AN ENHANCED INTELLIGENT FACTS DEVICE FOR REDUCTION OF LOSSES ON POWER LINES

ABSTRACT

In this research, an enhanced intelligent FACTS device for reduction of losses on power lines using intelligent Static Synchronous Series Compensator **(**SSSC) devices for Nigerian 330kv network has been presented. The result showed the total real power losses of 127.9131 before compensation emanating from the network, the transmission lines constitute about 125.7MW and the generating stations gave 2.2131MW. After compensation using Static Synchronous Series Compensator **(**SSCS), the total Real power losses were reduces to 104.53MW, while the total Reactive losses (MVar) reduced to 26.87MVar. The research concludes that the injection of reactive power by Static Synchronous Series Compensator **(**SSCS) devices compensates for the drop in voltage, leading to improvement in voltage and reduces power losses for the network.

Keywords: SSSC, Losses, 330kv network, FACTS, Voltage

1.0 INTRODUCTION

Electricity demand has increased drastically due to growing population and industrialization in developing countries and therefore it has become important to operate power plant that deliver energy to transmission and distribution lines at maximum efficiency. The present situation of losses in the power sectors in Nigeria is worrisome. No matter how carefully the system is designed, losses are present. These losses, due to discrepancy between energy produced and energy sold to end users, are wasteful energy dissipated in the system and cannot be accounted for [1]. This loss comprises technical and non-technical; technical losses consist of naturally occurring losses associated with the heat dissipation in electricity system components such as transmission and distribution lines, transformers, and measurement systems while non-technical losses on the other hand, are generally associated with electricity theft arising from commercial, administrative, and non-payment losses. All these losses translate to high operating costs as well as huge revenue losses to utilities and consequently they result in high cost of electricity. Since system loss represents a considerable cost for utilities, customers and host country, its evaluation and reduction have been recognized as a unique area of interest by researchers [2]. Moreover, literature reveals different methods of loss estimation but the existing approaches focus mainly on theoretical calculation and probabilistic data that are based on simple model data, insufficient to give a correct evaluation assessment of losses. Hence, there is still a clear gap between practical information and the theoretical one which tends to be poor and not precise and the reduction of system losses is analyzed on the accuracy of the technical losses.

Fundamentally, this research work will evaluate the technical losses associated with the existing 52 bus test system.

The basic problem is the computation of the actual power loss in transferring power across a line in a transmission network. In order to evaluate the peak technical losses, the 52 transmission network will be simulated under various aspect of unbalanced faults to examine the resulting bus voltages and line currents that can further be used to evaluate actual power losses, predict the electrical behaviour of the system and proffer solutions for reducing the losses in order to enhance the transmission line efficiency.

This research intend to dwell on the use SSCS, one of the FACTS devices in regulating the voltage to bring out most effective voltage that will enhance electric power transmission which the 330kv network of Nigeria is used as a case study. The compensation will be done with Flexible Alternating current transmission system (FACTS) devices. The term Flexible Alternating Current Transmission System (FACTS) devices describes a wide range of high voltage, large power electronic converters that can increase the flexibility of power systems to enhance AC system controllability, stability and increase power transfer capability [3].

FACTS devices stabilize transmission systems with increased transfer capability and reduced risk of line trips. Other benefits attributed to FACTS devices are additional energy sales due to increased transmission capability, reduced wheeling charges due to increased transmission capability and due to delay in investment of high voltage transmission lines or even new power generation facilities. These devices stabilize transmission systems with increased transfer capability and reduced risk of line trips [4].

2.0 BENEFITS OF UTILIZING FACTS DEVICES

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows: they lead to increased loading capacity of transmission lines, prevention of blackouts, boosting generation productivity, reduce circulating reactive power, improvement of system stability limit, reduction of voltage flickers, damping of power system oscillations, guaranteeing system stability, security, availability, reliability and system economic operation [5].

2.1 STATIC SYNCHRONOUS SERIES COMPENSATOR (SSSC)

SSSC is a solid-state Voltage Sourced Converter (VSC) based device, which generates a controllable AC voltage, and connected in series to power transmission lines in a power system. SSSC virtually compensates transmission line impedance by injecting controllable voltage (*VS*) in series with the transmission line. *VS* are in quadrature with the line current, and emulate an inductive or a capacitive reactance so as to influence the power flow in the transmission lines [6]. The variation of *VS* is performed by means of a VSC connected on the secondary side of a coupling transformer. A capacitor connected on the DC side of the VSC acts as a DC voltage source. To keep the capacitor charged and to provide transformer and VSC losses, a small active power is drawn from the line. VSC uses IGBT-based inverters. This type of inverter uses PWM technique to synthesize a sinusoidal waveform from a DC voltage with a typical chopping frequency of a few kilohertz. Harmonics are cancelled by connecting filters at the AC side of the VSC. This type of VSC uses a fixed DC voltage. Converter voltage *VC* is varied by changing the modulation index of the PWM modulator [7]. The controllable parameter is the magnitude of the series voltage source *VS*. This voltage source is regulated by the damper [8]. This controller is used for constant power flow for the line.

3.0 MATERIALS AND METHOD

3.1 Algorithm of N-R Method

The steps for solving power flow problem by the N-R method are given below:
For the load buses where P and Q are given, we assume the bus voltage magnitude and phase angle for all the buses except the slack bus where V and 8 are specified. Normally we have the flat voltage start, *i.e.,* we set the assumed bus voltage magnitude and its phase angle *(i.e.,* the real and imaginary components *e* and /of the bus voltages) equal to the slack bus quantities.
Substituting this assumed bus voltages *(i.e., e* and *f*), we calculate the real and reactive components of power, *i.e.,* P_i and Q_i for all the buses i = 2, 3, 4, ..., n except the slack bus (bus no. 1).
Since $P_t$and Q_i for any bus i is given, *i.e.*, specified, the error in power will be
$\Delta P_i^r = P_{ispecified} - P_i^r$ ……………………….(1)
$\Delta Q_i^r = Q_{ispecified} - Q_i^r$
where r is an iteration count.
Here P_i^r and Q_i^r are the power calculated with the latest value of bus voltages at any iteration *r*.
Then the elements of Jacobian matrix (J_1, J_2, J_3 and J_4) are determined with the latest bus voltages and calculated power equations.
After this the linear set of equation (1) is solved by iterative technique or by the method of elimination (normally by Gaussian elimination method) to determine the voltage correction, *i.e.*, $\Delta e_i$and Δf_i at any bus *i*.
This value of voltage correction is used to determine the new estimate of bus voltages as follows:
$e_i^{r+1} = e_i^r + \Delta e_i^r$……………………….(2)
$f_i^{r+1} = f_i^r + \Delta f_i^r$
where *r* is an iteration count.
Now this new estimate of the bus voltage, *i.e.* $e_i^{r+1}$and $f_i^{r+1}$is for power to re-compute the error in power and thus entire algorithm starting from step 3 as listed above is repeated.
Here in each iteration, the elements of Jacobian are computed as these depend upon the latest voltage estimate and calculated power. The process is continued till the error in power becomes very small.
i.e., $\Delta P < \varepsilon$and $\Delta Q < \varepsilon$ ………....(3)
where $\varepsilon$is very small number.

3.2: 52 Bus test system.

Load flow analysis is carried out in 52 bus test system. Output Voltage magnitude and Voltage Angle values from Newton Raphson method for 52 bus system is shown in Table 1 Appendix1. All values are in per unit and angle is given in radian. Figure 1 shows one-line diagram of the improved 52-bus 330kV Nigerian transmission network.

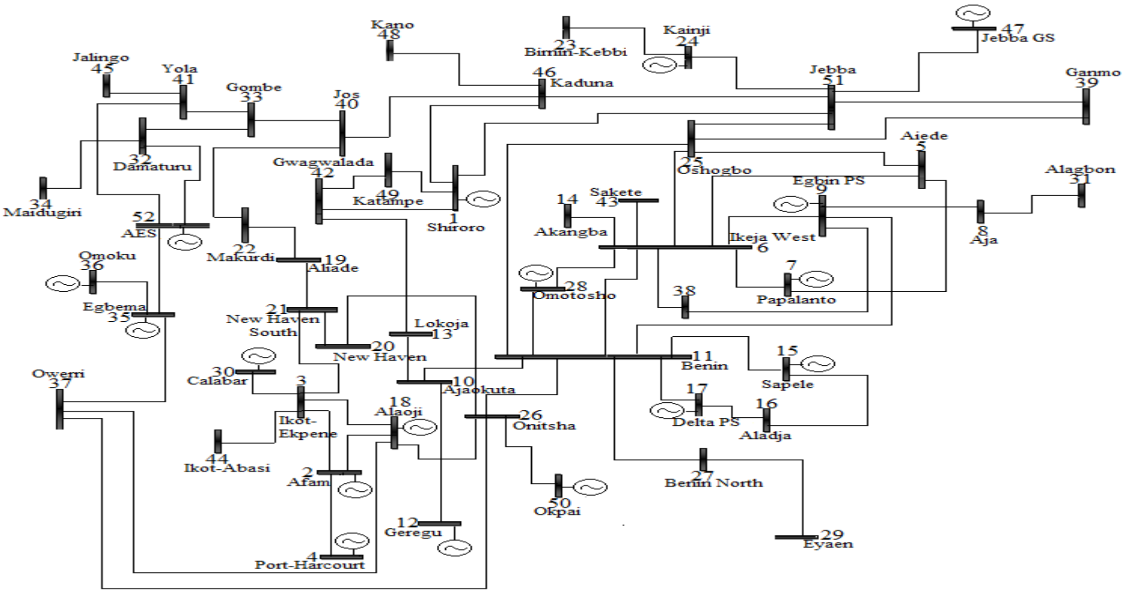

Fig.1: One-line diagram of the improved 52-bus 330kV Nigerian transmission network

3.3 Load flow Input Data

The input data for the power flow analysis include load flow data showing load and generation at the buses. Figure 2 shows the Flowchart for Power Flow Solution by Newton-Raphson.

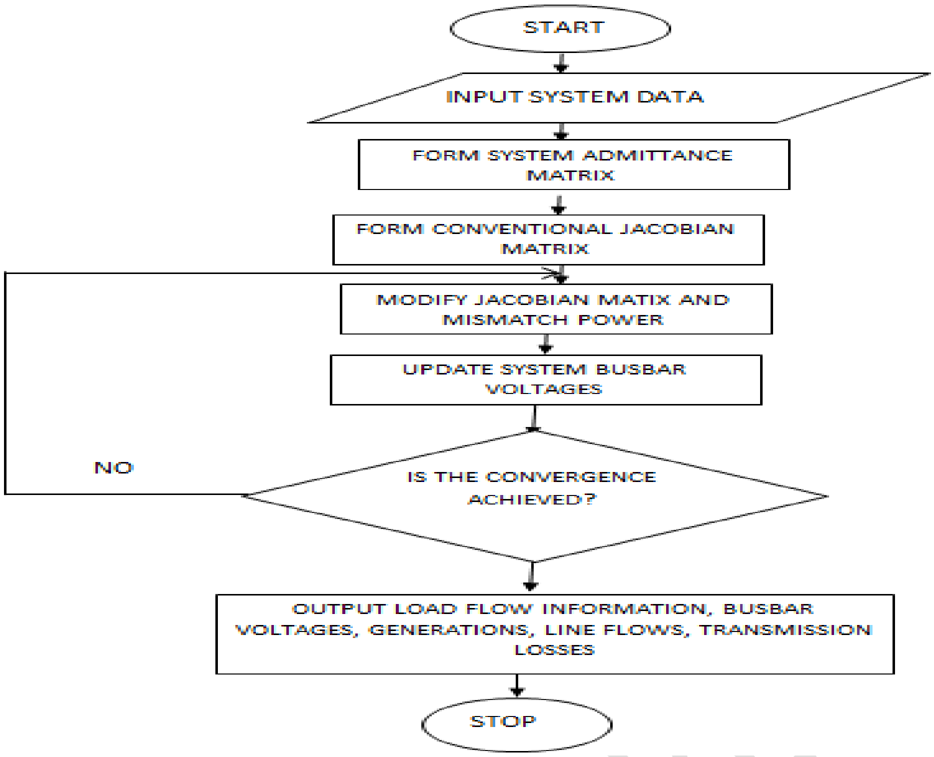

Fig.2: Flowchart for Power Flow Solution by Newton-Raphson.

4.0 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Result of load flow with and without FACTS

The first procedure was to run computation of the case study program in software. Then, the simulation was done with and without incorporation of FACT devices.

Table 2 in Appendix 2 shows the Line flow and Losses before compensating with FACTS devices

The active power loss for the voltage without SSSC is shown in Figure 3.

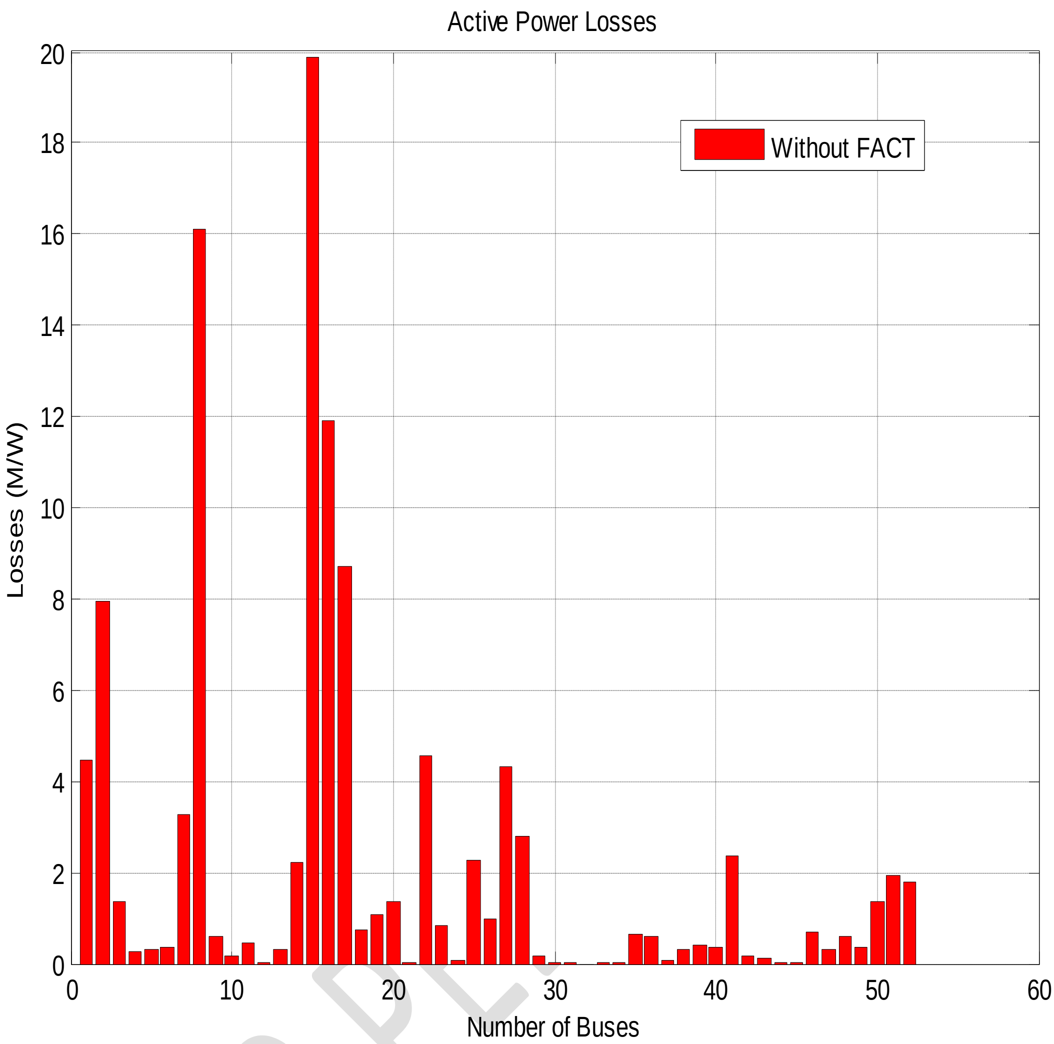

Fig. 3: The active power loss for the voltage without SSSC

Table 3 in Appendix 3 shows the Line flow and Losses after compensating with FACTS devices.

The active power loss for the voltage with SSCS is shown in Figure 4.

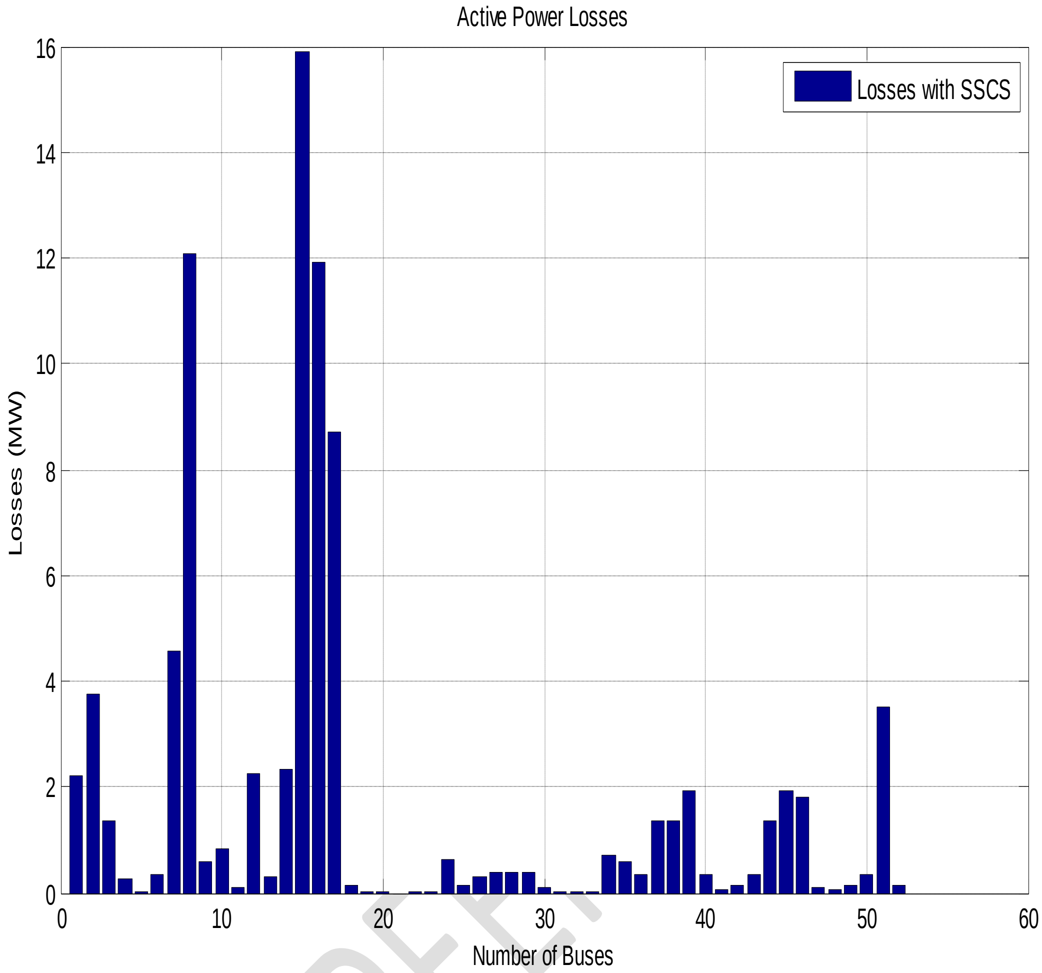

Fig. 4: The active power loss for the voltage with SSCS.

4.2 Discussion

The obtained results based on the test case (Nigeria 330 kv integrated power system) showed that there was obvious improvement in voltage profile and improvement in power transfer in the network.

The result shown that of the total real power losses of 127.9131 before compensation emanating from the network, the transmission lines constitute about 125.7MW and the generating stations gave 2.2131MW. Also, of the total reactive power losses of 62.2924MVar generated in the network, the transmission lines constitute 30.75MVar, and the generating stations constitute 31.5424MVar.

After compensation using SSSC, the total Real power losses were reduces to 104.53MW, while the total Reactive losses (MVar) reduce to 26.87MVar.

5.0 CONCLUSION

The voltage instability in Nigerian grid is a serious operational problem facing electricity supply utility. The Nigeria 330KV integrated network has a relatively low voltage drop in the transmission. Though, there was an obvious improvement over the existing case, some buses and generators of high reactive power values need to be compensated using either the conventional compensators such as reactors, capacitor banks, and tap changing transformers or the use of FACTS devices.

In this research, the an enhanced intelligent facts device for reduction of losses on power lines using intelligent Static Synchronous Series Compensator **(**SSCS) devices for Nigerian 330kv network has been presented.

The injection of reactive power by SSSC device compensates for the drop in voltage on weak buses, leading to improvement on voltage magnitudes of buses and reduction in the total active and reactive power losses for the network.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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List of Appendices

Appendix1

Table 1: Bus voltages and angles of the integrated 52 network using N-R algorithm

Bus Number	Bus Name	PU Voltages	Angles (degrees)
1	Shiroro	1.040	-36.32
2	Afam	1.036	-24.45
3	Ikot-Ekpene	1.040	-18.23
4	Port-Harcourt	1.023	-13.34
5	Aiyede	1.036	-15.23
6	Ikeja west	1.002	-23.41
7	Papalanto	1.041	-16.23
8	Aja	1.022	-23.42
9	Egbin PS	1.038	-33.45
10	Ajaokuta	0.989	-9.15
11	Benin	1.030	-11.32
12	Geregu	1.042	-10.24
13	Lokoja	1.025	-14.32
14	Akangba	1.019	21.23
15	Sapele	1.027	-21.12
16	Aladja	1.001	-14.23
17	Delta PS	1.047	-11.34
18	Alaoji	1.037	-9.39
19	Aliade	1.039	-23.43
20	New Haven	1.055	-13.58
21	New Haven South	0.965	-19.31
22	Makurdi	0.912	-16.62
23	B-kebbi	0.988	9.46
24	Kainji	1.014	-11.45
25	Oshogbo	1.046	-18.34
26	Onitsha	1.022	-29.23
27	Benin North	1.043	-23.16
28	Omotosho	1.052	-18.23
29	Eyaen	1.024	-9.34
30	Calabar	1.036	-7.34
31	Alagbon	0.995	-10.56
32	Damaturu	0.924	-12.32
33	Gombe	0.941	-22.15
34	Maiduguri	0.943	-6.34
35	Egbema	1.033	-12.10
36	Omoku	1.045	-26.21
37	Owerri	1.023	-6.21
38	Erunkan	0.982	-14.23
39	Ganmo	0.984	-23.03
40	Jos	0.937	-10.41
41	Yola	0.921	-16.21
42	Gwagwalada	0.998	-23.21
43	Sakete	0.986	-9.45
44	Ikot-Abasi	1.024	-11.45

45	Jalingo	0.922	-6.11
46	Kaduna	0.992	-10.23
47	Jebba GS	1.023	-11.22
48	Kano	0.994	-11.25
49	Katampe	1.001	-9.28
50	Okpai	1.034	-23.15
51	Jebba	1.045	-17.37
52	AES	1.023	-32.11

Appendix 2

Table 2: Line flow and Losses before compensation

From bus	To Bus	From Bus P	Inje-ction Q	To Bus P	Inje-ction Q	Loss P (MW)	Loss Q (MW)
49	1	102.0	75	-100	-84.1	1.31	4.44
14	6	97.77	-4.64	-94.9	4.46	2.79	7.97
2	18	60.21	-8.18	-59.7	5.89	0.42	1.38
2	3	13.80	-4.43	-13.6	2.24	0.13	0.28
2	4	14.16	-5.09	-14.0	2.08	0.09	0.33
16	15	-17.8	-1.71	17.8	-0.62	0.06	0.34
5	25	-42.5	-6.56	43.1	5.22	0.64	3.29
5	6	178	19.8	-174	-9.12	3.15	16.1
5	7	17.17	-9.23	-17.0	5.58	0.13	0.60
8	9	12.90	2.07	-12.8	-3.99	0.04	0.16
8	31	2.55	-15.8	-2.45	8.64	0.10	0.47
10	11	2.32	-1.9	-2.31	-1.93	0.03	0.01
10	12	-10.3	22.3	10.4	-23.1	0.87	0.29
10	13	-48.8	4.89	49.5	-4.91	0.68	2.20
16	17	148.9	33.7	-145	-23.9	3.90	19.9
18	26	79.25	-0.87	-76.6	7.08	2.63	11.9
18	3	93.34	3.94	-91.4	1.77	1.92	8.73
18	37	33.77	-18.1	-33.5	13.6	0.23	0.75
19	21	13.96	2.44	-13.9	-1.35	0	1.09
19	22	17.87	1.19	-17.8	0.18	0	1.37
23	24	0.67	-6.24	-0.66	5.07	0.01	0.02
11	6	-77.9	-12.1	78.8	15.0	0.89	4.56
11	15	-17.6	-20.0	17.7	17.6	0.18	0.85
11	17	-9.93	-4.39	9.95	2.68	0.02	0.09
11	25	-0.49	60.3	1.18	-64.0	0.69	2.27
11	26	-33.4	8.82	33.6	-10.0	0.21	0.96
11	27	-48.4	9.17	49.4	-9.77	0.95	4.32
11	9	-68.8	-9.60	69.7	10.9	0.87	2.80
11	28	4.63	1.39	-4.53	-1.23	0.10	0.16
27	29	1.23	0.63	-1.22	-0.62	0.06	0.01
30	3	1.08	0.39	-1.08	-0.38	0	0.01
32	33	-1.08	-0.39	1.08	0.40	0.01	0
32	34	9.65	3.11	-9.64	-3.10	0.01	0.02
35	37	3.34	1.00	-3.32	-1.81	0.02	0.03
35	36	7.07	1.71	-7.07	-1.09	0	0.63
9	6	6.79	1.65	-6.79	-1.05	0	0.60
10	38	-10.5	-1.55	10.5	1.61	-0	0.06
38	6	-10.5	-1.61	10.7	1.93	0.20	0.31
39	25	-20.0	-2.43	20.3	2.83	0.26	0.40
39	51	-24.9	-5.13	25.1	5.51	0.27	0.38
33	40	60.09	13.3	-60.0	-10.6	0.00	2.36
44	41	7.56	4.63	-7.45	-4.46	0.11	0.16
42	49	3.85	2.66	-3.77	-2.55	0.07	0.12

42	13	-2.03	-0.35	2.05	0.39	0.02	0.04
42	1	3.81	1.91	-3.80	-1.90	0.08	0.01
6	5	7.46	3.79	-7.46	-3.10	0	0.70
6	28	-7.46	-3.79	7.50	3.55	0.03	0.32
6	7	-13.5	-6.55	13.6	6.53	0.10	0.59
6	43	-17.1	-10.6	17.1	10.7	0.12	0.35
44	3	-21.0	-13.7	21.4	14.1	0.42	1.36
3	21	3.86	2.93	-3.85	-2.9	0.06	1.93
45	41	3.46	4.01	-3.46	-4.07	0.09	1.79
51	25	-10.7	-3.51	10.7	3.54	0.02	0.10
51	47	9.19	3.53	-9.19	-2.83	0	0.06
51	24	8.88	3.27	-8.69	-2.95	0.18	0.13
51	1	-11.5	-2.95	11.5	3.55	0	0.35
40	46	-24.4	5.23	24.5	-5.08	0.17	1.36
40	22	37.33	-0.73	-37.3	2.09	0	1.93
46	1	47.89	27.4	-47.8	-25.4	0	1.79
46	48	47.89	25.4	-47.2	-24.0	0.60	0.10
20	26	17.59	12.4	-17.5	-12.3	0.79	0.06
20	21	0.08	-7.38	-0.04	6.93	0.40	0.13
50	26	9.96	4.43	-9.58	-4.30	0.84	0.35
26	37	-11.4	-6.20	11.6	6.56	0.22	0.66
49	1	29.6	12.5	-29.6	-11.8	0	3.50
14	6	32.4	33.8	-32.4	-30.3	0	0.60
2	18	17.9	2.55	-17.4	-1.95	0.46	0.16
2	3	12.55	-0.25	-12.1	0.41	0.12	0.16
2	4	13.59	4.85	-13.5	-4.55	0	0.31
16	15	-36.5	3.28	37.3	-2.09	0.81	1.62
5	25	3.46	4.07	-3.46	-3.74	0	0.33
5	6	3.85	2.92	-3.85	-2.61	0	0.31
5	7	-2.85	0.61	2.86	-0.58	0.02	0.02
8	9	-4.66	-10.5	4.80	10.4	0.14	0.22
8	31	-17.2	-19.3	17.4	19.7	0.20	0.32
10	11	18.93	10.3	-18.9	-9.86	0	0.52
Total						30.75	125.7

Appendix 3

Table 3: The line flow and losses of 52 bus system using SSCS

From bus	To Bus	From Bus P	Inje-ction Q	To Bus P	Inje-ction Q	Loss P (MW)	Loss Q (MW)
1	2	102.0	75	-100	-84.1	1.11	2.42
2	3	97.77	-4.64	-94.9	4.46	1.66	3.77
3	4	60.21	-8.18	-59.7	5.89	0.42	0.38
4	5	13.80	-4.43	-13.6	2.24	0.13	0.24
4	6	14.16	-5.09	-14.0	2.08	0.09	0.33
6	7	-17.8	-1.71	17.8	-0.62	0.06	0.34
6	8	-42.5	-6.56	43.1	5.22	0.64	3.29
8	9	178	19.8	-174	-9.12	2.18	12.1
9	10	17.17	-9.23	-17.0	5.58	0.13	0.60
9	11	12.90	2.07	-12.8	-3.99	0.04	0.16
9	12	2.55	-15.8	-2.45	8.64	0.10	0.47
9	13	2.32	-1.9	-2.31	-1.93	0.03	0.01

13	14	-10.3	22.3	10.4	-23.1	0.87	0.29
13	15	-48.8	4.89	49.5	-4.91	0.68	2.20
1	15	148.9	33.7	-145	-23.9	3.20	15.9
1	16	79.25	-0.87	-76.6	7.08	2.63	11.9
1	17	93.34	3.94	-91.4	1.77	1.92	8.73
3	15	33.77	-18.1	-33.5	13.6	0.23	0.75
4	18	13.96	2.44	-13.9	-1.35	0	1.09
4	18	17.87	1.19	-17.8	0.18	0	1.37
5	6	0.67	-6.24	-0.66	5.07	0.01	0.02
7	8	-77.9	-12.1	78.8	15.0	0.89	4.56
10	12	-17.6	-20.0	17.7	17.6	0.18	0.85
11	13	-9.93	-4.39	9.95	2.68	0.02	0.09
12	13	-0.49	60.3	1.18	-64.0	0.69	2.27
12	16	-33.4	8.82	33.6	-10.0	0.21	0.96
12	17	-48.4	9.17	49.4	-9.77	0.95	1.32
14	15	-68.8	-9.60	69.7	10.9	0.87	2.80
18	19	4.63	1.39	-4.53	-1.23	0.10	0.16
19	20	1.23	0.63	-1.22	-0.62	0.06	0.01
21	20	1.08	0.39	-1.08	-0.38	0	0.01
21	22	-1.08	-0.39	1.08	0.40	0.01	0
22	23	9.65	3.11	-9.64	-3.10	0.01	0.02
23	24	3.34	1.00	-3.32	-1.81	0.02	0.03
24	25	7.07	1.71	-7.07	-1.09	0	0.63
24	25	6.79	1.65	-6.79	-1.05	0	0.60
24	26	-10.5	-1.55	10.5	1.61	-0	0.06
26	27	-10.5	-1.61	10.7	1.93	0.20	0.31
27	28	-20.0	-2.43	20.3	2.83	0.26	0.40
28	29	-24.9	-5.13	25.1	5.51	0.27	0.38
7	29	60.09	13.3	-60.0	-10.6	0.00	2.36
25	30	7.56	4.63	-7.45	-4.46	0.11	0.16
30	31	3.85	2.66	-3.77	-2.55	0.07	0.12
31	32	-2.03	-0.35	2.05	0.39	0.02	0.04
32	33	3.81	1.91	-3.80	-1.90	0.08	0.01
34	32	7.46	3.79	-7.46	-3.10	0	0.70
34	35	-7.46	-3.79	7.50	3.55	0.03	0.32
35	36	-13.5	-6.55	13.6	6.53	0.10	0.59
36	37	-17.1	-10.6	17.1	10.7	0.12	0.35
37	38	-21.0	-13.7	21.4	14.1	0.42	1.16
37	39	3.86	2.93	-3.85	-2.9	0.06	1.63
36	40	3.46	4.01	-3.46	-4.07	0.09	1.79
22	38	-10.7	-3.51	10.7	3.54	0.02	0.10
11	41	9.19	3.53	-9.19	-2.83	0	0.06
41	42	8.88	3.27	-8.69	-2.95	0.18	0.13
41	43	-11.5	-2.95	11.5	3.55	0	0.35
38	44	-24.4	5.23	24.5	-5.08	0.17	1.36
15	45	37.33	-0.73	-37.3	2.09	0	1.93
14	46	47.89	27.4	-47.8	-25.4	0	1.79
46	47	47.89	25.4	-47.2	-24.0	0.40	0.10
47	48	17.59	12.4	-17.5	-12.3	0.79	0.06
48	49	0.08	-7.38	-0.04	6.93	0.40	0.13
49	50	9.96	4.43	-9.58	-4.30	0.84	0.35
50	51	-11.4	-6.20	11.6	6.56	0.22	0.66
10	51	29.6	12.5	-29.6	-11.8	0	2.10
13	42	32.4	33.8	-32.4	-30.3	0	0.60
29	52	17.9	2.55	-17.4	-1.95	0.46	0.16
52	52	12.55	-0.25	-12.1	0.41	0.12	0.16
51	51	-7.57	-4.47	7.72	4.66	0.15	0.19
51	50	-11.8	-6.06	12.1	6.46	0.30	0.40

11	43	13.59	4.85	-13.5	-4.55	0	0.31
44	45	-36.5	3.28	37.3	-2.09	0.31	0.62
40	50	3.46	4.07	-3.46	-3.74	0	0.33
39	43	3.85	2.92	-3.85	-2.61	0	0.31
38	49	-4.66	-10.5	4.80	10.4	0.14	0.22
38	48	-17.2	-19.3	17.4	19.7	0.20	0.32
9	50	18.93	10.3	-18.9	-9.86	0	0.52
Total						**26.87**	**104.53**