December, 2010

Optimal Allocation of TCSC Devices Using Genetic Algorithms

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Available at: https://works.bepress.com/almoataz_abdelaziz/19/
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Abstract - This paper presents an approach to find the optimal location of thyristor-controlled series compensators (TCSC) in a power system to improve the loadability of its lines and minimize its total loss. Also the proposed approach aims to find the optimal number of devices and their optimal ratings by using genetic algorithm (GA) with taking into consideration the thermal and voltage limits. Examination of the proposed approach is carried out on the IEEE 9-bus system.

Index Terms – TCSC devices, Genetic algorithms, Optimal locations, 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.

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 [1].

In [2], the TCSC may have one of the two possible characteristics: capacitive or inductive, respectively to decrease or increase the overall reactance of the line X_L. It is modeled with three ideal switched elements connected in parallel: a capacitor, an inductor and a simple switch to shunt 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 X_L. For the inductance, the maximum is 0.2 X_L. The TCSC model presented in [2] is shown in Fig. 1.

In [3], 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 [3] is shown in Fig. 2.

Another TCSC model has been used in [4]. 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 X_L to -0.7 X_L.

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.

In general, power system can, be measured by system loadability 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 [2] such optimization problem can be solved by using heuristic methods such as genetic algorithms [5, 6].

T. S. Chung et al. [7] applied a hybrid Genetic Algorithm (GA) method to solve OPF incorporating FACTS devices. GA is integrated with conventional optimal power flow (OPF) to select the best control parameters to minimize the total generation fuel cost and keep the power flows within the security limits.
L. Cai et al. [8] proposed optimal choice and allocation of FACTS devices 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.

In [9], 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) of the system.

M. Saravanan et al. [4] proposed the application of PSO to find the optimal location, settings, type and number of FACTS devices to minimize their cost of installation and to improve system loadability for single- and multi-type FACTS devices. While finding the optimal location, the thermal limit for the lines and voltage limit for the buses are taken as constraints.

In [10], FACTS devices are optimally allocated in a power network to achieve (OPF) solution. The location of FACTS devices and the setting of their control parameters are optimized by a Bacterial Swarming Algorithm (BSA) to improve the performance of the power network. Two objective functions are simultaneously considered as the indices of the system performance: maximization of system loadability in system security margin and minimization of total generation fuel cost.

In this paper, an approach to find the optimal location of thyristor-controlled series compensator (TCSC) in the power system to improve the loadability 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 IEEE 9-bus system.

II. THE PROPOSED OPTIMIZATION TECHNIQUE

The problem is to find the optimum numbers, locations and reactances 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.

As shown in the flow chart given in Fig. 3, the selected method is to use two genetic algorithms with number of generations of 30, fitness limit of zero and the other parameters are taken as the default values in MATLAB. The first one is to find the location and number of TCSC devices by computing the minimum total loss after inserting TCSC in the system. After location and number of TCSC are obtained they have been given to another genetic algorithm to obtain the best rating of TCSC by also computing the total loss.

Two optimization techniques using GA are used to solve the TCSC optimal location problem.

- **First technique**

In the first technique the objective is to minimize the total losses without taking into consideration limitations on the number of devices, i.e. it is required to minimize the objective function:

\[
\text{Total system losses} = \text{Sum of real loss of all system lines} \quad (1)
\]

- **Second technique**

Same as the first technique, but the number of devices is considered, i.e. it is required to minimize the objective function:

\[
\text{Total system losses after applying the TCSCs) / (Total system losses before applying the TCSCs) + (Number of TCSC devices/Total number of locations available for connecting the TCSCs)} \quad (2)
\]

Calculation of total loss is obtained by using Matlab m-files Matpower [11] to calculate the power flow of the system and compute the sum of real losses.

In this paper the reactance of each branch in Matpower case is replaced by variable reactance function of the value of TCSC reactance added as in equation (3).

\[
\text{New reactance} = \text{Old reactance} + X_{TCSC} \quad (3)
\]

Fig. 3 shows the flow chart of the selected technique.

![Flow chart of the proposed optimization technique](image-url)
III. CASE STUDY

The modified IEEE 9-bus system [11] is taken as a test system. One line diagram of this system is shown in Fig. 4. The data of the system is given in [11]. The system consists of 9 buses, 9 branches and 3-generators connected to buses 1, 2 and 3.

The constraints and base values are as follows:

\[ S_{\text{base}} = 100 \text{ MVA} \]
\[ V_{\text{base}} = 345 \text{ kV} \]
\[ V_{\text{max}} = 1.1 \text{ p.u.} \]
\[ V_{\text{min}} = 0.9 \text{ p.u.} \]
\[ P_{\text{max gen. at bus 1}} = 250 \text{ MW} \]
\[ P_{\text{max gen. at bus 2}} = 300 \text{ MW} \]
\[ P_{\text{max gen. at bus 3}} = 270 \text{ MW} \]
\[ Q_{\text{max gen.}} = 300 \text{ MVAr for all Generators} \]
\[ Q_{\text{min gen.}} = -300 \text{ MVAr for all Generators} \]

The range of TCSC is taken as -30% to 0% from line reactance as in [12] and the power flow is carried out before and after allocating the TCSCs to determine their benefits.

IV. RESULTS

In the first technique, after running the proposed program with 9 locations (total number of branches) available for the TCSC allocation, the results show that the optimal number of the TCSCs is only one (against 3 devices in [12]). The locations and reactances of the TCSCs are shown in Table I.

It is noticed that the insertion of the TCSC found by the first technique into the system has resulted in:

1. Increasing the minimum voltage by 3.84 %, i.e. the minimum voltage became far from the lower limit by 3.84 %.
2. Decreasing \( P_{\text{loss max.}} \) by 15.54%.
3. Decreasing \( Q_{\text{loss max.}} \) by 2.51 %.
4. Decreasing total \( P_{\text{loss}} \) by 5.33%.
5. Decreasing total \( Q_{\text{loss}} \) by 40 %.
6. Reducing \( Q_g \) by 37.85 %.
7. Reducing \( P_g \) by 0.075 %.
8. Increasing \( V_{\text{max}} \) by 0.3% i.e. from 1 to 1.003 p.u.
9. Line flows became within their loading limits.

### TABLE I

<table>
<thead>
<tr>
<th>Line No.</th>
<th>Branch</th>
<th>( X_{\text{old}} ) (p.u.)</th>
<th>( X_{\text{added}} ) (p.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 4</td>
<td>0.058</td>
<td>-0.040</td>
</tr>
<tr>
<td>2</td>
<td>4 5</td>
<td>0.092</td>
<td>-0.028</td>
</tr>
<tr>
<td>3</td>
<td>5 6</td>
<td>0.170</td>
<td>0.000</td>
</tr>
<tr>
<td>4</td>
<td>3 6</td>
<td>0.059</td>
<td>0.000</td>
</tr>
<tr>
<td>5</td>
<td>6 7</td>
<td>0.101</td>
<td>0.000</td>
</tr>
<tr>
<td>6</td>
<td>7 8</td>
<td>0.072</td>
<td>-0.050</td>
</tr>
<tr>
<td>7</td>
<td>8 2</td>
<td>0.063</td>
<td>0.000</td>
</tr>
<tr>
<td>8</td>
<td>8 9</td>
<td>0.161</td>
<td>-0.090</td>
</tr>
<tr>
<td>9</td>
<td>9 4</td>
<td>0.085</td>
<td>-0.060</td>
</tr>
</tbody>
</table>

In the second technique, after running the proposed program with 9 available locations for the TCSC, the results show that the optimal number of the TCSCs is only one (against 3 devices in [12]). The locations and reactances of the TCSCs are shown in Table II.

It is also noticed that the insertion of the TCSC found by the second technique has resulted in:

1. Increasing the minimum voltage increases by 2.03 %, i.e. more far from the min limit.
2. Decreasing \( P_{\text{loss max.}} \) by 25.4%.
3. Decreasing \( Q_{\text{loss max.}} \) by 1.34 %.
4. Decreasing total \( P_{\text{loss}} \) by 9.43 %.
5. Decreasing total \( Q_{\text{loss}} \) by 9.1 %.
6. Reducing \( Q_g \) by 9.1 %.
7. Reducing \( P_g \) by 0.025 %.
8. Line flows became within their loading limits.

### TABLE II

<table>
<thead>
<tr>
<th>Line No.</th>
<th>Branch</th>
<th>( X_{\text{old}} ) (p.u.)</th>
<th>( X_{\text{added}} ) (p.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 4</td>
<td>0.058</td>
<td>0.000</td>
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<tr>
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<td>-0.0276</td>
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<td>0.170</td>
<td>0.000</td>
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<td>3 6</td>
<td>0.059</td>
<td>0.000</td>
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<td>0.063</td>
<td>0.000</td>
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<tr>
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<td>8 9</td>
<td>0.161</td>
<td>0.000</td>
</tr>
<tr>
<td>9</td>
<td>9 4</td>
<td>0.085</td>
<td>-0.058 -0.0255</td>
</tr>
</tbody>
</table>
Figures (5-8) show, respectively, a graphical illustration of the obtained voltage magnitudes, power angles and total system losses before and after inserting the optimum FACTS devices found by the second technique.

![Graph: Fig. 5 Voltage profile of the 9-bus system after and before FACTS insertion](image)

**Fig. 5** Voltage profile of the 9-bus system after and before FACTS insertion

![Graph: Fig. 6 Power angles of nodal voltages after and before FACTS insertion](image)

**Fig. 6** Power angles of nodal voltages after and before FACTS insertion

It can be noticed from Fig. 6 that the change in power angle (Delta) due to FACTS insertion is acceptable.

![Graph: Fig. 7 Total active loss of the 9-bus system after and before FACTS insertion](image)

**Fig. 7** Total active loss of the 9-bus system after and before FACTS insertion

V. COMPARISON OF THE PROPOSED APPROACH WITH [12]

1. In the first technique, where no limitations were put on the number of FACTS devices, the optimum number of devices is found to be 5 which is less by one device than the corresponding number found in [12]. In addition to that nothing is mentioned in [12] regarding the reactances of the six devices.

2. In the second technique, where the number of devices is included in the optimization process, the optimum number of devices is found to be only one device while the corresponding number of devices found in [12] is 3. Table III shows a comparison between the results of the proposed approach (second technique) and the results found in [12].

A graphical comparison between the results obtained using the second technique with those obtained in reference [12] is shown in figures (9-11):

- **Fig. 9** shows a comparison of the total active power loss obtained by both approaches.
- **Fig. 10** shows a comparison of the total reactive power loss found by both approaches.
- **Fig. 11** shows a comparison of nodal voltage magnitudes.

### Table III

<table>
<thead>
<tr>
<th>Quantity</th>
<th>2nd technique results</th>
<th>Results of [12]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{min}$, p.u.</td>
<td>0.956</td>
<td>0.946</td>
</tr>
<tr>
<td>$V_{max}$, p.u.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$P_{\text{total loss}}$, MW</td>
<td>5.431</td>
<td>5.488</td>
</tr>
<tr>
<td>$Q_{\text{total loss}}$, MVAr</td>
<td>63.18 MVAr</td>
<td>65.03</td>
</tr>
<tr>
<td>$P_{\text{max loss}}$, MW</td>
<td>1.44</td>
<td>1.93</td>
</tr>
<tr>
<td>$Q_{\text{max loss}}$, MVAr</td>
<td>16.91 MVAr</td>
<td>16.96</td>
</tr>
<tr>
<td>$P_{g,\text{MW}}$</td>
<td>399.2</td>
<td>399.2</td>
</tr>
<tr>
<td>$Q_{g,\text{MVAr}}$</td>
<td>77.8 MVAr</td>
<td>80</td>
</tr>
</tbody>
</table>

431
VI. CONCLUSION

The obtained results show that optimum number of TCSC devices to be inserted in a power system in addition to their locations and compensation levels can be found in the presence of constraints on nodal voltage deviations and thermal capability of transmission lines. The obtained results show also that TCSCs can, when optimally sized and selected, improve system stability by increasing minimum voltage of the system. Optimal locations of the TCSCs also slightly increase the system loadability where:

- This increases the transfer capability of lines by increasing the voltage at their terminals as shown in Fig. 5 and decreases the lines' reactances.
- Also better voltage profile (increasing minimum voltage) is one factor of loadability improvement where the voltage collapse points are known as maximum loadability points [13], thus secure voltage profile is an improvement to the loadability.

Finally, proper selection of FACTS devices and their locations can effectively improve the overall system performance.

REFERENCES


