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Teaching Learning Based Optimization algorithm for reactive power planning

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ABSTRACT

Reactive power planning is one of the most challenging problem for efficient and source operation of an interconnected power network. It requires effective and optimum co-ordination of all the reactive power sources present in the network. Recently, Teaching Learning Based Optimization (TLBO) algorithm is evolved and finds its application in the field of engineering optimization. In the proposed work TLBO based optimization algorithm is used for reactive power planning and applied in IEEE 30 and IEEE 57 bus system. The results obtained by this method are compared with the results obtained by other optimization techniques like PSO (Particle swarm optimization), Krill heard, HSA (Harmony search algorithm) and BB-BC (Big Bang-Big Crunch). At the end, TLBO appears as the most effective method for reactive power planning among all the methods discussed and can be considered as one of the standard method for reactive power optimization.

Introduction

Reactive power control has become an important aspect for many reasons. First, the need for most efficient operation of power systems has increased with the price of fuel. For a given distribution of power, the losses in the system can be reduced by minimizing the flow of reactive power. Second, the extension of the transmission network has been curtailed in general by high interest rate, and in particular cases by right-of-way. In many cases power transmitted through older circuit has been increased, requiring the application of reactive power control measures to restore stability margins. Third, voltage is considered as one of the most important parameters of the quality of power supply. Its deviation from normal value may be harmful and expensive. A large amount of research has appeared dealing with reactive power/voltage control in power systems. In this paper, the main concerns are proper planning and coordination of control variables like transformer tap changers, shunt capacitors, generators reactive Var in an interconnected power system for minimum real power loss as well as minimum operating cost. Voltage stability aspect is incorporated in reactive power planning problem by the authors in [1]. Interior point method is used for reactive power control in [2]. A methodology for reactive power planning for Iranian power grid is presented in [3]. Simulated annealing based programming technique for the planning of Var sources is presented in [4]. Authors have investigated the utility of chance constrained programming on reactive power planning in [5]. Comparative analysis of different evolutionary programming for the optimal reactive power flow is presented in [6]. An algorithmic approach is integrated with the heuristic technique for the simultaneous control of voltage and reactive power in [7]. The principle of harmony search algorithm is explained in [8]. This algorithm can be used for the reactive power planning problem. However, the effectiveness of this algorithm is investigated with other optimization techniques in the present paper. A detail review of reactive power planning problems, it's objective and limitations is presented in [9]. The problems and solution methodology for the control of reactive power and voltage is presented by the authors in [10]. An hybrid approach for security constrained reactive power planning is presented in [11]. Simulated annealing based programming approach is presented for both active and reactive dispatch in [12]. Improvement of voltage stability can be achieved by rescheduling of reactive power is the main concern of the paper [13]. Quantam genetic algorithmic approach is presented for reactive power and voltage control in [14]. Transmission loss of an interconnected power system is a function of the voltage profile of the system. An operation strategy for the improvement of voltage profile by reducing the system loss is presented in [15]. Particle swarm based optimization approach for reactive power planning is presented in [16]. Covariance matrix adapted evolutionary strategy

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is applied for the voltage stability enhancement and reactive power optimization in [17]. Solution methodology for optimum reactive power planning is described in [18]. Description of new optimization technique, namely Krill-herd is given in [19] which can also be a new tool for reactive power planning problem. Stochastic method of reactive power planning in a distribution system using wind generators is presented in [20]. An hybrid heuristic method is used for the expansion of transmission network and reactive power planning in [23]. Teaching Learning Based Optimization (TLBO) method for optimization is described in [24]. Big Bang-Big Crunch (BB-BC) is also an optimization method which is used for distance protection in a series compensated transmission lines in [25]. In the present work, authors have applied PSO (Particle Swarm Optimization), KH (Krill-Herd), BB-BC (Big Bang-Big Crunch), HAS (Harmonic Search Algorithm) & TLBO (Teaching Learning Based Optimization) techniques for the minimization of active power loss and operating cost of the connected power system. IEEE-30 and IEEE-57 bus test system are taken as standard. Finally, a comparative analysis between TLBO and other optimization methods are presented.

Problem formulation

The objective of the reactive power planning problem is to minimize the active power loss and the overall operating cost that includes cost due to energy loss and the investment cost of shunt capacitors installed at weak buses determined either by modal analysis or L-index method. Also the improvement of voltage stability is addressed along with the effective planning of the reactive power sources in the present work. Hence in the present work, reactive power planning is a multi-objective problem and different objective functions and constraints are formulated as follows:

Objective functions

Minimization of active power loss

Minimization of the active power loss in the transmission lines can be formulated as follows:

Minimize,

$$F_1 = P_{loss} = \sum_{k=1}^{m} g_k \left[V_i^2 + V_j^2 - 2V_iV_jCos(\delta_i - \delta_j) \right] \quad (1)$$

where P_{loss} denotes active power loss, m is the number of lines, g_k is the conductance of branch k connected between ith and jth bus. V_i and V_j are the voltage magnitudes of the ith and jth buses. δ_i and δ_j are the voltage phase angles of the ith and jth bus respectively. The active power loss can be minimized by proper controlling of different control variables represented by vector U.

$$U = \left[V_g^1, \ldots, V_g^b, Q_c^1, \ldots, Q_c^q, t_n^1, \ldots, t_n^t \right] \quad (2)$$

where V_g^i is the voltage of the voltage controlled bus, where $i = 1, 2, \ldots, b$, Q_c^i is the shunt capacitor value installed at the ith weak bus, where $i = 1, 2, \ldots, q$. q is the total number of shunt capacitors or the total number of weak nodes, t is the total number of tap changing transformer. And the dependent variables associated with the function F_1 is represented by the following vector X.

$$X = \left[P_G^1, V_L^1, \ldots, V_L^n, Q_g^1, \ldots, Q_g^k \right] \quad (3)$$

where P_G^1 is the slack bus power, V_L^i is the voltage of the ith load bus, where $i = 1, 2, 3, \ldots, n$. n is the number of load bus. Q_g^i is the reactive power output of the ith generator. Where, $i = 1, 2, \ldots, k$. Where k is the number of generator bus.

Now in the present problem, main objective is to reduce the active power loss by proper coordination of the control variables as represented by Eq. (2). Further, transformer tap setting arrangements and controlling of Var output of generators do not require investment of additional cost but installation of shunt capacitors at weak nodes add extra cost to the operating cost. Hence objective of the reactive power planning problem becomes minimization of the cost which is the sum of the cost due to energy loss and the installation cost of shunt capacitors. Therefore, the objective function can be expressed as,

$$\text{Minimize, } F_1' = C_1 + C_2 \quad (4)$$

where $C_1 = f(F_1)$

Here, C_1 is the cost due to the energy loss. C_2 is the cost of shunt capacitor. Fixed installation cost of capacitor = 1000$. Energy cost = 0.06$/kwh. Capacitor Cost/KVar = 3$ where,

$$C_1 = P_{loss} \times \text{Energy rate.} \quad (5)$$

$$\text{Energy rate} = 0.06 \times 100000 \times 8760.$$

Hence minimization of F_1' is nothing but minimization of total operating cost of the system.

All the cost data's are obtained from [26].

Voltage profile improvement

For the secured operation of the power system and to provide quality service to the consumer, maintaining steady voltage profile even under increased loading condition is one of the challenging criteria for the power generation companies. The objective function can be formulated as,

Minimize,

$$F_2 = \sum_{i=1}^{n_b} \left| V_i - V_{specified} \right| \quad (6)$$

where n_b is the total number of bus and $V_{specified}$ is the specified bus voltage.

The above mentioned objective functions are to be minimized under the following quality and inequality constraints.

Now if F_2 is added with F_1' the total objective function would appear as

$$\text{Minimize, } F_3 = F_1' + F_2 \quad (7)$$

The resultant objective function F_3 is to be minimized subject to the following equality and inequality constraints.

Equality constraints. These constraints are load flow equations as described below

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{n_b} V_j [G_{ij} Cos(\delta_i - \delta_j) + B_{ij} Sin(\delta_i - \delta_j)] = 0, \quad i = 1, 2, \ldots, n_b \quad (8)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{n_b} V_j [G_{ij} Sin(\delta_i - \delta_j) - B_{ij} Cos(\delta_i - \delta_j)] = 0, \quad i = 1, 2, \ldots, n_b \quad (9)$$

where n_b is the total number of buses, P_{Gi} and Q_{Gi} are active and reactive power generation at the ith bus, P_{Di} and Q_{Di} are active and reactive power demand at the ith bus, G_{ij} and B_{ij} are the transfer conductance and susceptance between ith bus and jth bus respectively.

Inequality constraints

Generator constraints. The generator voltage magnitudes and reactive power outputs are constrained by design specifications.