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Power System Loss Minimization by Using UPFC Placed at Optimal Location Given by Artificial Bee Colony Algorithm

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Abstract: In this paper, heuristic technique based minimization of losses in the power system using Unified Power Flow Controller is proposed. Here, the Artificial Bee Colony Algorithm (ABC) 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 UPFC at the optimum location minimum power loss is attained. 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 power loss at different conditions. The comparison results demonstrate the superiority of the proposed approach and confirm its potential to solve the problem.

Index words: UPFC, ABC, power loss, power flows.

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 minimizing power loss of the power system using UPFC. The novelty of the proposed method is to use the Artificial Bee Colony Algorithm to find optimal location of 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 ABC algorithm. The objective of this paper is to improve the power flows and reduce the power loss. 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.

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 [18], 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.

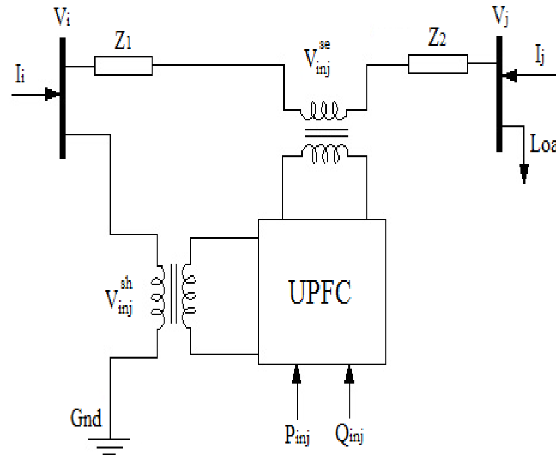

Figure.1 UPFC installation in power system

By using the load flow solution, the real and reactive power at the bus i and j is calculated. The importance of the power injection representation is that the symmetric characteristics of admittance matrix will not be destroyed [18].

The problem formulation of loss minimization is briefly explained in the following section 3.1.

3.1 Problem Formulation

The Power system loss minimization is a nonlinear optimization problem. To achieve this, control variables should be maintained at the secure limits. The control variables in terms of a certain objective function are various equality and inequality constraints. The required objective function is mathematically described in the following equations (3.1), (3.2) & (3.3)

$$Minimize\ F(t,u) \tag{3.1}$$

$$Subject\ to\ g(t,u)=0 \tag{3.2}$$

$$h(t,u)\le 0 \tag{3.3}$$

Where, $F(t,u)$ is the objective function of the power system stability, which minimizes the power system loss and voltage deviation under generator outage conditions. The outage of generator(s) causes increase in the power loss and increase in voltage deviations at buses, which affects the dynamic stability of the system. Here two objective functions are considered. First one is minimization of system loss and second one is minimization of voltage deviations at all the buses in the power system. Then, $g(t,u)$ are the equality constraints and $h(t,u)$ are the inequality constraints. The active power loss, equality and inequality constraints are explained in the following section.

3.1.1 Objective function

Here objective is to minimize active power loss. The active power loss in the transmission network can be defined as follows: [19]

$$P_{loss} = \sum_{k \in N_E} g_k (V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij}) \quad (3.4)$$

Where $k=(i,j)$; N_E is the set of numbers net work branches, g_k is the conductance of branch k. θ_{ij} is the voltage angle difference between bus i and j.

3.1.2 Equality constraints

This section explains the power system equality constraints. Here, in the power system the 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 required power balance equations are given below.

$$\sum_{i=1}^{N_B} P_G^i = P_D + \sum_{i=1}^{N_B} (P_L^i) \quad (3.5)$$

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 inequality constraints are explained in the following section.

3.1.3 Inequality Constraints

This section explains the inequality constraints [19] of the power system, i.e., voltage, real and reactive power, transformer Tap limits. These constraints should be maintained within the limits to maintain the system stability. Power system stability mainly considers the voltage stability at every node, hence bus voltage limits are mainly considered in the problem. For the stable operation of power system, bus voltage should be $V_i^{\min} \le V_i \le V_i^{\max}$. Normally voltage limit of every node may be *0.95 to 1.05 pu*. Other Inequality constraints are given below.

$V_i^{min} \le V_i \le V_i^{max}$ Bus voltage limits (3.6)
$T_i^{min} \le T_i \le T_i^{max}$ Tap position limits (3.7)
$Q_i^{min} \le Q_i \le Q_i^{max}$ Reactive power generation (3.8)
$P_i^{min} \le P_i \le P_i^{max}$ active power generation (3.9)

These constraints are satisfied under normal stable condition. During the generator outage condition, the power flow constraints are affected, which makes increase in power loss. In these conditions, the power system loss can be minimized by connecting an UPFC at optimal location. This can be achieved using proposed ABC algorithm.

3.2 Determination of optimum location of UPFC using ABC algorithm

In the proposed heuristic algorithm, the first stage involves finding normal power flows using N-R load flows. Then generator outage is introduced, power flows and power loss are determined using the Newton-Raphson (N-R) algorithm. At this condition optimal location of UPFC is determined using ABC algorithm subjected to required objective function i.e. minimization of system power loss. The algorithmic steps to optimize the location are given in the following section.

3.2.1 Steps to determine optimum location of UPFC using ABC algorithm

Step1: Initialize the population of the line power loss and voltage at all the buses.
Step 2: Generate the random number of population input voltage and the power loss.
Step 3: The employ bee phase evaluates the fitness of the population and the required fitness function is given in the following equation (3.10) [20].

$$P_{loss} = \sum_{k \in N_E} g_k (V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij}) \quad (3.10)$$

Step 4: Set the iteration count as 1, i.e., iteration I=1.
Step 5: Repeat
Step 6: The onlooker bee attains the elite fitness function of the bus system and improves the velocity of the populations using the following equation (3.11).

$$v_{i,j} = x_{i,j} + \Phi_{i,j}(x_{i,j} - x_{k,j}) \quad (3.11)$$

Where, k signifies the solution in the neighborhood of i, ψ is a a random number in the range [-1, 1], $k = (1,2,3\ldots n)$ and $j = (1,2,3\ldots n)$, the randomly chosen index and v_{ij} is the neighborhood solution of x_i.
Step 7: Apply the selection process to find the better fitness of the new solutions and determine the probability.

$$probability = \frac{\Phi}{\sum_{i=1}^{n} \Phi} \quad (3.12)$$

Step 8: If better solutions are not achieved, abandon the solutions and produce the random number of scout bee solution using the following equation (3.13).

$$x_i^j = x_{\min}^j + rand[0,1](x_{\max}^j - x_{\min}^j) \quad (3.13)$$

Step 9: Memorize the best solution achieved so far.
Step 10: Check the iteration range, if the iteration has not achieved the maximum range, increase the iteration count I=I+1, or else terminate the process.

Once the above process is finished, the system is ready to produce the maximum power loss bus at the specified generator bus fault condition. The optimum sizing of the UPFC is selected as per the following section.

Once the above process is completed, the system is ready to give optimum placing of the UPFC. The proposed ABC algorithm is implemented in the MATLAB platform and its performance is checked with various operating conditions. It is given in the following section.

3.3 Results and Discussions for ABC algorithm

The proposed ABC algorithm is implemented in MATLAB platform. The numerical results of the proposed ABC algorithm are presented and discussed in this section. The obtained results are compared with different individual algorithms. Here, the ABC algorithm is applied to the IEEE 30 bus system. The discussions about the two systems are given as follows.

3.3.1 Validation of results for IEEE 30 bus system with ABC algorithm

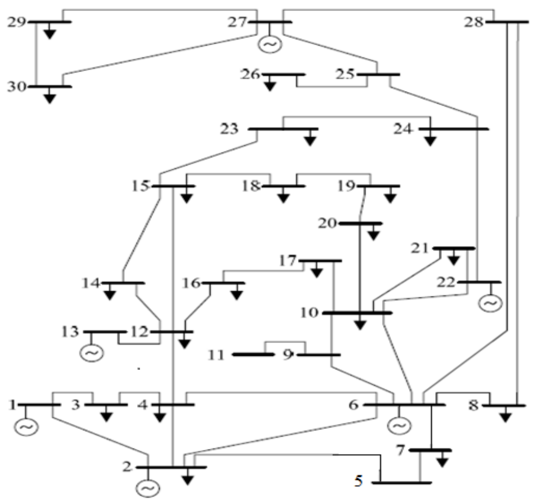

Figure 2 Structure of the IEEE 30 bus system

The Structure of the IEEE 30 bus system is shown in Fig 2. IEEE-30 bus benchmark system consists of six generator buses, 21 load buses and 42 transmission lines and is analyzed in this section. Initially, the system base case load flow analysis is done by the standard Newton-Raphson (N-R) algorithm. Here, the IEEE 30 bus system standard data is used. Afterwards, the generator outages (single and double) are introduced and the corresponding power flows are analyzed. Due to the generator outages the system loses increases. Increased Power loss can be minimized by connecting UPFC placed at optimal location, which can be determined by the proposed ABC algorithm.

- **Single generator outage**

In this case at a time one generator is given outage and corresponding stability is analyzed.

Table 1 shows power flows during normal condition, generator outage condition and after connecting UPFC placed at optimal location for different single generator outage conditions. Here, it is observed that power flows are improved after connecting UPFC whose location is determined by ABC algorithm.

Table 2 shows power loss at normal condition, generator outage condition and after connecting optimal sizing of UPFC placed at optimal location for different single generator outage conditions. Here, it is observed that by connecting UPFC power loss of the system is reduced. Here, it can be observed that power loss is increased to 11.903MW during single generator outage and it is reduced to 9.233MW after connecting UPFC whose location is given by proposed ABC algorithm

Table 1 Power flow analysis for single generator outage condition with the ABC algorithm

Outage of generator at bus no.	Optimum location of UPFC		Power flow					
			During normal condition		During generator outage condition		After placing UPFC at optimal location	
	From bus	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2	12	15	19.675	7.789	19.797	7.755	20.457	7.715
6	5	7	23.744	13.824	24.763	14.248	21.010	17.649
13	10	22	4.043	6.617	4.044	6.581	1.316	7.105
22	12	15	19.672	7.794	19.801	7.755	20.015	7.222
27	10	22	4.044	6.618	4.044	6.581	1.704	8.118

Table 2 Power loss analysis for single generator outage condition with the ABC algorithm

Outage of generator at bus. no	Optimum location of UPFC		Power loss in MW		
	From bus	To bus	During normal condition	During generator outage condition	After placing UPFC at optimal location
2	12	15		12.766	9.219
6	5	7		12.553	8.370
13	10	22	10.809	12.794	8.346
22	12	15		11.885	8.671
27	10	22		11.910	9.229

Table 3 Power flow analysis for double generator outages using the ABC algorithm

Outage of generator at bus nos.	Optimum location of UPFC		Power flow					
	From bus	To bus	During normal condition		During double generator outage condition		After UPFC placed at optimal location	
			P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2 and 6	10	22	1.051	6.517	4.044	6.581	4.035	6.468
2 and 13	5	7	23.844	13.805	24.763	14.248	21.938	13.076
6 and 13	2	5	72.823	2.549	71.715	2.679	78.743	1.915
22 and 27	12	15	19.635	7.767	19.797	7.760	22.474	6.496
13 and 27	10	22	1.041	6.617	4.044	6.579	2.387	6.891

Table 4 Power loss analysis for double generator outages using ABC algorithm

Outage of generator at bus nos.	Optimum location of UPFC		Power loss in MW		
	From bus	To bus	During normal condition	During double generator outage condition	After placing UPFC at optimal location
2 and 6	10	22	10.809	14.729	9.212
2 and 13	5	7		15.018	8.995
6 and 13	2	5		14.833	9.598
22 and 27	12	15		13.049	8.706
13 and 27	10	22		14.005	9.896

- **Double generator outage condition**

In this case at a time two generators are given outages and corresponding stability is analyzed.
Table 3 shows power flows for normal condition, double generator outage condition and after connecting UPFC whose optimal location is determined by ABC algorithm. Here, it is observed that power flows are improved after connecting the UPFC.

Table 4 shows power loss at normal condition, double generator outage condition and after connecting UPFC at optimal location which is determined by ABC algorithm. Here, it is observed that by connecting UPFC, power loss of the system is reduced. Here, it can be observed that power loss is increased to 14.005MW during double generator outage and it is reduced to 9.901MW after connecting UPFC whose location is given by proposed ABC algorithm.
Table 2 and Table 4 show effectiveness of proposed method of finding optimal placement of UPFC to reduce power loss in the system.

4. CONCLUSION

In this paper, the effectiveness of the proposed ABC algorithm to determine the optimal location of UPFC in order to minimize power loss of the power system is presented. The advantage of this proposed heuristic algorithm is effective searching ability in order to find the optimum solutions accurately. Here, the proposed algorithm is applied to the IEEE 30 bus benchmark system and the effectiveness is tested against different generator outage conditions. Initially, single generator outage is introduced at different buses in the system and afterwards double generator outages are introduced. In all these conditions, the power loss and the power flows are analyzed. From the presented result analysis, it is concluded that, the proposed heuristic ABC algorithm is effective in minimizing power loss of the power system through the improvement in power flows by the effective determination of optimum location of UPFC.

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