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Improvement of Power System Security by Optimal Location of FACTs Devices using Contingency Sensitivity Index (CSI) Approach

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***Abstract*— In rising electric power system, expanded transaction, often lead to situations where system no longer stays in the secure operating region. The FACTs controllers play an important role in the system security enhancement. However, due to high capital investment, it is necessary to locate these controllers optimally in power system. In this paper contingency sensitivity index (CSI) has been used to decide the optimal location of TCSC and TCPAR. Here simulation and analysis has been done for optimal location of FACTs devices like TCSC and TCPAR for 5-bus system for severe contingency cases using contingency sensitivity index (CSI) and simulation also for different loading. And final result analysis, it is observed that placement of the FACTs device at optimal location, power system security has been enhanced which can be verified by related PI index.**

***Keywords*— power system security, contingency ranking, FACTs devices, contingency sensitivity index (CSI) approach.**

I. INTRODUCTION

Now days, load on the power system increased and also increased severe contingency so transmission networks are working near to its thermal limits and voltage limits, leading threat to power system security. The whole system can lead to blackout because of severe condition of overloading. It is very important for power system security that system would work within safe limits.

The power system security defined as "its ability to withstand set of severe but credible contingencies and to survive transition to an acceptable new steady state condition" [1]. The system overloading can be recovered which improve system security by two alternative, firstly restructuring of power system and secondly by controlling the line parameter of a system. The power system restructuring requires expanding unused potentials of system but environmental, right of way and cost problems are major problems for power transmission network expansion. Controlling the power flow of line in power system without generation rescheduling can improve the performance.

Hence, for better utilization of available capacities and power flow control flexibility, installing FACTs devices such as Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Angle Regulator (TCPAR), Unified Power Flow Controlled (UPFC). These devices can play important role to reduce the flows in heavily loaded lines, increasing load ability, low system loss, improve stability, reduce cost of production, stability margin increased. These devices used to control the power flows in the line so power system security enhanced.

But here, FACTs devices have high cost for installing, so placement of FACTs devices at optimal location is a very important concept. There are several methods for location of FACTs such as sensitivity index, contingency sensitivity index (CSI), line outage distribution factor (LODF), Genetic Algorithm (GA), Particle Swarm Optimization (PSO)[10].

In this paper the FACTs devices like as TCSC and TCPAR are used to improve power system security. But as per their high cost, the optimal location finds from the *contingency sensitivity index (CSI)* approach. There are three steps in this paper. Firstly, the Contingency Sensitivity Index (CSI) has been found. Secondly contingency ranking has been done using CSI index. Thirdly shows the result to control the PI after placing TCSC and TCPAR at optimal location and improve power system security.

II. CONTINGENCY SENSITIVITY INDEX (CSI) APPROACH

The essential principle utilized in TCSC and TCPAR placement for upgrading static security of power system is to decide a branch, which is most sensitive to the largest number of contingency. This section portrays the definition and estimation of CSI and optimal placement strategy for TCSC and TCPAR. The array ad matrixes used for the calculation of CSI is described below:

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The participation matrix U

This is an (m x n) binary matrix, where m is the aggregate of single contingency and n is the aggregate of branches of interest. u_{ij} is an element of matrix U, whose values are "1" or "0" depending on comparing branch is overloaded. If u_{ij} =0, the branch 'j' is not overloaded for contingency 'i'. If u_{ij} =1, the branch 'j' is overloaded for contingency 'i'[14].

The Ratio Matrix W

This is a matrix of normalized excess overload branch flow as for to the base case flow through branch "j" during contingency "I" in dimensions of (m x n) and it is given by bellowing equation:

$$W_{ij} = \frac{P_{ij}, cont}{P_{nj}, norm} - 1$$

Where,

P_{ij},cont = power flow through branch "j" during single contingency "i"

P_{nj},norm =base case power flow through branch "j"

The Contingency Probability array P

This is an (m x 1) array of branch blackout probabilities. The probability of branch blackout is calculated in view of the verifiable information about the faults occurring along that specific branch in a predetermined duration of time [6]. It is of the following form,

$$P_{mx1} = [p_1\ p_2\ \ldots\ p_m]^T$$

Where,

P_i = probability of occurrence for contingency "i" and taken as 0.02

m= the number of contingency

The whole of the sensitivities of branch "j" to all viewed as single contingencies are known as the CSI of branch "j". The CSI is expressed as underneath [14]:

$$CSI_j = \sum_{i=1}^{m} p_i u_{ij} w_{ij} \qquad (1)$$

Where,

m= the total number of single contingency

p_i , u_{ij}, w_{ij} = the element of matrix P,U,W

CSI values are computed for each branch utilizing equation. Branches are ranked by using corresponding CSI values. The line is more sensitive for placement of FACTs which branch has bigger CSI value.

The branch with the largest CSI is considered as the best location for one TCSC. At the point when more than TCSC needs to install, they will be chosen beginning from the top of this ranked list and proceeding downward with many branches as the numbered of available TCSCs.

III. Contingency Ranking Using CSI Index

Performance index is finding from below equation [14]:

$$PI = \sum_{i=1}^{m} p_i u_{ij} w_{ij} \qquad (2)$$

Where,

m= the total number of single contingency

p_i ,u_{ij}, w_{ij} = the element of matrix P,U,W

This equation is defined as the sum of considered contingency 'i' for all branches. About the all terms of equations are considered in section II. There are u is taken in this ranking, so only overloaded lines are considered in ranking after each outage. So there are masking effect is removed because of the only consider the overloaded line. In active power performance index the sum of all line after contingency , there are consider all line so unwanted line also do effect on the PI value. So remove the effect of unwanted line this index is found in which the only overloaded lines consider after each outage. So using this equation calculates the performance index. The line is most severe after outage which has the highest value of performance index.

IV. Simulation And Result Analysis

Here 5-bus system is used for simulation and result analysis which is consist three generators and two loads as shown in Fig.6 [1].

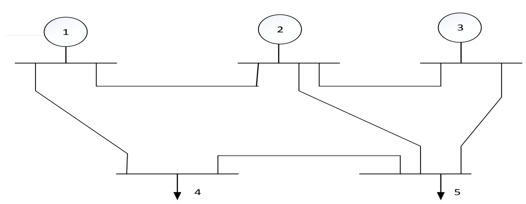

Fig.1 bus system [1]

The line 1-2 and line 3-5 have impedance 0.0258+j0.0866 pu and for other line the impedance is 0.0129+j0.0483 pu. The line flow set up 1.2 pu. The bus-1 has been taken as a slack bus. The system data has been shown in Table 1.

Table 1
System Data [1]

Bus	Pgen (MW)	Qg^{max} (MVAR)	Vspecified (PU)
2	130	100	1.04
3	90	100	1.05

A. Simulation for Case-1

For Case-1, the line data are same as shown in Table 1 and the bus load data for this case as shown below Table 2.

Table 2
Bus Loading Data for Case-1

Bus no.	P_d (MW)	Q_d (MW)
4	80	20
5	200	20

The CSI approach gives the optimal location of FACTs devices which have considered all contingencies for particular line. The line is most sensitive for placement of FACTs device which have the highest value of CSI. The CSI index is to find from the equation 1 for 6 lines considering 6 contingencies and branches are ranked as per highest CSI value. Table 2 shows the CSI ranking for 5-bus system.

Table 3
CSI Index (case-1)

Line	CSI	Rank
2_5	0.0229	1
3_5	0.019	2
1_4	0.0131	3

Then after, performance index is found for each contingency using equation and theory for this PI is mentioned in section III. After calculation of PI rank them as per highest value and find the most severe line. As shown in Table 4 line 2-5 have highest performance index which rank first. Then after line 1-4 has second highest value of the index which is ranked second. Line 3-5 has a third ranking and so on. So line 2-5 is most severe line.

Table 4
Contingency ranking (PI) (case-1)

Line From – to bus	Performance index	Ranking
2_5	0.0321	1
1_4	0.0104	2
3_5	0.0099	3
1_2	0.0023	4
4_5	0.0004	5
3_2	0	6

From the Table 4 obtained the severe contingency, which is reduced by the TCSC and TCPAR at optimal location which is found from the contingency sensitivity index (CSI), so security is improving. Table 5 and Table 6 described the PI value reduce after placing TCSC or TCPAR respectively. Also describe optimal setting for TCSC and TCPAR in Table 5 and Table 6 respectively.

Table 5
PI Before and after placing single TCSC (case-1)

Severe Contin-gency	PI before TCSC	TCSCat line 2-5		TCSC at line 3-5		TCSC at line 1-4	
		X	PI	X	PI	X	PI
2_5	0.032	-	-	-0.06	**0.0116**	-0.033	0.028
1_4	0.010	-0.033	**0.007**	-0.008	0.0103	-	-
3_5	0.009	-0.033	**0.005**	-	-	-0.033	0.0097
1_2	0.002	0.0338	**0**	-0.06	0.0007	0.03381	0.0009

Table 6
PI Before and after placing single TCPAR (case-1)

Severe contin-gency	PI before TCPAR	TCPAR at line 2-5		TCPAR at line 3-5		TCPAR at line 1-4	
		Φ	PI	Φ	PI	ϕ	PI
2_5	0.0321	-	-	-4°	0.0092	-4°	0.0252
1_4	0.0104	-4°	0.0053	4°	0.009	-	-
3_5	0.0099	-4°	0.004	-	-	4°	0.0092
1_2	0.0023	2°	0	-2°	0	2°	0.0004

B. Simulation for Case-2

For Case-2, the line data are same as shown Table 1 and the load data for this case as shown below Table 7. In this case-2 the load is exchange between bus 5 and bus 4. So in this section we had done same procedure for different loading.

Table 7
Bus Loading Data for Case-2

Bus no.	P_d (MW)	Q_d (MW)
4	200	20
5	80	20

The CSI approach provides the optimal location of TCSC and TCPAR which have mentioned all contingencies for particular line. The line is more sensitive for placement of FACTs device which have the highest value of CSI.

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Table 8
CSI Index (case-2)

Line	CSI	Rank
2_5	0.034	1
1_4	0.0278	2
3_5	0.0174	3

Then after, performance index is found for each contingency using equation and theory for this PI is taken from section III. Rank the PI value as per highest values after calculation of PI and find the most severe line. As shown in Table 9 line 2-5 have highest performance index which rank first. Then after line 1-4 has second highest value of the index which is ranked second. Line 4-5 has a third ranking and so on. Line 2-5 most severe line.

Table 9
Contingency ranking (PI) (case-2)

Line From – to bus	Performance index	Ranking
2_5	0.0256	1
1_4	0.0168	2
4_5	0.0168	3
3_5	0.0134	4
1_2	0.0066	5
3_2	0	6

From the Table 9 obtained the severe contingency, which is reduced by the TCSC and TCPAR at optimal location which is found from the contingency sensitivity index (CSI), so security is improving. Table 10 and Table 11 described the PI value reduce after placing TCSC or TCPAR respectively. Also describe optimal setting for TCSC and TCPAR in Table 10 and Table 11 respectively. So from the Table 10 and 11 observed that after placing TCSC or TCPAR the severity of line is decreased so power system security is improved.

Here optimal setting of TCSC is between (-70% to +70% of X) and optimal setting for TCPAR is (-4º to +4º).

Table 10
PI Before and after placing single TCSC (case-2)

Severe contingency	PI before TCSC	TCSC at line 2-5		TCSC at line 1-4		TCSC at line 3-5	
		X	PI	X	PI	X	PI
2_5	0.0256	-	-	-0.033	0.0068	0.06062	0.0109
1_4	0.0168	-0.0338	0.0134	-	-	-	-
4_5	0.0168	0.03381	0.014	0.0338	0.0114	0.06062	0.0156
3_5	0.0134	-0.0338	0.0065	0.03381	0.0105	-	-
1_2	0.0066	0.03381	0	0.03381	0.004	-0.06062	0

Table 11
PI Before and after placing single TCPAR (case-2)

Severe contingency	PI before TCPAR	TCPAR at line 2-5		TCPAR at line 1-4		TCPAR at line 3-5	
		Φ	PI	Φ	PI	Φ	PI
2_5	0.0256	-	-	-4º	0.005	4º	0.0097
1_4	0.0168	-4º	0.0088	-	-	4º	0.0138
4_5	0.0168	4º	0.0105	-4º	0.0088	4º	0.0142
3_5	0.0134	-4º	0.0037	4º	0.0097	-	-
1_2	0.0066	-4º	0.0021	4º	0.0017	-4º	0.0018

C. Simulation for Case-3

For Case-3, the line data are same as shown Table 1 and the load data for this case as shown below Table 12.

Table 12
Bus Loading Data for Case-3

Bus no.	P_d (MW)	Q_d (MW)
4	240	20
5	40	20

The CSI approach provides the optimal location of TCSC and TCPAR which have mentioned all contingencies for particular line. The line is more sensitive for placement of FACTs device which have the highest value of CSI.

Table 13
CSI Index (case-3)

Line	CSI	Rank
2_5	0.0389	1
1_4	0.0304	2
3_5	0.0168	3

Then after performance index is found for each contingency using equation and theory for this PI is taken from section III. Rank the PI value as per highest values after calculation of PI and find the most severe line. As shown in Table 14 line 2-5 have highest performance index which rank first. Then after line 1-4 has second highest value of the index which is ranked second. Line 4-5 has a third ranking and so on.

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Table 14
Contingency ranking (PI) (case-3)

Line from – to bus	Performance index	Ranking
2_5	0.0239	1
4_5	0.0209	2
1_4	0.0197	3
3_5	0.0134	4
1_2	0.0083	5
3_2	0	6

From the Table 14 obtained the severe contingency, which is reduced by the TCSC and TCPAR at optimal location which is found from the contingency sensitivity index (CSI), so security is improving. Table 15 and Table 16 described the PI value reduce after placing TCSC or TCPAR respectively. Also describe optimal setting for TCSC and TCPAR in Table 15 and Table 16 respectively.

Table 15
PI Before and after placing single TCSC (case-3)

Severe contin-gency	PI before TCSC	TCSC at line 2-5		TCSC at line 1-4		TCSC at line 3-5	
		X	PI	X	PI	X	PI
2_5	0.0239	-	-	-0.033	0.005	0.06062	0.0094
4_5	0.0209	0.033	0.018	-0.033	0.014	0.06062	0.0197
1_4	0.0197	-0.033	0.016	-	-	-	-
3_5	0.0134	-0.033	0.006	0.0338	0.010	-	-
1_2	0.0083	0.033	0	0.0338	0.005	-0.06062	0

Table 16
PI Before and after placing single TCPAR (case-3)

Severe contin-gency	PI before TCSC	TCPAR at line 2-5		TCPAR at line 1-4		TCPAR at line 3-5	
		Φ	PI	Φ	PI	ϕ	PI
2_5	0.0239	-	-	-4º	0.0043	4º	0.0085
4_5	0.0209	4º	0.0143	-4º	0.0126	4º	0.0182
1_4	0.0197	-4º	0.0103	-	-	4º	0.0158
3_5	0.0134	-4º	0.0036	4º	0.0099	-	-
1_2	0.0083	-4º	0.003	4º	0.0029	-4º	0.0023

V. CONCLUSION

Simulation and analysis shows that when severe contingencies occur the system will have the problem of overloaded lines. When FACTs devices placed at optimal location the overloading (severity) of lines effectively reduced and the system security will enhanced. The optimal location for 5-bus system for placement of TCSC and TCPAR for different loading is as below Table 17.

Table 17
5-bus system location for TCSC and TCPAR for different loading

Ranking	Optimal Location of TCSC			Optimal Location of TCPAR		
	Case -1	Case-2	Case-3	Case-1	Case-2	Case-3
1	2-5	2-5	2-5	2-5	2-5	2-5
2	3-5	1-4	1-4	3-5	1-4	1-4
3	1-4	3-5	3-5	1-4	3-5	3-5

The effect of the placement of FACTs devices at optimal locations for different loading is shown below Table 18.

Table 18
Analysis for 5-bus system

Different loading	Severe line	PI before placement FACTs	PI after placement TCSC	PI after placement TCPAR
Case-1	2-5	0.0321	0.0116	0.0092
	1-4	0.0104	0.0075	0.0053
	3-5	0.0099	0.0059	0.004
Case-2	2-5	0.0256	0.0068	0.005
	1-4	0.0168	0.0134	0.0088
	4-5	0.0168	0.014	0.0088
Case-3	2-5	0.0239	0.0057	0.0043
	4-5	0.0209	0.0148	0.0126
	1-4	0.0197	0.016	0.0103

From above analysis conclude that the optimal location of FACTs devices for different loading was same and after placing FACTs devices the severity on line was reduced and power system security is improved.

REFERENCES

[1] S.N.Singh, "Location of FACTs Devices for Enhancing Power System Security" IEEE large engineering system conference, 2001, 7042364.

[2] S.N.Singh and A.K.David, "Optimal Location Of FACTS Devices for Congestion Management" Electric power system research,vol 58, issue 2, 21 June 2001, Pages 71–79.

[3] G.C.Ejebe, B.F.wollenberg "Automatic Contingency Selection" IEEE transactions on power apparatus and systems, vol.pas-98, no.1 jan/feb1979.

[4] A.J.Wood and B.F.Wollenberg,"Power Generation, Operation and Control", John Wiley,New York,1996.

[5] Narain G. Hingorani, Laszlo Gyugyi, "Understanding FACTS" ISBN 81-86308-79-2, IEEE Press.

[6] N. M. G. Kumar, P.Venkatesh, and Dr. P. SangamewaraRaju, "Modeling and Analysis of SVC, TCSC, TCPAR in Power Flow Studies" International Journal of Engineering Technology and Advanced Engineering, ISSN 2250-2459, Vol:3, Issue 1, January 2013.

[7] G.D.Galiana et al,"Asssessment and Control of the Impect of FACTs Devices on Power System Performance", IEEE Trans on Power System, Vol.11, No.4, Nov.1996,pp.1931-1936.

[8] R.Baldick and E Kahn, "Contract Paths, Phase Shifters and Efficient Electricity Trade", IEEE Trans on Power Systems, Vol.12, no.2, May 1997, pp.749-755.

[9] R.Rajaram, F.Alyarado, A.Maniaci, R.Camfield and S.Jalali, "Determination of Location and Amount of Series Compensation to Increase Power Transfer Capability", IEEE Trans. On Power Systems, Vol.13,no.2, May 1998,pp.294-299.

[10] Atiyanaaz L. Sayyed, Pramod M. Gadge, RuhiUzma Sheikh, "Contingency Analysis and Improvement of Power System Security by locating Series FACTS Devices TCSC and TCPAR at Optimal Location ", International Journal (IOSR-JEEE) 2014.

[11] Seyed Abbas Taher and HadiBesharat, "Transmission Congestion Management by Determining Optimal of FACTS Devices in Deregulated Power Systems" American journal of applied sciences,2008, ISSN:1544-9239.

[12] S. Sutha, and N. Kamarj, "Optimal Location of Multi Type Facts Devices for Multiple Contingencies Using Particle Swarm Optimization" International journal of Electrical, Computer, Energetic, Electronic and communication Engineering Vol:2,No:10, 2008.

[13] Marouani Ismail, GuesmiTawfik, HadjAbdallahHsen, "Optimal Location of Multi Type FACtS Devices for Multiple Contingencies Using Genetic Algorithms " systems signals and devices,2011 international multi conference IEEE.11990229

[14] S.Mary Raja Slochanal,M.saravanan and A.Chitra Devi, "Application of PSO technique to find optimal settings of TCSC for Static security enhancement considering installation cost" IEEE Power Engineering conference,2005.IPEC 2005.

[15] S. Sutha, and N. Kamarj, "Optimal Location of Multi Type Facts Devices for Multiple Contingencies Using Particle Swarm Optimization" International journal of Electrical, Computer, Energetic, Electronic and communication Engineering Vol:2,No:10, 2008.

[16] R.NarmathaBanu, D.Devaraj, "Optimal Power Flow for Steadt State Security Enhancement using Genetic Algorithm with FACTs Devices" industrial and information system IEEE conference 2008.