Assessment of Total Transfer Capability Enhancement Using Optimization Technique

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Abstract:- In this expose, a Particle Swarm Optimization (PSO) based method has been suggested to find the optimal location and setting of Thyristor Controlled Series Compensator (TCSC) for simultaneously enhancing the Total Transfer Capability (TTC) and reducing total real power losses of deregulated electricity markets. While solving multi objective OPF, various inequality constraints have been handled by penalty function. The strength of the proposed algorithm has been tested on IEEE 14 bus system. PSO gives accurate results which may be used for online TTC calculation at the energy management centre.

Keywords:- Total Transfer Capability (TTC), Active Power loss Minimization, Particle Swarm Optimization (PSO), Thyristor Controlled Series Compensator (TCSC).

I. INTRODUCTION

This article is prepared in response to a need to better understand the role of the transmission network for effective energy management. Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred from one area to another over the interconnected transmission network in a reliable manner based on pre-contingency and post-contingency conditions. In recent time, electrical supply systems of many countries have been transformed to competitive structure on the objective of increasing efficiency, reliability, stability and to reduce cost. In this new era, there should be sufficient TTC to fulfill scheduled transactions between the customers and power generators and to provide non-discriminatory open access to market participants. Large increase in power demand, competition and scare natural resources are some factors due to which transmission systems operate very near to their thermal limits. But because of economic, environmental and political reasons it is not preferable to build new transmission lines. So there is an interest in better utilization of existing capacities of power system by installing Flexible A.C. Transmission System (FACTS) device such as Thyristor Controlled Series Compensator. FACTS are the power electronics based converter-inverter circuits which can enhance TTC, voltage stability, load ability, security etc. and can reduce Active power losses or real power loss or simply called transmission loss, production cost of generation, can remove congestion and fulfill transaction requirement rapidly and efficiently. Due to the following two reasons it is necessary to “optimally” locate FACTS devices in order to obtain their full benefits. (1) They are costly devices; (2) They may have negative effects on system stability unless they are optimally placed.

It is the responsibility of the power system operator to quantify the transfer capability and to update available transfer capability (ATC) as real time index for its optimal commercial use maintaining security of the system. Various mathematical and optimization methods have been proposed to maximize TTC/ATC with and without FACTS devices. The parameters for optimisation in this paper include ATC enhancement, voltage profile improvement and active power losses reduction. The Particle Swarm Optimisation (PSO) method [4, 5 and 6] is used in this paper to solve the problem of installation and capacity allocation of FACTS devices in power transmission networks. M.Rashidnejad et al [3] proposed to locate FACTS devices to enhance ATC. So in this article, PSO based algorithm has been suggested to find the best location and setting of TCSC to maximize TTC and to minimize losses of the competitive electricity markets consisting of mutual and multi-party transactions under normal and contingency states.

In this article, we review possible ways for increasing transmission capacity, while in the final part, the emphasis is on the role of transmission capacity in the context of competitive energy management. Two basic questions are addressed, namely, (1) TTC under load Condition and (2) TTC under contingency condition.

This paper is organized as follows: Section 2 describes the modeling of TCSC. Section 3 deals with problem formulation which relates the objective function. A general idea of Mutual and Multi-party Transaction is given in section 4. Particle Swarm Optimization for proposed system is given in section 5.
Implementation steps to Enhance TTC using PSO has been explained in section 6. Results are discussed in section 7. Finally, Conclusion are presented in section 8.

II. MODELING OF TCSC

As shown in below figure TCSC has been represented by a variable capacitive/inductive reactance inserted in series with the transmission line. The reactance of the transmission line can be adjusted directly by using TCSC. Let, \( X_{mn} \) is the reactance of the transmission line, \( X_c \) is the reactance of TCSC and \( X_{new} \) is the new reactance of the line after placing TCSC between bus m and n. Mathematically, 
\[
X_{new} = X_{mn} - X_c
\]

Fig.1. Equivalent circuit of line with TCSC.

The modified power flow equations of the transmission line in the presence of TCSC are given as below:

\[
P_{mn} = V_m^2 G_m - V_m V_n (G_m \cos \delta_m + B_m \sin \delta_m)
\]

\[
Q_{mn} = V_m^2 (B_m + \frac{B_c}{2}) - V_m V_n (G_m \sin \delta_m - B_m \cos \delta_m)
\]

\[
P_{mn} = V_n^2 G_n - V_m V_n (G_n \sin \delta_n + B_n \cos \delta_n)
\]

\[
Q_{mn} = V_n^2 (B_n - \frac{B_c}{2}) - V_m V_n (G_n \sin \delta_n - B_n \cos \delta_n)
\]

Where,
\[
G_m = \frac{R_m}{2} + \frac{(X_m - X_c)^2}{2}
\]

\[
B_m = \frac{-(X_m - X_c)^2}{2}
\]

\[
P_{mn}, Q_{mn} : \text{Active and reactive power flow from bus m to n}
\]

\[
P_{nm}, Q_{nm} : \text{Active and reactive power flow from bus n to m}
\]

\[
G_{mn} : \text{New line conductance between bus m and n}
\]

\[
B_{mn} : \text{New line susceptance between bus m and n}
\]

\[
R_{mn} : \text{Line resistance between bus m and n}
\]

III. PROBLEM FORMULATION

A multi-objective optimal power flow is used to optimally locate TCSC for maximizing TTC and minimizing total real power loss, subject to satisfy various equality and inequality constraints. The OPF is given in (7).

\[
\text{Max} \left\{ K_1 \times \sum_{m=1}^{N_L} \text{Load Sink} \ P_{nm} - K_2 \times \sum_{r=(m,n):r \in N_L} (P_{mn} + P_{nm}) - PF \right\}
\]

Subject to the power balance equations (equality constraints)

\[
\begin{align*}
P_{Gm} - P_{Dm} - \sum_{m=1}^{N_B} |V_m| |V_n| |Y_{mn}| \cos(\delta_m - \delta_n - \theta_{mn}) &= 0 \\
Q_{Gm} - Q_{Dm} - \sum_{m=1}^{N_B} |V_m| |V_n| |Y_{mn}| \sin(\delta_m - \delta_n - \theta_{mn}) &= 0
\end{align*}
\]

Various operating constraints (inequality constraints)

\[
\begin{align*}
P_{Gm}^\text{min} &\leq P_{Gm} \leq P_{Gm}^\text{max} \quad \forall m \forall N_c \\
Q_{Gm}^\text{min} &\leq Q_{Gm} \leq Q_{Gm}^\text{max} \quad \forall m \forall N_c \\
|s| &\leq s_{1}\text{max} \quad \forall l \forall \mathcal{N}_l \\
V_m^\text{min} &\leq V_m \leq V_m^\text{max} \quad \forall m \forall N_0
\end{align*}
\]
\[ X_C^{\text{min}} \leq X_C \leq X_C^{\text{max}} \text{ p.u.} \] (13)

where,

\[ K_1, K_2 : \text{Constants in the range } [10^3, 10^8] \]
\[ \text{LOAD}_SINK : \text{Total number of load buses in sink Area} \]
\[ \sum_{m=1}^{\text{LOAD}_SINK} P_{Dm} : \text{TTC value} \]
\[ \sum_{m=1}^{\text{LOAD}_SINK} \left( P_{mn}^+ + P_{mn}^- \right) = P_{loss} : \text{Total real power loss of the transmission system} \]
\[ \text{PF} : \text{Penalty Function} \]
\[ P_{Gm}, Q_{Gm} : \text{Active and reactive power generation at bus m} \]
\[ \text{PF} = K_3 \times \sum_{m=1}^{N_G} f(Q_{Gm}) + K_4 \times \sum_{m=1}^{N} f(V_m) + K_5 \times \sum_{m=1}^{N_L} f(S_{lm}) \] (14)

\[ F(x) = \begin{cases} 
0 & \text{if } x^{\text{min}} \leq x \leq x^{\text{max}} \\
(x - x^{\text{max}})^2 & \text{if } x > x^{\text{max}} \\
(x^{\text{min}} - x)^2 & \text{if } x < x^{\text{min}}
\end{cases} \] (15)

Where,

\[ K_3, K_4, K_5 : \text{Penalty coefficients for reactive power output of generator buses } (Q_{Gm}), \text{ voltage magnitude } (V_m) \text{ of all buses and transmission line loading } S_{lm} \text{ respectively. Their values exist in the range } [10^8, 10^{10}] \]
\[ x^{\text{min}}, x^{\text{max}} : \text{Minimum and maximum limits of variable x} \]

IV. MUTUAL AND MULTI-PARTY TRANSACTIONS

A mutual transaction is made directly between a seller and a buyer without any third party intervention. Mathematically, each mutual transaction between a seller at bus m and buyer at bus n satisfies the following power balance relationship:

\[ P_{Gm} - P_{Dm} = 0 \] (16)

A multi-party transaction is a trade arranged by energy brokers and involves more than two parties. It may take place between a group of sellers and a group of buyers at different nodes.

\[ \sum_{m \in \text{SELLER}} P_{Gm} - \sum_{m \in \text{BUYER}} P_{Dm} = 0 \] (17)

\[ P_{Gm} : \text{Active power generation at bus m in a source area} \]
\[ P_{Dm} : \text{Active power demand at bus n in a sink area} \]
\[ \text{SELLER} : \text{A group of seller buses which sell power to the buyers} \]
\[ \text{BUYER} : \text{A group of buyer buses which buy power from the sellers} \]
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Contingency analysis has been also carried out to study the impact of severe contingencies on the value of feasible TTC.

Feasible TTC = \(\min_n\{TTC_{IN}, TTC_{CON}^n\}\)  
(18)

Where,
- \(TTC_{IN}\): Max. power transfer in system intact condition without considering any contingency
- \(TTC_{CON}^n\): Max. power transfer under \( nth \) contingency.

V. PARTICLE SWARM OPTIMIZATION

PSO is a fast, simple and efficient population-based optimization method which was proposed by Eberhart and Kennedy. It has been motivated by the behavior of organisms such as fish schooling and bird flocking. In PSO, a “Swarm” consists of number of particles which represent the possible solutions. The coordinates of each particle is associated with two vectors, namely the position \( (x_i) \) and velocity vectors \( (v_i) \). The size of both vectors is same as that of the problem space dimension. All particles in a swarm fly in the search space to explore optimal solutions. Each particle updates its position based upon its own best position, global best position among particles and its previous velocity vector according to the following equations:

\[
v_{i}^{k+1} = w \times v_{i}^{k} + c_1 \times r_1 \times (p_{best \ i} - x_i^{k}) + c_2 \times r_2 \times (g_{best \ i} - x_i^{k})
\]
(19)

\[
x_{i}^{k+1} = x_i^{k} + \chi \times v_{i}^{k+1}
\]
(20)

Where,
- \(v_{i}^{k+1}\): The velocity of \( i^{th} \) particle at \((K+1)\) iteration
- \(V_{i}^{k}\): The velocity of \( i^{th} \) particle at \( k^{th} \) iteration
- \(c_1, c_2\): Positive constants having values between \([0,2.5]\]
- \(r_1, r_2\): Randomly generated numbers between \([0,1]\]
- \(p_{best \ i}\): The best position of the \( i^{th} \) particle obtained based upon its own experience
- \(g_{best \ i}\): Global best position of the particle in the population
- \(x_{i}^{k+1}\): The position of \( i^{th} \) particle at \((K+1)\) iteration
- \(x_{i}^{k}\): The position of \( i^{th} \) particle at \( k^{th} \) iteration
- \(\chi\): Constriction factor It may help insure convergence. Its low value facilitates fast convergence and little exploration while high value results in slow convergence and much exploration. If no restriction is imposed on the maximum velocity \((V_{max})\) of the particles then there is likelihood that particles may leave the search space. So velocity of each particle is controlled between \((-V_{max})\) to \((V_{max})\).

VI. IMPLEMENTATION STEPS TO ENHANCE TTC USING PSO.

(i) Input the data of lines, generators, buses and loads. Choose population size of particles and convergence criterion. Define type of power transaction.
(ii) Select reactance setting and location of TCSC as control variables.
(iii) Randomly generate population of particles such that their variables exist in their feasible range.
(iv) Randomly install one TCSC in a transmission line and check that TCSC is not employed on the same line more than once in each iteration. Modify the bus admittance matrix.
(v) Run full A.c. Newton-Raphson load flow to get line flows, active power generations, reactive power generations, line losses and voltage magnitude of all buses.
(vi) Calculate the penalty functions of all particles using eqn. (13)
(vii) Calculate the fitness functions of all particles using eqn. (6)
(viii) Find out the “global best” particle having maximum value of fitness function in the population and “personal best”\((p_{best \ i})\)of all particles.
(ix) Generate new population using eqns. (18) and (19).
(x) Depending upon the type of power transaction increase the unit power generations at selected generator buses and increase loads at selected load buses keeping load power factor constant.
(xi) Go to step no. (iv) until maximum number of iterations are completed.
(xii) Fitness value of best g particle is the optimized (maximized) value of TTC and minimized value of losses. Coordinates of best g particle give optimal setting and location of TCSC respectively.

VII. RESULTS AND DISCUSSIONS
The performance of the proposed algorithm optimization method is tested in the medium size IEEE 14 bus system. The algorithm is implemented using MATLAB environment and a Core 2 Duo, 2.8 MHz, 2GB RAM based PC is for the simulation purpose.

![Fig.2. Single line diagram of standard IEEE 14 Bus system](image)

The test system taken has five generating units connected to buses 1,2,3,6 and 8. There are 3 regulating transformers connected between bus numbers 5-6, 4-7 and 4-9. The system is interconnected by 20 transmission lines to attain the objective function i.e. to maximize TTC and thereby minimizing the active power loss which enhances the power flow in the transmission line.

A. Load Condition:
Below given table shows the Total Transfer Capability at load condition with and without using of facts device. For example: Let us consider the 13th line of the table 1 which shows the value 9.122 without TCSC and with TCSC is 9.796.

<table>
<thead>
<tr>
<th>Line No</th>
<th>Without TCSC in MVA</th>
<th>With TCSC in MVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.95</td>
<td>16.901</td>
</tr>
<tr>
<td>2</td>
<td>14.067</td>
<td>14.91</td>
</tr>
<tr>
<td>3</td>
<td>16.364</td>
<td>16.322</td>
</tr>
<tr>
<td>4</td>
<td>13.98</td>
<td>13.810</td>
</tr>
<tr>
<td>5</td>
<td>17.999</td>
<td>18.236</td>
</tr>
<tr>
<td>6</td>
<td>5.522</td>
<td>5.724</td>
</tr>
<tr>
<td>7</td>
<td>9.0999</td>
<td>7.381</td>
</tr>
<tr>
<td>8</td>
<td>27.863</td>
<td>28.711</td>
</tr>
<tr>
<td>9</td>
<td>14.044</td>
<td>8.993</td>
</tr>
<tr>
<td>10</td>
<td>6.951</td>
<td>8.825</td>
</tr>
<tr>
<td>11</td>
<td>3.841</td>
<td>5.040</td>
</tr>
<tr>
<td>12</td>
<td>7.333</td>
<td>7.506</td>
</tr>
<tr>
<td>13</td>
<td>9.122</td>
<td>9.796</td>
</tr>
<tr>
<td>14</td>
<td>8.97</td>
<td>12.325</td>
</tr>
<tr>
<td>15</td>
<td>39.153</td>
<td>41.143</td>
</tr>
<tr>
<td>16</td>
<td>11.515</td>
<td>10.517</td>
</tr>
<tr>
<td>17</td>
<td>21.357</td>
<td>20.614</td>
</tr>
<tr>
<td>18</td>
<td>7.720</td>
<td>8.777</td>
</tr>
<tr>
<td>19</td>
<td>13.648</td>
<td>13.806</td>
</tr>
<tr>
<td>20</td>
<td>7.781</td>
<td>8.568</td>
</tr>
</tbody>
</table>
B. Contingency Condition

Following Table shows the Total Transfer Capability at Contingency condition without using the facts device is 35.783 and thereby Enhancement of Total Transfer Capability at Contingency condition after using the facts device is 40.230

<table>
<thead>
<tr>
<th>LINE NO</th>
<th>WITHOUT TCSC IN MVA</th>
<th>WITH TCSC IN MVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.824</td>
<td>16.616</td>
</tr>
<tr>
<td>2</td>
<td>13.724</td>
<td>14.351</td>
</tr>
<tr>
<td>3</td>
<td>16.064</td>
<td>16.050</td>
</tr>
<tr>
<td>4</td>
<td>14.056</td>
<td>13.495</td>
</tr>
<tr>
<td>5</td>
<td>18.593</td>
<td>18.341</td>
</tr>
<tr>
<td>6</td>
<td>4.442</td>
<td>5.954</td>
</tr>
<tr>
<td>7</td>
<td>7.595</td>
<td>5.979</td>
</tr>
<tr>
<td>8</td>
<td>28.066</td>
<td>31.041</td>
</tr>
<tr>
<td>9</td>
<td>13.591</td>
<td>6.783</td>
</tr>
<tr>
<td>10</td>
<td>7.649</td>
<td>10.507</td>
</tr>
<tr>
<td>11</td>
<td>12.040</td>
<td>12.040</td>
</tr>
<tr>
<td>12</td>
<td>6.738</td>
<td>7.146</td>
</tr>
<tr>
<td>13</td>
<td>6.816</td>
<td>8.416</td>
</tr>
<tr>
<td>14</td>
<td>7.469</td>
<td>6.737</td>
</tr>
<tr>
<td>15</td>
<td>35.783</td>
<td>40.230</td>
</tr>
<tr>
<td>16</td>
<td>5.211</td>
<td>5.212</td>
</tr>
<tr>
<td>17</td>
<td>23.649</td>
<td>21.919</td>
</tr>
<tr>
<td>18</td>
<td>13.088</td>
<td>13.455</td>
</tr>
<tr>
<td>19</td>
<td>5.042</td>
<td>6.873</td>
</tr>
</tbody>
</table>
VIII. CONCLUSION

In this article the proposed algorithm is used to find optimal location and setting of TCSC for maximizing TTC. The paper shows step by step procedure for implementation of the Particle Swarm Optimization method to solve the problem of optimal placement of TCSC in a medium size power network. The algorithm is easy to implement and it is able to find multiple optimal solutions to this objective problem. Matlab program were performed on IEEE 14 bus system. Test results indicate that optimally placed TCSC by PSO could significantly increase TTC, under normal and contingency conditions. The paper shows that such outstanding results by enhancing power flow in transmission line which shows that the proposed optimization technique is good in dealing with power system optimization problems. Test results based on the IEEE reliability test system and a utility system illustrate the effectiveness of the TCSC.

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