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Original Research Paper

Engineering

IMPROVEMENT OF POWER SYSTEM VOLTAGE STABILITY BY USING UPFC PLACED AT OPTIMAL LOCATION GIVEN BY GRAVITATIONAL SEARCH ALGORITHM

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ABSTRACT In this paper, heuristic technique based improvement of the power system stability using Unified Power Flow Controller is proposed. Here, the Gravitational Search Algorithm (GSA) optimizes the location of the UPFC, while the generator outage occurs. The optimum location is referred as the maximum power loss bus, because the generator outage affects the power flow constraints like power loss, voltage magnitude, real and reactive power. By using the optimum location parameters the minimum voltage deviation is attained using the bat algorithm. Then UPFC is placed in the optimum location and the corresponding results are analyzed. The proposed method is implemented in the MATLAB/Simulink platform and the performance is evaluated by using the comparison at ABC, based optimal placement of UPFC. The comparison results demonstrate the superiority of the proposed approach and confirm its potential to solve the problem

KEYWORDS : UPFC, GSA, power loss, voltage stability

1. Introduction

The amount of electric power, that can be passed on between two positions via a transmission network is limited by safety and steadiness constraints [1]. Electric power systems have been forced to work to more or less their full capacities around the world due to the environmental and economic limitations to upright new generating plants and transmission lines [2] [3]. Power flow in the lines and transformers should not be allowed to increase to a level where a arbitrary incident could cause the network fall down as cascaded outages [4] [5]. For managing the power transmission system, Flexible Alternating Current Transmission System (FACTS) is a fixed device that is applied [6] [7]. FACTS is recognized as "a power electronic based system and other fixed device that present control of one or more AC transmission system parameters to develop controllability and magnify power transfer capability" [8]. UPFC is one of the FACTS devices, that can administer the power flow in transmission line by including active and reactive voltage component in chain with the transmission line [9].

An optimal location of UPFC device allows to control its power streams for a interconnected network, and as a result to increase the system load ability [10]. The optimal location and optimal capacity of a particular number of FACTS in a power system is a hinder of combinatorial revise [11]. Different types of optimization algorithms have been used to effort out this kind of problem, such as genetic algorithms, reproduced annealing, tabu search and etc. [12].

This paper proposes a heuristic method for improving the voltage stability of the power system using UPFC. The novelty of the proposed method is to use the Bat algorithm to find optimal location UPFC under generator outage conditions. When the generator outage occurs, which in turn affects the power flow constraints like voltage, power loss, real and reactive power? For improving the system performance, UPFC is placed in the optimum location given by Bat algorithm. The objective of this paper is to improve the bus voltage profile and the power loss reduction. The rest of the paper is organized as follows: Past to current exploration works are discussed in section 2. Section 3 deals with UPFC structure, problem formulation and algorithm. Section 4 gives the results and within section 5 the paper is usually concludes.

2. Recent Research Work: A Brief Review

Numbers of related works are available in literature, which based on improving the power transfer capability of power system. Some of them are reviewed here.

Husam I. Shaheen et al. has proposed method according to differential evolution technique under single line contingencies, to identify the optimal location and parameter establishing connected with UPFC intended for improving the electric power system safety measures. [13] They executed simulations upon IEEE 14-bus and 30-bus test system.

Seyed Abbas Taher et al. have got introduced this demands connected with hybrid immune algorithm to have the optimum location of UPFCs for attaining minimum total active and reactive power production cost of generators and reducing the installation cost of UPFCs [14].. They executed simulations upon IEEE 14-bus and 30-bus test system.

A.R. Phadke et al. have suggested an approach regarding engagement and sizing of shunt FACTS controller by means of Fuzzy logic and Real Coded Genetic Algorithm [15]. A fuzzy appearance index according to distance to impede node bifurcation, voltage profile and capacity of shunt FACTS controller is proposed. The proposed strategy has been used with IEEE 14-bus along with IEEE 57-bus test systems.

To work out the optimal power flow (OPF) problems, a competent and dependable evolutionary based strategy has been suggested by Sanjeev Kumar *et al.* [16]. The combination of Fuzzy Systems with Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm for optimal setting of OPF problem control variables.

B.Vijay kumar *et al* have attempted the problem of optimal location of UPFC to improve power system voltage stability using Artificial Bee Colony algorithm [17]. They were carried out simulation studies on IEEE 14 bus system.

Purwoharjono *et al* attempted the problem of optimal location and rating of TCSC using GSA. They shown that GSA method can be used efficiently to solve various optimization problems in the process of determining the optimal location and rating of FACTS devices in power systems and can assist the engineer in an effort to improve the voltage deviation or to increase the voltage profile and to minimize power loss in power system transmission lines [18].

3. UPFC Structure and Power Flow Model

The UPFC consists of two identical inverters, i.e., parallel inverter and series inverter, which are connected in parallel and series to power systems through corresponding power transformers. The UPFC is connected between the buses *i* and *j* through the series and parallel power transformers [30,31], the structure of the UPFC is described in the figure 1. The parallel inverter can operates either voltage controller or constant reactive power source. It injects constant positive or negative reactive power at i^{th} bus reactive power (Q_i) and regulates the voltage of the bus. The series inverter independently controls the active power (P_j) and reactive power (Q_j) of the j^{th} bus at associated settings, which distinguishes the UPFC from the STATCOM and SSSC. Also the series inverter is used to regulate the difference between the i^{th} bus voltage (V_i) and j^{th} bus voltage (V_j)bus. The UPFC installation structure in power system is given in the figure 1.

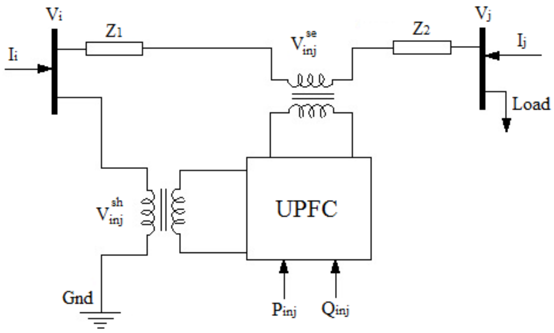

Figure.1: UPFC installation in power system

By using the load flow solution, the real and reactive power at the bus i and j is calculated. The important of the power injection representation is that the symmetric characteristics of admittance matrix will not be destroyed [19]. The real and reactive power injection at each bus is described in the following equations (1) and (2).

Power flows from to:

$$\begin{aligned} P_{ij}(t) = &\left(V_i^{2(t)} + V_{kl}^{2(t)}\right)G_{ij}^{(t)} + 2V_i^{(t)}V_{kl}^{(t)}G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) \\ &- V_j^{(t)}V_{kl}^{(t)}\left[G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) + b_{ij}^{(t)}(\sin\alpha_{kl} - \phi_j)\right] \\ &- V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\cos\phi_{ij} + b_{ij}^{(t)}\sin\phi_{ij}\right) \end{aligned} \tag{1}$$

$$\begin{aligned} Q_{ij}(t) = &-V_i^{(t)}I^{(t)} - V_i^{2(t)}\left(b_{ij}^{(t)} + B/2\right) \\ &- V_i^{(t)}V_{kl}^{(t)}\left[G_{ij}^{(t)}\sin(\alpha_{kl} - \phi_i) + b_{ij}^{(t)}(\cos\alpha_{kl} - \phi_i)\right] \\ &- V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\sin\phi_{ij} - b_{ij}^{(t)}\cos\phi_{ij}\right) \end{aligned} \tag{2}$$

Where, $G_{ij} + jb_{ij} = \frac{1}{R_{ij} + jX_{ij}}$, V_i and V_j are the voltage of the buses i and j and V_{kl} is the voltage of the compensating device.

The problem formulation of voltage stability is briefly explained in the following section 3.1.

3.1. Problem formulation of Dynamic Stability

The voltage stability is a nonlinear optimization problem. The main goal of the voltage stability should maintain the control variables at the secure limits. The control variables in terms of a certain objective function subjected to various equality and inequality constraints. The required objective function is mathematically described in the following equations (3), (4) and (5).)

$$\textit{Minimize } F(t,u) \tag{3}$$

$$\textit{Subject to } g(t,u) = 0 \tag{4}$$

$$h(t,u) \le 0 \tag{5}$$

Where, $F(t,u)$ is the objective function of the voltage stability, which minimizes voltage deviation. Then, $g(t,u)$ are the equality constraints and $h(t,u)$ are the inequality constraints. The equality and inequality constraints are explained in the following section (I).

(I). Equality constraints

This section explains the power system equality constraints. Here, the power system generators need to ensure the customers total demand and the transmission loss. It is also known as power balance condition of the power system. The power balance condition is described in the following equation (6).

$$\sum_{i=1}^{N_B} P_G^i = P_D + \sum_{i=1}^{N_B} (P_L^i) \tag{6}$$

Where, P_G^i is the power generated in the i^{th} bus, P_D is the demand, P_L^i is the real power loss of the i^{th} bus, The real power loss can be calculated in the following equations (7).

$$P_L^i = |V_i||V_j||Y_{ij}|\sum_{j=1}^{N}\cos(\alpha_{ij} - \delta_i - \delta_j) \tag{7}$$

Where, V_i and V_j are the voltage of the buses i and j, Y_{ij} is the bus admittance matrix, α_{ij} is the angle between the buses i and j, δ_i and δ_j are the load angle of i and j. The inequality constraints are explained in the following section (ii).

(ii). Inequality Constraints

This section describes the inequality constraints of the power system, i.e., voltage limits. These constraints should be maintained at the stability limit, because the voltage stability mainly considers the voltage deviations of every node. The stable voltage limit of the every node may be *0.95 to 1.05 pu*. The change in voltage can be described by the following equations (8) and (9).

$$\Delta V_i = \frac{1}{\sqrt{l}}\sqrt{\sum_{i=1}^{l}\left(V_i^k\right)} \tag{8}$$

Where, $$V_i^k = V_{slack} - \sum_{i=1}^{n} Z_i\left(\frac{P_i - jQ_i}{V_i}\right) \tag{9}$$

With, V_{slack} is the slack bus voltage, ΔV_i is the voltage stability index of the bus i, V_i is voltage of the bus, where $i = 1,2,3\ldots n$, Z_i is the impedance of the i^{th} bus, P_i and Q_i are the real and reactive power of bus i and j is the number of nodes. The bus voltage lies between the limits, i.e., $V_i^{\min} \le V_i \le V_i^{\max}$.

During the generator fault condition, the power flow constraints are affected, which makes the instability in the system. In these conditions, the voltage stability is achieved by selecting the optimum location of the UPFC using the proposed method. The proposed method is briefly explained in the following section 3.2.

3.2. Optimum location determination using GSA

This section describes about the GSA based optimum location determination. Gravitational Search Algorithm is an optimization algorithm based on the law of gravity [34]. In the proposed algorithm, agents are considered as objects and their performance is measured by their masses. All these objects attract each other by the gravity force, and this force causes a global movement of all objects towards the objects with heavier masses. Hence, masses cooperate using a direct form of communication, through gravitational force. The heavy masses – which correspond to good solutions – move more slowly than lighter ones, this guarantees the exploitation step of the algorithm. In GSA, each mass (agent) has four specifications: position, inertial mass, active gravitational mass, and passive gravitational mass. The position of the mass corresponds to a solution of the problem, and its gravitational and inertial masses are determined using a fitness function. In other words, each mass presents a solution, and the algorithm is navigated by properly adjusting the gravitational and inertia masses. By lapse of time, we expect that masses be attracted by the heaviest mass. This mass will present an optimum solution in the search space.

Initially the IEEE standard benchmark system normal power flow is analyzed using the N-R load flow analysis. Then the generator outage is introduced in the bus system, so the system becomes instable. Here, the GSA technique is used to find the most affected location to place the UPFC, i.e., maximum power loss bus. The maximum power loss bus is the most suitable location to locate the UPFC.

The steps to find the optimum location are given in the following section.

Steps to find the optimum location

Step 1: In the first step, the input agents are randomly generated at N dimensions. Here, the bus voltage and the line losses are selected as the agents.

Step 2: Apply load flow solution and then, evaluate the fitness values of the random number of agents.

Step 3: In the high mass, agents are selected as the best solutions and the corresponding load flow is analyzed.

Step 4: The best solutions are separated into two groups, the first groups have the minimum best solutions and another group has maximum best solutions.

Step 5: For each best solution groups, the agent's positions and velocity is modified.

Step 6: Run load flow analysis and evaluate the new agents. Select the best agent from each group.

Step 7: Find the voltage, real and reactive power flow and power loss.

Step 8: Check the termination criterion. If it is satisfied terminate or else go to step 9.

Step 9: Generate the new agents to generate new solutions. Go to Step 2.

Once the process is finished, the GSA is ready to give the optimal location of the UPFC.

The proposed method is tested in the MATLAB platform and the numerical results are analyzed with various techniques, which are briefly described in the next section 4.

4. Results and Discussions

The proposed method is implemented in MATLAB/Simulink 7.10.0 (R2012a) platform, 4GB RAM and Intel(R) core(TM) i5. Here IEEE 14 bus systems is used to validate the proposed method. The numerical results of the proposed method is presented and discussed in this section. The effectiveness of the proposed method is analyzed by comparing with other techniques i.e., ABC algorithm. The proposed method is applied in the IEEE 14 bus system and discussed in the following section 4.

4. Validation of IEEE 14 bus system

This section describes the proposed method when it is applied to the IEEE 14 bus system. It consists of 2 generator buses, i.e., one generator in slack bus and another one in the second bus. The IEEE 14 bus test system structure is illustrated in the following figure 2. The load flow solution at normal condition is determined using the N-R load flow analysis, which identifies all the system constraints like bus voltage, power loss etc. Here, we turned off the generator at the second bus. At this time the power flow meets the difficulties, which is resolved by identifying the location and fixing the UPFC. The power loss comparison is illustrated in the table 1. The power loss of IEEE 14 bus system is effectively reduced to 11.679 MW using the proposed method, which is better compare to the ABC algorithm.

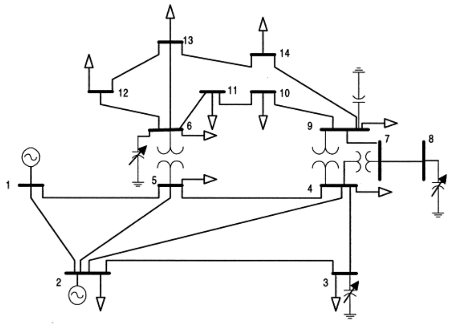

Figure.2: Structure of the IEEE 14 bus system

Table.1: Power loss comparison using different techniques

Outage Generator bus no.	Selected lines		Power loss in MW			
	From bus	To bus	Normal	Outage	ABC	GSA
2	4	5	13.592	15.428	11.765	11.679

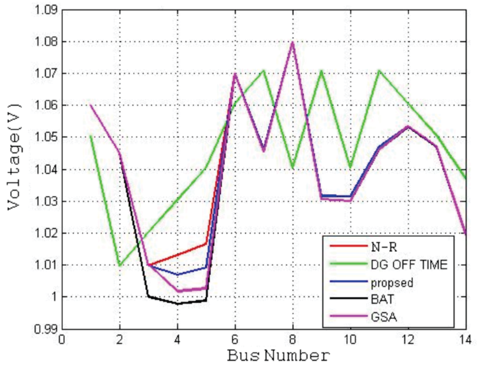

Figure.3: Voltage profile comparison at single generator outage

The voltage profile of the IEEE 14 bus system using different techniques at single generator outage is described in the figure 3. From that, the voltage profile is actively maintained at the stability limit by using the proposed method compared to the other techniques. From the comparison results we obtained that the proposed method is the well effective method to maintain the voltage stability of the power system compared to the other techniques.

5. Conclusion

This paper proposed a heuristic technique based voltage stability improvement of the power system using UPFC. Here, the maximum power loss bus was optimized by using the GSA technique. The proposed method is tested against IEEE 14 bus system at generator outage. In these conditions, the voltage profile and the power loss is analyzed at normal condition, ABC algorithm and GSA algorithm. The obtained numerical results were compared and the performances were discussed. From the comparison results we concluded that the proposed heuristic technique is the well effective technique to maintain the voltage stability of the power system, which is competent over the other techniques.

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