International Journal of Scientific & Engineering Research, Volume 5, Issue 3, March-2014 153
ISSN 2229-5518

Optimal Location and Parameter Settings of TCSC under Single Line Contingency using PSO Technique

S.Raju, G.Madhavi

Abstract— The Flexible AC Transmission System (FACTS) in a Power System improves stability, reduces the cost of generation, losses and also improves loadability of the system. In order to use FACTS devices in a Power system to maximum extent, optimal location of FACTS devices is an important consideration. This paper presents the optimal location of series FACTS device for eliminating or minimizing the line overloads under single contingency. Among various types of FACTS devices TCSC with reactance control is used to control the power flow in congested lines for different operating conditions. The optimal location of the device is ascertained by using CSI and optimal setting of the device by PSO technique. The effectiveness of this method has been tested on IEEE-14 bus system using MATLAB Programming.

Index Terms— FACTS, Contingency analysis, TCSC, PSO, CSI, Optimal location, optimal setting.

I. Introduction

The working of power system[1] becomes more complex due to the continuous increase in load demand which leads to an enlarged stress of the transmission lines. So, power system can be operated in less protected state following unexpected line congestions voltages. To overcome this problem we can construct new transmission lines. However it takes more time due to administrative and environmental reasons.

Static security of the power system can be enhanced by generation rescheduling and load shedding as the primary corrective strategies for alleviating overloads on transmission lines. The rescheduling of generation and load shedding may not be acceptable by both power providers and customers, due to their significant effect on the existing power transaction contracts. An alternate solution can be devised through the use of FACTS technology. So FACTS [2-3] devices are used as a solution because these devices are used to improve the transient stability of the power system, to reduce the overloading of lines and they maintain the constant bus voltages.

Thyristor Controlled Series Capacitor (TCSC) [4-5] is one of the most efficient FACTS devices which are in use today. It provides better control of line impedance with faster response compared to the other devices.TCSC can increase the power transfer [6-7] capability by decreasing transfer reactance and it eliminates line overloads. For this purpose, TCSC should be properly installed in the power system network.

- S.Raju, M.Tech student, Department of EEE, PVP Siddhartha Institute of Technology, Vijayawada, India E-mail:rajusava5310@gmail.com.
- G.Madhavi, Assistant Professor, Department of EEE, PVP Siddhartha Institute of Technology,Vijayawada,India E-mail:gudavalli.madhavi@gmail.com.

To find the location [8-10] of TCSC an index called contingency sensitivity index (CSI) is used for each branch. After finding location of TCSC, the optimal settings of TCSC with respect to contingencies can be obtained by solving an optimization problem.

In power systems Contingency analysis [11-15] is performed to take preventive actions for each contingency. A Contingency is the outage of a line, a transformer or a generator. Contingency analysis procedure consists of line contingency analysis, contingency selection, detection of overloaded lines and low bus voltage violations, and ranking of the severest contingency cases. In this paper we focus only on the single contingency resulted from line outage. By performing contingency analysis we can determine contingency sensitivity index (CSI) [16] for each branch. After finding CSI the lines are ranked according to the severity of the contingency. After determining the most critical contingencies scenarios, TCSC is installed in the network .In this paper Particle Swarm Optimization (PSO) [16-17] technique is used to find the optimal parameter setting of TCSC device. Installing TCSC in such optimal location with such optimal parameters will eliminate or minimize the overloaded lines and the bus voltage violations.

II. Problem Formulation

A. Optimal placement of TCSC

In power system network, to get the optimal location [14, 15] of TCSC we have to determine a branch which is most sensitive to the largest number of contingencies [17] by contingency sensitivity index (CSI). The matrices used for the calculation of CSI index are described below.

The participation matrix U *:* This is an (m x 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 single or double contingencies. U_{ij} Is the element

ISSN 2229-5518

of U matrix and U_{ij} =1 indicates that, the branch 'j' is Overloaded for contingency 'i'.If U_{ij} =0, the branch 'j' is not overloaded for contingency 'i'.

The ratio matrix W *:* This is an (m x n) matrix ,whose (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

$$W_{ij} = \frac{P_{ij,}cont}{P_{oj,}norm} - 1 \quad (1)$$

Where

$P_{ij,}cont$ Power flow through branch "j" during contingency "i" (single or double);

$P_{oj,}norm$ Base case power flow through branch "j"under normal conditions

The contingency probability array P: This is an (m x 1) array of branch outage probabilities. It is of the following form

$$P_{m\times 1} = \left[p_1 p_2 ...... p_m \right]^T \quad (2)$$

Where p_i is the probability of occurrence for contingency "i" (single or double) and is taken as 0.02.

The CSI for branch "j" is defined as the sum of the sensitivities of branch "j" to all the considered single or double contingencies, and is expressed as

$$CSI_j = \sum_{i=1}^{m} p_i u_{ij} w_{ij} \quad (3)$$

Where p_i, U_{ij} and W_{ij} are elements of matrices P, U and W respectively. m is the total number of considered single contingencies. CSI values are calculated for every branch using equation (3). Branches are then ranked by their corresponding CSI values. In general, the larger CSI value a branch has, the more sensitive it will be. The branch with the largest CSI is considered as the best location for placement of one TCSC. When more than one TCSC has to be installed, they will be chosen starting from the top of this ranked list and proceeding downward with as many branches as the number of available TCSCs.

B. Optimal settings of TCSC

Possible setting of TCSCs considering all the possible contingencies (single or double), the PSO optimization problem is solved.

The objective function is,

$$obj = \min \left\{ \begin{matrix} W_1 * JPP + \begin{pmatrix} W_2 * TCSC \\ installation\cos t \end{pmatrix} + \\ (\lambda_2 * VS) \end{matrix} \right\} \quad (4)$$

Where

$$JPP = \sum_{c=1}^{m} \sum_{k=1}^{n} a_k \left(\frac{p_k}{p_k^{\max}} \right)^4 \quad (5)$$

m Number of single or double contingencies Considered;

n Number of branches considered;

a_k Weight factor=1;

p_k Real power transfer on branch k;

$p_k^{\max}$ Maximum real power transfer on branch k;

JPP represents the severity of overloading considering all single contingencies or critical double contingencies.

TCSC installation cost includes the sum of installation cost of all the TCSCs and it can be calculated using the cost function for TCSC given by,

$$C_{TCSC} = 0.0015S^2 - 0.713S = 153.75\left(USS / k\,\text{var}\right) \quad (6)$$

Where S is the operating range of TCSC in MVAR.

VS includes voltage stability constraints in the objective function and is given by,

$$VS = \begin{cases} 0 if\ 0.9 < Vb < 1.1 \\ 0.9 - Vb if Vb < 0.9 \\ Vb - 1.1 if Vb > 1.1 \end{cases} \quad (7)$$

λ_2 Is the penalty factor.

W_1 (0.8) &W_2(0.2) are the weighing factors

The impedance limits of TCSC is given by,

$$-0.8X_L < X_{TCSC} < 0.8X_L \quad (8)$$

Where X_L is the original line reactance

While solving the optimization problem, power balance equations are taken as equality constraints. The power balance equations are given by,

$$\sum P_G = \sum P_D + P_L \quad (9)$$

Where

$\sum P_G$ Total power generation;

$\sum P_D$ Total power demand;

P_L Losses in the transmission network;

III. Overview of PSO

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. PSO has some advantages over other similar computational techniques, such as GA. It is easier to implement and there are few parameters to adjust .It has a most effective memory capability than GA.

PSO is developed through simulation of bird flocking

ISSN 2229-5518

in two dimensional spaces. The position of each agent is represented in X-Y plane with position (Sx, Sy), Vx (velocity along X-axis), and Vy (velocity along Y-axis). Modification of the agent position is realized by the position and velocity information. Each agent knows its best value so far, called 'Pbest', which contains the information on position and velocity. This information is the analogy of personal Experience of each agent. Moreover, each agent knows the best value so far, in the group 'Gbest' among all 'Pbest'. This Information is the analogy of knowledge, how the other neighboring agents have performed. Each agent tries to modify its position by considering current positions (Sx, Sy), current velocities (Vx, Vy), the individual intelligence (Pbest), and the group intelligence (Gbest).

The following equations are utilized, in computing the position and velocities, in the X-Y plane:

$$V_{id} = W * V_{id} + C_1 * rand * \left(P_{id} - X_{id}\right) + C_2 * rand * \left(P_{gd} - X_{id}\right) \quad (10)$$

$$X_{id} = X_{id} + X_{id} \quad (11)$$

Where

V_{id} Particle velocity;

X_{id} Current particle position;

P_{id} , P_{gd} Pbest & Gbest;

Rand Random number between (0, 1);

C_1 & C_2 Learning factors, usually $C_1 = C_2 = 2$

W Inertia weight and is given by

$$W = W_{\max} - \frac{\left(w_{\max} - w_{\min}\right)}{iter_{\max}} * iter \quad (12)$$

Where

$w_{\max}$ Initial weight;

$w_{\min}$ Final weight;

$iter$ Current iteration number;

$iter_{\max}$ Maximum iteration number;

The velocity of each agent is modified according to (10) and the position is modified according to (11). Each particle in the population is a solution. The number of particles in the population is to be between 20 and 100. Each particle contains Settings (reactance) of TCSCs to be installed. If 7 TCSCs are to be installed and 20 particles are taken, then the population will be a $20 * 7$ matrix.

The step by step algorithm for finding the optimal settings of TCSCs is given below.

Algorithm:

Step 1. The number of TCSCs to be placed is fixed from CSI ranking.

Step 2. The initial population of individuals is created satisfying the FACTS device's constraints.

Step 3. For each individual in the population, the fitness function given by (4) is evaluated.

Step 4. The velocity is updated by (10) and new population is created by (11).

Step 5. If maximum iteration number is reached, then go to next step else go to step3

Step 6. Print the best individual's settings and cost of installation.

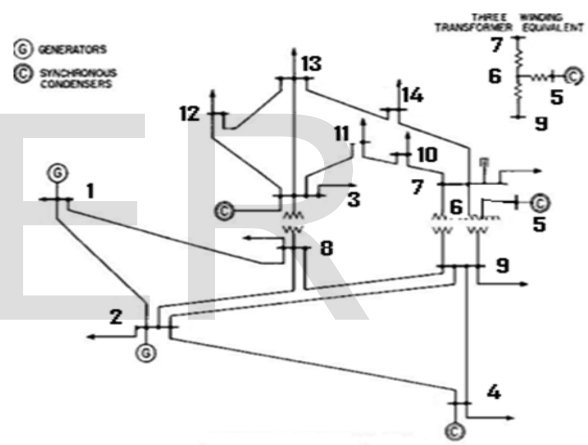

Fig.1 IEEE 14 BUS SYSTEM

For PSO the parameters utilized in these Results are shown in Table 1.

TABLE1: PARAMETER VALUES FOR PSO

Parameters of PSO	
C_1,C_2	2
W_{max}	0.8
W_{min}	0.2
Population Size	20
No.of iterations	50

IV. RESULTS AND DISCUSSIONS

ISSN 2229-5518

The effectiveness of proposed approach is illustrated using IEEE 14-Bus system. This system consists of five generators, fourteen buses, twenty transmission lines, and eleven loads. The simulations are carried out in MATLAB 9a environment.

There are 17 possible single line contingencies. Overloading of different branches when each line is removed and the total number of overloads are shown in table 2.In this test system the lines 1, 2 and 9 are overloaded for one time and the line 14 is overloaded three times. So the total number of overloads is six for all the 17 possible single contingencies.

To find the location of TCSC, the contingency sensitivity index (CSI) is calculated for 17 branches, considering all the possible single line contingencies and the lines are ranked according to the value of CSI which is shown in table 3.CSI is zero for the remaining branches.

TABLE 2: OVERLOADING OF LINES FOR ALL THE 17 POSSIBLE CONTINGENCIES

Line no	From-to bus	No. of times overloaded
2	1-8	1
14	8-9	3
1	1-2	1
9	4-9	1

In this case, According to CSI ranking transmission line 1-8 is chosen as the best location to place the first TCSC based on the available budget, the placement of TCSCs can be preceded by following the ranked list given above. Where branch 8-9 will be the second choice, branch 1-2 will be the third choice and so on.

TABLE 3: RANKING OF LINES FOR 14-BUS SYSTEM

Line no	From-to bus	CSI	Rank
2	1-8	0.0465	1
14	8-9	0.0386	2
1	1-2	0.0100	3
9	4-9	-0.0862	4

By applying PSO technique, the optimal settings of TCSC are obtained. Table 4 shows the setting values of TCSC for different lines. The PSO technique generates setting value corresponding to the line in which the TCSC is to be installed.

Once the parameter settings of TCSC are obtained we will place the TCSC in the corresponding line. The power flows in lines before and after placing the TCSC under single contingency are shown in table 5.

TABLE 4: OPTIMAL PARAMETER SETTINGS OF TCSC

Line no	From bus-to bus	Settings in (p.u)
2	1-8	0.1784
14	8-9	0.0302
1	1-2	0.0473
9	4-9	0.1368

As shown in Table 5, before placing TCSC the power flow in Line 14 (8-9 line) is 51.77MVA. When contingency occurs in line 5(2-9), the power flow in line 14 is 74.77MVA i.e. overloaded. But when TCSC is placed in line 14 under contingency in line 5, the power flow in line 14 is 68.78MVA (i.e. Overloading is eliminated). By obtaining optimal location and setting of TCSC, the overloading of lines can be eliminated or minimized. Now in this case the overloading is eliminated by placing TCSC in line 14.

TABLE 5: POWER FLOWS IN TRANSMISSION LINES FOR 14 BUS SYSTEM UNDER SINGLE LINE CONTINGENCY IN LINE 5 WITH TCSC IN LINE 14

Line No	From bus-to bus	Base case power flow	Power flow under contingency In line – 5 Without TCSC	Power flow under contingency In line – 5 With TCSC In line -14	Max. limit (MVA)
1	1-2	92.06	82.73	84.17	130
2	1-8	43.01	53.00	51.62	130
3	2-4	52.38	62.26	65.68	130
4	2-8	22.65	38.14	35.94	65
5	2-9	34.70	-	-	65
6	3-11	14.07	15.04	16.55	32
7	3-12	8.80	8.93	9.10	32
8	3-13	21.92	22.45	23.17	32
9	4-9	23.86	14.87	12.65	65
10	5-6	25.10	26.19	26.36	32
11	6-7	27.42	26.57	25.35	65
12	7-10	7.75	7.73	8.71	32
13	7-14	7.94	7.43	7.16	32
14	**8-9**	**51.77**	**74.77**	**68.78**	**70**
15	10-11	10.47	11.34	12.86	32
16	12-13	2.40	2.53	2.71	32
17	13-14	9.77	10.38	11.34	32

The value of JPP i.e. severity of overloading considering all single line contingencies is 41.53 before the placement of TCSC in line 14 and after placement of TCSC the JPP is reduced to 36.99.

V. CONCLUSION

This paper presents the application of PSO technique to find the optimal settings of TCSC in order to eliminate or reduce the line overloads during single contingencies and to minimize the installation cost of TCSC. The validation of this method was tested on IEEE 14-bus System and the results show that overloading of lines was minimized i.e. after placement of TCSC total number of overloaded lines was minimized to five.

VI. Future Scope

In this paper, PSO algorithm is used to determine the optimal settings of TCSC device to minimize overloads under single line contingency. The optimization problem is considered as single objective function. It can be extended to multi objective function by including multiple objectives. This can be extended to multiple contingencies by placing various types of FACTS devices. This can be extended to generator outage and transformer outage.

References

1. N. G. Hingorani, "Power electronics in electrical utilities: role of power electronics in future power systems," Proceedings of the IEEE, vol. 76, No.4, pp.481-482, Apr.1988.
2. Comparison of series FACTS devices via optimal location in a power system for congestion management-V.P.Rajdekar, V.K.Chandrakar.
3. Optimal location of FACTS devices for congestion management,S.N.Singh.A.K.David.
4. C. R. Fuerte-Esquivel, E. Acha, and H. Ambriz-Perez, "A thyristor controlled series compensator model for the power flow solution of practical power networks," *IEEE Trans. Power System*, vol. 15, No. 1, pp.58-64, Feb. 2000.
5. Y. Lu, Ali Abur, "Static security enhancement via optimal utilization of Thyristor-Controlled Series Capacitors,"IEEE Trans. Power System, vol.17, pp.324-329, May 2002.
6. C. R. Puerle-Esquivel and E. Acha, "A Newton-type algorithm for the control of power flow in electrical power networks," IEEE Trans. Power System, vol. 12, No. 4, pp. 1474-1480, Nov. 1997.
7. M. A. Abdel Moamen, and P. P. Narayana, "Newton- Raphson TCSC model for the power flow solution of practical power networks," IEEE Power Engineering Society Summer Meeting, vol. 3, pp.1488 – 1493, 2002.
8. L.J. Cai, I. Erlich, "Optimal Choice and Allocation of FACTS devices using Genetic Algorithms", *Proc. on Twelfth Intelligent Systems Application to Power Systems Conf.*, 2003, pp. 1-6
9. Y. Lu, Ali Abur, "Improving system static security via optimal placement of thyristor controlled series capacitors (TCSC)," *IEEE Power Engineering Society Winter Meeting*, vol. 2, pp.516-521, Feb. 2001.
10. Optimal Location and Parameter Settings of Multiple TCSCs for Increasing Power System Loadability Based on GA and PSO Techniques
G. I. Rashed1, Student Member, IEEE, H. I. Shaheen2, Student Member, IEEE, S. J. Cheng3.
11. Evolutionary optimization techniques for optimal location and parameter settings of TCSC under single line contingency, G.I.Rashed, H.I.Shaheen, S.J.Cheng.
12. D .Sobajic and Y.Pao, " An artificial intelligence system for power System contingency screening," *IEEE Trans. Power Systems*, vol.3, pp 647-653, May 1988.
13. C.Ejebe et al.,"Fast contingency screening and evaluation for voltage stability analysis," *IEEE Trans. Power System*, vol.3, pp 1582-1588, Nov.1988.
14. R .Chen et al.,"Multi-contingency preprocessing for security analysis using physical concepts and CQR with classifications," *IEEE Trans. Power Systems*, vol.8, pp 840-846, Aug. 1993.
15. Ahlada Sudersan, Mohamed Abdelrahman, Ghadir Radman,"Contingency selection and static security enhancement in powersystems using Heuristics-based genetic algorithms," *IEEE Proc. Of the Thirty-Sixth Southeastern Symposium* on 2004, pp.556 - 560 .
16. S.Mary Raja Slochanal, etal, "Application of PSO technique to find optimal settings of TCSC for static security enhancement considering installation cost,"Power Engineering Conference, vol. 2, Dec. 2005.
17. M. Saravanan, etal, "Application of PSO technique for optimal location of FACST devices considering system lodability and cost of installation,"*Power Engineering Conference*, vol. 2 pp.716 - 721, Dec. 2005.