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TRANSMISSION AND WHEELING SERVICE PRICING: TRENDS IN DEREGULATED ELECTRICITY MARKET

Anuprita Sandeep Mishra[1]*, Ganga Agnihotri[2] and N.P.Patidar[3]

1 - Research Scholar, Maulana Azad National Institute of Technology, Bhopal, India
2 - Professor, Dept. of Electrical Engg., Maulana Azad National Institute of Technology, Bhopal, India
3 - Professor, Dept. of Electrical Engg., Maulana Azad National Institute of Technology, Bhopal, India

ABSTRACT

Electricity transmission and wheeling service pricing are becoming a more complex and more important task with the ongoing deregulation of electric power industry. In a competitive electricity market, transmission services have to be classified into two categories - transmission service and wheeling service. As distributed generation (DG) becomes more widely deployed in transmission system as well as in distribution networks to fulfill the demand in support of traditional generation, makes the transmission and wheeling pricing complicated. In this context authors have reviewed number of transmission / wheeling pricing methodologies with/without considering DG. In conjunction with traditional methods of pricing new methods were also reviewed which takes into account the pricing of both active and reactive powers because in few DG technologies reactive power flow direction becomes more important. Authors also reviewed the literature furnishing comparison of pricing methods related to DG. Specifically comparisons of MW-mile method based methodologies have been explored. In addition authors have discussed the Indian pricing methodology and inevitability of perfection.

Index Terms : *Dispersed Generation, Embedded Cost, Marginal Cost and Incremental Cost, Supplementary Cost.*

I. INTRODUCTION

ELECTRICITY transmission service pricing is becoming a more complex and more important task with the ongoing deregulation of electric power industry. It significantly affects the market efficiency, the development of the transmission systems, the sitting of power plants, the demand growth and its geographical distribution. The complication arose due to incorporation of transmission into deregulated competitive framework eventually becomes subject of an ongoing debate among utilities, consumers and suppliers. For obvious reasons, it is neither feasible nor economical to build independent transmission systems for each generation-load pair. As transmission network is the single electric business where important economies of scale are present, hence competition is not feasible and natural monopolies develop. In this way, pricing and investments of transmission system are frequently at the heart of regulation problems. Therefore to achieve better results of non-discriminatory open access, first challenge is to develop an efficiently regulated monopoly that permits competition to take place and the second challenge is to define a pricing scheme for the transmission services that provides coherent economic incentives for the business to efficiently operate and expand.

In deregulated electric industry the presence of dispersed generation or DG further complicates the problem of pricing because it introduces additional supplying nodes and changes power flows [4]. Rational being the shortage of transmission system capacities along with the need for reliable power supply is causing an increased interest in Distributed Generation or Dispersed Generation (DG). Eventually affects the transmission pricing / wheeling charges which are different from previous existing power network (without DG). Reasons being distribution

anuprita_mishra10@yahoo.co.in

system with DG becomes active network (unlike passive distribution networks without DG) due to counter flows. Thus in a competitive electricity market, it is beneficial to classify transmission services in two categories

1. Transmission service: Services given by main transmission network i.e. supplies power from PSP to Distribution network.
2. Wheeling service: Transmission services given by Distribution network to the end users.

Pricing of transmission or wheeling services is an unresolved issue. It is impossible to have a pricing methodology that can be used in all circumstances. Each methodology has its own specific strengths and weaknesses. Different pricing methodologies are suitable for different circumstances and different requirements under which transmission services are being provided though the diversity is too rich. The primary objective of pricing is to ensure economic efficiency. Furthermore determination of prices must be transparent, audible and the pricing regime must be practical to implement.

This paper mainly reviews various transmission pricing methods proposed by different authors. Lima et al. [2], Kovacs et al. [7] and Shirmohammadi et al. [11] presented different methods of allocation cost to evaluate transmission capacity. As given in [11] existing methodologies have been categorized under three criteria of transmission pricing and these are (typically four).

- Embedded cost based transmission pricing methods
- Marginal / Incremental cost based transmission pricing methods
- Composite embedded and incremental cost based transmission pricing methods

This paper has organized as follows. In section II literature review of embedded cost based pricing methods, marginal or incremental cost based pricing methods and reviewed composite embedded and marginal/incremental based pricing methods. Whereas section III introduces importance of distributed generation and wheeling service pricing. Few other methods are being reviewed under recent techniques category in section IV. Comparison of different methods is tackled in section V allied to DG. In section VI authors gave DG mean to India and wheeling service pricing in India. Finally section VII gives conclusion.

II. REVIEW OF TRANSMISSION SERVICE PRICING METHODOLOGIES (WITHOUT DG)

In this section authors deal with review of different transmission service pricing as listed in section I. Richard [60], implicated the six principles for transmission pricing, furnished by members of a working group organized by the Energy Modeling Forum of Stanford University on Electrical restructuring and competition and these should be followed while designing electricity transmission pricing. They are

- Promote the efficient day-to-day operation of the bulk power market
- Signal locational advantages for investment in generation and demand
- Signal the need for investment in the transmission system
- Compensate the owners of existing transmission assets
- Be simple and transparent

A. Embedded Cost Based

The embedded cost methods allocate the system total costs among the transmission users based on some ‘extent of use’ rule. Embedded cost is defined as the revenue requirements needed to pay for all existing facilities plus any new facilities added to the power system during the life of the contract for transmission service. In October, 1989 Shrimahammadi et al. [6], suggested MW-mile method to evaluate the wheeling charges. In this methodology transmission network capacity use for a transaction is a function of the magnitude of electric power, the length of the transmission lines and the type of facilities involved in the transaction. This capacity value provides an equitable means of allocating the cost of transmission facilities among users of the firm transmission service. In August 1996

Marangon [2], suggested a set of methods derived from MW-mile rule to allocate transmission fixed costs. Actually this attempt focuses on their main features and their ability to provide reasoning economic signals. An updated review of recent progress in November 2000 on the subject of usage-based transmission cost allocation is attempted by Jiuping et al. [26]. It has presented some basic conclusions and observations. In the same year Lee et al. in [28] suggested a next version of MW-mile method i.e. Vector Absolute Mega-Watt Mile (VAMM) and along with that a numerical example is provided to illustrate the method. Authors also discussed and compared several commonly used wheeling calculation methods followed by utility companies. In the year 2001 Ching-Tzong, et al. [29], introduced an up gradation of MW-Mile method, a new wheeling pricing technique called MVA-KM method, which applies to AC power flow and considers apparent power. This proposed approach is more reasonable and valid than the commonly used MW-MILE method which is based on DC power flow. But this method doesn't workout correct pricing results with dispersed generation. This fact is being discussed in section V. Further in 2004 Hur et al. [32] expanded upon the concept of MW-mile method. This study also goes beyond previous work including an analysis of the relative reliability contributions of each generator to the unscheduled transmission capacity in a circuit. This leads to the effective and efficient recovery of all embedded costs, assuming that all transmission users are responsible to pay for both the actual capacity-use and the transmission of reserves from a reliability standpoint.

Different from MW-mile method, in January 1995, Farmer, et al. [9] suggested an optimal pricing strategy for the allocation of capacity and operational costs for transmission. They have been also formulated and evaluated wheeling services in electricity supply. The methodology takes full account of prevailing generation costs and capacities as well as the distribution of the demand in space and time. Further in August, 1996 by Perera et al. [10] described a methodology on time-of-use basis for evaluating an optimal set of transmission prices, which are charged for the use of a transmission system to maximize the global benefit of using the transmission system.

For evaluating flows of electricity through power networks J. Bialek [16], in July 1996 proposed a method which became an icon of tracing flow methods and known as Bialek's tracing method. It allows quantifying how much of the active or reactive power flows from a particular source to a specific load. It also allows quantifying the contribution from each generator or load to flows and losses in a given line. By the same author J. Bialek [27], in April 2000 proposed another tracing flow methodology known as unifying tracing-based methodology of transmission pricing for inter-system trades. The methodology can handle any pricing methodology used within each country. It is simple, transparent and very fast and it can deal effectively with circular flows. Wang and Furong [33] calculated wheeling charges with power flow based MW-Mile approach, where the power tracing from each generator is carried out using the Bialek's tracing method [16]. It uses genetic algorithms as the dispatch algorithm for the economic environmental dispatch problem, considering the wheeling charges. On the same concept of tracing flows a transmission and wheeling pricing method based on the monetary flow tracing along power flow paths: the monetary flow-monetary path method is proposed by Gang, et al. [37], in 2005. Most of the published literatures only discuss either transmission pricing or wheeling service pricing but this method introduces a uniform measurement for transmission service/wheeling service usages by active and reactive powers. By using Bialek's tracing method [16] Ahiakwor et al. [42] have developed an algorithm which will ensure a major practical implementation of fair rules in the allocation of transmission line pricing and usage in the Nigerian electricity industry.

In February 1997 Kirschen et al. [17], proposed an algorithm which is based on the solution of a series of load flows, identifying buses that are reached by the power generated in each generator. Then, the method groups all the buses supplied by the same generators. Assuming proportionality, it is possible to calculate the contribution of each generator to the loads and to the line flows and then transmission pricing can be evaluated. This method is known as

Kirschen's method. Same author, Kirschen and another author Strbac [23], in November 1999 proposed a method for determining how much of the active and reactive power output of each generator is contributed by each load. In this all power injections are translated into real and imaginary currents. These current contributions can then be translated into contributions to the active and reactive power output of the generators. In November 2001 Wen-Chen et al. [30], derived the wheeling cost functions from-bus matrix and represented the functions as the function of power output for each unit. The proposed method can fully reflect the extent-of-use of transmission facilities in the system. It is noticed that a higher wheeling charge may raise the total generation cost. This paper involves the real power and reactive power of both supply and demand sides. Whereas in 2006 Sood et al. [1] proposed a method which allocates in a non-discriminatory manner the embedded cost of transmission facilities among its users and provides the correct economical signals in a simplest possible way. The effect of reactive power flow caused by a transaction has also been taken into consideration, while allocating embedded cost. The results so obtained are found to be fair and of very much of practical use. Another new reactive power allocation method is proposed in 2007 by Mustafa and Shareef [41]. In this paper instead of power tracing, the algorithm traces real and imaginary currents to handle the problem of system losses and loop flows. The traces from current sources to current sinks are then converted to power contributions. The method is beneficial to resolve difficult reactive power pricing and costing issues which arise from the introduction of competition to ensure fairness and transparency.

In 2006 A. R. Abhyankar, et al. [38] proposed a tracing compliant approach for modified postage stamp allocation to overcome problem of postage stamp method which is actually unfair to those who make limited usage of the network. It is observed that the tracing compliant postage stamp method achieves fairness to both small and large users of the network. Recently in 2009 Lima, [43] has given a comparison of the main methods of network cost allocation present in different literatures. It analyses the main characteristics of several methods and give recommendations for their use in different situations. Actually work is devoted to study and discussing the main methods to solve the network cost allocation problem both for generators and demands.

B. Marginal or Incremental Cost Based

Since the transmission system is subject to the economics of scale, short-run operation marginal system revenues implicitly resulted from the spatial discrimination of spot prices cannot recover all investment, operation, maintenance and development costs alone. Marginal cost is the revenue requirements needed to pay for any new capacity on the transmission business. Whereas incremental cost can be defined as the revenue requirements needed to pay for any new facilities that are specifically attributed to the transmission service customer. These facilities must be identified for all years across the life of the contract for transmission service. Marginal transmission pricing or marginal wheeling rates are sometimes called an extension of spot-pricing theory. Spot pricing is a method for pricing electricity that maximizes the economic efficiency of the power system. Liam et al. [3] derived an expression for the spot prices in a radial distribution system, in terms of system quantities such as power line flows in February 1994. Other contributions of this paper make a consideration of how the pricing computations are to be carried out, and how line flow limits are incorporated into the price expressions.

If marginal cost based pricing is used to price transmission services, an additional difficulty arises as the income will not be sufficient for financing the investment (past or future), given the economies of scale i.e. a supplement revenue generation is required. In this context in May 1995 Rudnick et al. [8] suggested need for the collection of a supplement to finance the transmission system above the marginal cost based pricing. Because pricing scheme is not able to support financially to transmission service providers. Author also describes the difficulties faced in allocating the supplement cost among parties involved. Alternative methods for defining the allocation have also been formulated. In November 1998 another paper by Choi et al. [18] presented a theory of social benefit maximizing real time price of real and reactive powers and provides its simulation results. The objective function, is the sum of participant's social benefit of participating in the electricity energy market, is the sum of benefit functions and cost functions of participants. This real time price of real and reactive powers smoothes the peak power demand and fills the valley of power demand. Further Rudnick et al. [19] in 1999 contributed with the formulation of alternative numerical approaches to implement the schemes, taking into account energy and capacity use of the system by participant agents. In this distribution factors based on DC power flows are the basic elements of the formulation. Authors suggested that depending on the service provided by transmission network, different allocation schemes can be formulated to condition transmission expansion and cost. But authors favor a scheme where energy use is the base to allocate transmission payments among agents. In 1999 an optimal pricing algorithm is presented by Muchayi and Hawary [21] which includes transmission costs beside generation costs in electricity supply and it has been formulated and evaluated. It has very wide potential applications and also derived prices send optimal messages to all participants. Other authors, in 1999 Oliveiraa, et al., [22] focused on the allocation of FACTS devices and their impacts on transmission charges. They suggested that operational costs (marginal cost) can be minimized with the inclusion of FACTS devices in an overloaded transmission system. Actually FACTS devices are able to change power flows by modifying the network parameters. Whereas in 2001 Somruedee and Chaiyut, [31] presented descriptive comparison that consists of the principle of conceivability, forecasting assumption, financial model including the tariff results based on marginal cost. In 2004 based on spot pricing strategy and marginal cost concepts, an approach was proposed by Yousefi and Seifi [35], in which active and reactive power transition costs were calculated while voltage dependent load models were observed. The authors said that they are in the process of considering frequency as a determining factor on active and reactive power pricing. In November 2007 a novel approach to an LRIC charging methodology proposed by Furong and David [39], to create a forward-looking, economically efficient pricing message to guide the development of the future generation and demand. Thus proposed approach seeks to reflect the cost of advancing or deferring future investment on a distribution or transmission network. Up to this, what so ever literature have been discussed that can be applicable to both transmission network as well as distribution network. But for distribution network in February, 2002 Lima, et al. [45] proposed a new distribution pricing scheme to fulfill the new economic requirements of electrical energy retail markets. It also provides a mechanism to enforce the efficiency and competition among the distribution companies because of the yardstick regulation.

C. Methods Evaluating Supplement Cost

These pricing methodologies include both the existing system cost and the incremental or marginal costs of transmission transactions in evaluating overall transmission charges. Since the transmission system is subject to the economics of scale, operation marginal system revenues Individual charges (locational) Real power loads charge (postage stamp) Reactive power loads implicitly resulted from the spatial discrimination of spot prices cannot recover all investment, operation, maintenance and development costs alone. To solve the problem other supplement payments are required. Under this paradigm Yu et al. [12] in February 1997 suggested an approach which distinguishes between operating and embedded costs and develops separate methods in respect of each of these components. In this capacity use as well as reliability benefits derived by different users are taken into account for disbursement of charges for investment recovery. New insights into the marginal pricing approach to the recovery of operating costs are also briefly mentioned. In May 1999 another paper by u and David [20], co-ordinates different pricing altematives to achieve an integrated pricing mechanism including appropriate price signals for bulk power users of the transmission system. It has also presented logical split amongst (a) embedded, (b) operating, and (c) expansion cost based pricing and pricing of transmission services. Further few methods have been deduced to evaluate supplement cost in conjunction with marginal or incremental cost based pricing. One of the methods as introduced by Bailek [13], in August 1997, a simple novel method of transmission supplement charge allocation based on topological analysis of power flows in the network. By the assistance of MW-Mile method it analyses the share, not the impact of individual loads and generators. This results in positive contributions from all the users hence withdraws the problem of counterflows. In August 1998 the same author J. Bialek [14], suggested another method to allocate the transmission supplementary charge to real as well as reactive power loads through MW- Mile methodology. In this the charge for usage of an individual transmission asset is split into a non-locational component, due to the unused capacity of the asset, and a locational component, due to actually used capacity of the asset as shown in Fig. 1. Further in February 2000 Rubio-Oderiz and Ignacio [25], evaluated numerically and qualitatively-three different allocation methods of the complementary charge: Marginal Participation Factors, Mean Participation Factors, and Benefit Factors. Whereas in February 2003, Maria and Saraiva, [46] presented an integrated approach to compute LTMP of distribution networks used to set tariffs for their use. This additionally deals with revenue reconciliation problem.

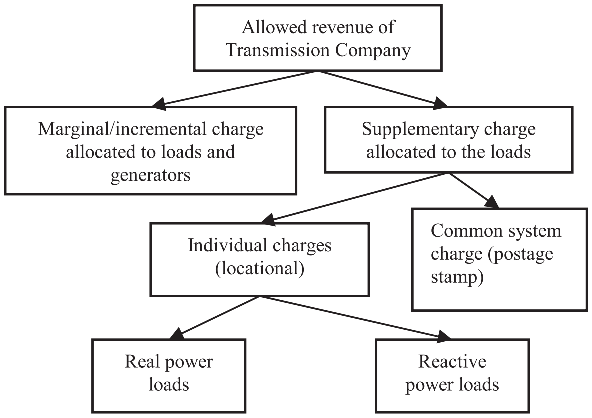

Figure 1 : Charging Strategy

III. WHEELING SERVICE PRICING METHODS (WITH DG)

The shortage of transmission system capacities along with the need for reliable power supply is causing an increased interest in Distributed Generation or Dispersed Generation (DG). Distributed generation offers significant benefits like grid reinforcement, reduction in power loss and on-peak operating costs, improvement in voltage profiles and load factors, deferment or elimination of system upgrades, improvement of system integrity, reliability and efficiency, lowers the nation's overall costs of producing and delivering power. It also promotes the development and use of renewable energy sources and fuel-efficient technologies, which could improve the quality of the air and the security of the nation's energy supply.

Thus distributed generation complements the central electricity supply infrastructure and allows further regional load growth on a fixed central generation and T&D asset base by increasing the central asset's utilization. The bulk of the energy demands, however, will still be satisfied by central station generation. The close matching of output and load is made possible by the modularity and scalability of distributed technologies. These alternative energy sources are becoming more cost reflective and many utilities are providing incentives for alternative power. A study to explore the applicability and cost-effectiveness of DG generation using few resources is explored in [4]. Whereas issues of small isolated power networks with DG is discussed in [5]. Placing these alternative energy sources, as well as other smaller traditional energy sources, on the distribution power system, allows the development of a new paradigm related to distributed generation. In this respect November 1998 Park et al. in [15] developed an analytical method, a variation of the embedded cost based methods (very similar to MW-mile method), to determine the wheeling costs at the buses where IPP's are connected without solving, a set of power flow problems. Individual participant's impact is determined by evaluating sensitivities of the flow wrt. power generation at all buses. Articles like [44], by Larry in 1998 help in giving alternatives for reducing renewable-based electricity transmission cost. Author has also discussed alternatives being considered for pricing transmission, provides qualitative impacts of those choices on renewable electricity transmission costs. Publication in 2001, [67] proposes a method based on circuit theory, a node based strategy from either seller or buyer's point of view is used to determine the branch current components contributed by each generator or load. Further that helps to allocate fixed cost of network.

Specifically the review [48], in March 2004 concerns the structure of the charging policies. It presents a comparison of tariffs applied in other countries and states, is intended as a guide to what alternatives may be considered. Tariffs levied are categorized by function for cross-comparison purposes. In 2004 & 2006, Vignolo and Sotkiewicz presented [49] & [50] the widely used nodal pricing scheme applied to distribution networks. Authors have shown that this economically efficient scheme provides better incentives for the deployment of DG than simple loss averaging. By which increased incentive arises since DG is paid for the reduction of losses and for the provision of reactive service. Same authors in 2006 [51] presented a new methodology for the allocation of fixed costs at the medium voltage distribution level. This methodology is "Amp-mile" or "I-mile", based on the widely used MW-mile for transmission networks. It uses power to current distribution factors in order to measure the extent of use imposed by customers to the network and therefore referred as the method for distribution networks. The advantage of this method is the price signals sent become stronger as network utilization increases. Same authors, Vignolo and Sotkiewicz in [53], 2007 summarizing [49], [50] and [51], i.e. examined the changes in distribution charges in moving from a tariff that averages the cost of losses and fixed network costs over all load to a cost-causality based tariff that uses nodal pricing to recover the cost of losses and the Amp-mile Method as proposed in [51] to recover fixed network costs through a locational charge based on the "extent of use" at the coincident peak. In 2006 Li et al. in [52] introduced, a new MW+MVAr-Mile charging methodology that takes into care the power factor as well as the leading or lagging nature of power factor by separating the MW and MVAr power flows. It acknowledges the full cost-benefit of network users, especially embedded generators. In February 2008 same authors [58] stated that the principle of MW+MVAr-Miles charging methodology, developed to reflect three key cost drivers in distribution network development:

1) The distance used to support nodal real and reactive power injection/withdrawal;
2) The degree of support offered by the network assets; and
3) The operating condition of the supporting assets in terms of their power factors.

As a consequence, it is able to provide forward-looking incentives for network customers to behave in a manner to better the network condition, which will in turn help to reduce the cost of future network development. On the same path May 2007 Wang and Furong [40] moved and proposed a LRMC MW+MVAR-Miles methodology which is capable of deriving economically efficient charges to encourage customers to improve the circuit's operating power factor and embedded generator to set up in more benefit location. By incorporating reactive power into the cost allocation, the charging model can fully recognize the cost and benefit introduced by potential users, either generator or demand. 2007 Lima [54], worked to diagnose the main drawbacks of current regulation of distribution pricing in Brazil. The main problem is related to the Distribution Usage Tariff (DUT) signal that is based on old concepts of a radial system. An alternate methodology is under construction and author has discussed in this paper. Whereas in February 2003, Maria and Saraiva, [46] presented an approach to compute LTMP of distribution networks used to set tariffs for their use. The formulation represents the long-term expansion planning problem in an accurate way using binary variables to represent investment decisions and fuzzy concepts to take into account load and dispersed generation uncertainties. LTMP display very good properties in terms of their stability, fairness, and ability to recover regulated costs to a larger extent. March 2004 a review document [47] sets out the Regulatory Impact Assessment (RIA) for the introduction of a new incentive scheme for electricity distribution network operators (DNOs) in respect of distributed generation. It proposed a framework for structure of electricity distribution charges. In 2007 Mutale, et al. [55] discussed distribution network pricing and the critical role that it plays in the economic and technical integration of distributed generation (DG) into power systems i.e. forward looking investment cost is proposed. Based on the same rational of forward or deferred of future investment in network asset in 2007 the research by Zhong and Lo [56], focuses on the mathematical formulation and case studies of a proposed charging methodology for optimal use and expansion of a distribution network, especially when the network contains Distributed Generation (DG). 2007 Bialek [57], paper discusses the main results and conclusions from the work commissioned by UK government's Department of Trade and Industry to quantify the effect of the proposed GB-wide transmission charging methodology on the future growth of renewable electricity so as to ascertain the impact on the likelihood of meeting the Government's 2010 renewable target. The charges were simulated until 2015. The conclusion was that a dispensation from high charges in Scotland, if applied, would not significantly change the level of UK renewable capacity. In the same direction [66] 2008 presents a new method for calculating the individual generators' shares in line flows, line losses and loads. This method takes care of reactive power along with active power. This method is claimed to be the least computationally demanding amongst all of the similar methods.

IV. RECENT TECHNIQUES

Few other methods are there which are different from above discussed methods. Actually the method that customers are charged for the use of the services is important. Most of the existing methods based their charges on the user's influence, like on

- The loadability of the system,
- The fixed assets involved in a specific path
- The marginal costs to dispatch an additional power unit.

Lo [24], in 2000 demonstrated that because of the TOA, who determines wheeling charges can be simulated or established by using co-operative game theory concepts. In the work two solutions concepts have been used: Nucleolus and Shapley value. Both try to search for a unique optimal solution allocation vector that satisfies all transmission facilities customer (players). Same on the game theory in 2004 Erli [36], proposed a scheme for cost allocation of transmission line expansion to tackle with congestion problem in the network. The cooperative games (Core and Nucleolus) concept of the participants in the equitable manner. Whereas in 2004 Inda et al. [34], presented a practical and fast solution to the problem of determining wheeling charges in the Mexican electrical system through a public web application. The model established in the Web Site allows potential investors to study different options for a possible service and select the most convenient one for them, without having to deal directly with the service suppliers, reducing time, costs and improving efficiency.

V. COMPARISON OF DIFFERENT METHODS ALLIED TO DG

In 2000 year Lee et al. in [28] suggested Vector Absolute Mega-Watt Mile (VAMM) and along with this, authors also compared several commonly used wheeling calculation methods followed by utility companies. Besides this in 2001, Tipmabutr and Chaiyut [31] presented a descriptive comparison that consists of principle of conceivability, forecasting assumption, financial model including the tariff results based on marginal cost. Specifically the review [48], in March 2004 concerns the structure of the charging policies. It presents comparison of tariffs applied in other countries and states, is intended as a guide to what alternatives may be considered. Here tariffs levied are categorized by function for cross-comparison purposes. In the year 2005 [37], Gang et al. given the advantages and disadvantages to find supplementary revenue by long run incremental (marginal) cost methodology and rolled in cost methodology. Recently in 2009, Delberis [43] has given a comparison of the main methods of network cost allocation present in different literatures. This paper provides an analysis of the main characteristics of several methods and given the recommendations for their use in different situations. In 2006, [52] quotes difference between MW-Mile method and its versions. Given that MVA-Miles method is an up gradation of methodology over MW-Miles, it considers the extent of use of the network by network users due to their active and reactive power injection/drawn. But main drawback of the MVA-Miles method is that it cannot distinguish the direction of real and reactive power flow. The method work well for demand and generation where they either withdrawn both real and reactive power or inject both. But in case of wind generators the MVA-Miles method fails to distinguish the difference in the direction of the same network user, resulting in misleading network charges. Because it injects real power and withdraws reactive power. Whereas the new MW+MVAr-Mile charging methodology not only takes care of the power factor of network users but also the leading or lagging nature of power factor. Firstly it separates the MW and MVAr power flows, and then acknowledges the full cost-benefit of network users, especially embedded generators. The author also gave the comparison with the MW-Miles and MVA-Miles methodologies.

Table I : Customer Characteristics with different Cases

	Customer 1	**Customer 2**	**Power flow over L_f (MVA)**
Case 1	14.28+j11.54	15.38+j19.43	29.68+j30.97=42.896
Case 2	-20+j20	29.66+j31.03	9.92+j51.13= 52.08

Table II : Use of Network Charges for Bus -2 Customers

Charging models	**Demand charges (£/year)**	**Generation charges (£/year)**	**Un-recovered recovered revenue**	**Un-recovered revenue (unit price)**
MW-Mile	77,763	0	159,000	392 £/MW/yr
MVA-Mile	113,490	0	123,270	£250 £/MVA/yr
MW+MVAr- Mile	111,310 MW: 46,041 MVAr: 65,271	0	125,450	£254 £/MVA/yr

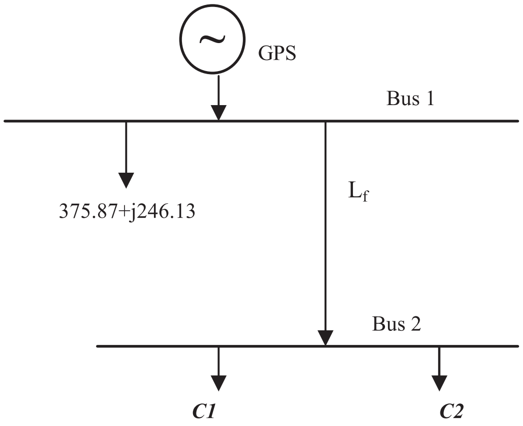

Figure 2 :. A base load flow on the reduced 2-busbar system.

The test system taken by author is a subset of the practical Western Power Distribution network with loads connected to buses at 132KV voltage level. The study illustrates the proposed charging principle by allocating network asset L_f cost to bus 2 customers and bulk customer according to their extent of use of the circuit. The annuity cost of circuit L_f is £236760/ yr, supporting 90MVA power flow. The basic diagram is shown in Figure 2.

Two test cases were derived representing changes in customer's nature of bus 2 customers: (1) demand users only; (2) demand and generator users, where the generator reduces the circuit's real power flow but increases its reactive power flow, this is shown in Table I.

A) Case 1

Case 1 is the base case only demand customers were connected to bus 2, where the charges to customers are based on the extent of the use of circuit L_f by the load customers. Pf of demand customer 1 is 0.77, while customer 2 has a pf of 0.62. Table II gives comparative network charges for the two demand customers at bus 2. It clearly shows that the MW-mile method can not distinguish the differences of two customer's power factor, simply impose the circuit cost according to the MW flow. Where both MVA-Mile and MW+MVAr-Mile methods acknowledge the poorer power factor of customer 2, hence accordingly penalize the customer. The MW+MVAr- Mile method and MVA-Mile method, provides same results because nature of customers are same. Only slight difference lies as MVA-Mile method treats real and reactive power the same, while MW+MVAr takes their respective true contribution according to flow direction.

B) Case 2

When embedded generators came into play the difference between MW+MVAr-mile and MVA-Mile charging methodologies becomes prominent. To demonstrate the benefit of the proposed charging methodology, an embedded wind generator was introduced at bus 2, while demand customers were grouped to one demand D. In this case, the generator's power output at the time of system peak is: 20-j20. From the load flow results it has been found that the real power drawn by the demand customers were reduced due to the injection caused by the generator. But the loading of the connected assets have increased by 21% due to reactive power drawn by the same generator. Table III gives the charges to both generation and demand customers in comparison with three charging methods.

When the MW-Mile methodology is adopted here, the cost due to the reactive power will be lost, leading to a favorable assessment for embedded generators. While the MVA-Mile methodology will ignore the real power contribution from the generator, network charges for its 20MW power injection, despite the power has been immediately consumed by its neighbor demand customer and has reduced net power flow of the circuit from the original 29.68 MW to 9.92 MW. This gives poor assessment of contribution from embedded generator. Thus author suggested the proposed MW+MVAr method is able to respect both cost and benefit of network users, in case of embedded generators. As network facility is not being used by embedded generator to transport its real power, therefore, no charges have been assigned to the generation customer for its real power provision; however, it uses the network to draw reactive power, hence charged for its use of the circuit to draw reactive power.

Table IV shows that authors have reviewed many publications and furnished inferences for different methods of wheeling pricing considering DG. It is an assessment surrounded by wheeling pricing methodologies showing trends in deregulated electricity market.

Table III : Use of Network Charges for Bus-2 Customers (generation and demand customers) in comparison with three charging methods

Charging models	Demand charges (£/year)	Generation charges (£/year)	Un-recovered recovered revenue	Un-recovered revenue (unit price)
MW-Mile	77,763	-52613	211,612	521.8 £/MW/yr
MVA-Mile	113,490	-74395	197,670	£401 £/MVA/yr
MW+MVAr- Mile	94,799 MW: 46,041 MVAr: 65,271	41,501 MW: -10,022 MVAR: 51,522	125,450	£254 £/MVA/yr

Table IV : Comparison of charging methods

Methods	Postage stamp	MVA-Mile	MW+Mvar-Mile	Tracing flow methods	Amp-Mile
Easy in Implementation	Easy	Easy	Easy	Easy	Easy
True Signals pricing	No	No	Try to	No	Yes (Current Sensitivity)
Reactive power-handling	No	Handles MVA Power	Yes	Yes (Few Methods)	Yes
Accounts Counter flows	No	Only MW flows	Yes	Yes (but not correctly)	Yes
Signal for DG sitation	No	No	Yes	No	Yes
Cross-subsidies	Allows	Allows	Allows	Allows	Avoids
Distance Wheeled consider	No	Yes	Yes	Yes	Yes

VI. WHAT DOES DG MEAN TO INDIA AND WHEELING SERVICE PRICING IN INDIA

Discussing about the Indian scenario in [62] there are about 1,12,000 villages yet to be electrified, which do not have a single grid electricity pole anywhere near [63]. These remote villages are characterized by the features such as:

- Inaccessible location, 3 to 30 km away from existing grid,
- Number of households range from 2 to 200,
- Power demand is quite low,
- Transport and communication facilities are minimal,
- Income levels and paying capacities are low [64].

Thus above state of affairs suggests deployment of DG's in India because requirement of on-site generation / distributed generation (DG) using local resources with high potential can help in the process of complete electrification of villages. The shortage of transmission system capacities along with the need for reliable power supply is causing an increased interest in DG. These devices can be strategically placed in power systems for the advantages quoted in introduction by authors.

In India the regional postage stamp method is the present mechanism of allocation of transmission charges amongst various network users [61]. Though postage stamp method has served its purpose well till now. However, due to deregulation of electricity market, the flow patterns across the country have changed. Postage stamp method is more suited under the situations viz. when the geographical area in consideration / the electrical network is relatively small, flows are simple and do not cause parallel flows for intervening / electrically contiguous regions and when need of simplicity and social acceptability is required over economic efficiency. In the changed deregulated market circumstances regional postage stamp method is overwhelmed with problems of pancaking of transmission charges which deter economy trades across regions and hence prevents competition and efficient use of resources. Further, regional postage stamp method does not satisfy the efficiency requirements of the National Electricity Policy, which require transmission prices to be distance and direction sensitive, independent of Bulk Power Transmission Agreements and reflect the utilization of the network by each network user. In India it is requisite to put into practice new charging methods based on real flows taking place in the circuit, as followed in other countries which go with deregulation electricity market.

As given in [51] charging methodology based on Amp-Mile method suits to Indian scenario since method gives true pricing based on PIDF's wrt active power as well as reactive power. It takes into account counter flows and avoids cross subsidies as not was done in currently used method Postage Stamp Method. This method also provides signals where to site DG's which is beneficiary for deregulation of Indian Power Sector to achieve reliability and efficiency of electricity market.

VII. CONCLUSION

This paper mainly reviews various transmission service pricing methods (without DG) and wheeling service pricing methods (with DG) proposed by different authors. Actually pricing is a complex issue in restructured electricity industry and it is impossible to have a single pricing methodology that can be used in all circumstances. Each methodology has its specific strengths and weaknesses. Thus different pricing methodologies are suitable for different circumstances and different requirements under which transmission services are being provided. In this context author has reviewed number of transmission / wheeling pricing methodologies with DG and without considering DG. Hence methodologies have been reviewed under different categorization like embedded cost methods, marginal / incremental cost methods, composite methods and few methods related to game theory.

As significance of DG is being increased due to the necessity of reliable and efficient operation of electric power industry, and as the presence of DG introduces additional supplying nodes and changes power flows therefore along with traditional methods of pricing new methods also have been reviewed which takes into account the pricing of both active and reactive powers concerned to DG. Comparison of pricing methods is also given allied to DG suggesting the suitability of pricing methods. Authors furnished inferences amongst implemented methodologies. Also raised the problems of non-electrified India as well as reviewed the advantages and disadvantages of existing pricing method (postage stamp method) in India and also suggested a method to be implemented in India out of reviewed publications.

REFERENCES

1. Yog Raj Sood, Narayana Prasad Padhy and H. O. Gupta, “A New Method for Allocating Embedded Cost of Transmission under Deregulated Environment of Power system”, 2006 IEEE.
2. J W Marangon Lima “Allocation of Transmission Fixed Charges: An Overview” IEEE Transactions on Power Systems, Vol. 11, No. 3, August 1996.
3. Liam Murphy, R. John Kaye and Felix F. Wu “Distributed Spot Pricing in Radial Distribution Systems,” IEEE Transactions on Power Systems, Vol. 9. No. 1, February 1994.
4. Yan Li and George Gross, “Production Cost Analysis of Dispersed Generation Options in a Transmission-Constrained Load Pocket of an Interconnected System,” IEEE Transactions on Power Systems, Vol. 19, No. 1, March 2004.
5. M. B. Sivapriya, S. V. Kulkarni and R. Banerjeer, “Issues of Small Isolated Power Networks with Distributed Generation” Fifteenth National Power Systems Conference (NPSC), IIT Bombay, December 2008.
6. D. Shrimohammadi, Paul R. Gribik, Eric T.K. Law, James H. Malinowski, and Richard E.O’Donnell, “Evaluation of Transmission Network Capacity Use For Wheeling Transactions”, Pacific Gas and Electric Company San Francisco, California, IEEE Transactions on Power System, Vol. 4, October 1989.
7. R.R. Kovacs, Allen L. Leverett “A load flow based method for calculating embedded incremental and marginal cost of transmission capacity”, IEEE Transaction on Power System, Vol. 9, No. 1, Feb.1994.
8. H.Rudnick, R. Palma, J.E.Fernandez, “Marginal Pricing and Supplement Cost Allocation in Transmission Open Access”, IEEE Transactions on Power System, Vol. 10, No. 2, May 1995.
9. E.D. Farmer, B.J.Cory, B.L.P.P.Perera, “Optimal Pricing of Transmission and Distribution Services in Electricity Supply”, IEE Proc.-Gener. Transm. Distrib., Vol. 142, No. 1, January 1995.
10. B.L.P.P. Perera E.D. Farmer B.J. Cory, “Revenue Reconciled Optimum Pricing Of Transmission Services” IEEE Transactions on Power Systems, Vol. 11, No. 3, August 1996.
11. D Shirmohammadi, Xisto Vieira Filho and Boris Gorenstin, M.V.P.Pereir, “Some Fundamental Technical Concept About Cost Based Transmission Pricing,” IEEE Transactions on Power Systems, Vol. 11, No. 2, May 1996.
12. C.W. Yu, A.K. David, “Pricing Transmission Services in the Context of Industry Deregulation” IEEE Transactions on Power Systems, Vol. 12, No. 1, February 1997.
13. J. Bailek, “Topological Generation And Load Distribution Factors For Supplement Charge Allocation Transmission Open Access”, IEEE Transaction on Power Systems, Vol. 12, No. 3, August 1997.
14. J. Bialek, “Allocation of Transmission Supplement Charge to Real and Reactive Loads,” IEEE Transaction on Power Systems, Vol. 13, No. 3, August 1998.
15. Y M Park, J B Park, J.-UK Lim and J R Won, “Analytical Approach for Transaction Costs Allocation In Transmission System,” IEEE Transaction on Power Systems, Vol. 13, No. 4, November 1998.

16. Bialek J., “Tracing the Flow of Electricity,” IEEE Proceedings on Generation, Transmission and Distribution, Vol. 143, Nº4, July 1996, pp 313-320.
17. Kirschen D., Allan R., Strbac G., “Contributions of Individual Generators to Loads and Flows”. IEEE Transactions on Power Systems, Vol. 12, No. 1, February 1997, pp 52-60.
18. J Y Choi, S H Rim and J K Park, “Optimal Real Time Pricing of Real and Reactive Powers” IEEE Transactions on Power Systems, Vol. 13, No. 4, November 1998.
19. H.Rudnick, M. Soto and R. Palma “Use of System Approaches for Transmission Open Access Pricing,” Electrical Power and Energy Systems, 1999(2)
20. C.W. Yu and A.K. David, “Integrated approach to transmission services pricing”, IEE Proc. Gener. Transm. Distrib., Vol. 146, No. 3, May 1999.
21. Maxwell Muchayi, M.E. El-Hawary, “A method for optimal pricing of electric supply including transmission system considerations,” Electric Power Systems Research 50 (1999) 43-46.
22. E.J. de Oliveiraa, J.W. Marangon Lima, J.L.R. Pereirac “Flexible AC transmission system devices: allocation and transmission pricing,” Electrical Power and Energy Systems 21 (1999) 111-118.
23. Daniel Kirschen, Goran Strbac “Tracing Active and Reactive Power between Generators and Loads Using Real and Imaginary Currents,” IEEE Transactions on Power Systems, Vol. 14, No. 4, November 1999.
24. K. L. Lo, Carlos A. Lozano, Juan M. Gers O, “Game Theory Application for Determining Wheeling Charges,” Electric Utility Deregulation and Restructuring and Power Technologies, Proceedings, International Conference, April 2000, IEEE, Page(s):308 - 313.2000 IEEE.
25. Fco. Javicr Rubio-Oderiz and Ignacio J. Perez-Arriaga, “Marginal Pricing of Transmission Services: A Comparative Analysis of Network Cost Allocation Methods,” IEEE Transaction on Power System. Vol. 15, NO.1, Feb. 2000.
26. Jiuping Pan, Yonael Teklu, Saifur Rahman and Koda Jun, “Review of Usage-Based Transmission Cost Allocation Methods under Open Access” IEEE Transactions on Power Systems, VOL. 15, No. 4, November 2000.
27. Janusz W.Bialek, “Tracing-Based Unifying Framework for Transmission Pricing of Cross-Border Trades in Europe,” IEEE, April, 2000.
28. W.J.Lee, C. H. Lin and L. D. Swift, Wheeling Charge Under a Deregulated Environment,” IEEE, 2000.
29. Ching-Tzong Su, Ji-Horng Liaw, “Power Wheeling Pricing Using Power Tracing and MVA-KM Method,” IEEE, 2001.
30. Wen-Chen Chu, Bin-Kwie Chen, and Neng-Sheng Hsu, “The Economic Dispatch With Consideration of Transmission Service Charge for a Generation Company,” IEEE Transaction on Power Systems, Vol.. 16, No. 4, November 2001.
31. Ms. Somruedee Tipmabutr and Mr. Chaiyut Krurungrodrat, “Comparison Study of Transmission Pricing Techniques in Thailand,” 2001 IEEE.
32. Don Hur, Jong-Keun Park, Won-Goo Lee, Balho H. Kim and Young-Hwan Chun, “An alternative method for the reliability differentiated transmission pricing,” Electric Power Systems Research 68 (2004) 11-17.
33. Ji Wang and Furong Li, “Optimal Economic Environmental Dispatch Considering Wheeling Charge,” 39th International Universities Power Engineering Conference, September 2004, University of the West of England (UWE), Bristol, UK.
34. Adrián Inda, Gustavo Bravo and Federico Flores, “Web Site To Determine Wheeling Charges In The Mexican System,” 2004, IEEE. [35] G. R. Yousefi and H. Seifi, “Wheeling Charges with Consideration of Consumer Load Modeling” 2004, IEEE.
36. Ge Erli, Kazuhiro Takahasi, Luonan Chen and Ikuo Kurihara, “Transmission expansion cost

allocation based on cooperative game theory for congestion relief," Electrical Power and Energy Systems 27 (2005) 61-67.

37. Duan Gang, Zhao Yang Dong, Wei Bai and Xin Feng Wang, "Power flow based monetary flow method for electricity transmission and wheeling pricing," Electric Power Systems Research 74 (2005) 293-305.

38. A. R. Abhyankar, S. A. Soman, and S. A. Khaparde, "Allocation of Fixed Transmission Costs by Tracing Compliant Postage Stamp Method," Proceedings of the 7th International Power Engineering Conference, Singapore, 29 November-2 December 2005, 1-6. [39] Furong Li and David L. Tolley, "Long-Run Incremental Cost Pricing Based on Unused Capacity," IEEE Transaction on Power Systems, Vol. 22, No. 4, November, 2007.

40. Ji WANG and Furong LI, "LRMC Pricing Based on MW+MVAR-MILES Methodology in Open Access Distribution Network," C I R E D, 19th International Conference on Electricity Distribution Vienna, 21-24 May 2007.

41. Mohd. Wazir Mustafa and Hussain Shareef, "Unbundling Generators' Reactive Power Output in a Competitive Market by Using Graph and Circuit Theory," ELEKTRIKA, VOL. 9, NO. 1, 2007, 42-47. [42] C. O. Ahiakwor, U. C. Chukwu and D. O. Dike, "Optimal Transmission Line Pricing Algorithm for a Restructured Power System," 2008, IEEE.

43 Delberis A. Lima, Antonio Padilha-Feltrin, Javier Contreras, "An overview on network cost allocation methods," Electric Power Systems Research 79 (2009) 750-758.

44. Larry Prete "Transmission Pricing Issues For Electricity Generation From Renewable Resources," Energy Information Administration/ Renewable Energy Annual 1998 Issues and Trends.

45. J. W. Marangon Lima, J. C. C. Noronha, H. Arango, and P. E. Steele dos Santos, "Distribution Pricing Based on Yardstick Regulation," IEEE Transaction on Power Systems, Vol. 17, No. 1, February 2002.

46. Maria Teresa Ponce de Leão and João Tomé Saraiva, "Solving the Revenue Reconciliation Problem of Distribution Network Providers Using Long-Term Marginal Prices, " IEEE Transaction on Power Systems, Vol. 18, No. 1, February 2003.

47. Electricity Distribution Price Control Review, "Regulatory Impact Assessment for Distributed Generation and Structure of Distribution Charges," March 2004.

48. "Electricity Tariff Structure Review: International Comparisons," An Information Paper, CER, March 2004.

49. J. Mario Vignolo and Paul M. Sotkiewicz, "Distribution Network Loss Allocations with Distributed Generation Using Nodal Prices," IASTED International Conference in Power and Energy Systems, 7. Proceedings. Clearwater Beach, FL, USA. - Nov 2004

50. Paul M. Sotkiewicz and Jesus M. Vignolo, "Nodal Pricing for Distribution Networks: Efficient Pricing for Efficiency Enhancing Distributed Generation," IEEE Transactions on Power Systems, Volume 21, Number 2, page 1013-1014 - May 2006.

51. Paul M. Sotkiewicz and J. Mario Vignolo, "Allocation of Fixed Costs in Distribution Networks With Distributed Generation," IEEE Transaction on Power Systems, Vol. 21, No. 2, May 2006.

52. F. Li, N.P. Padhy, J. Wang and B. Kuri, "MW+MVAr-Miles Based Distribution Charging Methodology," 2006 IEEE.

53. Paul M. Sotkiewicz and J. Mario Vignolo, "Towards a Cost Causation Based Tariff for Distribution Networks with DG," IEEE Transactions on Power Systems, Volume 22, Number 3, page 1051—1060 -Aug 2007.

54. J. W. Marangon Lima (SM) , "Integrating Spatial and Temporal Aspects in Distribution Pricing: the Brazilian Experience," 2007 IEEE.

55. J. Mutale, G. Strbac and D Pudjianto, “Methodology for Cost Reflective Pricing of Distribution Networks with Distributed Generation,” 2007 IEEE.

56. Xiaotao Zhong, and Prof. K.L. Lo, “Proposed charging method for distribution networks with distributed generation,” UPEC 2007-1024.

57. J. W. Bialek, “Transmission charging and growth of renewable in the UK,” 2007 IEEE.

58. Furong Li, Narayana Prasad Padhy, Ji Wang, and Bless Kuri, “Cost-Benefit Reflective Distribution Charging Methodology,” IEEE Transaction on Power Systems, Vol. 23, No. 1, February 2008.

59. Chapter 3, “The Benefits and Risks of Distributed Generation”, Prospects for Distributed Electricity Generation, September 2003.

60. Richard Green, “Electricity transmission pricing: an international comparison,” Utility Policy, Vol. 6, No.3, pp, 177-184,1997, Elsevier Science Ltd.

61. Central Electricity Regulatory Commission, “Formulating Pricing Methodology for Inter-State Transmission in India,” Approach Paper, May 15, 2009.

62. M.B.Sivapriya, S.V.Kulkarni and R. Banerjee, “Issues of Small Isolated Power Networks with Distributed Generation,” Fifteenth National Power Systems Conference (NPSC), IIT Bombay, December 2008.

63. M.R.Nouni, S.C.Mullick and T.C.Kandpal, “Providing electricity access to remote areas in India: An approach towards identifying potential areas for decentralized electricity supply,” Renewable and sustainable Energy Reviews, Vol. 12, No. 5,pp. 1187-1220, June 2008. [64] E.V.R. Sastry, “Village electrification programme in India,” Third World Conference on Photovoltaic Energy Conservation, Osaka, Japan, May 11-13, 2003.

65. S.V.Kulkarni, S.A.Khaparde, and A.P. Agalgaonkar, “Optimal placement and penetration level assessment of DG in Medium Voltage distribution system,” Power Systems 2003: Distributed Generation and Advanced Metering, Clemson, USA, March 12-14, 2003. [66] S. Abdelkader, “Determining generators’ contribution to loads and lineflows & losses considering loop flows,” Electrical Power and Energy Systems 30 (2008) 368-375.

67. Ya-Chin Chang, Chan-Nan Lu, “An electricity tracing method with application to power loss allocation,” Electrical Power and Energy Systems 23 (2001) 13-17.

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