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Application of pattern search method to power system security constrained economic dispatch with non-smooth cost function

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Abstract

Direct search methods are evolutionary algorithms used to solve optimization problems. (DS) methods do not require any information about the gradient of the objective function at hand while searching for an optimum solution. One of such methods is *Pattern Search* (PS) algorithm. This paper presents a new approach based on a constrained pattern search algorithm to solve a security constrained power system economic dispatch problem (SCED) with non-smooth cost function. Operation of power systems demands a high degree of security to keep the system satisfactorily operating when subjected to disturbances, while and at the same time it is required to pay attention to the economic aspects. Pattern recognition technique is used first to assess dynamic security. Linear classifiers that determine the stability of electric power system are presented and added to other system stability and operational constraints. The problem is formulated as a constrained optimization problem in a way that insures a secure-economic system operation. Pattern search method is then applied to solve the constrained optimization formulation. In particular, the method is tested using three different test systems. Simulation results of the proposed approach are compared with those reported in literature. The outcome is very encouraging and proves that pattern search (PS) is very applicable for solving security constrained power system economic dispatch problem (SCED). In addition, valve-point effect loading and total system losses are considered to further investigate the potential of the PS technique. Based on the results, it can be concluded that the PS has demonstrated ability in handling highly nonlinear discontinuous non-smooth cost function of the SCED.

Keywords: Security constrained economic dispatch; Direct search method; Optimization; Valve-point effect and non-smooth cost function

1. Introduction

Power system security analysis is the process of detecting whether the power system is in a secure state or alert state. Secure state implies that the load is satisfied and no limit violations will occur under present operating conditions and in the presence of unforeseen contingencies. The alert state implies that either some limits are violated and/or the load demand cannot be met and corrective actions must be taken in order to bring the power system back to the secure state. The power system security problems are classified as static and dynamic. The static security problem implies evaluating the system steady state performance for all possible postulated contingencies. This means neglecting the transient behavior and any other time-dependent variations due to load-generation conditions. The dynamic analysis evaluates the time-dependent transition from the pre-contingent state to the post-contingent state. Dynamic security has been analyzed either by deriving dynamic security functions only, or along with the development of some preventive action techniques [1–5].

Often, security analysis is introduced, to the economic study of an electric power system, in the form of security constraint had to be satisfied. A wide variety of optimization techniques have been applied in solving economic load dispatch problems (ELD). Some of these techniques are based on classical optimization methods while others are based on artificial intelligence methods or heuristic algorithms. Many references present the application of classical optimization methods, such as linear programming, quadratic programming, to solve the ELD problem [1,2]. Classical optimization methods are highly sensitive to staring points and some times converge to local optimum solution or diverge altogether. Linear programming methods are fast and reliable but the main disadvantage associated with the piecewise linear cost approximation. Nonlinear programming

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methods have a problem of convergence and algorithmic complexity. Newton based algorithms have a problem in handling a large number of inequality constraints [5]. Methods based on artificial intelligence techniques, such as artificial neural networks, were also presented in many Refs. [3,4]. Recently, many heuristic search techniques such as particle swarm optimization [5] and genetic algorithms [6] were applied successfully to the ELD problem. Hybrid methods were also presented in some references such as Ref. [7]. In this reference, the conventional Lagrangian relaxation approach, first order gradient method and multi-pass dynamic programming are combined together.

Recently, particular family of global optimization methods, introduced and developed by researchers in 1960 [8], has received a great attention. This family of methods called direct search methods. Direct search methods are simply designed to search a set of point, around the current point, looking for a point that has less objective value that the current one has. This family includes *pattern search* (*PS*) algorithms, *simplex methods* (*SM*) (different form the simplex used in linear programming), *Powell optimization* (*PO*) and others [9].

Direct search methods, as apposed to more standard optimization methods, are often called derivative-free optimization methods, where they do not require any information about the gradient or even higher derivative of the objective function to search for an optimal solution. Therefore direct search methods may very well be used to solve non-continues, non-differentiable and multimodal, i.e. multiple local optima, optimization problem. Since the economic dispatch is one such problem, then the proposed method appears to be a good candidate to handle the economic dispatch problem.

The main objective of this study is to introduce the use of pattern search (PS) optimization technique to the subject of power system dynamic security with the most economical operating conditions. In this study pattern search (PS) method is employed to solve the security constrained economic dispatch problem (SCED). This new approach will be used to minimize the system objective cost function satisfying a set of dynamic security constraints. The pattern recognition technique, used in a previous work [10,11], is utilized to introduce dynamic security constrained economic dispatch problem in a simple, powerful, and quick approaches. Such constraints have been employed in the development of the approach of preventive action under economic operation. In this approach, the goal is to shift the system state from an unstable area to stable area, if the system is in an alert condition, and at the same time, minimize the objective function.

2. Security assessment by pattern recognition method

As introduced, the dynamic security problem implies evaluating the system performance for all possible postulated contingencies. This means, for actual large systems, thousand of cases to be considered. The use of such approach in economic study of power system, as in our case, adds more computational difficulties which make it impossible to be practically applicable. Therefore, it is simpler and desirable to have an indicator for different modes of security. Such indicator may be presented in the form of simple mathematical function (classifier). The security assessment is then considered as a two class classification problem, namely secure or insecure. The classifier function is given as [12,13]

$$\phi(x) = \omega^{\mathrm{T}} x + \phi_0 \tag{1}$$

where x is the vector of the system chosen features, ω the coefficient vector, and ϕ_0 is an arbitrary constant.

Now, the system is considered secure if $\phi(x)$ greater or equal zero. On the other hand if the function value is negative, then the system is insecure.

Power generations, in the power system, can be considered as features in deriving the classifier due to the great effect of it on the dynamic security [11]. In addition, this choice has the additional advantage of reducing the number of optimization variables, since the cost function is also formulated in terms of such powers.

3. Problem formulation

In this section the optimization problem is formulated as minimization of summation of the fuel costs of the individual generators, as in the economic dispatch. The objective function is then minimized subject to limits on generators outputs, as well as to the linear dynamic security constraints, set by pattern recognition technique [11]. A dynamic security constraint is derived for each contingency to be considered in the system.

It should be noted that the economic problem formulated here refers to a vertically-integrated system, where a central dispatcher is directly asked to define the hourly production of each generating unit, minimizing the overall fuel costs and satisfying a set of dynamic security constraints.

In mathematical form the problem can be stated as minimization of:

$$F = \sum_{i=1}^{N} F_i = \sum_{i=1}^{N} (d_i + b_i P_{\mathrm{g}i} + c_i P_{\mathrm{g}i}^2) + |e_i \times \sin(f_i \times (P_{\mathrm{g}i_{(\min)}} - P_{\mathrm{g}i}))| \tag{2}$$

Subject to:

$$\sum_{i=1}^{N} P_{\mathrm{g}i} = P_{\mathrm{D}} + P_{\mathrm{L}} \tag{3}$$

$$P_{\mathrm{g}i_{(\min)}} < P_{\mathrm{g}i} < P_{\mathrm{g}i_{(\max)}}, \quad i \in N_{\mathrm{s}} \tag{4}$$

$$\phi_j(P_{\mathrm{g}}) > 0, \quad j = 1, 2, \ldots N_{\mathrm{f}} \tag{5}$$

where F is the system overall cost function; N the number of generators in the system; d_i, b_i, c_i the constants of fuel function of generator number i; e_i, f_i the constants of the value point effect of generator number i; $P_{\mathrm{g}i}$ the active power generation of generator number i; P_{D} the total power system demand; $P_{\mathrm{g}i_{(\min)}}$ the minimum limit on active power generation of generator i; $P_{\mathrm{g}i_{(\max)}}$ the maximum limit on active power generation of generator i; N_{s} the set of generators in the system; P_{g} an array of active power generation in the system; ϕ_j the classifier function related