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Pricing methodologies for congestion management in a deregulated electricity market: A bibliographical survey

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Abstract

Exhaustive research has been done for addressing the problems arising out of unbundling and restructuring of power market. The prime objective of every research was oriented towards managing the congestion in transmission corridors as well as providing cost effective production to utilities and low tariff energy to the end consumers. The key factors involved in the pricing of energy identified till now are network security, reliability, transmission losses allocation, technical, and social issues. This bibliographical survey was an attempt towards summarizing the recognized works and publications oriented towards pricing of electricity market. The purpose of this survey was to collect information from the previous literatures to help those, currently, working towards establishing a novel pricing scheme.

Keywords: Congestion, Deregulation, Power market, Pricing, Restructuring, Unbundling.

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1. Introduction

In the present deregulated electricity market, the increasing demand of power has not only caused congestion over the existing lines but also the stability of the lines has reached to its vulnerable limits [1-6]. This problem can be assisted by building new transmission lines but that would require additional capital investment and would also result in more complex grid management. Also the cost of erecting new transmission lines and the resulting losses are major factors which would limit the expansion of existing transmission system. This would also adversely affect the sharing of reserve capacity, thereby, leading to uneconomic (high tariff) energy. As the power flow increases through the existing lines, the system becomes more vulnerable to contingency conditions. This limits the use of transmission lines to their full thermal capacity, and hence, the increased cost of transmission. This increased cost is to be either borne by the utilities or by the end consumers in form of increased tariff [7-12]. The need for cost effective pricing methodology is the requirement of today's deregulated electricity market to make the congestion free transmission and to transfer the benefits of deregulation to the competitive private bidders as well as to the end customers [13-23].

Many researchers have worked hard and have come out with various algorithms, models and strategies to address the problem of pricing scheme since last two decades. Most of the researchers believe that pricing scheme should be such as to penalize those responsible for causing congestion i.e. whether suppliers or the consumers.

This bibliographical survey is inspired by the previous surveys performed in [24-26] to analyze the effects of deregulation and restructuring of power market over simultaneous management of congestion and pricing. This paper, mainly, focuses on the pricing methodologies applied for transmission transactions.

The rest of the paper is organized as follows. Section 2 provides the information about the various cost components involved in the pricing of electricity. Section 3 provides information about various types of proposed methodologies involved in the pricing of electricity. Conclusion is drawn in Section 4.

2. Cost components of electricity

The various cost components involved in the pricing of electricity are broadly classified into fixed costs, variable costs, operating costs and customer related costs. Fixed charge allocation is, mainly, the cost involved in initial investment for providing the facilities such as construction of plants, transmission lines and sub-stations. Variable cost component involves the unplanned rescheduling and redispatch of utilities, unplanned wheeling transactions between various utilities, and part of it includes curtailable and as available transactions. The operating cost, mainly, consists of fuel costs, cost of manpower, accommodation of new facilities into the existing system and the long term firm transactions. The customer related costs are of variety of nature and they vary from society to society based upon their geographical, social, economical as well as their political conditions [27-28].

Numerous methods have been proposed for evaluation of these cost components. In [29-30], demand related factors have been considered for taking into account price elasticity of demand. The system capacity based cost components have been evaluated using long run marginal cost in [31-34]. In [35-38], long run incremental cost component have been evaluated taking into account various factors related to network security.

A variety of methodologies have been proposed in [39-44] for allocation of cost of losses incurred over transmission. The branch current decomposition method has been proposed in [45] and power as well as energy summation method has been proposed in [46-47] for radial distribution system.

3. Pricing methodologies

Based upon the existing literatures available, there are many methodologies employed for electricity pricing. Some of these schemes utilize dynamic (real time and spot) pricing whereas others utilize probabilistic pricing as well as MW-mile methodology. The methodologies being proposed earlier include day ahead pricing, reliability pricing, ramp rate based pricing, optimal power flow (OPF) based pricing, marginal (incremental) pricing and many more.

An analysis of cost based transmission pricing has been done in detail in [48]. It gives information about allocation type pricing methodologies such as (a) postage stamp methodology, (b) contract path methodology, (c) distance based MW-mile methodology, and (d) power flow based MW-mile methodology. Also incremental pricing methodologies such as (a) short run incremental cost pricing, (b) long run incremental cost pricing, (c) short run marginal cost pricing, and (d) long run marginal cost pricing have been discussed.

A. MW-Mile methodology

In [49-53], an algorithm has been presented to trace the flow of electricity by applying proportional sharing principle. It has been shown how by application of this principle it is possible to allocate share of each generator’s output to each load present in the network. Also, in the same manner, the share of each line can be allocated towards each load. Thus, it is possible to devise an algorithm to allocate the losses to each generator’s output or to the each load input. In [54-55], the topological method of power flow analysis has been utilized to implement the MW-mile methodology for transmission supplement charge allocation. In [56-57], a different method has been proposed to trace and allocate active and reactive power flows to individual loads and lines. In [58], comparison of various cost components allocated using MW-mile methodology has been compared for Malaysian power system. In [59-60], a comparison between MW-mile and MVA-mile charging methodology has been done for Western Power Distribution. In [61], the same methodology has been applied to analyze its effect over Indian power system.

In [62], three different approaches viz. (a) reverse (b) absolute, and (c) dominant have been utilized to study the effect of MW-mile methodology over cost allocation.

B. Marginal pricing

This type of pricing employs, mainly, spot pricing principle and was first suggested in [63]. The probabilistic costing approach has been followed in [64] to develop an algorithm for costing transmission services in IEEE New England network. The probabilistic approach [65] devised a method to compute expected energy not produced which could have helped in auction and bidding process for installing of new units as well as enhancement of existing transmission lines. In [66-68], probabilistic approach has been suggested for spinning reserve wheeling transactions among various utilities. The approach has been tested for IEEE reliability test system in [69]. In [70-72], electricity future price forecasting has been developed from risk management point of view. The probabilistic approach has been applied in [73-77] to OPF to compute the locational marginal pricing.

Various day-ahead forecasting models such has GARCH model, ARIMA model has been presented to predict the cost of electricity. A variety of techniques such as neural fuzzy and many more have been implemented for day ahead pricing based on locational marginal methodology [78-87]. In [88], the proposed approach is evaluated by analyzing and forecasting of the day-ahead electricity prices in the Australian and Spanish electricity markets. The proposed self-scheduling model in [89] is tested on the IEEE 118-bus test system. The day ahead pricing methodology to evaluate the performance and incentive compatibility of the suggested recovery mechanisms in [90] has been tested over the model of the Greek electricity market.

An adaptive wavelet neural network (AWNN) model is used to show the efficiency of the proposed method for New York Independent System Operator market in [91]. The demand curve approach suggested in [92] pays more when reserve margins are smaller and provides a reduced incentive for investment when installed reserves are above the target. Another goal which is being fulfilled by this approach is to make revenues more predictable for generators, making investment less costly and, ultimately, lowering prices for consumers. A dynamic representative agent model is presented for projecting effects upon reserve margins, generator profitability, and consumer costs and is applied to alternative demand curves proposed for the PJM market.

The ramp rate model of generators for optimal scheduling and redispatch algorithm has been used in [93-94] for price formulation resulting in dynamic dispatch and unit commitment. The idea has been implemented on IEEE 17-units system with 57 buses for reserve and energy cost optimization under all operating constraints.

C. Real time and dynamic pricing

The model, presented in [95-96], provides optimal nodal specific real-time prices for active and reactive powers, and the method to decompose them into different components corresponding to generation, loss, and other ancillary services such as spinning reserve, voltage control and security control. The proposed model has been implemented on 5-bus and IEEE 30-bus systems. An integrated approach for real-time power market operations and monitoring in decentralized markets has been proposed in [97]. An interruptible tariff mechanism utilizing OPF has been implemented in [98] in the real time to reduce the costs during peak load periods for IEEE 30 bus system.

D. Demand response based pricing

This type of pricing is also a kind of real time pricing but the concept utilized differs somehow. In [99], an adaptive system based model has been simulated to study the impact of consumer's price elasticity of demand over various power market parameters such as price spikes, energy bills, and emissions of greenhouse gases and other pollutants. The results have been analyzed for Korean power system. A price forecast function has been developed in [100] by a dynamic approach. The trend in the prices has been determined by clustering the various prices at different times into Lyapunov function. The approach has been tested for Italian, New England and New York electricity markets. In [101], the demand response has been analyzed by employing dynamic time of use pricing model. The results have been compared with that of single pricing mechanism and have been shown to be superior one. In [102], the impacts of different non linear demand response price elasticity characteristics and demand response participation levels on the convergence of load value or the price value have been studied. Two different methods have been used for the study. One is closed-loop iterative simulation method and the other is non-iterative method based on the contraction mapping theorem. The auto regressive model of stochastic block flexible electricity contract price has been used in dynamic programming to achieve the optimal scheduling of utilities in [103]. By using this model the price of block flexible electricity contract is determined by the variables and schedule of this contract is determined. The results have shown that improved power market efficiency can be obtained. A different type of model has been used in [104] to demonstrate the similar results.

. Conclusions

This paper gives an overview of the different types of pricing methodologies being, currently, adopted and those, currently, being analyzed by the researchers for future implementation. Still there are a lot of challenges faced by power sector. The need for the power market is to adopt a pricing scheme which shall be globally accepted to facilitate the open, transparent and deregulated electricity market for private players through competitive bidding process. This paper may be of help to those working towards a novel pricing scheme of electricity market.

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