VOLTAGE STABILITY IMPROVEMENT AND REDUCE POWER SYSTEM LOSSES BY BACTERIAL FORAGING OPTIMIZATION BASED LOCATION OF FACTS DEVICES

J. Vivekananthan¹, R. Karthick²

¹ PG Scholar, Department of Electrical and Electronics Engg,
² Assistant Professor, Department of Electrical and Electronics Engg.

¹ vivekjobmail@gmail.com, ² karthick.ketti@gmail.com

Abstract—Modern power systems are prone to widespread failures. Power demand is increase then the operation and planning of large interconnected power system are becoming more and more complex, so the power system will be less secure system. So the problem of instabilities in entire system working environment, regular planning and method of operation. In power industry, voltage instability is one of the most important problem. Recently several network blackouts have been related to voltage collapse. The problem voltage stability play a major role in fast development of restructuring in deregulated power system. FACTS devices can maintain the active and reactive power control as well as adaptive to voltage-magnitude control simultaneously because of their flexibility and fast control characteristics. Placing of FACTS devices in a suitable location is important to improves the voltage stability and reduce power system losses.

This paper presents an effective method to find best optimal location of FACTS controllers using Bacterial Foraging Optimization (BFO). Proposed algorithm is tested on IEEE 30 bus power system for optimal allocation of FACTS devices and results are presented.

Keywords—Power Flow Study, Voltage Stability, FACTS Devices, Optimal location, Bacterial Foraging Optimization Algorithm (BFOA).

I. INTRODUCTION

MODERN, power systems are prone to extending over a wide area of failures. Power demand is increase then the operation and planning of large interconnected power system are becoming more and more complex, so the power system will be less secure system. So the problem of instabilities in entire system working environment, regular planning and method of operation. In power industry, voltage instability is one of the most important problem. Voltage collapse is the main reason for network blackouts.

Besides, with the electricity market deregulation, increases the number of unplanned power exchanges due to the competition among utilities and direct contracts concluded between generation companies and consumers. So the problem of overloading is takes place in some transmission lines. Because many of the existing transmission lines could not deal with increasing power demand, the problem of voltage stability and voltage collapse has also become a major concern.

Transmission system operator (TSO) is in interest with the control of power flow to have more reliable, secure and efficient. To overcome this problem, FACTS devices are introduced.

FACTS devices can regulate the active and reactive-power control as well as adaptive to voltage magnitude control simultaneously by their fast control characteristics and their continuous compensating capability and so reduce flow of heavily loaded lines and maintain voltages in desired level.

Besides, FACTS devices can improve both transient and small signal stability margins. Controlling the power flows in the network, under normal and abnormal conditions of the network, can help to reduce flows in heavily loaded lines, reduce system power loss, and so improve the stability and performance of the system without generation rescheduling or topological changes in the network. Because of the considerable costs of the FACTS devices, it is so mementos to find out the
optimal location for placement of these devices to improve voltage stability margins and enhance network security.

Effect of FACTS devices on power system reliability, loadability and security are studied according to control objectives in proper manner. Some of papers have been tried to find suitable location for FACTS devices to improve power system security and loadability. Optimal allocation of these devices in deregulated power systems has been presented in.

Some of papers use heuristic approaches and intelligent algorithms to find suitable location of FACTS devices. Voltage stability index has been used to find the suitable location of UPFC to improve power system security/stability after evaluating the degree of severity of considered contingencies. This paper presents a novel heuristic method based on GA to find optimal location of multi-type FACTS devices to enhance voltage stability level considering investment cost these devices and power system losses.

Previously used technique for many optimization problems like economic dispatch, optimal power flow, and congestion management, controller optimization and etc in power system is Genetic Algorithm. Proposed method is tested on IEEE 30 bus system and results are presented.

II. FACTS DEVICES MODEL

A. FACTS Devices

In this paper, three different FACTS devices have been selected to place in suitable location to improve voltage stability margins in power system. These are: SVC (Static VAR Compensator), TCSC (Thyristor Controlled Series Capacitor) and UPFC (Unified Power Flow Controller). These are shown in below Fig. 1.

![FACTS Devices Diagram](image)

Figure 1. Considered FACTS Devices (a) TCSC (b) SVC (c) UPFC.

Power flow through the transmission line i-j namely is $P_{ij}$ depended on line reactance, bus voltage magnitudes, and phase angle between sending and receiving buses. This is expressed by Eq. 1.

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin(\delta_i - \delta_j),$$

TCSC can change line reactance and SVC can be used to control reactive power in network. UPFC is the most versatile member of FACTS devices family and can be applied in order to control all power flow parameters (i.e. bus voltage, line impedance and phase angle). By changing power system parameters using FACTS devices Power flow can be controlled and optimized. So optimal choice and allocation of FACTS devices can result in suitable utilization in power system.
B. Mathematical Model of FACTS Devices

In this paper steady state model of FACTS devices are developed for power flow studies. So TCSC is modeled simply to just modify the reactance of transmission line. SVC and UPFC are modeled using the power injection models. Models integrated into transmission line for TCSC and UPFC and SVC is modeled is incorporated into the bus as shunt element of transmission line.

Mathematical models for FACTS devices are implemented by MATLAB programming language.

TCSC:

TCSC acts as the capacitive or inductive compensator by modifying reactance of transmission line. This changes line flow due to change in series reactance.

In this paper TCSC is modeled by changing transmission line reactance as below:

$$X_{ij} = X_{\text{line}} + X_{\text{TCSC}},$$

(2)

$$X_{\text{TCSC}} = \rho_{\text{TCSC}} X_{\text{line}},$$

(3)

where $X_{\text{line}}$ is reactance of transmission line and $\rho_{\text{TCSC}}$ is compensation factor of TCSC. Rating of TCSC is depended on transmission line where it is located. To prevent overcompensation, TCSC reactance is chosen between $-0.7 X_{\text{line}}$ to $0.2 X_{\text{line}}$ [18].

SVC:

SVC can be used for both inductive and capacitive compensation. In this paper SVC is modeled as an ideal reactive power injection at bus:

$$\Delta Q_i = Q_{\text{SVC}}$$

(4)

UPFC:

Two types of UPFC models are reported in papers. One is coupled model and other is decoupled model. In the first type, UPFC is modeled with series combination of a voltage source and impedance in the transmission line. In decoupled model, UPFC is modeled with two separated buses. First model is more complex compared with the second one because modification of Jacobian matrix in coupled model is inevitable.

While decoupled model can be easily implemented in conventional power flow algorithms without modification of Jacobian matrix elements, in this paper, decoupled model used for modeling UPFC in power flow study (Fig. 2).

Figure 2. Decoupled model for UPFC

UPFC controls power flow of the transmission line where is installed. To obtain UPFC model in load flow study, it is represented by four variables: $P_{u1}$, $Q_{u1}$, $P_{u2}$, $Q_{u2}$. Assuming UPFC to be lossless, real power flow from bus $i$ to bus $j$ can be expressed as:

$$P_{ij} = P_{u1}$$

(5)

Although UPFC can control the power flow, but can not generate the real power. So:

$$P_{u1} + P_{u2} = 0$$

(6)

Each reactive power output of UPFC $Q_{u1}$, $Q_{u2}$ can be set to an arbitrary value depend on rating of UPFC to maintain bus voltage.
III. VOLTAGE STABILITY INDEX

Consider a power network where \( n \) is the total number of buses with 1, 2, ..., \( g \) generator buses, and \( g+1, ..., n \) remaining \((n-g)\) buses. For a given system operating condition, using the load-flow (state-estimation) results, the voltage-stability \( L \) index is obtained as [20, 30]:

\[
L_j = 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j}
\]  

(7)

where \( j = g+1, ..., n \) and all the terms inside the sigma on the right-hand side of (7) are complex quantities. The complex values of \( F_{ij} \) are obtained from the \( Y \)-bus matrix of power system. For a given operating condition:

\[
\begin{bmatrix}
I_G \\
I_L
\end{bmatrix} = \begin{bmatrix}
Y_{GG} & Y_{GL} \\
Y_{LG} & Y_{LL}
\end{bmatrix} \begin{bmatrix}
V_G \\
V_L
\end{bmatrix}
\]  

(8)

where \( I_G \), \( I_L \), and \( V_G \), \( V_L \), represent complex current and voltage vectors at the generator nodes and load nodes. \([Y_{GG}], \ldots[Y_{GL}], \ldots[Y_{LL}], \text{and } [Y_{GG}]\) are corresponding partitioned portions of the \( Y \)-bus matrix. Rearranging (8),

\[
\begin{bmatrix}
I_G \\
I_L
\end{bmatrix} = \begin{bmatrix}
Y_{GG} & Y_{GL} \\
Y_{LG} & Y_{LL}
\end{bmatrix} \begin{bmatrix}
V_G \\
V_L
\end{bmatrix}
\]  

(9)

For stability, the index \( L_j \) must not be more than one for any of the nodes \( j \). Hence, the global index \( L \) demonstrating the stability of the complete sub-system is given by \( L \) = maximum of \( L_j \) for all \( j \) (load buses). An \( L \)-index value far away from 1 and close to 0 indicates improved voltage stability. For an unloaded system with generator/load buses voltages, the \( L \)-index values are close to zero, indicating that the system has maximum voltage stability margin. For a given network, with the increase in load/generation, the voltage magnitude and angles change near maximum-power-transfer condition and the propensity of voltage-stability is to be close to unity, indicating that the system is close to voltage collapse. The \( L \) index gives a scalar number to each load bus. Among the various indices for voltage-stability and voltage-collapse prediction, the \( L \) index gives fairly compatible results. The \( L \) indices for given loads conditions are calculated for all the load buses and the maximum of the \( L \) indices gives the proximity of the system to voltage collapse.

IV. BACTERIAL FORAGING OPTIMIZATION

In the bacterial foraging process, four motile behaviors (chemotaxis, swarming, reproduction, and elimination and dispersal) are mimicked.

i) Chemotaxis:

This process simulates the movement of an \( E.coli \) cell through swimming and tumbling via flagella. Biologically an \( E.coli \) bacterium can move in two different ways. It can swim for a period of time in the same direction or it may tumble, and alternate between these two modes of operation for the entire lifetime. Suppose \((j, k, l)\) represents \( i \)-th bacterium at \( j \)-th chemotactic, \( k \)-th reproductive and \( l \)-th elimination-dispersal step. \( C(i) \) is the size of the step taken in the random direction specified by the tumble (run length unit). Then in computational chemotaxis the movement of the bacterium may be represented by

\[
\theta^i(j+k,l) = \theta^i(j,k,l) + C(i) \frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}},
\]  

(10)

where \( \Delta \) indicates a vector in the random direction whose elements lie in \([-1, 1]\). 

ii) Swarming:

An interesting group behavior has been observed for several motile species of bacteria including \( E.coli \) and \( S. typhimurium \), where intricate and stable spatio-temporal patterns (swarms) are formed in semisolid nutrient medium. A group of \( E.coli \) cells arrange themselves in a traveling ring by moving up the nutrient gradient when placed amidst a semisolid matrix with a single nutrient chemo-effector. The cells when stimulated by a high level of \( succinate \), release an attractant \( aspartate \), which helps them to aggregate into groups and thus move as concentric patterns of swarms with high bacterial density. The
cell-to-cell signaling in E. coli swarm may be represented by the following function.

\[ J_{cc} (\theta, P(j, k, l)) = \sum_{i=1}^{S} J_{cc} (\theta, \theta_i(j, k, l)) \]

where \( J_{cc} (\theta, P(j, k, l)) \) is the objective function value to be added to the actual objective function (to be minimized) to present a time varying objective function, \( S \) is the total number of bacteria, \( p \) is the number of variables to be optimized, which are present in each bacterium.

\[ J_{cc} (\theta, P(j, k, l)) = \sum_{i=1}^{S} J_{cc} (\theta, \theta_i(j, k, l)) \]

\[ = \sum_{i=1}^{S} \left[ \sum_{j=1}^{p} \left[ \text{constant} \exp(-w_{ striving} \sum_{j=1}^{p} \left( \theta_i - \theta_j \right)^2) \right] + \sum_{j=1}^{p} \left[ \text{constant} \exp(-w_{replana} \sum_{j=1}^{p} \left( \theta_i - \theta_j \right)^2) \right] \right] \]

where \( J_{cc} (\theta, P(j, k, l)) \) is the objective function value to be added to the actual objective function (to be minimized) to present a time varying objective function, \( S \) is the total number of bacteria, \( p \) is the number of variables to be optimized, which are present in each bacterium.

iii) **Reproduction:**

The least healthy bacteria eventually die while each of the healthier bacteria (those yielding lower value of the objective function) asexually split into two bacteria, which are then placed in the same location. This keeps the swarm size constant.

iv) **Elimination and Dispersal:**

Gradual or sudden changes in the local environment where a bacterium population lives may occur due to various reasons e.g. a significant local rise of temperature may kill a group of bacteria that are currently in a region with a high concentration of nutrient gradients. Events can take place in such a fashion that all the bacteria in a region are killed or a group is dispersed into a new location. To simulate this phenomenon in BFOA some bacteria are liquidated at random with a very small probability while the new replacements are randomly initialized over the search space.

V). **FACTS devices Cost Function:**

Using Siemens AG Database [33], cost function for SVC, TCSC and UPFC are developed as follows:

TCSC:

\[ C_{TCSC} = 0.0015s^2 - 0.713s + 153.75 \]  \( \text{(12)} \)

SVC:

\[ C_{SVC} = 0.0035s^2 - 0.3051s + 127.38 \]  \( \text{(13)} \)

UPFC:

\[ C_{UPFC} = 0.0003s^2 - 0.2691s + 188.22 \]  \( \text{(14)} \)
V. SIMULATION RESULTS

Simulation studies were done for different scenarios in IEEE 30 bus power system. Five different scenarios are considered:

- Scenario 1: power system normal operation (without FACTS devices installation).
- Scenario 2: one TCSC is installed
- Scenario 3: one SVC is installed
- Scenario 4: one UPFC is installed

The first scenario is normal operation of network without installing any device. In second, third and forth scenario just installation of one device is considered. Each device is placed at an optimal location obtained by GA introduced in Chapter IV.

<table>
<thead>
<tr>
<th>scenario</th>
<th>Losses</th>
<th>Location</th>
<th>Voltage stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.56</td>
<td>-</td>
<td>9.5</td>
</tr>
<tr>
<td>2</td>
<td>7.24</td>
<td>4-12</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>7.3</td>
<td>10-22</td>
<td>5.787</td>
</tr>
<tr>
<td>4</td>
<td>7.12</td>
<td>6-28</td>
<td>4.32</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

In this paper a novel approach for optimal placement of FACTS devices based on Bacterial Foraging Optimization (BFO) algorithm is presented. Simulation of IEEE 30 bus test system for different scenarios shows that the placement of FACTS devices leads to improve in voltage stability margin of power system and reduce losses.

REFERENCES


