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Dynamic security consideration in multiobjective electricity markets

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ABSTRACT

After electricity energy market clearing, the network may be operated with a low transient stability margin because of hitting security limits or increasing the contribution of risky participants. Therefore, a new multi-objective model for electricity energy market clearing, considering dynamic security aspect of the power system, is proposed. Indeed, in addition to the economical aspects of electricity markets, i.e. offer cost of generating units, linearized Corrected Transient Energy Margin (CTEM) of system is also considered as new objective function of market clearing problem. A Multi-Objective Genetic Algorithm (MOGA) is utilized to solve the multi-objective market clearing problem. The New England test system is used to demonstrate the performance of the proposed method.

1. Introduction

Electricity market emergence has basically reformed the situation for maintaining reliable and secure power supplies. Growing inter-regional trade has placed new demands on transmission systems, creating a more integrated and dynamic network environment with new real-time challenges for reliable and secure transmission system operation. These operational challenges are increased as additional transmission capacity is absorbed [1]. Due to increasingly more vital role of electric energy in all over the world, its security remains to be the most important feature of power systems operation which cannot be compromised in a market-driven approach [2]. Accordingly, management of system security needs to keep improving to maintain reliable electricity services in this more dynamic operating environment. The challenges raise fundamental issues for policymakers. An effective policy response should also consider how best to employ market-based approaches to match regulatory arrangements to strengthen system security at least cost.

Power system security assessment refers to analysis and methods used to security evaluation of a system, based on pre-established criteria. Depending on modeling and used techniques, security assessment can be classified as static or dynamic. Static security is related to a stability point of the system, where voltage of buses and thermal limits of transmission lines are in an acceptable range while considering $N-1$ contingency states. Regularly, static security is assessed using load flow algorithms. Dynamic security is a more complicated issue and it consists of different types of stability, including transient, voltage and small-signal [3]. This paper implements a methodology for power systems dynamic security assessment in market environment focusing on transient stability. Traditionally, transient stability assessment has been performed using full time-domain simulations from the pre-contingent state to the post-contingent state [4]. Regarding static security considerations in electricity market clearing tools, different indices (including voltage security margin, voltage drop and overloading index) have been incorporated in the market clearing framework to account for static security using multiobjective optimization in [5]. In [6,7], security-constrained models including the line flow constraints with pre-specified nodal or area reserves, concerning static security, are considered. Also, Arroyo and Galiana [8] proposed a formulation for market clearing process in the form of an optimization problem that accounts for transmission flow limits (using DC load flow) and two types of reserves offered by both generators and loads. In [9], a multi-objective approach based on interior point method is used in an optimal power flow to optimize social welfare and the voltage security margin, simultaneously. It is noted that, considering static security cannot guarantee system security. Indeed, the power system may lose its stability in the transition period. On the other hand, many advances on dynamic security assessment have been observed on the last years, especially on methods associated to real-time [10,11]. There are two classifications for dynamic security assessment: time domain simulation [12,13] and direct methods [14]. Time domain simulation method is implemented by solving the state space differential equations and then it determines transient stability. Results of time-domain simulation are the most accurate and reliable ones with respect to other methods with the cost of higher computational burden and low speed. Also, time domain simulations method does not reveal any

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Nomenclature

i, j	indices of bus
NB	number of system buses
NU	number of system units
r	index for Pareto optimal solution
n	index of objective functions
Z_i	a binary variable indicating that the unit of ith bus accepted or not in the energy market
P_{Gi}	energy output of the unit at ith bus
ρ_i^e	bid price of the unit at ith bus for energy
NC	number of credible contingencies
SF_j	the sensitivity of CTEM with respect to the generation of unit j (P_{Gj})
$CTEM_0$	the system CTEM at the base case
$CTEM_j$	the system CTEM after a little change ΔP_{Gj} applied in the generation of the unit j with respect to the base case
$\lvert V_i\rvert$	voltage magnitude of the ith bus
$\lvert V_{\max,i}\rvert$ and $\lvert V_{\min,i}\rvert$	upper and lower limits of voltage magnitude of ith bus, respectively
Q_{Gi}	reactive power output of the unit at ith bus
$P_{G\max,i}$ and $P_{G\min,i}$	upper and lower limits of active power of the unit at ith bus, respectively
$Q_{G\max,i}$ and $Q_{G\min,i}$	upper and lower limits of reactive power of the unit at ith bus, respectively
P_{Di} and Q_{Di}	active and reactive loads of ith bus, respectively
δ_{ij}	difference between voltage angles of buses i and j
$\lvert Y_{ij}\rvert$	magnitude of element located in ith row and jth column of the admittance matrix of the power system
θ_{ij}	angle of element located in ith row and jth column of the admittance matrix of the power system
$\lvert S_{ij}\rvert$	magnitude of apparent power flow of branch between ith and jth buses
$\lvert\bar{S}_{ij}\rvert$	apparent power flow capacity of branch between ith and jth buses

information about the degree of stability of the system [15]. In contrary, direct methods, such as the transient energy function (TEF) method, profit by high computational speed and ability of providing a security margin or index to evaluate the degree of stability. However, the method sometimes fails to yield a practical result because of non-convergence problems encountered in attempting to compute the relevant "unstable equilibrium point," especially in the case of stressed systems [15]. To cope with this shortcoming, the hybrid approach which combines time-domain simulation and transient energy analysis has been proposed in [16]. However, as shown in [15] sometimes the hybrid approach may lead to unreliable results. Accordingly, the corrected hybrid method merging time-domain simulation and corrected transient energy function (CTEF) has been proposed in [15–17] to present a dynamic stability index called Corrected Transient Energy Margin (CTEM). An important feature of the CTEM is its linear relationship in the wide range of control variables such as generator power exchanges [15–17].

Multi-objective mathematical programming (MMP) models in the deterministic framework [18] and stochastic framework [19] have been proposed for energy market clearing in our previous works. In these works, the objective functions of the MMP model consist of generation offer cost and static security indices including overload index, voltage drop index, and voltage security margin. Moreover, the epsilon-constraint method is used to solve the MMP problem in all of these works [18,19]. The new contribution of this paper with respect to our previous works and the other ones (especially [14]) is proposing multiobjective energy market clearing considering dynamic security aspect of power system. For this purpose, a linearized form of Corrected Transient Energy Margin (CTEM) of system is implemented as dynamic security index. Furthermore, multiobjective market clearing is solved using MOGA.

The remainder of this paper is organized as follows: in Section 2, the proposed MMP model for the market clearing problem, considering dynamic security aspects, is formulated in the form of a Mixed Integer Non-Linear Programming (MINLP) problem. Section 3 introduces MOGA approach for the MMP problem. In the next section, obtained results for the New England test system are presented and discussed to demonstrate the effectiveness of the proposed scheme. Some relevant conclusions are drawn in Section 5.

2. Market clearing formulation

To better illustrate the underlying ideas of the proposed MMP solution method, deterministic formulation is adopted in this paper. Also, we consider single-period scheduling without inter-temporal constraints (including ramp rate limits and minimum up/down time constraints), as this model is simpler to describe and analyze. However, the proposed model can be easily extended to the stochastic formulation with inter-temporal constraints based on the procedures presented in our previous work [19]. Considering these assumptions, the objective functions and constraints of the proposed MMP model are presented in the following subsections, respectively.

2.1. Objective functions

2.1.1. Minimize f_1: offer cost of energy

In the energy market clearing, the objective function is to minimize energy offer cost

$$f_1 = \sum_{i=1}^{NB} \rho_i^e \cdot P_{Gi} \tag{1}$$

2.1.2. Maximize f_2: corrected transient energy margin

Due to the responsibility of ISOs in secure operation of power systems, it is an essential mission for ISOs to prevent the generation of critical generators to keep the transient stability of the power system after market clearing. Indeed, if the effect of generating units' patterns on transient stability issues of power system is considered, the output results of market clearing would be more secure from transient stability viewpoint. Particularly, for the most probable contingencies and faults, the power system should be able to encounter with the faults without losing synchronism. In order to consider transient stability issues of power system, in the proposed energy market clearing framework, Corrected Transient Energy Function (CTEF) as a well-known and widely used transient stability index is utilized. Mathematical details and formulation of CTEM for the dynamic security enhancement in power-market systems can be found in [20].

In theory, it is proved that CTEF is of conservation during post-fault transient period and there is no erratic nonlinearity exhibited on the variation of CTEM both for plant and inter-area mode disturbances [16]. Consequently, CTEM establishes a linear and proper criterion to evaluate transient stability. To derive the sensitivity of the CTEM with respect to each generation in the proposed multi-objective framework, the first order approximation (linear approximation) of the Taylor series around the operating point of the power system is used. In this paper, only the effect of generators on the CTEM is modeled. Since the CTEM retains linearity in a wide range with respect to several operating parameters such as fault clearing time, pool generation rescheduling, and curtailment of a bilateral transaction [20], the