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Abstract - The increase in power demand has forced the power system to operate closer to its stability limit. Voltage instability and line overloading have become challenging problems due to the strengthening of power system by various means. The nature of voltage stability can be analyzed by the production, transmission and consumption of reactive power. One of the major causes of voltage instability is the reactive power unbalancing which occurs in stressed condition of power system. Flexible AC transmission system (FACTS) devices play an important role in improving the performance of a power system, but these devices are very costly and hence need to be placed optimally in power system. FACTS device like thyristor controlled series compensator (TCSC) can be employed to reduce the flows in heavily loaded lines, resulting in a low system loss and improved stability of network. In this paper, a method based on line stability index, real power performance index and reduction of total system VAR power losses has been proposed to decide the optimal location of TCSC. The effectiveness of the proposed method is demonstrated on IEEE 30-bus power system.

Keywords- *Voltage stability, FACTS devices, TCSC, Line stability index, Performance index, Reactive power VAR loss..*

I. INTRODUCTION

In recent years, power system operation faces new challenges due to deregulation and restructuring of the electric supply industry. Due to this, voltage instability and line overloading problems have become of great concern to power system operators. Such problems are often associated with contingencies like unexpected line and generator outages, insufficient local reactive power support and increased loading of transmission lines [1]. The main cause of voltage collapse may be due to the inability of the power system to supply the reactive power or an excessive absorption of the reactive power by the system itself. Voltage stability concerned with the ability of a power system to maintain acceptable voltages at all buses in the system under normal conditions.

Voltage stability divided into two categories namely dynamic and static. The static voltage stability methods are mainly depends on steady state model in the analysis, such as power flow model or a linearized dynamic model [2]. Dynamic stability analysis describes the use of a model characterized by nonlinear differential and algebraic equations which include generators dynamics, tap changing transformers etc. Several methods have been used in static voltage stability analysis such as the P-V and Q-V curves, model analysis, artificial neural networks etc [3]. Line stability index (LSI) provides important information about the proximity of the system to voltage instability and also used to identify the critical line of the system.

To improve the voltage profile and voltage stability of a power system an alternative solution is to locate an appropriate Flexible AC transmission system (FACTS) device [4]. FACTS devices are the solid state converters having capability of improving power transmission capacity, improving voltage profile, enhancing power system stability, minimizing transmission losses etc. In order to optimize and to obtain the maximum benefits from their use, the main issues to be considered are the type of FACTS devices, the settings of FACTS devices and optimal location of FACTS devices [5].

The flexible AC transmission system (FACTS) devices are Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor Controlled Series Compensator (TCSC), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC) etc [6]. SVC and Statcom are connected in shunt with the system and the TCSC is connected in series with the system [7-9].

Thyristor controlled series compensators are connected in series with transmission lines [7]. TCSC is a series-control capacitive reactance that can provide continuous controlled of power on the AC line over a wide range. TCSC may be a single, large unit, or may consist of several equal or different sized smaller capacitors in order to achieve a superior performance [8]. In the transmission network it is important to locate TCSC devices at suitable place so, that transmission loss become less and stability of system is also improved. Owing to the huge cost of TCSC involved, it is important to find the optimal location of this device in a power system to obtain maximum benefits from it [9].

In this paper, optimal location of thyristor controlled series compensator (TCSC) has been selected on the basis of line stability index (LSI) for improvement of voltage stability of power system. Line stability index can be used for determining the weakest line in a power system [15]. This line stability index considers both active and reactive powers to evaluate voltage stability. Line stability index provides information about the stability condition of the lines and also determines the weakest line in the system. The effectiveness of proposed method has been tested on IEEE 30-bus system [10].

II. STATIC MODELING OF TCSC

Thyristor controlled series compensator is one of the most important and best device of FACTS controllers. TCSC is in use for many years to increase line power transfer and to maintain stability. The thyristor controlled series compensator can enhance the power system stability by effectively controlling the line power flows [11]. Controlling the power flows in the system helps in reducing the flows in heavily loaded lines, resulting increased system loadability and improved stability of the system.

The transmission model with a TCSC [12] connected between two buses i and j is shown in Figure 1. The equivalent model is used to represent transmission line. TCSC can be considered as a static reactance of magnitude equivalent to -jXc. The controllable reactance Xc is directly used as control variable to implement in power flow equation.

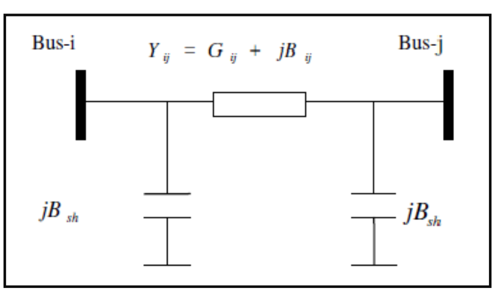

Fig. 1 Model of transmission line

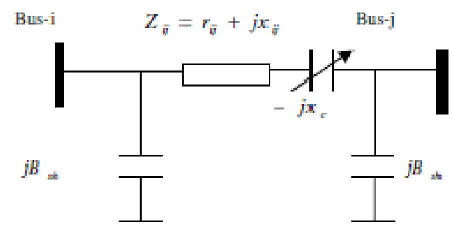

Fig. 2 Model of transmission line with TCSC

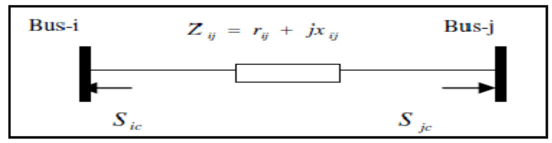

Fig.3.Injection model of TCSC

Let $V_i\ \delta_i$ and $V_j\ \delta_j$ are the complex voltages at buses i and j. The real and reactive power flow from bus-i and bus-j.

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij} \cos\left(\delta_{ij}\right) + B_{ij}(\delta_{ij})] \quad (1)$$

$$Q_{ij} = -V_i^2\left(B_{ij} + B_{sh}\right) - V_i V_j\left[G_{ij}\left(\delta_{ij}\right) - B_{ij} \cos\left(\delta_{ij}\right)\right] \quad (2)$$

where, $\delta_{ij} = \delta_i - \delta_j$ and then, the real and reactive power flow from bus-j to bus -i is as

$$P_{ij} = V_j^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) B_{ij} \sin(\delta_{ij})] \quad (3)$$

$$Q_{ij} = -V_j^2 (B_{ij} + B_{sh}) + V_i V_j [G_{ij} \sin(\delta_{ij}) + B_{ij} \cos(\delta_{ij})] \quad (4)$$

Figure 2 shows the model of transmission line with a TCSC connected between two buses -i and j. In steady state condition TCSC is considered as a static reactance -jXc [13]

$$P_{ij}^C = V_i^2 G_{ij}' - V_i V_j\left(G_{ij}' \cos \delta_{ij} + B_{ij}' \sin \delta_{ij}\right) \quad (5)$$

$$Q_{ij}^C = -V_i^2\left(B_{ij}' + B_{sh}\right) - V_i V_j\left(G_{ij}' \sin \delta_{ij} - B_{ij}' \cos \delta_{ij}\right) \quad (6)$$

$$P_{ji}^C = V_j^2 G_{ij}' - V_i V_j\left(G_{ij}' \cos \delta_{ij} - B_{ij}' \sin \delta_{ij}\right) \quad (7)$$

$$Q_{ij}^C = -V_j^2\left(B_{ij}' + B_{sh}\right) + V_i V_j\left(G_{ij}' \sin \delta_{ij} + B_{ij}' \cos \delta_{ij}\right) \quad (8)$$

The line having TCSC then the active and reactive power loss can be written as,

$$P_L = P_{ij} + P_{ji} = G'_{ij} \left(V_i^2 + V_j^2\right) - 2V_iV_jG'_{ij} \cos \delta_{ij} \quad (9)$$

$$Q_L = Q_{ij} + Q_{ji} - \left(V_i^2 + V_j^2\right)\left(B'_{ij} + B_{sh}\right) + 2V_iV_jB'_{ij} \cos \delta_{ij} \quad (10)$$

where, $G'_{ij} = \frac{r_{ij}}{r_{ij}^2+(X_{ij}-X_c)2}$ $\quad B'_{ij} = \frac{-(X_{ij}-X_c)}{r_{ij}^2+(X_{ij}-X_c)^2}$

Figure 3 shows the change in the line flow due to series capacitance can be represented as a line without series capacitance with power injected at the receiving and sending ends of the line. The real and reactive power injection at both buses i and j can be expressed as [12,13] ,

$$P_{iC} = V_i^2 \Delta G_{ij} V_i V_j \left[\Delta G_{ij} \cos \delta_{ij} \Delta B_{ij} \sin \delta_{ij}\right] \quad (11)$$

$$P_{jC} = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos \delta_{ij} - \Delta B_{ij} \sin \delta_{ij} \quad (12)$$

$$Q_{jC} = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij} \sin \delta_{ij} - \Delta B_{ij} \cos \delta_{ij}] \quad (13)$$

$$Q_{jC} = -V_j^2 \Delta B_{ij} + V_i V_j \left[\Delta G_{ij} \sin \delta_{ij} + \Delta B_{ij} \cos \delta_{ij}\right] (14)$$

where, $\Delta G_{ij} = \frac{X_c r_{ij}(X_c - 2X_{ij})}{\left(r_{ij}^2+X_{ij}^2\right)(r_{ij}^2+(X_{ij}-X_c)^2)}$ and

$$\Delta B_{ij} = \frac{-X_c(r_{ij}^2 - X_{ij}^2 + X_c X_{ij})}{\left(r_{ij}^2+X_{ij}^2\right)(r_{ij}^2+((X_{ij}-X_c)^2)}$$

III. OBJECTIVE FUNCTION

Due to high cost of FACTS devices, it is necessary to use cost-benefit analysis to analyze whether new FACTS device is cost effective among several candidate locations where they actually installed. The TCSC cost in line-k is given by [12],

$$C_{TCSC}(k) = c \cdot X_c(k). P_L^2. Base_{power} \quad (15)$$

where, c is the unit investment cost of FACTS, xc (k) is the series capacitive reactance and PL is the power flow in line-k. The objective function for placement of TCSC will be

$$\min \textstyle\sum_i C_i(P_i) + C_{TCSC} \quad (16)$$

IV. OPTIMAL LOCATION OF TCSC

4.1 Line Stability Index

The line stability index determines the critical line and the voltage collapse point of the system. In an interconnected system the value of line index that closed to one indicates the line has reached its instability limit. The overall voltage stability of the system can be determined by the largest value of index. There are different types of voltage stability indexes. Here, we use line stability index (LSI).

The line stability index considers both active and reactive power to determine voltage stability. This index gives more accurate results than other voltage stability indexes. For the security of the system voltage stability and contingency analysis both are important factors. In any power system the voltage stability analysis is done in two ways: (a) Any voltage stability index that determines about how any system close to its instability limit, (b) which is the critical line or weak bus in a system. In this paper, voltage stability and contingency analysis are based on this index. The mathematical formulation for line stability index is deduced from analysis of two-bus system model [15].

$$LSI_{ij} = \frac{R_{ij} P_j + X_{ij} Q_j}{0.25 V_i^2} \quad (17)$$

4.2 Total system reactive power loss sensitivity

Here, we describe the method based on the sensitivity of the total system reactive power loss with respect to the control variable of the TCSC. For TCSC placed between buses i and j we consider net line series reactance as a control parameter. Loss sensitivity with respect to control parameter of TCSC placed between buses i and j can be written as [13],

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}} = \left[V_i^2 + V_j^2 - 2V_iV_j \cos \delta_{ij}\right] \cdot \frac{r_{ij}^2 - X_{ij}^2}{(r_{ij}^2+X_{ij}^2)^2} \quad (18)$$

4.3 Real power flow performance index sensitivity

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index as given below.

$$PI = \sum_{m=1}^{N_L} \frac{W_m}{2n} \left(\frac{P_{Lm}}{P_{Lm}^{max}}\right) \quad (19)$$

where, P_{Lm} is the real power flow and P_{Lmax} is the rated capacity of line-m, n is the exponent and m w a real non-negative weighting coefficient which may be used to reflect the importance of lines. PI will be small when all the lines are within their limits and reach a high value when there are overloads. Thus, it provides a good measure of severity of the line overloads for given state of the power system. Most of the works on contingency selection algorithms utilize the second order performance indices which, in general, suffer from masking effects [14]. The lack of discrimination, in which the performance index for a case with many small violations may be comparable in value to the index for a case with one huge violation, is known as masking effect. By most of the operational standards, the system with one huge violation is much more severe than that with many small violations [12-15]. Masking effect to some extent can be avoided using higher order performance indices that are n > 1. However, in this study, the value of exponent 'n' has been taken as 2 and W_m =1.

The real power flow PI sensitivity factors with respect to the parameters of TCSC can be defined as,

$$b_k = \frac{\partial PI}{\partial x_{ck}} \Big| x_{ck=0} \tag{20}$$

The sensitivity of PI with respect to TCSC parameter connected between bus-i and bus-j can be written as,

$$\frac{\partial PI}{\partial x_{ck}} = \sum_{m=1}^{N_L} W_m P_{Lm}^3 \left(\frac{1}{P_{Lm}^{max}}\right)^4 \frac{\partial P_{Lm}}{\partial x_{ck}} \tag{21}$$

4.4 Procedure for optimal location of TCSC

The sensitivity factor methods are used to determine the location to enhance the static performance of the system. The sensitivity methods used for finding the optimal location of FACTS devices. The FACTS device should be placed on the most sensitive line. In this paper, these sensitivity methods determine the best location of thyristor controlled series compensator (TCSC).With the sensitivity indices computed for TCSC, following criteria can be used for its optimal placement [15].

(I)In LSI based method, TCSC should be placed in a line having the most positive loss sensitivity index.

(I)In reactive power loss reduction method, TCSC should be placed in a line having the most positive loss sensitivity index.

(II)In PI method TCSC should be placed in a line having most negative sensitivity index.

V. RESULT AND DISCUSSION

The effectiveness of proposed method is illustrated by applying the approach in IEEE 30-bus system. The IEEE 30-bus system includes one slack bus, 5 generation buses, 24 load buses, and 41 transmission lines. In this paper, line stability index, reactive power VAR loss, performance index are computed to determine the optimal location of TCSC. The criteria for these three methods are given below,

Criteria (1) Analysis for line stability index

Line stability index (LSI) is used for finding the optimal location of TCSC. The line which has the highest value of LSI is considered as a weakest line compared to a line which have the lower value of LSI. TCSC having the reactance is installed on weakest lines one by one .The line stability index values for all the lines in the IEEE 30-bus system are calculated and their results are given in Table 1. TCSC device has installed on line no. 12, 13, 5, 1, 14 one by one based on their rankings. Compared with TCSC in other lines, the line stability index values for more number of lines are found to have the least possible value with TCSC in the line no. 1. It describes that more number of lines are improved after placing TCSC in line no.1 as shown in Table no. 2. Therefore, optimal place for installation of TCSC is line no. 1.

Criteria (2) Analysis for reactive power loss reduction and real power flow performance index

The power flow results for IEEE 30-bus system have been computed and are shown in Table 4. In reactive power loss reduction method, TCSC should be placed in a line having the most positive loss sensitivity index. It can be observed from Table 3 (column 3) that placement of TCSC in line-1 is suitable for reducing the total reactive power loss. System power flow result after placing TCSC in line-1 is shown in Table 4. The value of control parameter of TCSC for computing power flow is taken as 0.01 p.u.

In PI method TCSC should be placed in a line having most negative sensitivity index. It can be observed from Table 3 (column 4) placement of TCSC in line-2 will also reduce the total system real power flow performance index (PI) value. The value of control parameter of TCSC for computing power flow is taken as 0.005 p.u. Hence, it is clear from Table 4 and from equation (15) that PI method is more economical than reduction of total system VAR power loss method for optimal placement of TCSC.

Criteria (3) Single line outage as a contingency analysis

In a power system, if a line is corrupted, its power flow will be shared among other lines of the system.

S. No.	Line No.	i - j	Rank
1.	12	6 - 10	1
2.	13	9 - 11	2
3.	5	2 - 5	3
4.	1	1 - 2	4
5.	14	9 - 10	5

This will lead to possible overloading of some of the lines. We consider the PI index method, among 41 lines in IEEE 30- bus System, we selected 3 more important lines (line 2, 15, 20) that have larger line outage sensitivity factors for placement of TCSC. By opening each of the lines of the system, we consider the effect of opened line on remaining of the system.

Table 2 : Line stability index values for each lines for IEEE30-bus system with TCSC

Line no.	i - j	Line without TCSC	Line stability index with TCSC in lines				
			6-10	9-11	2-5	1-2	9-10
1.	1 - 2	0.0969	0.0968	0.0956	0.0919	0.0031	0.0966
2.	1 - 3	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111
3.	2 - 4	0.0164	0.0164	0.0164	0.0164	0.016	0.0164
4.	3 - 4	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035
5.	2 - 5	0.102	0.102	0.1000	0.0619	0.044	0.1019
6.	2 - 6	0	0	0	0	0	0
7.	4 - 6	0	0	0	0	0	0
8.	5 - 7	0.0621	0.0621	0.0621	0.0621	0.0601	0.0621
9.	6 - 7	0.0427	0.0427	0.0427	0.0427	0.0423	0.0427
10.	6 - 8	0.0022	0.0022	0.0044	0.0032	0.0265	0.0024
11.	6 - 9	0	0	0	0	0	0
12.	6 - 10	0.3873	0.3524	0.3876	0.3874	0.3827	0.3873
13.	9 - 11	0.1481	0.1476	0.1324	0.1474	0.1629	0.1501
14.	9 - 10	0.0826	0.0826	0.0832	0.0827	0.0821	0.0450
15.	4 - 12	0.0788	0.0788	0.0788	0.0788	0.0778	0.0788
16.	12 - 13	0.0653	0.0653	0.0619	0.0648	0.0792	0.0633
17.	12 - 14	0.0259	0.0259	0.0260	0.0259	0.0258	0.0260
18.	12 - 15	0.02	0.02	0.0200	0.02	0.0199	0.0200
19.	12 - 16	0.0193	0.0193	0.0193	0.0193	0.0192	0.0193
20.	14 - 15	0.0398	0.0398	0.0399	0.0398	0.0397	0.0398
21.	16 - 17	0.0561	0.0561	0.0562	0.0561	0.0558	0.0562
22.	15 - 18	0.0119	0.0119	0.0119	0.0119	0.0119	0.0119
23.	18 - 19	0.0246	0.0246	0.0247	0.0246	0.0245	0.0247
24.	19 - 20	0.0027	0.0027	0.0028	0.0028	0.0027	0.0028
25.	10 - 20	0.0084	0.0084	0.0085	0.0084	0.0084	0.0085
26.	10 - 17	0.0243	0.0243	0.0244	0.0243	0.0242	0.0244
27.	10 - 21	0.0427	0.0427	0.0429	0.0427	0.0424	0.0429
28.	10 - 22	0	0	0	0	0	0
29.	21 - 22	0	0	0	0	0	0
30.	15 - 23	0.0171	0.0171	0.0172	0.0171	0.017	0.0171
31.	22 - 24	0.0283	0.0283	0.0284	0.0283	0.0282	0.0284
32.	23 - 24	0.0388	0.0388	0.0389	0.0388	0.0387	0.0389
33.	24 - 25	0	0	0	0	0	0
34	25 - 26	0.0452	0.0452	0.0453	0.0452	0.0449	0.0452
35.	25 - 27	0	0	0	0	0	0
36.	28 - 27	0	0	0	0	0	0
37.	27 - 29	0.021	0.021	0.0210	0.021	0.0209	0.0210
38.	27 - 30	0.0821	0.0821	0.0822	0.0822	0.0817	0.0822
39.	29 - 30	0.0603	0.0603	0.0604	0.0603	0.06	0.0603
40.	8 - 28	0	0	0	0	0	0
41	6 - 28	0	0	0	0	0	0

Table 3 : Calculated VAR power loss and PI sensitivities

Line no.	i - j	a_{ij}	b_{ij}
1.	1 - 2	**233.4514**	14.1009
2.	1 - 3	68.3079	**-2.5957**
3.	2 - 4	21.3735	4.7086
4.	3 - 4	64.5183	-2.5591
5.	2 - 5	69.6231	-2.3963
6.	2 - 6	37.8014	0.3927
7.	4 - 6	55.8207	7.0958
8.	5 - 7	2.8634	0.4819
9.	6 - 7	13.5524	1.6137
10.	6 - 8	12.7455	0.5650
11.	6 - 9	6.7195	1.0843
12.	6 - 10	2.5051	-0.1213
13.	9 - 11	0.2259	0.0407
14.	9 - 10	8.4497	1.1283
15.	4 - 12	17.1425	-1.2755
16.	12 - 13	2.9422	-0.0824
17.	12 - 14	0.6085	-0.0582
18.	12 - 15	3.3950	-0.1190
19.	12 - 16	0.4751	-0.1210
20.	14 - 15	0.0182	-0.0134
21.	16 - 17	0.0883	-0.0625
22.	15 - 18	0.3394	-0.0415
23.	18 - 19	0.0579	-0.0199
24.	19 - 20	0.6251	0.0508
25.	10 - 20	1.0487	0.0685
26.	10 - 17	0.6530	0.1000
27.	10 - 21	3.6273	0.4092
28.	10 - 22	0.7937	-0.0367
29.	21 - 22	0.0651	-0.0324
30.	15 - 23	0.2638	-0.0485
31.	22 - 24	0.3867	0.0436
32.	23 - 24	0.0146	-0.0182
33.	24 - 25	0.0247	0.0038
34	25 - 26	0.1951	-0.0008
35.	25 - 27	0.3220	0.0123
36.	28 - 27	3.9637	0.0490
37.	27 - 29	0.4384	0.0036
38.	27 - 30	0.5654	-0.0050
39.	29 - 30	0.1560	0.0020
40.	8 - 28	-0.0222	-0.0091
41	6 - 28	3.6929	-0.1090

Table 4 : Power flow results after placing TCSC

Line no.	i - j	Power flow (without TCSC)	Power flow (withTCSC in line1)	Power flow (with TCSC in line 2)
1.	1 - 2	1.77743	1.45249	1.00827
2.	1 - 3	0.83197	1.16244	1.73954
3.	2 - 4	0.45702	0.31019	0.10141
4.	3 - 4	0.78034	1.08391	1.5532
5.	2 - 5	0.8299	0.78075	0.7162
6.	2 - 6	0.61905	0.50841	0.35399
7.	4 - 6	0.70132	0.84541	1.05159
8.	5 - 7	0.1421	0.18778	0.24938
9.	6 - 7	0.37537	0.4229	0.48913
10.	6 - 8	0.29534	0.29499	0.29479
11.	6 - 9	0.27687	0.27136	0.2634
12.	6 - 10	0.15828	0.15502	0.14929
13.	9 - 11	0.003	0	0
14.	9 - 10	0.27731	0.27136	0.2634
15.	4 - 12	0.44131	0.45197	0.47386
16.	12 - 13	0.00021	0	0
17.	12 - 14	0.07852	0.07965	0.082
18.	12 - 15	0.17852	0.18319	0.19288
19.	12 - 16	0.07206	0.07712	0.08698
20.	14 - 15	0.01592	0.01689	0.01916
21.	16 - 17	0.03658	0.04153	0.05124
22.	15 - 18	0.06009	0.06283	0.06787
23.	18 - 19	0.02779	0.03041	0.03537
24.	19 - 20	0.06703	0.06465	0.05971
25.	10 - 20	0.09018	0.08758	0.08263
26.	10 - 17	0.05347	0.04874	0.03911
27.	10 - 21	0.15723	0.15667	0.1572
28.	10 - 22	0.07582	0.0754	0.07576
29.	21 - 22	0.01849	0.01943	0.01899
30.	15 - 23	0.05004	0.05292	0.05949
31.	22 - 24	0.05643	0.05545	0.0562
32.	23 - 24	0.01771	0.02058	0.02707
33.	24 - 25	0.01322	0.01146	0.00435
34	25 - 26	0.0352	0.03545	0.03548
35.	25 - 27	0.04866	0.04697	0.03992
36.	28 - 27	0.18192	0.18002	0.17312
37.	27 - 29	0.06178	0.0619	0.06199
38.	27 - 30	0.07093	0.07092	0.07103
39.	29 - 30	0.03716	0.03704	0.03706
40.	8 - 28	0.0057	0.00603	0.00679
41	6 - 28	0.1884	0.18682	0.18059

Table 5 : Power flow results after line outages using PI index

Line no.	i - j	Power flow (p.u.)		
		Line 2 out	Line 15 out	Line 20 out
1.	1 - 2	2.70813	2.0628	2.02819
2.	1 - 3	**0**	0.68004	0.71066
3.	2 - 4	0.86538	0.79083	0.82455
4.	3 - 4	0.024	0.63364	0.66137
5.	2 - 5	0.96888	0.81241	0.7925
6.	2 - 6	0.93153	0.56344	0.51759
7.	4 - 6	0.30782	1.25701	0.8404
8.	5 - 7	0.0155	0.15882	0.17742
9.	6 - 7	0.24531	0.39476	0.41441
10.	6 - 8	0.29703	0.31256	0.29616
11.	6 - 9	0.29138	0.5194	0.27149
12.	6 - 10	0.16592	0.29469	0.15409
13.	9 - 11	0	0	0
14.	9 - 10	0.29138	0.5194	0.27149
15.	4 - 12	0.41674	**0**	0.45596
16.	12 - 13	0	0	0
17.	12 - 14	0.07625	0.0323	0.06249
18.	12 - 15	0.16824	0.01062	0.19989
19.	12 - 16	0.06025	0.13368	0.08158
20.	14 - 15	0.01352	0.03002	**0**
21.	16 - 17	0.0248	0.17072	0.04594
22.	15 - 18	0.05381	0.05237	0.06218
23.	18 - 19	0.02148	0.08481	0.02976
24.	19 - 20	0.07356	0.18033	0.06529
25.	10 - 20	0.09667	0.20738	0.08835
26.	10 - 17	0.06545	0.26544	0.04438
27.	10 - 21	0.15976	0.18762	0.15834
28.	10 - 22	0.07742	0.09565	0.07651
29.	21 - 22	0.01639	0.01109	0.01785
30.	15 - 23	0.04384	0.07123	0.05297
31.	22 - 24	0.06048	0.10595	0.05808
32.	23 - 24	0.01155	0.10409	0.02064
33.	24 - 25	0.01552	0.08823	0.00886
34	25 - 26	0.03546	0.03547	0.03547
35.	25 - 27	0.05112	0.12558	0.04441
36.	28 - 27	0.18429	0.26031	0.17761
37.	27 - 29	0.06193	0.06195	0.06197
38.	27 - 30	0.07096	0.07099	0.07101
39.	29 - 30	0.03705	0.03705	0.03706
40.	8 - 28	0.00456	0.01069	0.00567
41	6 - 28	0.18956	0.25085	0.18401

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VI. CONCLUSION

In this paper, a method for optimal placement and sizing of TCSC has been proposed for improving the voltage stability in a power system. FACTS devices such as TCSC by controlling the power flows in the network can help to reduce the flows in heavily loaded lines. The effectiveness of these methods has been demonstrated on IEEE 30-bus system. In this paper two sensitivity-based methods (reduction of system VAR power loss and PI index) and one stability index have been developed for determining the optimal location of TCSC in any power system.

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