Fuzzy Based Particle Swarm Optimization Technique for Congestion Management

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Abstract: - Congestion phenomenon in power system occurs when electrical power generation is not able to transmit power at the prescribed rate. This leads the deregulated power sectors to suffer the congestion problems. Installation of devices such as Flexible Alternating Current Transmission System (FACTS) is one of the options to solve the problem of congestion. This presents fuzzy based particle swarm optimization technique for congestion management. It aims to reduce congestion and control the voltage profile through the installation of UPFC. A Fuzzy Congestion Index (FCI) is developed to determine the level of congestion in a transmission line and subsequently investigate the location for UPFC installation. A pre-developed voltage stability index, termed as Fast Voltage Stability Index (FVSI) is utilized as an indicator for voltage stability. The fuzzy logic based results have been compared with the solution given by FVSI. The Particle Swarm Optimization (PSO) technique is used to determine the optimal sizing for UPFC. The simulation results proved the efficiency of the proposed technique by optimal location and sizing of the UPFC to minimize congestion in power system.

Key-Words: - Congestion management, Flexible Alternating Current Transmission System (FACTS) devices, Fuzzy Congestion Index (FCI), Fast Voltage Stability Index (FVSI), Particle Swarm Optimization (PSO).

1 Introduction
Congestion phenomenon in power system can be resulted from the over limit regions of generation and consumption. Congestion is the most fundamental transmission management problem. Congestion management is the process to avoid or relieve the congestion. In a broader sense, congestion management is considered as a systematic approach for scheduling and matching generation and loads in order to reduce congestion [1]. Flexible Alternating Current Transmission System (FACTS) devices can be introduced as an appropriate tool to overcome this problem.

FACTS devices can improve the performance of the network in some areas, such as transient and small signal stability, reduce the power flow of heavily loaded lines and support the voltages [2]. This improvement can be achieved when the FACTS device parameter such as shunt impedance, series impedance, voltage amplitude, current and phase angle are controlled. Many issues associated with the implementation of FACTS devices such as optimal location, appropriate size, cost, setting and modelling. In [3], the performance index and var

index methods are applied to solve the congestion problem with the complement of contingency analysis. For optimal location of series FACTS devices, an overload sensitivity factor (power flow index) is used for analyzing the static congestion management [4]. Although, the author in ref [5] used a sensitivity factor method in order to determine the suitable location of FACTS devices. However, this method does not capture the non-linearity associated with the system. Another method such as Tabu and Genetic Algorithm (GA) are used to solve the combinations problem of FACTS devices allocation [6-7].

Therefore, the main intent of the present work is to propose a new index for congestion management using a fuzzy based swarm technique in order to determine the location and sizing of UPFC. The proposed index was implemented onto the fuzzy technique. After placing the UPFC, the optimal size of UPFC is determined using PSO with power loss minimization. The IEEE 30 Bus RTS is used to serve as test systems for showing the capability of the proposed method is efficient.
2 Methodology
These approaches are based upon two voltage stability index. This proposed index is based on voltage stability index. From this index, the level of congestion on the transmission line can be determined.

2.1 Fuzzy Congestion Index
The objective fuzzy index suggested in this paper is to analyse the voltage stability in the transmission line at the steady state condition. There is an index that has been developed before, the FVSI will also be used in the paper as an indicator of the maximum level of congestion in the system. A new equation is developed based on sensitivity analysis. This index is expressed in Eqn. (1).

\[
FCI = \frac{\partial FVSI}{\partial P} = \frac{\partial FVSI}{\partial Qd} \times \frac{\partial Qd}{\partial V} \times \frac{\partial V}{\partial P}
\]  

(1)

In electric power systems, PV diagram always used to analyse the state of voltage stability. Information based on figures obtained from repeated power flow calculation. With the power flow analysis, FVSI also be counted together voltage and loss of real and reactive power for every line in the system. In this study, power flow analysis takes a long time to execute the result. In order to improve the computational time of this conventional power flow program, fuzzy technique is proposed.

2.2 Fast Voltage Stability Index (FVSI)
In this work, Fast Voltage Stability Index (FVSI) is used as a predicting index of the voltage stability condition in the system. The mathematical formulation is simple that could speed up the computation. This index can rather be referred to a bus or line. The line that shows the index close to 1.000 will show had already unstable voltage. Values close to 1.000 indicate that a certain line is close to the point of instability that could lead to the collapse of the entire power system voltage. To maintain a secure condition the value of FVSI should be maintained well below 1.000 [8]. Taking the symbol ‘i’ as the sending bus and ‘j’ as the receiving bus, the fast voltage stability index, FVSI can be defined by Eqn. (2).

\[
FVSI_{ij} = \frac{4z^2Q_i}{V_i^2X}
\]  

(2)

where:  
- \(Z\) = line impedance  
- \(X\) = line reactance  
- \(Q_i\) = reactive power at the receiving end  
- \(V_i\) = sending end voltage

2.3 Fuzzy Logic Technique
This section explains the mechanics of fuzzy logic. It involves the basic fuzzy logic theory, its mathematical, command line instruction and determination of fuzzy rules.

2.3.1 Fuzzy logic basics theory
Boolean logic is based on the concept of Truth (1) and False (0). It has long been used in industry, science and mathematics. The output is the same as the input as shown in the figure below.

![Fig. 1 Basic fuzzy logic process](image)

A researcher, Zadeh has suggested a linguistic logic, knowledge which is similar as what as the human brain has. Figure 1 shows the basic process in the fuzzy logic system. There are four main blocks which play the role of each of fuzzifier, rules, inference and defuzzifier.

- **Fuzzifier:**
  In this part, the original information (crisp) will be converted into a fuzzy form.

- **Rules:**
  Fuzzy rule is a rule based IF-THEN condition. Through the rules, the input of membership function and the output membership function are intertwined expertise to produce fuzzy results.

- **Inference:**
  Each input coming from crisp carrier brings different information. When the input is converted to fuzzified form, each entry will be mapped into the membership functions, so that the fuzzy output can be produced.

- **Defuzzifier:**
  After all processes are done, the final output should be changed into a form defuzzifier form. Defuzzifier is the process to convert the fuzzy output into ordinary information.
2.3.2 Building Fuzzy Logic System by Using Command Line

Membership function represents the input and output behaviour of the system. In the fuzzy system, the selection of MF is chosen according to the suitability of the system. In this system, two inputs are required to be fed into the fuzzy system. The first input is the reactive loading, Qd. While the second input is the bus number of the system. It is obtained and linearly normalized within the range [1,30]. The output is called as the Fuzzy Congestion Index (FCI) where its range is from 0 and 1. FCI. Furthermore, FCI is the output of the fuzzy logic used to determine the suitable location to install TCSC on the proper transmission line. All the membership functions (MF) are in a triangular shaped for reactive loading, Qd, bus number and FCI. Each of MF is assigned as S, SM, M, MH and H as shown in Figure 2, 3 and 4. The limitation of input 1 and input 2 are tabulated in Table 1.

<table>
<thead>
<tr>
<th>Input 1 (Reactive Loading, Qd)</th>
<th>Input 2 (Bus Number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 ≤ Qd ≤ 3512</td>
<td>Bus 3</td>
</tr>
<tr>
<td>16 ≤ Qd ≤ 3166</td>
<td>Bus 4</td>
</tr>
<tr>
<td>10 ≤ Qd ≤ 309</td>
<td>Bus 7</td>
</tr>
<tr>
<td>2 ≤ Qd ≤ 820</td>
<td>Bus 10</td>
</tr>
<tr>
<td>7 ≤ Qd ≤ 875</td>
<td>Bus 12</td>
</tr>
<tr>
<td>16 ≤ Qd ≤ 686</td>
<td>Bus 14</td>
</tr>
<tr>
<td>2 ≤ Qd ≤ 162.5</td>
<td>Bus 15</td>
</tr>
<tr>
<td>10 ≤ Qd ≤ 1118</td>
<td>Bus 16</td>
</tr>
<tr>
<td>5 ≤ Qd ≤ 160.8</td>
<td>Bus 17</td>
</tr>
<tr>
<td>16 ≤ Qd ≤ 92.6</td>
<td>Bus 23</td>
</tr>
<tr>
<td>19 ≤ Qd ≤ 349</td>
<td>Bus 30</td>
</tr>
</tbody>
</table>

2.3.3 Determination Fuzzy Rules

The fuzzy inputs depend on the rule that has been set in the system. The basic rule in fuzzy can be stated as:

- IF premise (antecedent)
- THEN conclusion (consequent).

Since the fuzzy technique is used in determining the location of congested line, hence multiple antecedents have been created. The rules are tabulated in Table II. From the table above, there are 25 rules being developed; some of the rules are as follows:

- If is Reactive Loading is S and Bus Number is S then FCI is S
- If Reactive Loading is MH and Bus Number is SM then FCI is SM
- If Reactive Loading is H and Bus Number is M then FCI is M

All of the rules are written by using MATLAB. All inputs and outputs depend on the fuzzy rules which are given in the Table 2. Abbreviations used in the insert of fuzzy sets are shown in Table 3

2.4 Particle swarm optimization (PSO)

Beginning with the simple and efficient population based optimization method, Kennedy and Eberhart in [9] introduce a PSO. It is motivated by social behaviour of organisms such as bird flocking and fish schooling. Population of particles is called a swarm. Particles fly around the multi-dimensional problem space are known a potential solution in
PSO. A group of particles and each particle flies with its own velocity through a multidimensional search space. Then, they will be constantly updated by the particle’s previous best performance. It also updated by the previous best performance of the particle’s neighbors.

To achieve the optimum level of a particle, the position and velocity of every particle will be updated at each time. Two kinds of 'best value are produced from particle update their velocity and position. The location of its highest fitness value is known as personal best (pbest). While in global version, the location of overall best value, obtained by any particles in the population is known as global best (gbest). Particles update their positions and velocities according to Eqn. (3) and (4) [10].

\[
V_{id}(t+1) = \omega V_{id}(t) + r_{1} \varphi_{1}(p_{id}(t) - x_{id}(t)) + \varphi_{2} r_{2} \left( p_{gd}(t) - x_{id}(t) \right)
\]

\[
x_{id}(t+1) = x_{id}(t) + V_{id}(t+1)
\]

Here, \(V_{id}(t)\) is the velocity of \(d^{th}\) dimension of the \(i^{th}\) particle in the \(i^{th}\) iteration, \(x_{id}(t)\) is the corresponding position and \(p_{id}(t)\) and \(p_{gd}(t)\) is the personal best and global best respectively. The variable \(\omega\) is the inertia weight, the parameters \(\varphi_{1}\) and \(\varphi_{2}\) are the accelerate parameters, which respectively adjust the maximal steps particles flying to the personal best and the global best, \(r_{1}\) and \(r_{2}\) are two random numbers in \([0,1]\).

### 4 FACTS Devices Installation of Power System

For the purpose of this work, only two type FACTS devices are chosen for installation in power system. It is Static Var Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC). SVC is modelled as a reactive source added at both ends of the line and TCSC has been modelled as a reactance inserted in the line.

#### 4.1 Modelling of Static Var Compensator (SVC)

The Static Var Compensator (SVC) is a shunt connected static VAR generator or absorber. At the same time, the output is adjusted to exchange capacitive or inductive current in order to maintain or control specific parameters of the electrical power system (typically bus voltage) [11].
shunt reactive power (var) compensation as illustrated in figure 5.

4.2 Modelling of Thyristor Controlled Series Compensator (TCSC)

The model of a transmission line with a series impedance and a TCSC connected between bus-i and bus-j is shown in figure 6 [12]. TCSC can be considered as a static reactance, –j/Xc during the steady state condition. The TCSC can be acted as the inductive and capacitive compensation respectively by modifying the reactance of the transmission line. In order to avoid over compensation, the working range of the TCSC is chosen between -0.7Xline and 0.2Xline [13].

Fig. 6 Model of TCSC

5 Problem Formulation

The objective of this paper is to find the optimal location and size of FACTS devices. It aims to reduce congestion and power loss while increasing the voltage in the power system.

5.1 Objective function for loss minimization

The active power losses can be expressed by the following equation.

\[\text{Min } \sum_{i=1}^{N} \sum_{j=1}^{N} Y_{ij} V_i V_j \cos(\delta_{ij} - \theta_{ij})\]  \hspace{1cm} (5)

Subject to:

Equality or power balance constraint

\[P_i(\theta, V) - P_{Gi} + P_{Di} = 0, \text{ for any node} \]  \hspace{1cm} (6)

\[Q_i(\theta, V) - Q_{Gi} + Q_{Di} = 0, \text{ for any node} \]  \hspace{1cm} (7)

If TCSC is located in line between bus i and bus j, the power balance equations in nodes i and j are given by:

\[P_i(\theta, V) - P_{Gi} + P_{Di} + P_{i}^F = 0 \text{ for node } i \]  \hspace{1cm} (8)

\[P_j(\theta, V) - P_{Gj} + P_{Dj} + P_{j}^F = 0 \text{ for node } j \]  \hspace{1cm} (9)

\[Q_i(\theta, V) - Q_{Gi} + Q_{Di} + Q_{i}^F = 0 \text{ for node } i \]  \hspace{1cm} (10)

\[Q_j(\theta, V) - Q_{Gj} + Q_{Dj} + Q_{j}^F = 0 \text{ for node } j \]  \hspace{1cm} (11)

The inequality constraints are as follows:

Apparent line flow limit

\[|S_{ij}(\theta, V)| \leq S_{ij}^{\text{max}} \]  \hspace{1cm} (12)

Power generation limits

\[P_{Gi}^{\text{min}} \leq P_{Gi} \leq P_{Gi}^{\text{max}} \]  \hspace{1cm} (13)

\[Q_{Gi}^{\text{min}} \leq Q_{Gi} \leq Q_{Gi}^{\text{max}} \]  \hspace{1cm} (14)

Bus voltage limit

\[V_i^{\text{min}} \leq V_i \leq V_i^{\text{max}} \]  \hspace{1cm} (15)

TCSC reactance limit

\[X_c^{\text{min}} \leq X_c \leq X_c^{\text{max}} \]  \hspace{1cm} (16)

6 Simulation results

The IEEE 30 bus test system composed of 6 generators, 21 loads and 41 transmission lines has been used to demonstrate the validation and effectiveness of the proposed method.

Table 4 shows the fuzzy results based on ± 5% of a voltage limit. From the table, it can be seen that before installing the FACTS devices, there are four same congested lines at the different buses 3, 4, 7 and 30. Line 15 which is the most occur the congested line is the best locations for the placement of FACTS devices to minimize the power losses is captured in this table. The congested line that will be chosen for location FACTS devices is according to the occurrence of congested line. The FVSI are used as indicator to verify the level of voltage stability voltage condition. Apparently, voltage limit is the important criteria to justify which lines are congested. After selecting the placement of SVC and TCSC for congestion management, then the optimal sizing for these devices are determined using PSO technique.

Results based on fuzzy swarm optimization with FACTS device installation are tabulated in Table 5. The results show the location of SVC and TCSC with the optimal sizing respectively to minimize power losses. For instance, the power losses have been reduced from 18.5644MW to 17.9269MW when a single unit of SVC and TCSC is installed in the system at load bus 3. In order to achieve this value, the location of SVC is bus 3 with SVC sizing value of 29.8417 Mvar. While the location of TCSC is line 15 with a TCSC sizing value of -0.0161pu. Obviously, with the SVC and TCSC installation at the proper location and sizing, the voltage improvement is better than before installation. The same explanation applied for load buses 4, 7 and 30.

7 Conclusion

In this paper, a method based on fuzzy swarm has been suggested is applied to find the location and optimal sizing of SVC and TCSC in a stressed power system. The FCI is proposed to solve congestion problem in a power system. Hence, fuzzy technique is an alternative means of dealing
with conventional power flow analysis. The FVSI is used in comparing the proposed index. From the results, it can be observed that the installation of FACTS devices can significantly improve the voltage and minimized the power losses.

Table 4. Results fuzzy based on voltage limit

Table 5. Result based on Fuzzy Swarm with FACTS device installation

7 Acknowledgement

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