CHAPTER 5

OPTIMAL LOCATION OF FACTS DEVICES FOR SOLVING MULTI OBJECTIVE OPF USING IMPROVED SHUFFLED LEAPING FROG ALGORITHM

5.1 INTRODUCTION

Nowadays wind farms contributing to the energy production is continuously growing because of their economical and environmental protection attraction. However, large wind farms have higher reactive power demand that may not be easily satisfied. Therefore, connecting the wind farms to the power network becomes a more challenging task and their impacts are likely to be more widespread. (Thomas et al 1996) shows that the ability of a power network to meet wind farms reactive power requirement is a major factor determining the amount of power that can be integrated into the system. Moreover, the operational wind farms may bring voltage stability problem since the main factor causing voltage instability is the deficiency of reactive power in the system (Kundur 1994). Therefore, it is necessary to provide reactive power locally, and as close as possible to the demand levels. In order to meet the wind farm reactive power requirement, capacitors or SVC are employed to compensate reactive power commonly. They are used to carry out energy loss reduction, voltage regulation, and system security improvement. Economic benefits of the capacitor compensation depends mainly on where and how many capacities of the capacitor are installed, as well as proper control schemes of the capacitors at different wind turbines
power output levels in the wind farms. Optimal capacitor compensation has been investigated since the 60’s. Considerable variety of methods has been brought on to solving this problem. In the early, the conventional analytical methods in conjunction with some heuristics were very commonly employed to relax this problem. Later, the capacitor sizes were considered as discrete variables and employed dynamic programming to solve the problem in (Duran 1983).

Regarding capacitor size as continuous variables, a gradient search based iterative procedure was proposed to deal with fixed and switched type capacitor installation problem in (Grainger et al 1984). In the 90’s, combinatorial optimization algorithms were introduced as a means of solving the capacitor placement problem: simulated annealing was proposed in (Chiang et al 1990), genetic algorithms in (Sundharajan et al 1994), and Tabu search algorithms in (Huang et al 1996).

Flexible ac transmission systems (FACTS) have been developed to improve the performance of weak ac systems and enhance transmission capabilities over long ac lines. FACTS controllers can be used in all the three states of the power system, namely: steady state, transient and post transient steady state. Consequently, evolutionary algorithms because of their independency from the type of objective functions and constraints have been used by many researchers in recent years (Niknam et al 2005, Niknam et al 2010). One of the new evolutionary algorithms with a great potential for optimization applications is the Shuffled Frog Leaping Algorithm (SFLA). In fact, this algorithm can solve complex optimization problems, which are nonlinear, non-differentiable and multi-modal but it may trap in local optima. To overcome this problem, in this paper a new SFLA algorithm is proposed to
improve the local exploration of the algorithm in the entire search space. The main idea behind the new frog leaping rule is to extend the direction and the length of each frog’s jump by emulating the frog’s perceptions. The modification expands the local search space and improves the performance of the SFLA.

Swarm Optimization techniques are derived from Darwin’s Evolutionary Theory of ‘Survival of fittest’. In this developed method an improved SLFA and compared PSO, BFO and other optimization techniques for finding the optimal location of FACTS devices for minimizing the loss. Milano (2005) developed a power system analysis toolbox (PSAT) which is an open source Matlab software package for analysis and design of power system related problems.

MATLAB2008a and PSAT (Power System Analysis Toolbox) software’s are used for modeling and running the simulation. Normally in wind mill there is no fuel cost involvement. Hence in this chapter, fuel cost function is not included.

5.2 PROBLEM FORMULATION

The objective of this work is to minimize losses and maximize the system load ability by optimal location of FACTS devices using optimal power flow. Hence, the multi objective function can be proposed as:

\[ f_1(x,u) = P_L + \lambda_p (V_{Gm} - V_{Gm}^{\text{base}})^2 + \lambda_{QB} (\sum Q_{Gm}^{\text{base}})^2 \]  

\[ f_2(x,u) = \lambda_i \times (\sum_{m=1}^{N_L} VI_m + \sum_{j=1}^{N_R} Bol_n + c) \]
Subject to

\[
P_{Gm} + P_m - P_{Dm} - \sum_{n=1}^{N_G} V_{mn} V_{nm} \cos(\theta_{mn} + \delta_m - \delta_n) = 0; \forall m \in N_B \tag{5.3}
\]

\[
Q_{Gm} + Q_m - Q_{Dm} - \sum_{n=1}^{N_G} V_{mn} V_{nm} \sin(\theta_{mn} + \delta_m - \delta_n) = 0; \forall m \in N_B \tag{5.4}
\]

\[
\sum_{m=1}^{N_G} P_{Gm} + P_D - P_L = 0 \tag{5.5}
\]

\[
\sum_{m=1}^{N_G} Q_{Gm} + Q_D - Q_L = 0 \tag{5.6}
\]

\[
P_{Gm}^{\text{max}} \leq P_{Gm} \leq P_{Gm}^{\text{min}}, \forall m \in N_G \tag{5.7}
\]

\[
Q_{Gm}^{\text{max}} \leq Q_{Gm} \leq Q_{Gm}^{\text{min}}, \forall m \in N_G \tag{5.8}
\]

\[
V_{Gm}^{\text{max}} \leq V_{Gm} \leq V_{Gm}^{\text{min}}, \forall m \in N_B \tag{5.9}
\]

\[
|S_m| \leq S_m^{\text{max}}, \forall m \in N_L \tag{5.10}
\]

\[
X_{Sm}^{\text{max}} \leq X_{Sm} \leq X_{Sm}^{\text{min}}, \forall m \in N_{TCSC} \tag{5.11}
\]

\[
Q_{Sm}^{\text{max}} \leq Q_{Sm} \leq Q_{Sm}^{\text{min}}, \forall m \in N_{SVC} \tag{5.12}
\]

where $F$ is known as the objective vector, $f_1$ and $f_2$ are the two objective functions to be optimized, $x$ is the vector of dependent variables, and $u$ is the vector of control variables. The first objective is to minimize the losses, $P_{Gm}$, the active power output generated by the $m^{th}$ generator, $N_G$ is the total number of generators in the power network.

The second objective is to enhance the system loadability within security margin. The FACTS devices are placed in the network in order to increase the system loadability, and at the same time to prevent overloads and
voltage violations. The objective function is based on indexes quantifying the system load ability and the security state in terms of voltage levels and branch loading, which is expressed in equation (5.2) where $V_l$ and $Bol_m$ represent voltage levels and branch loading respectively. $N_B$ and $N_L$ are the total numbers of load buses and transmission lines respectively; $c$ is a positive constant; and $\lambda l$ is a load parameter of the system, which aims to find the maximum amount of power that the network is able to supply within system security margin.

5.3 MODELING OF FACTS DEVICES

5.3.1 SVC Model

SVC state variables are combined with the nodal voltage magnitudes and angles of the network in a single frame of reference for unified, iterative solutions using the Newton–Raphson method. Shunt Variable Susceptance Model (SVC) is considered. In practice the SVC can be seen as an adjustable reactance with either firing-angle limits or reactance limits (Ambriz-Pérez, Acha and Fuerte-Esquivel 2000). The equivalent circuit shown in Figure 5.1 is used to derive the SVC nonlinear power equations and the linearised equations required by Newton’s method.

![Figure 5.1 Variable shunt susceptance of SVC](image-url)
With reference to Figure 5.1, the current drawn by the SVC is

\[ I_{SVC} = jB_{SVC}V_k, \]  

(5.13)

and the reactive power drawn by the SVC, which is also the reactive power injected at bus \( k \),

\[ Q_{SVC} = Q_k = -V_k^2 B_{SVC} \]  

(5.14)

The linearised equation is given by Equation (5.15), where the equivalent susceptance \( B_{SVC} \) is taken to be the state variable:

\[
\begin{bmatrix}
\Delta P_k \\
\Delta Q_k
\end{bmatrix}^{(i)} =
\begin{bmatrix}
0 & 0 \\
0 & Q_k
\end{bmatrix}^{(i)}
\begin{bmatrix}
\Delta \theta_k \\
\Delta B_{SVA} / B_{SVC}
\end{bmatrix}^{(i)}
\]  

(5.15)

At the end of the iteration \( (i) \), the variable shunt susceptance \( B_{SVC} \) is updated according to

\[ B_{SVC}^{(i)} = B_{SVC}^{(i-1)} + \left( \frac{\Delta B_{SVC}}{B_{SVC}} \right)^{(i)} B_{SVC}^{(i-1)} \]  

(5.16)

The changing susceptance represents the total SVC susceptance necessary to maintain the nodal voltage magnitude at the specified value.

5.3.2 STATCOM Model

![Figure 5.2 STATCOM Model](image-url)
STATCOM is a shunt compensation device which can be used for improving the voltage profile. It is a shunt controller and it injects current to the transmission line. System voltage is greater than generator voltage, it absorbs the reactive power and if smaller then it generates the reactive power. It can be used on both voltage sourced and current sourced convertor. It can be designed to be an active filter to absorb system harmonics. Different FACTS devices and their different location have varying advantages. STATCOM modeling was done as per suggestions in (Shahgholian, et al., 2008). STATCOM is always located on a load bus. The bus on which STATCOM is being placed is converted from PV bus to PQ bus. Thus STATCOM is considered as a synchronous generator whose real power output is zero and its voltage is set to 1 p.u..

The power flow equations for the STATCOM are derived below from first principles and assuming the following voltage source representation:

Power flow model of STATCOM

\[ E_{vR} = V_{vR} (\cos \delta_{vR} + j \sin \delta_{vR}) \]  

(5.17)

Based on the shunt connection shown in Figure 5.2, the following may be written:

\[ S_{vR} = V_{vR} I_{vR}^* = V_{vR} Y_{vR} V_k^* (V_{vR}^* - V_k^*) \]  

(5.18)

The following active and reactive power equations are obtained for the converter and bus k, respectively:

\[ P_{vR} = V_{vR}^2 G_{vR} + V_{vR} V_k [G_{vR} \cos(\delta_{vR} - \theta_k) + B_{vR} \sin(\delta_{vR} - \theta_k)], \]  

(5.19)
\[ Q_{vR} = -V_{vR}^2 B_{vR} + V_{vR} V_R [G_{vR} \sin(\delta_{vR} - \theta_k) - B_{vR} \cos(\delta_{vR} - \theta_k)], \quad (5.20) \]

\[ P_k = V_k^2 G_{vR} + V_k V_{vR} [G_{vR} \cos(\theta_k - \delta_{vR}) + B_{vR} \sin(\theta_k - \delta_{vR})], \quad (5.21) \]

\[ Q_k = -V_k^2 B_{vR} + V_k V_{vR} [G_{vR} \sin(\theta_k - \delta_{vR}) - B_{vR} \cos(\theta_k - \delta_{vR})], \quad (5.22) \]

### 5.3.3 Modeling of TCSC

The TCSC power flow model presented in this work, based on the simple concept of a variable series reactance, the value of which is adjusted automatically to constrain the power flow across the branch to a specified value. The amount of reactance is determined efficiently using Newton’s method. The changing reactance \(X_{TCSC}\), shown in Figures 5.3(a) and 5.3(b), represents the equivalent reactance of all the series-connected modules making up the TCSC, when operating in either the inductive or the capacitive regions.

![Figure 5.3 TCSC equivalent circuit: (a) inductive (b) capacitive](image)

For inductive operation,

\[ B_{kk} = B_{mm} = -\frac{1}{X_{TCSC}}, \]

\[ B_{km} = B_{mk} = \frac{1}{X_{TCSC}}, \quad (5.23) \]
And for capacitive operation the signs are reversed.

The active and reactive power equations at bus $k$ are:

$$P_k = V_k V_m B_{km} \sin(\theta_k - \theta_m)$$  \hspace{1cm} (5.24)  

$$Q_k = -V_k^2 B_{kk} - V_k V_m B_{km} \cos(\theta_k - \theta_m).$$  \hspace{1cm} (5.25)  

$$\Delta P_{km}^{TCSC} = P_{km}^{reg} - P_{km}^{TCSC,act}$$  \hspace{1cm} (5.26)  

$$\Delta X_{TCSC} = X_{TCSC}^{(i)} - X_{TCSC}^{(i-1)}$$  \hspace{1cm} (5.27)

### 5.4 SFLA ALGORITHM

The OPF problem is a non-linear optimization problem. By considering the increased emission non-linearity degree and local optima numbers of this problem, it is necessary to solve it with a very accurate algorithm to prevent it from being trapped in local optima and to converge it to globally optimum results in proper time. SFLA mimics the metaphor of natural biological evolution that is based on populations of frogs in nature searching for food (Eusuff, Lansey 2003). The SFLA is a decreased based stochastic search algorithm which is started with an initial frog population whose characteristics represent the decision variables of the optimization problem. An initial population of $F$ frogs is created randomly. For $K$-dimensional problems ($K$ variables), a frog $i$ is represented as $X_i = (x_{i1}, x_{i2}, \ldots, x_{ik})$. Initially, the objective function is calculated for each frog, and afterwards frogs are sorted in a descending manner according to their fitness. In SFLA, the total population is divided into groups (memeplexes) that search independently.

In this process, the first frog goes to the first memeplex, the second frog goes to the second memeplex, frog $m$ goes to the $q$th memeplex, and
frog mq goes to the first memeplex, and so on. In the each memeplex, the frogs with the best and the worst fitness are recognized as Xb and Xw, respectively. Also, the frog with the best fitness in all memeplexes is recognized as Xg. Then, the following process is applied to improve only the frog with the worst fitness (not all frogs) in each iterate. Correspondingly, the location of the frog with the worst fitness is regulated as follows:

Change in the location

\[ V_i = \text{rand}(.) \times (X_b - X_w) + \text{rand}(.) \times (X_g - X_w) \]  
\[ X_w^{(new)} = X_w^i + V_i \quad -V_{\text{max}} \leq V_i \leq V_{\text{max}} \]  

where \( \text{rand}(.) \) is a random number between 0 and 1, and \( V_{\text{max}} \) is the maximum permitted change in a frog’s location. If this process generates a better solution, it replaces the worst frog. Otherwise, the calculations in Equations (5.28) and (5.29) are repeated for specific iterations (Itermax1). In addition, to provide the opportunity for random generation of improved information, random virtual frogs are generated and substituted in the population if the local search cannot find better solutions respectively in each iterate. After a number of iterations (Itermax1), all groups are combined and share their ideas with themselves through a shuffling process. The local search and the shuffling processes continue until the defined convergence criteria are satisfied. The aim of the entire process is to determine global optimal solutions. Besides the privileges of SFLA, it also has some problems, such as the possibility of being trapped in the local optima or premature convergence to local optima. Therefore, for solving the complicated optimization problem it is necessary to enhance the SFLA algorithm’s search ability by mutation or hybrid this algorithm by other optimization problems.
In this chapter, a new proposed Improved SLFA (ISLFA) has been introduced in order to support the SLFA drawbacks.

5.4.1 Improved SLFA algorithm (ISFLA)

The original SFLA may be trapped in local optima due to its drawback in finding the worst frog position. In this chapter, two new modifications are employed to overcome the aforementioned deficiencies. In each memeplex, the position of the frog with the worst fitness is adjusted as follows:

\[
\Delta X_{\text{improved}} = \text{rand}() \cdot (X_{\text{best}} - T_F \cdot X_M)
\]  

(5.30)

\[
X_{\text{worse}}^{\text{old}} = X_{\text{worse}}^{\text{old}} + \Delta X_{\text{improved}}
\]  

(5.31)

where, \(X_M\) is the mean value of individuals in each memeplex. \(T_F\) is a heuristically determined constant factor and is chosen randomly from values 1 or 2.

\((T_F = \text{round} [1 + \text{rand} (0, 1)])\). To improve the diversity of the search space vector, a frog \(X_j\) is selected from the population of the frogs such that \(X_j \neq X_i\). Subsequently,

The position is determined using the following equation.

\[
\begin{align*}
\text{if, } f(X_n) &\geq f(X_m) \\
\Delta X_{\text{improved}}^2 & = \text{rand}() \cdot (X_n - X_m) \\
\text{else} & \\
\Delta X_{\text{improved}}^2 & = \text{rand}() \cdot (X_n - X_m)
\end{align*}
\]  

(5.32)
The new improved individual is generated as follows:

\[ X_{m}^{\text{new}} = X_{m}^{\text{old}} + \Delta X_{\text{improved}} \]  
\[ (5.33) \]

If the performance of the generated frogs given in Equations. (5.30) or (5.31) are better than the worst frog, it replaces the worst frog. Otherwise a new solution is generated by a Chaotic Local Search (CLS), as follows:

At first, the best solution in each memeplex is considered as an initial solution \( (X_{cls}^0) \) for CLS, where \( X_{cls}^0 \) is scaled into \([0,1]\) according the following equation:

\[ X_{cls}^0 = [X_{cls,0}^1, X_{cls,0}^2, \ldots, X_{cls,0}^n]_{\text{cls}} \]
\[ C_{so} = [cX_0^1, cX_0^2, \ldots, cX_0^n] \]
\[ \alpha_{j}^0 = \frac{X_{cls,0}^j - x_{j,\text{min}}}{x_{j,\text{max}} - x_{j,\text{min}}}, j = 1,2,\ldots,n \]
\[ (5.34) \]

Then, the chaos population for CLS is generated as:

\[ X_{cls}^i = [X_{cls,i}^1, X_{cls,i}^2, \ldots, X_{cls,i}^n]_{\text{cls}}, i = 1,2,\ldots,N_{\text{choas}} \]
\[ x_{cls,i}^j = cx_{i-1}^j \times (x_{j,\text{max}} - x_{j,\text{min}}) + x_{j,\text{min}}, j = 1,2,\ldots,n \]
\[ (5.35) \]

where, \( cx_{i}^j \) indicates the jth chaotic variable and \( N_{\text{choas}} \) is the number of individuals for CLS. Then, the best solution among them is replaced with the worst solution. Fig. 3 shows the single line diagram of IEEE 30 system.

### Table 5.1 ISLFA Algorithm parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of frogs</td>
<td>15</td>
</tr>
<tr>
<td>Number of memeplex</td>
<td>15</td>
</tr>
<tr>
<td>Iteration max(_1)</td>
<td>80</td>
</tr>
<tr>
<td>Iteration max(_2)</td>
<td>100</td>
</tr>
<tr>
<td>Iteration of mutation</td>
<td>10</td>
</tr>
</tbody>
</table>
Figure 5.4 Flow chart for improved shuffled leaping frog algorithm
5.5 SIMULATION AND RESULTS

In order to illustrate the efficiency and robustness of the proposed ISLFA algorithm, this algorithm is performed on 9 bus, 14 bus and 30-bus IEEE test system with the help of PSAT (Power system analysis tool box) considering constant speed squirrel cage induction generator (CSIG). In this simulation Reactive power flow across circuits is determined by the difference in the voltage magnitudes between the terminating buses; if this difference is high then the reactive power flow across circuits is increased and causes an increase in power loss. Also one of the important aims of OPF is to keep all voltages at values between 0.95 p.u and 1.05 p.u around the nominal point of operation, thus ensuring that the system is sufficiently far away from the point of the collapse. Table 5.2 shows the power flow results for different locations of STATCOM on single with wind machine SCIG (Constant speed Squirrel cage induction motor). STATCOM connected in bus number 4, 5, 6, 7, 8 and 9. Minimum losses obtained the STATCOM should be placed at bus number 5. Figure 5.4 gives the flow chart for improved shuffled leaping frog algorithm. Figure 5.5 shows the IEEE 14 bus system with STATCOM at bus number 9. This simulated results are given in Table 5.3. From the table STATCOM gives minimum result at bus 9 compared to other. Figure 5.6 shows the simulation on IEEE 14 bus system STATCOM located at multiple buses. The results of the simulation given in Table 5.4. Figure 5.7 shows the IEEE 14 bus system with SVC at bus 9. The corresponding results of this simulink tabulated in Table 5.5. Figure 5.8 shows IEEE 14 bus system with multiple SVC’s. The power flow results for this simulation given in Table 5.6.
Figure 5.9 shows the IEEE 14 bus system with TCSC at bus 9. The simulation results are given in Table 5.7. Figure 5.10 shows the IEEE 14 bus system with multiple TCSC. The corresponding simulation results are given in Table 5.8.

The comparisons of all FACTS devices for 14 bus system are given in Table 5.9. From this table, STATCOM has given the better results compared to other FACTS devices. Table 5.10 shows the comparisons of losses for different algorithms for IEEE 30 bus system. Figure 5.11 shows the effectiveness of this proposed approach. More than 10% of losses reduced by this improved shuffled leaping Frog algorithm.

**Table 5.2 Power flow report for different location of STATCOM on single bus**

<table>
<thead>
<tr>
<th>Type of Generator</th>
<th>Type of FACTS</th>
<th>BUS</th>
<th>Ploss(p.u)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIG</td>
<td>-</td>
<td>-</td>
<td>0.04648</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>4</td>
<td>0.04642</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>5</td>
<td>0.04473</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>6</td>
<td>0.04861</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>7</td>
<td>0.10377</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>8</td>
<td>0.0941</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>9</td>
<td>0.10016</td>
</tr>
</tbody>
</table>

Above Table 5.2. Shows that for minimum real power loss the STATCOM should be placed at Bus 5.
Figure 5.5  IEEE 14 bus system with STATCOM at Bus 9
Proposed System Specifications:       Specification for SCIG:

Buses: 14               Power: 600MVA

Lines: 16               Voltage: 69 KV

Transformers: 4          Frequency: 60 Hz

Generators: 4

Loads: 11

Wind turbine (SCIG): 1

Table 5.3 Power flow report for 14 bus system with STATCOM at different single buses

<table>
<thead>
<tr>
<th>Type of generator</th>
<th>Type of FACTS</th>
<th>BUS number (load)</th>
<th>P loss (per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SCIG)</td>
<td>--</td>
<td>--</td>
<td>0.17384</td>
</tr>
<tr>
<td>(SCIG)</td>
<td>STATCOM</td>
<td>9</td>
<td>0.0966</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>10</td>
<td>0.10058</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>11</td>
<td>0.10939</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>12</td>
<td>0.11642</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>13</td>
<td>0.10117</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>14</td>
<td>0.09701</td>
</tr>
</tbody>
</table>
5.5.1 SCIG with multiple STATCOM

Figure 5.6  IEEE 14 bus system with STATCOM at multiple buses
Table 5.4  Power flow report for 14 bus system with Multiple STATCOM

<table>
<thead>
<tr>
<th>Type of generator</th>
<th>Type of FACTS</th>
<th>BUS number (load)</th>
<th>P loss (per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>10,11,12</td>
<td>0.04904</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>10,12</td>
<td>0.06551</td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>11,12</td>
<td>0.07653</td>
</tr>
</tbody>
</table>

5.5.2 SCIG with SVC at bus 9

Figure 5.7  IEEE 14 bus system with SVC at bus 9
Table 5.5. Results for 14 bus system with Single SVC

<table>
<thead>
<tr>
<th>Type Of generator</th>
<th>Type of FACTS</th>
<th>BUS number (load)</th>
<th>P loss (per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIG</td>
<td>SVC</td>
<td>9</td>
<td>0.15356</td>
</tr>
<tr>
<td>SCIG SVC</td>
<td>10</td>
<td>0.15674</td>
<td></td>
</tr>
<tr>
<td>SCIG SVC</td>
<td>11</td>
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</tr>
<tr>
<td>SCIG SVC</td>
<td>12</td>
<td>0.16756</td>
<td></td>
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<td>SCIG SVC</td>
<td>13</td>
<td>0.16148</td>
<td></td>
</tr>
<tr>
<td>SCIG SVC</td>
<td>14</td>
<td>0.16041</td>
<td></td>
</tr>
</tbody>
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5.5.3 SCIG with multiple SVC’s

Figure 5.8  IEEE 14 bus system with multiple SVC’s
Table 5.6 Results for 14 bus system with multiple SVC’s

<table>
<thead>
<tr>
<th>Type of generator</th>
<th>Type of FACTS</th>
<th>Bus Number (load)</th>
<th>P loss (per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squirrel cage induction generator (SCIG)</td>
<td>-</td>
<td>--</td>
<td>0.17384</td>
</tr>
<tr>
<td>SCIG</td>
<td>SVC</td>
<td>9,10,11</td>
<td>0.15261</td>
</tr>
<tr>
<td>SCIG</td>
<td>SVC</td>
<td>10,11,12</td>
<td>0.15502</td>
</tr>
<tr>
<td>SCIG</td>
<td>SVC</td>
<td>12,13,14</td>
<td>0.15725</td>
</tr>
<tr>
<td>SCIG</td>
<td>SVC</td>
<td>9,10,11,12,13,14</td>
<td>0.15113</td>
</tr>
</tbody>
</table>

5.5.4 SCIG with TCSC at bus 14

Figure 5.9 IEEE 14 bus system with TCSC at bus 9
Table 5.7 Results for 14 bus system with TCSC

<table>
<thead>
<tr>
<th>Type of generator</th>
<th>Type of FACTS</th>
<th>Bus Number (load)</th>
<th>P loss (per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>9</td>
<td>0.17351</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>10</td>
<td>0.17313</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>11</td>
<td>0.17256</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>12</td>
<td>0.17136</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>13</td>
<td>0.17252</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>14</td>
<td>0.16822</td>
</tr>
</tbody>
</table>

Figure 5.10  IEEE 14 bus system with multiple TCSC
Table 5.8 Results for TCSC on multiple buses for 14 bus system

<table>
<thead>
<tr>
<th>Type of generator</th>
<th>Type of FACTS</th>
<th>Bus Number (load)</th>
<th>P loss (per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>9,10,11</td>
<td>0.17162</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>10,11,12</td>
<td>0.16945</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>12,13,14</td>
<td>0.16562</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>9,10,11,12,13,14</td>
<td>0.15113</td>
</tr>
</tbody>
</table>

Table 5.9 Comparisons of all FACTS devices for 14 bus system

<table>
<thead>
<tr>
<th>Type of generator</th>
<th>Type of FACTS</th>
<th>Bus Number (load) (load)</th>
<th>P loss (per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squirrel cage</td>
<td>--</td>
<td>--</td>
<td>0.17384</td>
</tr>
<tr>
<td>induction generator (SCIG)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCIG</td>
<td>STATCOM</td>
<td>9</td>
<td>0.0966</td>
</tr>
<tr>
<td>SCIG</td>
<td>SVC</td>
<td>9</td>
<td>0.15356</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>14</td>
<td>0.16822</td>
</tr>
<tr>
<td>SCIG</td>
<td>SVC</td>
<td>9,10,11,12,13,14</td>
<td>0.15113</td>
</tr>
<tr>
<td>SCIG</td>
<td>TCSC</td>
<td>9,10,11,12,13,14</td>
<td>0.15113</td>
</tr>
</tbody>
</table>
Table 5.10  Comparisons of losses for different algorithms for IEEE 30 bus system

<table>
<thead>
<tr>
<th>Algorithm name</th>
<th>FACTS device used</th>
<th>Real power Loss (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard GA (SGA)</td>
<td>STATCOM</td>
<td>9.517</td>
</tr>
<tr>
<td>Enhanced GA (EGA)</td>
<td>STATCOM</td>
<td>9.390</td>
</tr>
<tr>
<td>Ant Colony Optimization (ACO)</td>
<td>STATCOM</td>
<td>9.8520</td>
</tr>
<tr>
<td>Fuzzy based GA (FGA)</td>
<td>STATCOM</td>
<td>9.494</td>
</tr>
<tr>
<td>Particle Swarm Opt.(PSO)</td>
<td>STATCOM, SVC</td>
<td>--------</td>
</tr>
<tr>
<td>Evolutionary Program.(EP)</td>
<td>STATCOM</td>
<td>--------</td>
</tr>
<tr>
<td>Improved Shuffled Leaping Frog Algorithm (ISLFA)</td>
<td>STATCOM</td>
<td>8.298</td>
</tr>
</tbody>
</table>

Figure 5.11  Comparisons of real power losses with different FACTS devices
5.6 SUMMARY

The above results show the losses obtained at the buses when the various types of FACTS devices (series, shunt, and series-shunt) are placed. We can conclude that Static Synchronous Compensator provide minimal losses at the critical buses out the three FACTS devices used. This helps us meet our first objective. Also applying ISLFA for loss minimization provides an improved result in comparison to Optimal Power Flow transmission loss. This helps us meet our second objective.

It can be seen from the simulation results, with ISFLA, it was possible for utility to place FACTS devices in a transmission system and wind form such that the optimal reactive power planning can be achieved and the system real power loss can be minimized.

This method has immense potential for future studies. The exact distance between bus and STATCOM for optimum location of STATCOM can be found out to change the parameters of buses, loads etc., So that after placing STATCOM, increase the load ability of the buses even further, keeping in mind its stability after incorporating STATCOM can be studied in the future.