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Optimal location of FACTS devices using Improved Particle Swarm Optimization

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ABSTRACT

In this paper a new, an Improved Particle Swarm Optimization (IPSO) is proposed for optimizing the power system performance. Recently, the Particle Swarm Optimization (PSO) technique has been applied to solve power engineering optimization problems giving better results than classical methods. Due to slow convergence and local minima, particle swarm optimization fails to give global results. To overcome these drawbacks, in this paper presents the application of improved particle swarm optimization for optimal sizing and allocation of a Static Compensator (STATCOM) and minimize the voltage deviations at all the buses in a power system. This algorithm finds an optimal settings for present infrastructure as well as optimal locations, sizes and control settings for Static Compensator (STATCOM) units. A 30 bus system is used as an example to illustrate the technique. Results show that the Improved Particle Swarm Optimization (IPSO) is able to find the best solution with statistical significance and a high degree of convergence. The simulation results are presented to show a significant improvement of the power system reliability and feasibility and potential of this new approach.

1. Introduction

The concept of flexible AC transmission system was first defined by Hingorani [1] in 1988. In recent years in the deregulation of the electricity market, the traditional concepts and practices of power system have been changed. Better utilization of the existing power system to increase capacities by installing FACTS devices becomes imperative [2,3].

The electric power grid is the largest man-made machine in the world. It consists of synchronous generators, transformers, transmission lines, switches and relays, active/reactive components and controllers. Various control Objectives operation actions and/or deign decision in such a system require solving an optimization problem. For such a nonlinear non-stationary system with possible noise and uncertainities, as well as varies deign/operational constraints, the solution to the optimization problem is by no means trivial.

FACTS devices control the power flow in the network, and reduces unwanted loop flows in the heavily loaded lines there by resulting in increase loadability, improved security and stability of the network are reported in [4,5].

Population based cooperative and competitive stochastic search algorithms are very popular in the recent years in the research are of computational intelligence. Some well established search algorithm such as GA [6] and evolutionary programming [7] are successfully implemented to solve the complex optimization problems. Evolutionary computation algorithms consistently perform well to approximate solutions to all types of problems because they do not make any assumption about the underlying fitness landscape [8].

The PSO algorithm was introduced by Kennedy and Eberhart [9,10] and further modifications in PSO algorithm were carried out in [11].

In this paper, the problem of optimally allocate FACTS devices corresponds to ECTS (evolutionary computation techniques), in this case the main objective is to find the optimal types, number, sizes and locations for the FACTS devices in the system. To achieve this goal, several criteria are considered such as maximum load ability minimum cost (installation and maintenance), transmission loss minimization, improvement of security margin and maximization of TTC, some studies also include N–1 contingency analysis [12] and the power generation and dispatch problem in deregulated markets [13].

The results obtained for steady state analysis [14,15] are satisfactory in finding global optimum in reasonable computational time.

In [20], a new multi-objective fuzzy-GA formulation for optimal placement and sizing of shunt FACTS controllers has been discussed. In [21], congestion management is included with FACTS devices.

In [22], Huang et al. proposed the loadability of power systems and optimal SVC placement. In [23], Mahmoudabadi and Rashidinejad et al. introduced an application of hybrid heuristic

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method to solve concurrent transmission network expansion and reactive power planning. However there is no clear indication that one algorithm outperforms all others.

This paper introduces the IPSO for the optimal location and sizing of a Static Compensator (STATCOM), shunt devices, in a power system. A 30-bus system [24] is used as an example to illustrate the methodology.

2. Problem formulation

2.1. Objective function

In this case, two goals have to be accomplished: (i) minimize the voltage deviations at all the buses in the system and (ii) minimize the STATCOM, sizes/ratings. Thus, two metrics J_1 and J_2 are defined as in (1) and (2).

$$J_1 = \sqrt{\sum_{i=1}^{N_{bus}} (V_i - 1)_i - 1} \tag{1}$$

where J_1 is the voltage deviation metric, V_i is the value of the voltage at bus i in p.u., and N_{bus} is the total number of buses in the system.

$$J_2 = \sum_{j=1}^{N_{units}} \eta_j \tag{2}$$

where J_2 is the STATCOM size metric, η_j is the sizes, in MVA, of STATCOM unit j, N_{units} is the number of STATCOM units to be allocated.

The multi-objective optimization problem can now be defined using the weighted sum of both metrics J_1 and J_2 to create the objective function J shown in (3).

The best solution is the one for which J is a minimum.

$$J = \omega_1 \cdot J_1 + \omega_2 \cdot J_2 \tag{3}$$

where J is the overall objective function.

The weight that multiplies each metric is adjusted to reflect the relative importance that each goal has with respect to the other. In this case, it is decided to give equal importance to both metrics, giving values of $\omega_1 = 1$ and $\omega_2 = 1/500$, so that the two terms in the objective function are comparable in magnitude.

2.2. Search space (constraints)

There are several constraints in this problem regarding the characteristics of the power system and the desired voltage profile. Each of these constraints represents a limit in the search space. For instance, the network in IEEE30 bus has six generator buses where voltages are regulated by each generator's automatic voltage regulator (AVR). These generator buses do not need a STATCOM and are omitted from the search process, leaving 21 other possible locations for the STATCOM units.

Also, considering the topology of the system, the bus numbers are limited to the range from 1 to 30, thus the constraint shown in (4) have to be considered.

$$1 \le \lambda_j \le N_{bus}, \quad j \in \{1, 2, \ldots, N_{units}\} \tag{4}$$

where λ_j is the location of STATCOM unit j.

Additionally, the event of having more than one STATCOM unit connected to the same bus is considered infeasible, giving the restriction in the following equation:

$$\lambda_i \neq \lambda_j \quad \forall_{i,j} \tag{5}$$

The desired voltage profile requires restrictions defined as the following equation:

$$0.95 \le V_{bus} \le 1.05, \quad i \in \{1, 2, \ldots, N_{bus}\} \tag{6}$$

Each solution that does not satisfy the above restrictions is considered infeasible. Finally, to limit the sizes of the STATCOM units the restrictions in (7) are applied to the particles.

$$0 \le \eta_j 250, \quad j \in \{1, 2, \ldots, N_{units}\} \tag{7}$$

3. Modeling of STATCOM

STATCOM is a shunt compensation device which can be used for improving the voltage profile. It is a shunt controller and it injects current to the transmission line. System voltage is greater than generator voltage, it absorbs the reactive power and if smaller then it generates the reactive power. It can be used on both voltage sourced and current sourced converter. It can be designed to be an active filter to absorb system harmonics. Different FACTS devices and their different location have varying advantages. STATCOM modeling was done as per suggestions in [26].

STATCOM is always located on a load bus. The bus on which STATCOM is being placed is converted from PV bus to PQ bus. Thus STATCOM is considered as a synchronous generator whose real power output is zero and its voltage is set to 1 p.u.

The power flow equations for the STATCOM are derived below from first principles and assuming the following voltage source representation:

Power flow model of STATCOM

$$E_{vR} = V_{vR}(\cos \delta_{vR} + j \sin \delta_{vR}) \tag{8}$$

Based on the shunt connection shown in Fig. 1, the following may be written:

$$S_{vR} = V_{vR} I^*_{vR} = V_{vR} Y^*_{vR} (V^*_{vR} - V^*_k) \tag{9}$$

The following active and reactive power equations are obtained for the converter and bus k, respectively:

$$P_{vR} = V^2_{vR} G_{vR} + V_{vR} V_k [G_{vR} \cos(\delta_{vR} - \theta_k) + B_{vR} \sin(\delta_{vR} - \theta_k)], \tag{10}$$

$$Q_{vR} = -V^2_{vR} B_{vR} + V_{vR} V_k [G_{vR} \sin(\delta_{vR} - \theta_k) - B_{vR} \cos(\delta_{vR} - \theta_k)], \tag{11}$$

$$P_k = V^2_k G_{vR} + V_k V_{vR} [G_{vR} \cos(\theta_k - \delta_{vR}) + B_{vR} \sin(\theta_k - \delta_{vR})], \tag{12}$$

$$Q_k = -V^2_k B_{vR} + V_k V_{vR} [G_{vR} \sin(\theta_k - \delta_{vR}) - B_{vR} \cos(\theta_k - \delta_{vR})], \tag{13}$$

4. Over view of IPSO and its implementation

For the other algorithms, GA, BFA, Bender's decomposition and B&B, which are used to compare the performance of the proposed IPSO method, a brief theoretical background, problem formulation, and parameter settings are presented [17–19].

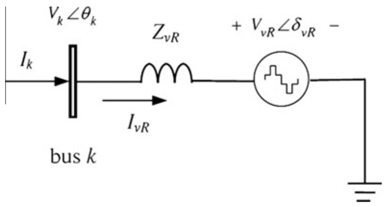

Fig. 1. STATCOM model.