

Optimal Allocation of FACTS Device with Multiple Objectives Using Genetic Algorithm

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ABSTRACT: In this paper Multi objective functions are simultaneously considered as the indexes of the system performance minimize total generation fuel cost and maximize system load-ability within system security margin. To find the optimal location and optimal value for Thyristor Controlled Series Compensator (TCSC) using optimization technique Genetic Algorithm (GA) to maximize system load-ability and minimize the system losses considering multi objectives optimization approach. A GA based Optimal Power Flow (OPF) is proposed to determine the type of FACTS (Flexible AC Transmission system) controllers, its optimal location and rating of the devices in power systems. The value of TCSC and line losses is applied as measure of power system performance. The type of FACTS controllers are used and modeled for steady-state studies: TCSC, minimize total generation fuel cost and maximize system load-ability within system security margin. Simulations will be carrying on IEEE30 bus power system for type of FACTS devices.

Keywords: FACTS Device, Genetic algorithm, Optimal Power Flow (OPF), Loss minimization.

I. Introduction

Deregulated power systems suffer from congestion management problems. Also they cannot fully utilize transmission lines due to excessive power loss that it could cause. FACTS devices such as Thyristor-controlled series compensators (TCSC) can, by controlling the power flow in the network, help reducing the flows in heavily loaded lines. Also they can minimize the power loss of the systems. However, because of the considerable cost of FACTS devices, it is important to minimize their number and obtain their optimal locations in the system [1].

The TCSC is one of the series FACTS devices. It uses an extremely simple main circuit. In this FACTS device a capacitor is inserted directly in series with the transmission line to be compensated and a Thyristor-controlled inductor is connected directly in parallel with the capacitor, thus no interfacing equipment, like high voltage transformers, are required. This makes the TCSC much more economic than some other competing FACTS technologies [2].

In [3], the TCSC may have one of the two possible characteristics: capacitive or inductive, respectively to decrease or increase the overall reactance of the line XL. It is modeled with three ideal switched elements connected in parallel: a capacitor, an inductor and a simple switch to short circuit both of them when they are not needed in the circuit. The capacitor and the inductor are variable and their values are dependent on the reactance and power transfer capability of the line in series with which the device is inserted. In order to avoid resonance, only one of the three elements can be switched at a time. Moreover, in order to avoid overcompensation of the line, the maximum value of the capacitance is fixed at $-0.8 XL$. For the inductance, the maximum is $0.2 XL$. The TCSC model is presented in [3] is shown in Fig. 1.

In [4], the TCSC is a capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor to provide a smooth control of the series capacitive reactance. Model of the TCSC presented in [4] is shown in Fig. 2.

Another TCSC model has been used in [5]. According to this model a variable reactance is inserted in series with the line to be compensated. This model is used in this paper and the reactance is assumed to vary in the range from $-0.3 XL$ to $-0.7 XL$.

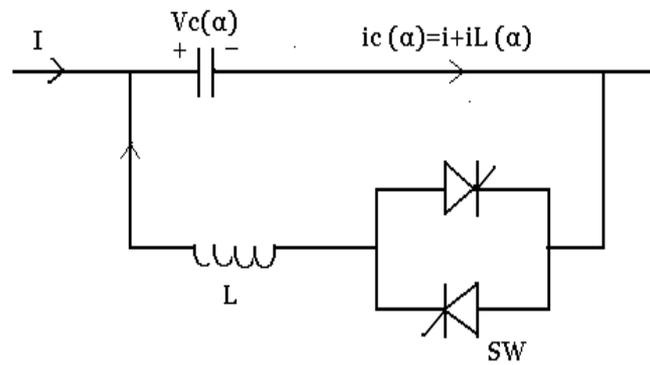


Figure.1. Thyristor controlled-series capacitor

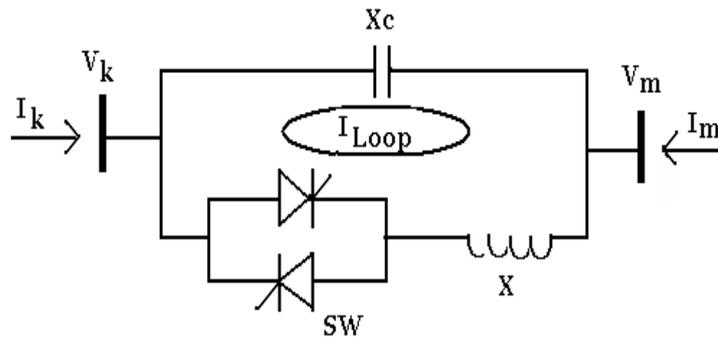


Figure.2. TCSC Model

Several research works are carried out to solve the optimal location problem of the TCSC. Optimization techniques applied in most of these works cannot be accepted as general optimization techniques as they used a fixed pre-specified number of FACTS devices. Some other works did not select the proper type or the proper working range of FACTS devices used in the optimization problem. Power system can, in general, be measured by system load-ability and/or system losses at a condition that nodal voltage magnitudes are kept within acceptable limits and thermal constraints of system elements are not violated.

According to such optimization problem can be solved by using heuristic methods such as genetic algorithms [6,7]. GA is integrated with conventional optimal power flow (OPF) [8] to select the best control parameters to minimize the total generation fuel cost and keep the power flows within the security limits. In proposed optimal choice and allocation of FACTS devices [9] in multi-machine power systems using genetic algorithm. The objective is to achieve the power system economic generation allocation and dispatch in a deregulated electricity market.

The objective is to achieve the power system economic generation allocation and dispatch in a deregulated electricity market. In implementation of the proposed real genetic algorithm has performed well when it is used to determine the location and compensation level of TCSC with the aim of maximizing the Total Transfer Capability (TTC) [10] of the system. The location of FACTS devices and the setting of their control parameters are optimized by a Bacterial Swarming Algorithm (BSA) [11] to improve the performance of the power network. Two objective functions are simultaneously considered as the indices of the system performance: maximization of system load-ability in system security margin and minimization of total generation fuel cost.

In this paper, an approach to find the optimal location of TCSC in the power system to improve the load-ability of the lines and minimize the total loss using GA is presented. The proposed approach aims to find the optimal number of devices and their optimal ratings with taking into consideration the thermal and voltage limits. Examination of the proposed approach is carried out on IEEE30-bus system.

II. The Proposed Optimization Technique

The problem is to find the optimum numbers, locations and reactance of the TCSC devices to be used in the power system. This problem is a nonlinear multi-objective one. The GA method will be used in this paper where it only uses the values of the objective function and less likely to get trapped at a local optimum.

Minimize the total losses without taking into consideration on the number of devices. That is it is required to minimize the objective function. Total system losses are equal to Sum of real losses of all system lines. Total loss and real losses are founded using MATPOWER [12].

New reactance = Old reactance + X_{TCSC} . Power flows are calculated before and after placing TCSC's.

TCSC Modeling

Thyristor controlled series compensation (TCSC) is shown in figure 3.

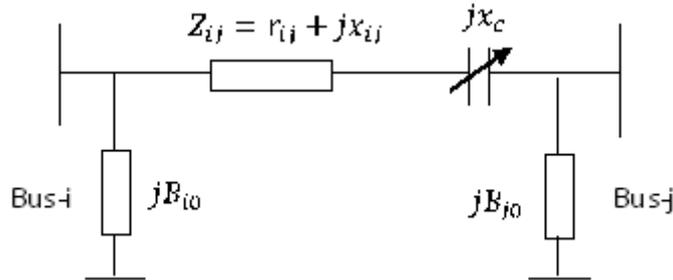


Figure.3 Thyristor controlled series compensation

Where x_{ij} is the reactance of the line, r_{ij} is the resistance of the line, B_{i0} and B_{j0} are the half-line charging susceptance of the line at bus-i and bus-j. The difference between the line susceptance before and after the addition of TCSC can be expressed as:

$$\Delta y_{ij} = y'_{ij} - y_{ij} = (g'_{ij} + jb'_{ij}) - (g_{ij} + jb_{ij}) \quad (1)$$

$$g_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} \quad (2)$$

$$b_{ij} = -\frac{x_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} \quad (3)$$

$$g'_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + (x_{ij} + x_c)^2}} \quad (4)$$

$$b'_{ij} = -\frac{r_{ij} + x_c}{\sqrt{r_{ij}^2 + (x_{ij} + x_c)^2}} \quad (5)$$

$$Y'_{BUS} = Y_{BUS} + \begin{bmatrix} 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & \Delta y_{ij} & 0 & \dots & 0 & -\Delta y_{ij} & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & -\Delta y_{ij} & 0 & \dots & 0 & \Delta y_{ij} & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \end{bmatrix} \quad (6)$$

III. Problem Formulation

Problem Variables

Optimal power system operation seeks to optimize the steady state performance of a power system in terms of an objective function while satisfying several equality and inequality Constraints [7]-[9]. Generally, Optimal Power Flow is formulated an optimization problem as follows:

Minimize $J(x,u)$

Subject to

$$g(x, u) = 0 \quad (7)$$

$$h(x, u) \leq 0 \quad (8)$$

u : Vector of problem control variable

x : Vector of system state variables

$J(x, u)$: Objective function to be minimized

$g(x, u)$: Equality Constraints represents non-linear load flow equations.

$h(x, u)$: Inequality Constraints i.e. system functional operating constraints.

Where u is a vector of control variables consisting of generator voltages V_G , generator real power outputs P_G except at slack bus P_{G1} , transformer tap settings T and shunt VAR compensation Q_c .

Hence u can be expressed as:

$$u^T = [V_{G_1} \dots V_{G_{NG}}, P_{G_2} \dots P_{G_{NG}}, T_1 \dots T_{NT}, Q_{C_1} \dots Q_{C_{NC}}] \quad (9)$$

Objective Functions

J is the objective function to be minimize, which is one of the following:

Fuel cost minimization

It seeks to find the optimal active power outputs of the generation plants so as to minimize the total fuel cost.

This can be expressed as

$$J = \sum_{i=1}^{NG} f_i \left(\frac{\$}{hr} \right) \quad (10)$$

Where f_i is the fuel cost curve of the i th generator and it is assumed here to be represented by the following quadratic function:

$$f_i = a_i + b_i P_{G_i} + c_i P_{G_i}^2 \left(\frac{\$}{hr} \right) \quad (11)$$

Where a_i, b_i , and c_i are the cost coefficients of the i^{th} generator.

Active power loss minimization

The objective function J is considered as active power loss of the system.

$$J = f_c(x, y) = \sum_{i=1}^{n_{line}} Loss_i \quad (12)$$

Where n_{line} is the number of branches.

Problem Constraints

Equality constraints: The equality constraints that are the power flow equations corresponding to both real and reactive power balance equations, which can be written as:

$$P_{G_i} - P_{D_i} - P_i(V, \delta) = 0 \quad (13)$$

$$Q_{G_i} - Q_{D_i} - Q_i(V, \delta) = 0 \quad (14)$$

$$P_i = \sum V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad (15)$$

$$Q_i = \sum V_i V_j (B_{ij} \cos \delta_{ij} - G_{ij} \sin \delta_{ij}) \quad (16)$$

Inequality constraints: The inequality constraints are the system operating limits. The inequality constraints that are real power outputs, reactive power outputs and generator outputs.

$$\begin{aligned} P_{G_i}^{min} &\leq P_{G_i} \leq P_{G_i}^{max} && i \in N_G \\ Q_{G_i}^{min} &\leq Q_{G_i} \leq Q_{G_i}^{max} && i \in N_G \\ |S_k| &\leq S_k^{max} && k \in N_E \\ V_i^{min} &\leq V_i \leq V_i^{max} && i \in N_B \end{aligned} \quad (17)$$

IV. Results And Discussions

The proposed approach has been tested on the standard IEEE 30 bus test system. In order to show the effectiveness of proposed method, a developed program in MATLAB environment is used.

Case Study: IEEE 30 bus system [12]:

IEEE 30 bus system is taken as a test system. That the system consists of 30 buses, 41 branches and 5 generators. The range of TCSC is taken as -30% to -70% from line reactance as in [13] and the power flow is carried out before and after allocating the TCSCs to determine their benefits. The cost coefficients of IEEE 30 bus system is as shown in below table.1.

Table.1 a,b,c constants for generators

Generator No	a	b	c
1	0	2	0.00375
2	0	1.75	0.0175
3	0	1	0.0625
4	0	3.25	0.002075
5	0	3	0.025
6	0	3	0.025

Table.2 Generator Voltages, Pg and Cost values

Unit No	Bus no	Voltage Before TCSC	Voltage After TCSC	Pgen Before TCSC	Pgen After TCSC	Cost Before TCSC	Cost After TCSC
1	1	1.050000	1.050000	176.35828	175.01343	469.34998	464.88824
2	2	1.038235	1.039999	50.342983	49.727625	132.45249	130.29798
3	5	1.045077	1.005882	20.435657	21.315960	46.536663	49.714096
4	8	1.027835	1.005882	23.680715	22.166740	81.639197	76.139884
5	11	1.008730	1.059999	10.854663	12.632362	35.509582	41.886502
6	13	1.055293	1.045294	12.047861	12.252980	39.772357	40.512329

Table.3 Fuel Cost

Before TCSC	After TCSC
804.144360 \$/hr	802.936280\$/hr
problem converged in 47 iterations	problem converged in 52 iterations

Voltage magnitudes of IEEE30-bus system without TCSC

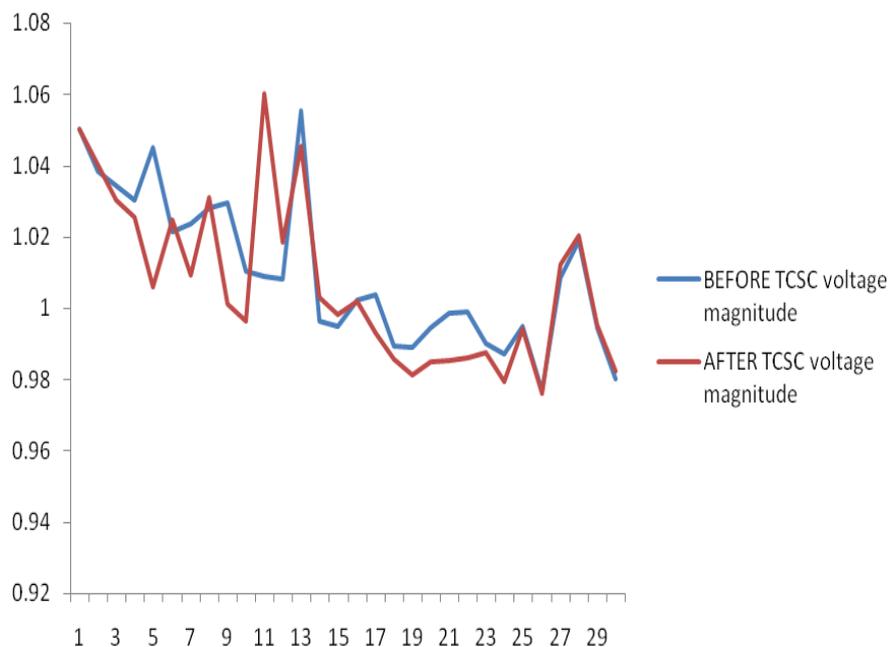


Figure 4. Voltage magnitudes before and after placement of TCSC

Active power loss and Reactive power loss of IEEE30-bus system with and without TCSC

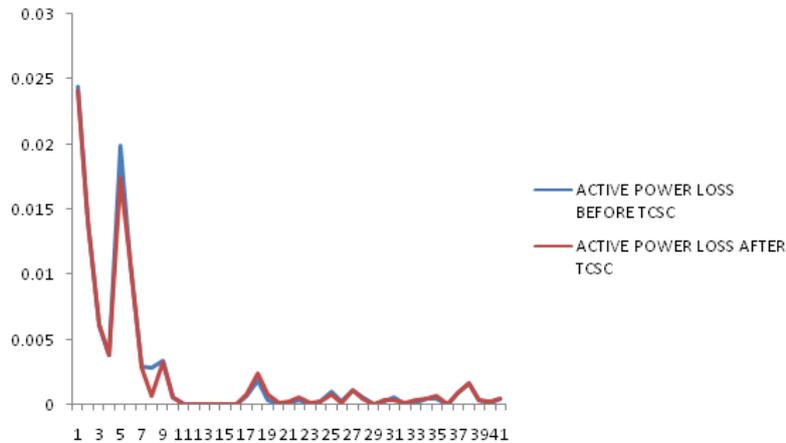


Figure 5. Active Power Loss before and after placement of TCSC

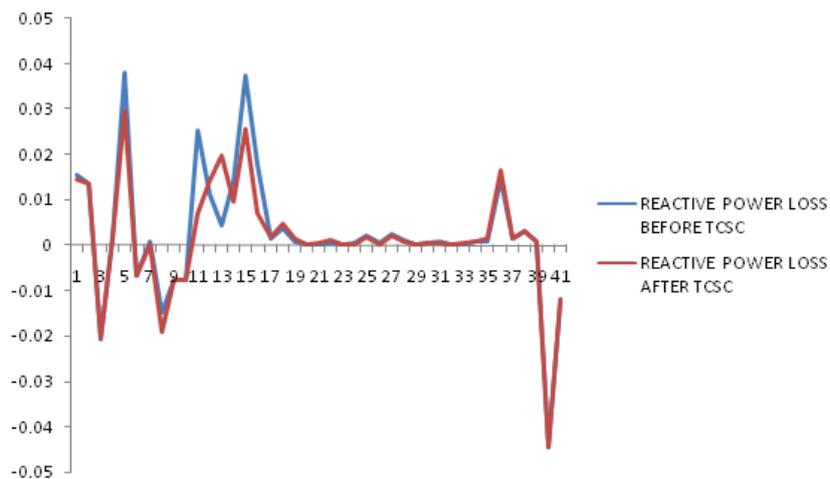


Figure 6. Reactive Power Loss before and after placement of TCSC

V. Conclusion

Optimal location of TCSC is placed in line number 20 and rating of TCSC is -0.084375(Reactance value) using GA is proposed in this paper. TCSC in a power system is improved the load-ability of its lines and minimize its total loss. The proposed technique minimizes the real power loss and reactive power loss. And also it improved the voltage profile. The fuel cost also reduced from 804.144360\$/hr to 802.936280\$/hr. The power angles of nodal voltages are increased. A MATLAB program for optimal allocation and rating of TCSC using GA results are presented.

REFERENCES

- [1] A. Y. Abdelaziz, M. A. El-Sharkawy, M. A. Attia "Optimal Allocation of TCSC Devices Using Genetic Algorithms" Proceedings of the 14th International Middle East Power Systems Conference, Cairo University, Egypt, December 19-21, 2010.
- [2] S. Meikandasivam, Rajesh Kumar Nema and Shailendra Kumar Jain, "Behavioral Study of TCSC Device - A Matlab/Simulink Implementation," World Academy of Science, Engineering and Technology, Vol. 45, 2008, pp. 694-699.
- [3] Stéphane Gerbex, Rachid Cherkaoui, and Alain J. Germond, "Optimal Location of Multi-Type FACTS Devices in a Power System by Means of Genetic Algorithms," IEEE Transactions on Power Systems, Vol. 16, No. 3, August 2001, pp. 537-544.
- [4] R. Narmatha Banu and D. Devaraj, "Genetic Algorithm Approach for Optimal Power Flow with FACTS Devices," 4th International IEEE Conference Intelligent Systems, Varna, September 2008.

- [5] M. Saravanan, S. M. R Slochanal, P. Venkatesh and J. P. S. Abraham, "Application of Particle Swarm Optimization Technique for Optimal Location of FACTS Devices Considering Cost of Installation and System Loadability", *Electric Power Systems Research*, Vol. 77, No. 3/4, 2007 , pp. 276-283.
- [6] S. M. Sait and H. Youssef, "Iterative Computer Algorithms with Application in Engineering: Solving Combinatorial Optimization Problems," IEEE Computer Society Press, 1999.
- [7] D. E. Goldberg, "Genetic Algorithms in Search Optimization and Machine Learning", Addison-Wesley Publishing Company, 1989.
- [8] T. S. Chung and Y. Z. Li, "A Hybrid GA Approach for OPF with Consideration of FACTS Devices," *IEEE Power Engineering Review*, August 2000, Vol. 20, Issue 8, pp. 54-57.
- [9] L. J. Cai, I. Erlich and G. Stamsis, "Optimal Choice and Allocation of FACTS Devices in Deregulated Electricity Market Using Genetic Algorithms," in *Proceeding of the IEEE Power Systems Conference and Exposition*, October 2004, Vol. 1, pp. 201-207.
- [10] W. Feng and G. B. Shrestha, "Allocation of TCSC Devices to Optimize Total Transmission Capacity in a Competitive Power Market," *Proceedings of the IEEE Power Engineering Society Winter Meeting*, Columbus, OH, Vol. 2, 2001, pp. 587-593.
- [11] Z. Lu., M. S. Li, L. Jiang and Q. H. Wu, "Optimal Allocation of FACTS Devices with Multiple Objectives Achieved by Bacterial Swarming Algorithm," *IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century*, Pittsburg, PA, July 2008, pp. 1-7.
- [12] Ray D. Zimmerman and E. Carlos Murillo-Sanchez, "Matpower A Matlab™ Power System Simulation Package Version 3.2", User's Manual, September 21, 2007. <http://www.Pserc.Cornell.Edu/Matpower/>
- [13] G. Y. Yang, G. Hovland, R. Majumder and Z. Y. Dong, "TCSC Allocation based on Line Flow Based Equations Via Mixed-Integer Programming," *IEEE Transactions on Power Systems*, Vol. 22, No. 4, November 2007, pp. 2262-2269.
- [14] W. Shao and V. Vittal, "LP-based OPF for corrective FACTS control to relieve overloads and voltage violations," *IEEE Transactions on Power Systems*, vol. 21, no. 4, pp. 1832–1839, Dec., 2006.
- [15] S. Gerbex, R. Cherkaoui, and A. J. Germond, "Optimal location of multi type facts devices in a power system by means of genetic algorithms," *IEEE Transactions on Power Systems*, vol. 16, no. 3, pp. 537–544, Aug., 2001.
- [16] N.G.Hingorani and L.Gyugyi, "Understanding FACTS", the Institution of Electric and Electronics Engineers, 1998.

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