Voltage Indices Improvement Using UPFC Based on Specific Coefficients Algorithm

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Abstract— **Improvement in power system performance can be obtained using flexible AC transmission systems (FACTS). These devices can improve system various highly important parameters; hence the maximum potential of the utilization of the transmission system can be achieved. Unified power flow controller (UPFC) is one of the FACTS devices with capability of the simultaneous control of the bus voltage and real and reactive power flow in transmission systems independently; but because of excessive cost, the number and the location of these devices should be indicated optimally. This paper proposes a method of optimization of UPFC allocation based on specific coefficients algorithm (SCA) to specify the number, location and input values by minimizing the voltage indices of system buses. The proposed SCA noticeably improves the accuracy and performance of traditionally used optimization processes especially in large scale networks. This method is applied to the 118-bus IEEE standard system. The results of ordinary and new optimization algorithm have shown the great improvement in optimization process using SCA.**

Keywords- Unified Power Flow Controller (UPFC); equivalent impedance modeling; optimization; voltage index (VI)

I. INTRODUCTION

Voltage stability plays an important role in the operation of power system and there are major concerns about it for better utilization of the system. This purpose can be achieved by installing FACTS devices in transmission lines. These devices can control the power flow and increase the performance in a power system without necessity of reorganizing the generation of system. Unified power flow controller (UPFC) is one of the FACTS devices that gets more attentions to be used to enhance voltage stability due to its simultaneous ability to control both shunt and series variables in a transmission line. The investment cost of the UPFC can be justified by concerning the aspect that the optimal placement of the UPFC develops the voltage stability index along with the minimization in total loss of the system.

Finding the proper location of UPFC has been discussed in several papers using different methods of optimization and different goals. In [1] Optimal placement of UPFC in power system is done using Imperialist Competitive Algorithm to result in a flat voltage profile and increased stability and capacity of the power transmission lines. Using the particle swarm optimization for the exact real power loss minimization including UPFC is applied in [2]. J. G. Singh in [3] has projected new sensitivity factors, called system loading distribution factors, to define the optimal location of unified power flow controllers in the power systems. The paper [4,5] optimized the cost and real power losses of the power system with UPFC by developing a simple genetic algorithm (GA) and the location and rating of UPFC is also achieved by Newton Raphson's load flow method. In [6] GA is used for determining optimal place of UPFC in the power system. Optimal location in this paper is meant finding line number for UPFC location and its parameters for specific number of UPFCs. A genetic algorithm (GA) is used in [7] to find the optimal location and settings of UPFC to enhance the transmission lines overloading issue and the outage cost of the power system is used to verify the impact of the optimized UPFC on reliability. Particle swarm optimization (PSO) technique has been used in [8, 9, 10] to obtain maximum system loadability and minimum cost of installation. [11] presents an optimal allocation algorithm for FACTS devices based on a novel particle swarm optimization method considering both power system costs and short circuit level. A valuable comparison between (GA) and (PSO) techniques are used in [12, 13, 14] to set the parameters of UPFC to optimize the cost for energy loss and the cost related to UPFC. A new meta heuristic algorithm called Hybrid Genetic and PSO Algorithm (HGAPSO) with global search capability is introduced in [15].

In this paper the main purpose is to find an algorithm to optimize the location and number of UPFCs mounted in power system to minimize the voltage index (*VI*). The major aspect of this method is to define different coefficients in objective function (O.F.), each of them has a different level of effectiveness in minimizing the O.F. and makes the process of optimization faster in convergence and more accurate. This method is called the Specific Coefficient Algorithm (SCA) and there are two different kinds of coefficients known as specific coefficients.

The proposed method is applied on 118-bus IEEE standard network using GA to optimize the defined O.F. and results are presented to illustrate the effectiveness of presented algorithm.

II. UPFC MODELING

A. Structure of UPFC

A UPFC is mainly formed of two transformers, one of them is connected in series with the transmission line (exciting transformer) and the other connects in shunt (boosting transformer), as illustrated in Fig. 1. The DC terminal is a corridor to pass the real power provided with the shunt converter, to the series converter. The reactive power can be injected or absorbed through this converter. The series converter injects V_{se} into the transmission line through boosting transformer. The magnitude of V_{se} can vary between 0 and $V_{se,Max}$ and its angle can vary between 0 and 2π .

B. Equivalent modeling of UPFC

The UPFC can be presented by two equivalent models: impedance model and voltage source model. In fact these two models are expressing the same circuits, but in this paper the voltage source model, presented in Fig. 2, is used to represent the voltage, current and impedance of the UPFC and their relations.

Using impedance model of UPFC [16, 17, 18], the relations between the voltage, current and impedance of it can be represented by:

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

$\vec{I}_{ij}$ is the current flows from bus i to j. $\vec{V}_i$ is the voltage of bus i and $\vec{V}_{ij}$ is the output voltage of the series part of UPFC. Xt_{ij} and Z_{ij} are the series transformer impedance and the impedance of the line between buses i and j respectively. Then the series equivalent impedance between buses i and j (Ze_{ij}) can be achieved:

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

Moreover, Eq. (3) and Eq. (4) present the related equations for parallel part of the UPFC in which r_i and x_i are the auxiliary parameters used for calculating the parallel equivalent impedance of UPFC (Ze_i):

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

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

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

III. SPECIFIC COEFFICIENTS ALGORITHM (SCA)

A. Objective Function

The *O.F.* defined in this paper is based on SCA which considers voltage indices (*VI)* for each bus:

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

VI_i^{comp} : Voltage index of bus i, calculated after compensation.

VI_i^{init} : Voltage index of bus i, calculated before compensation.

Where the definition of *VI* is as follows:

$$VI_i = | 1 - V_i | \tag{6}$$

The purpose is to minimize this *O.F.* to find the optimal place of UPFC in power system. “*n*” is the number of UPFCs which is used for compensation of power network initial state. Also, “*N*” is the number of possible places for locating UPFCs.

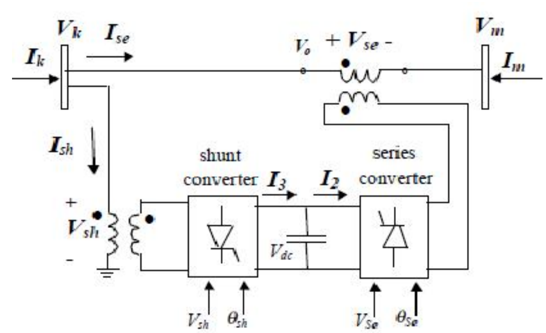

Figure 1. Structure of Unified Power Flow Controller (UPFC)

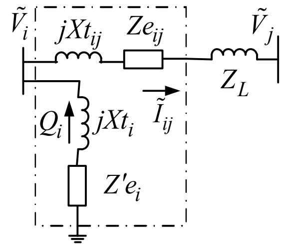

Figure 2. Impedance model of UPFC.

The maximum possible amount for "n" (n_{max}) is determined by power system designers and operators based on their budget (e.g. n_{max} is taken 3 for the 118-bus network in this paper).

B. Specific Coefficients

The ordinary methods for optimization of such above mentioned *O.F.*s are usually summing of different terms with limited and strict initially determined coefficients. However in this paper, a new algorithm is applied to automatically determine the importance of each term of *O.F.*

As presented in *O.F.* the coefficient A_i is multiplied in the main percent of improvement formula. In fact, A_i is constructed by multiplication of two different coefficients. One of them which is called "individual coefficient" is based on the importance of the VI_i term used in *O.F.* The more the value of VI_i, the more important that term is. The aim of the smart optimization is to improve the critical terms of *O.F.* rather than the initially desired ones. The individual coefficient depends on the ratio of the *VI* of each bus to the summation of the *VI*s. So, the importance of the *VI* of each bus can be considered differently (according to the condition of its voltage) in optimization process. This method of optimization with consideration of individual coefficients has been named SCA.

However, the level coefficient depends on the limits defined for three levels of *VI*, namely the desired area (e.g. $0<VI_i<0.05$), critical area (e.g. $0.05<VI_i<0.1$) and unfeasible area (e.g. $0.1<VI_i$). The *VI* values that stand in the unfeasible area, has got a more significant weight that is the level coefficient; hence it will be minimized drastically in optimization process. Then, a lower weight is allocated for *VI*s which are in critical area (e.g. for *VI*s which are located between 5% and 10%).

IV. TEST RESULTS

The proposed method is applied to the 118-bus IEEE standard network. The information of this network has been shown in TABLE I. For any possible reason, the generator 5 which is connected to the bus 10 gets out. This outage results in the reduction of some buses voltage profiles, and the increment of those buses *VI*s. Due to this outage, 9 buses took undesired voltage profiles which 3 of them is in unfeasible area (e.g. upper than 10% difference with unit voltage) and other 6 buses have critical voltage profiles (e.g. in the range between 5% and 10%). The power flow of this network is obtained using Matpower1.4 and MATLAB. In this paper, three optimization algorithms have been applied and compared with each other. All optimizations are accomplished with genetic algorithm toolbox of MATLAB with the generation size of 200 and the population size of 5000. These amounts of calculations have been executed in just approximately 11 hours. Their high speed is due to the indirect simulations with equivalent impedance modeling of UPFCs proposed in [16]. Also, the selection function of all three optimizations is stochastic uniform.

As shown in TABLE II and III, the first algorithm of optimization (traditional optimization) improved voltage profile conditions with 3 UPFCs placed in lines 26, 85 and 109. Each UPFC's series and parallel section's equivalent voltages are indicated in TABLE II.

TABLE I. 118-BUS IEEE STANDARD NETWORK INFORMATION

Network Data				
No. of buses	***No. of lines***	***No. of generators***	***Total active power consumption (MW)***	***Total reactive power consumption (MVAR)***
118	186	54	132.86	783.79

TABLE II. NUMBER AND LOCATION OF UPFCS RESULTED FROM ORDINARY, SCA AND ISCA OPTIMIZATION PROCESSES

UPFC	**Different Optimization Algorithms**				
	No. of UPFCs	***Line number***	***Buse number***	***Voltage of series part***	***Voltage of parallel part***
Compensation without SCA	3	26	15-19	0.213	1.422
		85	56-59	1.114	2.454
		109	24-70	1.056	1.327
Compensation with SCA	2	9	9-10	0.563	1.072
		73	52-53	0.475	1.023
Compensation with ISCA	2	9	9-10	0.621	1.365
		74	53-54	0.589	1.246

TABLE III. RESULTS OF ORDINARY, SCA AND ISCA OPTIMIZATION PROCESSES

VI	**Different Optimization Algorithms**			
	VI^{init}	VI^{comp} ***without SCA***	VI^{comp} ***with SCA***	VI^{comp} ***with ISCA***
No. of UPFCs	0	3	2	2
No. of unfeasible *VI* values	3	2	2	0
No. of critical *VI* values	6	5	3	3
Maximum value of *VI*s	0.1553	0.1485	0.1167	0.0954
Average value of *VI*s	0.0268	0.0219	0.0213	0.0205

However, this traditional optimization algorithm has decreased *VI*s, its accuracy and performance to find the best result is not enough. Fig. 3 shows the voltage indices for all buses in initial and compensated state without using SCA.

Secondly, using proposed algorithm (SCA) without consideration of unfeasible and critical levels has increased the performance and precision of optimization process. Consequently, the amount of required UPFCs and the average of *VI*s have decreased to 2 and 0.0213, respectively. As a clear result, the costs of installation and operation phases have noticeably decreased and the conditions of voltage profiles have been apparently improved. As shown in TABLE III and Fig. 4, the number of critical *VI*s and the maximum value of *VI*s have lessened further in comparison with traditionally used optimization.

Thirdly, the improved version of proposed algorithm (ISCA) has even caused a better result. The number of needed UPFCs equals with the second algorithm (SCA). The number of unfeasible and critical *VI*s has decreased more in comparison with first and second algorithms. The average of *VI*s and the maximum value of them have reduced from 0.0213 and 0.1167 for SCA optimization to 0.0205 and 0.0954 with ISCA optimization, respectively. Also, Fig. 5 indicates the obtained results.

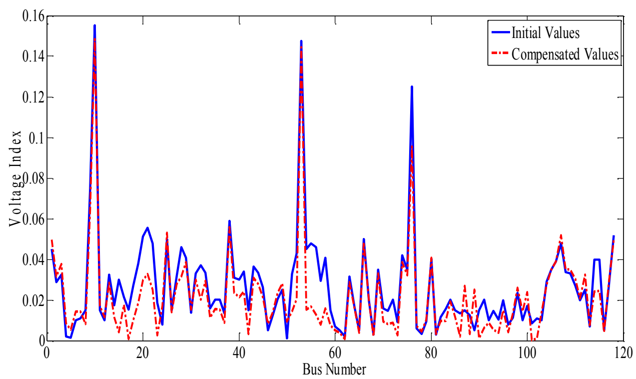

Figure 3. Voltage indices of initial and compensated states for ordinary algorithm

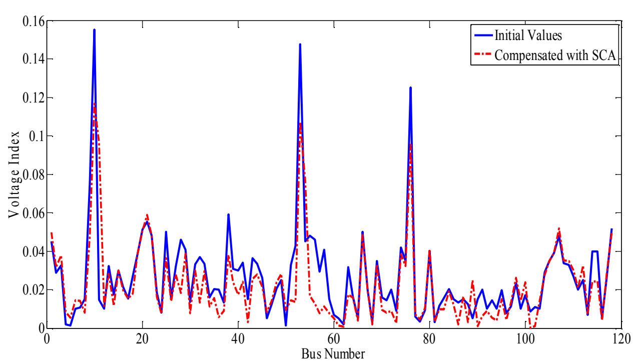

Figure 4. Voltage indices of initial and compensated states with SCA

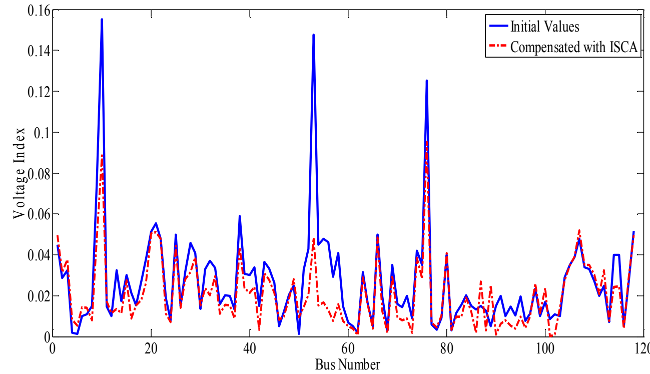

Figure 5. Voltage indices of initial and compensated states with ISCA

V. CONCLUSION

Traditionally, ordinary *O.F.*s were defined to optimize different parameters of power networks with a limit consideration of different terms importance. In this paper, a novel approach based on SCA was introduced to improve the accuracy, speed of convergence and performance of optimization process. Also, this method was further improved and another algorithm named ISCA is proposed to reach even much better results. These two algorithms were applied to a large scale standard network (118-bus IEEE network). The results of three different optimization algorithms and the comparison between them demonstrated the high precision of proposed algorithms to find the best result for optimization of large scale networks.

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