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Hybrid Tabu search-simulated annealing method to solve optimal reactive power problem

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ABSTRACT

Reactive power optimization problem has a substantial inspiration on secure and economic operation of power system. In this work we utilized Hybridized Tabu Search-Simulated Annealing (HTSSA) algorithm to solve reactive power problem. At first both the algorithm separately solved the reactive power problem, then hybridization has been done and the hybridized algorithm has been utilized to solve the reactive power problem. Detailed comparisons have been done between three modes. The validity of the proposed algorithm has been tested in standard IEEE 30 bus system. And the results show the proposed algorithm HTSSA efficiently solved the reactive power problem. Simulation results clearly show that real power loss considerably reduced and voltage profiles also within the limits.

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Introduction

The key objective of reactive power dispatch problem is to reduce the real power loss and to keep the voltage profiles within the specified limits. Various numerical methods like the gradient method [1,2], Newton method [3] and linear programming [4–7] have been utilized to solve the optimal reactive power dispatch problem. The problem of voltage stability and collapse play a key role in power system planning and operation [8]. In [9], an improved evolutionary programming is used to solve the optimal reactive power dispatch problem. In [10], the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [11], a programming based approach is used to solve the optimal reactive power dispatch problem. In [12], A. Kargarian et al present a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. This paper weights hybridization of both the algorithms to obtain better results. Goodness of the algorithms is used for proposed HTSSA. The results of all three algorithms are obtained and analyzed. These algorithms are tested on standard IEEE30-bus system and results obtained from HTSSA show better performance than the parent algorithms. Simulation study show the better performance of the proposed algorithm in reducing the real power loss and also profiles are within the limits.

Problem formulation

Reactive power problem has been formulated in two modes. In first mode of problem formulation penalty has not been included and the second mode of problem formulation includes penalty. Both the cases have different augmented objective function. But the equality constraints, inequality constraints and control variables remains the same.

Objective function

The objective function of this problem is to find the optimal settings for reactive power control variables which minimize the function.

(a) Without penalty [13]:

The objective function without penalty is expressed as,

$$f = (w * P_l) + (1 - W) * VD \tag{1a}$$

P_l – real power loss of the system,
VD – load bus voltage deviations,
W – Weighting factor and is set to 0.69.

(b) With penalty [14]:

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The objective function describes the fitness value of the system with quadratic penalties. Where k_1, k_2, k_3, k_4 are chosen to be around 10 (from trial and error method),

$$f = (w * P_l) + (1 - w) * VD + k_1 \sum_{i=1}^{nl} L_i^2 + k_2 \sum_{i=1}^{npq} V_i^2 + k_3 \sum_{i=1}^{npv} Q_i^2 + k_4 P_{sl}^2 \tag{1b}$$

where

w – Weighing factor and is set to 0.7,
P_l – real power losses,
VD – voltage deviation of the load buses,
L_i – sum of thermal limit violation of all lines,
V_i – sum of voltage limit violation of all load buses,
Q_i – sum of reactive power limit violation of all generating buses,
P_{sl} – slack bus real power limit violation,
nl – total number of branches (lines),
npq – total number of load buses,
npv – total number of generator buses.

$$L_i = \begin{cases} L_i - L_i^{max}, & if\ L_i > L_i^{max}; \\ L_i^{min} - L_i, & if\ L_i < L_i^{min}; \\ else & 0; \end{cases}$$

$$V_i = \begin{cases} V_i - V_i^{max}, & if\ V_i > V_i^{max}; \\ V_i^{min} - V_i, & if\ V_i < V_i^{min}; \\ else & 0; \end{cases}$$

$$Q_i = \begin{cases} Q_i - Q_i^{max}, & if\ Q_i > Q_i^{max}; \\ Q_i^{min} - Q_i, & if\ Q_i < Q_i^{min}; \\ else & 0; \end{cases}$$

$$P_{sl} = \begin{cases} P_{sl} - P_{sl}^{max}, & if\ P_{sl} > P_{sl}^{max}; \\ P_{sl}^{min} - P_{sl}, & if\ P_{sl} < P_{sl}^{min}; \\ else & 0; \end{cases}$$

(i) Real power loss minimization (P_l)

The total real power of the system is given in Eq. (2)

$$P_l = \sum_{k=1}^{N_l} G_k (V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)) \tag{2}$$

where N_l – total number of transmission lines in the system; G_k – conductance of the line k; V_i and V_j are the magnitudes of the sending end and receiving end voltages of the line; δ_i and δ_j are angles of the end voltages.

(ii) Load bus Voltage deviation minimization (VD)

Bus voltages magnitudes are maintained within the allowable limit to ensure quality service. As shown in Eq. (3) below, voltage profile is improved by minimizing the deviation of the load bus voltage from the reference value and it is taken as 1.0 p.u.

$$VD = \sum_{k=1}^{N_{pq}} |(V_k - V_{ref})| \tag{3}$$

Constraints

The minimization problem is subjected to the equality and inequality constraints as follows.

Equality constraints:

Load flow constraints:

The real and reactive power constraints are according to Eqs. (4) and (5) respectively as given below:

$$P_{Gi} - P_{Di} - \sum_{j=1}^{N_B} V_i V_{ij} Y_{ij} \cos(\delta_{ij} + \gamma_j - \gamma_i) = 0 \tag{4}$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{N_B} V_i V_{ij} Y_{ij} \sin(\delta_{ij} + \gamma_j - \gamma_i) = 0 \tag{5}$$

Inequality constraints:

Generator bus voltage (V_{Gi}) inequality constraint:

$$V_{Gi}^{min} \leqslant V_{Gi} \leqslant V_{Gi}^{max}, i\varepsilon ng \tag{6}$$

Load bus voltage (V_{Li}) inequality constraint:

$$V_{Li}^{min} \leqslant V_{Li} \leqslant V_{Li}^{max}, i\varepsilon nl \tag{7}$$

Switchable reactive power compensation (Q_{Ci}) inequality constraint:

$$Q_{Ci}^{min} \leqslant Q_{Ci} \leqslant Q_{Ci}^{max}, i\varepsilon nc \tag{8}$$

Reactive power generation (Q_{Gi}) inequality constraint:

$$Q_{Gi}^{min} \leqslant Q_{Gi} \leqslant Q_{Gi}^{max}, i\varepsilon ng \tag{9}$$

Transformer tap setting (T_i) inequality constraint:

$$T_i^{min} \leqslant T_i \leqslant T_i^{max}, i\varepsilon nt \tag{10}$$

Description of algorithms

Tabu search

Tabu search (TS), which was firstly developed by Glover [15–17]. Neighborhood explorations take a potential solution to a problem and authenticate its instantaneous local opportunities, which is, solutions that are similar except for one or two minor details to recognize a better-quality solution. Local search methods incline to become stuck in suboptimal regions. Tabu search takes advantage of the performance of these tactics by using memory structures, which elucidate the visited solutions. If a potential solution has been already visited within a certain short-term period or if it has already violated a rule, it is marked as "tabu" (forbidden) so that the algorithm would not reconsider that possibility.

1. Arbitrarily develop an initial solution.
2. Calculate neighborhood.
3. Choose a candidate move.
4. Is candidate tabu? If yes then go to step 4a or go to step 5.
   4a. Will solution be the absolute best? Or go to step 4b.
   4b. Reject candidate move and adjust the neighborhood then go to step 3.
5. Update solution by incorporating the candidate move, set z value
6. Have we reached the stopping criteria?
   6a. if yes – Stop and report the best solution found during search.
   6b. if no – go to step 2.

Tabu search Algorithm for reactive power problem

Step 1. Let S be the preliminary feasible solution and Z its objective function value; then, set $S^* = S$, $Z^* = Z$, max short-term memory (STM) = 5, and max iteration = 1000; iter = 1. Best O value = O value.

Step 2. Arbitrary (i, j) = rand/Long-term memory (LTM) (i, j), $(n1, n2)$ = the indices of maximum value in arbitrary.

Step 3. If there is none $(n1, n2)$ in STM matrix, alter $n1$ and $n2$ locations; or else, repeat step 2.

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