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Evaluation of Thyristor Controlled Series Capacitor Effects on Reduction of Lines Overload in Fault Occurrence

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Abstract: In this paper we initially introduce a method to determine the optimum allocation of installing one or more thyristor controlled series capacitor. The target function to determine the TCSCs installing place is reducing power system lines overload during fault contingency. After determining TCSCs optimum installation place, their success rate in reducing lines overload is studied by new following index called transmitting index and it is presented that in oppose to our expectation, TCSCs do not have a great roll in reducing lines overload during fault contingency. TCSC installation effect on amount of load shedding reduction is also presented as a new subject to keep buses voltage stability. IEEE 14&30 bus power systems are selected as the studied systems and mentioned analysis are applied on this system.

Key word: Thyristor controlled series capacitor (TCSC), TCSC allocation, fault contingency, lines overload, load shedding

INTRODUCTION

Power system as a large scale system is always under various faults. A great part of these faults is related to connection of transmitting lines. These faults can lead lines to outage which causes two following main problems:
1. Overload creation in other correct lines.
2. Voltage unstable conditions in system buses.

In order to decrease mentioned problems, various methods are presented and Thyristor controlled series capacitor as a FACTS device is one of them. This system generally is used to create a controlled series capacitor in lines (Gama and Tenorio, 2002). Thyristor controlled series capacitor can increase lines and buses voltage stability domain by fast impedance control of lines during power system ordinary work (Huang and Nair, 2002),(Kamarposhti and Alinezhad, 2009),(Laifa and Boudour, 2009).

It is necessary to mention that, TCSC effect on increasing the voltage static stability in system's ordinary operation point is an accepted issue, but the study of TCSC effect on the above issues during fault contingency conditions can be interesting (He *et al*, 1999). It seems that TCSC can also be applied to reduce above problems during fault contingency because of its high operation speed and lines inductive reactance reduction.

In order to optimum use of TCSC in power system, it is necessary to initially recognize the best point of their installation and make sure that their operation is not under not optimized installation effect (Shizawa *et al*, 2004),(Yorino *et al*, 2004). In this paper a new method is presented to optimum TCSC allocation in an associated power system which is a kind of sensitivity analysis method. It should be noted that since we assume no limit in used TCSCs and more important than that because of real power systems expansion, TCSCs optimum installing location is time consuming by using methods like try and error and so an appropriate method is necessary to determine TCSC optimum installing place. For example, in order to two different TCSCs with different values in a IEEE 14 bus power system which has 20 transmitting lines, the studied conditions, by applying mentioned methods and assuming that the TCSCs are not located on a single line will be 19^{20} conditions.

Also in this paper, by presenting new numerical indexes it is shown that TCSC cannot efficiently be applied to reduce lines overload during fault contingency during fault contingency.

MATERIALS AND METHODS

This paper is consisted of four main parts. First of all, this paper investigates the TCSC Optimum Allocation in section I. Then, Applying Proposed Method in IEEE 14 Bus System is presented in section II.

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Modeling Applying Proposed Method in IEEE 30 Bus System is presented in section III and TCSC Efficiency on reducing lines overload during Fault Contingency is presented in section IV.

I. TCSC Optimum Allocation:

In order to study TCSC efficiency in reducing lines overload and buses voltage stabilization the best point of TCSC installation should be determined at the first stage. In this part, a method is presented to achieve this aim. The main idea of suggested optimum allocation method is defining an index named Single Contingency Sensitivity (SCS) to each line. This method is based on the transmitting lines sensitivity analysis related to different faults. This index is used to select the best place of TCSC installation. It should be mentioned that, if places defined for TCSC are optimized to reduce lines overload, these places would be optimized for bus voltages. The reason is that, as the P-V characteristics in power buses, the line under more overload during different fault conditions, will create a sever voltage unstable condition probability if it outages the system (Eidiani, 2010),(Zare, 2009). SCS_j coefficient which is defined by relation (1) shows the sum of j^{th} line normalized overload caused by m faults leading the j^{th} line overload.

$$SCS_j = \sum_{i=1}^{m} P_i U_{ij} W_{ij} \tag{1}$$

It should be noted that if power system has n transmitting lines, fault contingency in all of them will not lead to overload in j^{th} line necessarily and generally just m faults may increase j^{th} line overload to more than the maximum transmittable load. It is obvious that m can be equal to or less than n.

Relation (1) also considers the i^{th} line outage probability (P_i) according to system background. Also, it is assumed that the system lines have single contingency outage and two lines never outage at the same time.

The used matrixes and arrays applied for this issue are defined as follow:

U MATRIX:

$m \times n$ binary matrix whose elements are "1" or "0". Each row of this matrix shows a specific fault. For example if (i) faults occur in transmitting system, elements in i^{th} row whose related transmitting line is overloaded under effect of this fault will obtain the value of "1" and naturally other elements of this row will obtain "0" value. It is obvious that the aim of defining this matrix is making j^{th} line SCS index zero which dose not overload if (i) circumstance occurs.

W MATRIX:

An $m \times n$ matrix that normalizes overload value of the lines overloaded during fault contingency. Actually this matrix determines the lines overload value. j^{th} line's normalized load distribution under (i) circumstance is obtained by relation (2) as following:

$$\frac{P_{ij,cont.}}{P_{oj,nor.}} - 1 \tag{2}$$

Where $P_{ij,cont}$ and $P_{oj,nor}$ respectively are the j^{th} line transmitted power in i^{th} line outage and ordinary work.

P Circumstance Probability Array:

This array is an $m \times 1$ array. In this array the probability of lines outage is computed by system's background information.

$$P_{m*1} = [P_1, P_2, ...P_m]^T \tag{3}$$

After computing different lines SCS, the lines are classified upon their SCS values. The line with the least SCS is the best place to install TCSCs, because in compare with the other lines, there is it has overloading probability during fault contingency condition and thus by installing TCSC on this mentioned line and reducing induction reactance of it, we can increase the load amount and the overload of other lines towards this line. (It is obvious that if we consider only the induction domain of TCSC the classification arrange will be changed). TCSCs locations are determined according to the lines rankings and the number of TCSCs which should be installed. Suggested TCSC optimum allocation method steps are as follow:

1. Refer to studied system's background and determine outages of each power system line to define P array elements.
2. Exploitation experiments in more appropriate lines (such as the lines with higher voltage levels) are determined to limit seeking domain.
3. U and W matrixes and arrays are composed and transmitted power in system's ordinary work is obtained. In this paper 1.2 times of line transmitting power is considered as its maximum transmittable power.
4. Each line's SCS is computed by relation 1.
5. First and second TCSCs are placed in obtained places upon mentioned classification but it should be noted that the rest of them should not be placed on the line which forms a loop with others and if so, TCSC is installed on the next ranked line.

For more clarification, we use IEEE 14 and 30 bus systems as the studied systems and obtain the optimum location of TCSC capacitors in them. Assume that the TCSC can change from zero to 50% of considered line impedance.

Considering the grid construction in our studies is the reason of applying two systems.

II. Applying Proposed Method in IEEE 14 Bus System:

IEEE 14 bus system structure is shown in fig. 1 (Kodsi and Canizares, 2003). 1-2, 1-5, 2-3, 2-4, 2-5, 3-4, 4-5 lines are selected as the main candidates of TCSC installation places to limit the seeking domain. In this example all lines probability of outage are considered the same and equal to 0.05.

Lines SCS values and their rankings are shown in table 1. In respect to table 1, line 3-4 is the best place to install the first TCSC because it has the least SCS value. According to this table lines 2-3 and 1-2 are in the next ranks and next TCSCs can be installed on them.

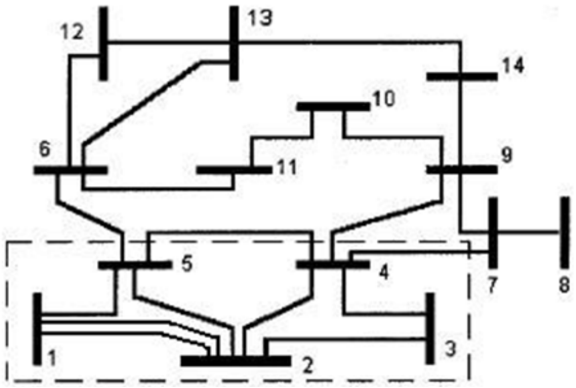

Fig. 1: IEEE 14 bus system structure

Table 1: IEEE 14 bus Lines SCS values and their rankings

Line	SCS value	Rating
1-2	0.0185	3
1-5	0.0198	4
2-3	00157	2
2-4	0.0414	5
2-5	0.0436	7
3-4	0.0030	1
3-5	0.0422	6

III. Modeling Applying Proposed Method in IEEE 30 Bus System:

In order to generalize the mentioned method, TCSC optimum allocation in IEEE 30 bus system is also applied. Fig. 2 shows this mentioned system. This system's lines outage probability with SCS values and their ranks are mentioned in table 2. According to this table we can see that the line 5-7 is the best place to install the first TCSC because of owning the least SCS in compare with the other lines.

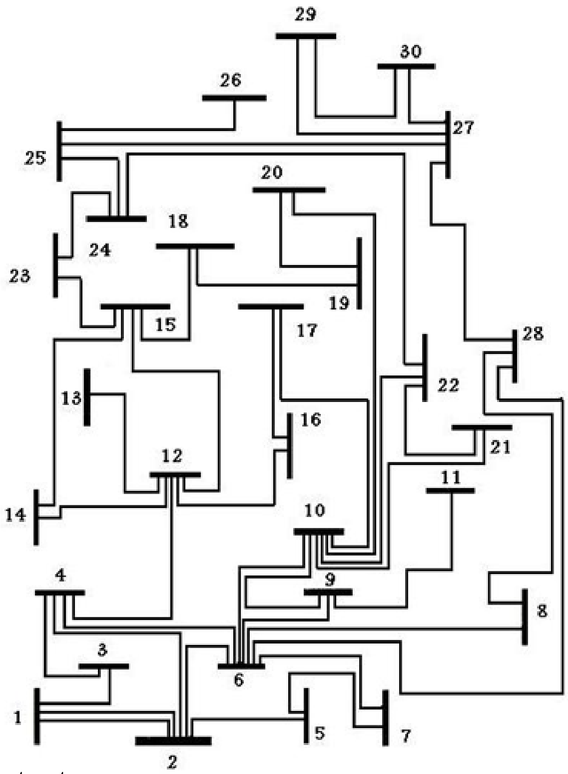

Fig. 2: IEEE 30 bus system structure

Table 2: IEEE 30 bus Lines SCS values and their rankings

Line	outage probability	SCS value	Rating
1-2	0.02	0.0383	5
1-3	0.03	0.0417	7
2-4	0.03	0.1395	12
3-4	0.03	0.0406	8
2-5	0.06	0.0404	6
2-6	0.06	0.1166	11
4-6	0.05	0.0749	9
5-7	0.05	0.0047	1
6-7	0.05	0.0049	2
6-8	0.04	0.0060	3
8-28	0.04	0.0176	4
6-28	0.04	0.1709	10

IV. TCSC Efficiency in Reducing Lines Overload During Fault Contingency:

After optimum allocation of TCSCs, determining their efficiency in reducing lines overload is very important. Upon the N-1 security standard, it is necessary to consider the transmitting power of each line more than the transmitting power of each line in ordinary work by assuming fault contingency probability and lines outage that will lead lines constructing expense to increase. In this part, TCSC effect in reducing correct lines transmittable power during fault contingency and line outages is studied. Assume that optimum allocation for studied system is applied as the suggested method in part 2 and TCSCs are installed in obtained places. For this study following stages are necessary to be executed.

1. Each system line should outage once and power distribution is applied for system using Gausian-sidel method. We obtain each line's maximum transmitting power during outage. Note that only abstract value of each line is considered and (-) sign just shows the direction of flowing power between two buses.

2. Maximum transmitting power of a line during other lines' outage is considered as the mentioned line's security margin and line transmitting power should not be more than this value in any cases.

3. Sum of all system lines security margin. This value is named as "Transmitting index" and is used as study measure. Note that this measure shows total system reducing power using TCSC and has no relation with the solution of overloaded lines problem.

According to the above issue it is obvious that the aim of installing TCSC is reducing transmitting index. For more study, 14 bus system is used initially and then 30 bus system is applied.

IEEE 14 bus system:

In table 3, transmitting power values of IEEE 14 bus system during outage of each line is shown. Note that there are two lines between 1 and 2 buses and so in column 2 we consider just outage of one of them. Scores in each highlighted box of each row show the maximum transmitting power of the line relating to that row during the different lines outage.

By summing the scores in highlighted boxes up the transmitting power of this system in TCSCless condition is obtained. Now in respect to the results obtained in part 2, we use TCSC compare different conditions of "transmitting index". The results of this comparison are shown in table 4.

In this table, the transmitting index of IEEE 14 bus system is studied under three conditions. First row is the TCSCless condition. In second row a TCSC is installed in lines 3-4 which leads to 40% impedance reduction upon the results of part 2. In third row, in addition to previous TCSC another similar TCSC is installed in line 2-3, but we see that in both of them transmitting index is reduced just 1% in compare with the TCSCless condition and this fact shows that TCSC is not successful to reduce this system's overload. In order to be sure of the obtained results, IEEE 30 bus system is studied too.

Table 3: Transmitting power values of IEEE 14 bus standard system during outage of each line

	1-2 outage	1-5 outage	2-3 outage	2-4 outage	2-5 outage	3-4 outage	4-5 outage
1-2	137.132	120.125	74.151	71.251	71.022	81.213	89.154
1-5	98.748	----------	96.432	93.283	92.441	70.226	56.305
2-3	69.542	87.898	----------	89.590	81.704	98.971	90.174
2-4	48.271	83.582	94.378	----------	75.568	45.109	92.104
2-5	31.031	78.137	69.500	68.123	----------	33.292	10.848
3-4	-27.183	-9.979	-94.201	-8.619	-15.834	----------	-8.030
4-5	-72.590	-95.472	-103.54	-99.428	-38.132	-50.292	----------

Table 4: Comparison of transmitting index of IEEE 14 bus standard system for different conditions

Number of installed TCSC	Location of installed TCSC	impedance reduction value	transmitting index	transmitting index reduction
0	-----	-----	842.638	----
1	3-4	40%	839.795	0.34%
2	3-4	40%	834.310	0.99%
	2-3	40%		

Table 5: Comparison of transmitting index of IEEE standard 30 bus system for different conditions

Number of installed TCSC	Location of installed TCSC	impedance reduction value	transmitting index	transmitting index reduction
0	-----	-----	1310.22	----
1	5-7	40%	1308.38	0.14%
2	5-7	40%	1306.58	0.28%
	6-7	40%		

IEEE 14 bus system:

Previous process is applied to this system and the results are shown in table 5. According to the obtained results we can see that TCSC is not successful to reduce correct lines' overload during fault contingency and outage.

Conclusion:

In this paper a new index named "transmitting index" is used to study the TCSC efficiency in reducing lines overload during fault contingency. A new method is suggested to optimum allocation of TCSC. According to the results, TCSCs have not a great efficiency in correct lines overload reduction during fault lines outage. On the other hand, results show that we can greatly reduce the amount of load shedding during fault contingency in order to keep the stability by installing TCSCs in optimum points.

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