A NOVEL APPROACH FOR OPTIMAL LOCATION AND SIZING OF MULTI-TYPE FACTS DEVICES FOR MULTI-OBJECTIVE VOLTAGE STABILITY OPTIMIZATION USING HYBRID PSO-GSA ALGORITHM

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ABSTRACT –

A new modified severity function is proposed, based on which the N-2 line contingencies in the IEEE 30 bus system are analyzed and ranked. FACTS devices like Static VAR Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC) are used for achieving reduction in under voltage severity value and reduction in voltage deviation from the nominal value. A hybrid combination of two heuristic algorithms, Particle Swarm Optimization (PSO) and Gravitational Search Algorithm (GSA) are used, which combines the exploiting and exploring features of the two algorithms respectively, to determine the objective of optimal placement and optimal size of the FACTS devices. A trade- off analysis of the choice of the SVC and TCSC devices, their optimal MVAr requirement in view of the system stability and system severity has been performed. The test results of the proposed work are compared with the conventional PSO algorithm. The computational time substantiate the feasibility of the proposed method to application in real time environment for voltage security assessment and enhancement.

KEYWORDS- N-2 contingency ranking, Voltage stability, Modified Severity Index, Hybrid PSO-GSA, SVC, TCSC, Optimal Location and sizing.

1. INTRODUCTION

Voltage instability has now become a concern in highly developed networks for several reasons owing to the recent changes in the economic, political and environmental aspects of the system. Deregulation policies impose economic competition among utility and non-utility entities causing the transmission system and especially the interties to be used in a manner other than it was originally designed. This has led to new loading patterns, increased transmission congestion, and reduced operating margins throughout the system. Moreover, in present days more distribution companies desire to utilize the existing transmission system at its maximum thus avoiding the extra cost of construction of new power transfer corridors. Thus, voltage instability has become a peril to the normal operation of the power system.

Earlier techniques of voltage stability assessment such as PV curve method, sensitivity analysis, minimum singularity value, loading margin and closest loadability [1-3] suffer from the disadvantage of high computational efforts and difficulty in on-line implementation. Voltage instability assessment, using indices helps to overcome these disadvantages. Many deterministic voltage stability indices are available. An index, called the equivalent node voltage collapse index, to trace the weakest bus was proposed by Yang in [4]. Fast voltage stability index (FVSI), voltage collapse index (VCI), new voltage stability index (NVSI), line stability factor (LQP) and loss sensitivity factor are some of the indices that have been proposed in literature. [5-8]

Voltage stability is accomplished by controlling the production, absorption, and flow of reactive power at key locations in the power system [9]. The placement of the FACTS device and the amount of MVAR delivered/absorbed by the device has intense influence on the stability of the system. The placements of SVC by simultaneous and non-simultaneous methods are discussed in [10]. Optimal allocation of UPFC using sensitivity analysis by LP based OPF was discussed in [11]. The tangent vector technique for SVC and TCSC installation, for attaining maximum power system loadability, was proposed by Chang et al in [12]. A bifurcation analysis was applied in [13], to find the optimal location and rating of the SVC and TCSC. The stability index analysis is also proposed for the optimal location of TCSC [14] to control voltage and reactive power.

Different optimization techniques are being employed for ideal placement of FACTS devices. PSO, an evolutionary algorithm, is adopted in [15] for voltage stability improvement and power loss reduction. A non-dominated Sorting Particle Swarm Optimization technique (NSPSO) was employed by Benabid et al in [16], for the optimal placement and sizing of the SVC and TCSC, to improve the voltage profile. The hybrid algorithm, composed of Tabu search and Simulated Annealing is proposed in [17] for solving the optimal location of different types of FACTS devices in power systems. E. Rashedi et al in 2009 [18] first proposed the Gravitational Search Algorithm (GSA), a metaheuristic algorithm, inspired by Newton’s theory of gravity. An improved Gravitational Search Algorithm (GSA) for determining the optimal location and sizing of the SVC compensator for voltage profile improvement and loss reduction was adopted in [19].

In this paper, a new severity function is proposed, to quantify both overvoltage and under-voltage contingency situations. Also, deviating from other research works, double line contingency is considered, and contingency ranking is done based on the proposed severity function. Hybrid PSO-GSA algorithm is employed to determine the optimum positioning and reactive power supply to achieve reduction in the severity value and improvement in the voltage profile, by the FACTS devices like SVC and TCSC. Also a trade- off between the size of the SVC and TCSC and the voltage severity value of the system, by optimally locating the compensating device for voltage stability enhancement is attained.

2. Modified Severity Index

In Continuous severity function, for each bus, the severity function takes a value of 1.0 at the deterministic low voltage limit and the severity function increases linearly as the decrease in magnitude of the bus voltage [20].
This conventional severity function assertion results in a severe deficiency in correct quantification of over voltage situations. Hence a new modified severity function is designed which quantifies both the severity of under voltage and over voltage risks thereby ensuring that the value stays within the limit [21].

In this case, when the bus voltage magnitude stays equal or above the nominal value of the bus, then the severity magnitude is zero. For voltage magnitude values smaller than 1.0, severity is a linear function with 1.0 corresponding to a voltage of 0.95 p.u. The modified severity function is given by

\[
S_{ev}(V_i) = \begin{cases} 
\frac{1}{V_i^b} & V_i > V_i^b \\
\frac{V_i^b - V_i}{V_i^b} & V_i^b > V_i > V_i^l \\
0 & V_i < V_i^l
\end{cases}
\]

where \( V_i^b \) is the nominal voltage of the bus ‘i’, \( V_i^l \) is the Low voltage rating of the bus ‘i’, \( V_i^b \) is the upper limit of voltage for bus ‘i’ and \( V_i^l \) is voltage magnitude of the bus.

3. MODELLING OF FACTS DEVICES

3.1 Modeling of SVC

The SVC can be viewed as an adjustable reactance, with either firing angle limits or reactance limits. In this paper, the SVC is treated as a shunt connected variable susceptance \( B_{SVC} \) as shown in fig.3.

\[
I_{SVC} = B_{SVC}V_i \tag{2}
\]

The reactive power injected at bus ‘i’ is the negative of the reactive power drawn by the SVC. Therefore,

\[
Q_{SVC} = Q_i = -V_i^2B_{SVC} \tag{3}
\]

3.2 Modeling of TCSC

TCSC is modeled as a variable series reactance which is adjusted automatically to constrain the power flow across the branch to a specified value as shown in fig.4.

\[
B_{km} = B_{mn} = \frac{1}{X_{TCSC}} \tag{4}
\]

4. PROBLEM FORMULATION

The multi-objective function \( H \) is to reduce the severity index value \( (H_1) \), to minimize the voltage deviation \( (H_2) \) to optimally place the SVC, and minimize the size of the FACTS device \( (H_3) \).

The net objective function to be minimized is:

\[
\min H = w_1H_1 + w_2H_2 + w_3H_3 \tag{5}
\]

where \( w_1, w_2 \) and \( w_3 \) are the weights attached to individual functions. The multi-objective optimization function is subject to the following constraints.

4.1. Equality Constraints and Inequality Constraints

Equality constraints ensure power balance of the system. Inequality constraints includes

(i). Voltage limit constraints: For the generator bus (PV bus) and for the load bus (PQ bus), the upper and lower limits are generally as follows:

\[
0.95 \leq V_i \leq 1.05, \text{ For PV Bus} \tag{6}
\]

\[
0.95 \leq V_i \leq 1.1, \text{ For PQ Bus} \tag{7}
\]

(ii). Generator Limit Constraints: The real and reactive power generations at each generator are characterized by lower and upper operating limits as shown below

\[
P_{g,min} \leq P_g \leq P_{g,max} \tag{8}
\]

\[
Q_{g,min} \leq Q_g \leq Q_{g,max} \tag{9}
\]

where \( P_{g,min} \) and \( Q_{g,min} \) are the lower real and reactive power generation limit respectively, and \( P_{g,max} \) and \( Q_{g,max} \) are the upper real and reactive power generation limit respectively.

(iii). FACTS Device Constraints: The operating range is constrained for SVC and TCSC as below

\[
-100 \text{ MVAR} \leq Q_i \leq 100 \text{ MVAR} \tag{10}
\]

\[
-0.8X_L \leq X_{TCSC} \leq 0.2X_L \tag{11}
\]

where \( Q_i \) is the reactive power supplied by the SVC to the connected bus, \( X_L \) is the reactance of the line in which TCSC is placed and \( X_{TCSC} \) is the reactance added to the line by placing TCSC.

5. Hybrid PSO-GSA Algorithm

Step 1: Initialize all agents randomly in the search space within the search area limits. Calculate the fitness of all the agents based on their position in the search space, using the fitness function.

Step 2: Calculate the Gravitational force and gravitational constant.

\[
G_{Frn}(t) = G(t) \frac{M^{(i)}M^{(j)}}{R_{mn}^{(i)}+\varepsilon} \tag{12}
\]

where \( G_{Frn}(t) \) is the gravitational force from agent ‘m’ on agent ‘n’ at time ‘t’, \( G(t) \) is the gravitational constant at time ‘t’, \( \varepsilon \) is the constant of very low value, \( M^{(i)} \) is the passive gravitational mass related.
to agent ‘m’, and \( m^{(3)} \) is the active gravitational mass related to agent ‘n’. The Gravitational constant can be computed by:

\[
G(t) = G_0 \exp(-\alpha \frac{N}{m^{(3)}})
\]

where \( G_0 \) is the initial value, \( \alpha \) is the descending coefficient, \( N \) is the current iteration, and \( m \) is maximum number of iterations.

**Step 3:** Calculate the total force acting on agent ‘m’

\[
F_m(t) = \sum_{n=1}^{N} \text{rand}(n) F_{mn}(t)
\]

where \( d \) is the dimension, \( \text{rand}(n) \) is the random number in the interval \([0, 1]\), and \( F_{mn}(t) \) is the total force acting on agent ‘m’ and depends on agent ‘m’ due to agent ‘n’.

**Step 4:** The mass of each agent is calculated by

\[
m_m(t) = \text{present} - \text{fitness} + 0.5 \times \text{worst}(t)
\]

**Step 5:** Calculate the acceleration of all the agents. The acceleration of all agents is given by

\[
a_c(t) = \frac{F_m(t)}{m_m(t)}
\]

where \( a_c(t) \) is the acceleration of the agent ‘m’ at time instant ‘t’.

**Step 6:** Finally, the velocity and position of all the agents are updated using

\[
V_m(t) = w V_m(t) + C_1 \times \text{rand} \times a_c(t) + C_2 \times \text{rand} \times (g_{\text{best}} - x_m(t))
\]

\[
x_m(t+1) = x_m(t) + V_m(t+1)
\]

where \( V_m(t) \) is the velocity of agent ‘m’ at iteration \( t \), \( C_1 \) is the weighing factor, \( w \) is a weighing function, \( rand \) is a random number between 0 and 1, \( a_c(t) \) is the acceleration of the agent ‘m’ at iteration \( t \), \( x_m(t) \) is the position of the agent ‘m’ at iteration \( t \), and \( F_m(t) \) is the force acting on the agent ‘m’ with mass \( m_m(t) \).

6. **Test System**

System 1: The test system is the standard IEEE 30 bus system. The IEEE 30 bus system consists of 6 generators, 41 transmission lines with a total real power demand of 189.2 MW and a reactive power demand of 107.2 MVAR.

7. **Optimum facts device positioning**

Table 1 shows the top 5 highly severe contingency states as determined during the N-2 contingency analysis.

<table>
<thead>
<tr>
<th>Table 1 Highly Severe N-2 contingencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outage of Line 1</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>31</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

The contingency state of outage of Line 10 & 39 has 8 voltage limit violating buses namely 23, 24, 25, 26, 27, 28, 29 and 30 with the overall system severity of 40.015 as shown in table 2.

<table>
<thead>
<tr>
<th>Table 2 List of Number of Limit Violating Buses in Top 5 Highly Severe N-2 Line Contingency</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.No</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3 Results with TCSC Placement at Each of the 8 Limit Violating Buses for Line Contingency 10-39 Based On Modified Severity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compensated Bus</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>23</td>
</tr>
<tr>
<td>24</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>26</td>
</tr>
<tr>
<td>27</td>
</tr>
<tr>
<td>28</td>
</tr>
<tr>
<td>29</td>
</tr>
<tr>
<td>30</td>
</tr>
</tbody>
</table>

It can be inferred from table 3 that the effect of Compensating MVAr and the choice of compensated bus play a vital role in the system severity after compensation. From the point of view of System severity the optimum compensation would be to compensate bus 24 with 400 MVAr results in system severity of 3.31 with all buses within their operational range. However from the techno-economic point of view, it can also be ascertained that compensating bus 23 with 157 MVAr produces a similar system condition compared to the optimum solution but has an added advantage over the economic point of view due to the comparatively lesser requirement of MVAr. The operator based on the current situation may also opt to go for compensating bus 27 with 46.66 MVAr resulting in a state with all buses within their operating limits and a system severity of 3.38. Table 4 gives the result when SVC is used as a compensating device for outage of line 10-39.
Table 4 Results with SVC Placement at Each of the 8 Limit Violating Buses for Line Contingency 10-39 Based On Modified Severity Index

<table>
<thead>
<tr>
<th>Compensated Bus</th>
<th>No. of limit violating bus after compensation</th>
<th>Compensating MVAR</th>
<th>Severity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>7</td>
<td>35.8532</td>
<td>2.9690</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
<td>90.5334</td>
<td>15.563</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>66.6945</td>
<td>5.8916</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>64.4514</td>
<td>7.3317</td>
</tr>
<tr>
<td>27</td>
<td>0</td>
<td>39.6150</td>
<td>6.3691</td>
</tr>
<tr>
<td>28</td>
<td>6</td>
<td>24.0727</td>
<td>15.563</td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>70.1088</td>
<td>9.6418</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>38.3430</td>
<td>11.626</td>
</tr>
</tbody>
</table>

It is inferred from table 3 and 4 that, for compensation at bus 30, TCSC is more suitable than SVC, as the value of severity has reduced to 9.99 compared to 11.626 which is the severity obtained with SVC as the compensating device, for the same value of compensating MVAr. Table 5 gives the comparison of optimum compensation MVAr calculated with the placement of TCSC for the N-2 contingency of lines 10 & 39.

Table 5 Comparison of results with PSO and PSO-GSA algorithm for outage of line 10 -39

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Compensating Bus</th>
<th>Compensating MVAr Required</th>
<th>Severity of System after Compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSO</td>
<td>25</td>
<td>47.79</td>
<td>3.79</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>46.66</td>
<td>4.03</td>
</tr>
<tr>
<td>PSO-GSA</td>
<td>25</td>
<td>47.23</td>
<td>3.70</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>46.66</td>
<td>3.38</td>
</tr>
</tbody>
</table>

It is inferred from the above results that PSO-GSA algorithm provides better results in terms of the compensating MVAr and in terms of severity. When TCSC is placed at bus 25, PSO-GSA provides a lower value of compensating MVAr and also with a reduction in severity value. When TCSC is placed at bus 27, though the compensating MVAr was found to be the same, PSO-GSA algorithm provides reduced value of system severity.

Fig 5 predicts the voltage profile improvement at buses 24, 25 and 26 after the placement of TCSC. It is inferred that placement of TCSC at bus 24 results in an improved voltage profile, when compared to bus 25 and 26.

8. CONCLUSION
The present day power system is often subjected to stressful operating conditions which are not considered during the system planning and design phase. Hence the need for a methodology to determine the control actions to be taken by the system operator using real time data is inevitable and is of great importance. In this work, a thorough voltage stability analysis has been performed with N-2 contingency analysis. The state of the system is numerically quantified which leads to a better realization about the stability of the system. The methodology of contingency ranking using system severity results in better characterization of a contingency state and proposes a way for the operator to plan the control actions during the occurrence of the particular contingency. The results substantiate that the proper choice between SVC and TCSC device, the ideal choice of its location, its compensation range and the optimal amount of MVAr, with a compromise between economy and severity are achieved with the modified severity index based hybrid PSO-GSA algorithm. The effectiveness of the work is compared with conventional PSO algorithm. The computational time also enumerates the feasibility of the proposed algorithm. As outlined in this paper, the proposed method will help in assisting planners in optimizing the transmission system expansion, and in improving system voltage and stability during stressful conditions.

REFERENCES


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