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Power flow tracing based transmission congestion pricing in deregulated power markets

S. Chellam [a,*,1], S. Kalyani [b,2]

[a] Dept. of Electrical and Electronics Engg., Latha Mathavan Engg. College, Madurai 625301, Tamil Nadu, India
[b] Dept. of Electrical and Electronics Engg., Kamaraj College of Engg. and Tech., Virudhunagar 626001, Tamil Nadu, India

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ABSTRACT

The objective of this paper is to propose a simple transmission congestion pricing scheme based on tracing principle by considering generator fixed cost, cost for incurring loss and transmission congestion cost. Restructuring has brought about considerable changes by the virtue of which electricity is now a commodity and has converted into deregulated type. Such a competitive market has paved way for innumerable participants. This concept of restructuring has led to overloading of transmission lines. In this paper, power flow tracing has been employed by using suitable optimization algorithm, where the real power generation has been maximized. Congestion in the transmission line has been produced in a new fashion by maximizing the real power demand. The power flow under normal operating condition and congestion is determined and hence the difference in power flow is estimated. Based on the estimated power flow difference, the transmission line congestion cost is computed. Pool model and bilateral model has been considered in simulation study to introduce the concept of deregulation. The proposed method is tested and validated on Modified IEEE 30 bus test system and Indian utility 69 bus test system.

Introduction

The vertically integrated structure of power industry is being replaced by market structure in the world range. In such a structure, a transmission system is being used by multiple generation and load entities that do not own the transmission system. Formerly, when the electric network was operated by one vertically integrated utility, there was not much interest in this subject. However, with the unbundling of generation and transmission facilities, and with accompanying deregulation of the power, the topic has acquired new significance as the different parties acting in the power grid are interested in a fair operation and fair allocation of transmission costs. In view of market operation it becomes more important to know the contribution of individual generators and loads to transmission lines and power transfer between individual generators to loads.

Rosado et al. explain the tracing of power flow using commons method and node method. The results obtained from these methods are not perfect and time required is more [1]. Bialek proposes a topological approach for allocating the power flow from a particular generator or a load in every branch flow based on an electricity tracing method [2].

Bialek and Kattuman recommend a tracing methodology is based on the assumption that the incoming flows are proportionally distributed among the out coming flows at any network node [3]. Panto et al. introduce modified Topological Load Distribution Factor (TLDF) based method to trace the power flow in the transmission losses to enable the decoupling of the extended matrices [4]. Xie suggests a new method using direct path from buses to buses by multiplying with the incidence matrix and to find the power transfers from individual generators to loads and branches. [5].

Abhyankar et al. discusses optimization technique based tracing algorithms using the continuity equations for the lossy flow networks with modified bus incidence matrix to discriminate the power flow between the sending end and the receiving end. [6]. Mustafa and Shareef elaborates about graph method, node method and common method for the allocation of power flow in the power system network. [7].

Hamid et al. introduces a concept of load tracing and generator tracing using Evolutionary Programming (EP). The power flow from generator to all system loads is traced and losses are allocated in the transmission lines. These method have the advantage of no assumption to formulate the tracing of power flow [8,9].

* Corresponding author.
E-mail addresses: chellameee@lathamathavan.edu.in (S. Chellam), hodeee@kamarajengg.edu.in (S. Kalyani).
[1] Assistant Professor.
[2] Professor and Head.

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Yang and Anderson explain the congestion management using Power Flow Comparison Method and the Proportional Sharing Method. The congestion management in two generators has conflicts of the one generator with higher MW contribution than the other [10].

Congestion [12] takes place when the transmission lines are not sufficient to transfer the power according to the market desires. Farahani et al. demonstrates the operation of restructured power system in bilateral power market and pool market. Singla et al. explains the causes for congestion and various congestion pricing calculations in the transmission network [16].

Murali et al. explains GA based congestion cost calculation using LMP for various generation bids and load bids. GA is implemented to find the fuel cost of generators. The main drawback of this paper is that time consumption for the convergence of GA is more [14]. Manikandan et al. proposes a power flow tracing algorithm using the new set of equations based on the concept of dominions and proportional sharing principle [15].

Modi and Parekh explain a method using game theory to determine the Congestion pricing with different zones using Locational marginal price (LMP) [17]. Jana explains the calculation of transmission congestion cost using Line Wise Cost and Line Impact Cost from the distribution of power flow among the congested lines [18]. Nikoukar and Haghifam propose a simple transmission pricing scheme using tracing based proportional tree, in which transmission fixed cost, congestion cost and loss cost are considered [19]. Liu et al. explains a method in which the incentives are provided to use and build a transmission line [20].

The basic power flow tracing methods include Node method, graph method and commons methods. Results obtained from commons methods are not accurate and this method takes more time for computation. The proportion sharing principle based power flow tracing provides rationalized results. By using the topological factors, the power flow tracing yield more computational time and memory. With matrix multiplication using directed path, the power flow tracing has been done which gives complexity in matrix multiplication. Evolutionary based algorithm has the capability to allocate losses and generated power to all loads with satisfaction of power system constraints. But this method cannot identify which transmission line causes the highest losses to the load.

To overcome above mentioned drawbacks, this paper presents a new method for evaluating the transmission congestion cost in pool power market and bilateral power market. The power flow in these markets is computed using power flow tracing principle. The power flow from generator to load and from generator to transmission lines has been traced by employing optimization technique. The congested power flow in these markets has been estimated by maximizing the real power demand. The fixed cost of generator, fixed cost of load and fixed cost due to the occurrence of loss in the transmission lines have been determined based on the power flow. Using these costs, the transmission congestion pricing (TCP) and congestion pricing (CP) in pool market and bilateral market has been calculated. This method of congestion cost calculation has been tested on Modified IEEE 30 bus system and Indian Utility 69 bus system.

This paper is organized as follows. The proposed methodology with block diagram is given in section 'Proposed methodology'. The discussion on concept of power flow tracing is shown in section 'Power flow tracing concepts'. A generic class of optimal tracing problem is introduced in section 'Problem formulation' with the detailed problem formulation. The implementation of PSO for maximizing the real power generation and real power load is given in section 'PSO algorithm for maximization of real power'. PSO constraint handling mechanism is given in section 'PSO constraint handling mechanism'. The detailed discussion of the test results are explained in 'Results and discussions'. The section 'Pool market' deals with the maximization of real power generation and load in Pool market. The maximization of real power generation and load in bilateral market is conferred in section 'Bilateral market'. The power flow tracing results for generator tracing and load tracing are given in section 'Power flow tracing results'. The transmission fixed cost calculation is shown in section 'Transmission fixed cost calculation'. The congestion cost estimation is discussed in section 'Congestion cost estimation'. The summary of the test results are discussed in section 'Summary'. Section 'Conclusions' draws the conclusion of the paper.

Proposed methodology

This paper intends to propose a new method for determining the transmission congestion cost. The congestion cost has been calculated based on power flow tracing principle. Bialek's tracing principle is implemented in this paper to find the power flow from generator to transmission lines and from generator to load. Basically, upstream algorithm and downstream algorithm is used in this work. The power flow tracing problem is formulated in two ways; one is generator tracing and another is load tracing. The real power generation is kept as similar in the load buses. The congestion in deregulated market is created by maximizing the real power demand at load buses. The power flow in base case and in congested condition is found using the optimization technique. The transmission congestion pricing and congestion pricing is estimated from the fixed cost of generator, load and loss occurrence in the transmission lines. The basic block diagram of the proposed methodology is given in Fig. 1.

The power flow from generator to load and from generator to transmission lines has been obtained using power flow tracing principle. Power flow tracing is achieved by maximizing the real power generation. The power flow at congested condition is obtained by maximizing the real power demand. The congested power from the load to the transmission lines has been found using downstream algorithm. The difference between power flow at basecase condition and power flow at congested condition is computed. The fixed cost of generation, fixed cost of load and fixed cost due to the occurrence of loss is determined based on the congested power flow.

Power flow tracing concepts

Tracing is the important process in a power system network. Due to the unbundling of the power system network, the power flow from the generator to load and from the generator to transmission lines become an important issue. Tracing gives a clear picture about the total power flow of the power system network. Power flow tracing comprises of two cases namely generator tracing and load tracing. In generator tracing, power transfer from generator to transmission lines are found. In load tracing, the power transfer from the load to transmission lines is determined.

Concept of generator tracing

An optimization technique based power flow tracing is implemented to determine the power flow from generator to transmission lines and from generator to load. The contribution of line flow by the generator is given as,

$$P_{gi} = \sum_{L1}^{Lm} P_{Lm} \tag{1}$$

$$P_{Lm} = P_{Lm}^{g1} + P_{Lm}^{g2} + \ldots + P_{Lm}^{gi} \tag{2}$$