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Looking for optimal number and placement of FACTS devices to manage the transmission congestion

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ABSTRACT

Some applications of FACTS devices show that they are proper and effective tools to control the technical parameters of power systems. However determination of optimal number, location, size and type of these devices is a difficult problem. Moreover, applying a suitable objective function for optimal placement of FACTS devices plays a very important role in economic improvement of a power market. In this paper optimal placement of parallel and series FACTS devices is studied. The STATCOM is selected as a parallel FACTS device and SSSC as a series one. The optimization problem is formulated in regard to restructured environment and a new objective function is defined so that its minimization can alleviate the congestion and provide fairer conditions for power market participants. Moreover, an index based on objective function value is presented to determine the optimal number of each FACTS device in a specific designed algorithm. The power injection models for STATCOM and SSSC are adopted by applying neural models based on the averaging technique. This model takes the converter power losses into account and produces the required PQ-phasor that is suitable for power system steady state analysis. The proposed method is applied on modified IEEE 14-bus, 30-bus and 118-bus test systems and the results are analyzed.

1. Introduction

Recently, the electric power industry is changing to be more competitive. In this new environment, optimal operation of the power system is more important. Power market participants try to transfer optimally large amounts of electric power through the transmission lines in order to gain more revenues. Thus, power systems are often operated very close to their boundary conditions and transmission lines are congested. In this situation, the expansion of transmission system is more significant due to the impact of power transfer capacity of transmission lines on power market transactions. However, today the expansion of transmission systems is restricted. Achieving acceptance to place and construct new transmission capacity is becoming more difficult due to environmental considerations, potential health effects of electric and magnetic fields and the budgetary problems. On the other hand, the use of Flexible Alternating-Current Transmission Systems (FACTS) may be a cost effective option for enhancement of power delivery of the system. FACTS devices are able to change the routes of exchanged powers through the transmission lines by changing amplitude and angle of bus voltages as well as reactance of transmission lines. Therefore, the congestion can be removed or alleviated effectively by forcing power flows to be transferred in routes which do not cause congestion problem. But selecting the optimal type, number, placement and size of these devices is a difficult problem.

According to the relevant literature about FACTS devices considering power market, reveals that researchers, in recent years, have examined the impacts of FACTS devices on improving the operation of power system, while providing the algorithms for finding the best number of each type of device has not received much attention yet. In other words, they only present different algorithms for optimal placement of a specific number of FACTS devices. Some of the reported researches about FACTS devices are reported here.

In [1], a method is presented to decide the optimal placements of Thyristor Controlled Phase Shifter (TCPS), in order to minimize active power losses of transmission lines and to augment the stability of power system. In this work, the minimization of power losses is based on the phase shifter distribution factor; moreover the selection of the placement of phase shifters is performed on the basis of the influence of each device on the active power losses of transmission lines.

In [2], Thyristor Controlled Series Capacitor (TCSC) which is modeled as variable reactance in the capacitive mode is used to maximize the Available Transfer Capacity (ATC). The number of TCSCs is limited to two devices and the amount of compensation is limited to 60%. The Genetic Algorithm (GA) is used to determine the optimal placement and compensation.

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In [3], a GA is used to determine the optimal placement of Unified Power Flow Controller (UPFC) in order to maximize the loadability of the system. Placement of UPFC is determined for different situation of active and reactive loads on the grid. The number of UPFCs is increased as long as the loadability of the system is increased considerably. Considerable increment of the objective function is not quantified by authors. Thus, it is not clear how many UPFCs are required to be applied.

In [4], a GA is used to determine the best placement of a given set of phase shifters based on the cost of production and on the return of investment of the devices. The problem of the selection of the best number of phase shifters is not taken into consideration; however the results of optimal placement of one, two and three phase shifters are compared.

The authors of [5] use a GA to seek the optimal placement of multi-type FACTS devices in a power system consist of TCSC, Static Var Compensator (SVC), TCPS and Thyristor Controlled Voltage Regulator (TCVR). The number of each FACTS device was assigned before the optimization process is solved. Optimization is performed to determine three parameters, i.e. the placement of the devices, their types and their sizes. The system loadability is employed as an index for power system performance.

In [6], TCPS and TCSC are simultaneously and individually used to maximize the Total Transfer Capacity (TTC). The optimal solution is determined using Mixed Integer Linear Programming (MILP). Only in the individual case, the number of FACTS devices increases as far as the loadability of the system is improved considerably. In this work, considerable improvement of objective function is not quantified; therefore the stop point for increasing the number of FACTS devices is not clear. In simultaneous case, the number of each device is assumed to be known.

The authors of [7] locate individually one Static Synchronous Compensator (STATCOM) and one UPFC considering the change of voltage profile of buses due to increment of the system load. The suitable bus for installing FACTS devices is the bus in which the voltage drop is more than the other buses.

In [8], one UPFC and one Interline Power Flow Controller (IPFC) are used to maximize the power transfer capacity. Linear Programming (LP) is used to determine their optimal placement and size of FACTS devices.

The authors of [9] locate individually one TCSC, four TCPS and one UPFC to alleviate the congestion. Simultaneous use of two TCPAR and two UPFC is also studied. The objective function is the sum of total generation cost and the usage cost of FACTS devices. The objective function is minimized via LP method.

The authors of [10] locate individually TCSC, TCPS and SVC to manage the congestion. The objective function is the maximization of social welfare. The optimization problem is solved by Mixed Integer Nonlinear Programming (MINP). The number of each FACTS device is increased until the objective function is improved considerably. However, the improvement of objective is not quantified.

In [11], the impacts of some combination of FACTS devices, i.e. SVC, SVC along with TCPS and SVC along with UPFC, on maximization of ATC are studied. It is assumed that the placements of FACTS devices are known.

In [12], SVC and UPFC are individually used to compensate the reactive power and to minimize the total generation cost, respectively. The placement of SVC for reactive compensation is determined considering the reduction of reactive marginal cost. The placement of UPFC was known before the optimization process is solved. The impact of UPFC on total generation cost is studied in several scenarios.

In [13], the combination of FACTS devices and the transmission rights are considered for congestion management. Two market models, i.e. bilateral contracts and multilateral contracts, are investigated. Two types of FACTS devices, i.e. one TCSC and one SVC, are applied and they are modeled as variable reactance. Two cases are investigated for TCSC. In the first case, TCSC is introduced in inductive mode for the congested lines. In the second case, TCSC in capacitive mode is introduced in the lightly loaded lines. In both cases, the optimal location of TCSC is determined by a trial and error method. SVC is introduced in different buses and its optimal location is determined by observing the rate of improvement of the objective function. The objective function is the minimization of deviations from transaction requests made by market participants.

Briefly, in previous researches several objectives such as minimizing of transmission losses, maximizing the ATC or TTC, maximizing social welfare, minimizing total generation cost and so on are considered for optimal placement of FACTS devices without present an algorithm for determining optimal number of an applied FACTS device.

This paper presents a new objective function for optimal placement of FACTS devices. In addition, an algorithm is proposed for determining the optimal number of an employed FACTS device. Two types of FACTS devices are selected, STATCOM as a parallel device and SSSC as a series device, and the optimal number of each device is determined using the presented algorithm. Due to the impact of congestion on power market transactions as well as power market efficiency, the optimization problem is formulated to alleviate the transmission congestion in a restructured environment. When transmission lines are congested, the difference of nodal prices is increased. If a congested power system is managed so that the difference of nodal prices is decreased, the congestion of transmission lines is decreased too. Moreover, it is desired to decrease the mean of nodal prices along with their differences. Therefore, the objective function is selected as the product of mean of nodal prices and their variance so that its minimization can alleviate the congestion and provide fairer condition for power market participants. It should be noted that the proposed algorithm can be used for other types of objective functions such as minimizing transmission losses, minimizing total generation cost and maximizing social welfare.

Another main subject is that, in the previous works lossless models for FACTS devices are used. In fact, power losses of FACTS devices are not included in the analysis by these models, assuming negligible energy consumption by the device itself. When the number and capacity of the employed FACTS devices increases, considerable energy losses is cancelled in power flow analysis (i.e. part of the network load is cancelled). This undermines the correctness of the process of energy pricing system by using inaccurate models for FACTS devices. In other words, the more accurate are the developed models, the fairer pricing condition is established. In fact, if equipments are modeled close to their exact operation, the energy pricing will be more precise. In particular, this would be more crucial when FACTS devices are engaged in Optimal Power Flows (OPFs) for mitigation of congestion of transmission systems. Thus, in this paper power injection models for STATCOM and SSSC is adopted by applying a neural model based on the averaging technique. This model can take the DC-link of the converter and the power losses into account and produce the required PQ-phasor that is suitable for power system steady state analysis. The case studies on modified IEEE 14-bus, 30-bus and 118-bus test systems show that the proposed method is helpful to extract the optimal number of FACTS devices as well as to create fairer condition for power market participants.

2. FACTS devices modeling

In order to demonstrate the proposed method for determining optimal number of a FACTS device in an optimization problem