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Multi-objective optimization in the presence of ramp-rate limits using non-dominated sorting hybrid fruit fly algorithm

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Abstract A novel optimization algorithm is proposed to solve single and multi-objective optimization problems with generation fuel cost, total power losses and voltage stability index as objectives. Fruit fly Algorithm (FFA) along with real coded Genetic Algorithm (GA) cross-over operation treated as Hybrid Fruit fly Algorithm (HFFA) is proposed to select best value as compared with existing single-objective evaluation algorithms and the proposed non-dominated sorting hybrid fruit fly algorithm (NSHFFA) is used for the multi-objective optimal power flow problem. A fuzzy decision making tool is used to select the best Pareto front from the total generated solutions by the proposed algorithm. The effectiveness of the proposed algorithm is analyzed for various standard test systems such as Booth's function, Schaffer 2 function and IEEE 30 bus system. The obtained results using proposed algorithm are compared with the existing optimization methods. The results reveal better solution and computational efficiency of the proposed algorithm.

1. Introduction

Power flow studies are of great importance for reliable, stable and secure operation of a power system and for proper planning as well as designed for future extension. In the past few decades, optimal power flow (OPF) problem has received greater attention, because it is one of the most powerful tools to analyze static systems of electrical energy. The main aim of OPF problem solution was to optimize a selected objective function such as fuel cost, power loss and voltage stability index (L-index).

Santos and da Costa describe a new approach for the optimal-power-flow problem based on Newton's method which is operated with an augmented original problem [1]. Momoh and Zhu proposed an improved quadratic interior point (IQIP) method used to solve comprehensive OPF problem with a variety of objective functions, including economic dispatch, VAR planning and loss minimization [2]. AlRashidi and El-Hawary investigated the applicability of hybrid partial swam optimization (HPSO) in solving the OPF problem under different formulations and considering different objectives [3]. Capitanescu et al. proposed interior-point based algorithms

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for the solution of optimal power flow problems for the minimization of overall generation cost, minimization of active power losses, maximization of power system loadability and minimization of the amount of load curtailment [4]. An approach for the multi-objective OPF problem using 'differential evolution' is presented by Varada Rajan and Swarup [5]. Bai et al. described new solution using the semi definite programming (SDP) technique to solve the OPF problems. This involves reformulating the OPF problems into a SDP model and developing an algorithm of interior point method (IPM) for SDP [6]. Yang and Deb intend to formulate a new meta-heuristic algorithm, called Cuckoo Search (CS), for solving optimization problems [7]. Niknam et al. [8] have proposed improved particle swarm optimization for multi-objective OPF considering cost, loss, and emission voltage stability index. Bakirtzis et al. proposed a Strength Pareto Evolutionary Algorithm (SPEA) [9] with strong-dominated solutions is used to form the Pareto optimal set.

In the literature several algorithms have been proposed for multi-objective optimization problem. One of these methods is converting multi-objective problem to single-objective problem by considering one object as main object and other as a constraint. Another technique is combining all objectives into one objective function and solving using weighted sum technique. All these techniques have drawbacks such as limitation of the available choices of solution. The above methods will give only one solution for the multi-objective problem and this is the major drawback in these methods. To overcome these problems some of the techniques are proposed in the literature [10–13]. These algorithms are population based methods, and multi-Pareto-optimal solutions can be found in one program run. In the proposed technique non-dominated sorting approach is used along with the hybrid fruit fly algorithm to solve multi-objective optimization problem.

2. Problem formulation

The aim of optimal power flow solution was to optimize a selective objective function through optimal adjustment of control variables by satisfying equality and inequality constraints. The OPF problem can be mathematically formulated as follows:

$$\text{Minimize } C(x,u) \tag{1}$$

$$\text{Subjected to constrain } g(x,u) = 0 \tag{2}$$

$$h_{\min} \leqslant h(x,u) \leqslant h_{\max} \tag{3}$$

where $C(x,u)$ is the objective function, x is the vector of dependent variables, u is the vector of independent or control variables, $g(x,u)$ represents equality constraints, and $h(x,u)$ represents inequality constraints.

Equality constraints: These constraints are usually load flow equations described as

$$P_{Gi} - P_{Di} - \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) = 0$$

$$Q_{Gi} - Q_{Di} + \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) = 0$$

In-Equality Constraints: These are generator, voltage, transformer tap setting, shunt VAr compensators and security constraints are considered [14].

Ramp-rate limits: The operating range of the generating units is restricted by their ramp-rate limits, which force the generators to operate continuously between two adjacent periods. The inequality constraints imposed by these ramp-rate limits are

$$\max(P_{Gi}^{\min}, P_i^0 - DR_i) \leqslant \min(P_{Gi}^{\max}, P_i^0 + UR_i)$$

where P_i^0 is the power generation of ith unit at previous hour. DR_i and UR_i are the respective decreasing and increasing ramp-rate limits of ith unit.

3. Objective functions

The main objective of OPF problem was to minimize the generation fuel cost, total real power loss of a transmission line in a system and voltage stability index (L-Index).

3.1. Case 1. Generation fuel cost

The fuel cost curves of thermal generators are modeled as a quadratic cost curve which can be represented as,

$$C_T = \sum_{i=1}^{NG} C_i(P_{Gi}) \tag{4}$$

$$C_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + d_i \quad \$/\text{h} \tag{5}$$

where a_i, b_i and d_i are ith generating unit cost coefficients, P_{Gi} is real power generation of ith generating unit, and NG is total number of generating units.

3.2. Case 2. Total real power loss (TPL)

The total real power loss is

$$C_{Loss} = \sum_{i=1}^{nl} g_l[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)] \quad \text{MW} \tag{6}$$

where g_l is the conduction of lth line which connects buses i and j, and V_l, V_j and δ_i, δ_j are the voltage magnitude and angle of the lth and ith bus, respectively.

3.3. Case 3. Voltage stability index (VSI)

The significance of L-index of load buses in a power system is to monitor the voltage stability. It uses information from the normal load flow. It is in the range of 0–1. Voltage collapse can be controlled by minimizing the sum of squares of L-indices for a given operating condition.

$$C_{\text{L-Index}} = \sum_{j=NG+1}^{NB} L_j^2 \tag{7}$$

where NG is the number of generator buses and NB is the total number of buses in the system.