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Loadability enhancement with FACTS devices using gravitational search algorithm

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A R T I C L E I N F O

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A B S T R A C T

In the present work, GSA (gravitational search algorithm) based optimization algorithm is applied for the optimal allocation of FACTS devices in transmission system. IEEE 30 & IEEE 57 test bus systems are taken as standards. Both active and reactive loading of the power system is considered and the effect of FACTS devices on the power transfer capacity of the individual generator is investigated. The proposed approach of planning of reactive power sources with the FACTS devices is compared with other globally accepted techniques like GA (Genetic Algorithm), Differential Evolution (DE), and PSO (Particle Swarm Optimization). From the results obtained, it is observed that incorporating FACTS devices, loadability of the power system increases considerably and each generator present in the system is being able to dispatch significant amount of active power under different increasing loading conditions where the steam flow rate is maintained corresponding to the base active loading condition. The active power loss & operating cost also reduces by significant margin with FACTS devices at each loading condition and GSA based planning approach of reactive power sources with FACTS devices found to be the best among all the methods discussed in terms of reducing active power loss and total operating cost of the system under all active and reactive loading situations.

Introduction

In power system, engineers and researchers are in process to reduce reactive power and transmission loss to boost system efficiency. Reactive power has a deep effect on the security of power networks as it influence voltages throughout the entire network. To increase the amount of active power that can be transferred across a congested transmission network, reactive power flows must be minimized. Likewise, increase in reactive power generation of a particular generator has impact on it's active power generation capacity. In addition, reactive power is essential (i) for the flow of active power through the transmission and distribution system and (ii) to maintain the voltage to deliver active power through transmission lines. Flexible AC Transmission System (FACTS) devices can be effective for static as well as for dynamic state of voltage control in power transmission and distribution. It's principal function is to inject reactive power into the system which helps to support the system voltage profile. FACTS devices regulate desired power flow in a power network provide the best voltage profile in the system as well as to minimise the system transmission loss.

The elementary idea of FACTS devices was first came into existence in 1988 [1]. Lagrangian decomposition approach is applied in [2] for active power congestion management. Optimal placement of capacitor in a radial distribution system is presented in [3]. An elaborative discussion for the optimum placement of series capacitor and phase shifter is presented in [4]. Sensitivity analysis and linear programming technique is presented for the optimal location and size of Static Var Compensator (SVC) in a connected power system in [5]. In [6], Authors have used TCSC device based on the use of LMP (Locational Marginal Pricing) difference and congestion rent. Real power performance index is used in [7], as an indicator for the determination of location of Thyristor Controlled Series Capacitor (TCSC) positions in a connected power network. In [8], solution of transmission system congestion management problem is addressed by the authors using TCSC where the system loadability is increased keeping in view of the voltage stability of the system. Optimal placement of TCSC for increasing loadability and minimizing transmission loss by Genetic Algorithm (GA) is presented in [9]. Use of static phase shifters and series power flow controller (SPFC) and Unified Power Flow Controller (UPFC) to increase power transfer capacity in transmission lines is described in [10]. Solution technique for the power flow problem with TCSC

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and UPFC devices is presented in [11]. Enhancement of available transfer capacity with UPFC devices is described in [12]. Power flow control approach in consideration with available transfer capacity using static synchronous series compensator (SSSC), UPFC and STATCOM devices is discussed in [13]. Authors have used STATCOM, SSSC and UPFC devices in [14] for congestion management considering voltage stability as loadability limit. Authors have proposed a technique in [15], for the optimal coordination of SVC, TCSC and thyristor controlled phase angle regulator (TCPAR) on the basis of demand responses in the restructured power market. Optimal reactive power dispatch along with switchable TCSC and SVC devices is presented in [16]. Improvement in power flow control with TCSC, SVC and UPFC devices is presented in [17]. This paper shows how the system loadability improves with simultaneous use of multi type FACTS devices. An hybrid Genetic Algorithmic approach with TCSC and thyristor controlled phase shifter (TCPS) devices for optimal power flow is described in [18]. The placement of TCSC, TCPST, TCVAR and SVC devices in a power system using GA is discussed in [19]. Utility of different types of UPFC, TCSC, PCPST and SVC devices in deregulated electricity market is explained in [20]. In [21], congested areas of an interconnected power networks are determined and then TCSC's and SVC are allocated using GA based optimization technique to solve transmission congestion. In [22], authors have developed a model to solve congestion management problem by proper placement of unified power flow controller's (UPFC) in suitable locations of the power system. PSO based solution methodology is applied in determining proper size of UPFC to reduce the generation cost as well as congestion cost in a restructured power market in [23]. In order to minimize active power loss, improvement of voltage profile and enhancement of voltage stability, GSA is proposed in [24]. In [25], simulation results indicate that GSA can provide effective and robust high-quality solution for the OPF problem. Applicability of different computational algorithms for load ability enhancement with TCSC, SVC, TCPST devices is presented in [26]. In [27], authors have proposed the application of FACTS devices in a deregulated environment for the solution of combined active and reactive congestion management. In [28], authors suggested model of three FACTS devices i.e. SVC, TCSC and TCPAR and unified into new FDLF (n-FDLF) program. By using above said program, a model of the Hellenic power system is developed.

In the present work, authors have implemented GSA based optimization algorithm for the optimal planning of FACTS devices for the minimization of active power loss and operating cost of the system under different loading conditions. Moreover, ability of each generators to transfer active power in under different loading conditions are investigated where the steam input to each generators are kept corresponding to the base demand.

Modeling of facts devices

For an interconnected congested power network FACTS devices can be modeled as power injection model. The injection model describes the FACTS as a device that injects a certain amount of real and reactive power to a node. Both TCSC and SVC devices control the power flow and voltages by adjusting the reactance of the system. There are two possible characteristic for TCSCs; capacitive and inductive, to increase or decrease the transmission line reactance. These devices can cause increase in the transmission power capacity of lines, static voltage security margin enhancement, voltage profile improvement, and decrease in active power loss. SVCs have also capacitive and inductive characteristics and are predominantly utilized to improve and amend voltage in static and dynamic conditions, reduce reactive power loss, and enhances static voltage security margin. The injection power model and variable susceptance model shown in Figs. 1–3.

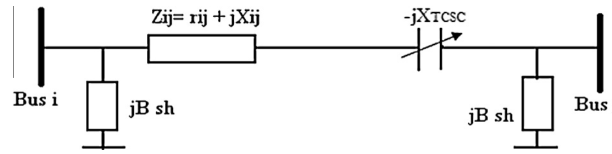

Fig. 1. TCSC model.

Cost function and problem formulation

The objective of the proposed work is to minimize the transmission loss of the system using FACTS devices under different loading conditions. Increase in transmission loss as well as problem of voltage stability is the main concern with the increased load. So, when the system loading is increased gradually, it requires reactive power support to maintain voltage stability. Hence the main aim of the present work is to reduce the real power loss which is expressed by Eq. (1) and to minimize voltage deviation at weak buses under different loading conditions.

$$P_L = \sum_{\substack{x=1 \\ k=(i,j)}}^{n} g_x(v_i^2 + v_j^2 - 2v_i v_j \cos\theta_{ij}) \tag{1}$$

where g_x is the conductance of line x, v_i, v_j are the voltages of ith and jth node respectively, and $\theta_{i,j}$ is the phase angle difference between ith and jth node.

Hence the objective of the present work is transmission loss minimization problem subject to the satisfaction of equality and inequality constraints. Cost functions for TCSC's and SVC's are given below:

TCSC:

$$C_{TCSC} = 0.0015S^2 - 0.7130S + 153.75 \text{ (US \$/kVar)} \tag{2}$$

SVC:

$$C_{SVC} = 0.0003S^2 - 0.3051S + 127.38 \text{ (US \$/kVar)} \tag{3}$$

Here, S is the operating value of the FACTS devices. Energy cost is taken as 0.06$/kW h and cost functions are obtained from [20].

The main objective is to find the optimal location of FACTS devices along with network constraints so as to minimize the total operational cost and relieve transmission congestion at different loading conditions. Installation costs of various FACTS devices

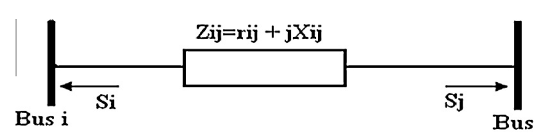

Fig. 2. TCSC injection model.

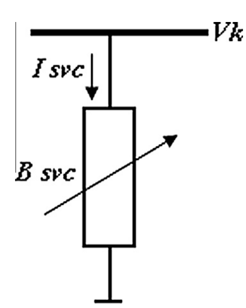

Fig. 3. Variable susceptance model of SVC.