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Reactive power planning with FACTS devices using gravitational search algorithm

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Abstract In this paper, Gravitational Search Algorithm (GSA) is used as optimization method in reactive power planning using FACTS (Flexible AC transmission system) devices. The planning problem is formulated as a single objective optimization problem where the real power loss and bus voltage deviations are minimized under different loading conditions. GSA based optimization algorithm and particle swarm optimization techniques (PSO) are applied on IEEE 30 bus system. Results show that GSA can also be a very effective tool for reactive power planning.

1. Introduction

Reactive power planning is one of the most difficult optimization problem of power system. It requires effective control of reactive power generation by the all reactive power sources present in the system. The sources of reactive power are generators, tap changing transformers, static capacitors, etc. Reactive power optimization problem mainly deals with the minimization of active power loss. It is also observed that the optimum use of the above mentioned reactive power sources reduces active power loss to a certain extent. Now if FACTS devices like SVC and TCSC are used simultaneously with the existing reactive power sources present in the system, not only the transmission loss reduces significantly but also satisfactory improvement of the voltage profile is observed through the entire power network. Hence, the problem that has to be solved in a reactive power optimization problem is to determine the reactive power generation by the all sources, so as to optimize a certain optimization problem.

The concept of Flexible AC transmission system (FACTS) was first introduced by Hingorani [1] in 1988. Use of static phase shifters and FACTS controllers to increase power transfer capacity in transmission lines is described in [2]. A detail discussion for the optimum placement of FACTS devices is presented in [3]. Improvement in power flow control with FACTS devices is presented in [4]. Power flow control approach in consideration with available transfer capacity using FACTS devices is discussed in [5]. The placement of different type of FACTS devices in a power system using Genetic Algorithm is discussed in [6]. This paper shows how the system loadability improves with simultaneous use of multi type FACTS devices. A hybrid Genetic Algorithmic approach with FACTS devices for optimal power flow is dealt in [7]. Solution technique for the power flow problem with multi type FACTS devices is presented in [8]. Utility of different types of FACTS

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devices in deregulated electricity market is explained in [9]. Enhancement of available transfer capacity with FACTS devices is described in [10]. Optimal reactive power dispatch along with the setting of switchable series and shunt FACTS devices is presented in [11]. Sensitivity analysis and linear programming technique are presented for the optimal location and size of Static Var Compensator (SVC) in a connected power system in [12]. Optimal placement of Thyristor Controlled Series Capacitor (TCSC) for increasing loadability and minimizing transmission loss by Genetic Algorithm (GA) is presented in [13]. Loss sensitivity approach is applied for the optimal placement of Var sources in [14]. Applicability of different computational algorithms for load ability enhancement with FACTS devices is presented in [15]. An optimization method is used in [16] to reduce active power loss by network reconfiguration. Optimal placement of capacitor in a radial distribution system is presented in [17].

In order to minimize active power losses, improve the voltage profile and enhance the voltage stability, Gravitational Search Algorithm (GSA) is proposed in [18]. In [19] network reconfiguration problem has been discussed and network losses are reduced using GSA. Opposition-based gravitational search algorithm is used in [20] to find the settings of control variables such as generator voltages, tap positions of tap changing transformers and amount of reactive compensation to optimize certain objectives. In [21], simulation results indicate that GSA provides effective and robust high-quality solution for the OPF problem.

In the present work, gravitational search algorithm is used to coordinate two types of FACTS devices, namely SVC and TCSC with the reactive generation of the generators and the transformer tap setting arrangement to minimize the transmission of loss of the system.

2. Problem formulation

The objective of the proposed work was 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 was to reduce the real power loss which is expressed by Eq. (1) and to minimize voltage deviation at weak buses under different loading conditions.

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

Hence the objective of the present work was transmission loss minimization problem subject to the satisfaction of following equality and inequality constraints.

From the Eq. (1), it is evident that the active power loss is function of the bus voltages, their phase angles and line

TCSC	SVC	Transformer Tap	Reactive Generation of Generators
4 nos.	4 nos.	4 nos.	5 nos.

Figure 1 Agents of GSA and PSO within a string.

conductance. Existing Var sources present in the power network i.e. generators, OLTCs, static capacitor, improve voltage profile to certain extent but has no role in changing line conductance. TCSC is one FACTS controller that changes line reactance and has great impact in power flow control. It also has a vital role in limiting line conductance, which is one of the important parameter for the reduction of transmission loss as observed from Eq. (1). SVC is the other kind of FACTS devices that injects reactive power into the system and has important role in improving the voltage profile of the entire power network. Hence effective placement of SVC at weak nodes is one of the key issues for the minimization of the transmission losses. Lastly total operating cost of the system is calculated which is nothing but the addition of cost of energy loss and the cost of the FACTS controller. Here the objective function becomes minimization of total operating cost which is the sum of the cost due to energy loss and the cost of the FACTS devices.

Cost function of FACTS devices is as follows:

$$\text{Cost}_{\text{SVC}} = 0.0003(\text{S})^2 - 0.3051(\text{S}) + 127.38(\text{US\$/kVar}) \quad (2)$$

$$\text{Cost}_{\text{TCSC}} = 0.0015(\text{S})^2 - 0.7130(\text{S}) + 153.75(\text{US\$/kVar}) \quad (3)$$

where S = operating value of FACTS devices. Energy cost is taken as 0.06 $/Kwh and cost function of the FACTS devices is taken from [9]. Therefore the objective function to be minimized can be expressed as

$$\text{Cost}_{\text{Total}} = \text{Cost}_{\text{Energy Loss}} + \text{Cost}_{\text{SVC}} + \text{Cost}_{\text{TCSC}} \quad (4)$$

where, cost due to energy loss is the cost due to active power loss.

Equality constraints:-

Nodal active and reactive power balance

$$P_{g_i} - P_{d_i} - V_i\sum_{j=1}^{n}(G_{ij}\text{Cos}\theta_{ij} + B_{ij}\text{Sin}\theta_{ij}) = 0 \quad (5)$$

$$Q_{g_i} - Q_{d_i} - V_i\sum_{j=1}^{n}V_j(G_{ij}Sin\theta_{ij} - B_{ij}\ln\theta_{ij}) = 0 \quad (6)$$

where P_{g_i}, P_{d_i} are the active power generation and demand at its lines.Q_{g_i}, Q_{d_i} are the reactive power generation and demand at its lines. G and B are the real and imaginary part of admittance lines matrix i.e. Conductance and Susceptance respectively.

Inequality constraints:-

(i) Voltage magnitude constraints

$$V_i^{\min} \leqslant V_i < V_i^{\max} \quad (7)$$

(ii) OLTC constraints

$$T_K^{\min} < T_K < T_K^{\max} \quad (8)$$

(iii) Nodal reactive generation constraints by the genarators, TCSC and SVC in together

$$Q_{C_i}^{\min} \leqslant Q_{C_i} \leqslant Q_{C_i}^{\max} \quad (9)$$

In an interconnected power network, reactive generation by the generators and the transformer tap setting arrangements are the sources of reactive power. In the present problem, two types