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Controlling power systems with price signals

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Abstract

This paper revisits the possibility of controlling the power system entirely by means of price signals. It expands on notions introduced in an earlier paper and addresses several unresolved issues: problems with linear cost structures, response delays, varying costs, market power and stability problems caused by market/system interactions. The results suggest that control by price can, in fact, be made to work with some caveats.

Keywords: Congestion management; Real time pricing; RTP; Stability; Optimal power flow; OPF

1. Introduction

Fred Schweppe and his co-workers [4,12–14] published a series of seminal papers on homeostatic control of a power system. These papers laid the foundation for the notion of using prices to control a power system. An important extension of the work of Schweppe was provided by William Hogan, who in 1992 introduced the concept of contract networks as a practical extension to these earlier notions because it permitted the establishment of property rights within networks and allowed (approximately) efficient prices to be determined from a dispatch that was influenced by the judgment of human operators [8]. More recently, Glavitsch and Alvarado [6] illustrated how (at least in principle) an operator could use prices to control congestion in the power system even under conditions where no information was explicitly shared by the generators with the system operator. The work by Glavitsch and Alvarado not only used prices (and prices alone) to resolve the problem of managing congestion, but further established in a theoretical setting that the system operator (who in this work was also in charge of "clearing" a real time market) could "post" prices for every node location that attained the desired objective of attaining optimal system dispatch without the need for any bids. Even after a serious disturbance, an operator could, in theory, post prices that would result in a new system equilibrium that would not only be optimal but also resolve the congestion. This was possible under the assumption that every generator would choose to operate anytime the price offered was above its marginal cost of

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production. Furthermore (and significantly) this work illustrated how the operator could infer and anticipate the behavior that any particular price pattern would elicit from generators prior to issuing and posting prices. This was, of course, subject to several clearly stated assumptions about the costs (there were assumed to be quadratic) and the behavior of the generators (costs were fixed over time and no market power was ever exercised). More recently, Alvarado described in detail how to resolve many of the problems associated with "control by price" [2]. This chapter extends this work.

The chapter begins with a review of the main concepts from [6] and describes issues left unresolved by this earlier work and only partially covered in Ref. [2]:

- The requirement that cost functions be quadratic. Linear functions, although seemingly simpler, complicate the control problem because their all-on all-off characteristics. Linear costs would render control by prices jumpy at best, seemingly erratic under more extreme conditions, and completely unfeasible in some cases.
- Response dynamics and delays. Even if we assume that posting a price elicits a response, attaining the new equilibrium takes time and the delays in achieving the transition can create serious operational difficulties which may include the excitation of unstable electromechanical system modes [1,3] as a result of the interaction between prices and system response characteristics. Anecdotal evidence has referred to this type of problem as "price chasing behavior" that has apparently been observed in several systems.
- Non-stationary costs. This refers to the possibility that generator costs may change with time faster than the operator can track them. The assumption that an operator can infer marginal costs from observed behavior relies on the assumption that costs do not change over time. However, in energy-constrained situations (such as hydro systems) or in cases where fuel costs are volatile, such assumption may be invalid. Of particular interest is an understanding of how bidding behavior is affected by fixed costs, ramping constraints and the existence of multiple interacting markets for a given product (the output of a generator). For additional references on expected bidding behavior, refer to [10,11].
- The possibility that generators may attempt to exercise market power and fail to respond even when the price should ordinarily induce a desired behavior [7].

One additional topic addressed in this chapter is the possibility of using price signals for controlling all aspects of system operation, including such items as reactive power injection, reserve provision and other necessary system quantities. For example, real time prices may be posted for reactive power injection (and consumption), prices may also be posted in real type related to reserve requirements (although these would be a bit harder to monitor and measure than energy prices), and a price component associated with frequency (the original component in homeostatic control) may also be posted. These prices would not only vary over the course of a day depending on system conditions, but would vary by location based on system losses and congestion conditions.

2. Locational marginal pricing overview

A locational marginal price (LMP) at a given point in time and at a given system location is nothing more than the cheapest way by which one can deliver one MW of electricity to a particular node while from the available generators while respecting all the constraints and system limits in effect. The locational marginal prices themselves can be calculated in a variety of ways:

1. The system can be operated optimally "before" the 1 MW increase and "after" the 1 MW increase of demand at any given location. The additional cost of operating the system optimally after delivering the additional MW to the location in question is the LMP of that location at that time. This particular method of determining LMPs is, of course, highly impractical, but it is of great value to understand the meaning of LMPs and why they are the correct "price signal" by which the system should be operated.
2. The LMPs can also be obtained from a knowledge of "sensitivity factors" (sensitivity of constraining