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Analysis of optimal power flow problem based on two stage initialization algorithm

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ABSTRACT

This paper focuses on providing a new and comprehensive optimization algorithm to solve constrained Optimal Power Flow (OPF) problem in the power system. Unlike the OPF solution algorithms existing in the literature, in the proposed algorithm, a two stage initialization process is adopted and the mutation operation is not used. Also, it gives optimal solution with less number of generations which results in the reduction of the computation time. The feasibility of the proposed algorithm is demonstrated for a Himmelblau function and IEEE 14 bus system. The obtained results using proposed method are compared with the existing optimization techniques. The results reveal better solution and computational efficiency of the proposed algorithm.

1. Introduction

The Optimal Power Flow (OPF) problem has received much attention in power system planning, operation and control. The OPF problem optimizes an objective function while satisfying various equality and inequality constraints. In the past, conventional methods were employed for the solution of OPF problem. Recently, evolutionary methods are used to solve OPF problem. An approach for the optimal power flow problem in a deregulated power market using Bender's decomposition is presented by Alguacil and Conejo [1], Yamin et al. [2,3]. Gnanadass et al. [4] devoted an evolutionary programming algorithm to solve the optimal power flow problem with non-smooth fuel cost functions. Al-Rashidi and El-Hawary [5] have reported a hybrid particle swarm optimization algorithm as a modern optimization tool to solve the discrete optimal power flow problem with valve loading effect.

Shunmugalatha and Mary Raja Slochanal [6] utilizes the hybrid particle swarm optimization, which incorporates the breeding and subpopulation process in genetic algorithm into particle swarm optimization for the optimum cost of generation with respect to maximum load ability limit of power system. Varadarajan and Swarup [7] presented differential evolution approach to solve optimal power flow problem with multiple objectives. Different methods to find the solution for OPF problem have been discussed in [8–11]. Selvan [12] proposed an approach based on the object-oriented design pattern to develop a comprehensive optimal power flow analysis program. Sailaja Kumari and Sydulu Maheswarapu [13] proposed a decoupled quadratic load flow solution with enhanced genetic algorithm to solve the optimal power flow problem. Roy et al. [14,15] discussed a biogeography based optimization algorithm for solving constrained optimal power flow problem considering valve point non-linearity of generators in power systems.

Careful study of the former literature reveals that there is a single stage initialization process along with mutation operation. But, in this paper, a comprehensive optimization method known as intelligent search evolution method to solve optimal power flow problem in the power system is proposed. Unlike the OPF solution methods existing in the literature, in the proposed method, a two stage initialization process has been adopted and the mutation operation is not used. The feasibility of the proposed method is tested for different examples. In this paper, because of the limit in number of pages, two examples namely, Himmelblau function and IEEE 14 bus system are demonstrated. The obtained results using proposed method are compared with the existing methods.

The remaining portion of the paper is organized as follows: Section 2 presents the general optimal power flow problem formulation along with the objective function and constraints. Section 3 discusses the overview of existing differential evolution algorithm. Section 4 gives brief description of the proposed method with its

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operations. The main steps of the proposed algorithm are represented as flow chart in section 5. Section 6 demonstrates the effectiveness of proposed algorithm through numerical examples and finally, conclusion is drawn in Section 7.

2. OPF problem formulation

In its general form, the OPF problem can be mathematically represented as

$$Minimize \quad f(x,u) \tag{1}$$

$$subjected\ to \quad g(x,u)=0 \tag{2}$$

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

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

The OPF solution determines a set of optimal variables to achieve a certain goal such as minimum generation cost, power loss etc., subject to all the equality and inequality constraints. The dependent variables are slack bus active power, load bus voltage magnitudes and its angles, generators reactive powers and line flows. The independent variables consist of continuous and discrete variables. The continuous variables are active powers of all generators, except slack bus and generator voltages. The discrete variables are tap settings of regulating transformers and reactive power injections.

2.1. Objective function

The minimization of fuel cost is considered an objective function to examine the performance of the proposed method. The aim of the fuel cost minimization is to determine optimal generation settings of thermal generating units which minimize the total fuel cost while satisfying all the equality and inequality constraints. The total fuel cost function (F_c) for a number of thermal generating units can be represented by a quadratic function as

$$F_c = \sum_{i=1}^{ng}\left(a_i P_{gi}^2 + b_i P_{gi} + c_i\right) \quad \$/h \tag{4}$$

where a_i, b_i and c_i are cost coefficient of ith generator, P_{gi} the generation of the ith generator and ng is the number of generator buses.

2.2. Constraints

The following are the two types of constraints considered for OPF problem

- Equality constraints.
- Inequality constraints.

The *equality constraints* represent the set of nonlinear power flow equations as

$$P_{gi} - P_{di} - \sum_{j=1}^{nb}|V_i||V_j||Y_{ij}|cos(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{5}$$

$$Q_{gi} - Q_{di} + \sum_{j=1}^{nb}|V_i||V_j||Y_{ij}|sin(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{6}$$

where P_{gi} and Q_{gi} are the active and reactive power generation at ith bus, P_{di} and Q_{di} the active and reactive power demand at ith bus, nb the number of buses, V_i and V_j the voltage magnitudes of ith and jth bus respectively, δ_i and δ_j the voltage angles of ith and jth bus respectively, $|Y_{ij}|$ and θ_{ij} are bus admittance matrix elements between ith and jth bus.

The following are *inequality constraints* for OPF problem:

- Generators real and reactive power constraints

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}; \quad i = 1,2,\ldots,ng \tag{7}$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}; \quad i = 1,2,\ldots,ng \tag{8}$$

where P_{gi}^{min} and P_{gi}^{max} are the minimum and maximum active power generation limits at ith bus. Q_{gi}^{min} and Q_{gi}^{max} are the minimum and maximum reactive power generation limits at ith bus.

- Voltage constraints

$$V_i^{min} \leq V_i \leq V_i^{max}; \quad i = 1,2,\ldots,nb \tag{9}$$

where V_i^{min} and V_i^{max} are the minimum and maximum voltage limits at ith bus.

- Transformer tap setting constraints

$$T_i^{min} \leq T_i \leq T_i^{max}; \quad i = 1,2,\ldots,nt \tag{10}$$

where T_i^{min} and T_i^{max} are the minimum and maximum tap settings of ith transformer and nt represents number of transformer tap settings.

- Shunt compensator constraints

$$Q_{ci}^{min} \leq Q_{ci} \leq Q_{ci}^{max}; \quad i = 1,2,\ldots,nc \tag{11}$$

where Q_{ci}^{min} and Q_{ci}^{max} are the minimum and maximum reactive power injection limits of ith compensator and nc represents number of compensators.

3. Overview of differential evolution

Differential Evolution (DE) algorithm is a population based evolutionary computation technique developed by Storn and Price [16]. DE has been applied to many optimization problems and it has been observed that it gives better performance because of a special kind of differential operator used to create new off springs from parent chromosomes. The major stages of DE are described as follows.

3.1. Single stage initialization

The population of a specified size is generated for each control variable by using the following equation

$$x_{i,j} = x_j^{min} + rand(0,\ 1)\ \left(x_j^{max} - x_j^{min}\right) \tag{12}$$

where $i = 1, 2, \ldots, ps$; $j = 1, 2, \ldots, ncv$, ps = population size, ncv = number of control variables, x_j^{min} and x_j^{max} are the lower and upper bounds of jth control variable, $rand(0, 1)$ is a uniformly distributed random number between 0 and 1.

In general, the initial population vector (pv) or target vector of size ($ps \times ncv$) is generated and it is used for evolutionary operations. The single stage initialization process of DE is same to all existing algorithms as shown in Fig. 1.

3.2. Mutation

A different type of mutation operation is used in DE compared to other evolutionary algorithms. The following equation is used to form a mutation vector (mv) or donor vector for every ith individual in the population.

$$mv_i = x_{r1} + F(x_{r2} - x_{r3}) \tag{13}$$