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A unified management of congestions due to voltage instability and thermal overload

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Abstract

This paper proposes two approaches for a unified management of congestions due to voltage instability and thermal overload in a deregulated environment. Both techniques aim to remove, in some optimal manner, voltage and thermal congestions stemming from base case or post-contingency states, by a simultaneous handling of operating and security constraints with respect to several contingencies. The objective of the first approach is to adjust the market-based power injections (generator output and possibly load consumption) at the least cost while the second one aims at curtailing power transactions in a transparent and non-discriminatory way. These techniques rely on sensitivities which pinpoint the best remedial actions against congestions owing to voltage instability and thermal overload. Numerical results with both approaches are provided on a realistic 80-bus system model.

Keywords: Voltage stability; Thermal overload; Dynamic security analysis; Congestion management; Generation rescheduling; Load curtailment

1. Introduction

Nowadays the process of electricity market deregulation has prevailed in many countries. Depending on the particular characteristics of every power system, various forms of electricity services unbundling have been implemented. However, despite specific achievement differences, two conceptual models emerged: the pool model and the bilateral contract model [1–3].

In a deregulated environment a system is said to be "congested" when some specified operating constraints (e.g., branch current, bus voltage magnitude, etc.) or security constraints (e.g., thermal, voltage stability, angle stability, etc.) are violated in the current or in a foreseen operating state. Operating constraints refer to the normal system configuration (in "N") while security constraints refer to "$N-1$" and some plausible "$N-k$" system configurations. Congestion management consists in controlling the system such that all operational and security constraints are satisfied. Whatever the implemented deregulation model, the Transmission System Operator (TSO) is responsible for relieving or removing congestions in foreseen operating states (established after the day-ahead market clearing) as well as in real-time. Clearly, power systems were confronted to congestions in the vertically integrated environment as well. In this environment congestion management was most often performed by modifying the economic dispatch at the least cost until no operating or security constraint was violated.

Thermal overload and *voltage instability*, the main concern in this paper, are two significant causes of congestions in many power systems.

The available means to remove congestions linked to voltage instability – actions on voltages through transformer ratios, generator voltages and reactive power injections – are somewhat limited either by the range of variation allowed for these variables or by their impact on the pre-contingency system configuration. For instance, in order to restore voltage security, it is unlikely that large amounts of shunt compensation can be switched (if available) in the pre-contingency configuration, owing to the risk of overvoltages. The same holds true for generator terminal voltages. Additionally, the above-mentioned control

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variables are usually set in the day-ahead market, by running an Optimal Power Flow (OPF) to minimize the transmission losses. On the other hand, active power generation rescheduling and load curtailment can have a significant impact on both voltage stability and thermal overloads. However, these actions have a cost and hence must be taken in a transparent and widely agreed manner. In the sequel we will concentrate on congestions that cannot be removed by "cost-free" means such as: capacitors, transformer taps, phase shifters, FACTS devices, topological changes, etc.

The methods to tackle congestions can be divided into two main categories [4–6]: *economical* (e.g., market splitting, auctioning) and *technical* (e.g., generation redispatch, transaction curtailment). The approaches considered in this work fall in the second category.

This paper proposes two congestion management approaches that differ by the control means. A first approach, referred to as *Injection Control* (IC), relies on power injections, i.e., generator productions and load consumptions. A second approach, referred to as *Transaction Control* (TC), relies on power transactions. These approaches are suited to deal with congestions appearing in day-ahead market clearing as well as in real-time.

The IC approach can be implemented in any deregulated model. It consists in modifying the market-based generation scheme at the least cost, according to the generator bids [1,3,5,7–12]. In order to ensure higher competition this method can be easily extended to load curtailment [9,10,13,14].

As an alternative, the TC approach is applied in deregulated systems operated under the bilateral contract model. It consists in curtailing non-firm transactions in some optimal manner in order to relieve congestions [2,15–18].

The management of *thermal overload congestions* has been widely analyzed [1,2,5,7,11,12,14,16,18]. It is most often based on the very fast dc load flow model. Although valid in many practical cases, the latter approximation may be less satisfactory when voltage and thermal aspects are strongly coupled as well as under high load conditions.

The management of *voltage instability congestions* has been comparatively less investigated so far [8–10,13,19]. Most of these approaches aim at keeping security margins with respect to plausible contingencies above some threshold. Multiple contingencies are treated through heuristics [8,13] or through constrained optimization [9,10,19].

Up to now both problems have been considered separately because voltage stability analysis requires more accurate tools than a mere dc load flow. This work proposes an integrated handling of both problems.

The benchmark when dealing with voltage instability and thermal overload congestions is a classical security constrained OPF [20] including voltage stability constraints [19,21,22]. This approach has, however, two drawbacks: (very) high dimensionality, especially when many contingencies have to be incorporated, and static modelling of voltage instability phenomena by algebraic load flow equations. Therefore, it may not have the accuracy and robustness of time-domain methods, while being heavy for real-time applications.

We propose instead simplified optimization approaches coupled with the fast time-domain Quasi-Steady-State (QSS) simulation [23,24] used to evaluate the system response to contingencies. The QSS simulation allows a more accurate modelling of the voltage instability phenomena and yields, at very low computational cost, sensitivities indicating the best remedial actions to remove congestions due to voltage instability [25] and thermal overload [26].

As regards the security criteria used for congestion management, it has been argued that the deterministic "$N-1$" security criterion is too conservative (e.g., [27–30]). In the deregulated context, the "$N-1$" criterion is felt by some authors as an obstacle to competition. First, it is deemed to yield unnecessarily high operating costs. Second, it does not take into account the likelihood of the various contingencies, but rather treats them all as equiprobable. On the other hand, during severe weather conditions likely to affect transmission lines or in view of the non-negligible probability of having protection failures, the "$N-1$" (or even the "$N-2$") criterion may not provide enough security, as demonstrated by some blackouts worldwide (e.g., North America 2003, Italy 2003, etc.). The latter events raised reticences against the "take-risk" congestion management strategies. The future is most probably in a careful tradeoff between preventive congestion management and corrective (emergency) control [27–30]. The objective will be to minimize the overall cost of both preventive and corrective actions. However, while the cost of preventive actions is rather easy to calculate, getting a reliable estimate of the corrective costs is a challenging problem for voltage unstable scenarios as well as for severe post-contingency thermal overloads.

In our congestion management framework, we take into account the traditional requirement that none of the specified contingencies causes voltage instability nor thermal overload, and no branch is overloaded in the base case situation. Any contingency causing voltage instability or thermal overload is labelled harmful. Otherwise it is said harmless.

The paper is organized as follows. Section 2 presents the derivation of voltage and thermal security constraints. The IC and TC approaches are successively presented in Sections 3 and 4, respectively. Section 5 offers some numerical results with the proposed methods while some conclusions are drawn in Section 6.

2. Linearized security constraints

If the power system is deemed voltage and/or thermal insecure, the TSO should modify the pre-contingency operating point in a such a way that voltage and/or thermal security are restored. To this end the TSO needs to know *where* and of *how much* to act in order to optimally remove congestions taking care that these actions do not create other security violations. To tackle this problem one needs to derive security constraints. The latter take on the form of linear inequality constraints and are obtained as explained hereafter. We first derive these constraints for power injections (generator active power and load consumption) as control variables and then extend them to transactions as well.