

Transmission expansion cost allocation based on cooperative game theory for congestion relief

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Abstract

In conventional power systems, upstream and downstream of power were distinct. However, due to the competition, power injection and sink can appear at unexpected locations, and cost sharing for such a new power system configuration must be considered. This paper proposes a scheme for transmission expansion cost allocation among electric market participants by using Core and Nucleolus concepts of game theory, which are developed particularly for the transmission users. A solution of the n -person cooperative game is adopted to distribute the line transmission expansion cost among the players. Congestion is assumed to be the transmission constraint, and expansion of transmission line is expected to relieve transmission congestion. A case study is illustrated to demonstrate the proposed method.

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1. Introduction

All over the world, there is a trend toward competitive markets in the electric power industry. After competition mechanism is introduced further into the retail level of the electricity market, the electricity transmission system is strongly required to be used efficiently and fair competition in the electricity market is also demanded to be strictly maintained among all participants. Because of the emergence of independent power producers (IPPs) as well as the changing structure of the electricity supply industry, it becomes more realistic to improve economics and reliability of power systems by enlisting market forces. For example, to maximize his payoffs, a player (e.g. eligible customer) seeks to displace expensive generation by importing power from neighboring players with lower cost energy. Likewise, a player (an IPPs or a Utility) with excess generation

capacity can choose to export power and receive an immediate return on its investment. So far there have been many research works published in the literature for the cost allocation methods but mainly on the generation side or price analysis [1–3]. In contrast, this paper aims to propose a cost allocation of transmission expansion among electric market participants by using Core and Nucleolus concepts of game theory [3–6,14]. Core and Nucleolus value concepts are used for cost allocation among the transmission users. In particular, congestion is assumed to be the transmission constraint, and expansion of transmission line is mainly to relieve transmission congestion. Besides critical index of economics, clearly reliability is also an important factor in equitable cost allocation, which is incorporated in our model. The cost allocation of transmission line expansion planning is based on the benefit of each participant. In this paper, we adopt a simple model with one Utility, several IPPs and eligible customers to analyze the effects of each related factor. Calculation of joint benefits for all possible coalitions to relieve transmission line congestion accrues from the expansion of the transmission line. Cooperative game theory (Core and Nucleolus) is applied to this model, providing a clear

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and simple explanation for expansion cost allocation. This paper is organized as follows: in Section 2, we formulate a transmission expansion cost allocation problem as a cooperative game. In Section 3, basic requirements of the transmission expansion are described. The concept of the benefit allocation based on cooperative game theory is derived in Section 4. Section 5 provides cost allocation of the IPPs, Utility and eligible customers. Illustrative applications are numerically explained in Section 6. Finally, the conclusion is given in Section 7.

2. Cost allocation of transmission expansion

Power transmission expansion cost allocation becomes a realistic issue due to the deregulation of the electric power industry [9–11,13]. In this paper, we assume that there is transmission congestion in a power system. The cost of transmission line expansion is shared among participants for the new line based on the benefit, by applying Core and Nucleolus concepts of cooperative games [3,6].

2.1. Power market model

Fig. 1 is the model of a power market under study. For each participant, we make the following assumptions.

- (1) IPPs: if the congestion occurs in the transmission line, the output of the related IPP generator will be curtailed, thereby diminishing the profit of the IPP. However, if the transmission line is expanded, the congestion will be relieved and the outputs of the IPP generator will increase as a result, which means that more electric power can be sold and more benefit of the IPP can be expected.
- (2) Utility: if there is some congestion in the transmission line, then power wheeling will be limited. As a consequence the profit of the Utility will decrease due to the restriction of total wheeling. On the other hand, when transmission line is expanded, the congestion is relieved and more power can be transmitted. In other words, the Utility is able to sell its own generator power with more benefits.

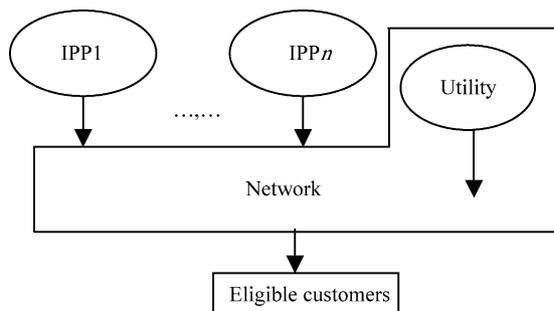


Fig. 1. A power market model with the IPPs, a Utility and eligible customers.

- (3) Eligible customers: in the same way, if there is some congestion in the transmission lines, the electricity price purchased by the eligible customers becomes expensive. However, when transmission line is expanded, the congestion will be relieved and the price becomes inexpensive so that eligible customers can purchase more power from IPP or Utility company.

3. Requirement of the transmission expansion

Since all participants have benefits due to the transmission expansion, the expansion cost allocation should be shared among them. Here, the profit obtained by the participants is defined as the following equation in this paper.

$$\pi'_i = \pi_i - \frac{x'_i \times \beta\%}{8760} \geq 0 \quad i = 1, \dots, 3 \quad (1)$$

where π'_i and $\pi = (\pi_1, \pi_2, \pi_3)$ are the pure profit and profit for each participant, respectively. π_1 for IPPs, π_2 for Utility, and π_3 for eligible customer. x'_i is the cost allocation of each participant, $\beta\%$ is the annual charge rate of the transmission line, and 8760 is the hours a year. Qualitative relation between transmission expansion cost and pure profit of each participant is shown in Fig. 2.

4. Benefit allocation based on cooperative game theory

This paper focuses on applying Core and Nucleolus concepts of cooperative games to cope with the benefit allocation problem among participants. There are n participants, i.e. $N = (1, \dots, n)$. Let subset of N be S ($S \subset N$) which is also called coalition. Assume $B(N)$ to be total benefit accrued from joint coalition of all participants. Likewise, assume $B(S)$ to be total benefit from joint coalition of parts S of all participants. Let $X = (x_1, \dots, x_n)$

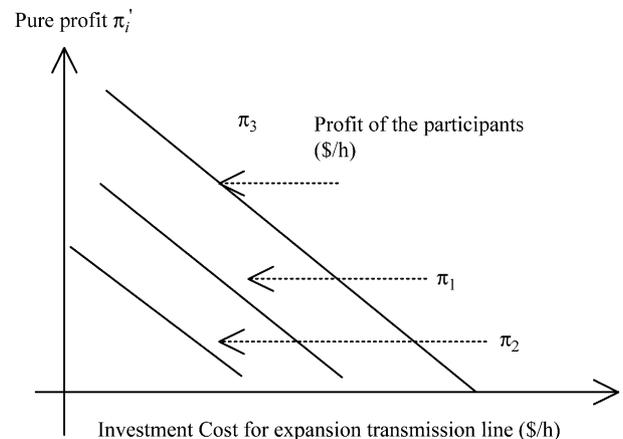


Fig. 2. Cost of the expansion transmission line and the pure profit of the participants.

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