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Preventive analysis and solution of overloads in the Spanish electricity market

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Abstract

The technical feasibility of a power generation dispatch in competitive electricity markets consists of not having any overloaded equipment, not only in case of normal operating condition, but also when any contingency established in the security criteria occurs. In addition, bus voltages should be within their limits. This paper describes an optimization method to analyze and solve the transmission overloads that arise in each hourly scenario of the Spanish power system, after the electricity market has been cleared. Overloads are solved in the Spanish market by increasing and decreasing generation of connected units, and by connecting off-line ones. The proposed method comprises three steps: (a) contingency analysis, (b) preventive active dispatch and (c) classification of generation re-dispatch. The performance of the method is illustrated using an actual example of the Spanish electricity market.

Keywords: Power system dispatch; Security assessment; Congestion management; Optimal power flow; Unit commitment

1. Introduction

Competitive electricity markets can be organized and operated in different ways. The Spanish electricity market [1] as it started on 1 January 1998, is based on two separate entities: the market operator (MO) and the system operator (SO). The MO receives the bidding of generation and demand for each hour of the following day and clears the market according to economic criteria. The SO is responsible for the secure operation of the power system and owns the transmission system. One of the main tasks of the SO consists of solving the power system constraints that arise after the market has been cleared. Power system constraints are addressed by increasing and decreasing the generation of connected units, and by connecting off-line ones.

Power system constraints are solved in Spain minimizing the system cost variation of the initial market clearing, fulfilling the power system security criteria. The units that increase their output are paid at their bid prize. Generators that decrease their output are not compensated for their income reduction. Therefore, the total system cost is computed by adding the bid cost of new connected generation, and subtracting the decreased energy times the system marginal price.

The SO computes the unit re-dispatch taking into account the bids submitted by the generating agents into the market. A generation bid consists of a set of power-prize blocks for each hour of the following day. A minimum income complex condition is also submitted in the bid. This condition consists on a fixed income term and a variable income term. The fixed term internalizes the start up cost of the thermal generating units.

As has been established in the market rules, both the SO and the MO participate in the solution procedure. The generation re-dispatch determined by the SO to solve power system constraints is sent to the MO. It should be noted that the SO must submit to the MO only the variation of generation needed to eliminate power system constraints. The MO includes the re-dispatch provided by the SO in the initial market clearing, and restores the generation-demand balance

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by adjusting the least expensive units according to the bids submitted by the agents.

The security criteria of the Spanish power system require that power system variables (system frequency, branch power flows and bus voltages) are within their limits not only in normal operating conditions but also when any credible contingency occurs [2]. The contingencies under consideration are the loss of any single transmission line, generator or transformer, the loss of the double circuits that share more than 30 km and the combined loss of certain generators and transmission lines. Spanish regulation imposes a preventive operation of the power system for these postulated contingencies. Of course, branch and bus limits in case of $n-1$ and $n-2$ contingencies are different than the limits under normal operating condition. Branch power flow limits also depend on the season of the year.

The system frequency is controlled according to the UCTE rules. Constraints due to voltage limit violations have been addressed in [3,4]. This paper focuses on constraints due to branch power flow violations. Overloads are solved in the Spanish market by increasing and decreasing generation of connected units, and by connecting off-line ones.

This paper describes an optimization method to analyze and solve the transmission overloads that arise in the Spanish power system after the electricity market has been cleared. The method proposed comprises three steps: (a) contingency analysis, (b) preventive active power dispatch and (c) classification of generation re-dispatch.

The contingency analysis routine firstly identifies the contingencies that result in non-admissible branch power flows. A dc contingency analysis routine is used as a screening tool to detect which contingencies may cause overloaded branches. Within the dc contingency analysis the branch reactive power flows are approximately taken into account reducing the branch MW ratings [5]. The troublesome contingencies identified by the screening tool are fully analyzed using an ac contingency analysis program. It provides the post fault branch power factor as needed by the preventive active power dispatch.

The preventive active power dispatch modifies the generation dispatch to alleviate the detected overloads with a preventive criteria. It has been formulated as an optimization program that determines the minimum cost variation of the generation dispatch that removes the constraints. The main advantages of the active power dispatch over other algorithms developed in the literature [6,7] for removing branch overloads are: (a) the possibility of connecting off-line units to remove overloads, (b) the solution of not only single but also multiple contingencies with a preventive criteria and (c) the consideration of approximate branch reactive power flows in a dc power system model.

Spanish regulation establishes that the SO must send to the MO only the generator re-dispatch that remove the overloads. Thus, practical application of the preventive active dispatch requires the separation of the generation re-dispatch that resulted in the optimization problem in: (a) effective generation re-dispatch and (b) compensation generation re-dispatch. Effective generation re-dispatch are generation movements that remove the overloads. Compensation generation re-dispatch are generation movements that equal generation to demand. Hence, compensation generation re-dispatch simulate the generation adjustments that the MO performs to restore the generation-demand balance. A novel approach has been designed to carry out the generation dispatch separation.

The next sections of the paper describe the three steps in detail.

The method described in this paper is part of a tool designed to analyze and solve power system constraints in the Spanish electricity market. This tool is used daily by Red Electrica de España (the Spanish SO) to remove the power system constraints.

The paper is organized as follows. Section 2 reviews the contingency analysis routine that detects the postulated contingencies that result in overloaded branches. Section 3 details the preventive active power dispatch. The procedure to classify the optimization problem results is explained in Section 4. Section 5 shows the performance of the method using an illustrative example of the Spanish electricity market. Section 6 contains implementation details. Finally, conclusions are presented in Section 7.

2. Contingency analysis

The contingency analysis is performed in two steps. Firstly, a dc contingency analysis routine is used as a screening tool to identify which contingencies may cause overloaded branches. The screening tool uses a dc load flow model of the power system with losses approximation and with phase shifters [8]. Phase shifters play an essential role in solving overloads in the French–Spanish interconnection ties. The solution of a branch contingency is speeded up using partial matrix re-factorization. Generator contingencies are modeled according to the criteria that the generation lost is provided by the UCTE system through the French–Spanish interconnection ties. Therefore, the equivalent generators that represent the UCTE system provide the generation lost. The dc load flow determines for each contingency the branch active power flows. The branch reactive power flows are approximately taken into account reducing the branch MW rating according to

$$F^{c}_{\ell\,\max}\,(\mathrm{MW}) = F^{\max}_{\ell}\,(\mathrm{MVA})\cos(\varphi_{\ell 0}) \tag{1}$$

where $F^{c}_{\ell\,\max}$ (MW) is the branch MW rating in the contingency c, $F^{\max}_{\ell}$ (MVA) is the branch MVA rating and $\cos(\varphi_{\ell 0})$ is the pre-fault power factor of the branch power flow.

Secondly, the contingencies selected by the dc contingency analysis are fully analyzed by an ac contingency analysis module to confirm the overloads. The ac contingency analysis is carried out using a fast decoupled load flow algorithm. In addition, the ac contingency analysis rou-