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Optimal reactive power dispatch based on harmony search algorithm

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ABSTRACT

This paper presents a harmony search algorithm for optimal reactive power dispatch (ORPD) problem. Optimal reactive power dispatch is a mixed integer, nonlinear optimization problem which includes both continuous and discrete control variables. The proposed algorithm is used to find the settings of control variables such as generator voltages, tap positions of tap changing transformers and the amount of reactive compensation devices to optimize a certain object. The objects are power transmission loss, voltage stability and voltage profile which are optimized separately. In the presented method, the inequality constraints are handled by penalty coefficients. The study is implemented on IEEE 30 and 57-bus systems and the results are compared with other evolutionary programs such as simple genetic algorithm (SGA) and particle swarm optimization (PSO) which have been used in the last decade and also other algorithms that have been developed in the recent years.

1. Introduction

The Optimal Reactive power dispatch problem is affective on secure and economical operation of power systems. This problem denotes optimal settings of control variables such as generator voltages, tap ratios of transformers and reactive compensation devices to minimize a certain object While satisfying equality and inequality constraints. Transformer tap settings and reactive compensation devices are discrete values while bus voltage magnitudes and reactive power outputs of generators are continuous variables so the ORPD problem can be modeled using mixed integer nonlinear programming.

Up to now a number of mathematical programming approaches have been implemented to the ORPD problem. In [1–4] gradient based optimization algorithms have been used to solve the ORPD problem.

Recently interior-point methods have been implemented to the ORPD and the OPF problem. Interior-point linear programming [5] was used by Granville. Quadratic programming [6] was also implemented by momeh. These methods are incapable in handling nonlinear, discontinuous functions and constraints, and problems having multiple local minimum points. In all these techniques simplifications have been done to overcome the limitations. In [7] Aoki handled discrete variables by an approximation–search method and Bakirtziss in [8] represented a linear-programming to handle the shunt reactive compensation devices.

Recently, stochastic search methods have been used widely for the global optimization problem. In [9] an Evolutionary Programming (EP) is applied by Wu for global optimization of a power system to accomplish optimal reactive power dispatch and voltage control. Lai in [10] showed EP is more capable of handling noncontinuous and non- smooth functions comparing nonlinear programming. In [11] Lee used simple genetic algorithm (SGA) combined with successive linear programming to solve reactive power operational problem. Particle swarm optimization (PSO) was applied by Yoshida in [13] for reactive power and voltage control considering voltage security assessment. [14] Proposed a multi-agent based PSO by Zhao for the ORPD problem. In [15] Zhang used a fuzzy adaptive PSO for reactive power and voltage control. In [16] Differential evolutionary algorithm is implemented to the optimal reactive power dispatch problem. Kannan in [17] solved the ORPD problem by a CLPSO approach. Other approaches for solving this problem such as SARCGA and SOA are introduced in [18,19]. Finally a stochastic reactive power approach is solved by GA in [20].

In the few years harmony search algorithm (HSA) has been used for global optimization. HSA is a meta-heuristic algorithm which mimics the improvisation process of music players and has been developed in the recent years [21]. This algorithm has been used for optimization problems in a wide variety [22–26] which shows several advantages in comparison with conventional methods. These advantages are:

1. The mathematical operations used in this algorithm are very simple and also the control variables are selected randomly.

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2. As the entire search process is a random process no derivative operations are used in this algorithm.
3. In HSA for generating the elements of the new vector solution all of the existing vector solutions are regarded. In other basic heuristic algorithms such as genetic algorithm only two solution vectors are considered for generating the new solution vector. Or in PSO only the best answer among all of the solutions and the best answer of each particle during the previous iterations are used to generate the new solution vector.

2. Problem formulation

The proposed algorithm is tested and compared with other conventional algorithms on optimal performance in terms of minimization of: (a) Power losses in transmission lines. (b) Sum of voltage deviations on load busses. (c) Voltage stability. The function is optimized while satisfying equality and inequality constraints. The first objective is to minimize the real power losses that can be expressed as:

$$F_1 = P_{loss}(x,u) = \sum_{L=1}^{Nl} P_L \tag{1}$$

where x is the vector of dependent variables, u is the vector of control variables, P_L is the real power losses at line-L and Nl is the number of transmission lines.

The second object is the voltage deviation at load buses and can be expressed as [12]:

$$F_2 = VD(x,u) = \sum_{i=1}^{Nd} |V_i - V_i^{sp}| \tag{2}$$

where V_i is the voltage at load bus-i, which is usually set to 1.0 p.u. and Nd is the number of load buses.

The third objective which is minimized is the L voltage stability index. This index is calculated for all load buses and the maximum amount of all buses is the objective [27]. It can be expressed as:

$$F_3 = VL(x,u) = L_{\max} \tag{3}$$

In all of the problems the dependent vector is considered as:

$$x^T = [[V_L]^T, [Q_G]^T, [S_L]^T] \tag{4}$$

where x is the vector of dependent variables, $[V_L]$ is the vector of load bus voltages, $[Q_G]$ is the vector of generator reactive power outputs and $[S_L]$ is the transmission line loadings.

The vector of control variables is presented as below.

$$u^T = [[V_G]^T, [T]^T, [Q_C]^T] \tag{5}$$

$[V_G]$ is the vector of generator bus voltages, $[T]$ is the vector of transformer taps and $[Q_C]$ is the vector of reactive compensation devices.

The equality constraints are the load flow equations as:

$$P_{Gi} - P_{Di} = V_i \sum_{j \in N_i} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \tag{6}$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{j \in N_i} V_j (B_{ij} \cos\theta_{ij} - G_{ij} \sin\theta_{ij}) \tag{7}$$

The inequality constraints in all of the problems represent the system operating constraints:

- Generator constraints: Generator voltages V_G and reactive power outputs are restricted by their limits as the below relations:

$$V_{G_i}^{\min} \leqslant V_{G_i} \leqslant V_{G_i}^{\max} i = 1,2,\ldots,NG \tag{8}$$

$$Q_{G_i}^{\min} \leqslant Q_{G_i} \leqslant Q_{G_i}^{\max} i = 1,2,\ldots,NG \tag{9}$$

where NG is the number of generators.

- Reactive compensation sources: These devices are limited as follows:

$$Q_{C_i}^{\min} \leqslant Q_{C_i} \leqslant Q_{C_i}^{\max} i = 1,2,\ldots,NC \tag{10}$$

where NC is the number of reactive compensation devices.

- Transformer constraints: Tap settings are restricted as:

$$T_i^{\min} \leqslant T_I \leqslant T_i^{\max} i = 1,2,\ldots,NT \tag{11}$$

where NT is the number of transformers.

- Operating constraints: Which are the constraints of voltage load buses and line loadings.

$$V_{L_i}^{\min} \leqslant V_{L_i} \leqslant V_{L_i}^{\max} i = 1,2,\ldots,Nd \tag{12}$$

$$S_{L_i} \leqslant S_{L_i}^{\max} \cdots i = 1,2,\ldots,Nd \tag{13}$$

The inequality constraints are considered in the objective function by penalty coefficients.

3. Harmony search algorithm

In the recent years harmony search algorithm (HSA) has been extended with music improvisation where music players improvise the pitches of their instruments to obtain better harmony [21]. The procedure of this algorithm is shown in Fig. 1 and the stages are as following [28,29]:

1. Selecting the problem and algorithm parameters.
2. Generating harmony memory.
3. Generating a new harmony (solution vector).
4. Changing the harmony memory.
5. Terminating criteria.

These steps are detailed in the next sections.

3.1. Selecting the problem and algorithm parameters

In the first stage the problem is specified as following:

$$\begin{aligned} &\min f(x) \\ &g(x) > 0 \\ &h(x) = 0 \end{aligned} \tag{14}$$

where $f(x)$ is the object function, $g(x)$ is the inequality constraint and $h(x)$ is the equality constraint function. x is the set of each decision variable. The amount of x is restricted to $x_{L_i} \leqslant x_i \leqslant x_{U_i}$, where x_{L_i} and x_{U_i} are the lower and upper limits for each variable. Parameters of the algorithm such as harmony memory size (HMS) that is the number of solutions stored in a memory matrix, pitch adjusting rate (PAR) and the number of improvisations (iterations) are selected in this stage. Also the numbers of control variables are chosen in this step.

The harmony memory (HM) is a matrix composed of control variables which each row represents a solution to the problem.

3.2. Generating harmony memory

In this stage solution vectors for the problem are generated randomly and placed in the rows of the harmony memory matrix.

$$\mathrm{HM} = \begin{bmatrix} x_1^1 & \cdots & x_N^1 \\ \vdots & \vdots & \vdots \\ x_1^{HMS} & \cdots & x_N^{HMS} \end{bmatrix} \tag{15}$$