STABILITY INDEX IMPROVEMENT IN POWER SYSTEMS BY UPFC BASED ON SMART COEFFICIENTS ALGORITHM

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ABSTRACT: *Flexible AC transmission systems (FACTS) can be used to improve power system performance. These devices can improve system parameters; hence the maximum potential of the transmission system can be used. Unified power flow controller (UPFC) is one of the FACTS devices which can simultaneously control the bus voltage and real and reactive power flow in transmission systems. However, their excessive cost causes the optimal choice for the number and the location of these devices. This paper proposes a method for optimized UPFC allocation based on smart coefficients algorithm (SCA) to specify the location, number and input values by minimizing the voltage phase of system buses. The proposed SCA remarkably improves the accuracy and performance of traditional optimization processes in large scale networks. This new method is applied to the 118-bus IEEE standard system. The results of traditional and new optimization algorithm demonstrate the great improvement in optimization process using SCA.*

Key Words: Unified Power Flow Controller (UPFC); equivalent impedance modeling; optimization; voltage index (VI)

1. INTRODUCTION

Voltage stability plays a remarkable role in the power system and major concerns are about it for better utilization of the systems. This goal can be made by installing FACTS devices in transmission lines. These devices can control the power flow and enhance the performance of the power system without necessity of reorganizing the system generation. Unified power flow controller (UPFC) is one of the FACTS devices that gets more attentions to be used to improve stability index because of its ability to simultaneously control both shunt and series variables in a transmission line. The high cost of the UPFC can be justified by concerning the fact that the optimal placement of it may develop the voltage stability index and minimize the total loss of the system.

Finding the appropriate location for UPFC has been discussed in several papers using different methods of optimization. In [1] Optimal placement of UPFC in power system is discussed by using Imperialist Competitive Algorithm to get a flat voltage profile and increased stability in power transmission lines.

The particle swarm optimization is applied in [2] for the real power loss minimization including UPFC. Reference [3] has shown new sensitivity factors to choose the optimal location of UPFCs in the power systems. In [4,5] the cost and real power losses of the power system are optimized by developing a simple genetic algorithm (GA) and the location and rating of UPFC is also optimized using Newton Raphson's method. GA is also used in [6] to determine the optimal place of UPFC by finding line number and its parameters for specific number of UPFCs. In [7]-[10], different algorithms for UPFC allocation are presented with concentration on the voltage stability indices, cost function and reduction of power system losses. References [11] and [8] develop some methods that result in a flat voltage profile and improved power transmission capacity.

A comparison between the results of (GA) and (PSO) techniques are presented in [7, 12] to optimize the cost for energy loss and the cost of using UPFC. A meta heuristic algorithm is introduced in [9]. This method is called Hybrid Genetic and PSO Algorithm (HGAPSO) which has the capability of global searching.

In this paper the main purpose is introducing an algorithm to find the optimized location and number of UPFCs in a power system for enhancement in stability index. The parameter of stability index that is used in this paper is phase angle. The main aspect of this new method is the different coefficients in objective function (O.F.) with different levels of efficiency in minimizing the O.F. In fact, this kind of coefficients selection makes the process of optimization more accurate and faster in convergence. This method is called the Smart Coefficients Algorithm (SCA).

The SCA method is applied on 118-bus IEEE standard network using GA as the optimization algorithm. The results can illustrate the effectiveness of proposed algorithm.

2. UPFC MODELING

2.1. Overall structure

A UPFC is mainly made up of two transformers. As illustrated in Fig. 1, the exciting transformer is connected in series with the transmission and the boosting transformer connects in shunt. The active power of the shunt converter passes through the DC terminal and approaches to the series converter [13]. This converter can inject or absorb the reactive power. V_{se} is injected into the transmission line through the boosting transformer. The magnitude of V_{se} varies between 0 and $V_{se,Max}$ and its angle is between 0 and $2p$.

2.2. Equivalent modeling

There are two equivalent models to represent the characteristics of UPFC: the voltage source model and the impedance model. In fact, these two models are equal. However, the impedance model, presented in Fig. 2, is used in this paper to evaluate the relations among voltage, current and impedance of the UPFC.

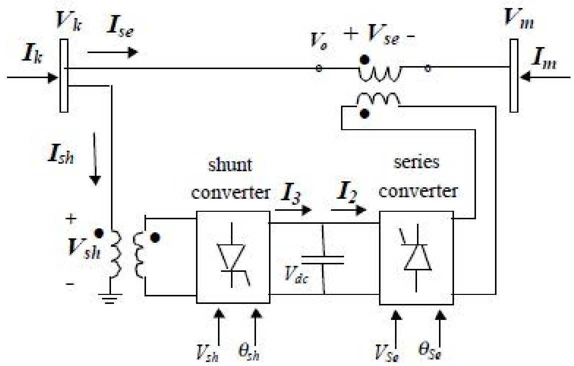

Figure 1 Structure of Unified Power Flow Controller (UPFC)

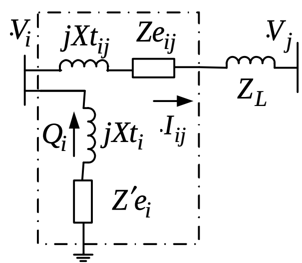

Figure 2 Impedance model of UPFC

The impedance model of UPFC [14, 15, 16] shows the relations among the voltage, current and impedance of it as follows:

$$\vec{I}_{ij} = \frac{\vec{V}_i - \vec{V}_j + \vec{V}e_{ij}}{jXt_{ij} + Z_{ij}} \tag{1}$$

$\vec{I}_{ij}$ represents the current that flows from bus *i* to *j*. $\vec{V}_i$ is the voltage of bus *i* and $\vec{V}_{ij}$ shows the output voltage of the series part. Xt_{ij} and Z_{ij} are the impedance of series transformer and the impedance of the line between buses *i* and *j*, respectively. Hence, the series equivalent impedance between buses *i* and *j* (Ze_{ij}) is obtainsed as follows:

$$Ze_{ij} = \frac{\vec{V}e_{ij}}{\vec{I}_{ij}} \tag{2}$$

In addition, equations for parallel part of the UPFC are presented in Eq. (3) and Eq. (4) in which r_i and x_i are the auxiliary parameters used to get the parallel equivalent impedance of UPFC (Ze_i) [13]:

$$r_i = -\frac{\vec{V}_i^2}{\vec{I}_{ij}^2 . real\left(Ze_{ij}\right)}, \quad x_i = -\frac{\vec{V}_i^2}{Q_i} \tag{3}$$

$$Ze_i = \frac{r_i . jx_i}{r_i + jx_i} - jXt_i \tag{4}$$

Q_i is the output reactive power of parallel branch in equivalent modeling of UPFC and Xt_i is the impedance of the series transformer for parallel branch which connected to the bus i.

3. Smart coefficients algorithm (SCA)

3.1. Objective function formula

The *O.F.* used in this paper is based on SCA which considers phase angle (δ) for each bus:

$$O.F = \frac{1}{2} . \sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} [(A_i \frac{d_{ij}^{comp} - d_{ij}^{init}}{d_{ij}^{init}})] + \frac{n}{N} \quad n < n_{\max} \tag{5}$$

d_{ij}^{comp} : phase angle between buses *i* and *j*, calculated after compensation.

d_{ij}^{init} : phase angle between buses *i* and *j*, calculated before compensation.

Where the definition of δ_{ij} is as follows:

$$d_{ij} = \angle V_i - \angle V_j \tag{6}$$

The purpose is finding the optimal place of UPFC in power system for the minimized *O.F.*, because a smaller phase angle results in a better stability power line. "*n*" is the number of UPFCs for compensation of initial state of power network. "*N*" is the total number of possible places for UPFCs. The maximum possible value for "*n*" (n_{max}) is determined by power utilities and operators based on their budget. In this approach n_{max} is assumed 6 for the 118-bus network.

3.2. Specific coefficients definition

The ordinary methods for optimization of mentioned *O.F.* is usually based on the summation of different terms with strict constant coefficients that are initially determined. However, in this paper, the introduced algorithm can automatically determine the importance of each term in *O.F.*

The *O.F.* shows that the coefficient A_i is multiplied in the main part of improvement formula. In fact, A_i is calculated by multiplication of two other coefficients. The first one is called "individual coefficient" which is based on the importance of the δ_{ij} term in *O.F.* The more the value of δ_{ij}, the more important it is. The purpose of the smart optimization is to minimize the critical terms of *O.F.* rather than all of them. The individual coefficient depends on the ratio of the δ_{ij} of each line to the summation of all them. Therefore, the importance of the δ_{ij} of each line can be determined according to the condition of its phase angle in optimization process. This method of optimization with concentration on individual coefficients is called SCA.

On the other hand, the level coefficient depends on the boundaries defined for three levels of δ_{ij}. They are the desired area (e.g. $0 < \delta_{ij} < 10^o$), critical area (e.g. $10^o < \delta_{ij} < 15^o$) and infeasible area (e.g. $15^o < \delta_{ij}$). The δ_{ij} values that stand in the infeasible area, will get a more significant weight as their level coefficients. Hence, a lower weight is allocated to δ_{ij}s in critical area.

4. TEST RESULTS

The mentioned method is applied on the 118-bus IEEE standard system. TABLE 1 shows the information of this network. It is assumed that the generator 5 which is connected to the bus 10 gets out due to any possible reason. Admittedly, this outage results in the reduction of voltage profile in some buses and the increment of the δij on the lines connected to these buses. After to this outage, there are 6 lines with infeasible δij value and 5 of them are in critical area. The Matpower1.4 and MATLAB are used to obtain the power flow of this network. In this paper, two optimization algorithms are applied to the test system and compared with each other. The optimization processes are accomplished using genetic algorithm toolbox of MATLAB. The generation size is 200 and the population size is 5000. The indirect simulations are used with equivalent impedance modeling of UPFCs that is proposed in [13]. Besides, the stochastic uniform is used as the selection function of optimization.

TABLES 2 and 3 illustrate that the ordinary algorithm of optimization could improve stability conditions by placing 6 UPFCs in this test power system. The series and parallel equivalent voltages of each UPFC are indicated in TABLE 2. Although this traditional optimization algorithm has decreased the mean value *of* δ_{ij}s, its accuracy and performance in not enough to find the best. Fig. 3 shows the phase voltages of all lines in initial and compensated states in ordinary approach.

According to the results presented in TABLES 2 and 3, the new proposed algorithm (SCA) increased the performance and precision of optimization process by decreasing the amount of required UPFCs and the average value of δijs. As presented in TABLE 3 and Fig. 4, the number of infeasible δijs and the maximum value of them significantly reduced in comparison with ordinary optimization. In fact, the SCA could eliminate infeasible δij values and reduce the number of critical values from 5 in ordinary optimized system to 1.

In addition, the maximum of δij values is decreased from 18.0918 to 12.1014 that is a total improvement even in critical values. Fig. 5 reveals the compensated results of both algorithms for a clear comparison. Admittedly, the costs of installation and operation phases have noticeably decreased and the conditions of voltage profiles have been apparently improved. Fig. 6 demonstrates a comparative bar-graph among the δij of those lines in which the UPFC in placed after proposing SCA.

TABLE 1

INFORMATION OF 118-BUS IEEE STANDARD NETWORK

Network Data				
Number of buses	***Number of lines***	***Number of generators***	***Total active power consumption (MW)***	***Total reactive power consumption (MVAR)***
118	186	54	132.86	783.79

TABLE 2

NUMBER AND LOCATION OF UPFCS RESULTED FROM ORDINARY AND SCA OPTIMIZATION PROCESSES

UPFC	Different Optimization Algorithms				
	Number of UPFCs	*Lines number*	*Buses number*	*Voltage of series part*	*Voltage of parallel part*
Compensation with constant coefficients	6	8	8-5	1	1.2
		73	52-53	0.7	0.9
		102	65-66	0.2	1.7
		152	80-98	0.3	1.9
		158	98-100	0.2	1.2
		183	68-116	0.3	1.6
Compensation with SCA	4	33	25-27	1.0	1.6
		102	65-66	0.7	2.1
		108	69-70	0.9	2.0
		151	80-97	0.4	2.0

TABLE 3

RESULTS OF ORDINARY AND SCA OPTIMIZATION PROCESSES

δ_{ij}	**Different Optimization Algorithms**		
	d_{ij}^{init}	d_{ij}^{comp} ***with ordinary method***	d_{ij}^{comp} ***with SCA***
Number of UPFCs	0	6	4
Number of infeasible δ_{ij} values	6	4	0
Number of critical δ_{ij} values	5	5	1
Maximum value of δ_{ij}s	27.3954	18.0918	12.1014
Average value of δ_{ij}s	3.3848	2.8965	2.1554

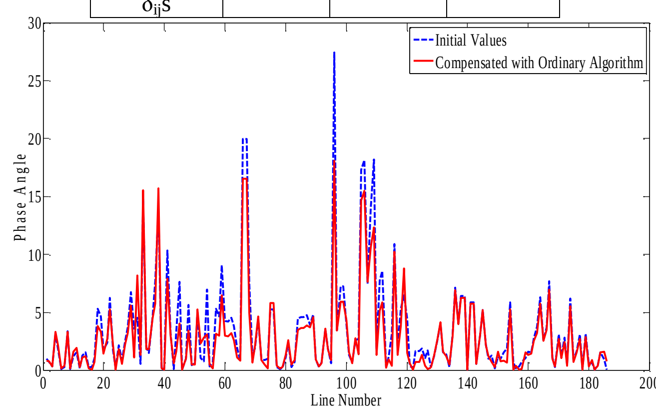

Figure 3 Phase angles of initial and compensated states in ordinary algorithm

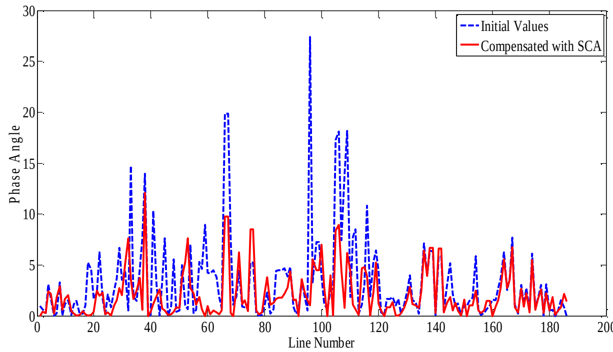

Figure 4 Phase angles of initial and compensated states with SCA

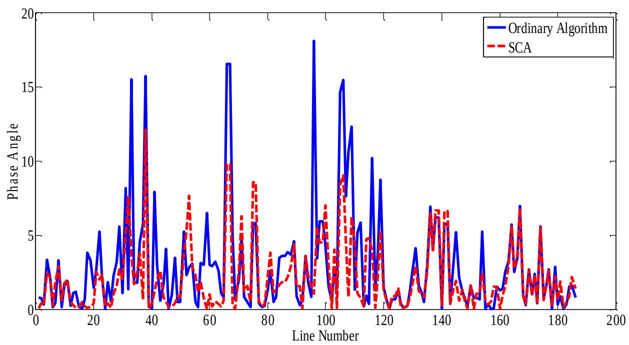

Figure 5 Comparision among compensated phase angles of ordinary algorithm and SCA

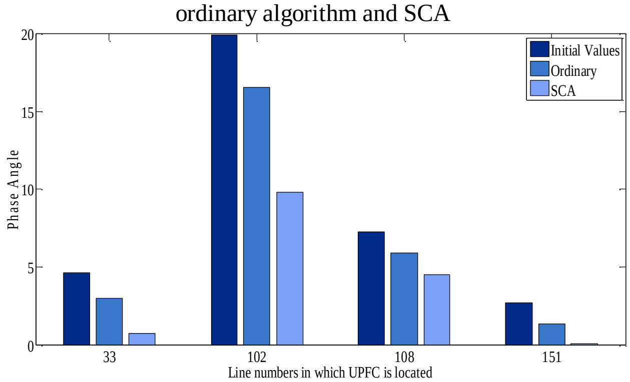

Figure 6 Comparision among phase angles of lines in which UPFC is located in SCA

5. CONCLUSION

In traditional optimization approaches, *O.F.*s were constantly defined to optimize different parameters of power systems without considering the importance of different terms. A novel approach called SCA is presented in this paper to enhance the precision, performance and speed of convergence in optimization processes. The ordinary algorithm and the new SCA were applied to a large scale standard network (118-bus IEEE network). The results of these two different optimization algorithms and the comparison between them illustrated the high accuracy of SCA to find the best result for optimization in large scale networks.

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