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Power System Transmission Pricing-A Review

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***Abstract*— Restructuring in the power supply industries has given rise to a competitive electricity market. The allocation of the transmission cost is a vital issue in this power market. The transmission pricing should be economical, transparent, efficient and ensure the reliable operation of the electricity market. This paper puts forward the review of different transmission pricing techniques and methods. The transmission cost allocation by nodal pricing and power flow tracing techniques along with the congestion management, optimization techniques and the transmission loss allocation constitute the body of this paper.**

Keywords*— Loss Allocation; Nodal Pricing;Optimization Techniques; Power Flow Tracing; Transmission Pricing.

I. INTRODUCTION

In the restructured power system the transmission pricing is considered as one of the most complex issue because the nature of the power flows in the power system and the need to satisfy the demand and the supply. The monopolistic nature in the transmission sector prevented the introduction of the competition in the transmission sector. So there is always a demand of efficient transmission pricing which will recover the transmission cost by properly allocating the cost among the several transmission service users.

The allocation of the transmission charges for different transmission services to all the customers should be on non discriminatory basis and should be simple and transparent. The transmission tariff structure should be such that it should reflect the embedded cost, future expansion cost and the operating cost. The embedded costs in the transmission are huge as compared to the other operating cost so the pricing structure should be very efficient to recover the cost from all its users. In 1991 Shirmohommadi et al. has discussed basic concepts and issues regarding the transmission pricing in the vertically integrated unit and have shown that the transmission pricing has been one of the most critical and vital issue in the power system. The cost associated with the transmission services are shown in the Fig.1.

A. Transmission cost components

Operating cost: The operating cost of a transmission transaction is defined as the fuel cost which the utility incur in order to accommodate the transaction due to the generation rescheduling and re dispatch. The generator rescheduling is influenced by the start up of the generating unit and spinning reserves.

Opportunity cost: Opportunity cost of a transmission transaction is defined as the benefits the grid company takes as a result of the operating constraint subjected to specific transaction.

Reinforcement cost: System expansion cost deals with the investment to promote new users and also encourage promoting expansion in the new developing countries.

Embedded cost: Existing system cost comprises the cost which was invested in the establishment of the transmission system network and maintaining the same. This mainly termed as the embedded cost and the Operation & Maintenance cost.

Shirmohammaddi et al. in 1996 have put forward the main pricing schemes which illustrates the basic of the pricing paradigm which are rolled in methods, incremental methods and both the embedded and incremental methods which is shown in the Fig.2

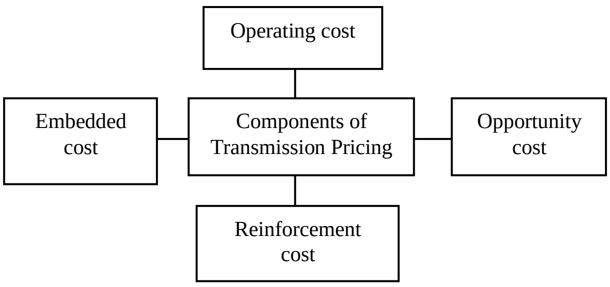

Fig1. Components of Transmission Pricing

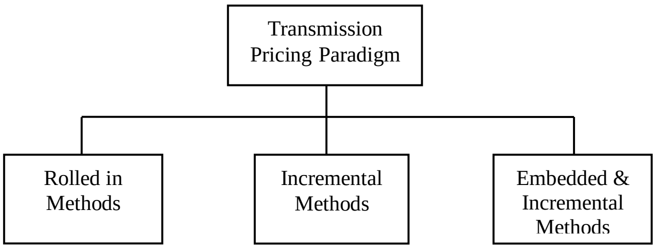

Fig.2 Transmission Pricing Methods

B. Transmission Pricing Paradigm

Rolled in methods: In this method the transmission system existing cost and the cost involved in the transmission system operation and maintenances are allocated among the various transmission system users.

Incremental Methods: This method allocates the variable or the incremental transmission cost to the user.

Embedded and Incremental Methods: In this transmission charges are evaluated by considering both the embedded and incremental cost for providing the services.

Khan and Agnihotri has embodied the comprehensive review of the embedded transmission pricing based on the power flowing techniques method, but the topics covered are only confined to the general methods which are based on the power flow tracing techniques [3]. Garg et al. has given a very brief review of the transmission pricing practices discussing the regulatory for power transmission system, methodology and the recent trends are discussed. An overview of the embedded cost and the incremental cost are discussed by Murali et al. and a review of the various cost allocation method in transmission system is also presented [4], [5]. This paper gives an overview of the approaches involved in the transmission cost allocation in Section II. Section III discusses the transmission network congestion pricing. The studies based on optimization techniques in transmission pricing are presented in Section IV. Section V present the views based on transmission loss allocation and followed by Conclusion in Section VI

II. TECHNIQUES OF TRANSMISSION COST ALLOCATION

A. *Nodal Pricing Approach*

In nodal pricing there is the variation of the price according to the change in the geographical location, hence it is also termed as the Locational Marginal Pricing. There is an abundant generation in case of Nodal pricing. The contract rights are paid by these huge surpluses. The right holder in the contract has the right to inject power in one node and remove it from the other in the transmission network [3]. The nodal pricing can be calculated by operating the system after 1 MW use and before 1 MW use and calculating the difference between the two cost of operation [6].

In a study Srivastava and Verma have come forward with an approach for maintaining the desirable locational signal, the generator and the loads with the higher tariff are sorted in order to minimize them. Locational based pricing concepts were used to develop a nonlinear programming problem formulation for the evaluation of the reactive power pricing and implementing the FACTS devices to reduce the overall operating cost and their effect on the transmission pricing [7]. Gang et al. in 2005 have proposed a transmission and wheeling pricing method in which the real and the reactive power are converted into monetary flows by using nodal pricing techniques [8]. An approach has been adopted by Gil et al. in 2006 to create a nodal price difference by introducing the generation and the nodal injection penalties in economic dispatch for the allocation of the transmission network cost [9]. In another study, it has been evaluated that the transmission pricing for the market participants also deals with the bilateral transaction in electricity market taking into account the optimal dispatch and the transmission pricing using optimal power flow [10]. Reta et al. developed a logarithmic function to evaluate the transmission system cost recovery in ideal and real power systems [11]. The nodal pricing is not sufficient to recover the total transmission cost so Ghayeni et al. has proposed a pricing methodology in which the marginal pricing is combined with the Ramsey pricing for the recovery of the total transmission cost [12]. With the further advancement in the research in the transmission system pricing Cebeci et al. came up with a methodology which assures the variegation of the zonal tariff by geographically combining the nodal transmission use of tariff in terms of weighted average approach [13]. In another study Érica et al. have come forward with a new methodology which is the combination of the Long Run Marginal Cost (LRMC) method and minimization maximization techniques to deal with the dispersed transmission tariff [14].

B. *Power Flow Tracing Techniques*

To recover fixed transmission costs and for transmission pricing, tracing methods are used. The tracing method proportionally shares nodal inflows among nodal outflows and can be used to with both dc power flow and as power flow. This method considers two flows in each line, one entering the line and the other exiting the line (to consider losses in line) and generation and load at each bus. Upstream-looking algorithm or downstream-looking algorithm can be used in this method. The upstream-looking algorithm allocates transmission usage charge to individual generators and losses are apportioned to loads whereas in downstream-looking algorithm, the transmission usage charge is assigned to individual loads only [15].

Ching-Tzong and Ji-Horng have taken the approach of the power flow tracing techniques along with the bus sorting with ordering rule is done to fasten the computation [16]. The real and the reactive power contributions are taken into account for the calculation of the contribution of the each generator in each transmission line and contribution of each generator in the transmission losses. The same author also proposed a method of MVA km method by applying AC power flow and came out with the conclusion that the apparent power for wheeling prices is more reasonable than the MW mile method. Bialek and Ziemianek have dealt with the two issues with the tracing based transmission pricing. In their paper they demonstrated a comparison between the graphs based algorithm and the algorithm based on the solution of the linear equation and the Bothe algorithm were equivalent when the diagraph of the power flow is acyclic [17]. The problem involving the transmission pricing of cross border trade can be overcome by proposing a new methodology in the tracing based transmission pricing by allocating the losses in a direct way [18]. Qian and Jihui has discussed the power flow tracing method and based on the graph theory the method of path searching is studied in [19]. The branch expunction is also used in the algorithm to optimize the node order. A network flow tracing method has been presented by Miloš and Ferdinand which is based on the matrix calculation considering the transmission losses. This method can be used for the transmission service pricing and security analysis [20]. Again, in 2006, Abhyankar et al. proposed the power flow tracing method as the linear constrained optimization problem which persuaded the bilateral transaction [21]. In 2009, Abhyankar and Khaparde developed an approach to determine the Point of Connection (POC) rates for the participants in the decentralized market [22]. The POC charges are calculated by optimal tracing and conventional tracing. In a similar study Kilyeni et al. have used the real and the reactive power flow tracing method based on the z bus system matrix for the transmission cost allocation [23]. A recent study conducted by

Rathore et al. has allocated the transmission usage cost to the generators by proposing technique based on the graph theory based on the contribution to the maximum line flows under n-1 contingency condition [24].

III. TRANSMISSION PRICING CONGESTION MANAGEMENT

In 1999, Yang et al. had implemented a power flow comparison method and the method came out to be much better than the Proportional sharing principal providing a detail guideline for controlling the line flows [25]. Bautista and Quintana have used GGDF and GLDF to quantify the usage of the transmission system by considering the day ahead market outcome. A software tool has been presented for the management of the congestion and the calculation of the transmission pricing [26], [27]. The congestion problems are overcome by minimizing the changes in the initial dispatch and the transmission prices are calculated taking in account the existing system cost, the losses cost, operational coast and the initial congestion cost. Cradell have proposed a method for the calculation of marginal loss component of nodal prices during congestion period which shows the contribution of each market participant to marginal losses [28]. In 2008, Silva and Cuervo have adapted the pay and use concept which is based on the bilateral exchange for the allocation of the congestion related cost in the transmission network [29]. The financial transmission rights have been used to collect the revenues in the congested network and the congestion and lost cost are determined in the proposed pricing scheme. In another paper Nikoukar and Haghifam have proposed a pricing scheme with the help of power flow tracing method the contribution of the generators and the load to the actual power flow [30],[31].

IV. TRANSMISSION PRICING USING OPTIMIZATION TECHNIQUES

Genetic algorithm has been used for the development of the transmission planning methodology for the purpose of forming an economically adapted transmission system in open access environment [32]. Abhyankar et al. have modified the tracing algorithm into a linear constrained optimization problem that minimizes the overall deviation from the postage stamp allocation. They again proposed a mini max fairness algorithm using optimization based real power tracing for solving the complex cost sharing problem by allocating the cost in the equitable manner on per unit basis while meeting the constraints [33], [34]. Naresh et al. in 2010 has used real coded genetic algorithm for the allocation of the transmission cost to the generators and the loads by comparing the MVA-Km method using AC power flow and genetic algorithm [35]. A review about the optimization techniques have been put forward by Kishore and Singla for the development of the model and cost of the transmission lines [36].

V. TRANSMISSION LOSS ALLOCATION

A new method has been proposed by Abdelkar in 2007 for complex power flow tracing in both directions, that is, from generators to loads and vice versa. The upstream tracing (UST) & downstream tracing (DST) algorithms introduced here are seen to be versatile and superior compared to similar methods as it takes losses into consideration during the tracing process, hence lessening the need for adding more nodes to represent losses and reduces computation burden as well. This method is unique as it is seen to be able to deal with unusual flow patterns, such as lines with reactive-power infeed from both ends and lines with different flow directions of active and reactive powers. Loop flow is the only area which requires further improvement to be well accommodated in this method [37]. Meng and Jeyasurya in 2007 presented a simple transmission pricing scheme which manages transmission costs and solve congestion and loss problems. This method helps calculate and allocate transmission costs, using a known power flow tracing method. Estimation of the locational marginal price has been shown by authors by using tracing method [38]. Abdelkader in 2009 has propounded a new modified method for complex power flow tracing and loss allocation. The proposed model is similar to the ABCD model but instead relates the partial flows caused by a load/generator at the receiving/sending end of the line to the partial flows caused by that load/generator through all lines following that line in the upstream/downstream direction. The signal flow graph and block diagram algebra can be used for direct determination of the extraction factors between a specific node and a specific generator. Unlike the previous methods for power flow tracing, this proposed method can well accommodate loop flows and pass over it to continue the process of power flow tracing and loss allocation [39]. A recent study has suggested a technique based on power tracing which identifies the actual transactions based on proportional sharing and power flow and determines the percentage of power injected by a generator reaching a load and in which path. De et al. suggested that loads under the transaction should pay for the loss to the generators who are actually supplying power to satisfy this loss [40]. Another study illustrates a reachability set based power flow tracing method which determines the line losses assigned to each generator. It is shown that progressive line loss calculation is performed with faster speed and accuracy and less complexity of calculation by applying the reachability set theory. The algorithm is tested on IEEE-14 power system and the comparative results illustrate that the numerical deviation is around 13%, which is within the acceptable range but further improvement is required [41]. A very recent work by Dusonchet et al. demonstrates the importance of the results provided by the power flow tracing methods and proves proportional sharing efficacy by obtaining exactly the same result while implementing two different tracing methods through Matlab scripts, on two electrical transmission test systems developed and simulated on purpose. The authors also prove that only few loads are responsible of the power flowing on a line, hence making it possible to define exactly the load consumptions on which a system led Demand Response program should act in order to meet system issues. The paper also hints at the future potential helpfulness of power flow tracing in the field of renewable energy by studying their effects while finding the contribution of the power injected by these systems to the networks elements [42].

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VI. CONCLUSION

This paper presents an overview on the power system transmission cost allocation. The review focuses on the techniques of transmission cost allocation. Necessary discussion has been made under each section. Each approach has its own benefits and flaws. Nodal pricing is quite efficient for allocation of incremental cost but cannot recover the total transmission cost. Whereas the power flow tracing is easy to implement but it lacks in providing efficient economic signal. The management of the congestion prices is important as it enhances the system reliability and security. The application of optimization techniques in the transmission cost allocation leads to some better results and fast responses. The losses in the transmission system should be allocated so that their pricing will improve the efficiency of the electricity market.
Furthermore the power system researcher should focus on the challenges faced in the development of the efficient transmission pricing. The work can be extended with the detailed analysis of the transmission pricing structure of the different countries and making an intelligent pricing methodology for allocating the transmission cost.

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