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OPTIMAL PLACEMENT OF UNIFIED POWER FLOW CONTROLLER IN POWER SYSTEM BY A NEW ADVANCED HEURISTIC METHOD

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Abstract- This paper presents a Shuffled Frog Leaping Algorithm to seek the optimal number and location of FACTS devices in a power system. Unified Power Flow Controller (UPFC) has great flexibility that can control the active and reactive power flow and bus voltages, simultaneously. Decoupled model of the UPFC is applied to maximize the system loadability subject to the transmission line capacity limits and specified voltage level. Shuffled frog-leaping algorithm (SFLA) is a new memetic meta-heuristic algorithm with efficient mathematical function and global search capability. Optimal placement of UPFC in power system by Shuffled Frog Leaping Algorithm, it leads to a flat voltage profile and increased stability and capacity of the power transmission in lines. At the end, the proof is performed by simulating and testing the 14-bus network and placement of the UPFC appropriately. The results show that the steady state performance of power system can be effectively enhanced due to the optimal location and parameters of the UPFC.

Keywords: Shuffled Frog Leaping Algorithm (SFLA), UPFC, Power Flow, Optimal Location.

I. INTRODUCTION

The steady state performance of power system has become a matter of grave concern in system operation and planning. As power system becomes more complex and more heavily loaded, it can be operated in unstable or insecure situations like the cascading thermal overloads, the frequency and voltage collapse. For a secure operation of the power system, it is essential to maintain the required level of security margin [1-3]. Then, power system controllability is required in order to utilize the available network capacitance adequately. The development of FACTS devices based on the advance of semiconductor technology opens up new opportunities for controlling the load flow and extending the loadability of the available transmission network. The UPFC is one of the family members of FACTS devices for load flow control, since it can either simultaneously or selectively control the active and reactive power flow along the lines [4, 5]. Several papers have been published about finding the optimal location of the UPFC with respect to different purposes and methods [6, 7]. In [6], augmented Lagrange multiplier method is applied to determine the optimal location of the UPFC to be installed. Although multi operating conditions can simultaneously be taken into consideration, the operating condition must be preassigned. Gerbex et al [7] provides the genetic algorithm to optimize three parameters of the multi-type FACTS devices including TCSC, TCPST, TCVR and SVC: the location of the devices, their types and their values, but another kind of FACTS device -UPFC has not been considered. Shuffled frog leaping algorithm (SFLA) is a memetic meta-heuristic that is based on evolution of memes carried by interactive individuals and a global exchange of information among the frog population. It combines the advantages of the genetic-based memetic algorithm (MA) and the social behavior-based PSO algorithm with such characteristics as simple concept, fewer parameters adjustment, prompt formation, great capability in global search and easy implementation. While proposed primarily for solving the multi-objective engineering problems such as water resource distribution [8], bridge deck repairs [9] and job-shop scheduling arrangement [10], the successful application of SFLA in solving TSP and the subsequent detailed analysis on its evolutionary mechanism may help for its widespread use in multi-objective optimization problem as well as the in-depth research in its theoretical aspect. The main objective of this paper is to develop an algorithm for finding and choosing the optimal location of the UPFC in order to maximizing the system loadability while simultaneously satisfying system operating constraints including transmission line capacity and voltage level limits. The optimal location problem of a given number of FACTS is converted to an optimization problem which is solved by the Shuffled Frog Leaping Algorithm that has a strong ability to find the most optimistic results. Main results of tests on the IEEE 14-bus power systems for proposed SFLA method are shown.

II. MATHEMATICAL MODEL OF UPFC

The UPFC may be seen to consist of two voltage source converters sharing a common capacitor on their DC side and a unified control system. A simplified schematic representation together with its equivalent circuit of the UPFC is given in Figure 1. The UPFC allows simultaneous control of the active and reactive power flow, and voltage magnitude at the UPFC terminals. Alternatively, the controller may be set to control one or more of these parameters in any combination or to control none of them [2].

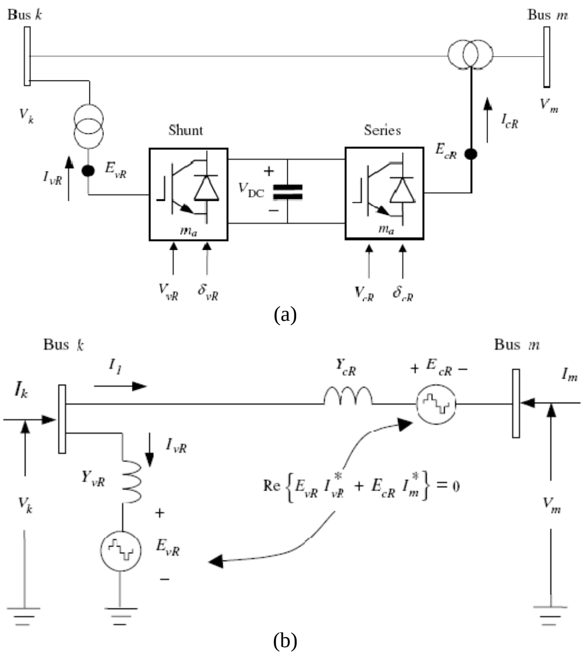

Figure 1. Block diagram of the UPFC system: (a) Two back-to-back voltage source converters (b) Equivalent circuit of a UPFC

The active power demanded by the series converter is drawn by the shunt converter from the AC network and supplied to bus m through the DC link. The output voltage of the series converter is added to the nodal voltage, say bus k, to boost the nodal voltage at bus m. The voltage magnitude of the output voltage V_{CR} provides voltage regulation, and the phase angle δ_{CR} determines the mode of power flow control [3].

III. IMPLEMENTED MODEL FOR OPTIMIZING LOCATION OF THE UPFC

Two types of UPFC model is represented in the papers. One is a coupled model and the other is decoupled model [2]. In the first type a UPFC is modeled with a voltage source series with impedance in the transmission line. In the second type a UPFC is model with two separated buses. The first type is more difficult compared with the second one and the modification of the Jacobean matrix of the system should be applied if it is used. On the other hand, the decoupled model can be easily used in conventional power flow methods without changing the Jacobean matrix of the system. In this paper the decoupled model, as shown in Figure 2, is used for the power flow study.

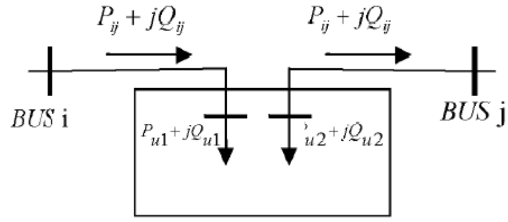

Figure 2. The decoupled model of UPFC

If the UPFC is assumed to be lossless, the real power flow P_{ij} that flows from bus i to bus j can be written as:

$$P_{ij} = P_{U1} \quad (1)$$

Although a UPFC can control the power flow, but cannot generate the real power. So equation (2) should be considered in the model.

$$P_{U1} + P_{U2} = 0 \quad (2)$$

The values of Q_{U1}, Q_{U2} can be set to an arbitrary value within the capacity of the UPFC to maintain the bus voltage. In the same way if multiple UPFCs are installed in the power system, the control variables for the k_{th} installed UPFC are shown as follows:

$$UPFC_{k-th} = \left[P_{K1}^U,\ Q_{K1}^U,\ P_{K2}^U,\ Q_{K2}^U\right] \quad (3)$$

So that:

$$P_{K1} + P_{K2} = 0 \quad (4)$$

IV. OPTIMIZATION STRATEGY

The aim of the optimization is to perform a best utilization of the existing transmission lines. In this respect, UPFC device is located in order to maximize the system loadability while observing thermal and voltage constraints. In other words, it was tried to increase the power transmitted by power system as much as possible to the costumers with holding power system in security state in terms of branch loading and voltage levels. The objective function is made in order to penalize configurations of the UPFC which lead to overload transmissions lines and over or under voltage at busses.

The objective function is defined as the sum of two terms. The first one is related to the branch loading which penalizes overloads in lines. This term is called LF and is computed for all lines of the power system, if branch loading is less than 100% its value is equal to 1; otherwise, it decreases exponentially with respect to the overload. To accelerate the convergence, product of values for all objective functions is calculated. The second part of the objective function is for voltage levels that are named BF. This function is calculated for all buses of power system. For voltage levels between 0.95 and 1.05, values of the objective functions are equal to 1. Outside this range, value decreases exponentially with the voltage deviations. Therefore, for a configuration of UPFCs, objective function is given as:

$$LF = \begin{cases} 1 & ,\ BL < 100 \\ \exp[0.0461(100 - BL)] & ,\ BL \ge 100 \end{cases} \quad (5)$$

$$BF = \begin{cases} 1 & , \ 0 \le V_L \le 100 \\ \exp[-23.0259\,|1-V_L\,| -0.05] & , \ 1.05 \le V_L \le 1.25 \\ & \text{or } 0.75 \le V_L \le 0.95 \end{cases} \quad (6)$$

$$\text{Objective Function} \quad OF = \prod_{i=lines} LF_i + \prod_{j=buses} BF_j \quad (7)$$

The Cost Function for the SFLA is computed by minimizing the inverse of the Objective Function, defined as follows:

$$\text{Cost Function} \quad CF = \frac{1}{OF} = \frac{1}{\prod_{i=lines} LF_i + \prod_{j=buses} BF_j} \quad (8)$$

where, LF is the line flow index and BL is the branch loading (percentage of the line flow with respect to the line capacity rate). BF is bus voltage index and V_L is per unit value of the bus voltages.

V. SHUFFLED FROG LEAPING ALGORITHM (SFLA)

Shuffled Frog Leaping Algorithm (SFLA) is a heuristic search algorithm presented for the first time by Eusuff and Lansey in 2003 [11]. The main purpose of this algorithm was achieving a method to solve complicated optimization problems without any use of traditional mathematical optimization tools [12], [13], [14]. In fact, the SFL algorithm is combination of "meme-based genetic algorithm or memetic Algorithm" and "Particle Swarm Optimization (PSO)". This algorithm has been inspired from memetic evolution of a group of frogs when seeking for food. In this method, a solution to a given problem is presented in the form of a string, called "frog" which has been considered as a control vector in this paper as follows in (9). The initial population of frogs is partitioned into groups or subsets called "memeplexes" and the number of frogs in each subset is equal. The SFL algorithm is based on two search techniques: local search and global information exchange techniques. Based on local search, the frogs in each subset improve their positions to have more foods (to reach the best solution). In second technique, obtained information between subsets is compared to each other (after each local search in subsets). The procedure of SFL algorithm will be as follows:

1) An initial population of "*P*" frogs (*P* solutions) created randomly which considered in this paper as follows:

$$Population = \begin{bmatrix} X_1 \\ \cdot \\ \cdot \\ X_P \end{bmatrix}_{(p)\times(2\times N_{tie})} \quad (9)$$

$$X = [Tie_1, Tie_2, ..., Tie_{N_{tie}}, Sw_1, Sw_2, ..., Sw_{N_{tie}}]$$

2) The entire population is divided into m subsets (m memeplexes), each containing n frogs (i.e. $P = m \times n$), in such a way that the first frog of sorted population goes to the first memeplex, the second frog goes to the second memeplex, frog m goes to m memeplex, and frog m+1 goes to the first memeplex again, etc. therefore, in each memeplex, there will be n frogs.

3) This step is based on local search. Within each local memeplex, the frogs with the best and the worst fitness are identified as and, respectively. Also, the frog with the global best fitness (the best solution) is identified as. Then, the position of the worst frog is updated (based on frog leaping rule) as follows:

$$D_i = \text{rand}(.) \times (X_b - X_w)$$

$$X_w(new) = X_w(old) + D_i \quad (10)$$

$$(-D_{\min} \le D_i \le D_{\max})$$

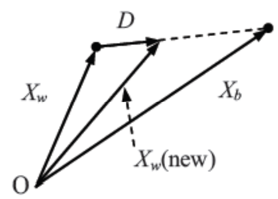

Figure 3. The original frog leaping rule

where rand is a random number between 0 and 1; $D_{\max}$ is the maximum allowed change in frog's position. If this process produces a better solution $(X_w(new))$, new position of the worst frog), it replaces the worst frog's position $(X_w(old))$. Otherwise, the calculations in equations 1 and 2 are repeated with respect to the global best frog (i.e. replaces). If no improvement becomes possible in this case, then a new solution is randomly generated to replace the worst frog (X_w). Because of all arrays in X are integers, obtained solutions from equations 1 and 2 must be rounded after each iteration.

4) Continue of previous step for a number of predefined iterations.

5) After improvement in frog's positions, new population is sorted in a descending order according to their fitness.

6) If the convergence criteria are satisfied, stop. Otherwise, go to step 2 and repeat again.

VI. SFLA PROCEDURE

The SFLA-based approach for solving the problem to minimized consists of objectives takes following steps:

Step 1: Input line and bus data, and bus voltage limits.

Step 2: Calculate the objective function using network load flow based on Newton Raphson method.

Step 3: Create an initial population of k frogs generated randomly.

$$X_i = [x_{i1} = \text{objective function},$$
$$x_{i2} = \text{location of the UPFC},$$
$$x_{i3} = P_1,\ x_{i4} = Q_1,\ x_{i5} = P_2,\ x_{i6} = Q_2]^{\mathrm{T}}$$

$$P = \{X_1, X_2, ..., X_N\}$$

Step 4: Sort the population increasingly and divide the frogs into p memplexes each holding q frogs such that $k = p \times q$. The division is done with the first frog going to the first memplex, second one going to the second memplex, the *p*th frog to the *p*th memplex and the (*p*+1)th frog back to the first memplex.

Step 5: For each memplex if the bus voltage is within the limits, calculate the total loss in equation (8). Otherwise, that memplex is infeasible.

Step 5-1: Set $p_1 = 0$ where p_1 counts the number of memeplexes and will be compared with the total number of memeplexes *p*. Set $y_1 = 0$ where y_1 counts the number of evolutionary steps and will be compared with the maximum number of steps ($y_{\max}$), to be completed with in each memeplex.

Step 5-2: Set $p_1 = p_1 + 1$.

Step 5-3: Set $y_1 = y_1 + 1$.

Step 5-4: For each memplex, the frogs with the best fitness and worst fitness are identified as X_w and X_b, respectively. Also the frog with the global best fitness X_g is identified. Then the position of the worst frog X_w for the memplex is adjusted as follows:

$$B_i = \text{rand}(.) \times (X_b - X_w)$$
$$new\ X_w = old\ X_w + B_i \quad (-B_{\max} \le B_i \le B_{\max}) \tag{11}$$

where rand(.) is a random number between 1 and 0 and $B_{\max}$ is the maximum allowed change in the frogs position. If the evolutions produce a better frog (solution), it replaces the older frog. Otherwise, X_b is replaced by X_g in (11) and the process is repeated. If non improvement becomes possible in this case a random frog is generated which replaces the old frog.

Step 5-5: If $P_1 \le P$, return to Step 3-2. If $y_1 \le y_{\max}$, return to Step 3-3. Otherwise go to step 2.

Step 6: Check the convergence. If the convergence criteria are satisfied, stop. Otherwise, consider the new population as the initial population and return to the step 4.The best solution found in the search process is considered as the output results of the algorithm.

Step 7: Print out the optimal solution to the target problem. The best position includes the optimal locations and size of UPFC or multi-UPFCs, and the corresponding fitness value representing the minimum Cost function and improvement in voltage profile.

VII. CASE STUDY

The load increasing studies on the real power system are done for different aims in planning and operation process of the system. For long term studies of the power system, it is necessary to consider both active and reactive load increasing. The standard IEEE 14-bus test system is shown in Figure 4 to demonstrate the effectiveness and validity of the proposed method. The numerical data and parameters are taken from [7]. In this way, new values of voltages and active and reactive powers of the net and also the value of the objective function are obtained. By iterating this process and a comparison between fitness values, the best chromosome meaning best found solution is introduced.

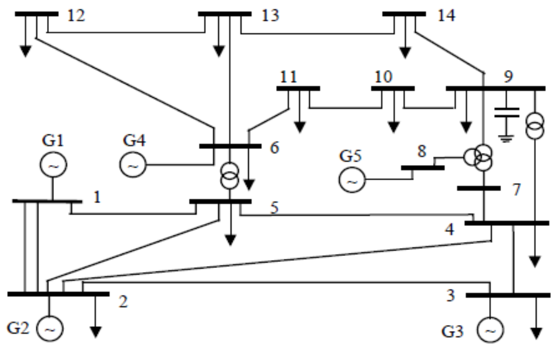

Figure 4. A standard IEEE 14-bus system

Suppose that the given number of UPFCs is set to 2. The dynamic optimization performance of the solution method is shown in Figure 5. In case of using just one UPFC in the system, the proposed algorithm yields a seven-segmented result as the optimal solution. In Table 1 the numbers one and four express the bus number which one UPFC is located between them. The second and third numbers show the values of injective active and reactive powers, respectively into the bus 9 and the fifth and sixth numbers, respectively show the injective active and reactive powers into the bus 4. Seventh number also gives the fitness value defined in the equation (14) for the UPFC.

In case of using two UPFC in the power system simultaneously, the proposed algorithm represents the optimum solution by thirteen segmented chromosome. The first UPFC is set between the buses number 3 and 4 and the second UPFC is set between the buses number 5 and 6. The simulation result is shown in Table 2. The numerical results before and after UPFC placement in the network is shown in Tables 3-5. It is observed form the simulation results that the voltages of buses of the network are in authorized range and the profile of the voltage is satisfactorily flat.

Table 1. The best results for one UPFC

1	2	3	4	5	6	7
Bus Number	P_i	Q_i	Bus Number	P_j	Q_j	Fitness
9	-41.67	-23.81	4	-204.9	-145.6	0.0593

Table 2. The best results for two UPFCs

1	2	3	4	5	6	7	8	9	10	11	12	13
Bus Number	P_i	Q_i	Bus Number	P_j	Q_j	Bus Number	P_i	Q_i	Bus Number	P_j	Q_j	Fitness
3	-132	97	4	-205	-143.6	5	-11.4	-2.24	6	-15.87	82.66	0.1201

Table 3. The result of buses voltages of power flow

Bus Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Voltage without UPFC	1.05	1.05	1.036	0.985	1.000	1.050	0.955	1.050	0.901	0.888	0.957	0.947	0.953	0.859
Voltage with one UPFC	1.050	1.050	1.011	1.023	1.032	1.048	0.981	1.050	1.051	0.970	1.008	1.015	1.023	0.987
Voltage with two UPFCs	1.050	1.050	1.011	1.005	1.014	1.048	1.005	1.050	1.068	0.999	1.002	0.995	1.006	0.998

Table 4. The result of active power flow

Line Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Power Flow without UPFC	0.907	0.123	0.035	0.288	0.170	0.115	0.014	0.086	-0.12	0.420	-3.71	-1.29	-0.02	1.621	1.494	1.278	0.093	0.739	0.420	0.002
Power Flow with one UPFC	0.467	0.141	0.053	0.340	0.257	0.187	-0.04	0.136	-0.17	0.326	-0.95	-0.98	0.163	0.894	1.019	1.059	0.178	0.895	0.626	0.003
Power Flow with two UPFCs	0.695	0.403	0.086	0.41	0.186	0.191	-0.01	0.195	-0.68	0.415	-0.90	-0.83	0.18	1.123	1.092	1.133	0.091	0.947	0.715	0.001

Table 5. The result of reactive power flow

Line Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Power Flow without PFC	0.406	0.055	0.028	0.186	0.207	0.169	-0.08	-0.03	-0.10	0.210	-0.56	0.286	0.655	0.443	0.344	0.539	-0.06	-0.16	-0.28	0.613
Power Flow with one UPFC	0.589	0.055	0.028	0.188	0.210	0.170	-0.08	-0.03	-0.10	0.214	-0.45	0.254	0.711	0.566	0.222	0.583	-0.06	-0.18	-0.29	0.624
Power Flow with two UPFCs	0.495	0.278	-0.01	0.188	0.188	0.150	-0.06	-0.06	-0.59	0.206	-0.61	0.254	0.711	0.596	0.222	0.583	-0.06	-0.18	-0.29	0.624

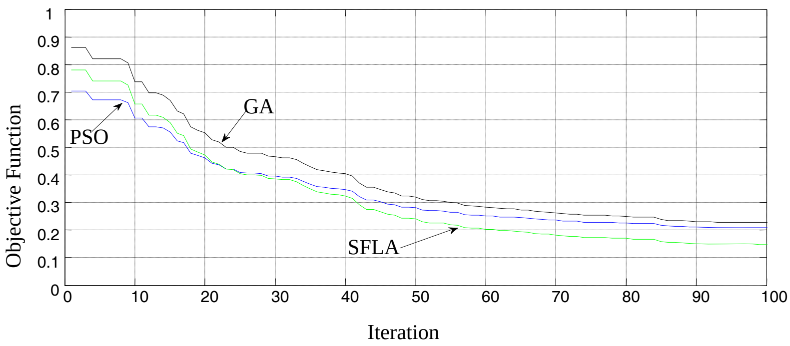

Figure 5. Dynamic Optimization Performance

VII. CONCLUSIONS

In this paper, the optimal UPFC placement on an unstable power system because of load increasing has been investigated. A mathematical model for simultaneously optimizing location and parameters of the UPFCs is presented in this paper. A shuffled frog-leaping algorithm is used to solve this nonlinear programming problem. The computation process are discussed in detail such as the construction of the chromosome, handling of equality and inequality constraints, the location of UPFC to be embedded and the load flow computation etc. The case study of the IEEE 14-bus system has confirmed that the developed algorithm is correct and effective.

The results of the simulations suggest a further use of the proposed tool in the planning field. With the proposed methodology, it can be seen that the FACTS device candidate should give the best locations with respect to various future load duration curves of the transmission system. Such information is of strategic importance to analyze the variation of the system parameters with respect to the number and optimal placement of the UPFC and consequently, with respect to the increase of the power transfers.

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BIOGRAPHIES

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