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Improving power system voltage stability using optimal placement of UPFC given by Bat algorithm

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ABSTRACT
In this paper a heuristic method for improving the voltage stability of the power system using Unified Power Flow Controller is proposed. The novelty of the proposed method is to use the Bat algorithm to find optimal location of UPFC. Bat algorithm provides improved searching ability and random reduction. Here, the bat algorithm optimizes location of UPFC when the generator outage occurs, which in turn affects the power flow constraints like voltage, power loss, real and reactive power. The UPFC placed in the optimal location and performance of the system is analyzed. The proposed method is implemented in the MATLAB/simulink platform with IEEE 14 standard bench mark system. The proposed method performance is evaluated by comparison with different techniques like Artificial Bee Colony algorithm. The comparison results proved the effectiveness of the proposed method and confirm its potential to solve the problem.
Key words: Bat algorithm, power loss, UPFC, voltage stability.

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I. INTRODUCTION

The quantity of electrical power transmitted safely by a transmission system is restricted [1]. Electrical power utilities through the world are working under pressured, in order to maximize total capacities due to the the environmental along with economic constraints to emerge a new generating plants and transmission lines [2] [3]. Power flow in the lines and transformers shouldn't be allowed to raise into a level in which a haphazard occurrence might lead to the actual system fall down as cascaded breakdowns [4] [5]. With regard to managing the power transmission system, Flexible Alternating Current Transmission System (FACTS) is often a better device that's utilized [6-7]. FACTS is regarded "an electric power automated dependent process along with other fixed device in which present management of a number of AC transmission system parameters to build up controllability in addition to magnify power transfer capability" [8]. The actual several types of FACTS devices available for this function contains Static Var Compensator (SVC), Thyristor controlled series Capacitor (TCSC), Static Synchronous series compensator (SSSC), Static Synchronous Compensator (STATCOM), Unified Power Flow Controller (UPFC) and Interlink Power Flow Controller (IPFC) [9]. UPFC is probably the best FACTS devices which can control both active and reactive power flow in transmission line. [10].

The optimum position of UPFC device permits to manage its power channels for an interconnected system, and thus to raise the system load ability [11]. Various kinds of optimization protocol are accustomed to attempt away this sort of issue, for example 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 Hybrid algorithm. Section 4 gives the results and within section 5 the paper is usually concludes.

II. RECENT RESEARCH WORK: A BRIEF REVIEW

Number of similar performs are available in literary works, which dependent on improving the power transfer ability to electrical power process. Some of them are usually assessed 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.

Chuan Wang et al. [16] have planned a new hybrid topology scale-free Gaussian-dynamic particle swarm (HTSFGDPS) optimization algorithm for real power loss minimization problem of power system. Many people focus on a new combination of swarm intelligence optimization theory and complex network theory, as well as its application to electric power system.

III. POWER SYSTEM MODEL WITH UPFC

The UPFC (unified power flow controller) is a FACTS device able to control simultaneously active power flows, reactive power flows and voltage magnitude at the UPFC terminals. UPFC consist of two voltage source converters, i.e., converter 1 and converter 2, connected back to back through a common DC link provided by a DC storage capacitor. The converter 1 is a shunt connected voltage source converter, which is used to generate or absorb controllable reactive power and shunt reactive compensation for the line [17]. The converter 2 performs the main function of UPFC by bringing in an AC voltage with magnitude that can be controlled and the phase angle is in series with the transmission line through a series transformer. The necessary reactive power is supplied or absorbed locally by converter 2 and active power is replaced as a consequence of the series injection voltage [17,18]. The UPFC structure basic arrangement between i and j bus is described in the following figure 1.

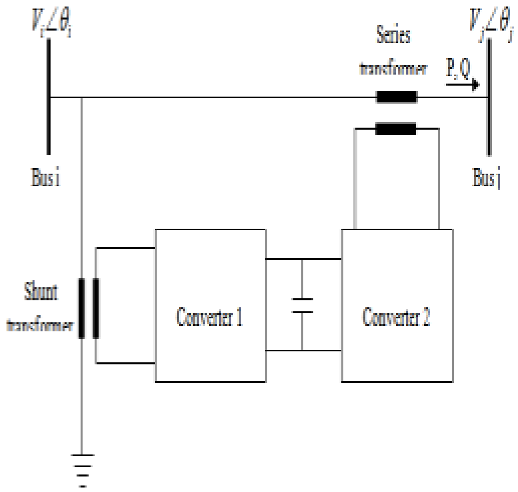

Figure.1: UPFC structure basic arrangement

Power flows from i to j :

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

(1)

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

(2)

Where, $G_{ij} + jb_{ij} = \dfrac{1}{R_{ij} + jX_{ij}}$, V_i and V_j are the voltage of the buses i and j and V_{kl} is the voltage of the compensating device, similarly the real and reactive power flow from the bus j to i is given by the following equation (3) and (4).

Power flows from j to i :

$$P_{ji}(t) = V_j^{2(t)}G_{ij}^{(t)} - [V_j^{(t)}V_{kl}^{(t)}G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) - b_{ij}^{(t)}G^{(t)}\sin(\alpha_{kl} - \phi_j)]$$
$$- V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\cos\phi_{ij} - b_{ij}^{(t)}\sin\phi_{ij}\right)$$

(3)

$$Q_{ji}(t) = -V_j^{2(t)}(b_{ij}^{(t)} + B/2) - V_j^{(t)}V_{kl}^{(t)}$$
$$\left[G_{ij}^{(t)}\sin(\alpha_{kl} - \phi_j) - b_{ij}^{(t)}(\cos\alpha_{kl} - \phi_j)\right]$$
$$+ V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\sin\phi_{ij} - b_{ij}^{(t)}\cos\phi_{ij}\right)$$

(4)

The above equations power flow equations of UPFC. Initially the system is in stable condition and whenever the generator outage occurs, the voltage profile of the system is disturbed. The voltage profile is improved by connecting UPFC at the optimum location, which is given by Bat algorithm. The required objective function and the constraints are described in the following section 3.1.

3.1. Power system stability constraints

The power system dynamic stability has been achieved by maintaining the dynamic stability constraints or the control variables at secure limits. The objective function is mainly used to optimize the most affected location and optimum capacity, i.e., maximum power loss and minimum voltage deviation. Here, the objective function is subject to the control variables such as power balance condition, power loss, voltage stability, UPFC cost, real and reactive power flow.

(i). Power balance equation

The power system generated power must satisfy the demand of the system as well as the power loss. The generators presented in the system may get outage, which means the power loss of the buses is increased, which violates the power balance condition. The required power balance condition is explained in the equation (5).

$$\sum_{i=1}^{N} P_G^i = P_D + \sum_{i=1}^{N} P_L^i \quad (5)$$

Where, Where, P_G^i is the power generated in the i^{th} bus, P_D is the demand, P_L^j and Q_L^j are the real and reactive power loss of the j^{th} bus. The generators generation limits and demand of the system are described in the following equation (6) and (7).

$$P_G^{i(\min)} \le P_G^i \le P_G^{i(\max)} \quad (6)$$

$$P_D^{(\min)} \le P_D \le P_D^{(\max)} \quad (7)$$

Where, $P_G^{i(\min)}$ and $P_G^{i(\max)}$ are the minimum maximum range of the generators generation limits, $P_D^{(\min)}$ and $P_D^{(\max)}$ are the minimum maximum range of the load demand limits. The bus power loss constraint is discussed in the following section.

(ii). Power loss

The real and reactive power loss can be formulated by the following equation (8) and (9).

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

$$Q_L^i = |V_i||V_j||Y_{ij}| \sum_{j=1}^{N} \sin(\alpha_{ij} - \delta_i - \delta_j)$$

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. Similarly the inequality constraints are described in the following.

(iii). Voltage stability

The voltage stability of the each bus is the main factor of the dynamic stability, which can be described by the following equations (12).

$$\Delta V_i = \frac{1}{\sqrt{l}} \sqrt{\sum_{i=1}^{l} \left(V_i^k\right)^2} \quad (12)$$

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

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 bat algorithm based optimum location of the UPFC determination is briefly described in the following section 3.2.

3.2. Bat algorithm based UPFC location determination

This section describes about the determination of the UPFC location using bat inspired algorithm. The bat inspired algorithm is the optimization algorithm, which works based on the echolocation behavior of bats [19]. Here, the Newton Raphson (N-R) method is used for the load flow analysis of the IEEE standard bench mark system. Then the generator outage is introduced in the system, during this time the bat-inspired algorithm is used to find the most affected bus, i.e., maximum power loss bus, which is the optimum location. The maximum power loss bus is the most suitable bus to locate the UPFC.

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

Steps to find the optimum location

Step 1: Initialize the micro-bats are randomly generated at N dimension. Here, the bus voltage and line losses are the input micro-bats.

Step 2: Evaluate the objective function for the random number of the micro-bats.

Step 3: The solutions are separated into two groups, the first groups have the minimum best solutions and another group has maximum best solutions.

Step 4: Find the best solution according to the objective function and store the current population.

Step 5: Randomly update the current micro-bats population to update position vector and velocity vector of the micro-bats.

Step 6: Evaluate the objective for the new micro-bats population and select the best solution among the solution.

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

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 this process is finished, the system is ready to give the optimum location to place the UPFC.

IV. RESULTS AND DISCUSSION

The proposed hybrid method is implemented in MATLAB/Simulink 7.10.0 (R2012a) platform, 4GB RAM and Intel(R) core(TM) i5. Here the IEEE 14 bus system is used to validate the proposed method. The numerical results of the proposed method are presented and discussed in this section. The effectiveness of the proposed method is analyzed by comparing with ABC algorithm. Results are discussed in the following Section 4.1.

4.1. Testing of IEEE 14 bus system

This section spells out the data on the innovative technique which is executed in the IEEE 14 bus system, which comprises 2 generator buses, with one generator in slack bus and the other in the second bus. The IEEE 14 bus test system structure is illustrated in the following Figure 20. The load flow solution at regular circumstances is estimated by means of the N-R load flow analysis, which recognizes the entire system parameters such as bus voltage, power loss and the like. Here, we are introduced to the generator fault at the second bus. At this time the power flow of the system faces difficulties like voltage instability and maximum power loss, which are solved by recognizing the problem location and setting up suitable capacity of the UPFC. The power flow comparisons at single generator problem using different techniques are described in Table 6. The single generator problem power loss comparison is illustrated in Table 7.

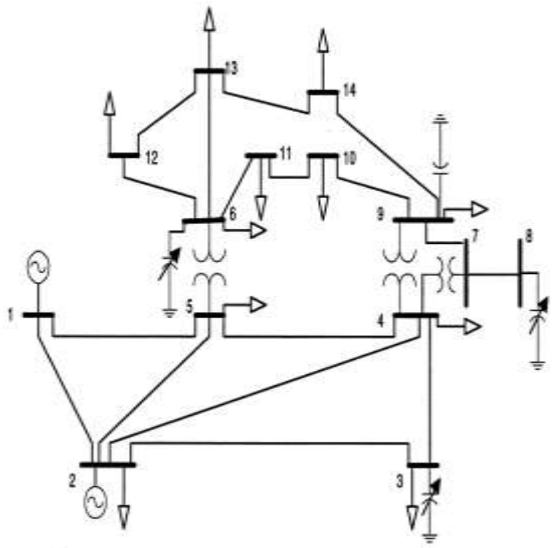

Figure.20: IEEE 14 bus system structure

Table.7: Power loss comparison using different techniques

Fault Gener	Best		Power loss in MW				
	From	To	Normal	Outage	ABC	GSA	Ba
2	4	5	13.592	15.428	11.175	10.275	9.623

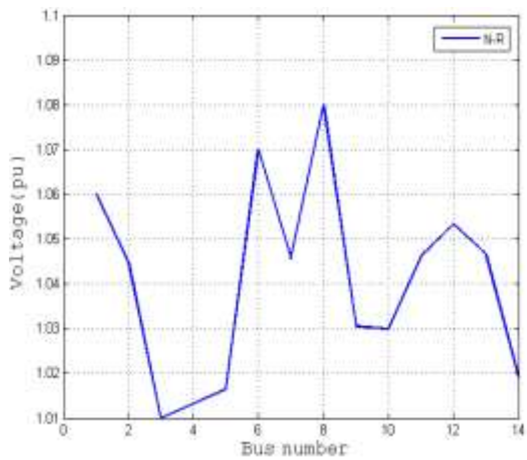

Figure.21: Normal bus voltage profile of IEEE-14 bus system

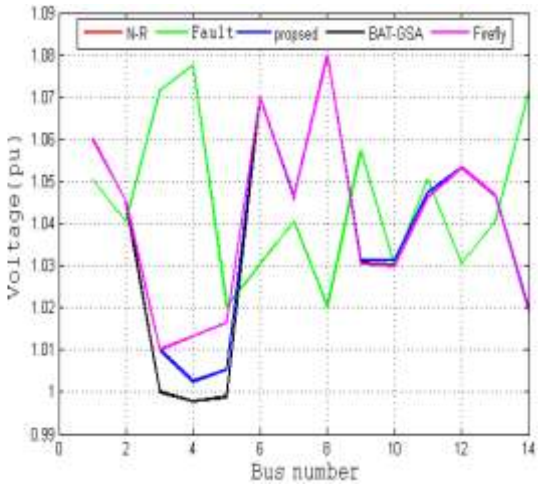

Figure.22: Voltage profile comparison at single generator problem

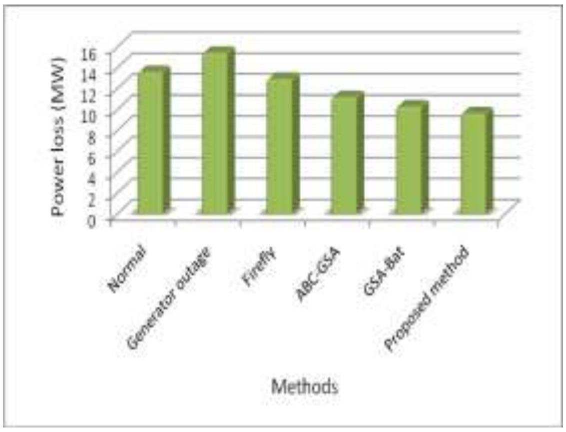

Figure.23: Power loss comparison at single generator outage problem

The IEEE 14 bus system normal voltage profile is described in the figure 21. The voltage profile of the IEEE 14 bus system employing diverse methods at single generator problem is picture in Figure 22. It is crystal clear that the novel technique considerably enhances the voltage profile from the divergence. The power loss by means of the innovative technique is analyzed and contrasted with the hybrid GSA-Bat algorithm as illustrated in Figure 23. From this it evident that the voltage profile is preserved at the stability limit by means of the novel technique in comparison to the parallel peer techniques. The power loss of IEEE 14 bus system is efficiently decreased to 9.623 MW by using the anticipated technique, which ushers in a superb performance in relation to the GSA and Bat algorithm. The cheering outcomes emerging out of the comparison and contrast of the systems underscore the overall supremacy of our magnificent technique which establishes itself as the most efficient technique by consistently preserving the stability of the power system vis-à-vis its peer techniques.

V. CONCLUSION

This paper describes about improvement on the voltage stability by optimal location of UPFC given by the bat algorithm. In the proposed technique, the maximum power loss bus is referred as the optimum location of the UPFC, which was obtained by the bat algorithm. By connecting UPFC at the optimum location, and the power flow has been analyzed. The advantage of the proposed method is capability and robustness to solve the complex optimization problem. In the results, system bus voltage, power loss were analyzed. Then the proposed method's effectiveness was tested by the comparison analysis with the ABC algorithm. The comparison results proved that the proposed method is the most effective technique to maintain the voltage stability of the power system, which is competent over the other techniques.

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