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Characterization of Facts Device for Optimal Mitigation of Technical Losses in Transmission Line

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ABSTRACT

The standard voltage operating condition in transmission line ranges from 0.95 to 1.05 in per unit system and the acceptable losses is 5%. Most times, low power quality and frequent power outages in the Nigeria power network are traceable to transmission line voltage violation. This has caused several damages on the power system facilities and incessant load shedding. The transmission line voltage violation may be due to losses resulting from heat effect on parallel conductors, magnetic fields between conductors, and low power factor of the system. These losses are generalized as technical losses. It was observed that there is voltage violation and the losses are not reasonable, leading to burning of power facilities, low power quality, frequent outages, incessant load shedding and it is traceable to technical losses. Hence, Thyristor Controlled Series Compensator (TCSC) was adopted to mitigate the technical losses in transmission line in an attempt for the network to behave accordingly. Characterization of transmission line was done by collecting the line data and bus data from National Control Center (NCC). System load flow study was carried out using Newton Raphson method. It was used to investigate the present state of transmission line network, to check if they were within the standard operating condition. Transmission line of 41 bus network was modeled using Power system analysis Tools Box (PSAT). TCSC was model and was integrated into the network using multiple sensitivity method. The simulation was run in three categories in order to reflect the dynamic nature of power system, which include normal condition, high voltage condition and low voltage condition. The result showed that out of 41 buses analyzed, there were voltage violations at 15- buses while total active power loss was 403.8555MW and that of the reactive power loss was 377.2228Mvar. TCSC model developed was integrated into the network of Nigerian 41 bus network using multiple sensitivity method. The result showed that violated voltage reduced from 15 to 6 buses with introduction of TCSC. The line losses reduced from 403.8555MW to 269.458MW. Then, with SVC the violated buses reduce from 15 to 6 while the line loss reduces from 403.8555 to 365.0895. The result showed that TCSC perform better than SVC.

Keywords: Facts Device, Technical, Losses, Transmission Line, Thyristor Controlled Series Compensator

1. Introduction

Demand for stable, available, and affordable power is very high all over the world. Developed countries have achieved a 75% stable, available and affordable power supply (Ademola, 2016). But in Africa, especially in Nigeria, a stable, available, and affordable power supply is a nightmare. Both in developed and underdeveloped, there is one common problem which is technical losses. Technical losses are inevitable in power systems, but the rate of technical losses, operational inefficiencies, voltage drop is high in Nigerias transmission line compared to other parts of the World. To this effect, the idea of this research work was conceived to address and/or minimize technical losses in the Nigerian 330 kV Network line and also to improve voltage drop, reduce line loss and improve operational inefficiency. In an ideal situation, the rates of losses suppose to be 5 percent (Ademola, 2016). But, in the Nigerian context, the rate of technical losses exceeds more than 20 percent. As the technical losses were exceeding the ideal situation, this development affects the efficiency of transmission lines, power quality, and huge economic losses. The discrepancies between the generated power and power received after the transmission was large. The difference was huge and run in billions of naira which is unaccounted for. Therefore, there was the need to minimize the technical losses thereby improving the transmission line efficiency and saving huge economic waste due to technical losses.

Technical losses have caused a lot of problems in the power system, and the economic losses run in billions of naira. This loss has caused the system to collapse. Some of the system collapses were partial while some were total system collapsed. Technical losses constitute at least 50% of problems experienced in the transmission line which resulted in total and partial system collapse experienced in the country (TCN logbook, 2018). This result is very bad for a developing nation like Nigeria. This also constituted low output in industrial production and high cost of goods through alternative power supply because technical losses have marred the availability of power supply from the national grid. From the transmission Company of Nigeria (TCN) station log book (2018) data showed that technical losses were a threat to the national grid which needed to be addressed so that Nigeria will enjoy an efficient and reliable power supply. Many factors led to technical losses in the transmission line. These include resistive reactance, capacitive reactance and, the inductive reactance of the line, low power factor due to phase angle difference, overloading of the power system network, obsolete power equipment, aging of power facilities, etc. The resistive reactance of the line occurred due to I^2R losses. Losses occurred as a result of the heating effect of the conductor. As power travel from transmission centers to the load center, the power was being transported through conductors; hence, power was being lost due to the heating effect of the conductor. This type of loss was called I^2R loss or loss due to the resistance of the line attributed to the opposition of power by the line conductor. This type of loss also occurred due to the resistive load of the consumer as a result of the resistive element of the consumer. This type of loss does contribute a greater percentage of losses when compared to inductive load.

Inductive losses occurred because of the magnetic field created around two or more conductors. As two or more conductors travel in a parallel path, they tend to create a magnetic field and this phenomenon causes a leakage current which was attributed to inductive reactance of the line. Another form of inductive loss was due to industrial consumers that used inductive elements like different kinds of A.C motors, these motors draw huge current which increases the phase angle thereby decreasing the power factor. Inductive loss constitutes a major loss factor in the power system.

The low power factor was another factor that constituted another major loss in the power system. In Nigerias power system, power was generated between 11kV to 16 kV. The generated power was raised to 330 kV and above so that it will travel a long distance. A Step-up transformer was usually used to achieve this goal. Because voltage and current were not in phase unlike in the D.C system, where voltage and current were in phase, losses were minimal. But in the A.C power system, voltage and current were not in phase, losses were huge in the A.C system because of phase angle difference which is traceable to inductive load in the A.C power system network. When the phase angle difference was large, there will be a low power factor which contributes to enormous power loss. But if the phase angle difference was small, the power factor will appreciate and there will be minimal losses in the system. Many researchers have adopted many methods of reducing technical losses and improving the efficiency of transmission which includes the following:

A. **High Voltage Direct Current (HVDC) transmission**: This approach of HVDC line will help overcome the problem of low power factor because voltage and current were in phase but there is no installed HVDC in Nigeria.

B. **Distributed Generation (DG):** This approach of generating and distributing to the final consumers will help to overcome I^2R losses. Because the generating plant is closer to the electricity consumers, the problem of lower power factor, inductive losses, and control of reactive power will be easy because of nearness to the generating station. These approaches mention above was good but converting the system was expensive in building a D.C transmission line, and also technical know-how is another problem. Nigeria as a country is not ripe for that, so, it is not feasible for now. Secondly, the law in Nigeria stated that all generations that were above 10 megawatts should be sent to the national grid, to that effect, distributed generation was out of consideration. A flexible Alternating Current Transmission system(FACTs) will be the best option for mitigation. The next question is which device among the FACTs will be best in reducing the line loss as well as reducing the voltage violations.

FACTS Device

FACTS mean Flexible Alternating Current Transmission System device. It was used to compensate for active power, reactive power, and reduction of line losses thereby stabilizing and improving the efficiency of transmission lines which include the following.

a. Static Var Compensator (SVC)

b. Synchronous Static Compensator (STATCOM)

c. Thyristor Controlled Series Compensator (TCSC)

d. Universal Power Flow Compensator (UPFC)

e. Synchronous Static Series Compensator (SSSC)

Simulink Model of FACTS

Some FACTS device from the FACTS family was selected and simulated. Which include TCSC and SVC. The result of the simulation was shown below.

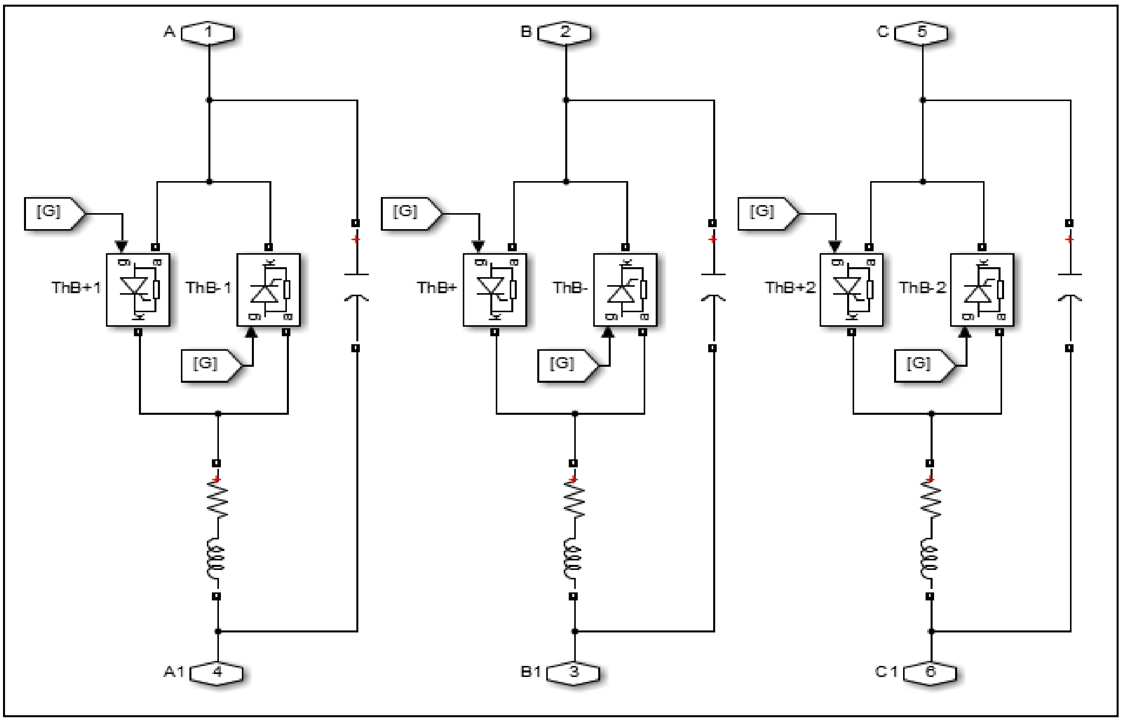

Figure 1: Simulink model of TCSC

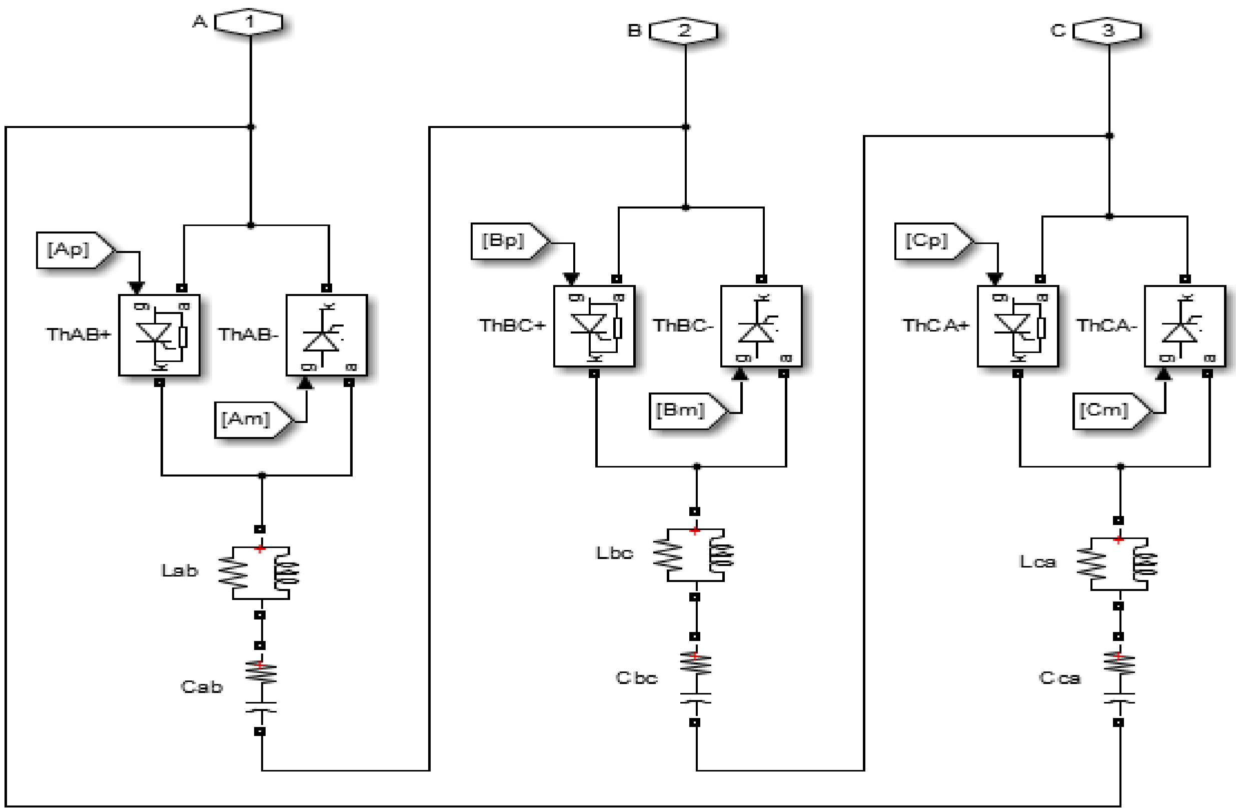

Figure 2: Simulink Model of SVC

Both TCSC and SVC were models from the Simulink library of Matlab software. Line data and bus data gathered from the National control Center were used to model the two facts device.

2. Simulation Results

After the successive model of the two facts device, it was introduced into the 41 bus network, and the result got was presented below.

Table 2.1 Transmission Line Power Flow for the Nigerian 330kV Network Data without Simulation

Bus number	*Bus name*	*Bus peak voltage magnitude*
1	B. Kebbi	305
2	Kainji	330
3	Jebba Ts	338
4	Jebba Gs	340
5	Shiroro	330
6	Osogbo	325
7	Aiyede	313
8	Ikeja West	313
9	Ihovbor	330
10	Ganmo	329
11	Mando	316
12	Katampe	305
13	Gwagwalada	308
14	Olorunsogo	317
15	Akangba	310
16	Egbin	340
17	Omotosho	330

18	Oke- Aro	318
19	Benin	322
20	Kano	303
21	Jos	299
22	Lokoja	311
23	Aja	339
24	Onitsha	321
25	Ajaokuta	316
26	Delta	334
27	Sapele	334
28	Makurdi	287
29	Gombe	291
30	New Haven	290
31	Okpai	334
32	Alaoji	330
33	Geregu	330
34	Aladja	331
35	Ugwuaji	289
36	Yola	286
37	Damaturu	285
38	Afam	331
39	Ikot Ekpene	319
40	Adiabor	325
41	Odukpani	328

Table 2.2 Transmission Line Power Flow for the Nigerian 330kV Network with TCSC

Bus number	*Bus name*	*Bus peak voltage magnitude*
1	B. Kebbi	325
2	Kainji	330
3	Jebba Ts	338
4	Jebba Gs	340
5	Shiroro	330
6	Osogbo	325
7	Aiyede	333
8	Ikeja West	333
9	Ihovbor	330
10	Ganmo	329
11	Mando	316
12	Katampe	325
13	Gwagwalada	328
14	Olorunsogo	317
15	Akangba	330
16	Egbin	340
17	Omotosho	330
18	Oke- Aro	318
19	Benin	322
20	Kano	323
21	Jos	319
22	Lokoja	331
23	Aja	339
24	Onitsha	321
25	Ajaokuta	316
26	Delta	334
27	Sapele	334
28	Makurdi	307
29	Gombe	311

30	New Haven	310
31	Okpai	334
32	Alaoji	330
33	Geregu	330
34	Aladja	331
35	Ugwuaji	309
36	Yola	306
37	Damaturu	305
38	Afam	331
39	Ikot Ekpene	319
40	Adiabor	325
41	Odukpani	328

Table 2.3 Transmission Line Power Flow for the Nigerian 330kV Network with SVC

Bus number	*Bus name*	*Bus peak voltage magnitude*
1	B. Kebbi	325
2	Kainji	330
3	Jebba Ts	338
4	Jebba Gs	340
5	Shiroro	330
6	Osogbo	325
7	Aiyede	333
8	Ikeja West	333
9	Ihovbor	330
10	Ganmo	329
11	Mando	316
12	Katampe	325
13	Gwagwalada	328
14	Olorunsogo	317
15	Akangba	330
16	Egbin	340
17	Omotosho	330
18	Oke- Aro	318
19	Benin	322
20	Kano	323
21	Jos	319
22	Lokoja	331
23	Aja	339
24	Onitsha	321
25	Ajaokuta	316
26	Delta	334
27	Sapele	334
28	Makurdi	307
29	Gombe	311
30	New Haven	310
31	Okpai	334
32	Alaoji	330
33	Geregu	330
34	Aladja	331
35	Ugwuaji	309
36	Yola	306
37	Damaturu	305
38	Afam	331
39	Ikot Ekpene	319
40	Adiabor	325
41	Odukpani	328

Data before simulation

Table 2.4 Line Loss before Simulation

From Bus	*To Bus*	*Line*	*P Loss [MW]*
Bus 2	Bus 3	1	0.997945
Bus 1	Bus 2	2	3.209888
Bus 5	Bus 12	3	1.622021
Bus 6	Bus 10	4	0.454404
Bus 3	Bus 6	5	1.617534
Bus 3	Bus 6	6	1.617534
Bus 8	Bus 6	7	17.02574
Bus 6	Bus 7	8	4.630652
Bus 10	Bus 3	9	1.329835
Bus 8	Bus 14	10	10.76449
Bus 7	Bus 14	11	0.882328
Bus 21	Bus 11	12	2.261907
Bus 8	Bus 15	13	0.511152
Bus 16	Bus 8	14	5.592091
Bus 23	Bus 16	15	0.105701
Bus 16	Bus 19	16	93.43781
Bus 8	Bus 18	17	1.340117
Bus 18	Bus 16	18	5.26163
Bus 8	Bus 17	19	34.84783
Bus 17	Bus 19	20	7.756228
Bus 4	Bus 3	21	0.350375
Bus 25	Bus 19	22	1.819107
Bus 19	Bus 24	23	22.39372
Bus 25	Bus 19	24	1.898271
Bus 33	Bus 25	25	1.951675
Bus 33	Bus 25	26	1.951675
Bus 19	Bus 27	27	10.4995
Bus 27	Bus 26	28	0.446038
Bus 2	Bus 3	29	0.997945
Bus 19	Bus 26	30	6.290402
Bus 24	Bus 30	31	7.390088
Bus 31	Bus 24	32	1.814081
Bus 24	Bus 31	33	1.814081
Bus 24	Bus 32	34	25.60944
Bus 32	Bus 38	35	1.520423
Bus 30	Bus 35	36	0.046144
Bus 25	Bus 22	37	5.010407
Bus 4	Bus 3	38	0.350375
Bus 9	Bus 19	39	0.586411
Bus 34	Bus 27	40	0.099193
Bus 34	Bus 26	41	0.676613
Bus 36	Bus 29	42	0.270384
Bus 11	Bus 20	43	10.50549
Bus 29	Bus 21	44	3.907073
Bus 29	Bus 37	45	0.431505
Bus 13	Bus 22	46	2.838329
Bus 3	Bus 5	47	0.128821
Bus 13	Bus 22	48	2.838329
Bus 5	Bus 13	49	1.5312274
Bus 12	Bus 13	50	0.739204
Bus 35	Bus 28	51	6.965058
Bus 21	Bus 28	52	5.803986

Bus 21	Bus 28	53	5.803986
Bus 35	Bus 28	54	6.965058
Bus 39	Bus 35	55	34.42425
Bus 3	Bus 5	56	0.128821
Bus 39	Bus 40	57	5.009042
Bus 6	Bus 9	58	16.50039
Bus 39	Bus 32	59	1.273186
Bus 39	Bus 38	60	2.396894
Bus 11	Bus 5	61	2.344886
Bus 40	Bus 41	62	1.921889
Bus 11	Bus 5	63	2.344886

Table 2.5 Line Loss with SVC

From Bus	*To Bus*	*Line*	*P Loss [MW]*
Bus 2	Bus 3	1	0.957945
Bus 1	Bus 2	2	3.109888
Bus 5	Bus 12	3	1.322021
Bus 6	Bus 10	4	0.354404
Bus 3	Bus 6	5	1.317534
Bus 3	Bus 6	6	1.417534
Bus 8	Bus 6	7	15.02574
Bus 6	Bus 7	8	4.130652
Bus 10	Bus 3	9	1.229835
Bus 8	Bus 14	10	8.76449
Bus 7	Bus 14	11	0.782328
Bus 21	Bus 11	12	2.161907
Bus 8	Bus 15	13	0.411152
Bus 16	Bus 8	14	5.192091
Bus 23	Bus 16	15	0.101701
Bus 16	Bus 19	16	89.43781
Bus 8	Bus 18	17	1.240117
Bus 18	Bus 16	18	5.16163
Bus 8	Bus 17	19	30.84783
Bus 17	Bus 19	20	7.156228
Bus 4	Bus 3	21	0.250375
Bus 25	Bus 19	22	1.619107
Bus 19	Bus 24	23	20.39372
Bus 25	Bus 19	24	1.598271
Bus 33	Bus 25	25	1.551675
Bus 33	Bus 25	26	1.551675
Bus 19	Bus 27	27	8.4995
Bus 27	Bus 26	28	0.346038
Bus 2	Bus 3	29	0.897945
Bus 19	Bus 26	30	5.290402
Bus 24	Bus 30	31	6.390088
Bus 31	Bus 24	32	1.814081
Bus 24	Bus 31	33	1.514081
Bus 24	Bus 32	34	23.60944
Bus 32	Bus 38	35	1.420423
Bus 30	Bus 35	36	0.044144
Bus 25	Bus 22	37	4.010407
Bus 4	Bus 3	38	0.250375
Bus 9	Bus 19	39	0.486411
Bus 34	Bus 27	40	0.099183
Bus 34	Bus 26	41	0.576613
Bus 36	Bus 29	42	0.170384

Bus 11	Bus 20	43	8.50549
Bus 29	Bus 21	44	3.507073
Bus 29	Bus 37	45	0.331505
Bus 13	Bus 22	46	2.538329
Bus 3	Bus 5	47	0.118821
Bus 13	Bus 22	48	2.538329
Bus 5	Bus 13	49	1.3312274
Bus 12	Bus 13	50	0.539204
Bus 35	Bus 28	51	6.565058
Bus 21	Bus 28	52	5.103986
Bus 21	Bus 28	53	5.103986
Bus 35	Bus 28	54	5.965058
Bus 39	Bus 35	55	32.42425
Bus 3	Bus 5	56	0.118821
Bus 39	Bus 40	57	4.009042
Bus 6	Bus 9	58	14.50039
Bus 39	Bus 32	59	1.173186
Bus 39	Bus 38	60	2.296894
Bus 11	Bus 5	61	2.244886
Bus 40	Bus 41	62	1.521889
Bus 11	Bus 5	63	2.144886

From the result, there is no significant change in loss reduction when SVC was connected to the network.

Table 2.6 Line Loss with TCSC

From Bus	*To Bus*	*Line*	*P Loss [MW]*
Bus 2	Bus 3	1	0.665297
Bus 1	Bus 2	2	2.139925
Bus 5	Bus 12	3	1.081347
Bus 6	Bus 10	4	0.302936
Bus 3	Bus 6	5	1.078356
Bus 3	Bus 6	6	1.078356
Bus 8	Bus 6	7	11.350493
Bus 6	Bus 7	8	3.087101
Bus 10	Bus 3	9	0.886557
Bus 8	Bus 14	10	7.176327
Bus 7	Bus 14	11	0.588219
Bus 21	Bus 11	12	1.507938
Bus 8	Bus 15	13	0.340768
Bus 16	Bus 8	14	3.728061
Bus 23	Bus 16	15	0.070467
Bus 16	Bus 19	16	62.291873
Bus 8	Bus 18	17	0.894113
Bus 18	Bus 16	18	3.728061
Bus 8	Bus 17	19	23.231887
Bus 17	Bus 19	20	5.170819
Bus 4	Bus 3	21	0.233583
Bus 25	Bus 19	22	1.212738
Bus 19	Bus 24	23	14.929147
Bus 25	Bus 19	24	1.265514
Bus 33	Bus 25	25	1.301117
Bus 33	Bus 25	26	1.301117
Bus 19	Bus 27	27	6.999667
Bus 27	Bus 26	28	0.297359
Bus 2	Bus 3	29	0.665297
Bus 19	Bus 26	30	4.193601
Bus 24	Bus 30	31	4.926725

Bus 31	Bus 24	32	1.209387
Bus 24	Bus 31	33	1.209387
Bus 24	Bus 32	34	17.07296
Bus 32	Bus 38	35	1.013615
Bus 30	Bus 35	36	0.0307627
Bus 25	Bus 22	37	3.340271
Bus 4	Bus 3	38	0.233583
Bus 9	Bus 19	39	0.390941
Bus 34	Bus 27	40	0.066129
Bus 34	Bus 26	41	0.451075
Bus 36	Bus 29	42	0.180256
Bus 11	Bus 20	43	7.00366
Bus 29	Bus 21	44	2.604715
Bus 29	Bus 37	45	0.28767
Bus 13	Bus 22	46	1.892219
Bus 3	Bus 5	47	0.085881
Bus 13	Bus 22	48	1.892219
Bus 5	Bus 13	49	1.020849
Bus 12	Bus 13	50	0.492803
Bus 35	Bus 28	51	4.643372
Bus 21	Bus 28	52	3.869324
Bus 21	Bus 28	53	3.869324
Bus 35	Bus 28	54	4.643372
Bus 39	Bus 35	55	22.9495
Bus 3	Bus 5	56	0.085881
Bus 39	Bus 40	57	3.339361
Bus 6	Bus 9	58	11.00026
Bus 39	Bus 32	59	0.848791
Bus 39	Bus 38	60	1.597929
Bus 11	Bus 5	61	1.563257
Bus 40	Bus 41	62	1.281259
Bus 11	Bus 5	63	1.563257

From Table 2.6, the total active line loses when the TCSC was introduced into the network was 269.458MW. Before the TCSC was introduced into the network, the total active line loss was 403.8555MW. In summary, the active line losses were minimized from 403.8555MW to 269.458MW, which was a significant improvement

3. Conclusion

TSCS was validated by comparing TCSC with other FACTS devices, which include Static Var Compensator(SVC). After running load flow analysis, TCSC was introduced into the network using the multiple sensitivity method, thereafter; SVC was introduced into the network. That is placing both TCSC and SVC at bus 37, line 16 and 19. The simulation was run in the PSAT test system of the 41 bus network.

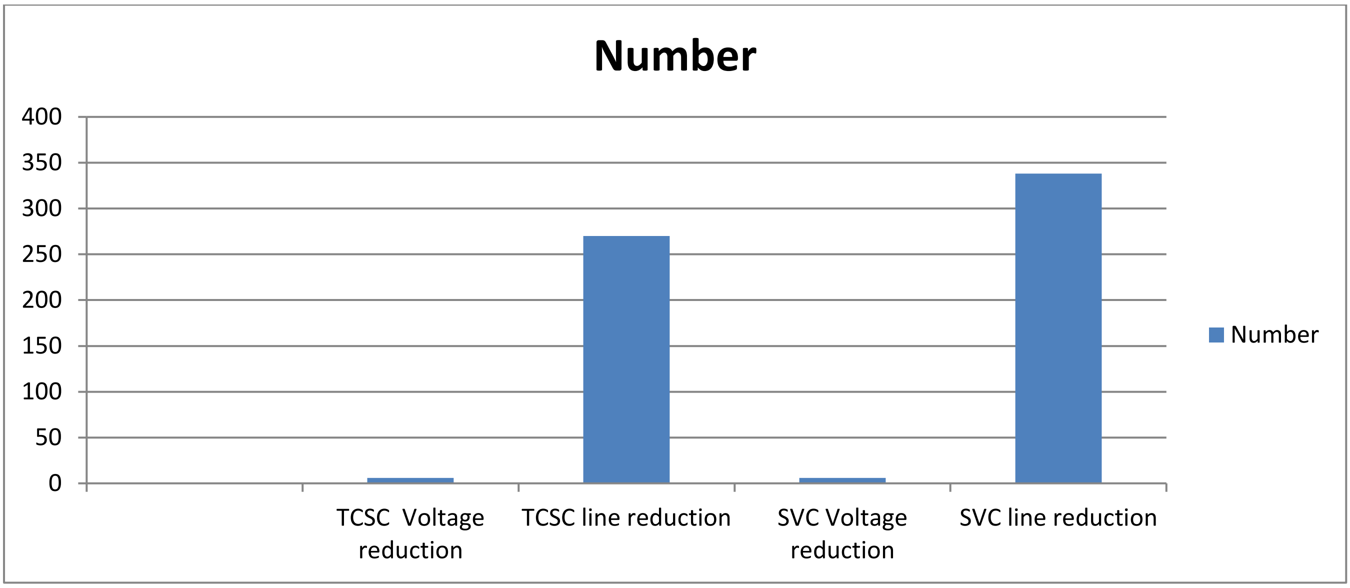

Figure 3: Validation result

The results of voltage violation and line losses showed that, when TCSC was connected to the network, violated buses were reduced from 15 to 6. Then, when SVC was connected to the network, violated buses were reduced from 15 to 6. Secondly, the introduction of TCSC reduced line losses from 403.8555MW to 269.458MW. Then, when SVC was connected to the network, the line losses were reduced from 403.8555MW to 365.0895MW. This result validated that TCSC is better than SVC in improving the efficiency of the line.

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