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Performance indices to measure and compare system utilization and congestion severity of different dispatch scenarios

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Abstract

In competitive electricity markets, energy Locational Marginal Prices (LMPs) are commonly used to allocate energy payments and transmission congestion charges and credits. In these markets, energy prices and transmission pricing are highly affected by transmission constraints, where a congested transmission is accompanied by congestion costs, lower system utilization, and higher energy prices due to resorting to out-of-merit order as expensive generating units are dispatched to alleviate congestion. The paper presents some performance indices to compare different dispatch options, where it proposes to use some congestion and system utilization measures. These measures are used in the paper to indicate level of system usage and congestion severity under different dispatch scenarios, and may enable the system operator or the qualified dispatch decision-making entity to decide which dispatch, among different dispatch scenarios, is the optimal. To show an example of using presented measures, planned line switching has been used to minimize transmission congestion cost and increase system utilization. The model used for energy market in the paper involves both spot (pool) transactions and firm bilateral contracts. The presented method is applied to a three-bus and an eight-bus test systems, where the results show that considering opening of some transmission lines may improve outcome of social-welfare problem, as reflected in reducing total congestion cost and improving system utilization.

Keywords: Energy markets; Locational Marginal Prices; Restructuring; Social welfare; Transmission congestion

1. Introduction

Transmission network the most important component in competitive electricity markets and serves as the key mechanism for generators to compete in the supply to reach energy consumers. Launching restructuring [1] in power industry worldwide has imposed new technical and economic dimensions on the power system and energy market operations, which in turn have made transmission business undergo an increased level of attention and significance. The factors that imposed these dimensions encompass the increased level of risk and uncertainty associated with transmission operations and investments, demand of power system operations for more power flow control needs, need to provide grown bulk power transfer capability, need to withstand a wider range of possible generation patterns, and realizing that transmission system is the sender of transparent price signals to market participants and investors to make demand decisions or to make right decisions for the resource allocation or system expansion and reinforcement [1,4].

Significance of transmission system and alleviating its constraints in competitive electricity markets have been also intensively highlighted and investigated as a consequence of the economic value originated from constrained transmission, where energy prices and transmission pricing are highly affected by transmission constraints that are accompanied by higher costs due to resorting to out-of-merit order operation to mitigate congestion [2–13].

Traditionally, a system operator or a qualified entity carries out optimal dispatch of generators and loads participating in the energy market, where a social-welfare function is maximized. The objective function is built from dispatch-cost curves of resources (generation and consumption) participating in the bidding process. If the dc load flow model is used

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[14], the dispatch problem respects lower and upper limits of resources participating in the bidding process and flow limits of transmission lines. Based on the solution of this problem, the optimal dispatch of each resource, and energy LMPs are determined. If constrained transmission occurs in this process, LMP values vary from bus to bus, and consequently, congestion costs are imposed on market participants [l–4,7–9]. If loads are participating in the bidding process, i.e., if loads are elastic, total optimal load served and total optimal generation would be different from those obtained from unconstrained dispatch. The unconstrained dispatch is the dispatch that assumes transmission lines have ample capacity to serve both connected generators and loads, where no congestion takes place and all LMP values are the same. The dispatch that gives optimal values as those of the unconstrained dispatch is the best dispatch that system operator wishes to face as it reflects the best system utilization. Unfortunately, this congestion-free situation is not always obtained, and an optimal dispatch is always accompanied by congestion costs, different energy prices and less system utilization.

The ON and OFF statuses of a line can be seen as control variables that can be utilized in the optimal dispatch decision process. As will be seen in the presented test cases, opening certain lines may give better results compared to the outcome of traditional optimal dispatch process that assumes all lines are in the ON status. Therefore, this paper proposes to consider line status in the dispatch process to minimize transmission congestion cost and maximize system usage.

Even though opening of certain lines may improve the congestion problems, it may unfortunately affect other unconsidered issues, such as system stability. Any line opening that is accompanied by a low congestion cost, congestion-free dispatch, or leads to a maximization of system usage, to be a feasible and a meaningful dispatch alternative, should not endanger system stability or security, and therefore, should pass the stability and security measures adopted by the system operators who is maintaining the integrity of the power system. Therefore, the system operator has to examine the candidate line openings for such problems. For example, system operators may resort to a full ac load flow modeling and add constraints of steady-state stability limits [15–17] to the proposed formulation and other constraints that guarantee system security.

The formulation proposed in the paper uses the dc load flow modeling of the power system [14] and adopts the model for energy market that involves both spot transactions and firm bilateral contracts [1]. The results of the two test systems in the paper will show that considering line opening may improve social-welfare outcome as reflected by improving system utilization and reducing total congestion cost.

2. The LMP-based approach for congestion pricing

The LMPs have been traditionally used in recently restructured power systems to evaluate energy payments of generators and loads and to allocate transmission congestion charges and credits among system users [1,7–9]. When the transmission system becomes congested, no additional power can be transferred from a specified point of injection to a specified point of withdrawal, therefore, more expensive generating units may have to be dispatched on some locations of the transmission system and cheaper generating units are dispatched back on other locations which, in a competitive market, would cause differences in LMPs at the different locations, i.e., differences in LMPs appear when one or some of the lines are constrained [1,4]. If it happens that any line is constrained, LMPs will be varying from bus to bus causing possible congestion charges, and consequently, energy price per MWh vary from location to location in the power system. On the other hand, if line flows are within limits (no congestion), LMPs will be the same for all buses, and in this case, no congestion charges apply and energy price is the same at all locations of the power system. In general, the difference in LMPs between the two ends of a line is an economic price of transmission congestion and transmission loss in this line [1,2,11]. As LMP acts as a price indicator of both transmission loss and congestion, it is used in many energy markets as an elementary part of transmission and energy pricing. Using LMP, buyers and sellers experience the actual price to deliver energy to their locations on transmission system.

An LMP is the marginal cost of supplying the next increment of electric energy at a specific location (bus) considering generation marginal cost and the physical aspects of the transmission system [7]. LMP at any bus in the system is the dual variable (shadow price) for the power balance equality constraint at that bus. Mathematically, shadow prices are the Lagrangian multipliers of the bus power balance equations. Equivalently, the LMP at a certain bus is interpreted as the amount by which the objective would improve given a unit increase in the right-hand side of the bus equality constraint, or, LMP is the additional cost in the objective function for providing one additional MW at a certain bus [1].

If line flow constraints are not included in the optimization problem or line flow limits are assumed very large, shadow prices (LMPs) will be the same for all buses as the marginal cost of the most expensive generation unit which is dispatched last (marginal unit). In this case, no congestion charges apply.

If λ_i refers to the LMP at bus i, then λ_i, in general, is the sum of three components; the LMP component of marginal cost of generation at the reference bus, the LMP component due to marginal cost of losses, and the LMP component due to congestion cost.

3. Mathematical formulation of the energy market

This paper assumes that the model for energy market involves both spot (pool) transactions and firm (noncurtailable) bilateral contracts. In the bilateral contracts, the transacted parties are free to negotiate their quantities, duration, prices and other terms, and the transacted parties pass