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Available transfer capability evaluation and enhancement using various FACTS controllers: Special focus on system security

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Abstract Nowadays, because of the deregulation of the power industry the continuous increase of the load increases the necessity of calculation of available transfer capability (ATC) of a system to analyze the system security. With this calculation, the scheduling of generator can be decided to decrease the system severity. Further, constructing new transmission lines, new substations are very cost effective to meet the increasing load and to increase the transfer capability. Hence, an alternative way to increase the transfer capability is use of flexible ac transmission system (FACTS) controllers. In this paper, SSSC, STACOM and UPFC are considered to show the effect of these controllers in enhancing system ATC. For this, a novel current based modeling and optimal location strategy of these controllers are presented. The proposed methodology is tested on standard IEEE-30 bus and IEEE-57 bus test systems with supporting numerical and graphical results.
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1. Introduction

One of the major advantage of competitive electricity market is the availability of power is open to all consumers to access power from the transmission system. This open access of power system network may create the overload on the power system network more frequently. In power system network, since ATC is an available transfer capability, and unless the calculations of ATC are being used optimally by the power transmission companies, huge amount of power losses will occur in the power system network. The result of this will be a challenging task for power system operation people to manage the system in secured conditions.

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In deregulated power system, the optimal location of FACTS devices for maximizing the power transfer capability, an Evolutionary Programming (EP) is proposed in [1]. This method will also search for FACTS locations, FACTS parameters, and real power generations except slack bus in source area, real power loads in sink area and generation bus voltages in a power system network. The existing real and reactive power equation can also be modified by using SSSC & UPFC, which will improve the power flow and security of the power system network [2]. The Unified Power Flow Controller (UPFC) consists of two coordinated synchronous voltage sources which will be connected in series and parallel to the transmission system. UPFC can improve the overall power system security [3–5]. To increase the ATC values of the system and to minimize the system losses, a suitable type, locations, and parameter settings of FACTS devices are identified by Evolutionary Programming (EP). Test results are witnessed that, optimally placed FACTS device systems will enhance the ATC, than compared to the ordinary power system network [6].

If existing transmission system is being used to the possible extent, then the transmission system owners and customers will receive enhanced services with reduced prices [7]. To improve the ATC, various adjustments will be made. These adjustments could be generator terminal voltage or under load tap changers or generator outputs. The ATC of power system network gives the status of unutilized power at any time and depends on many factors due to the thermal, voltage and stability considerations. The main factors which will decide the ATC are system load level, load distribution in network, power transfer between areas, the limit imposed on the transmission network, etc. This information will be helpful for power marketers, sellers and buyers to participate in the commercial activities [8]. The security constrained OPF (SCOPF) is another method which will solve the steady state security constrained OPF of the power system network. The steady state analysis approach is being used in this methodology and it is a time-consuming method [9,10]. As a replacement of SCOPF, the transfer-based security constrained OPF (TSOPF) method has been proposed for the calculations of ATC in the competitive markets [11]. In this method the TRM and CBM values are also assessed.

Genetic Algorithm (GA) approach has been extensively used in power system networks, in view of optimization approach, and this GA approach has also been extended in calculations of ATC. GAs can find a globally optimal solution [12]. Modern heuristic technique such as Particle Swarm Optimization (PSO) algorithms is one of the method, which is effectively proving that, the optimal values of ATC can be calculated for any power system network [13]. Generally ATC can be classified as Static ATC and Dynamic ATC and these optimal calculations are referred in [14]. Static ATC can be calculated based on continuous power flow and linear sensitivity methods. But in reality since the generation and loads are dynamic, therefore by maintaining static stability constraints, if the ATC is calculated with the dynamic stability limits, then the ATC is called as dynamic ATC. An iterative methodology has been implemented to check the dynamic behavior of the system in calculating the ATC. In this method the trajectories which lie on the stability margin must approach an unsteady equilibrium point [15].

To determine the ATC for bilateral and simultaneous transactions between seller and buyers OPF models are formulated for most of the FACTS devices viz. STATCOM, SSSC, and UPFC. In bilateral transaction a buyer bus demands real power from seller bus. This transaction can be maximized by maintaining equality and inequality constraints [16]. In general Power flows can be calculated between any seller and buyer buses. Since ATC is a function of power flow sensitivity, this will provide a better location for FACTS device in finding best possible ATC values. To enhance the ATC values in a power system network, the sensitivity factors known as Power Transfer Distribution Factors (PTDFs), will provide optimal locations for any FACTS device [17]. For effective increase of transmission system capacity, several studies have found that, by using FACTS devices, the current through a line can be controlled at a reasonable level, which will enable the increase of existing transmission lines [18,19].

From the careful review of the literature it is identified that, the evaluation of ATC using sensitivity approach is one of the effective methods. In this paper, ATC is evaluated by formulating power transfer distribution factors (PTDFs). Further, the system ATC is enhanced using the FACTS controllers. To increase the effectiveness of the problem, the FACTS controllers are placed in an optimal location. A methodology based on the total power loss minimization is presented to identify an optimal location of FACTS. From the literature, it is also identified that, voltage source converter type FACTS controllers are powerful and more effective when compared to the variable impedance type FACTS controllers. Hence, in this paper, the static synchronous series compensator (SSSC), static compensator (STATCOM) and unified power flow controller (UPFC) devices are considered. To identify the effect of these controllers on system performance and on OPF problem, a novel current based model of these controllers is also developed. Using this model, these controllers can be easily incorporated in a given system with decreased computation burden. The proposed methodology is tested on standard IEEE-30 bus and IEEE-57 bus test systems with supporting numerical and graphical results.

2. ATC evaluation

ATC gives the measure of the transfer capability of the existing transmission network for increase in load to meet the commercial activities [20]. The existing transmission network is restricted by the respective power carrying limits of the line and also, the transmission line connected buses have voltage limits. In general, the transfer capability means the ability to transfer/increase/divert the power from one area/bus to another area/bus through the existing system configuration.

There are various sensitivity factors available in the literature to calculate ATC for a given system [21]. From this literature, it is identified that, the calculation of ATC using these factors is easy, simple and less time consuming. Basically, these factors give the relationship between the amount of transaction and the actual power flow in a line. This relation is very commonly termed as power transfer distribution factor (PTDF). This PTDF resembles/reflects the change in generation/load on power flow in a line. The AC Power Transfer Distribution Factor (ACPTDF) is used to identify the system

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