanating from bus 17. This became obvious when the degree of compensation was increased to 60% result of which is tabulated on table 11 for the same chosen links.
Having obtained likely optimal position for our series compensator, degree of compensation was then varied and the resulting voltage profile is as depicted in table 12. At 72% degree of compensation, the system under voltage problem was adequately solved. Beyond this level of compensation, a problem of over-voltage would be created at bus 19 which corresponds to Gombe transmission station. At the optimal setting of the series compensator, system bus voltage stem plot was equally made and same presented as figure 3.
For the varying degree of compensation, the corresponding capacitance expressed both in micro-forced and ohms (capacitive reactance) as well as the equivalent MVAR per phase were recorded and tabulated. The corresponding was equally noted. Table 13 shows such result. The network bus impedance matrix after compensation is presented in table 14.
At the optimal positioning and level of compensation, the overall system loss was reduced by 0.78% (1.89/MW). This figure may appear small but time effect on it say for a period of one year may mean much. Further attempt to reduce the loss further became counter-productive as over voltage problem began to arise at Gombe transmission station.

Table 10 Bus Voltages in (PU) for 25% Degree of Compensation for Different Positions of the Series Compensator

	Position of Series Compensator (B/w Buses)		
Bus no.	13 and 26	26 and 17	26 and 18
1	1.0200	1.0200	1.0200
2	1.0200	1.0200	1.0200
3	0.9906	0.9906	0.9906
4	0.9906	0.9906	0.9906
5	0.9960	0.9961	0.9961
6	1.0098	1.0098	1.0098
7	1.0119	1.0120	1.0120
8	1.0268	1.0268	1.0268
9	1.0207	1.0207	1.0207
10	1.0174	1.0174	1.0174
11	1.0200	1.0200	1.0200
12	1.0291	1.0291	1.0291
13	0.9891	0.9891	0.9891
14	1.0300	1.0300	1.0300
15	1.0500	1.0500	1.0500
16	1.0457	1.0457	1.0457
17	0.9140	0.9060	0.9006
18	0.9860	0.9730	0.9694
19	1.0057	0.9918	0.9879
20	0.9678	0.9678	0.9678
21	1.0146	1.0146	1.0146
22	1.0327	1.0327	1.0327
23	1.0284	1.0284	1.0284
24	1.0302	1.0302	1.0302
25	1.0333	1.0333	1.0333
26	0.9646	0.9540	0.9534

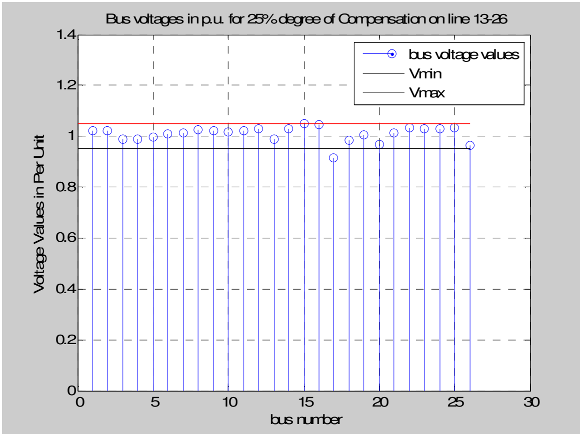

Figure 2a: Bus Voltage at 25% degree of compensation between buses 13 and 26

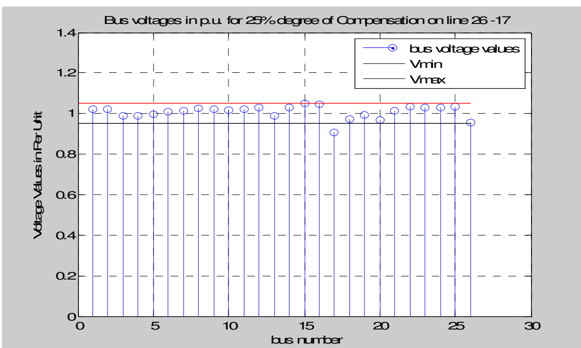

Figure 2b: Bus Voltage at 25% degree of compensation between buses 26 and 17

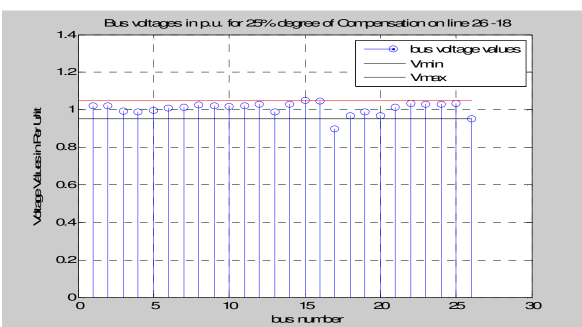

Figure 2c: Bus Voltage at 25% degree of compensation between buses 26 and 18

Table 11 Bus Voltages in (PU) for 60% Degree of Compensation for Different Positions of the Series Compensator

	Position of Series Compensator (B/w buses)		
Bus no	13 and 26	26 and 17	26 and 18
1	1.0200	1.0200	1.0200
2	1.0200	1.0200	1.0200
3	0.9890	0.9906	0.9906
4	0.9890	0.9906	0.9906
5	0.9943	0.9961	0.9961
6	1.0033	1.0098	1.0098
7	1.0103	1.0119	1.0120
8	1.0247	1.0268	1.0268
9	1.0107	1.0207	1.0207
10	1.0140	1.0174	1.0174
11	1.0134	1.0200	1.0200
12	1.0291	1.0291	1.0291
13	1.0091	0.9891	0.9891
14	1.0305	1.0300	1.0300
15	1.0500	1.0500	1.0500
16	1.0457	1.0457	1.0457
17	0.9499	0.9134	0.9016
18	1.0227	0.9749	0.9658
19	1.0449	0.9938	0.9840
20	0.9892	0.9678	0.9678
21	1.0146	1.0146	1.0146
22	1.0327	1.0327	1.0327
23	1.0263	1.0284	1.0284
24	1.0300	1.0302	1.0302
25	1.0333	1.0333	1.0333
26	0.9951	0.9555	0.9543

Table 12 Bus Voltages at Different Degrees of Compensation with Serial Compensator Permanently Inserted Between Buses 13 and 26

	Degrees of Compensation (%)					
Bus no.	65	70	72	73	74	75
1	1.0200	1.0200	1.0200	1.0200	1.0200	1.0200
2	1.0200	1.0200	1.0200	1.0200	1.0200	1.0200
3	0.9890	0.9890	0.9890	0.9889	0.9905	0.9905
4	0.9889	0.9889	0.9889	0.9888	0.9905	0.9905
5	0.9943	0.9943	0.9943	0.9940	0.9958	0.9958
6	1.0033	1.0033	1.0033	1.0033	1.0097	1.0097
7	1.0103	1.0103	1.0103	1.0099	1.0117	1.0117
8	1.0247	1.0247	1.0247	1.0247	1.0268	1.0268
9	1.0107	1.0107	1.0107	1.0107	1.0207	1.0207
10	1.0140	1.0140	1.0140	1.0140	1.0174	1.0174
11	1.0134	1.0134	1.0134	1.0133	1.0200	1.0200
12	1.0291	1.0291	1.0291	1.0291	1.0291	1.0291
13	1.0091	1.0091	1.0091	1.0191	1.0191	1.0191
14	1.0305	1.0305	1.0305	1.0299	1.0300	1.0300
15	1.0500	1.0500	1.0500	1.0400	1.0400	1.0400
16	1.0457	1.0457	1.0457	1.0341	1.0341	1.0341
17	0.9508	0.9515	0.9518	0.9635	0.9636	0.9637
18	1.0235	1.0243	1.0246	1.0365	1.0366	1.0367
19	1.0458	1.0466	1.0469	1.0596	1.0598	1.0598
20	0.9892	0.9892	0.9892	0.9998	0.9998	0.9998
21	1.0146	1.0146	1.0146	1.0146	1.0146	1.0146
22	1.0327	1.0327	1.0327	1.0327	1.0327	1.0327
23	1.0263	1.0263	1.0263	1.0263	1.0284	1.0284

24	1.0300	1.0300	1.0300	1.0300	1.0302	1.0302
25	1.0333	1.0333	1.0333	1.0333	1.0333	1.0333
26	0.9958	0.9964	0.9967	1.0066	1.0067	1.0068

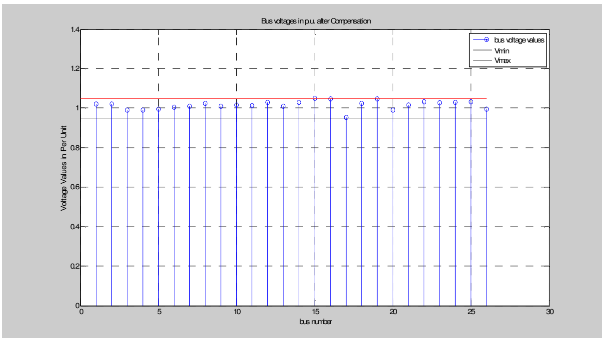

Figure 3: Voltage Profile of Our Model Network after Compensation

There is a problem of under voltage at bus 17

0.97025 + j 0.0036695 9.0965 + j 73.747

ABCD = -1.4803e-06 + j 0.0007948 0.97025 + j 0.0036695

Series capacitor compensation

Required Series Capacitor (3-phase): 53.0975 ohm, 49.9568 micro F, 13.062 Mvar

Table 13 Losses at various degrees of compensation (Compensator Inserted Permanently Between buses 13 and 26)

Degree of compensation in %	Capacitive Reactance, X_c, per phase in Ohms	Capacitance (µF)	Equivalent MVAR	Total system real power loss (MW)
0	None	0	0	241.583
25	6.1455	47.9587	1.5118	240.321
60	14.7493	19.9827	3.6283	239.769
65	15.9784	18.4456	3.9307	239.734
70	17.2075	17.1280	4.2331	239.703
72	17.6992	16.6523	4.3540	239.692
73	17.9450	16.4242	4.4145	239.073
74	18.2417	16.2022	4.4750	237.446
75	18.4366	15.9862	4.5354	237.443

IV. RECOMMENDATION AND CONCLUSIONS

Recommendation

I thereby recommend that the Nigeria power system should adopt this program as a tool to solving power system problem and also effort should be made to use the program for proper planning sitting, seizing and placement of compensators along the transmission line for more better output and reduces loss which in turn translates to monetary value.

Further study

It would be necessary if effort is made toward researching on shunt compensation of an admittance matrix for online application as another angle to completely eradicate inefficiency in power system network.

Knowledge added

This project was able to contribute its quota on area of minimizing losses and being able to simulate a computer program that will be able to identify optimal positions for capacitor compensations and best percentage of compensators with optimal results since we compensate both sides.

Conclusion

However, I want to conclude by saying that a minimal loss of 237.443mw was recorded as against uncompensated initial loss of 241.583mw as at the day of data collection which if multiplied over a period of year is a gross loss of energy and revenue to the power sector and to the country at large. Which otherwise would have been realized by a simulated model to enhance stability, loadability and steady state of power system network.

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