THE
UNIVERSITY OF
STRATHCLYDE
IN GLASGOW

MW-Mile Charging Methodology for Wheeling Transaction

A thesis submitted for the degree of
Doctor of Philosophy
at the University of Strathclyde

By

Mohammad Yusri Hassan

(B.Eng. and M. Eng.)

Supervisor: Professor K. L. Lo

Power System Research Group
Department of Electronic and Electrical Engineering
University of Strathclyde
Glasgow, United Kingdom
June 2004

Declaration of Author's Right

DEDICATION

TO

MY BELOVED FATHER

WHO DID NOT LIVE LONG ENOUGH TO SEE MY ACHIEVEMENTS

ABSTRACT

Deregulation of the electric utility industry has taken place in many countries. This resulted in the unbundling of the vertically integrated utilities into separate generation, transmission and distribution businesses. Since then, the pricing of the use of transmission system has become one of the major issues. The issue concerns the way the cost of transmission services is satisfactorily allocated among the involved parties. In the context of the transmission utilities, the issue is how the cost of transmission service can be recovered while in the customers of transmission services point of view, the issue is how such services can be offered at the most reasonable price. Several strategies for pricing the use of transmission services have been proposed but there is no clear evidence on which one is better in providing adequate economic signal to the different parties.

This thesis introduces a new approach called Negative Flow Sharing Approach to allocate the wheeling transaction charges among the users in transmission services. The proposed approach was developed using the properties of MW-mile method but taking into consideration the economic benefits of both trading parties through analysing their shares in negative power flow or counter flow. This approach is incorporated with the Justified Distribution Factor and an Incremental Absolute Approach to form a better wheeling charge allocation scheme that can overcome the problem that arises due to the allocation method, identification of counterflow users and revenue reconciliation of transmission services.

Four case studies which are based on the 5 bus system, 9 bus system, IEEE-14 bus system and the 6 bus system were used in order to evaluate its concept and application. This thesis concludes with discussions on the case studies results by highlighting the merit of the proposed approach over the existing MW-mile approaches in providing sufficient return revenue to the transmission owner as well as a fair charge to the transmission user regardless of transaction arrangements and locations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor, Prof. K. L. Lo, Head of the Power Systems Research Group (PSRG), University of Strathclyde for his supervision and valuable guidance and patience throughout my research work.

My appreciation also goes to my sponsor, Universiti Teknologi Malaysia for their full financial support throughout my research work.

Special thanks to Richard Lavender, Andrew Truswell and James Kite from the NGC, UK, Orla Thunder from the ESBNG, Republic of Ireland, Doug Evans from ERCOT and Julie Bernt from the Federal Energy Regulatory Commission (FERC), USA for their cooperation in providing a useful information for my research work.

Many thanks to all my colleagues at PSRG who helped directly of indirectly in the accomplishments of my research work.

Finally, my unlimited appreciation to my family especially my mother, my wife, my daughter and my sisters for their encouragement, love, inspiration and understanding during the period of my study.

GLOSSARY OF TERMS

AC	Alternating Current
ACS	Average Cold Spell
BB	Branch Based transmission service
BSC	Balancing and Settlement Code
BSUoS	Balancing Services Use of System
CAISO	California ISO
CIS	Chilean Central Interconnected System
DC	Direct Current
DCLF	DC Load Flow
EC	Embedded Cost
ERCOT	Electric Reliability Council of Texas (USA)
ESBNG	Electricity Supply Board National Grid (Republic Ireland)
FTR	Fixed Transmission Rights. FTR is a purchased right that can hedge congestion charges on constrained transmission paths. It provides FTR owners with a right to transfer an amount of power over a constrained transmission path for a fixed price.
GGDF	Generalised Generation Distribution Factor
GLDF	Generalised Load Distribution Factor
GSDF	Generalised Shift Distribution Factor
ICRP	Investment Cost Related Pricing
ISO	Independent System Operator. ISO is central entity to have emerged in all deregulated markets with the responsibility of ensuring system security and reliability, fair and equitable transmission tariffs and providing for other system services.
NE-ISO	New England ISO (USA)
JDF	Justified Distribution Factor
LUF	Line Utilisation Factor
LMP	Locational Marginal Price
LRMC	Long Run Marginal Cost

LRIC	Long Run Incremental Cost
MP	Marginal Price
NGC	National Grid Company (UK)
OPF	Optimal Power Flow
PFD	Power Flow Decomposition
PJM	Pennsylvania, Jersey, Maryland Power Pool (USA)
PTDF	Power Transfer Distribution Factor
PTP	Point-to-Point transmission service
PUCT	Public Utility Commission of Texas
PX	Power Exchange. PX is a new marketplace to trade energy and other services in the competitive manner
RPAF	Reactive Power Adjustment Factor
RPI	Retail Price Index
SHETL	Scottish Hydro Electric Transmission Limited (UK)
SPP	Southwest Power Pool, Inc.(USA)
SPTL	Scottish Power Transmission Limited (UK)
SRIC	Short Run Incremental Cost
SRMC	Short Run Marginal Cost
TCOS	Transmission Cost of Service
TNUoS	Transmission Use of System
TO	Transmission Owner
TRR	Transmission Revenue Requirement
VAMM	Vector Absolute Megawatt Mile

CHAPTER 1

INTRODUCTION

1.1 Introduction

Electric utility industry in many countries has been deregulated to further increase its competitiveness, such as efficiency and cost reduction in power generation, transmission and distribution. With deregulation, this industry would work in three major independent businesses, i.e. generation, transmission and distribution respectively. Among these, a transmission company plays a major role since it involves in the determining of charges due to the wheeling transactions. In the past, wheeling transactions have accounted for a small portion of the overall transmission network capacity usage. However, recent trends towards unbundling of electric services have resulted in renewed interest in pricing of transmission services, particularly as it relates to wheeling transactions [4].

Wheeling transaction is defined as the transmission of electric power for other entity(ies) by a utility that neither generates nor intends to use the power as a system resource for meeting its own native load. The receipt and delivery of the wheeled power must be simultaneous. At least three parties are involved in a wheeling transaction: a seller, a buyer and one or more wheeling utilities that transmit the power from the seller to the buyer. The third party is paid for the use of its network.

Many methods have been used or proposed to evaluate the costs of transmission transactions or so called wheeling transactions. Most methods attempt at least two basic measurements: the amount of transmission capacity used and the per-unit cost of transmission capacity [5]. These methods can be classified into one of these categories; embedded cost, incremental or marginal cost. The concept of these methods has been discussed by some of the authors [1,3,5,6] to show their ability to provide reasonable economic signal. Economic theory stipulates that goods and services should be charged on the marginal cost basis. It has been found, however, that the short-run marginal cost (SRMC) pricing of transmission service is highly volatile, fails to recover the total incurred networks costs and provides perverse economic signals for the transmission company [7,8]. On the other hand, establishing the long-run marginal cost (LRMC) pricing is a formidable task and depends on a number of assumptions about costs and scenarios of expansion [6]. For these reasons, the embedded cost methods are used commonly throughout the utility industry. This method offered several benefits, i.e. practical and fair to all parties and easy to measure and provides an adequate remuneration of transmission systems. However it also has some drawbacks, i.e. it does not reflect the degree to which these facilities are over-utilised or under-utilised and does not provide efficient means to allocate resources to relieve constrained transmission capacity.

There are four types of embedded cost methods extensively used to allocate the transmission transaction cost namely, postage stamp method, contract path method, distance based MW-mile method and power flow based MW-mile method.

In postage stamp method, the transmission charges are allocated based on an average embedded cost and the magnitude of transacted power. This method is popular because of its simplicity, however it ignores the actual system power flows. The contract path method, on the other hand, based upon assumption that the transaction is confined to flow along a specified electricity continuous path throughout the wheeling company's transmission system. The embedded capital costs, correspondingly are limited to those facilities lie along this assumed path. A drawback with the method is that the actual path taken by the transaction does not flow only along the specified contract path but also involves the use of other transmission paths outside the contracted one. As a result it affect the cost of transmission system outside the contract path. The distance based MW-mile method allocates the charges based on magnitude of transacted power and the airline distance between the point of delivery and receipt. This method has also found to give incorrect economic signal to the wheeling participant. The airline distance does not indicate the actual transmission facilities involved in the transaction.

Power flow based MW-mile method is more commonly widely used since it has been shown to be more reflective of actual usage of the transmission system in allocating the transmission cost. This method allocates the charges for each wheeling participant based on the extent of use of transmission facilities by these transactions

[4,9,10,11,12]. These allocated charges are then added up over all transmission facilities to evaluate the total price for use of transmission system. Unlike the contract path and the postage stamp methods, this method considers the changes in MW flows due to the wheeling in all transmission lines of the wheeling companies, and the line length in miles. Two power flows executed successively, with and without the wheeling, yield the changes in MW flows in all transmission lines.

There are three different MW-mile approaches that can be used to determine the wheeling charges for a particular transaction, and these are classified as net, absolute and positive only approaches respectively [13-14]. Based on these three approaches, further modified methods such as Modulus Method, Zero Counterflow Method, Dominant Flow Method and other associated methods have been proposed to allocate the cost of the use of the system network as addressed in [1,15,16,17]. However, the MW-mile method based on absolute approach is the most popular among the transmission utilities since it promises sufficient revenue [18,19]. This approach has contended by the transmission users because it ignores the contribution of users for negative power flow or counter flow [19]. On the other hand, the other two approaches may not be easier for the transmission owner to accept because they could cause a transmission owner unable to receive appropriate revenue return if the transactions coincidently create many counter flows across the transmission network. It can be noticed that the reason why there is no such an agreement among the trading parties for the acceptance of the aforementioned approaches is because the benefit of a counterflow is received once only by one trading party. Therefore an alternative approach is required to be developed so that the benefit of the counterflow could be shared among the trading parties.

Meanwhile, the allocation method used to identify the contribution of individual generators and loads to line flows and the real power transfers between individual generators and loads is another important issue in wheeling transaction since it reflects the way the cost of transmission services is satisfactorily allocated among the trading parties. Different allocation methods have been proposed in recent years. A novel, topological distribution factor method which determines the share, as opposed to the impact of a particular generator or a load in every line flow is presented in

[20], which is based on tracing method. Although this method is conceptually very simple but it requires inverting a sparse matrix of the rank equal to the number of network nodes. In [21], another tracing method is presented which introduces new concepts such as domain, common, link and state graph and is suitable for large-scale power system applications. Furthermore in [22] graph theory is applied to solve the problem of power flow tracing with the proof of two lemmas to show the feasible condition for the suggested method which is also complex in procedure. However, as far as the allocation method is concerned, there are no clear declaration and proof of the implementation of these methods in the transmission utilities.

The only allocation method that is presently in widespread use in transmission utilities is the power transfer distribution factor (PTDF) [23,24,25 26]. This factor is also known as a shift factor, impedance factor or generalised shift distribution factor (GSDF). Unlike the topological distribution factor which is based on topological analysis of network flows and represents the share of a particular generation in the total line flow, the PTDF represents the impact of a particular generation on the line flow. This distribution factor which is based on DC power flow is developed by taking into account the physical parameters, i.e. reactance of the transmission network and hence is capable of allocating MW flows to lines or transformers with "reasonable" accuracy [27]. However it is dependent on the location of the reference bus, i.e. different reference bus yields different distribution factors. This could cost the time in generating the new distribution factors if users are allowed to use different reference buses to accommodate their transactions. The shortcoming of the PTDF that varies according to reference bus however has successfully been overcome with the new developed distribution factor which is known as Justified Distribution Factor (JDF). The development of this factor is used to implement the congestion curtailment in bilateral tradings [28]. In this thesis, the application of JDF is extended to estimate the contribution of the transmission user to line flows as well as identifying the counterflow lines.

This thesis aims to improve the present MW-mile approaches used for allocating wheeling transaction charges among the users in transmission services. The proposed approach is developed using the properties of the MW-mile method but taking into consideration the economic benefits of both trading parties through analysing their shares in negative power flow or counter flow. This approach is incorporated with the Justified Distribution Factor and an Incremental Absolute Approach to form a better wheeling charge allocation scheme. The results show that the proposed approach has merit over the existing MW-mile approaches in the context of revenue reconciliation of transmission services regardless of transaction arrangements and locations. The profit sharing concept introduced in the proposed approach provides a better economic signal in allocating charges for counter flow lines, which could benefit trading parties.

1.2 Contribution of the Thesis

The main original contributions of this thesis are as follows:

1) The development of a negative flow sharing approach to solve the counterflow pricing problem. This approach uses the profit sharing concept to distribute the benefit of the negative flow or counter flow created in the line flow to both the transmission owner and user. Based on a profit sharing factor r that has been set in the trading, the share for the charge due to counterflow can be calculated. The proposed approach is capable of allocating the wheeling charges for both single and multiple simultaneous transactions.
2) Introduce the use of Justified Distribution Factor in estimating the contribution of users in the line power flows as well as identifying the counterflow lines. It is capable of dealing with multi reference bus users.
3) Introduce the use of incremental absolute approach in determining the power flow impact. Unlike marginal approach, this approach, which considers the difference of power flow irrespective of the flow direction successfully recognised the actual amount of power flow that should be rewarded to a user due to the counterflow.
4) Based on the combination of 1), 2) and 3) above, a new wheeling charge allocation scheme is formed to provide a better and fair charge for both parties involved in the trading.

5) The thesis contains a review, supplemented by work examples, of the transmission wheeling charge in the United Kingdom, Republic of Ireland and the United States of America.

1.3 Organisation of the Thesis

This thesis consists of six chapters. Chapter 2 deals with the issues of cost and pricing of transmission services under deregulated environment. This chapter will discuss basic structure of transmission services that cover the type of services, objectives and the methodologies used to recover the costs of transmission. It also discusses several alternatives of the allocation methods that can be used to evaluate the usage of the transmission services and the pricing methods that is currently used or under consideration in transmission services. Issue of revenue reconciliation of transmission services and its allocation options are addressed at the end of the chapter.

In Chapter 3 the issues of use of system charges will be discussed, as it is related to the pricing of the transmission services. It focuses on UK's use of system charges methodologies, which covers the conceptual, the components associated with the charges and the charge allocation. This chapter also discusses the phenomena of wheeling and the cost associated with wheeling to highlight the significant of the wheeling charges as the components of use of system charges. The current wheeling charge methodology used by transmission utilities in the United Kingdom, Republic of Ireland and the United States of America are presented in this chapter. An example will be used to illustrate each of this wheeling charge methodology.

Chapter 4 describes the methodology and the mathematical model of the proposed approach for the use of system charges; wheeling charges. It focuses on the concept and formulation of the MW-mile methodology as it is related to the development of the proposed approach. This chapter will also discuss the methodology and the mathematical model of the Justified Distribution Factor and Incremental Absolute Approach which is incorporated into the proposed approach. An example and flow chart will be used to describe the significant of the proposed approach in providing a better wheeling charge allocation scheme.

Chapter 5 presents the simulation results of wheeling charges based on the proposed approach developed in Chapter 4. The proposed approach is tested for different transaction arrangements and locations in order to evaluate its capability to provide sufficient revenue return to the transmission owner as well as a fair charge to the transmission user. Four case studies which are based on the 5 bus system, 9 bus system, IEEE-14 bus system and the 6 bus system will be used for comparison purposes.

Finally, Chapter 6 presents the conclusion of the research work in the thesis and some recommendations for future research work. The data for the different bus systems, the distribution factors matrixes that have been used to estimate the line flows and the results for some case studies are given in the appendices.

1.4 Publications

The following publications have been accepted or are under review as a result of the research work.

1. K.L.Lo and M.Y.Hassan, "Positive and Negative Aspects of MW-Mile Method for Costing Transmission Transaction",37th International Universities Power Engineering Conference(UPEC), United Kingdom, Vol.1, pp. 358-362, Sept 2002.

2. K.L.Lo and M.Y. Hassan, "Revenue Reconciliation of Transmission Services using Negative Flow Sharing Approach", The 6th International Power Engineering Conference, IPEC 2003, Singapore, Vol. 1, pp. 521-526, Nov 2003.

3. K.L.Lo and M.Y. Hassan, "Assessment of MW-Mile Method for Pricing Transmission Services – A Negative Flow Sharing Approach", Submitted to IEE Proc. Gener. Transm. Distri., 2004.

1.5 References

[1] J.W. Marangon Lima, "Allocation of Transmission Fixed Charges: An Overview", IEEE Trans, on Power Trans on Power App. Systems, Vol. 11, No.3, August 1996, pp 1409-1418.

[2] W.J. Lee, C.H.Lin and L.D. Swift: "Wheeling Charge under a Deregulated Environment", IEEE Transactions on Industrial Applications, Vol. 37, Issue 1, Jan-Feb 2001, pp 178-183.

[3] H.H. Happ: "Cost of Wheeling Methodologies." IEEE Trans on Power Systems, Vol. 9, No.1, Feb 1994, pp.147-156.

[4] Shirmohammedi, D., Gribik, P.R., Law, E.T.K., Malinowaski, J.H. and O'Donnell, R.E.: "Evaluation of Transmission Network Capacity Use For Wheeling Transactions." IEEE Trans on Power Systems, Vol. 4, No. 4, Oct 1989, pp.1405-1413.

[5] Ross R. Kovac, Allen L. Leverett: "*A* Load Flow Based Method For Calculating Embedded, Incremental and Marginal Cost of Transmission Capacity", IEEE Trans on Power Systems, Vol. 9, No.1, Feb. 1994, pp. 272-278.

[6] D. Shirmohammedi, X. V. Filho, B. Gorenstin and M.V.P. Pereira: "Some Fundamental Technical Concepts About Cost Based Transmission Pricing" IEEE Trans on Power Systems, Vol. 11, No. 2,May 1996, pp.1002-1008.

[7] M.C. Calviou, R.M. Dunnet and P.H. Plumptree, "Charging for Use of a Transmission System by Marginal Cost Methods", Proc. Power System Computation Conference, Avignon, 1993.

[8] I.J. Perez-Arriaga, F.J. Rubio, J.F. Puerta, J. Arculuz and J. Marin, "Marginal Pricing of Transmission Services: An Analysis of Cost Recovery", IEEE Trans on Power Systems, Vol. 10, No.1, Feb. 1995, pp. 546-553.

[9] J. Bialek, "Topological Generation and Load Distribution Factors for Supplement Charge Allocation in Transmission Open Access", ", *IEEE Trans on Power Systems*, Vol. 12, No. 1, Aug 1997, pp.1185-1193.

[10] J. Bialek, "Allocation of Transmission Supplementary Charge to Real and Reactive Loads", ", *IEEE Trans on Power Systems*, Vol. 13, No. 3, Aug. 1998, pp.749-754.

[11] Y. Tsukamoto and I. Iyoda, "Allocation of fixed transmission cost to wheeling transactions by cooperative game theory", IEEE Trans. Power Systems, Vol. 11, May 1996, pp. 620-629.

[12] E.J. de Olivera, J. W. M. Lima and J. L. R. Pereira, "Flexible AC Transmission System Devices: Allocation and Transmission Pricing", Int. Journal of EPES, Vol. 21, Issue 2, Feb. 1999, pp. 111-118.

[13] Kankar Bhattacharya, Math H.J. Bollen and Jaap E. Daalder, "Operation of Restructured Power Systems", Kluwer Academic Publishers, 2001.

[14] H.V. Hitzeroth, D. Braisch, G. Herold and D. Povh, " Compensation, Stability and Losses in the Presence of Wheeling Transactions with use of FACTS Devices", IEEE Power Tech '99 Conference, Budapest, Hungary, 1999.

[15] J. W. Lima, M.V.F. Pereira and J.L. R Pereira " An Intergrated Framework for Cost Allocation in a Multi-Owned Transmission System", IEEE Trans, on Power Trans on Power App. Systems, Vol. 10, No.2, May 1995, pp 971-977.

[16] Y. M. Park, J.B. Park, J.U. Lim and J.R. Won: "An Analytical Approach for Transaction Costs Allocation in Transmission System", IEEE Trans on Power Systems, Vol. 13, No. 4, Nov 1998, pp.1407-1412.

[17] J. P. da Silva, J. T. Saraiva and M. T. P. de Leao, " Use of Power Flow Embedded Methods to Set Tariffs for Use of Networks – A Case Study Using The Portuguese Transmission Company", IEEE Porto Power Tech Conference, Porto, Portugal, 2001.

[18] ERCOT, "Vector Absolute Megawatt Mile", ERCOT Load Flow Task Force

[19] SPP, "Order Accepting Transmission Tarriff for Filling, as Modified and Conditioned ", available at website; http://www.spp.org/Objects/FERC_filings.cfm

[20] J. Bialek, "Topological generation and load distribution factors for supplement charge allocation in transmission open access", ", *IEEE Trans on Power Systems*, Vol. 12, No. 1, Aug. 1997, pp. 1185-1193.

[21] D. Kirschen, R. Allan and G. Strbac, "Contributions of individual generators to load and flows", ", *IEEE Trans on Power Systems*, Vol. 12, No. 1, Feb. 1997, pp.52-60.

[22] F. F. Wu, Y. Ni and P. Wei, "Power Transfer Allocation for Open Access Using Graph Theory- Fundamentals and Applications in Systems without Loopflow", *IEEE Trans on Power Systems*, Vol. 15, No. 3, Aug. 2000, pp.923-929.

[23] H. Rudnick, R. Palma and J.E. Fernandez, "Marginal Pricing and Supplement Cost Allocation in Transmission Open Access, ", IEEE Trans on Power Systems, Vol. 10, No. 2, May 1995, pp.1125-1142.

[24] H. Rudnick, M. Soto and R. Palma, "Use of System Approaches for Transmission Open Access Pricing, ", *Int. J. Electr. Power Energy Syst.*, 21,(2), pp.125-135, 1999.

[25] Ross Baldick, "Shift Factors in ERCOT Congestion Pricing", available at website:

http://www.ksg.harvard.edu/hepg/Papers/baldick_shift.factors.ercot.cong_3-5-03.pdf

[26] CAISO Market Operation, "Shift Factors: Methodology and Examples", available at website:

http://www.caiso.com/docs/09003a6080/06/ba/09003a608006ba92.pdf.

[27] A. Fradi, S. Brignore and B. F. Wollenberg "Calculation of Energy Transaction Allocation Factors", *IEEE Trans on Power Systems*, Vol. 16, No. 2, Aug. 2000, pp.923-929.

[28] Y.S.C. Yuen, K L Lo:"Simulation of Bilateral Energy Markets Using Matlab", International Journal of Computation and Mathematics on Electrical and Electronic Engineering, Vol. 22, No 2, 2003.