Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 15 (2011) 908 – 914

Procedia Engineering

www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

Optimal Placement of Thyristor Controlled Series Compensation for Enhancing Power System Security Based on Computational Intelligence Techniques

Ghamgeen Izat Rashed*, Yuanzhang Sun

School of Electrical Engineering,Wuhan University, No.8 East Lake South Road,Wuhan 430072, Hubei, China

Abstract

The placement of Flexible Alternating Current Transmission Systems (FACTS) devices in a power network is of great importance to ensure the utilization of the full potential of the transmission network. Thyristor Controlled Series Capacitor (TCSC) is one of the most effective and widely used devices from the FACTS family which is installed in series with a transmission line and offers smooth and flexible control of the line impedance with much faster response compared to the traditional control devices. This paper presents a new approach based on Computational Intelligence (CI) techniques to find out the optimal placement and parameter setting of TCSC for enhancing power system security under single line contingency (N-1 contingency). Firstly, a contingency analysis and ranking process to determine the most severe line outage contingencies, considering lines overloaded and bus voltage limit violations as a performance index, is performed. Secondly, a relatively new evolutionary optimization technique, namely: Differential Evolution (DE) technique is applied to find out the optimal location and parameter setting of TCSC under the determined contingency scenarios. To verify our proposed approach and for comparison purposes, simulations are performed on an IEEE 6–bus power system and an IEEE 14–bus power system. The obtained results indicate that DE is an easy to use, fast, robust and powerful optimization technique compared with Genetic Algorithm (GA). Installing TCSC in the optimal location determined by DE can significantly enhance the security of power system by eliminating or minimizing the number of overloaded lines and the bus voltage limit violations.

Selection and/or peer-review under responsibility of [CEIS 2011]

Keywords: Contingency Analysis; Differential Evolution (DE); Genetic Algorithm (GA): TCSC; Loadability; Power Flow

* Corresponding author. Tel.: +086-189-639-63071; fax: +086-27-6877-5521.
E-mail address: ghamgeen@whu.edu.cn.

doi:10.1016/j.proeng.2011.08.168

1. Introduction

The concept of Flexible AC Transmission System (FACTS) devices was proposed by N. G. Hingorani [1], Thyristor Controlled Series Capacitor (TCSC) is one of the most effective FACTS devices which are increasingly used nowadays in stresses transmission systems. TCSC can enhance the stability, ameliorate the dynamic characteristics of power system, and increase the transfer capability of the transmission system by reducing the transfer reactance between the buses at which the line is connected. However, it has been generally acknowledged that the effectiveness of TCSCs depends importantly on their locations and sizes in power system.

A Newton-Raphson load flow algorithm to solve power flow problems in power system with thyristor controlled series capacitor (TCSC) was proposed in [2]. The optimal location of FACTS devices was solved based on genetic algorithm in [3].

Also a lot of work has been done in the contingency analysis research area. Operation scheme of FACTS devices to enhance the power system steady-state security level considering a line contingency analysis is suggested in [4]. A method for contingency selection and security enhancement of power systems by optimal placement of FACTS devices using GA is presented in [5]. Utilization of TCSC during single contingencies was investigated in [6]. A new procedure to place TCSC along system branches in an attempt to alleviate overloads during single contingency is presented in [7].

Recently, a relatively new, easy to implement, reasonably fast, and robust Evolutionary Algorithms (EAs) technique, known as Differential Evolution (DE) has been developed [8]. DE has shown great promise in several applications including the field of power system [9].

In this paper, one of the newest EAs techniques, namely DE, is applied to find out the optimal location and parameter setting of TCSC device for enhancing power system security under single line contingencies through eliminating or minimizing the overloaded lines and the bus voltage limit violations.

2. Simulation Results

2.1. Observed results

For the validation of the proposed techniques simulations are performed on an IEEE 6-bus power system and IEEE-14 bus power system and the results are shown below:

2.1.1 IEEE 6-bus test system

Contingency analysis and ranking process is performed on this system, there are 11 possible single contingencies. For each single line outage contingency: Firstly, we determined the number of over loaded lines (NOLL) and the Number of voltage violation buses (NVVB). Loading of the lines up to their thermal limits, 100% loading, is considered to be the threshold or the criterion for determining the overloaded lines, and the range [0.9-1.1] p.u. for bus voltage limits is considered to be the threshold or the criterion for determining the buses which have voltage limit violations. Secondly, we rank the tripped lines according to the severity of the contingency, in other words, according to the performance index $PI = (NOLL + NVVB)$ as shown in Table 1. PI is zero for the remaining lines. From the contingency analysis and ranking process performed on this system, we can see there are 6 lines which are the severest contingency scenarios in this system as shown in Table 1. Overloaded lines with their overloading percentage and bus voltage limit violations before and after using TCSC in the optimized locations obtained by applying DE, and GA techniques after 100 trials for each technique are shown in Table 2, and Table 3. Fig. 1 shows the minimization of the objective function achieved by both DE and GA techniques when line 6 is outage.

Table 1 .Contingency ranking of lines for IEEE 6-bus system

Tripped line			Number of Over Loaded Lines (NOLL)	Number of Voltage Violation Buses (NVVB)	Performance Index $PI = (NOLL + NVVB)$	Rank
Line number	From bus	To bus				
1	1	4	3	1	4	1
2	1	5	3	0	3	2
6	2	4	2	1	3	3
9	3	6	2	1	3	4
5	2	6	2	0	2	5
4	2	5	1	0	1	6

Table 2 .Overloaded lines and bus voltage violations before and after placing TCSC for IEEE 6-Bus system with optimal location and optimal parameter setting of TCSC by DE

Tripped Line		Before Placing TCSC			After Placing TCSC			Optimal Placement of TCSC	Optimal Setting of TCSC	Rank
From Bus	To Bus	Overloaded Lines	Overloading %	Voltage Violation Buses	Overloaded Lines	Overloading %	Voltage Violation Buses			
1	4	1-5 1-2 2-4	106.644 122.248 116.974	Bus_4	1-5 - 2-4	105.636 - 114.787	-	2	0.1058	1
1	5	1-4 1-2 3-5	115.153 108.066 103.960	-	1-4 - -	110.320 - -	-	7	-0.125	2
2	4	1-4 3-5	158.955 104.747	Bus_4	1-4 -	140.755 -	-	7	0.118	3
3	6	2-6 3-5	129.481 144.285	Bus_6	2-6 3-5	123.583 120.857	Bus_6	5	-0.0912	4
2	6	2-3 3-6	138.148 114.426	-	- 3-6	- 112.557	-	7	0.0989	5
2	5	3-5	102.436	-	-	-	-	2	-0.115	6

Table 3.Overloaded lines and bus voltage violations before and after placing TCSC for IEEE 6-Bus system with optimal location and optimal parameter setting of TCSC by GA

Tripped Line		Before Placing TCSC			After Placing TCSC			Optimal Placement of TCSC	Optimal Setting of TCSC	Rank
From Bus	To Bus	Overloaded Lines	Overloading %	Voltage Violation Buses	Overloaded Lines	Overloading %	Voltage Violation Buses			
1	4	1-5 1-2 2-4	106.644 122.248 116.974	Bus_4	1-5 - 2-4	104.681 - 114.217	-	3	-0.0978	1
1	5	1-4 1-2 3-5	115.153 108.066 103.960	-	1-4 - -	109.921 - -	-	4	0.1456	2
2	4	1-4 3-5	158.955 104.747	Bus_4	1-4 -	138.765 -	-	7	0.1086	3
3	6	2-6 3-5	129.481 144.285	Bus_6	2-6 3-5	121.791 118.857	Bus_6	5	-0.0945	4
2	6	2-3 3-6	138.148 114.426	-	- 3-6	- 111.128	-	7	0.0998	5
2	5	3-5	102.436	-	-	-	-	2	-0.143	6

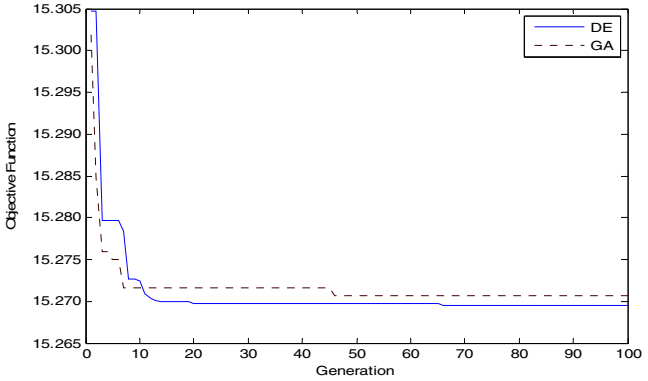

Fig. 1 Minimization of the objective function by both DE and GA techniques for IEEE 6-bus system when line 6 is outage.

2.1.2 IEEE 14-bus test system

Contingence analysis and ranking process is also performed on this system as mentioned in IEEE-6 bus system. There are 20 possible single contingencies in this system. The severest single line contingency scenarios are determined and the tripped lines are ranked according to the performance index, $PI = (NOLL + NVVB)$ as shown in table 4. PI is zero for the remaining lines. Table 5, and Table 6 shows the overloaded lines with their overloading percentage and bus voltage limit violations before and after using TCSC in the optimized locations obtained by applying DE, and GA techniques after 100 trials for each technique. The minimization of the objective function achieved by both DE and GA techniques when line 17 is outage is shown in Fig. 2.

Table 4.Contingency ranking of lines for IEEE 14-bus system

Tripped Line			Number of Over Loaded Lines (NOLL)	Number of Voltage Violation Buses (NVVB)	Performance Index $PI = (NOLL + NVVB)$	Rank
Line Number	From Bus	To Bus				
1	1	2	5	7	12	1
3	2	3	4	5	9	2
2	1	5	2	6	8	3
10	5	6	1	5	6	4
4	2	4	3	2	5	5
14	7	8	0	3	3	6
15	7	9	0	3	3	7
13	6	13	1	2	3	8
5	2	5	1	1	2	9
7	5	4	0	1	1	10
8	4	7	0	1	1	11
9	4	9	0	1	1	12
16	9	10	0	1	1	13
17	9	14	0	1	1	14
20	13	14	0	1	1	15

Table 5.Overloaded lines and bus voltage violations before and after placing TCSC for IEEE 14-Bus system with optimal location and optimal parameter setting of TCSC by DE

Tripped Line		Before Placing TCSC			After Placing TCSC			Optimal Placement of TCSC	Optimal Setting of TCSC	Rank
From Bus	To Bus	Overloaded Lines	Overloading %	Voltage Violation Buses	Overloaded Lines	Overloading %	Voltage Violation Buses			
1	2	1-5 2-3 3-4 4-5 9-10	110.918 191.963 189.112 170.627 133.141	Bus_2 Bus_4 Bus_5 Bus_6 Bus_7 Bus_13 Bus_14	3-4 6-11 6-13	143.854 140.611 112.038	-	7	0.02	1
2	3	1-5 2-5 3-4 4-5	119.381 135.284 190.521 175.416	Bus_3 Bus_9 Bus_10 Bus_12 Bus_13	2-4 3-4	121.051 171.452	-	4	-0.079	2
1	5	1-2 2-5	142.960 163.716	Bus_9 Bus_10 Bus_11 Bus_12 Bus_13 Bus_14	1-2 2-5	138.104 145.836	-	4	-0.051915	3
5	6	4-5	157.284	Bus_6 Bus_11 Bus_12 Bus_13 Bus_14	-	-	-	7	0.01789	4
2	4	1-5 2-5 4-5	116.822 135.755 173.714	Bus_10 Bus_14	4-5	156.941	-	5	0.08579	5
7	8	-	-	Bus_9 Bus_10 Bus_14	-	-	-	3	-0.079993	6
7	9	-	-	Bus_9 Bus_10 Bus_14	-	-	-	3	-0.09514	7
6	13	12-13	129.682	Bus_13 Bus_14	12-13	125.326	-	3	-0.081259	8
2	5	1-5	119.173	Bus_14	1-5	112.58	-	1	-0.014667	9
5	4	-	-	Bus_14	-	-	-	5	0.07698	10
4	7	-	-	Bus_14	-	-	-	3	-0.08658	11
4	9	-	-	Bus_14	-	-	-	3	-0.091786	12
9	10	-	-	Bus_10	-	-	-	3	-0.096589	13
9	14	-	-	Bus_14	-	-	-	3	-0.074798	14
13	14	-	-	Bus_14	-	-	-	3	-0.08	15

Table 6.Overloaded lines and bus voltage violations before and after placing TCSC for IEEE 14-Bus system with optimal location and optimal parameter setting of TCSC by GA

Tripped Line		Before Placing TCSC			After Placing TCSC			Optimal Placement of TCSC	Optimal Setting of TCSC	Rank
From Bus	To Bus	Overloaded Lines	Overloading %	Voltage Violation Buses	Overloaded Lines	Overloading %	Voltage Violation Buses			
1	2	1-5 2-3 3-4 4-5 9-10	110.918 191.963 189.112 170.627 133.141	Bus_2 Bus_4 Bus_5 Bus_6 Bus_7 Bus_13 Bus_14	1-5 3-4 4-5	129.609 178.561 167.141	-	3	-0.0896	1
2	3	1-5 2-5 3-4 4-5	119.381 135.284 190.521 175.416	Bus_3 Bus_9 Bus_10 Bus_12 Bus_13	2-4 3-4	121.051 166.721	-	4	-0.07105	2
1	5	1-2 2-5	142.960 163.716	Bus_9 Bus_10 Bus_11 Bus_12 Bus_13 Bus_14	1-2 2-5	133.747 145.985	-	4	-0.061936	3
5	6	4-5	157.284	Bus_6 Bus_11 Bus_12 Bus_13 Bus_14	4-5	114.443	-	7	0.021	4
2	4	1-5 2-5 4-5	116.822 135.755 173.714	Bus_10 Bus_14	2-5 4-5	126.357 152.163	-	5	0.06548	5
7	8	-	-	Bus_9 Bus_10 Bus_14	-	-	-	5	0.0798	6
7	9	-	-	Bus_9 Bus_10 Bus_14	-	-	-	5	0.05074	7
6	13	12-13	129.682	Bus_13 Bus_14	12-13	125.312	-	5	-0.0928	8
2	5	1-5	119.173	Bus_14	1-5	113.127	-	1	-0.013171	9
5	4	-	-	Bus_14	-	-	-	5	0.06987	10
4	7	-	-	Bus_14	-	-	-	3	-0.0518	11
4	9	-	-	Bus_14	-	-	-	3	-0.054141	12
9	10	-	-	Bus_10	-	-	-	3	-0.0786	13
9	14	-	-	Bus_14	-	-	-	3	-0.0988	14
13	14	-	-	Bus_14	-	-	-	5	0.0894	15

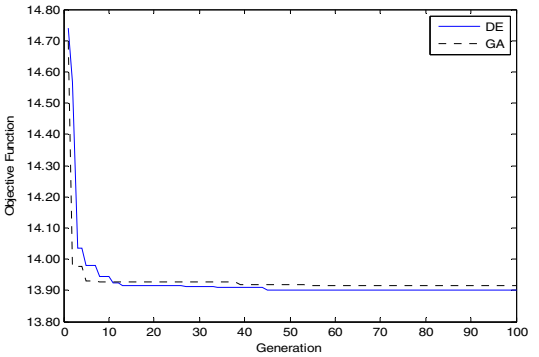

Fig. 2 Minimization of the objective function by both DE and GA techniques for IEEE 14-bus system when line 17 is outage.

3. Conclusion

In this paper, the effectiveness of the optimal installation of TCSC for enhancing the security of power systems under single line contingencies has been investigated. Determination of the most sever contingency scenarios were performed based on the contingency selection and ranking process. One of the newest computational intelligence techniques, namely: DE has been successfully applied to the problem under consideration. Maximization of power system security is considered as the optimization criterion. Also, in this paper, two case studies were conducted using an IEEE 6-bus system and IEEE 14-bus system. The obtained results show that DE technique has superior feature including high-quality solution, stable convergence characteristic, and good computation efficiency. Finally, our results show that using TCSC in the optimal location with the optimal parameter setting can significantly improve the security of power systems under single line contingencies.

Acknowledgements

This work was supported by Wuhan University, Basic Research Fund of National University (No.207271200) the authors would like to thank the organization for their support.

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] 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.

[3] G. I. Rashed, H. I. Shaheen, S. J. Cheng, "Optimal Location and Parameter Setting of TCSC by Both Genetic Algorithm and Particle Swarm Optimization," *2nd IEEE Conference on Industrial Electronics and Applications (ICIEA),* Harbin, China, May 2007.

[4] S. H. Song, J. U. Lim, S. W. Jung, and S. I. Moon," Preventive and Corrective Operation of FACTS devices to cope with a single line-faulted contingency," *IEEE Power Engineering Society General Meeting*, pp. 837-842, 2004.

[5] A. Sudersan, M. Abdelrahman, and M. Radman, "Contingency Selection and Static Security Enhancement in Power Systems Using Heuristics-based Genetic Algorithms," *IEEE Proceedings of the Thixty-Sixth Southeastern Symposium*, pp. 556-560, 2004.

[6] 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.

[7] Y. Lu, Ali Abur, "Improving system static security via optimal placement of thyristor controlled series capacitors (TCSC)," IEEE Power Society Winter Meeting, vol.2, pp.516-521, Feb. 2001.

[8] R. Storn, and K.Price, Differential evolution-a simple and efficient adaptive scheme for global optimization over continuous spaces, Technical Report, International Computer Science Institute, Berkley, 1995.

[9] S. Nagalakshmi, and N. Kamaraj, "Loadability enhancement for pool model with FACTS devices in transmission system using differential evolution and particle swarm optimization," 2010 India International Conference on Power Electronics (IICPE), pp.1- 8, 2011.