Power System Compensation by using Thyristor Controlled Series Compensator

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***Abstract*—The power system stability is a big challenge for the power engineers. There is a dire need of a methodology which is used to accelerate the load flow control effectively and to improve the power system reliability in the power transmission network. This paper presents an approach based on the Newton Raphson Model which is implemented on the Thyristor Controlled Series Compensator (TCSC) Controllerto maintain the stability to control the power flow in the transmission line of power system. The unwanted reactive power in the line can be reduced by using TCSC in the line. The methodology can be implemented by varying power system parameters to achieve stability in the line. The paper provides a detailed analysis of power fluctuations by employing the TCSC in the standard IEEE five bus system and thirty bus system in the transmission line of the power system. Finally, it provides the comparison of the performance of TCSC between five bus system and thirty bus system and concludes that the TCSC is more suitable for power system protection than thirty bus system.**

***Index Terms*—Load flow control, Power system protection, Power system reliability, Power system stability, Power transmission.**

I. INTRODUCTION

Power system compensation in transmission line means the use of various techniques in the transmission line of the power system to compensate the losses in the transmission network [1]. The techniques may be the use of FACTS [Flexible AC Transmission System] devices to improve the power in the power system. When large power systems are interconnected to each other by weak tie lines low frequency oscillations are observed. “These oscillations may sustain and grow to cause system separation if no proper system of damping is available” [2]. In the past, researches have been conducted to block these bottlenecks but a little success has been achieved in this field. The recent developments of Power electronics introduced the use of FACTS controllers in power system. The salient feature of FACTS devices is its use to improve the stability of the system [2].TCSC is one of the important members of FACTS family which are applied on the long transmission line. TCSC has role in the operation and control of power system: Scheduled power flow, decreasing unsymmetrical components in the transmission line, reduce net losses, damping power losses, mitigating sub synchronous resonance, enhancing transient stability. The problem of FACTS controller may cause destabilizing interaction. The goal of using TCSC is to make the better utilization of existing system is for FACTS Controller to obtain higher operational efficiency [3]. In this paper analysis is made on IEEE five bus system and thirty bus system and the results are simulated on Matlab. The contribution of the author is the use of TCSC model in two different scenarios of five bus system and thirty bus systems. After simulating the results in two different scenarios a general solution of the problem is presented which is valid for both in five bus system as well as thirty bus system.

Finally, it is proved that active power in the power system may be improved in both cases. But the stability and power degradation are better in five bus system than thirty bus system. The validity of TCSC Model in the less complex power network is more than in the thirty bus system.

II. THYRISTOR CONTROLLED SERIES COMPENSATOR

The Thyristor Controlled Series Compensator is an important compensator of the family of the FACTS devices. It is a variable reactance controlled device which is used to compensate the power loss in the transmission system. The advantage of the TCSC over the other FACTS devices is that its reactance can be instantaneously and accurately controlled. The power in the transmission network can be improved by controlling the firing angle of the TCSC. This salient feature has increased the importance of the TCSC model because it can improve the stability of the system. The TCSC model can be utilized in the protection of the transmission line.

III. POWER FLOW ANALYSIS

The power flow analysis is a solution obtained for power system under static condition of operation. The load flowstudy is caused to determine: line losses, bus voltage, system voltage Profile, effect of change in circuit configuration and incorporating new circuit on system loading and system transmission loss minimization.

Power flow analysis which are performed to calculate the magnitude of phase angle of voltage at buses and branch active and reactive power flow for given terminal on bus condition [4]. The possible parameters for each bus are magnitude of the voltage V_i, phase angle of the voltage $^{\delta}i$, active power P_i, reactive power Q_i and line losses.The TCSC configuration uses thyristor controlled reactor is parallel with a segment of capacitor bank. This configuration allows fundamental frequency capacitive reactance to be smoothly controlled over wide range and switch to condition where bidirectional thyristor pairs conduct continuously and insert an inductive reactance in the line [5,6].

IV. CASE STUDY

A. *Five Bus System*

The power flow will be implemented on IEEE five bus system and thirty bus system. The equations of Newton-Raphson method are as follows:

$$P=V_i\sum Y_{ik}.V_k\cos(\gamma_{ik}+\theta_i-\theta_k) \quad (1)$$

$$Q=-V_i\sum Y_{ik}.V_k\cos(\gamma_{ik}+\theta_i-\theta_k) \quad (2)$$

Consider an IEEE five bus system in which the declaration of the buses with respect to type is as follows:

Type....

% 1 - Slack Bus.., % 2 - PV Bus.., % 3 - PQ Bus..

%%%%%%%%%%%%%%%%%%%%%%%%%%%

% 1 – North, % 2 – South, % 3 – Lake, % 4 – Main, % 5 – Elm

Let us assume the bus data for the five bus system is given by:

%	Bus	Type	Vsp	theta	PGi	QGi	PLi	QLi	Qmin	Qmax
busdat5 =	[1	1	1.060	0	0	0	0	0	0	0;
	2	2	1.00	0	40	0	20	10	-300	200;
	3	3	1.0	0	0	0	45	15	0	0;
	4	3	1.0	0	0	0	40	5	0	0;
	5	3	1.0	0	0	0	60	14	0	0;

According to the above data of five buses, Newton Raphson Model is used to calculate the bus voltage and phase angle without using TCSC on all buses. The results of bus voltage and phase angle is calculated mathematically from Newton Raphson method and then verified from the Matlab software. The results from Matlab is as follows:

TABLE I

BUS VOLTAGE & PHASE ANGLE WITHOUT TCSC

Newton Raphson Loadflow Analysis

Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0600	0.0000	1.311	0.820	1.311	0.820	0.000	0.000
2	1.0000	-2.0871	0.200	-0.884	0.400	-0.784	0.200	0.100
3	0.9933	-4.7315	-0.450	-0.150	-0.000	0.000	0.450	0.150
4	0.9903	-5.0516	-0.400	-0.050	0.000	0.000	0.400	0.050
5	0.9736	-5.7884	-0.600	-0.140	0.000	0.000	0.600	0.140
Total			6.067	-40.384	171.067	3.616	165.000	44.000

Now, the branch active and reactive power of five bus system can be calculated from Newton Raphson Method mathematically and the results are matched with values from Matlab. The calculations of active and reactive power from Matlab without using TCSC is as follows:

TABLE II

BRANCH ACTIVE & REACTIVE POWER WITHOUT TCSC

Line Flow and Losses

From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	89.216	77.400	2	1	-86.733	-69.950	2.483	7.449
1	3	41.851	16.988	3	1	-40.399	-12.630	1.453	4.358
2	3	24.465	-5.852	3	2	-24.097	4.956	0.368	1.104
2	4	27.705	-3.108	4	2	-27.238	4.507	0.466	1.399
2	5	54.563	5.500	5	2	-53.360	-1.891	1.203	3.609
3	4	19.495	3.527	4	3	-19.456	-3.408	0.040	0.119
4	5	6.694	4.689	5	4	-6.640	-4.525	0.054	0.163
Total Loss								6.067	18.202

The above results are for the five bus system without using TCSC. Now the TCSC system is applied between bus 3 and 4 of five bus system. The results calculated forthis scenario is different from that without using TCSC. First, consider the bus voltage and phase angle results from Matlab with using TCSC between bus 3 and 4:

TABLE III

BUS VOLTAGE & PHASE ANGLE WITH TCSC

Newton Raphson Loadflow Analysis

Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0600	0.0000	1.311	0.824	1.311	0.824	0.000	0.000
2	1.0000	-2.0361	0.200	-0.889	0.400	-0.789	0.200	0.100
3	0.9924	-4.8054	-0.450	-0.150	0.000	0.000	0.450	0.150
4	0.9892	-5.1511	-0.400	-0.050	0.000	0.000	0.400	0.050
5	0.9755	-5.5787	-0.600	-0.140	0.000	0.000	0.600	0.140
Total			6.088	-40.443	171.088	3.557	165.000	44.000

It is obvious from above results that bus voltages of bus 3 changes from 0.9933 pu to 0.9924 pu by using TCSC. The phase angle of bus 3 changes from -4.7315 Deg. to -4.8054 Deg by using TCSC. The bus voltage of bus 4 changes from 0.9903 pu to 0.9892 pu by using TCSC. The phase angle of bus 4 changes from -5.0516 Deg. to -5.1511 Deg. No change is observed on bus 1. Similarly, no change occurs in the bus voltage of bus 2 by using TCSC. A minute change in bus angle of bus 2 is observed from -2.571 Deg. to -2.0361 Deg.

by using TCSC. The bus 5 observes minor change in bus voltage and phase angle by using TCSC.Secondly, the results for active and reactive power from Matlab are obtained byusing Newton Raphson Method for five bus system by applying TCSC in between bus 3 and 4.

TABLE IV

BRANCH ACTIVE & REACTIVE POWER WITH TCSC

Line Flow and Losses

From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	98.625	77.574	2	1	-96.156	-70.166	2.469	7.408
1	3	42.463	17.255	3	1	-40.968	-12.749	1.495	4.486
2	3	25.431	-3.621	3	2	-25.035	4.809	0.396	1.188
2	4	28.924	-2.818	4	2	-28.417	4.338	0.507	1.520
2	5	51.801	4.713	5	2	-50.719	-1.467	1.082	3.247
3	4	21.003	3.773	4	3	-20.957	-3.635	0.046	0.138
4	5	9.374	5.060	5	4	-9.281	-4.921	0.093	0.139
Total Loss								6.088	18.126

It is clear the above results that when TCSC is applied between line 3 and 4, the active and reactive power of the system also change. The active power from bus 2 to 3 improves from 24.465 MW to 25.431 MW by usingTCSC. The active power from bus 2 to 4 changes from 27.305 MW to 28.924 MW. The active power from bus 2 to 5 increases from 51.801 MW to 54.563 MW. The active power from bus 3 to 4 improves from 19.495 MW to 21.003 MW. Finally, the active power from bus 4 to 5 enhances from 6.694 MW to 9.374 MW. So, by using TCSC the active power in the power system may be improved. Although, the total power of the power system observes a minute change but power compensates in the power system appropriately.

The above simulations were valid for five bus system. Now consider a second system of transmission network of thirty bus system. The same type of the results will be obtained from the thirty bus transmission network in the next section.

B. Thirty Bus System

Let us assume the input data of thirty bus system is shown in the following table:

TABLE V

Sr. No.	Bus	Type	V (p.u.)	Θ	P_{Gi}	Q_{Gi}	P_{Li}	Q_{Li}
1.	1	1	1.00	0	230	0	200	100
2.	2	2	1.01	0	250	0	230	100
3.	3	3	1.00	0	0	0	100	0
4.	4	4	1.01	0	0	0	100	0
5.	5	5	1.02	0	0	0	110	0
6.	6	6	1.01	0	0	0	150	0
7.	7	7	1.03	0	0	0	100	0
8.	8	8	1.04	0	0	0	120	0
9.	9	9	1.05	0	0	0	130	0
10.	10	10	1.05	0	0	0	100	0
11.	11	11	1.06	0	0	0	150	0
12.	12	12	1.06	0	0	0	100	0
13.	13	13	1.05	0	200	0	110	0
14.	14	14	1.00	0	0	0	100	0
15.	15	15	1.01	0	0	0	100	0
16.	16	16	1.00	0	0	0	100	0
17.	17	17	1.01	0	0	0	150	0
18.	18	18	1.02	0	0	0	100	0
19.	19	19	1.03	0	0	0	110	0
20.	20	20	1.01	0	0	0	100	0
21.	21	21	1.00	0	0	0	100	0
22.	22	22	1.02	0	200	0	120	0
23.	23	23	1.01	0	250	0	100	0
24.	24	24	1.00	0	0	0	100	0
25.	25	25	1.01	0	0	0	120	0
26.	26	26	1.00	0	0	0	100	0
27.	27	27	1.01	0	200	0	100	0
28.	28	28	1.03	0	0	0	100	0
29.	29	29	1.01	0	0	0	100	0
30.	30	30	1.00	0	0	0	0	0

Consider the bus no. 23 to bus no. 30. The bus voltage and phase angle for bus no. 23 to 30 are calculated from Matlab. The results of Matlab for bus voltage and phase angle are as follows:

TABLE VI

BUS VOLTAGE & PHASE ANGLE WITHOUT TCSC

23	1.0291	-16.2528	-0.032	-0.016	0.000	0.000	0.032	0.016
24	1.0237	-16.4409	-0.087	-0.024	0.000	0.043	0.087	0.067
25	1.0202	-16.0539	-0.000	-0.000	-0.000	0.000	0.000	0.000
26	1.0025	-16.4712	-0.035	-0.023	0.000	0.000	0.035	0.023
27	1.0265	-15.5558	0.000	-0.000	0.000	-0.000	0.000	0.000
28	1.0109	-11.7436	0.000	-0.000	0.000	-0.000	0.000	0.000
29	1.0067	-16.7777	-0.024	-0.009	-0.000	0.000	0.024	0.009
30	0.9953	-17.6546	-0.106	-0.019	0.000	0.000	0.106	0.019
Total			17.528	20.921	300.928	147.121	283.400	126.200

Similarly, the active and reactive power for the bus no. 23 to 30 from Matlab without using TCSC is as follows:

TABLE VII

BRANCH ACTIVE & REACTIVE POWER WITHOUT TCSC

23	24	1.859	1.183	24	23	-1.853	-1.171	0.006	0.012
24	25	-1.142	1.748	25	24	1.149	-1.734	0.008	0.014
25	26	3.544	2.366	26	25	-3.500	-2.300	0.044	0.066
25	27	-4.694	-0.632	27	25	4.717	0.677	0.024	0.045
28	27	17.998	-3.529	27	28	-17.998	4.791	0.000	1.262
27	29	6.189	1.667	29	27	-6.103	-1.505	0.086	0.162
27	30	7.091	1.661	30	27	-6.930	-1.358	0.161	0.303
29	30	3.703	0.605	30	29	-3.670	-0.542	0.033	0.063

The TCSC system is applied in between bus 27 and 29. By applying TCSC, a change is observed in the bus voltage, phase angle, active and reactive power. First, consider the bus voltage and phase angle. The values are calculated from Newton Raphson Method and the results are verified from Matlab. The results from Matlab are as follows:

TABLE VIII

BUS VOLTAGE & PHASE ANGLE WITH TCSC

23	1.0292	-16.2526	-0.032	-0.016	0.000	0.000	0.032	0.016
24	1.0237	-16.4409	-0.087	-0.024	-0.000	0.043	0.087	0.067
25	1.0203	-16.0549	0.000	0.000	0.000	0.000	0.000	0.000
26	1.0027	-16.4721	-0.035	-0.023	0.000	0.000	0.035	0.023
27	1.0267	-15.5574	0.000	-0.000	0.000	-0.000	0.000	0.000
28	1.0109	-11.7443	0.000	-0.000	0.000	-0.000	0.000	0.000
29	1.0084	-16.4126	-0.024	-0.009	-0.000	0.000	0.024	0.009
30	0.9964	-17.4460	-0.106	-0.019	-0.000	0.000	0.106	0.019
Total			17.529	20.859	300.929	147.059	283.400	126.200

It is observed from the above calculations the bus voltage on bus 23 increases from 1.0291 p.u. to 1.0292 p.u. The bus voltage on bus 24 remains unchanged. The voltage on bus 25 reduces from 1.0203 p.u. to 1.0202. The voltage on bus 26 increases from 1.0025 p.u. to1.0027 p.u. The voltage on bus 27 enhances from 1.0265 p.u. to 1.0267 p.u. The voltage on bus 28 remains unchanged. The voltage on bus 29 changes from 1.0067 p.u. to 1.0084 p.u. Finally, the voltage on bus 30 improves from 0.9953 p.u. to 0.9964 p.u. Therefore; the increase in voltage is also verified for 30 bus system.

Secondly, consider the active and reactive power in case of applying TCSC in between bus 27 and 29. The values from Matlab are as follows:

TABLE IX

BRANCH ACTIVE & REACTIVE POWER WITH TCSC

23	24	1.856	1.173	24	23	-1.850	-1.161	0.006	0.012
24	25	-1.148	1.728	25	24	1.155	-1.715	0.008	0.014
25	26	3.544	2.366	26	25	-3.500	-2.300	0.044	0.066
25	27	-4.700	-0.651	27	25	4.723	0.697	0.024	0.045
28	27	18.005	-3.570	27	28	-18.005	4.833	0.000	1.264
27	29	6.740	1.486	29	27	-6.641	-1.360	0.099	0.126
27	30	6.542	1.784	30	27	-6.402	-1.521	0.140	0.263
29	30	4.241	0.460	30	29	-4.198	-0.379	0.043	0.081

It is clear from above calculations that the active power from bus 23 to 24 and 24 to 25 improves from 1.859 MW and -1.142 MW. No change in active power is observed from bus 25 to 26. The active power observes a minute change from bus 25 to 27 from -4.694 MW to -4.700 MW. The active power from bus 28 to 27 increases from 17.998 MW to 18.005 MW. The active power from bus 27 to 29 improves from 6.189 MW to 6.740 MW. The active power from bus 27 to 30 degrades from 7.091 MW to 6.542 MW. The active power from bus 29 to 30 improves from 3.703 MW to 4.241 MW. So, in the active power improves in the network on overall basis.

V. CONCLUSION

The Power transmission network is suffering from the issue of stability. TCSC is an important FACTS device which compensates the power losses in the transmission network. TCSC is an advanced technique of improving power flow in the transmission line system of power system [7,8]. It also acts as sources of stability in the power system. The results of TCSC are valid in both 5 bus system and 30 bus systems [9,10]. But the performance of TCSC device is much better in five bus system than in thirty bus system.

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