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Comparison of FACTS Devices Performances Used to Improve Voltage Stability Based on GA-GSA Hybrid Algorithm

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Abstract

For the improvement of voltage stability, it is suggested that Flexible AC Transmission System (FACTS) devices are to be incorporated properly in the transmission lines. In this paper the voltage stability enhancements with two FACTS devices namely unified power flow controller (UPFC) and interline power flow controller (IPFC) have been studied using GA-GSA hybrid algorithm. A comparative analysis is made between the two devices based on different factors such as voltage profile improvement, loss minimization, cost of investment and voltage stability improvement. Newton-Raphson method is used for power flow analysis before and after insertion of each FACTS device. Depending on the voltage collapse scenario the best locations for inserting the FACT device are determined by using GA algorithm. At each location the rating of FACTS device is determined by using GSA algorithm. After that final optimal location and the exact capacity of FACTS device is calculated by considering the losses and cost of device .That optimal rated FACT device is inserted at the selected location and the performance of the system is observed. The complete evaluation is done on IEEE-30 bus test system by using MATLAB. From the simulation results, an elaborate comparison has been made between UPFC and IPFC based on the performance of the system with each of these two FACTS devices for voltage stability improvement.

Keywords: *Voltage collapse, power loss, UPFC, IPFC, GA, GSA*

1. Introduction

Many resent situations show that power system is frequently suffering with severe voltage instability incidences [1]. This is due to various reasons such as increased power consumption in the areas where it is not feasible to have new generating plants, the environmental pressures on transmission expansion and typical loading patterns due to present day electricity market strategies *etc*. [2]. The main reason for voltage instability is improper absorption of reactive power [3, 4]. It occurs as a gradual decay in voltage magnitude at some buses. As a result cascaded outages can be taken and finally voltage collapse takes place in the system [5, 6].To prevent voltage instability, a better method is that the reactive power handling capacity of the transmission lines should be improved with proper installation of Flexible AC Transmission System (FACTS) devices [7].In these FACTS devices, unified power flow controller (UPFC) and interline power flow controller (IPFC) are considered as the best control devices to maintain voltages at required levels [8]. The major advantages of inserting these devices in the network are improving power handling capability with existing transmission system and also reducing generations cost [3, 9]. In the literature various techniques such as fuzzy logic, genetic algorithm and gravitational search algorithm viz. are proposed for optimal setting of

FACTS devices to improve voltage stability. These methods render the optimal results but they have some limits. Drawbacks of these algorithms are slower convergence properties, more execution time and algorithmic complexity. In order to overcome these disadvantages the best method is aimed to develop hybrid approach by merging the available optimization algorithms getting the required performance [10].

The literature shows many research works for improving voltage stability of the power system. Some of them are discussed here. By using conventional dynamic techniques, the results cannot be achieved accurately. They consume more computation time and also the post disturbance events are not controlled easily. Luis Aromataris *et al.* [11] has proposed a static technique to improve voltage stability. In their proposed technique they made modifications such that post-disturbance events are controlled through different time delay control devices. Thus this technique gives more accuracy than dynamic techniques. A. Y. Abdelaziz *et al.* [12] has presented a method based on genetic algorithm which mainly focused on the loadability of the transmission lines and the loss minimization. In this approach the optimal locations of thyristor controlled series compensators are decided by taking thermal and voltage limits in to account. They used IEEE 30 bus system for testing their approch. D. Mondal *et al.* [13] has applied a technique based on Particle Swarm Optimization (PSO) algorithm to choose the best location and size of Static Var Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC) by elevating small signal fluctuations in multi machine power system. Wen Shan Tan *et al.* [14] has offered a multi objective strategy for optimal location and sizing of multi DG units based on mixed algorithm which is a combination of particle swarm optimization (PSO) and gravitational search algorithm (GSA). Here voltage profile, power losses , capacity of DG units and the green house gases discharge are taken in to account. IEEE 69 bus system is used to expose the power of their proposed PSO-GSA technique.

In this paper, the optimal location and sizing of UPFC and IPFC are evaluated and studied based on GA-GSA hybrid algorithm. A comparative analysis has been done between the two devices in various parameters regarding their preferences to improve the stability of the system. Here Section 2 deals with the problem formation and necessary algorithm; Section 3 shows the simulation results; and Section 4 gives conclusions.

2. Problem Formulation

In this paper two FACTS devices, UPFC and IPFC are adopted for real and reactive power compensation to improve the voltage stability. The optimal location of the FACTS device is determined with GA algorithm and the rating of the device is decided by applying GSA algorithm. The optimal location and capacity of FACTS devices can be formulated as a multi-objective problem having the following objectives and constraints (3, 8).

2.1. Objective Function

$$\text{Minimize } F(t,u) \tag{1}$$

$$\text{Subjected to: } g(t,u) = 0 \tag{2}$$

$$h(t,u) \leq 0 \tag{3}$$

where, $F(t,u)$ is the objective function of the vibrant stability, which reduces the loss, voltage variation and cost of the FACTS device. Next, $g(t,u)$ is the equality constraint and $h(t,u)$ is the inequality constraint.

2.2. Voltage Stability Index (L-index)

The voltage stability indicator *L*-index values at every bus are supposed to minimize to improve Voltage stability [10]. This factor is used to assess the proximity of voltage collapse [15]. L-index for *jth* node is given by

$$L_j = \left| 1 - \sum_{i=1}^{NG} F_{ij} \frac{V_i}{V_j} \right| \tag{4}$$

$$J = \sum_{j=NG+1}^{NB} L_j^2 \tag{5}$$

where *NG* denotes number of generator buses, NB denotes total number of buses.

2.3. Constraints

2.3.1. Equality Constraints

The power balance condition is described as nonlinear equations given by,

$$P_{G_i} - P_{D_i} = \sum_{j=1}^{N} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{6}$$

$$Q_{G_i} - Q_{D_i} = \sum_{j=1}^{N} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{7}$$

where, P_{G_i} Q_{G_i} P_{G_i} Q_{G_i} are the injected real and reactive powers and P_{D_i} and Q_{D_i} are the load demands. Y_{ij} is the admittance matrix. V_i, V_j are the voltage magnitudes and δ_i and δ_j are the angles of i^{th} and j^{th} buses respectively.

2.3.2. Inequality Constraints

The limits of the generation, real and reactive power and voltage magnitude and angles are expressed as

$$P_n^{\min} \le P_n \le P_n^{\max} \tag{8}$$

$$Q_n^{\min} \le Q_n \le Q_n^{\max} \tag{9}$$

$$V_n^{\min} \le V_n \le V_n^{\max} \tag{10}$$

$$\delta_n^{\min} \le \delta_n \le \delta_n^{\max} \tag{11}$$

3. Modeling of FACTS Devices

3.1. Mathematical Model of UPFC

The power flow model of UPFC [16] is represented by mathematical equations as follows:

$$P_{i,inj,upfc} = 0.02 r b_{in} V_i^2 \sin\gamma - 1.02 r b_{in} V_i V_j \sin(\theta_i - \theta_j + \gamma) \tag{12}$$

$$P_{j,inj,upfc} = r b_{in} V_i V_j \sin(\theta_i - \theta_j + \gamma) \tag{13}$$

$$Q_{i,inj,upfc} = -r b_{in} V_i^2 \cos\gamma \tag{14}$$

$$Q_{j,inj,upfc} = r b_{in} V_i V_j \cos(\theta_i - \theta_j + \gamma) \tag{15}$$

where V_i and V_j are the magnitudes, θ_i and θ_j are the angles of i, j buses respectively and b_{in} is the series branch admittance.

3.2. IPFC Mathematical Model

The IPFC is modeled [17] in the following mathematical equations:

$$P_{i,inj,ipfc} = \sum_{n=j,k} V_i V_{se_{in}} b_{in} \sin\left(\delta_i - \delta_{se_{in}}\right) \tag{16}$$

$$Q_{i,inj,ipfc} = -\sum_{n=j,k} V_i V_{se_{in}} b_{in} \cos\left(\delta_i - \delta_{se_{in}}\right) \tag{17}$$

$$P_{n,inj,ipfc} = V_n V_{se_{in}} b_{in} \sin\left(\delta_n - \delta_{se_{in}}\right) \tag{18}$$

$$Q_{n,inj,ipfc} = -V_n V_{se_{in}} b_{in} \cos\left(\delta_n - \delta_{se_{in}}\right) \tag{19}$$

where $V_{se_{in}}$ is the magnitude of controllable series injected voltage source and b_{in} is the series branch admittance.

4. Hybrid Approach (GA-GSA)

4.1. Optimal Location of FACTS by Genetic Algorithm (GA)

In Genetic algorithm, individuals are denoted by coded number, called as chromosome which corresponding to each variable specified in the problem. The individual strength has taken as the objective function which should be minimized [18]. At the starting initial population is randomly generated. Next the genetic operations such as evaluation of Fitness function, crossover and mutation are taken place and continued up to best population obtained. The various steps involved for optimal location of the FACTS device are explained below. [3, 8]

At the beginning N numbers of chromosomes are randomly generated. Real power, reactive power, voltage of the bus and FACTS device location, F_L are taken as the input genes which are represented as First, second, third, fourth string respectively. The limit function for input genes are represented as, $[V_{\min}, V_{\max}]$, $[P_{\min}, P_{\max}]$ and $[Q_{\min}, Q_{\max}]$.

$$X = \left\{x_i^1, x_i^2 ......x_i^d\right\} \tag{20}$$

where d denotes the dimensions of the population space.

4.1.2. Fitness Function

Each chromosome fitness value is calculated by using fitness function which is the objective function represented by the following equation,

$$fitness\ \ function = \max \begin{pmatrix} \sum_{i=1}^{NP} v_i \\ \sum_{i-1}^{NP} p_i \\ \sum_{i=1}^{NP} q_i \end{pmatrix} \tag{21}$$

4.1.3. Crossover Operation

New set of chromosomes are developed by the crossover operation between two chromosomes. Depending on the crossover rate (CR) new child chromosomes are generated and the fitness function is applied to each new child. Crossover operator is applied to the mating pool until it creates a better offspring.

4.1.4. Mutation

The mutation is applied to each chromosome. Best chromosomes are selected depending on the mutation rate (MR) which is the ratio of the mutation point of the chromosome to the chromosome length.

4.1.5. Termination

The process stops until maximum number of iterations is achieved, otherwise crossover operation and mutation process repeats. Based on the fitness value, the best chromosomes of the real power and reactive power and voltage are obtained. Finally based on the fitness function the optimal location of the FACTS device is decided.

4.2. Optimal Capacity of FACTS Device by Gravitational Search Algorithm

In gravitational search algorithm objectives are represented by agents and output performances are measured by their masses. The optimal values of real and reactive powers and losses are calculated from the inputs which are the bus voltages and their angles. From those values the optimal rating of the FACTS device is decided. The algorithm involves the following steps. [3, 8]

Step 1) Voltage limits and their angles are taking as the agents and are initializing to obtain the search space. Let the system has N agents and the position of the i^{th} agent is given by

$$X = (x_i^1, ..., x_i^d, ... x_i^n) \quad \text{for } i = 1, 2, \ldots n \tag{22}$$

where, n is the search space dimension of the problem, x_i^d is the position of the i^{th} agent in the d^{th} dimension.

Step 2) Generate input values such as the voltage and their angles randomly. From those values, find fitness using the following equation.

$$F(t,u) = \min\left(\sum_{j=1}^{N} |V_i||V_j||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right)\right) \quad \text{for } i = 1, 2, \ldots n \tag{23}$$

Step 3) Calculate the fitness of the agents and determine the solution.

Step 4) Update the best fitness $F(B)$, worst fitness $F(W)$, gravitational constant $G(t)$ and mass of the agents $M_i(t)$. The gravitational search constant $G(t)$ is initialized at the beginning and it reduces the time to control the search precision.

The gravitational constant is given by, $G(t) = G(G_0, t)$.The best fitness $F(B)$, worst fitness $F(W)$ and mass of the agents $M_i(t)$ can be described by the following equations.

$$F(B) = \underset{j \in \{1 \ldots N\}}{Min} FITNESS_j(t) \tag{24}$$

$$F(W) = \underset{j \in \{1 \ldots N\}}{Max} FITNESS_j(t) \tag{25}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \tag{26}$$

where, $m_i(t) = \dfrac{F_i(t) - F(B)_t}{F(B)_t - F(W)_t}$, with $F_i(t)$ represents the fitness values of the i^{th} agent at time t.

Step 5) Calculate the total force of the agents at different directions using the equation.

$$TF_i^d(t) = \sum_{j \neq i} random_j \left(force_{ij}^d(t) \right) \tag{27}$$

where $$force_{ij}^d(t) = G(t) \frac{M_{pi}(t) * M_{aj}(t)}{R_{ij} + \varepsilon} * \left(y_j^d(t) - y_j^d(t) \right) \tag{28}$$

$R_{ij} = \left\| X_i(t), X_j(t) \right\|_2$ is the Euclidian distance between two agents i and j, $random_i$ is the random number at the interval [0, 1], ε is a small constant and M_{aj} and M_{pi} active and passive gravitational mass related to agent i and j.

Step 6) Calculate the acceleration of the i^{th} agent using the equation.

$$a_i^d(t) = \frac{TF_i^d(t)}{M_i(t)} \tag{29}$$

Step 7) Update the velocity and position of the agent using the equations.

$$V_i^d(t+1) = random_i V_i^d(t) + a_i^d(t) \tag{30}$$

$$X_i^d(t+1) = x_i^d(t) + V_i^d(t+1) \tag{31}$$

Where, $V_i^d(t)$ and $x_i^d(t)$ are the velocity and position of an agent at the t time and d dimension, $random_j$ is the random values, *i.e.*, [0, 1].

Step 8) Steps 3 to 7 are repeated until stop criteria reaches.

Step 9) Exit the process.

5. Simulation Results & Discussions

The insertion of IPFC and UPFC in the system improving voltage stability by using GA and GSA hybrid algorithm is observed IEEE 30-bus test system with MATLAB simulation and the performances of the two devices are compared. At first step the voltage instability problem is observed at different buses without FACT devices. As per the voltage collapse ratings the possible locations of FACT device are determined. By using GA algorithm optimal location is determined based on the fitness value. The optimal rating of the FACTS device is decided by GSA algorithm depending on the loss. FACTS device is inserted at various locations except the generator buses. The two FACTS devices, UPFC and IPFC are connected separately and their performances are analyzed.

The values of the important parameters are shown in Table 1. For load flow analysis N-R method is used. The optimal location between 12-15 buses for UPFC is selected and for IPFC is between 12-15-16 buses. By varying the load, the voltages of 30 buses are calculated with and without connecting UPFC and IPFC and the voltage profile comparison is shown in Figure 1.The performance of power loss verses iteration of the both devices is represented in Figure 2. After 20th iteration the system attains stable voltage level and having less power loss by inserting IPFC but with UPFC, it reaches only after 25th iteration. This shows that with IPFC the solution is obtained with less convergence time. The comparison of power loss with the two devices is illustrated in Figure 3. Fitness behavior is shown in Figure 4. L Index (Voltage stability index) comparison index is shown in Figure 5. This shows that the overall performance of the system is greatly improved with IPFC when compared with UPFC.

Table 1. Implementation Parameters

Parameters	Values
Population size	100
Crossover function	0.8
Number of iterations in GA	100
Dimension of particles	10×30
Number of iterations in GSA	100
Minimum and maximum Search space (Xmin, Xmax)	(0.9,1.06)

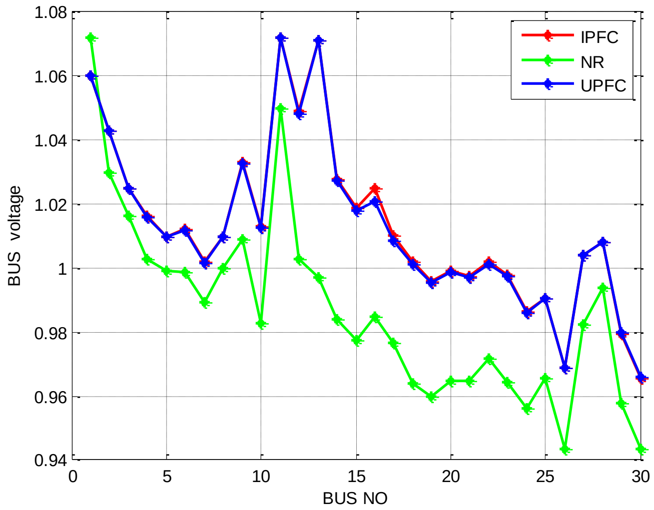

Figure 1. Comparison Performance of Bus Voltages

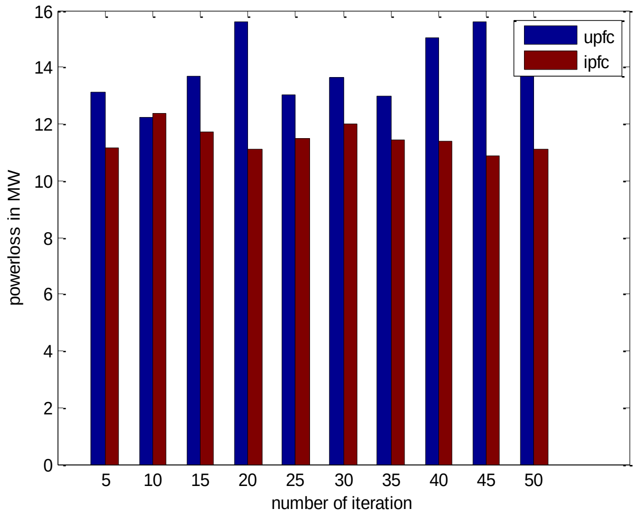

Figure 4. Comparison Performance of Loss Vs Iteration

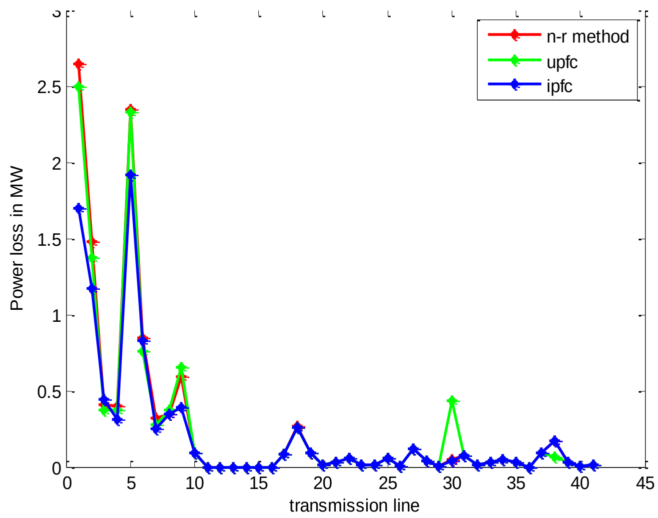

Figure 3. Comparison Performance of Transmission Line Power Loss

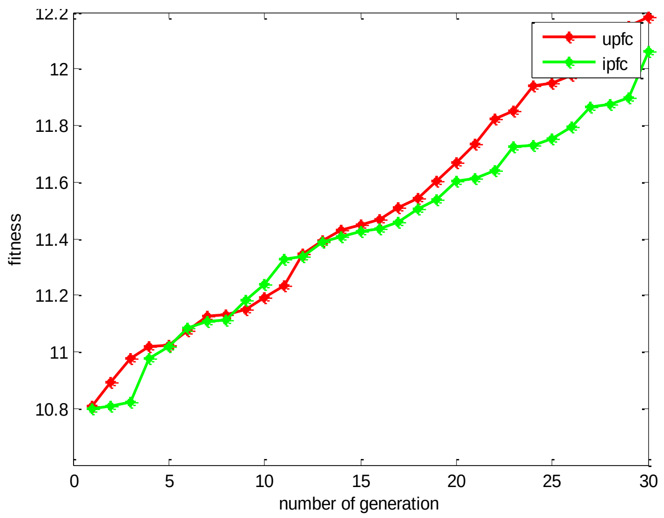

Figure 4. Comparison Performance of Fitness Vs No of Generations

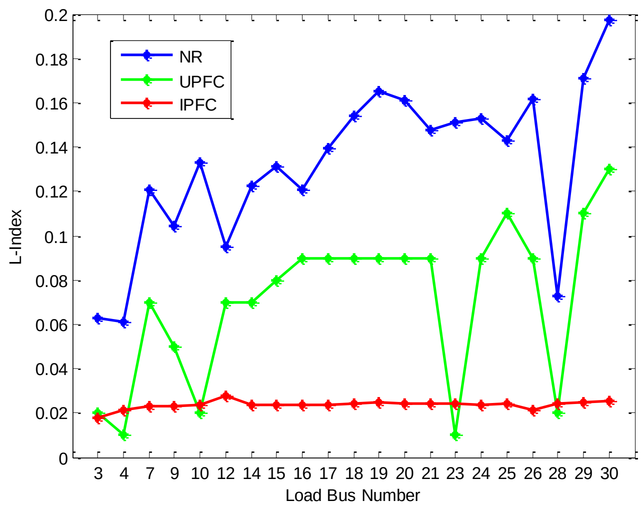

Figure 7. Comparison Performance of Voltage Stability

6. Conclusion

The suitability of two FACTS devices UPFC and IPFC for improving voltage stability based on GA and GSA hybrid technique has been studied and a detailed comparison between their performances in various parameters are shown in this paper. At the first step, for each FACTS device the optimal locations are determined by GA algorithm based on the voltage collapse conditions. FACTS device ratings at these locations are determined according to the voltage magnitude and angle by using GSA algorithm. From those values final optimal location and rating of the device is selected depending on the power loss and cost of the device. Then UPFC and IPFC are located independently at these optimal locations and their performances are analyzed with IEEE 30-bus system.

The results show that power flow and Voltage profiles are improved with both the compensating devices. It can be seen that UPFC is better to control the power flow through transmission line between two buses effectively where as IPFC is better to control the power flow through multiline efficiently besides maximum real and reactive power compensation is obtained with the insertion of IPFC in the system. From this analysis it is clear that the desired performance is obtained with the use of the IPFC when compared to UPFC in regulating the voltage stability. Thus this paper presents an elaborate comparison between UPFC and IPFC which helps in selecting the appropriate FACT device and its optimal location for achieving the required performance. But the utmost caution ought to be taken in determining the rating of the compensating device in order to make the system stable as well as cost effective. This analysis also helps for future investigations to observe the voltage stability improvement with multi FACTS devices either two UPFCs or two IPFCs inserting at a time in the power system.

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