DYNAMIC COMPENSATION OF REACTIVE POWER IN 330KV TRANSMISSION LINE USING STATIC VAR COMPENSATOR (SVC)

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Abstract

Reactive power and voltage control constitute part of major challenges in power system industry. The growing demand for power increases while the expansion of power generation and transmission is severely limited due to lean economic resources and environmental forces. These give cause for concern as they contribute to constant power failure and outage in Nigerian power system. In this paper, the Nigerian 330KV, 30-bus system network is considered and to eradicate some of these problems mentioned, compensation in power system becomes very essential. First, Newton-Raphson's solution method was employed to carry out the analysis because of its sparsity, fast convergence and simplicity attributes compared to other solution methods. Using the relevant data, MATLAB/SIMULINK software was used to carry out the simulation analysis. The result obtained showed that the bus voltages outside the statutory limit of $0.95 \le vi \le 1.05$ pu were buses 14 (Jos) with value of 0.9359pu, bus 17 (Gombe) 0.9175pu, bus 19 (Maiduguri) 0.9106pu, bus 22 (Kano) 0.8849pu, bus 28 (Berni-Kebbi) -0.734pu, bus 3 (Okpai) 1.090pu and bus 29 (Kaduna) 0.9880pu, while bus 30 (Makurdi) gave the value 0.8247pu under normal uncompensated conditions. The Static Var Compensator (SVC), a FACTS controller, shunt device was then selected, modeled and implemented on these buses and the results shown in fig. 5.8 indicated that although, SVC is a good compensator, it needs a supplementary controller e.g. fuzzy, P.I.D etc for a perfection.

Keywords: Reactive power and voltage, Nigerian 330KV system, Newton-Raphson's solution method, compensation, SVC, problem buse

1.0 Introduction

The Nigerian power network, like many practical system in developing countries, consists of a few generating stations mostly sited in remote locations near the raw fuel sources which are usually connected to the load centres by long transmission lines[1]. Generation, Transmission, Distribution and marketing of electricity in Nigeria are the statutory functions of the National Electric Power Authority (NEPA), now known as (GENCO-TRANSYSCO-DISCO).

Presently, the national electricity grid or the 330KV network consists of nine (9) generating stations, comprising three (3) hydro and six (6) thermal with a total installed generating capacity of 6500MW [1]. The thermal stations are mainly in the southern part of the country located at Afam, Okpai, Delta (Ughelli), Egbin and Sapele. The Hydro electric power stations are in the country's middle belt and are located at Kainji, Jebba, and Shiroro[2]. The transmission network shown in fig. 1.1 is made up of 5000km of 330KV lines, 6000Km of 132KV lines which include: New-Haven to Oji River, New-Haven to Nkalagu, New-Haven to Abakaliki, New-Haven to Otukpo/Yandev for Enugu sub-region; others are: 23km of 330/132KV sub-station and 91km of 132/33KV sub-stations. The distribution sector is comprised of 23,735km of 33KV lines, 19,226km of 11KV lines and 679km of 33/11KV substations. There are also 1,790 distribution transformers and 680 injection substations[1].

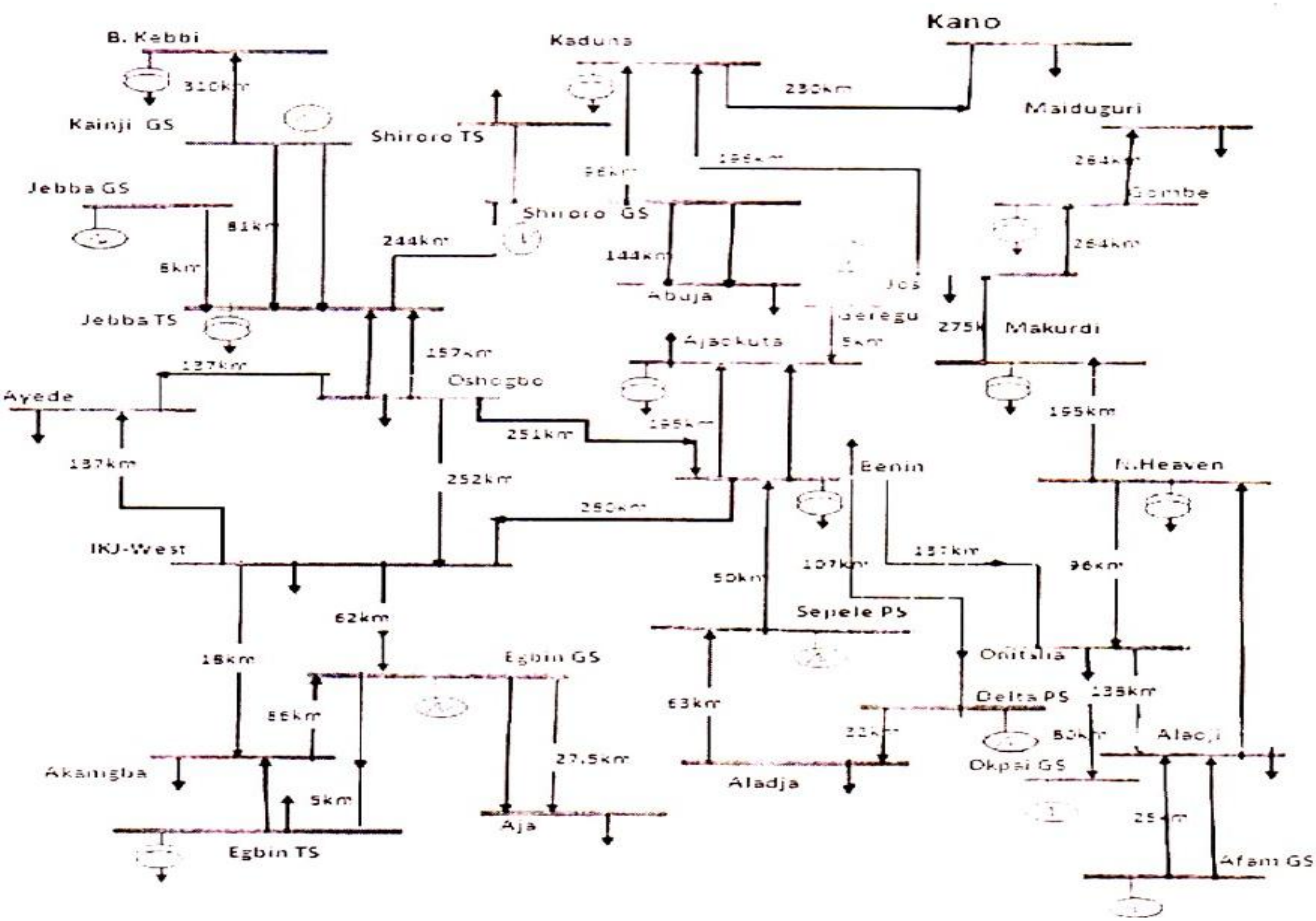

Figure 1.1: Line Diagram of Nigeria 330KV 30 Bus Interconnected Network.

1.1 What Informed This Research

Although the installed capacity of the existing power stations is 6500MW, the maximum load ever recorded was 4,000MW. Presently, most of the generating units have broken down due to limited available resources to carryout the needed maintenance. The transmission lines are radial and overloaded. The switch gears are obsolete while power transformers have not been maintained for a long time.

Again, the present installed generating capacity is about 6500MW and maximum generation of 4000MW for a population of about 160 million. This indeed is grossly inadequate to meet the demand of electricity consumers[3]. The current projected capacity that needs to be injected into the system is estimated at 10,000MW which is hoped to come in through the Independent Power Producers (IPPS), as soon as deregulation of electricity supply industry is successfully achieved[3].

And finally massive injection of funds is needed to expand the distribution and transmission networks to adequately transport the power generated to consumers.

The existing generating stations in the country are shown in Table 1 and those under construction are shown in Table 2.

Table 1: Existing Generating Stations in the Country

S/No	Power station name	Location/ State	Status	Capacity (MW)
1.	Egbin Thermal Power Station	Lagos	Operating	1320
2.	Afam Thermal Power Station	Rivers	Operating	969.6
3.	Sapele Thermal Power Station	Delta	Operating	1020
4.	Ijora Thermal Power Station	Lagos	Operating	40
5.	Delta Thermal Power Station	Delta	Operating	912
6.	Kainji Hydro Power Station	Niger	Operating	760
7.	Jebba Hydro Power Station	Niger	Operating	578
8.	Shiroro Hydro Power Station	Niger	Operating	600
9.	AES Thermal Power Station	Lagos	Operating	300
TOTAL CAPACITY =				**6500**

Table 2: Power Stations/Plants under Construction or Expansion.

S/N	Name	State
1.	Eyeon	Edo
2.	Sapele (under expansion)	Delta
3.	Omoku	Rivers
4.	Egbema	Rivers
5.	GbaranUbic	Beyelsa
6.	Onne	Rivers
Proposed Hydro Power Plant		
1.	Dadinkowa	Gombe
Proposed Biomass Power Plant		
1.	Ikeja	Lagos

2.0 DATA COLLECTION FROM TRANSMISSION COMPANY OF NIGERIA (TCN)

The bus and line data were obtained from TCN based on 2008 – 2010 daily operational reports of GENCO – TRANSYSCO-DISCO, National Control Centre (NCC) Oshogbo. Access to these data online was very difficulty, Kudoes to TCN for timely intervention and assistance. The raw data as obtained from TCN are displayed in Tables 3 and 4.

Table 3: Bus Data for 330KV lines.

S/No	Bus Name	Generation		Load		V	Angle	Remark
		P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	Volts	Degree	
1	Egbin-Gs (slack)	0.00	0.00	0.00	0.00	1.020	0.00	PV Bus
2	Delta – Ps	0.00	0.00	4.00	-10.00	1.000	0.00	PV Bus
3	Okpai – Ps	300.00	40.00	0.00	0.00	1.040	0.00	PV Bus
4	SAP/PS	0.00	0.00	140.00	30.00	1.000	0.00	PV Bus
5	Afam – Gs	0.00	0.00	90.00	30.00	1.000	0.00	PV Bus
6	Jebba – Gs	20.00	0.00	160.00	70.00	1.040	0.00	PV Bus
7	Kainji – Gs	400.00	60.00	0.00	0.00	1.000	0.00	PV Bus
8	Shiroro – Ps	0.00	0.00	150.00	70.00	1.000	0.00	PV Bus
9	Geregu (Ps)	0.00	0.00	300.00	90.00	1.000	0.00	PV Bus
10	Oshogbo	0.00	0.00	120.370	61.650	1.020	0.00	Load Bus
11	Benin	150.00	50.00	160.560	82.240	1.000	0.00	Load Bus
12	Ikeja-West	0.00	0.00	334.00	171.110	1.000	0.00	Load Bus
13	Ayede	0.00	0.00	176.650	90.490	1.000	0.00	Load Bus
14	Jos	0.00	0.00	82.230	42.129	1.000	0.00	Load Bus
15	Onitsha	0.00	0.00	130.510	66.860	1.000	0.00	Load Bus
16	Akangba	0.00	0.00	233.379	119.560	1.000	0.00	Load Bus
17	Gombe	0.00	0.00	74.480	38.140	1.000	0.00	Load Bus
18	Abuja (Katampe)	280.00	45.00	200.00	102.440	1.030	0.00	Load Bus
19	Maiduguri	0.00	0.00	10.00	5.110	1.000	0.00	Load Bus
20	EgbinTs	0.00	0.00	0.00	0.00	1.000	0.00	Load Bus
21	Aladja	240.00	55.00	47.997	24.589	1.020	0.00	Load Bus
22	Kano	700.00	68.00	252.450	129.330	1.050	0.00	Load Bus
23	Aja	0.00	0.00	119.990	61.477	1.000	0.00	Load Bus
24	Ajokuta	180.00	0.00	63.220	32.380	1.040	0.00	Load Bus
25	New Haven	0.00	0.00	113.050	57.910	1.000	0.00	Load Bus
26	Alaoji	190.00	-35.00	163.950	83.90	1.010	0.00	Load Bus
27	Jebba – Ts	150.00	51.00	7.440	3.790	1.030	0.00	Load Bus
28	Benin – kebbi	130.00	80.00	69.990	35.850	1.020	0.00	Load Bus
29	Kaduna	0.00	0.00	149.77	76.720	1.000	0.00	Load Bus
30	Makurdi	0.00	0.00	73.070	37.430	1.000	0.00	Load Bus

Source: TCN National Control Centre Oshogbo Daily Operational Report, 2008 – 2010.

Table 4: Transmission line Data for 330KV Lines

16.0000	12.0000	0.0006	0.0051	0.0650	1.0000
12.0000	1.0000	0.0022	0.0172	0.2570	1.0000
12.0000	11.0000	0.0101	0.0799	1.1620	1.0000
12.0000	13.0000	0.0049	0.0416	0.5210	1.0000
13.0000	10.0000	0.0041	0.0349	0.4370	1.0000
10.0000	11.0000	0.0089	0.0763	0.9540	1.0000
10.0000	27.0000	0.0056	0.4770	0.5970	1.0000
12.0000	6.0000	0.0056	0.4770	0.5970	1.0000
27.0000	8.0000	0.0087	0.0742	0.9270	1.0000
27.0000	7.0000	0.0022	0.0246	0.3080	1.0000
7.0000	28.0000	0.0111	0.9420	1.1780	1.0000
8.0000	29.0000	0.0034	0.0292	0.3640	1.0000
29.0000	22.0000	0.0082	0.0899	0.8740	1.0000
14.0000	17.0000	0.0095	0.0810	1.0100	1.0000
11.0000	24.0000	0.0070	0.0560	0.7450	1.0000
11.0000	4.0000	0.0018	0.0139	0.2080	1.0000
11.0000	15.0000	0.0049	0.0416	0.5210	1.0000
15.0000	25.0000	0.0034	0.0292	0.0355	1.0000
15.0000	26.0000	0.0049	0.0419	0.5240	1.0000
26.0000	5.0000	0.0090	0.0070	0.1040	1.0000
4.0000	21.0000	0.0023	0.0190	0.2390	1.0000
2.0000	21.0000	0.0011	0.0088	0.1710	1.0000
1.0000	23.0000	0.0022	0.0172	0.2570	1.0000
29.0000	14.0000	0.0070	0.0599	0.7480	1.0000
14.0000	30.0000	0.0029	0.0246	0	1.0000
10.0000	12.0000	0.0049	0.0341	0.5210	1.0000
11.0000	2.0000	0.0022	0.0190	0.2390	1.0000
15.0000	3.0000	0.0090	0.0070	1.0400	1.0000
8.0000	18.0000	0.0025	0.0195	0.1040	1.0000
9.0000	24.0000	0.0022	0.0172	0.2570	1.0000
19.0000	17.0000	0.0049	0.0416	0.5210	1.0000
20.0000	23.0000	0.0022	0.0172	0.2570	1.0000
27.0000	26.0000	0.0087	0.0742	0.9270	1.0000

```
>> lfybus
>> lfnewton
>> busout
```

3.0 DATA ANALYSIS, PREPARATION AND KEYING INTO COMPUTER

(a) BUS DATA FILE OR BUS DATA

The rest of this work was done by using a computer. The format for the bus entry was chosen so that the data required for each bus would be en...d in a single row in computer[4]. In the bus data or matrix, column 1 is the bus number. Column 2 is the bus code, column 3 and 4 are voltage magnitudes in p.u and phase angles in degrees. Column 5 and 6 are loads in MW and Mvar, column 7 through 10 are MW, Mvar, MinMvar and maxMvar of generation. The last column is the injected reactive power (Mvar) of shunt capacitor or reactor. Then for the bus code entered in column 2 [4]:

- 1 represents the slack bus
- 2 represents the voltage controlled bus, while
- 0 represents the load bus

Next, the bus data or matrix required for each bus were keyed in a square bracket row by row, of course, separating each row with a semi-colon and entered in MATLAB prompt or workspace (see table 5 and the output results).

Table 5:Keyed Bus Data or Matrix and Output

```
warning: Could not get change notification handle for local d:\.
Performance degradation may occur due to on-disk directory change checking.

  To get started, select "MATLAB Help" from the Help menu.

>> clear %clears all variable from workspace
>> basemva=100; accuracy=0.001; accel=1.8; maxiter=100;
>> busdata=[1 1 1.02 0 0 0 0 0 0 0 0;2 2 1 0 4 -10 0 0 0 0 0;3 2 1.04 0 0 0 300 40 0
110 0;4 2 1 0 140 30 0 0 0 0 0;5 2 1 0 90 30 0 0 0 0 0; 6 2 1.04 0 160 70 20 0 0 0
0;7 2 1 0 0 0 400 60 0 0 0;8 2 1 0 150 70 0 0 0 140 0;9 2 1 0 300 90 0 0 0 0 0;10 0
1.02 0 120.37 61.65 0 0 0 0 19;11 0 1 0 160.56 82.24 150 50 0 114 0;12 0 1 0 334
171.11 0 0 0 0 0;13 0 1 0 176.65 90.49 0 0 0 0 0;14 0 1 0 82.23 42.129 0 0 0 0 0;15
0 1 0 130.51 66.86 0 0 0 0 0;16 0 1 0 233.379 119.56 0 0 0 0 0;17 0 1 0 74.48 38.14
0 0 0 0 0;18 0 1.03 0 200 102.44 280 45 0 100 0;19 0 1 0 10 5.11 0 0 0 0 0;20 0 1 0
0 0 0 0 0 0;21 0 1.02 0 47.997 24.589 240 55 0 104 0;22 0 1.05 0 252.45 129.330
700 68 0 108 0;23 0 1 0 119.99 61.477 0 0 0 0 0;24 0 1.04 0 63.22 32.38 180 0 0 132
4.3;25 0 1 0 113.05 57.91 0 0 0 0 0;26 0 1.01 0 163.95 83.9 190 -35 0 126 0;27 0
1.03 0 7.44 3.790 150 51 0 100 0;28 0 1.02 0 69.99 35.85 130 80 0 150 0;29 0 1 0
149.77 76.72 0 0 0 0 0;30 0 1 0 73.07 37.43 0 0 0 0 0]

busdata =

    1.0000    1.0000    1.0200         0         0         0         0         0
         0         0         0
    2.0000    2.0000    1.0000         0    4.0000  -10.0000         0         0
         0         0         0
    3.0000    2.0000    1.0400         0         0         0  300.0000   40.0000
         0  110.0000         0
    4.0000    2.0000    1.0000         0  140.0000   30.0000         0         0
         0         0         0
    5.0000    2.0000    1.0000         0   90.0000   30.0000         0         0
         0         0         0
    6.0000    2.0000    1.0400         0  160.0000   70.0000   20.0000         0
         0         0         0
    7.0000    2.0000    1.0000         0         0         0  400.0000   60.0000
         0         0         0
    8.0000    2.0000    1.0000         0  150.0000   70.0000         0         0
         0  140.0000         0
    9.0000    2.0000    1.0000         0  300.0000   90.0000         0         0
         0         0         0
   10.0000         0    1.0200         0  120.3700   61.6500         0         0
         0         0   19.0000
   11.0000         0    1.0000         0  160.5600   82.2400  150.0000   50.0000
         0  114.0000         0
   12.0000         0    1.0000         0  334.0000  171.1100         0         0
         0         0         0
   13.0000         0    1.0000         0  176.6500   90.4900         0         0
         0         0         0
   14.0000         0    1.0000         0   82.2300   42.1290         0         0
         0         0         0
   15.0000         0    1.0000         0  130.5100   66.8600         0         0
         0         0         0
   16.0000         0    1.0000         0  233.3790  119.5600         0         0
         0         0         0
   17.0000         0    1.0000         0   74.4800   38.1400         0         0
         0         0         0
   18.0000         0    1.0300         0  200.0000  102.4400  280.0000   45.0000
         0  100.0000         0
   19.0000         0    1.0000         0   10.0000    5.1100         0         0
         0         0         0
   20.0000         0    1.0000         0         0         0         0         0
         0         0         0
   21.0000         0    1.0200         0   47.9970   24.5890  240.0000   55.0000
         0  104.0000         0
   22.0000         0    1.0500         0  252.4500  129.3300  700.0000   68.0000
         0  108.0000         0
   23.0000         0    1.0000         0  119.9900   61.4770         0         0
         0         0         0
   24.0000         0    1.0400         0   63.2200   32.3800  180.0000         0
         0  132.0000    4.3000
   25.0000         0    1.0000         0  113.0500   57.9100         0         0
         0         0         0
   26.0000         0    1.0100         0  163.9500   83.9000  190.0000  -35.0000
         0  126.0000         0
   27.0000         0    1.0300         0    7.4400    3.7900  150.0000   51.0000
         0  100.0000         0
   28.0000         0    1.0200         0   69.9900   35.8500  130.0000   80.0000
         0  150.0000         0
   29.0000         0    1.0000         0  149.7700   76.7200         0         0
         0         0         0
   30.0000         0    1.0000         0   73.0700   37.4300         0         0
         0         0         0
```

(b) LINE DATA FILE OR LINE DATA

Similarly, the line data were prepared, keyed in and 'entered' in MATLAB workspace. The line data were handled by using the line bus numbers, the line resistance R, the line reactance X, one half of the total line charging susceptance y/2 and the transformer tap-settings denoted by (1). The output result of the keyed line data in square bracket is shown in Table 6.

Table 6: Keyed Line Data and Output

```
> %linedata
> linedata=[16 12 0.0006 0.0051 0.065 1;12 1 0.0022 0.0172 0.257 1;12 11 0.0101
.0799 1.162 1;12 13 0.0049 0.0416 0.521 1;13 10 0.0041 0.0349 0.437 1;10 11 0.0089
.0763 0.954 1;10 27 0.0056 0.477 0.597 1;12 6 0.0056 0.477 0.597 1;27 8 0.0087
.0742 0.927 1;27 7 0.0022 0.0246 0.308 1;7 28 0.0111 0.9420 1.178 1;8 29 0.0034
.0292 0.364 1;29 22 0.0082 0.0899 0.874 1;14 17 0.0095 0.0810 1.010 1;11 24 0.0070
.0560 0.745 1;11 4 0.0018 0.0139 0.208 1;11 15 0.0049 0.0416 0.521 1;15 25 0.0034
.0292 0.0355 1;15 26 0.0049 0.0419 0.524 1;26 5 0.009 0.007 0.104 1;4 21 0.0023
.0190 0.239 1;2 21 0.0011 0.0088 0.171 1;1 23 0.0022 0.0172 0.257 1;29 14 0.007
.0599 0.748 1;14 30 0.0029 0.0246 0 1;10 12 0.0049 0.0341 0.521 1;11 2 0.0022 0.019
.239 1;15 3 0.009 0.007 1.04 1;8 18 0.0025 0.0195 0.104 1;9 24 0.0022 0.0172 0.257
;19 17 0.0049 0.0416 0.521 1;20 23 0.0022 0.0172 0.257 1;27 26 0.0087 0.0742 0.927
]

inedata =
```

16.0000	12.0000	0.0006	0.0051	0.0650	1.0000
12.0000	1.0000	0.0022	0.0172	0.2570	1.0000
12.0000	11.0000	0.0101	0.0799	1.1620	1.0000
12.0000	13.0000	0.0049	0.0416	0.5210	1.0000
13.0000	10.0000	0.0041	0.0349	0.4370	1.0000
10.0000	11.0000	0.0089	0.0763	0.9540	1.0000
10.0000	27.0000	0.0056	0.4770	0.5970	1.0000
12.0000	6.0000	0.0056	0.4770	0.5970	1.0000
27.0000	8.0000	0.0087	0.0742	0.9270	1.0000
27.0000	7.0000	0.0022	0.0246	0.3080	1.0000
7.0000	28.0000	0.0111	0.9420	1.1780	1.0000
8.0000	29.0000	0.0034	0.0292	0.3640	1.0000
29.0000	22.0000	0.0082	0.0899	0.8740	1.0000
14.0000	17.0000	0.0095	0.0810	1.0100	1.0000
11.0000	24.0000	0.0070	0.0560	0.7450	1.0000
11.0000	4.0000	0.0018	0.0139	0.2080	1.0000
11.0000	15.0000	0.0049	0.0416	0.5210	1.0000
15.0000	25.0000	0.0034	0.0292	0.0355	1.0000
15.0000	26.0000	0.0049	0.0419	0.5240	1.0000
26.0000	5.0000	0.0090	0.0070	0.1040	1.0000
4.0000	21.0000	0.0023	0.0190	0.2390	1.0000
2.0000	21.0000	0.0011	0.0088	0.1710	1.0000
1.0000	23.0000	0.0022	0.0172	0.2570	1.0000
29.0000	14.0000	0.0070	0.0599	0.7480	1.0000
14.0000	30.0000	0.0029	0.0246	0	1.0000
10.0000	12.0000	0.0049	0.0341	0.5210	1.0000
11.0000	2.0000	0.0022	0.0190	0.2390	1.0000
15.0000	3.0000	0.0090	0.0070	1.0400	1.0000
8.0000	18.0000	0.0025	0.0195	0.1040	1.0000
9.0000	24.0000	0.0022	0.0172	0.2570	1.0000
19.0000	17.0000	0.0049	0.0416	0.5210	1.0000
20.0000	23.0000	0.0022	0.0172	0.2570	1.0000
27.0000	26.0000	0.0087	0.0742	0.9270	1.0000

```
>> lfybus
>> lfnewton
>> busout
```

4.0 LOAD FLOW STUDIES USING NEWTON-RAPHSON'S SOLUTION METHOD

Now, with the output results of the bus and the line data still in MATLAB workspace in the computer, a command program called "lf newton" was employed and 'entered' in MATLAB prompt to obtain the power solution by Newton Raphson's method. Table 7 and 8 are the output results.

Table 7: Power Flow Solution by Newton Raphson's method

Power Flow Solution by Newton-Raphson Method
Maximum Power Mismatch = 7.16159e-006
No. of Iterations = 10

Bus No.	Voltage Mag.	Angle Degree	------Load------ MW	Mvar	---Generation--- MW	Mvar	Injected Mvar
1	1.020	0.000	0.000	0.000	822.324	-128.009	0.000
2	1.000	-1.822	4.000	-10.000	0.000	-276.417	0.000
3	1.090	5.248	0.000	0.000	300.000	-16.914	0.000
4	1.000	-2.731	140.000	30.000	0.000	-249.589	0.000
5	1.000	11.988	90.000	30.000	0.000	-91.000	0.000
6	1.040	-45.880	160.000	70.000	20.000	61.090	0.000
7	1.000	33.326	0.000	0.000	400.000	-201.357	0.000
8	1.050	23.639	150.000	70.000	0.000	-826.764	0.000
9	1.000	-11.322	300.000	90.000	0.000	11.443	0.000
10	1.055	-6.891	120.370	61.650	0.000	0.000	19.000
11	1.031	-2.775	160.560	82.240	150.000	50.000	0.000
12	1.022	-6.724	334.000	171.110	0.000	0.000	0.000
13	1.038	-8.611	176.650	90.490	0.000	0.000	0.000
14	1.618	16.163	82.230	42.129	0.000	0.000	0.000
15	1.058	4.682	130.510	66.860	0.000	0.000	0.000
16	1.015	-7.345	233.379	119.560	0.000	0.000	0.000
17	1.913	13.636	74.480	38.140	0.000	0.000	0.000
18	1.043	24.515	200.000	102.440	280.000	45.000	0.000
19	1.954	13.427	10.000	5.110	0.000	0.000	0.000
20	1.025	-1.192	0.000	0.000	0.000	0.000	0.000
21	1.006	-1.482	47.997	24.589	240.000	55.000	0.000
22	1.329	35.784	252.450	129.330	700.000	68.000	0.000
23	1.020	-1.159	119.990	61.477	0.000	0.000	0.000
24	1.017	-8.479	63.220	32.380	180.000	0.000	4.300
25	1.039	3.058	113.050	57.910	0.000	0.000	0.000
26	1.016	11.782	163.950	83.900	190.000	-35.000	0.000
27	1.048	26.916	7.440	3.790	150.000	51.000	0.000
28	-0.734	704.358	69.990	35.850	130.000	80.000	0.000
29	1.274	22.304	149.770	76.720	0.000	0.000	0.000
30	1.611	15.792	73.070	37.430	0.000	0.000	0.000
Total			3427.106	1603.105	3562.324	-1403.517	23.300

ineflow

Table 8: Line Flow and Losses

Line Flow and Losses

--Line-- from	to	Power at bus & line flow MW	Mvar	MVA	--Line loss-- MW	Mvar
1		822.324	-128.009	832.228		
	12	702.008	-84.789	707.110	10.492	28.465
	23	120.317	-43.219	127.844	0.312	-51.059
2		-4.000	-266.417	266.447		
	21	-74.498	-71.440	103.217	0.094	-33.644
	11	70.498	-194.977	207.331	0.753	-42.804
3		300.000	-16.914	300.476		
	15	300.000	-16.914	300.476	7.679	-234.099
4		-140.000	-279.589	312.682		
	11	-22.909	-241.547	242.631	0.887	-36.067
	21	-117.091	-38.042	123.116	0.320	-45.426
5		-90.000	-121.000	150.801		
	26	-90.000	-121.000	150.801	1.830	-19.709
6		-140.000	-8.910	140.283		
	12	-140.000	-8.910	140.283	1.175	-26.785
7		400.000	-201.357	447.822		
	27	456.882	-241.506	516.784	5.569	-2.377
	28	-56.882	40.150	69.624	3.128	84.300
8		-150.000	-896.764	909.222		
	27	-83.118	-87.673	120.811	0.562	-199.288
	29	12.922	-845.276	845.374	19.997	72.541
	18	-79.804	36.185	87.624	0.196	-21.255
9		-300.000	-78.557	310.115		
	24	-300.000	-78.557	310.115	2.041	-36.318
10		-120.370	-42.650	127.703		
	13	99.197	-6.374	99.402	0.428	-92.122
	11	-96.698	-57.667	112.588	0.936	-199.669
	27	-128.564	-24.203	130.822	0.921	-53.670
	12	5.695	45.594	45.949	0.474	-109.120
11		-10.560	-32.240	33.925		
	12	91.279	-119.789	150.603	0.793	-238.559
	10	97.634	-142.003	172.329	0.936	-199.669
	24	187.588	-67.322	199.302	2.326	-137.642
	4	23.796	205.479	206.853	0.887	-36.067
	15	-341.111	-60.778	346.483	5.364	-68.217
	2	-69.745	152.173	167.395	0.753	-42.804
12		-334.000	-171.110	375.279		
	16	233.771	109.414	258.109	0.392	-10.146
	1	-691.516	113.254	700.728	10.492	28.465
	11	-90.486	-118.770	149.311	0.793	-238.559
	13	78.277	-102.419	128.906	0.396	-107.161
	6	141.175	-17.876	142.302	1.175	-26.785
	10	-5.221	-154.714	154.803	0.474	-109.120
13		-176.650	-90.490	198.478		
	12	-77.881	-4.742	78.025	0.396	-107.161
	10	-98.769	-85.748	130.798	0.428	-92.122
14		-82.230	-42.129	92.394		
	17	98.313	-862.755	868.338	13.349	-520.325
	29	-253.688	782.557	822.650	27.320	-83.358
	30	73.145	38.069	82.459	0.075	0.639
15		-130.510	-66.860	146.639		
	11	346.475	-7.439	346.555	5.364	-68.217
	25	113.545	54.347	125.881	0.495	-3.563
	26	-298.209	103.417	315.632	5.039	-69.686
	3	-292.321	-217.185	364.171	7.679	-234.099

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16		-233.379	-119.560	262.222		
	12	-233.379	-119.560	262.222	0.392	-10.146
17		-74.480	-38.140	83.678		
	14	-84.964	342.430	352.813	13.349	-520.325
	19	10.484	-380.570	380.715	0.484	-385.680
18		80.000	-57.440	98.485		
	8	80.000	-57.440	98.485	0.196	-21.255
19		-10.000	-5.110	11.230		
	17	-10.000	-5.110	11.230	0.484	-385.680
20		0.000	0.000	0.000		
	23	-0.000	-0.000	0.000	0.015	-53.637
21		192.003	30.411	194.396		
	4	117.411	-7.384	117.643	0.320	-45.426
	2	74.592	37.795	83.621	0.094	-33.644
22		447.550	-61.330	451.733		
	29	447.550	-61.330	451.733	9.697	-189.952
23		-119.990	-61.477	134.822		
	1	-120.005	-7.840	120.261	0.312	-51.059
	20	0.015	-53.637	53.637	0.015	-53.637
24		116.780	-28.080	120.109		
	11	-185.261	-70.319	198.158	2.326	-137.642
	9	302.041	42.239	304.981	2.041	-36.318
25		-113.050	-57.910	127.019		
	15	-113.050	-57.910	127.019	0.495	-3.563
26		26.050	-118.900	121.720		
	15	303.248	-173.103	349.176	5.039	-69.686
	5	91.830	101.291	136.721	1.830	-19.709
	27	-369.028	-47.088	372.020	11.680	-97.925
27		142.560	47.210	150.174		
	10	129.485	-29.467	132.795	0.921	-53.670
	8	83.680	-111.615	139.500	0.562	-199.288
	7	-451.313	239.129	510.750	5.569	-2.377
	26	380.708	-50.837	384.087	11.680	-97.925
28		60.010	44.150	74.501		
	7	60.010	44.150	74.501	3.128	84.300
29		-149.770	-76.720	168.277		
	8	7.074	917.817	917.844	19.997	72.541
	22	-437.853	-128.622	456.354	9.697	-189.952
	14	281.009	-865.915	910.371	27.320	-83.358
30		-73.070	-37.430	82.099		
	14	-73.070	-37.430	82.099	0.075	0.639
Total loss					135.219	-2983.320

5.0 Development of the Svc Model

The TCR Block Model

The suitable model for the Thyristor Controlled Reactor (TCR) block is shown in fig. 5.1[5]. It consists of linearising circuit, the firing circuit, and the reactor susceptance block. The block represents the variation of reactor susceptance as a function of the firing circuit and the linearising circuit. The linearising circuit is used to compensate the nonlinear relationship between the reactor susceptance (B_L) and the conduction angle. The limit at the firing circuit represents the limit of the conduction angle which in turn determines the limiting values of B_L. The maximum value of this limit is 1.0 and the minimum value is 0.02 and may be assumed to be zero. T_d is the transport delay and is about 1ms, which is normally neglected, thus making $e^{-sTd} \approx 1.0$. The time constant T_B associated with the thyristor firing sequence control has a value of about 5ms and may be neglected for most studies. Hence, if the nonlinear relationship between δ and B_L is assumed to be perfectly compensated and T_d and T_B neglected, the TCR block may be represented by a unit gain shown in fig. 5.2[5].

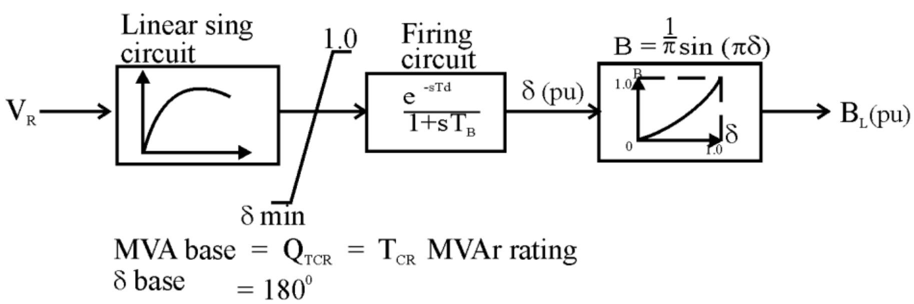

Fig. 5.1: Model of TCR [8]

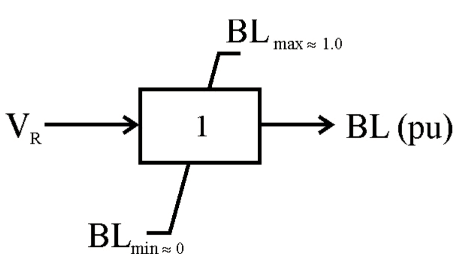

Fig. 5.2: The Resultant Unit Gain

The TSC Block Model

The Thyristor Switched Capacitor (TSC) model block with the parameters expressed in per unit MVA rating and KV rating of the TSC as base values is shown in fig. 5.3.

From the block diagram [5]:

T_c is the time constant associated with the thyristor firing sequence control.

N_T is the total number of individually switched capacitor bank unit, assumed to be equal sizes.

N_c is the total number of units switched at any point in time.

V_c attempts to maintain V_2 within a narrow band with the control action coordinated with TCR.

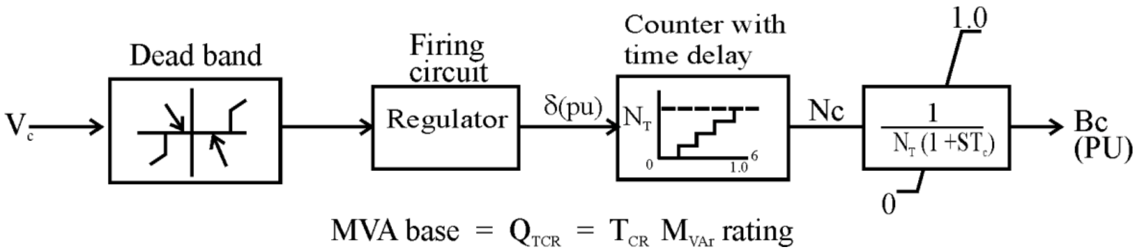

Fig. 5.3: Model of TSC [5]

Combined TCR and TSC Representation

Now, the two models and their respective MVA_r ratings can be combined as shown in fig. 5.4

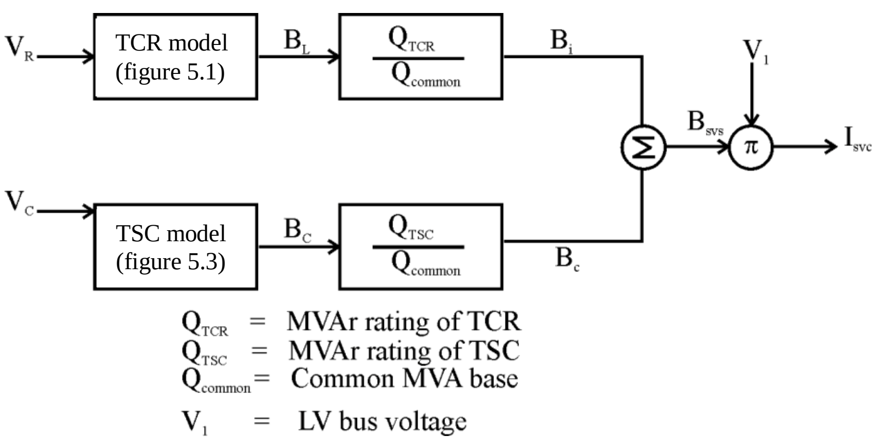

Fig. 5.4: Combined TCR, TSC Representation

The susceptances B_L and B_c are converted to common per unit system. Also, the net susceptance B_{SVC} and the total current I_{SVC} are expressed in common per unit system. The net susceptance B_{SVC} is inductive if positive, and capacitive if negative. The current is also positive if inductive.

It should be noted that for most studies, it is not necessary to represent a TSC explicitly as shown in fig. 5.3 The TSC response may be assumed to be instantaneous, and therefore, the SVC is represented by TCR and a Fixed Capacitor (FC) with the MVA rating selected. Fig. 5.6 is the simplified model of SVC (TCR + FC) [5].

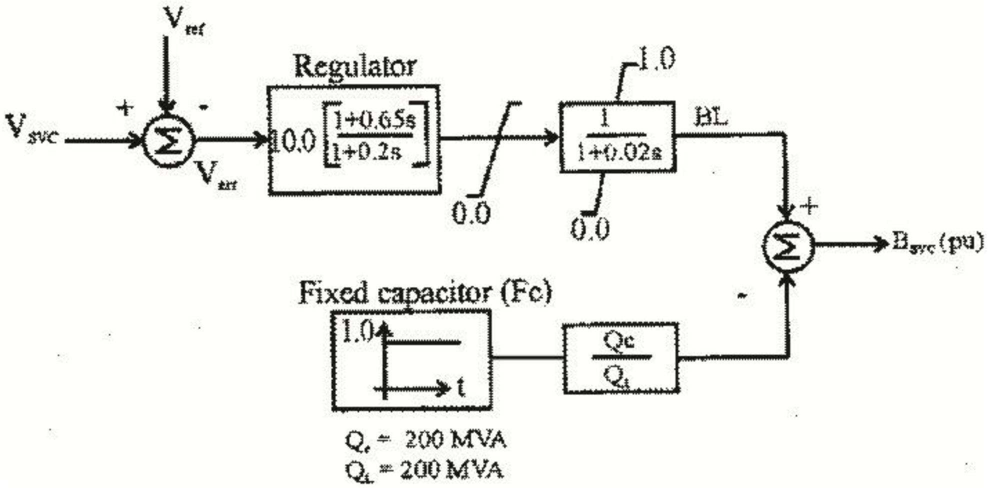

Fig. 5.5: Block diagram of TCR + FC with MVA rating selected (SVC and voltage regulator)[5].

SVC Data: (World academy of S & T, 52, 2009).

Typical Values

$K_{SVC} = 10.0$, $T_1 = 0.65$, $T_2 = 0.2$, $T_3 = 0.02$.

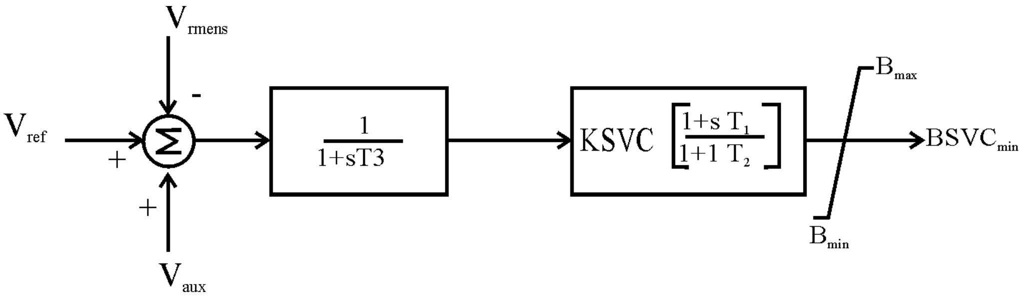

Fig. 5.6: Simplified Model of SVC (TCR and FC)

5.1 MATLAB/SIMULINK MODEL FOR THE IMPLEMENTATION OF SVC ON THE PROBLEM BUSES

The simplified model of the SVC (i.e. TCR + FC) was then implemented on the problem buses identified after the analysis, and simulated in MATLAB/SIMULINK environment. The result shown in fig. 5.8 indicates that, although there was a compensation on these problem buses, SVC still needs a supplementary controller like fuzzy, neural network or P.I.D for a perfection

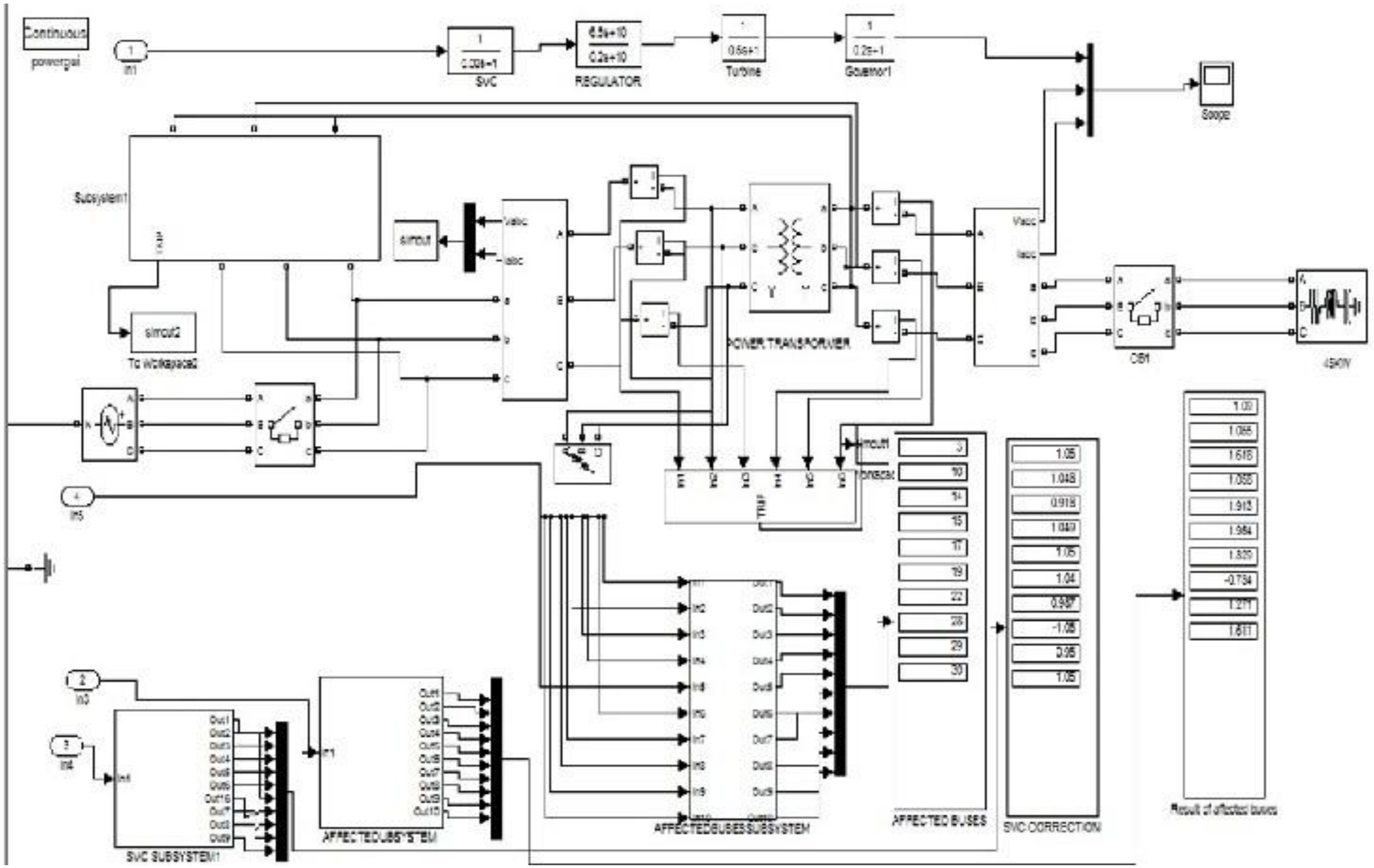

Fig. 5.7: MATLAB/SIMULINK Model of the SVC on the Problem Buses

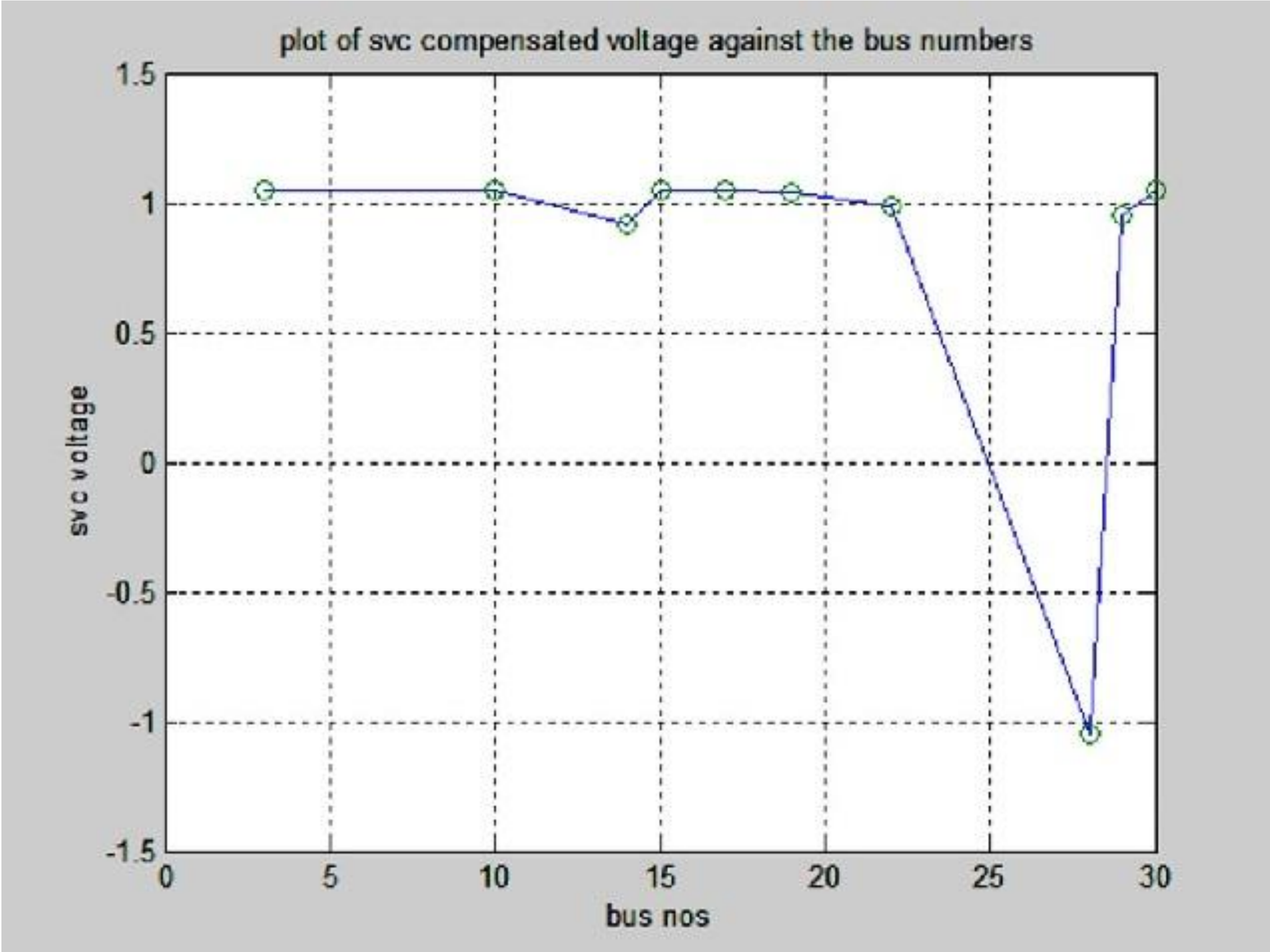

Fig. 5.8: The Plotted Graph of the Results shown in the SVC Scope

Analysis Results

From the results and the plotted curve, it is clear from the analysis result that some of these problem buses are not fully under the statutory limit of 0.95 ≤Vi≤ 1.05p.u after compensation, as stipulated by IEEE. These buses includes:- bus 14 (Jos), bus 19 (Maiduguri) and bus 28 (Berni-Kebbi). This shows that although there was a compensation, SVC still needs a supplementary controller like fuzzy, neural network or Proportional Integral Derivative (PID) for a perfection.

Conclusion

The SVC, a shunt FACTS device, is a good dynamic compensator but works more perfectly with supplementary controllers like fuzzy, neural network or P.I.D.

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