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Optimal Placement of FACTS Devices in a Typical Power System

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Abstract

This paper presents an approach for the optimal placement of FACTS devices. The devices considered are Static Var Compensator (SVC) and Thyristor Controller Series Capacitor (TCSC). Optimal location of TCSC is identified by computing an index called the single contingency sensitivity (SCS) which is used to rank the system branches according to their suitability. The objective of this approach is to minimize or eliminate line overloads as well as the unwanted loop flows under single contingencies. The presented approach for locating and controlling power flow through TCSC enhances the static security and reduces the power losses in a given power system. The approach for the selection of SVC location is based on static voltage stability analysis of the power systems. The analysis presented here uses the L index computed at load buses. L index gives voltage stability information and is in the range of 0 to 1. By using MiPower software, these approaches are tested on IEEE 14-bus and 30-bus test systems.

Keywords: Contingencies, Flexible AC Transmission System (FACTS), optimal placement, static VAR compensator (SVCs), Thyristor-controlled series capacitors (TCSCs)

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Introduction

Since few decades, with the deregulation of the electricity market, the traditional concepts and practices of power systems have changed. These changes have been prompted due to following reasons: lack of adequate funds to set up the required generation, transmission and distribution facilities, and to bring in improvement in overall efficiency of system. The deregulated structure is aimed at abolishing the monopoly in the generation and trading sectors, thereby introducing competition at various levels wherever it is possible [1]. Power systems are commonly planned and operated based on the N-1 security criterion, which implies that the system should remain secure under all important first contingencies. Designing the system to meet this criterion is somewhat conservative and costly. As the systems become deregulated, power companies become more and more cost conscious and they are driven to solutions where the system is operated more flexibly via the flexible AC transmission system (FACTS) devices [2]. During the outages of some critical lines, power system may become insecure and vulnerable to the voltage collapse due to lack of reactive power support and\or overloading of the network. Generators may have limited reactive power capability and sometimes, their reactive power cannot be efficiently used if the reactive power requirement in the network is far from their locations. Further, these generators may have to reduce their real power output to fulfil the reactive power demand of the system, resulting in loss of opportunity in the electricity market. Moreover, low voltage profile in the system may increase spot prices in the electricity market. Hence, reactive power compensators are required in the network to maintain the voltage profile and, thereby, improving the steady-state and dynamic performances of the system. Shunt FACTS controllers, such as static VAr compensator (SVC) are capable of effectively controlling the voltage profile by dynamically adjusting the reactive power output at the point of connection. However, these controllers are very expensive and hence, their optimal locations in the network must be ascertained[3]. TCSC is also one such device, which offers smooth and flexible control of the line impedance with much faster response compared to the traditional control devices. While there have been numerous studies concerning the utilization of these devices, so far, most of the research has focused on issues such as transient stability improvement, sub synchronous resonance (SSR) mitigation, damping of power swings, avoiding voltage collapse, enhancing power system reliability, etc. However, the use of TCSC to relieve line overloads during a single contingency, has not been investigated in great detail. System planners design their systems so that they can continue to operate securely in case of an unexpected line or transformer outage, an event that is referred to as a single contingency. A secure system is defined as one where none of the system's operating constraints is violated under any of the considered single contingencies. TCSC can be used effectively in maintaining system security in case of a contingency, by eliminating or alleviating overloads along the selected network branches. In this paper, we concentrate on the enhancement of steady-state system security against single contingencies via the use of TCSCs. It is indicated that the effectiveness of the controls for different purposes mainly depends on the location of control device [4]. In this paper, utilization of TCSC during single contingencies is investigated. In order to evaluate the suitability of a given branch for placing a TCSC, an index called the *single contingency sensitivity (SCS)* is introduced for each branch. This index is used to decide on the best locations for the TCSCs. Emergency line overload is a critical problem in power system operation, and the power flow through any overloaded branch has to be reduced down to the security limit rapidly. One way to alleviate line overloads by generation rescheduling and local load shedding, without any economic considerations, is presented here. Minimization of the transmission loss will increase transmission efficiency, reduce loop currents, and increase operation safety margin. The paper is organized into five sections. Section II describes the approach for the placement of TCSC. Voltage stability enhancement is carried out using SVC also. For carrying out this, L-index is computed at all the load buses and based on its value optimal SVC location is identified.

The presented methodologies are tested on some IEEE test systems as given in Section III. Section IV describes the approach for the placement of SVC. Numerical examples of some IEEE test systems for placement of SVC is given in section V. Finally, Section VI presents the main conclusions of the paper.

Approach for the Placement of TCSC

The essential idea of the proposed TCSC placement approach is to determine a branch, which is most sensitive to the largest number of contingencies. A TCSC that is in series with the chosen branch will provide the most efficient control of the system flows in the largest number of contingencies. This section will describe the definition and calculation of the sensitivity index, SCS and the optimal placement procedure for the TCSC. Let us first define the following matrices and array:

The participation matrix U : This is an *(m×n)* binary matrix, whose entries are "1" or "0" depending upon whether or not the corresponding branch is overloaded, where *n* is the total number of branches of interest, and *m* is the total number of considered contingencies.

The ratio matrix W: This is an *(m×n)* matrix of normalized excess (overload) branch flows. Its $(i,j)^{th}$ element, W*ij* is the normalized excess power flow (with respect to the base case flow) through branch "*j* " during contingency "*i* " and is given by

$$\mathbf{W}ij = \frac{Pij,cont}{P\mathbf{0}j,norm} - \mathbf{1} \qquad (1)$$

Where *Pij,cont* and P*0j,norm* are the power flows through branch "*j*" during contingency "*i* " and base case conditions, respectively.

The contingency probability array P: This is an *(m×1)* array of branch outage probabilities. The probability of branch outage is calculated based on the historical data about the faults occurring along that particular branch in a specified duration of time. It will have the following form:

$$P_{(m\times 1)}=[p1,p2\ldots\ldots\ldots\ldots pm] \qquad (2)$$

where "p*i*" is the probability of occurrence for contingency "*i*".

Thus, the SCS for branch "*j* " is defined as the sum of the sensitivities of branch "*j*" to all the considered single contingencies, expressed as

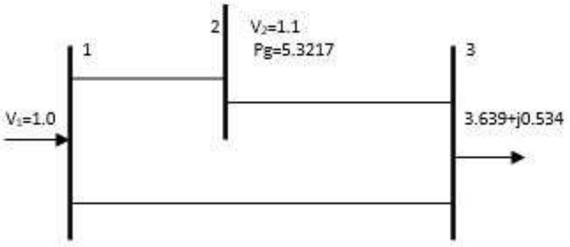
$$sj = \sum_{i=1}^{m} pi\ Uij\ Wij \qquad (3)$$

This definition of the index SCS is load-generation sensitive, i.e., the values of are calculated for a specific load-generation pattern. When this approach is used for power system planning, the values should reflect all the typical load-generation patterns in a specified time period such as the summer, the winter, etc. Thus, a composite value weighted by seasonal variations of load-generation patterns can be expressed as

$$S_j = \sum_{l=1}^{k} al\; s_{j,l}$$
(4)

where ‘*al’* is the weighting factor for one of the considered load-generation patterns; s*j,l* is the SCS value with respect to a load-generation pattern “*l* ” which is calculated by (3); and *‘k’* is the total number of considered typical load-generation patterns. SCS values are calculated for every branch using (4). Branches are then ranked by their corresponding SCS values. In general, the larger an SCS value a branch has, the more sensitive it will be. The branch with the largest SCS is considered as the best location for one TCSC. An illustrative example which shows how the TCSC devices can alleviate overloads without shedding any load during contingencies is described below.

Consider a 3-bus system shown in Fig. 1, with the line impedances Z12=*j0.1* p.u., Z13=*j0.2* p.u., and Z23=*j0.2* p.u.



All branch resistances are ignored. Bus-2 and bus-1 are generation buses, and bus-1 is set as the slack bus. Bus- All branch resistances are ignored. Bus-2 and bus-1 are generation buses, and bus-1 is set as the slack bus. Bus-3 is a load bus. The MVA ratings of branches are assumed, respectively, as S12=3.5 p.u., S13=2.0 p.u., and S23=2.3 p.u.

For this simple 3-bus system, power flow solution is $\partial 2= 15.4^0$, $\partial 3= -15.5^0$, and V3=0.9p.u. Therefore, the apparent power flows through the branches are: S12=2.86 p.u.,S13=1.18p.u., and S23=2.45 p.u., respectively. Branch 2–3 is clearly overloaded. When 0.4892+*j*0.1339 p.u. load at bus-3 is shed (with constant power factor assumed), the power flow solution becomes, $\partial 2= 15.9^0$, $\partial 3= -8.6^0$,and V3=0.9 p.u, and the apparent power flows are computed as S12=3.02 p.u., S13=0.85 p.u., and S23=2.29 p.u. Thus, the overload in branch 2–3 is successfully eliminated through load shedding.

Alternatively, if a TCSC is installed in branch 1–3 and its parameters are set properly, the same overload can also be eliminated completely. As an illustration, let the TCSC parameters be set to make the total impedance of branch 1–3 x13=0.1 p.u. Power flow solution for this case indicates no overload in branch 2–3. The power flow solution in this case is: $\partial 2=16.4^0$, $\partial 3=-8.6^0$, and V3=1.0p.u, and the apparent power flows are computed as S12=3.10p.u. S13=1.42 p.u, S23=2.21 p.u. Hence, the overload in branch 2–3 is eliminated through the use of a single TCSC. This case demonstrates that, instead of generation rescheduling or load shedding, properly placed and controlled TCSCs can effectively eliminate line overloads in a power system during any single contingency.

Numerical results

The effectiveness of proposed approach is illustrated using the IEEE 14 and 30-bus test systems. It is assumed that the impedance of all TCSCs can vary within 50% of the corresponding branch impedance. In this section, the given examples show the operation of TCSC in both capacitive and inductive modes.

A. IEEE 14-Bus System

Consider the IEEE 14-bus test system shown in Fig. 2. The area including branches 1–2, 1–5, 2–3, 2–4, 2–5, 3–4, and 4–5, is defined as the branch set. The apparent power limits for these lines are assigned as 2.0, 0.85, 0.85, 0.85, 0.85, 0.85, and 2.0 p.u., respectively.

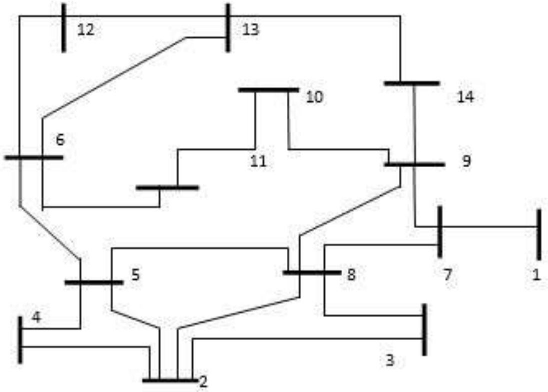
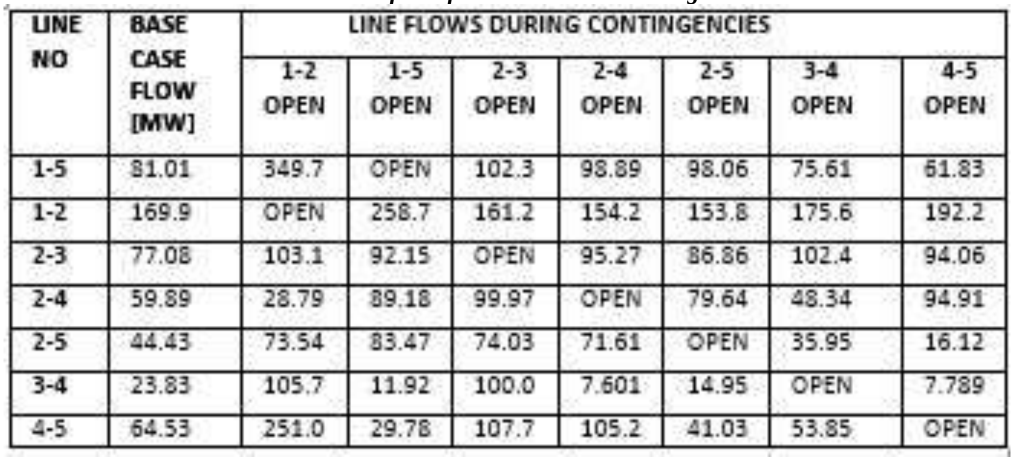


Fig. 2. IEEE 14-bus test system.

In this example, all possible branch contingencies are considered. The line flows in each of these contingencies are computed by Mipower software package. The line flows in each branch for base case and considered contingencies is shown in Table I. According to which the matrices U and W are computed.

Table I: Line flows for base case and contingencies



LINE NO	BASE CASE FLOW [MW]	LINE FLOWS DURING CONTINGENCIES						
		1-2 OPEN	1-5 OPEN	2-3 OPEN	2-4 OPEN	2-5 OPEN	3-4 OPEN	4-5 OPEN
1-5	81.01	349.7	OPEN	102.3	98.89	98.06	75.61	61.83
1-2	169.9	OPEN	258.7	161.2	154.2	153.8	175.6	192.2
2-3	77.08	103.1	92.15	OPEN	95.27	86.86	102.4	94.06
2-4	59.89	28.79	89.18	99.97	OPEN	79.64	48.34	94.91
2-5	44.43	73.54	83.47	74.03	71.61	OPEN	35.95	16.12
3-4	23.83	105.7	11.92	100.0	7.601	14.95	OPEN	7.789
4-5	64.53	251.0	29.78	107.7	105.2	41.03	53.85	OPEN

The Participation matrix 'U' and Ratio matrix 'W' are computed based on the values of line flows in the above Table 1. SCS values for each line is obtained as per as the approach explained in section II. It is assumed that the outage probabilities of all transmission lines are equal to 0.02. The different load generation patterns considered for the system in tabulated in Table II shown below.

Table I: Different Load Patterns For Ieee 14 Bus System

SL.NO	**LOAD PATTERN 1**		**LOAD PATTERN 2**		**LOAD PATTERN 3**	
	MW	**MVAR**	**MW**	**MVAR**	**MW**	**MVAR**
LOAD 1	22.134	12.95	22.568	13.208	2 3.002	13.462
LOAD 2	97.964	19.76	99.852	19.96	101.73	20.52
LOAD 3	50.668	-4.13	51.624	-4.212	52.58	-4.29
LOAD 4	8.208	1.728	8.36	1.76	8.512	1.792
LOAD 5	12.32	8.25	12.544	8.4	12.768	8.55
LOAD 6	33.04	18.592	33.63	18.924	34.22	19.256
LOAD 7	9.09	5.858	9.45	6.09	9.63	6.206
LOAD 8	3.605	1.854	3.745	1.926	3.815	1.962
LOAD 9	6.405	1.68	6.649	1.744	6.771	1.776
LOAD 10	14.445	6.206	14.985	6.438	15.255	6.554
LOAD 11	16.241	6.104	16.837	6.328	17.135	6.44

Line sensitivities SCS, that are calculated for each branch are listed in Table III. Those branches in set are then ranked according to their sensitivities values as shown in the last column of Table III.

TABLE III Ranks Of Studied Transmission Lines

BRANCHES	SCS VALUES	RANK
2-5	0.076827	1
2-4	0.058817	2
4-5	0.037159	3
1-5	0.05340	4

TCSCs are placed in series with the ranked branches, and the results are validated using Mipower package. Impedance of the TCSC is varied such that a maximum amount of power flows through the line. Validation results are as shown in Table IV.

Table Iv Validation Results For Ieee 14 Bus System

TCSC LOCATION	CONTINGENCIES SUSTAINED	MAX POWER FLOW	% INCREASE IN POWER FLOW	LOSSES [MW]
2-5	2	78.46	88.98	10.26
2-4	2	99.48	77.20	16.16
4-5	2	80.00	30.74	8.34
1-5	2	116.977	54.82	15.49

TCSCs placed according to their respective ranks, show an acceptable increase in the power flow and an acceptable decrease in the losses which can be observed in the above Table IV. Branch 4-5 is ranked 3 considering the least loss constraint.

B. IEEE 30-Bus System

IEEE 30-bus test system is also used to evaluate the proposed method. In th IEEE 30 bus system buses 1,2,3,4,5,6 and 7 are considered to analyse the approach, the area includes branches 1-2,1-3,2-4,3-4,2-5,2-6,4-6,5-7,6-7 and 6-8 which are considered to be the branch set. The line flows and matrix computation are done in the same manner of IEEE 14 bus system. The different loading patterns adapted for the system is shown in table V, the branches are then ranked according to the values of SCS obtained from the calculation and the ranking is as shown in table VI.

Table Ix Values Of Votage Magnitude And L Index Before And After Placing Svc

IEEE 30 BUS SYSTEM				
BUS NO	**BASE CASE**		**AFTER PLACING SVC AT BUS 30**	
	VOLTAGE MAGNITUDE	**L INDEX**	**VOLTAGE MAGNITUDE**	**L INDEX**
3	0.993674	0.011388	1.000905	0.010726
6	0.967012	0.012119	0.977599	0.011100
4	0.978431	0.013327	0.987168	0.012496
28	0.959740	0.015567	0.975912	0.014005
7	0.962156	0.015993	0.969252	0.014859
9	0.980788	0.035539	0.994421	0.033073
12	0.996404	0.038094	1.009917	0.035861
14	0.985353	0.054815	0.999680	0.051548
16	0.983024	0.055315	0.997253	0.051909
15	0.980999	0.059315	0.996022	0.055487
27	0.980490	0.066961	1.020855	0.056726
10	0.975429	0.067014	0.990489	0.062386
25	0.974329	0.067847	1.003983	0.063256
17	0.971479	0.072421	0.989189	0.063441
23	0.971363	0.073739	0.989156	0.066222
18	0.968712	0.076259	0.986517	0.069226
22	0.970905	0.076701	0.985296	0.070187
21	0.968161	0.076817	0.984413	0.070980
20	0.969100	0.077002	0.984275	0.072216
26	0.967632	0.079258	0.993228	0.073429
24	0.964088	0.083588	0.985213	0.074118
19	0.968303	0.083588	0.982834	0.074451
29	0.959769	0.089360	1.025512	0.077114
30	0.961248	0.099526	1.036758	0.094430

The results of the two systems considered are validating in MiPower software package. The values of L-indices can be obtained directly for any ‘n’ bus system with the help of MiPower software. Thus SVC helps in improving the system stability margin to a considerable extent.

Conclusions

This paper presents a methodology which can be used to place power flow controllers along system branches in an attempt to improve the performance of the system during contingencies. The paper considers SVC and TCSCs as such controllers. The proposed procedure is based on the sensitivity index SCS, which is developed as a measure of effectiveness of a given branch in relieving overloads under all considered contingencies for placement of TCSC. The approach for the SVC deals with the L-index values using which the system stability is improved. Once the device locations are determined the results obtained are validated using MiPower package.

IEEE 14-bus test system and IEEE-30bus test system are used to evaluate the performance of the proposed approaches. Numerical results confirm the effectiveness of the proposed procedures.

References

1. *S. K. Srivastava, "Advanced Power Electronics Based FACTS Controllers: An Overview". The paper first received 4 Sept 2009 and in revised form 5 July 2010. Digital Ref: A170801243*
2. *Yunqiang Lu and Ali Abur "Static Security Enhancement via Optimal Utilization of Thyristor-Controlled Series Capacitors", IEEE Transactions on Power Systems, Vol. 17, No. 2, May 2002.*
3. *J. G. Singh, S. N. Singh and S. C. Srivastava, "An Approach for Optimal Placement of Static VAr Compensators Based on Reactive Power Spot Price", IEEE Transactions on Power Systems, Vol. 22, No. 4, November 2007.*
4. *Daniel Hluben, Lubomir Bena, Michal Kolcun, "Use of TCSC for Active Power Flow Control in the Electric Power System", Technical University of Košice.*
5. *N.G.Hingorani, " Understanding FACTS" IEEE press.*