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A comprehensive fair nodal pricing scheme, considering participants' efficiencies and their rational shares of total cost of transmission losses

Mohammadreza Baghayipour, Asghar Akbari Foroud *, Alireza Soofiabadi

Electrical & Computer Engineering Faculty, Semnan University, Iran

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A B S T R A C T

The pricing framework in any economic environment indeed has a special situation, since it directs the incentives of all different participants. Locational Marginal Pricing as one of the power market clearing mechanisms has several drawbacks, which causes it to be sometimes irrational and discriminatory. This paper presents a new nodal pricing mechanism to resolve the previous drawbacks and to establish a fair and comprehensive pricing framework, such that it can respect participants' efficiencies and their extents of transmission use, as well as their rational shares of total cost of transmission losses. The new mechanism not only perfectly recovers all costs of generations, load curtailments, transmission investments, and transmission losses, but also it produces positive economic signals for all participants that encourage them for better performance. The rational profit shares for all participants are calculated in accordance with their own efficiency and profitability measures. The corresponding measure for Transco is defined according to a new definition of the Reference Transmission Network. Validity of the proposed mechanism is verified via numerical analysis and its comparison with previous pricing methods. This pricing mechanism indeed has capability to be used as a comprehensive fair nodal pricing framework.

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1. Introduction

In a deregulated power system, the way to clear the power market and assess the prices, revenues, and payments for different system participants (i.e. producers, consumers, and a monopolistic Transco) is indeed of a special importance. Without doubt, it is essential for a pricing scheme to be fair and comprehensive. This means that it should be able to reconcile participants' different incentives as much as possible, and can regard different aspects and phenomena that are associated with the pricing process or affecting it, as well. In this manner, the pricing mechanism certainly encourages all participants for better performances and thereby enhances the system social welfare. The different aspects that should be regarded in an efficient and perfect pricing scheme include:

1. The participants' extents of profitability to the society.
2. Their operational and investment costs.
3. Their extents of transmission use.
4. Their contributions in transmission losses.
5. Their environmental impacts.
6. Their reliability related indices.
7. Their roles in presenting the ancillary services (like reactive power, active and reactive reserve, ...).
8. etc.

Here, the previous papers so far have presented different pricing approaches, each concerning some of the above criteria and comprising some positive and negative features. The previous works are mostly founded on two market-clearing frameworks: 1 – system uniform pricing and 2 – system nodal pricing. In the uniform pricing framework, at first, the entire system is treated as a single node and the generation levels as well as a uniform price for the whole system are determined. Then, the complete (nonlinear) AC Optimal Power Flow (ACOPF) problem is solved in the actual system and the real generation levels are obtained regarding all the different generation and transmission constraints as well as the active and reactive transmission losses. It is obvious that the total operational cost (summation of generation and load curtailment costs) obtained from ACOPF solution is somewhat greater than the first Market Clearing Price (MCP), as ACOPF problem respects all generation and transmission constraints as well as transmission losses. Therefore, the resulted cost increment in ACOPF is induced by the both constraints and losses, and thus it is composed of two costs: cost of constraints or congestion cost, and cost of

* Corresponding author. Tel.: +98 9124618433.
E-mail address: aakbari@semnan.ac.ir (A. Akbari Foroud).

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transmission losses [1]. In most of the previous papers, the uniform pricing framework has been taken into account and various ex post approaches have been presented to allocate the above costs to different system participants. Most of the papers presented so far in the domains of cost or loss allocation are in this category. In this respect, [2–4] review the different previous approaches presented about transmission cost allocation and congestion cost allocation issues under the uniform pricing framework. Moreover, [5] reviews and compares different practical algorithms that have been presented up to 2002 about transmission loss allocation under the uniform pricing framework. That paper focuses on four alternative algorithms under the uniform pricing framework, namely, pro rata, marginal allocation, unsubsidized marginal allocation, and proportional sharing. Similar review is performed also in [6] for the loss allocation strategies (under the uniform pricing framework) presented up to 2004, concerning sensitivity relationships and participation factors.

The uniform pricing framework introduces a relatively fair market clearing mechanism. However, it does not present a unique price for each participant simultaneously accounting for the mentioned different pricing aspects, as instead, it firstly presents a uniform price, and then separately allocates the corresponding costs of the other affecting phenomena to the participants. On the contrary, the nodal pricing framework clears power market in one-step via some distinct prices determined for all different nodes in system. The conventional and common format of the nodal pricing methodology is based on using the Locational Marginal Prices (LMPs). LMP in each bus is defined as marginal cost to supply an additional increment of demanded power in that bus without violating any system security limits. In practice, LMPs are determined according to marginal costs of the marginal (part-loaded) generators obtained from the Lagrange multipliers associated with the equality constraints of nodal real power balances in ACOPF problem. The so-called conventional LMPs are very common in the papers presented so far in different fields related to power market. For example, [7] have exploited the conventional LMPs in order to clear the wholesale market. Even, some papers like [8] have extended the conventional definition of active power LMPs to be utilized for some new pricing purposes such as pricing the ancillary services. A modified nodal pricing method is presented in that paper to calculate reactive power price.

It is claimed in different papers that the conventional LMPs can account for different aspects consorted with fair pricing. In this concern, LMP is usually decomposed into three components: marginal energy price, marginal loss price, and marginal congestion price, which are carefully analyzed in [9]. Furthermore, a methodology based on ACOPF model has been proposed in [10] to break down LMP into a variety of parts corresponding to different factors, such as generations, transmission congestion, voltage limitations, and other constraints. Despite the above claim is somewhat true, the conventional LMP based pricing mechanism has several defects. For example, it neglects allocating the transmission investment costs, since its resulted congestion surplus may differ from the required transmission investment cost. As a result, some of previous papers like [11] have presented some approaches to modify slightly the conventional LMPs such that the new nodal prices can completely recover the entire transmission investment cost. Furthermore, [12] has demonstrated that the way in which the conventional LMPs regard the various pricing aspects is not so fair and rational. In this way, [12] has focused on a basic pricing scheme founded on the LMPs obtained from a simple DCOPF and has presented a thorough analysis and criticism about its different aspects remarking its positive features as well as its drawbacks. That paper then has proposed a new nodal pricing framework in which the nodal prices are determined according to the rational profit values evaluated for each of the different system participants. Although that paper has resolved most of the previous defects, it still has some principal drawbacks. For instance, it ignores the effect of transmission loss and its necessitated costs. On the other hand, the way in which the conventional LMPs regard the cost of transmission losses is also completely unfair.

This paper presents a new nodal pricing mechanism to resolve the previous drawbacks and to establish a fair and comprehensive pricing framework, such that it can respect participants' efficiencies and their extents of transmission use, as well as their rational shares of the total cost of transmission losses. The new mechanism not only perfectly recovers all the costs of generations, load curtailments, transmission investments, and transmission losses, but also it produces positive economic signals for all participants that encourage them for better performance. This goal is achieved via controlling the participants' economic profit shares from the total profit (social welfare) resulted in the entire system. The rational profit shares for all participants are calculated in accordance with their own efficiency and profitability measures. The corresponding measure for Transco is defined according to the definition of the Reference Transmission Network (RTN). Another important contribution is the new proposed practical way of RTN definition, which along with its simplicity, also considers the effect of transmission losses. Thereby, Transco also takes part in the loss reimbursement process, dependent on its role and capability of reducing the transmission losses. Validity of the proposed mechanism is verified via numerical analysis and its merit over the previous pricing methods (and specially the conventional LMPs) is then demonstrated. This new pricing mechanism indeed has capability to be used as a comprehensive fair nodal pricing framework.

Accordingly, the rest of this paper is organized as follows: First, for better demonstration, a brief analysis and criticism about how the conventional LMPs allocate the cost of transmission losses is presented in Section 2. Then in Section 3, a brief review of [12] (as the main foundation of this paper) is presented and its main positive features as well as its drawbacks are remarked. Afterwards in Section 4, the main modifications of this paper for resolving the defects of [12] are proposed, and thereby the new nodal pricing mechanism is formulated. In Section 4, validity of this mechanism is verified via numerical analysis; and finally, Section 5 concludes the paper.

2. A Brief Study about how the conventional LMPs allocate cost of transmission losses

This section gives a simple analysis of the LMP based revenue and payment assessment scheme from the viewpoint of its resulted loss allocation manner. To this end, a simple two-bus system is considered here, supposing either of two different cases, namely with and without transmission loss, and the corresponding LMP based revenue and payment formulations are extracted and analyzed. The two-bus system is depicted in Fig. 1, containing a generation unit at the first bus (#1), and a demand at the other bus (#2).

In the lossless case, generation level (G) equals to demand level (D), as seen in Eq. (1). Therefore, the resulted generation cost (GC), nodal prices (λ_1 and λ_2), generation revenue (GR), load cost (LC), and generation profit ($Gprofit$) can be formulated as in Eqs. (2)–(6).

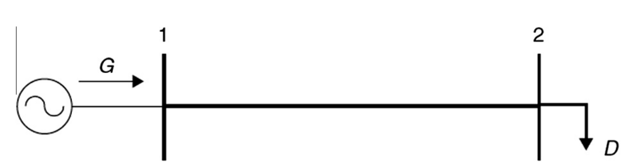

Fig. 1. A two bus power system with a generator on bus 1 and a demand on bus 2.

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