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Swarm intelligence based algorithms for reactive power planning with Flexible AC transmission system devices

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ABSTRACT

In the proposed work, authors have applied swarm intelligence based algorithms for the effective Co-ordination of Flexible AC transmission system (FACTS) devices with other existing Var sources present in the network. IEEE 30 and IEEE 57 bus systems are taken as standard test systems. SPSO (Simple Particle Swarm Optimization) and other two swarm based intelligence approaches like APSO (Adaptive Particle Swarm Optimization) and EPSO (Evolutionary Particle Swarm Optimization) are used for the optimal setting of the Var sources and FACTS devices. The result obtained with the proposed approach is compared with the result found by the conventional RPP (Reactive power planning) approach where shunt capacitors, transformer tap setting arrangements and reactive generations of generators are used as planning variables. It is observed that reactive power planning with FACTS devices yields much better result in terms of reducing active power loss and total operating cost of the system even considering the investment costs of FACTS devices.

Introduction

Effective planning of reactive power sources has significant effect in secure and economic operation of a power system. In the present day scenario, growing power demand, restriction in construction of new lines, unscheduled power flow in lines cause congestion in the transmission network and increases transmission loss.

Reactive power planning problems are solved by optimal allocation of Var sources at definite locations. In optimal Var planning, first the weak nodes or buses are identified as capacitor placement positions, then compensation to the entire power network is provided by proper co-ordination of other Var sources (i.e., transformer tap setting arrangements, generators) with the capacitors placed at the weak nodes of the system. It is observed that by proper planning of Var sources, voltage profile improves, active power loss reduces and system security enhances. There are numerous researches on RPP using both classical and Evolutionary approaches.

Optimal planning of Var sources using linear programming is discussed in [1]. Solution of reactive power problem by optimal placement of capacitor is presented in [2]. Hybrid expert system and simulated annealing technique method for optimal Var planning is presented in [3]. In [4], weak buses are detected first and Var support is provided at the buses to improve system security. Reactive power planning problem based on heuristics is presented in [5]. Binary search technique and special heuristics are applied to solve reactive power planning problem for a large scale electrical power network in [6]. A method for the determination of reactive power margin is presented in [7] for optimal Var planning. Evolutionary programming techniques are applied to solve RPP (Reactive power planning) problem in [8]. Comparative analysis of some evolutionary algorithms on reactive power planning for IEEE 30 bus system is presented in [9]. Simulated Annealing based algorithm for the optimal placement of capacitors in a connected power network is presented by the authors in [10].

Chance constrained programming method is used in [11] for reactive power planning. A simulated annealing based optimization algorithm is developed in [12] for active and reactive power dispatch of a connected power network using transformer taps and capacitor banks. Operation strategy for the improvement of voltage profile and simultaneous reduction of active power loss is described in [13]. PSO (Particle swarm optimization) based optimization algorithm is developed for optimal reactive power planning considering static voltage stability in [14]. Dynamic PSO based optimization technique is applied for minimization of real power loss in [15]. An AC model of transmission expansion planning is presented in [16] by optimal planning of reactive power

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sources. An iterative optimization algorithm is developed in [17] for optimal Var planning. An hybrid heuristic method is applied for the ORPF (Optimal reactive power problem) in the expansion of a transmission network in [18].

With the advent of FACTS (Flexible AC transmission system) devices a new horizon is created for the researchers in RPP issue. FACTS can provide benefits in increasing transmission capacity, flexible power flow control, improvement of steady state and dynamic stability and significant amount of transmission loss minimization. Flexible AC transmission devices are modeled and their optimal allocation strategy is presented in [20]. Authors in [21] have shown the effects of FACTS devices in the power flow of the interconnected power system. Authors in [22] have presented a guideline for the choice and allocation of FACTS devices in a large scale power system. A case of congestion relief by the proper placement of TCSC and improvement of power transfer capacity is addressed in [23]. TCSC location is determined by evolutionary programming in [24] under single line contingency. Authors have shown how system loadability can be increased by optimal setting of TCSC using Genetic Algorithm in [25]. Placement of multi type FACTS devices by GA and improvement of transfer capacity is discussed in [26]. Authors have presented OPF model with FACTS devices in [27]. Differential evolution based optimization algorithm is developed in [28] where authors have shown the impact of FACTS devices in optimal power flow. Loss sensitivity of buses is calculated in [29] by the authors to recognize weak buses for capacitor Var injection, then evolutionary algorithms are developed for optimal Var settings by the generators, capacitors and transformer taps.

In the present work, authors have used FACTS devices for solving RPP problem, where the main objective is to reduce the active power loss and operating cost of the system. Here two types of FACTS devices are used; first one is SVC (Static Var Compensators) and other type is TCSC (Thyristor controlled Switched Capacitors).

Proposed approach

In the present work, SPSO (Simple Particle Swarm Optimization) and other two swarm based intelligence approaches like APSO (Adaptive Particle Swarm Optimization) and EPSO (Evolutionary Particle Swarm Optimization) are applied for reactive power optimization. The main objective of the present work is to minimize the overall operating cost of the system. In the present work, firstly, the optimal planning of Var sources is done with shunt capacitors, transformer tap settings and reactive power generation of the generators present in the system. Capacitor placement positions are determined by weak node analysis. As the settings of transformer tap positions and reactive generations of the generators within the specified limit are independent on the system cost only, cost of shunt capacitors is to be considered only. Hence, the objective function is to minimize the overall operating cost has two parts. One is the cost due to energy loss attributed by active power loss of the system and the other is the cost of the shunt capacitors. The objective function is expressed as

$$C_{\text{Total}} = C_{\text{E}} + C_{\text{Sh}} \tag{1}$$

where C_{E} is cost due to energy loss (in \$) and C_{Sh} is the cost of the shunt capacitor (in \$). C_{E} arises due to the overall transmission loss in the system.

Installation cost of shunt capacitor = 3 (\$/kVar). Fixed installed cost of shunt capacitor = 1000 (\$). Cost due to energy loss = 0.06 (\$/KW h). The objective function represented by Eq. (1) is calculated with the following data as obtained from [10].

Now for reactive power planning with FACTS devices, the objective function becomes,

$$C_{\text{Total}} = C_{\text{E}} + C_{\text{Sh}} \tag{2}$$

where

$$C_{\text{FACTS}} = C_{\text{TCSC}} + C_{\text{SVC}} \tag{3}$$

where C_{FACTS} is the cost due to FACTS devices and C_{TCSC} & C_{SVC} is the cost due to TCSC and SVC respectively.

Again,

$$C_{\text{TCSC}} = 0.0015(\text{TCSC}_{\text{value}})^2 - 0.7130(\text{TCSC}_{\text{value}}) + 153.75(\text{US \$/KVAR}) \tag{4}$$

and

$$C_{\text{SVC}} = 0.0003(\text{SVC}_{\text{value}})^2 - 0.3051(\text{SVC}_{\text{value}}) + 127.38(\text{US \$/KVAR}) \tag{5}$$

Source of Eqs. (4) and (5) is [22].

Cost part $C_{\text{E},}$ due to energy loss arises from the transmission loss is given as:

$$P_{\text{Loss}} = \sum_{k=1}^{n} g_k \left[V_i^2 + V_j^2 - 2V_i \times V_j \times Cos(\delta_i - \delta_j)\right] \tag{6}$$

where g_k is the conductance of the kth line connected between ith and jth bus of the power system. V_i and V_j are the voltage magnitude and δ_i and δ_j are the voltage phase angle of the ith and jth bus respectively. And n is the total number of lines.

The following constraints are to be satisfied while minimizing the objective function for the optimal planning of reactive power sources as given in Eq. (1):

Voltage magnitude constraints:

$$V_i^{\min} \leqslant V_i \leqslant V_i^{\max} \tag{7}$$

Reactive generation limit of the generator's:

$$Q_{gi}^{\min} \leqslant Q_{gi} \leqslant Q_{gi}^{\max} \tag{8}$$

Transformer tap setting arrangements:

$$T_i^{\min} \leqslant T_i \leqslant T_i^{\max} \tag{9}$$

Var output of shunt capacitors:

$$Q_{\text{Ci}}^{\min} \leqslant Q_{\text{Ci}} \leqslant Q_{\text{Ci}}^{\max} \tag{10}$$

Now for reactive power planning with FACTS devices the following two inequality constraints are to be satisfied by objective function represented by Eq. (2) in addition to the satisfaction of inequality constraints shown by Eqs. (7)–(9).

$$Q_{\text{SVC}_i}^{\min} \leqslant Q_{\text{SVC}_i} \leqslant Q_{\text{SVC}_i}^{\max} \tag{11}$$

and

$$Q_{\text{TCSC}_i}^{\min} \leqslant Q_{\text{TCSC}_i} \leqslant Q_{\text{TCSC}_i}^{\max} \tag{12}$$

where min and max are the minimum and maximum values of the variables. The minimum and maximum limit of each variables are given below:

Transformer tap positions	Reactive Generation of Generators	Shunt Capacitors
$T_1, T_2, \ldots\ldots, T_n$	$Qg_1, Qg_2, \ldots.Qg_n$	$C_{sh1}, C_{sh2}, \ldots.C_{shn}$

Fig. 1. String representing the control variables.