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Fuzzy harmony search algorithm based optimal power flow for power system security enhancement

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ABSTRACT

This paper proposes the integration of fuzzy logic system with harmony search algorithm (FHSA) to find the optimal solution for optimal power flow (OPF) problem in a power system. The objective of the method is to minimize the total fuel cost of thermal generating units having quadratic cost characteristics and severity index (SI). The generator active power, generator bus voltage magnitude, transformer taps, VAR of shunts and the reactance of thyristor controlled series capacitor (TCSC) are taken as the control variables. The adjustment of proposed algorithm parameters such as pitch adjustment rate (PAR) and bandwidth (BW) is done through fuzzy logic system (FLS). The effectiveness of the proposed method has been tested on the standard IEEE 30 bus, IEEE 57 bus and IEEE 118 bus systems in MATLAB environment and their results are compared with conventional harmony search algorithm (HSA) and other heuristic methods reported in the literature recently.

Introduction

The power system security is the ability of the system to maintain the flow of electricity from the generators to the customers, especially under contingency conditions. A contingency is basically an outage of a generator; transformer and/or transmission line and its effects are monitored with specified security limits. The power system operation is said to be normal, when the power flows and the bus voltages are within acceptable limits in spite of changes in load or generation. In static security analysis, contingency analysis is used to predict the possible systems outage and their effect [1]. When outage of components in a power system occurs, system gets overloaded and the system parameters exceed their limits thus resulting in an insecure system. Hence, static security enhancement by alleviating overloads on the transmission lines is a vital role in an electric power system.

Optimal power flow is an important tool for power system management. OPF has been applied to regulate generator real power outputs and voltages, shunt capacitors/reactors, transformer tap settings and other controlled variables to minimize the total fuel cost of generators, real power loss, while satisfying a set of physical and operating constraints such as generation and load balance, bus voltage limits, power flow equations and active and reactive power limits. The OPF problem has been solved by using conventional and evolutionary based algorithms.

Conventional optimization techniques such as gradient method, linear programming method, nonlinear programming method and interior point method have been discussed in [2–5]. In conventional optimization methods, identification of global minimum is not possible. To overcome the difficulty, evolutionary algorithms like genetic Algorithm (GA) [6], tabu search algorithm [7], differential evolution [8], modified differential evolution algorithm (MDE) [9], cuckoo optimization algorithm [10], artificial bee colony algorithm [11], improved harmony search method [12] and improved teaching–learning-based optimization algorithm [13] had been proposed.

In [14], chaotic invasive weed optimization algorithm has been used to find the optimal solution for optimal power flow problem in a power system. Different non-smooth and non-convex cost functions were considered to minimize the fuel cost such as quadratic fuel cost function, fuel cost function with valve point effect, and fuel cost function with considering the prohibited zones. In [15], chaotic invasive weed optimization techniques have been used for solving environmental optimal power flow problem. Simultaneous minimization two conflicting objectives such as fuel cost and gaze emission were considered. Fuzzy particle swarm optimization based congestion management by optimal rescheduling of active powers of generators has been depicted in [16]. The

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generators had been chosen based on the generator sensitivity to the congested line. The results were compared with fitness distance ratio particle swarm optimization and conventional PSO. A contingency constrained economic load dispatch using improved particle swarm optimization to alleviate transmission line overloads has been discussed in [17]. The line overloads were relieved through rescheduling of generators with minimum fuel cost and minimum severity index.

In [18], fuzzy adaptive bacterial foraging has been used to alleviate overload through redispatch of generators. The participating generators were selected based on the generator sensitivity to the congested line. An alleviation of congestion in a power system by optimal sizing and placement of TCSC have been depicted in [19]. Minimization of severity index was taken as objective function. The optimal location of TCSC was done by sensitivity analysis and sizing of TCSC by using genetic algorithm.

HS algorithm was first proposed by Geem et al. in 2001 [20]. It is a population-based meta-heuristic optimization algorithm. It is inspired by the music improvisation process in which the musician searches for harmony and continues to polish the pitches to obtain a better harmony. In HSA, PAR and BW is very important parameters in fine tuning of optimized solution vectors and can be potentially useful in adjusting convergence rate of algorithm to get optimal solution. The fine adjustment of these parameters is of great interest.

The conventional HSA uses fixed value of PAR and BW. The PAR and BW is adjusted in initialization only and cannot be changed during new iterations. The main drawback of this method is to take more number of iterations to get an optimal solution. Small PAR values and large BW can cause to poor performance of an algorithm and great increase in iterations to find optimal solution. Large PAR values with small BW values usually cause the improvement of best solutions in final iterations which algorithm converged to optimal solution vector. In this paper, fuzzy logic based PAR and BW adjustment is presented.

The organization of the paper is as follows: section 'Optimal location of TCSC' presents overview of optimal location of TCSC. Section 'Problem formulation' presents the optimization problem formulation for power system security enhancement. Section 'Modeling of fuzzy logic system' presents modeling of fuzzy logic system. Section 'Proposed FHSA algorithm' presents the algorithm of proposed FHSA to find the optimal solutions. The results achieved by applying the proposed method on the standard IEEE 30 bus, IEEE 57 bus and IEEE 118 bus systems are presented in section 'Simulation results'. Finally, conclusion is given in section 'Conclusion'.

Optimal location of TCSC

To enhance the security of the system, the TCSC is to be placed at the suitable locations. To determine the best location of TCSC, an index called line overload sensitivity index (LOSI) is calculated for the selected contingency cases [21]. These factors have been obtained as:

$$\mathrm{LOSI}_l = \sum_{C=1}^{N_C}\left(\frac{S_l^C}{S_l^{\max}}\right) \tag{1}$$

where S_l^C = flow in line l (MVA) in contingency C; $S_l^{\max}$ = rating of the line l (MVA); N_c = Number of considered contingencies.

TCSC's are placed on the branches starting from the top of the ranking list.

Problem formulation

The objective of the proposed method is to minimize the total fuel cost and severity index.

Objective functions

Objective 1: Minimization of total fuel cost

$$F_T = \sum_{i=1}^{N_G}\left(a_iP_{gi}^2 + b_iP_{gi} + c_i\right) \tag{2}$$

where F_T = total fuel cost, N_G = number of generators, P_{gi} = Active power output of ith generator and a_i, b_i, c_i = cost coefficients of generator i.

Objective 2: Minimization of severity index

$$\mathrm{SI}_l = \sum_{l\in L_o}^{n}\left(\frac{S_l}{S_l^{\max}}\right)^{2m} \tag{3}$$

where S_l = flow in line l (MVA), $S_l^{\max}$ = rating of the line l (MVA), L_o = set of overloaded lines and m = integer exponent = 1 (Assumed) [22].

For secure system, the value of SI is zero. When the SI value is greater, the contingency becomes severe.

Problem constraints

The constraints are:

Generation/load balance Equation

$$\sum_{i=1}^{N_G}P_{gi} - \sum_{i-1}^{N_D}P_{Di} - P_L = 0 \tag{4}$$

where N_G = Number of generators, N_D = Number of loads, P_{gi} = Generation of generator i, P_{Di} = Active power demand at bus i, g = Generator, D = Demand and P_L = System active power loss.

Generator constraints

$$P_{gi,\min} \leqslant P_{gi} \leqslant P_{gi,\max} \tag{5}$$

where $P_{gi,\max}$ = Upper limit of active power generation at generator bus i and $P_{gi,\min}$ = Lower limit of active power generation at generator bus i.

$$V_{gi,\min} \leqslant V_{gi} \leqslant V_{gi,\max} \tag{6}$$

where V_{gi} = Voltage magnitude at generator bus i, $V_{gi,\max}$ = Upper limit of voltage magnitude at generator bus i and $V_{gi,\min}$ = Lower limit of voltage magnitude at generator bus i.

Voltage constraints

$$V_{i,\min} \leqslant V_i \leqslant V_{i,\max} \tag{7}$$

where V_i = Voltage magnitude at bus i, $V_{i,\max}$ = Upper limit of voltage magnitude at bus i and $V_{i,\min}$ = Lower limit of voltage magnitude at bus i.

Transformer constraints

$$T_{i,\min} \leqslant T_i \leqslant T_{i,\max} \tag{8}$$

where $T_{i,\min}$ and $T_{i,\max}$ are minimum and maximum tap settings limits of transformer i.

Shunt VAR constraints

$$Q_{ci,\min} \leqslant Q_{ci} \leqslant Q_{ci,\max} \tag{9}$$