A STUDY ON TRANSMISSION USE OF SYSTEM (TUOS) CHARGING METHODOLOGY

WAN MUNIRAH BINTI WAN NAZULAN

A project report submitted in partial fulfilment of the requirement for the award of the Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

JANUARY 2014
ABSTRACT

United States was the first country that organizes the power system restructuring in their country. Restructuring should emphasize several factors, especially in terms of economic planning. Pricing method should be done carefully to give justice and fairly to the generation, transmission and distribution. This paper presents about the study on the Transmission Use of System (TUoS) charging methodology. It is discussed about the transmission usage evaluation methods, allocating the charges to the generations and users and proposed transmission pricing methodology. The efficiency operation of the transmission system is the key to the efficiency in these markets. From this study, a suitable usage allocation method is identified. The transmission service charge percentage is allocated between customers and generators. TRANSCO is the important element to transmit the electricity in high voltage power from GENCOs to DISCOs for delivery electricity to the customers. The contribution of the power flow for each line was been used to make the fairly between every elements in the proposed pricing methods. The transmission pricing methods are used in this case study are MW-mile method and postage stamp method. The transmission access pricing must be non discrimination, transparent, economically, efficiency and allow full recovery of costs. Finally, the transmission use of system charging methodology is tested on the 9-bus system and IEEE 14-bus system to evaluate it effectiveness providing a fair transmission charges to the users.
ABSTRAK

## CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>i</td>
<td></td>
</tr>
<tr>
<td>DECLARATION</td>
<td>ii</td>
<td></td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iii</td>
<td></td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
<td></td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
<td></td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>vi</td>
<td></td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
<td></td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiii</td>
<td></td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td>xiv</td>
<td></td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xvi</td>
<td></td>
</tr>
<tr>
<td>LIST OF APPENDICES</td>
<td>xvii</td>
<td></td>
</tr>
</tbody>
</table>

### CHAPTER 1  PROJECT OVERVIEW

1.1 Introduction 1
1.2 Problem statement 2
1.3 Objective 3
1.4 Scope 3
1.5 Thesis outline 4
CHAPTER 2 LITERATURE REVIEW

2.1 Restructured Power System 5

2.2 Concept of Restructuring Elements 6
  2.2.1 Independent System Operator (ISO) 6
  2.2.2 GENCOs 7
  2.2.3 TRANSCO 7
  2.2.4 DISCOs 8

2.3 Market Models in Restructuring Power System 8
  2.3.1 PoolCo Model 8
  2.3.2 Bilateral Contracts Model 10
  2.3.3 Hybrid Model 11

2.4 Transmission Sector 11
  2.4.1 Transmission Capital Cost 11
  2.4.2 New Transmission 12
  2.4.3 Re-Conductoring 12
  2.4.4 Areas Factor 13
  2.4.5 Substation Capital Costs 13
  2.4.6 System Operator and Maintenance Costs 13

CHAPTER 3 METHODOLOGY

3.1 Flowchart of the project 14

3.2 Transmission Usage Evaluation 16

3.3 Usage Allocation through Bialek Method 16
  3.3.1 Numerical Example of Bialek Method 19

3.4 Usage Allocation through Kirschen Method 21
  3.4.1 Numerical Example of Kirschen Method 22

3.5 Usage Allocation through Distribution Factor 25
  3.5.1 Generation Shift Distribution Factor (GSDF) 26
3.5.2 Generalized Generation Distribution Factors (GGDF) 26
3.5.3 Generalized Load Distribution Factors (GLDF) 27
3.5.4 Numerical Example of Distribution Factor Methods 28
3.6 Comparison between Three Different of Usage Allocation Methods 33
3.7 Allocating Percentage of Usage 34
3.8 Transmission Pricing Methods 35
3.8.1 MW-mile Method 36
3.8.1.1 Numerical Example of MW-mile method 39
3.8.2 Postage Stamp Method 45
3.8.2.1 Numerical Example of postage stamp method 45
3.9 Bus System 51

CHAPTER 4 RESULT AND ANALYSIS
4.1 Introduction 52
4.2 Test System 1: 9-Bus System 53
4.2.1 Result and Analysis 54
4.3 Test System 2: IEEE 14-Bus Test System 59

CHAPTER 5 CONCLUSION AND FUTURE WORKS
5.1 Conclusion 65
5.2 Recommendations 67

REFERENCES 68
APPENDICES A-C
## LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE NO</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Power flow contribution of generator using Bialek method</td>
<td>21</td>
</tr>
<tr>
<td>3.2</td>
<td>Power flow contribution of generator using Kirchen method</td>
<td>25</td>
</tr>
<tr>
<td>3.3</td>
<td>Bus data of 4-bus system</td>
<td>28</td>
</tr>
<tr>
<td>3.4</td>
<td>Line data of 4-bus system</td>
<td>28</td>
</tr>
<tr>
<td>3.5</td>
<td>Power flow contribution of generators using GGDF method</td>
<td>31</td>
</tr>
<tr>
<td>3.6</td>
<td>Power flow contribution of generator using GLDF method</td>
<td>33</td>
</tr>
<tr>
<td>3.7</td>
<td>Comparisons of three usage allocation methods</td>
<td>34</td>
</tr>
<tr>
<td>3.8</td>
<td>Data of generator 1 for 4-bus system</td>
<td>39</td>
</tr>
<tr>
<td>3.9</td>
<td>Data of generator 2 for 4-bus system</td>
<td>39</td>
</tr>
<tr>
<td>3.10</td>
<td>Comparison of transmission services charges for generator on different MW-mile approaches</td>
<td>43</td>
</tr>
<tr>
<td>3.11</td>
<td>Comparison on the locational tariff using three different methods</td>
<td>44</td>
</tr>
<tr>
<td>3.12</td>
<td>Comparison of transmission services charges for generator on different postage stamp approaches</td>
<td>49</td>
</tr>
</tbody>
</table>
3.13 Comparison on the locational tariff using three different methods

3.14 Total transmission cost of generator s and loads using MW-mile + postage stamp method

4.1 Total power flow for each line

4.2 Generators usage of transmission lines system

4.3 Loads usage of transmission lines system

4.4 Tariff for Generator using absolute MW-mile + postage stamp method

4.5 Tariff for Generators using dominant MW-mile + postage stamp method

4.6 Tariff for generator using reverse MW-mile + postage stamp method

4.7 Comparison on the tariff (MW-mile + postage stamp) for each generator using three different methods

4.8 Comparison on the total payment (MW-mile + postage stamp) for each generator using three different methods

4.9 Tariff for loads using absolute MW-mile + postage stamp method

4.10 Tariff for loads using dominant MW-mile + postage stamp method

4.11 Tariff for Loads using reverse MW-mile + postage stamp method

4.12 Comparison on the tariff (MW-mile + postage stamp) for each load using three different methods

4.13 Comparison on the total payment (MW-mile + postage stamp) for each load using three different methods

4.14 Tariff for Absolute MW-mile + postage stamp
method
4.15 Tariff for Dominant MW-mile + postage stamp method
4.16 Tariff for Reverse MW-mile + postage stamp method
4.17 Comparison on the tariff (MW-mile + postage stamp) for each generator using three different methods
4.18 Comparison on the total payment (MW-mile + postage stamp) for each generator using three different methods
4.19 Tariff for Absolute MW-mile + postage stamp method
4.20 Tariff for Dominant MW-mile postage stamp method
4.21 Tariff for Reverse MW-mile + postage stamp method
4.22 Comparison on the tariff (MW-mile + postage stamp) of each load using three different methods
4.23 Comparison on the total payment (MW-mile + postage stamp) for each load using three different methods
4.24 Total cost of transmission system using three different methods
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>PoolCo Market Model</td>
<td>9</td>
</tr>
<tr>
<td>2.2</td>
<td>One Sided Pool Model</td>
<td>9</td>
</tr>
<tr>
<td>2.3</td>
<td>Stack of Bids and Offers</td>
<td>10</td>
</tr>
<tr>
<td>3.1</td>
<td>Flowchart of TUoS</td>
<td>15</td>
</tr>
<tr>
<td>3.2</td>
<td>4-bus system</td>
<td>19</td>
</tr>
<tr>
<td>3.3</td>
<td>Transmission Pricing Method</td>
<td>36</td>
</tr>
<tr>
<td>3.4</td>
<td>Comparison total payment of generators</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>using three different methods</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Comparison total payment of generators</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>using three different methods</td>
<td></td>
</tr>
<tr>
<td>3.6</td>
<td>IEEE 14-Bus system</td>
<td>51</td>
</tr>
<tr>
<td>4.1</td>
<td>9-bus system</td>
<td>54</td>
</tr>
<tr>
<td>A</td>
<td>4-Bus Test System</td>
<td>Appendix A</td>
</tr>
<tr>
<td>B</td>
<td>9-Bus Test System</td>
<td>Appendix BI</td>
</tr>
</tbody>
</table>
# LIST OF SYMBOLS

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_i$</td>
<td>Set of nodes supplying directly node i</td>
</tr>
<tr>
<td>$P_{i,j}$</td>
<td>Line flow into node i in line j-i</td>
</tr>
<tr>
<td>$P_{Gi}$</td>
<td>Generation at node i</td>
</tr>
<tr>
<td>$I$</td>
<td>Number of bus</td>
</tr>
<tr>
<td>$J$</td>
<td>Bus supply power to i</td>
</tr>
<tr>
<td>$A_u$</td>
<td>Distribution matrix per injected power</td>
</tr>
<tr>
<td>$P_G$</td>
<td>Vector of bus generations</td>
</tr>
<tr>
<td>$P$</td>
<td>Vector of Bus flows</td>
</tr>
<tr>
<td>$\Delta F_{l-k}$</td>
<td>Change in active power flow between buses $l$ and $k$</td>
</tr>
<tr>
<td>$A_{l-k,i}$</td>
<td>A factor (GSDF) of a line joining buses $l$ and $k$ corresponding to change in generator at bus $i$</td>
</tr>
<tr>
<td>$\Delta G_i$</td>
<td>Change generation at bus $i$, with the reference bus excluded</td>
</tr>
<tr>
<td>$\Delta G_r$</td>
<td>Change in generation at the reference bus (generator) $r$</td>
</tr>
<tr>
<td>$F_{l-k}$</td>
<td>Total active power flow between buses $l$ and $k$</td>
</tr>
<tr>
<td>$F_{l-k}^0$</td>
<td>Power flow between buses $l$ and $k$ from the previous iteration</td>
</tr>
<tr>
<td>$D_{l-k,i}$</td>
<td>D factors (GGDF) of a line between buses $l$ and $k$ corresponding to generator at bus $i$</td>
</tr>
<tr>
<td>$D_{l-k,r}$</td>
<td>GGDF of a line between buses $l$ and $k$ due to the generation at reference bus $r$</td>
</tr>
<tr>
<td>$G_i$</td>
<td>Total generation at bus $i$</td>
</tr>
<tr>
<td>$C_{l-k,j}$</td>
<td>C factors (GLDF) of a line between buses $l$ and $k$ corresponding to demand at bus $j$</td>
</tr>
<tr>
<td>$C_{l-k,r}$</td>
<td>GLDF of a line between buses $l$ and $k$ due to the load at reference bus $r$</td>
</tr>
<tr>
<td>$R(u)$</td>
<td>Allocated cost to customer $u$</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>$C_k$</td>
<td>Cost of circuit $k$</td>
</tr>
<tr>
<td>$f_k(u)$</td>
<td>$k$-circuit flow caused by customer $u$</td>
</tr>
<tr>
<td>$\bar{f}_k$</td>
<td>$k$-circuit capacity</td>
</tr>
<tr>
<td>$\sum_{a l i k} C_k$</td>
<td>Total Cost</td>
</tr>
<tr>
<td>$R_i$</td>
<td>Locational charges $i$</td>
</tr>
<tr>
<td>$P_{Gi}$</td>
<td>Power served by generator $i$</td>
</tr>
<tr>
<td>$R_t$</td>
<td>Transmission price for transaction $t$</td>
</tr>
<tr>
<td>$P_t/P_{peak}$</td>
<td>Transaction $t$ load and the entire system load at the peak time of the peak load condition</td>
</tr>
</tbody>
</table>
**LIST OF ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DISCO</td>
<td>Distribution Company</td>
</tr>
<tr>
<td>ESBNG</td>
<td>ESB National Grid</td>
</tr>
<tr>
<td>GENCO</td>
<td>Generation Company</td>
</tr>
<tr>
<td>GSDF</td>
<td>Generalized Shift Distribution Factor</td>
</tr>
<tr>
<td>GGDF</td>
<td>Generalized Generation Distribution Factor</td>
</tr>
<tr>
<td>GLDF</td>
<td>Generalized Load Distribution Factor</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronic Engineering</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt</td>
</tr>
<tr>
<td>NGC</td>
<td>National Grid System</td>
</tr>
<tr>
<td>Tuos</td>
<td>Transmission Use of System</td>
</tr>
</tbody>
</table>
# LIST OF APPENDICES

<table>
<thead>
<tr>
<th>APPENDICES</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPENDIX A</td>
<td>4-Bus Test System</td>
</tr>
<tr>
<td>APPENDIX B1</td>
<td>Test System 1: 9 Bus Test System (Bus Data)</td>
</tr>
<tr>
<td>APPENDIX B2</td>
<td>Test System 1: 9 Bus Test System (Line Data)</td>
</tr>
<tr>
<td>APPENDIX C1</td>
<td>Test system 2: IEEE 14-Bus System (Bus Data)</td>
</tr>
<tr>
<td>APPENDIX C2</td>
<td>Test system 2: IEEE 14-Bus System (Line Data)</td>
</tr>
</tbody>
</table>
CHAPTER 1

PROJECT OVERVIEW

This chapter describes the aim and objectives of the project and also elaborates on the problem statement, scope and limitation, importance of study and introduction of outline structure for the project.

1.1 Project Background

The current scenario in worldwide electrical supplies industry is towards unbundling and deregulation of the services. The new scheme established free access to the transmission lines and boosting competition among generator and customer. In this environment, the transmission network is considered to be key factor of the electricity markets. Transmission plays a vital role as separate business of transmitting energy from generator to the load. In addition, it maintaining the system integrity with all transaction treated in an equal and non discrimination. This project is focused on the transmission system. In the electricity market, cost of allocation of transmission line services is major issues nowadays. All the users of transmission facilities should pay for the network usage of the system following an efficient transmissions pricing mechanism that is able to recover the transmission cost and allocate transmission network user in a proper way [4]. The problem is how to allocate the total cost of all the users in an equitable way. One of outstanding issues in unbundling of electricity supply industry in transmission service pricing. Utility power generation, transmission and distribution used to be considered a natural
monopoly. It is a scheme that determines who “uses” a given line and identifies how to charge among the user based on the usage of the transmission line.

Electricity transmission and wheeling service pricing becomes more complex and more important task within the ongoing deregulation of electric power industry. It has significant impact on the market efficiency, the development of transmission systems, power plant, the demand growth and the geographical distribution [6]. Total transmission service cost is separated into more practical line cost and system wide cost. It also can be flexibly distributed between generators and loads.

There are a lot of methods that was used in this topic to solve these problems. Transmission system is assumed to be one integrated facility and all costs to meet transmission system revenue requirements are distributed across all customers. There are three flows to find the best transmission pricing charge. The first step is find the transmission usage evaluation (power flow DC), charge percentages of usage and transmission pricing methods. In the transmission usage evaluation, it has three methods that are Kirschen method, Bialek method and distribution factors (DF). These three methods also called as tracing algorithm method. The usage based allocation of the fixed transmission costs should be made through power tracing method in order to trace the actual contribution of each user (generator and load) to each line flow. Then, the transmission cost can be calculated and allocated based on these contributions following one of the embedded pricing method mentioned above [4].

1.2 Problem Statement

The rapidly changing business environment for electric power utilities all around the world has resulted in unbundling of service provided by these utilities. The price of electricity has become the focus of all activities in power market. The problem is how the pricing of the electricity can be charges to the users for the restructuring of the power system. Restructuring power system is when the generation, distribution and transmission is separate each other and become independent company such as Generation company (GenCo), Transmission company (TransCo) and Distribution company (DisCo). The model of independent company in electricity markets are pool market, bilateral contracts model and hybrid model. The highest of the
electricity charge will make the user feel burden. The power system has three
distributed part specifically generation, transmission and distribution. It is hard to
trace the contribution of power on the transmission line uses. So, it is difficult to
achieve the fairly pricing to the users. Hence, in this project is to identify the best
method of the contribution of power of uses through the transmission lines and the
development of the pricing methodology to make the pricing of the network is more
fairly and not burden the users.

1.3 Objectives

The objectives in order to achieve this case study:

1. To study about the transmission charging methodologies in
deregulated market environment
2. To compare the methods used for transmission usage evaluation
3. Allocating charges to the transmission line user
4. Determine the suitable transmission pricing method

1.4 Scopes of project

Scopes of this case study focused on:

1. Study on transmission usage evaluation, charge percentage and
   transmission pricing method
2. The methods used to find the power flow are using tracing method
   algorithm namely Kirschen, Bialek and Distribution Factor (DF)
3. Using the IEEE 14-bus system to find contribution of power flow
   network and the pricing that can be charge to the transmission users.
1.5 Structure of the Thesis

A study on transmission use of system (TUOS) charging methodology was implemented in every chapter. This structure of the thesis will summarize for every chapter. This report consists of several topics.

Chapter 1: Introduces about the basic concepts of restructured electricity market in industry. It also includes the problem statement, objectives and scopes of the project.

Chapter 2: The literature reviews of the study were discussed in this chapter. This chapter also includes the concepts of restructuring elements and transmission sectors.

Chapter 3: Transmission usage evaluation and pricing methodologies used will be discussed in this chapter, where transmission usage evaluation and pricing methodologies were compared and choose by the validity of the pricing itself.

Chapter 4: The pricing methodologies that were recommended in chapter 3 will be discussed in this chapter. The pricing methodologies that were chosen for this study will be compared in terms of generators and loads payment and their tariff for each loads and generators. These studies are on the 9-bus test system and IEEE 14-bus test system.

Chapter 5: The conclusion and recommendations of the study will be discussed in this chapter.
CHAPTER 2

LITERATURE REVIEW

This section is about the understanding of the project and the previous works. It gives more information related to the transmission pricing methods and tracing power flow methods. This chapter consists of the literature review and case study on the TUoS from the previous researcher. It is directly related to the project, providing information on theories, materials and techniques used in the research.

2.1 Restructured Power System

Restructuring in the electricity industry is spreading across the United States and around the world. United States is the first country that doing the restructured power system. Complicated industrial organization in the United States occurs since the end of the World War II [9]. The Federal Energy Regulatory Commission (FERC) Order No. 888 established and mandated to control the unbundled electricity markets in the newly restructured electricity industry [10]. Restructuring power system is to introduce the competition and thereby increase efficiency in the electricity industry. It is also to ensure a long term power system, inexpensive and stable electricity supply. Users can be demand for their power supply. Three types of the electricity markets models can be used to achieve electricity market goals. Three basic models are PoolCo, Bilateral Contracts and Hybrid model. These models can be choosing to be applying in the restructured power system.
Transmission companies (TRANSCOs) is the important elements in the power system. Competition occurs among the suppliers companies such as generation (GENCOs), transmission (TRANSCOs) and distribution (DISCOs) companies in fulfil the demand of the large users. So, independent system operator (ISO) is required to be independent of individual market participants such as TRANSCOs, GENCOs and DISCOs and end users. To ensure the reliability of the power system is efficient, ISO must be established some rules on energy and extra services markets to manage the transmission system in a fair and non-discriminatory and to ensure it is free from market power [10]. Basically, the objectives of electricity reforms are to allow competition among generators, to reduce the costs of energy production and distribution, to create market conditions in the industry, increase customer choice and enhance efficiency.

Deregulation of electric supply industry (ESI) is significantly reduced the cost of power charged to the small business and consumers. The cost of electricity generation will be reduced by the driving prices through market forces and more competitions. Factors that causes to deregulated power market are changes in political and ideological, advances technology, high tariff, depletion of natural resources to generate electricity at the generation part, global financial increase and others related to economic of country.

2.2 Concept of Restructuring Elements

In restructuring power market, several elements must be considered to function independently. The market structure is including the GENCOs, TRANSCOs, DISCOs, and RETAILSCOs, aggregators, brokers, marketers and customers. ISO is the leading entity in a power market and its function determine market rules [10].

2.2.1 Independent System Operator (ISO)

ISO established to control the grid system network. The ISO is responsible to administers transmission tariffs, maintain the system security, coordinate maintenance scheduling and has a role in coordinating in long term planning. ISO should be works in a fair and non-discrimination. It has two possible structures for
ISO. The first is mainly concerned about the maintaining transmission line security in power market system. The second structure includes power exchange (PX) that is integral to the ISO operation [10]. Bilateral contract between two or more company must be scheduled through the ISO. ISO will be evaluating the condition of transmission system and either to approve or deny request for transmission service. ISO have a eleven’s principles to ensure their reliability. A few principles of ISO are, their employees could not have any financial interest in any power market system and it should use and enforce the interest standard. ISO should be control the operation of the transmission facilities within its region. ISO is very important during the restructuring power system market to ensure the independent companies charges more to the customers and make it feels burdens to the users. ISO will regulate the price of electricity bids by the users and the suppliers.

2.2.2 GENCOs

Generation company (GENCOs) is operates and maintains existing generation plants. In the restructured power market, the objective of GENCOs is to maximize the profit. GENCOs have the opportunity to sell electricity to customers which the price is negotiable through sales contracts. Open transmission access allows GENCOs to access the transmission network without distinction and to compete [3].

2.2.3 TRANSCOs

Transmission system is the most important elements in electricity markets. The efficiency of the transmission operation system is the key to the efficiency in these markets. It is because the power generate from the GENCOs will be used the transmission system to dispatch the power to the DISCOs and users. Normally, the losses of power happened during the transfer of power through the transmission line. The TRANCOs should provide the efficient of the transmission service so that the losses could be reduce. TRANCOs are function as the company that give the service to the GENCOs, DISCOs and users for transferring the power. So, TRANSCOs shall ensure that service provided are not detrimental any parties.
2.2.4 DISCOs

A DISCO is the last elements in the grid power systems. It is provide the distribution of the electricity through its facilities to customer in a certain geographical region. DISCOs are the utility company that built the connection to the customers to supply the electricity that receives from the transmission line. It is responsible for building and operation in electric system to maintain the reliability and availability to end user customers. Another trend in developing countries is to sell to an investor and portions of the distribution system so that investment for reinforcement can be raised and better operating practices implemented.

2.3 Market Models in Restructuring Power System

The three models are being applied in the restructured power system. The three models are:

- PoolCo Model
- Bilateral Contracts Model
- Hybrid Model

2.3.1 PoolCo Model

The PoolCo model for dispatching and selling electricity is simple and well documented [Garber et al., 1994; Budhraja and Woolf, 1994]. In the poolco market model, the bid is dispatch based on the generating units and rules of the payment whereby the units will be dispatch in each time interval. It is also as the centralized marketplace that clears the market for buyers and sellers. Sellers or buyers submit the bids to the pool for the amounts of power that they are willing to trade in the market. If a market participant bids too high, it may not be able to sell. On the other hand, buyers compete for buying power and if their bids are too low they may not be able to purchase. Some of the poolco supporters, the competition in generation industry will force their company to bid the price based on the changes of generating units.
In pool market model, they have two bidding strategies that may adopted in the pool market which are one sided pool and two sided pool. In one sided pool bidding strategies, generator submits bids and their available capacity to the supply. Figure 2.1 shows the pool market model concepts. These bids are ranked in order of increasing price. The higher price bids that intersect with the demand forecast determine the market price which applied to whole system. For two sided pool, consumer can submit offers specifying quantity and price and ranking these offer in decreasing offer of price [10]. Figure 2.2 shows the one sided pool model which is the supplier offer the price for energy bid price. The bid price is depends on the energy bids for MWh/hour. Figure 2.3 shows the intersection bids between supply and demand that represent the equilibrium of market environment.
2.3.2 Bilateral Contracts Model

Bilateral contracts model is the agreements on delivery and receives the power between two trades. These contracts are specify the terms and conditions of the agreements from the ISO. However, in this model, ISO will confirm that a sufficient transmission capacity for fulfill the transaction and maintain the transmission security. Bilateral contracts model is very flexible as the trading parties specify their desired contracts terms. However, these trades have disadvantages because of the high cost of negotiating and writing contracts and the risk of partner’s credits. For example is GENCO and TRANSCOs, every company have their one contracts. It is about the agreements between to company that need each other. For example, GENCO use the transmission line of TRANSCO to transfer the power to the customer. So, GENCO must be pay to the TRANSCO because uses the service of transmission line and TRANSCO must be perform to give the best service during the power transferring [10].
2.3.3 Hybrid Model

Hybrid model is the combination of the bilateral model and pool model. In the hybrid model, the utilization of PoolCo is not obligatory and any customer would be allowed to negotiate a power supply agreement directly with suppliers or choose to accept power at the spot market price. In this model, PoolCo would serve all participants who choose not to sign bilateral contracts. In restructured power systems, generation companies or customers can sell or buy electricity either from a centralized power pool or directly through bilateral contracts [10].

2.4 Transmission Sector

Transmission system is the connection that supplies the electricity to the users. It consists of high voltage AC and DC overhead line and also underground cables. The building of the transmission line must be considered the generation plants and the substation because carrying the large of power. A function of the transformer in the substation is to decrease the voltage to distribute to the customer. Customer used the low voltage. Transmission system is interrelation between individual and companies in the same geographical area. Same as the generation side, transmission line has owned and operated by the utility companies. Although transmission line is seem like not expensive to build that system, transmission line needs the big size of land to build their transmission lines to deliver the electricity from the generation station. Individual utility currently owns and maintains their delivery systems, creating a relationship between the systems where it is mutually beneficial [10].

2.4.1 Transmission Capital Cost

Transmission sector or transmission company needs a big capital cost in the developing the transmission network and the maintenance of the transmission line. The costs are then adjusted to identify the differential cost of developing on different land with different terrain factor adjustments. The categories that must be consider from a capital cost perspective:
• Voltage level: Alternating Current (AC) or High Voltage Direct Current (HVDC)

• Line characteristics: Conductor type, pole structure and length of the line

• New construction or re-conductor

• Terrain type

• Location

It is utilized its internal knowledge of transmission equipment component costs as a starting point for the cost assumptions [3]. Capital costs also associated with transmission service include the require return on investment for installed equipment plus depreciation on that equipment. Also, included are insurance on the equipment, taxes on the equity return on investment various property taxes and other Texas [3].

2.4.2 New Transmission

For AC transmission lines, there are many components that make up the entire line cost. First, it identified the initial physical considerations. Without engineering a detailed design, there were many components that could be broken apart into individual cost multipliers. Three key components were determined to be the most important cost consideration for transmission line design which is conductor type, structure and length of line [3].

2.4.3 Re-conductoring

In areas where there are existing transmission lines, it may be necessary or more cost effective to re-conductor an existing transmission rather than to build a new line. Re-conductoring can be defined many different ways but for simplicity re-conductoring in this effort is define as replacing an existing conductor to increase capacity. These assume that the new conductor would be of similar size and weight, hence no upgrading of poles or insulators is required [3].
2.4.4 Areas factor

Transmission equipment capital costs are only a portion of the overall transmission line capital costs. A substantial factor in total transmission line costs is the construction cost for developing lines in different types of areas. Nine different area types and then developed cost multipliers to compensate for the difficulty of construction in each areas types. The terrain types are desert, scrub/flat, farmland, forested, rolling hill, mountain, wetland, suburban and urban. The lowest cost of development was identified as scrub or flat land and the most difficult type of land is forested area [3].

2.4.5 Substation Capital Costs

Transmission cost estimates often only consider the conductor cost without consideration of the requirements for new substations facilities needed to connect the transmission to the existing grid. There are numerous considerations that go into the design of a substation that will significantly impact the cost of the facility. The cost components that calculate the substation costs are base substation cost, line or transformer position, transformer, HVDC converter station and static VAR compensator, shunt reactors and series capacitors [3].

2.4.6 System Operator and Maintenance Costs

The provision of a transmission service to a customer may affect the transmission owner’s cost in a number ways and depends upon the characteristics of the transmission service offered. A transmission service that does not result in an actual change in power flow may affect the operating costs to the system. Cost associated with the operation of the transmission system can be grouped into the following classes as in operation and maintenance, energy losses, administrative transactions, system control, operational constrains and other miscellaneous costs [3].
CHAPTER 3

METHODOLOGY

This chapter discusses the flow of the project. It is also consisting of analyzing the methods that have been chosen focusing on the contribution of power flow and transmission pricing methods. This section also gives more detail about the project through the flowchart.

3.1 Flowchart of the project

Flowchart in figure 3.1 described about the flow and method used to find the comparison between each tracing method. The details of the methods can be explained more on this chapter. There are three parts of TUOS charging methodologies:

1) Transmission usage evaluation
2) Allocates the charge percentage among the users
3) Transmission pricing method
Design IEEE 14 bus system
Calculate power flow on transmission system using tracing methods
Compare the results of the tracing methods and distribution factor.
Trace the power contribution from each generator using tracing methods
Trace the power contribution from each load using tracing methods
Allocate charges as 50% to generator and 50% to loads
Locational
Calculate the charges by using the MW-mile methods
Non-Locational
Calculate the charges by using the Postage Stamp Method
Comparison and analysis the pricing method of transmission line used in case

END

Figure 3.1: Flowchart of TUOS
3.2 Transmission Usage Evaluation

Transmission usage evaluation is in terms of the power flow DC. The purpose of evaluation is to identify the power flows. It is also through the transmission line that connected with the bus bar. The purpose of the bus bar is to conduct the electricity from the one transmission line to others transmission line. In order to implement the usage based cost allocation methods, it is importantly to determine the accurately the transmission usage. Evaluation of the transmission usage can be determined using the tracing algorithms methods.

Tracing algorithms methods are the method that used to calculate the transmission usage by the users. There are two tracing algorithms that are available that are Bialek and Kirschen method. The method aims to trace the flows of electricity through power networks. The problem of tracing electricity gains importance as its solution could enhance the transparency in the operation of the transmission system. An electricity tracing method would make it possible to charge the suppliers and generators for the actual amount of losses caused and hence encourage efficiency. Recently, the tracing method has been proposed which under the assumption that nodal inflows are shared proportionally between the nodal outflows, allows one to trace the flow of electricity in a meshed network [9]. Tracing electricity can be used to solve the problems of determining how the power injected by generators and distributed that power to the lines and loads of the network [2]. The simplest way of obtaining losses flows from the lossy ones is by assuming that a line flow is an average over the sending and receiving end flows and by adding half of the line loss to the power injections at each terminal node of the line.

3.3 Usage Allocation through Bialek Method (Node Method)

It was proposed by J. Bialek and published in the IEEE in 1996 as “Tracing the flow of electricity” [9]. Bialek tracing algorithms has two types that are upstream looking algorithm and downstream algorithm. The upstream algorithm looking algorithm will allocate the transmission usage charge to individual generators while the downstream looking algorithm will allocate the transmission usage charge to individual loads. If the problems is analyzed using the upstream-looking algorithm, the power injection
in each bus of the system are given by:

$$P_i = \sum_{j \in \alpha_i^u} |P_{i-j}| + P_{Gi} \quad (3.1)$$

For the downstream-looking algorithm is chosen, then power passing through each bus to the loads is given by:

$$P_i = \sum_{j \in \alpha_i^u} |P_{i-j}| + P_{Li} \quad (3.2)$$

Where,

- $\alpha_i^u$: Set of nodes supplying directly node $i$
- $P_{r,j}$: Line flow into node $i$ in line $j$-$i$
- $P_{Gi}$: Generation at node $i$
- $i$: Number of bus (i.e $i = 1, 2, 3 \ldots, n$)
- $j$: Bus supply power to $i$

Losses have been eliminated because assuming the line flow is average of the sending and receiving end power. Hence,

$$|P_{i-j}| = |P_{j-i}|$$

$$|P_{i-j}| = C_{ij} \times P_j \quad (3.3)$$

Where,

$$C_{ij} = \frac{|P_{i-j}|}{P_j} \quad (3.4)$$

Substitute the equation above into the equation (3.1) and (3.2)

$$P_i = \sum_{j \in \alpha_i^u} C_{ij} \cdot P_j + P_{Gi} \quad (3.5)$$

and arranging it:
\[ P_i = \sum_{j \in \alpha_i^u} C_{ji} \cdot P_j = P_{Gi} \quad (3.6) \]

So,

\[ A_u P = P_G \]

Where,

- \( A_u \) : Distribution matrix per injected power
- \( P \) : Vector of Bus flows
- \( P_G \) : Vector of bus generations

The elements of matrix \( A_u \) are defined as below:

\[
[A_u]_{ij} = \begin{cases} 
1 & \text{for } i = j \\
-|P_{ji}| & \text{for } j \in \alpha_i^u \\
\frac{P_j}{P} & \text{others}
\end{cases} \quad (3.7)
\]

Then vector

\[ P = A_u^{-1} P_G \quad (3.8) \]

\[ P_{\text{gross}} = \sum_{k=1}^{n} [A_u^{-1}]_{ik} \cdot P_{Gk} \quad (3.9) \]

The power contribution of each generator can be traced using the equation (3.10) as:

\[ P_{ij} = \frac{P_{ij}}{P_i} \sum_{k=1}^{n} [A_u^{-1}]_{ik} \cdot P_{Gk} \quad (3.10) \]
3.3.1 Numerical Example of Bialek Method (Node Method)

1. Define the line flows of 3-bus system

\[ P_{12} = 131.87 \text{ MW} \]
\[ P_{24} = 251.87 \text{ MW} \]
\[ P_{G2} = 120 \text{ MW} \]
\[ P_{13} = 176.18 \text{ MW} \]
\[ P_{43} = 123.81 \text{ MW} \]
\[ P_{L3} = 300 \text{ MW} \]
\[ P_{14} = 71.94 \text{ MW} \]
\[ P_{G1} = 380 \text{ MW} \]
\[ P_{L4} = 200 \text{ MW} \]

2. Find power injections in each bus to the loads

For upstream looking algorithm

\[ P_1 = P_{G1} = 380 \text{ MW} \]
\[ P_2 = P_{12} + P_{G2} = 131.87 \text{ MW} + 120 \text{ MW} = 251.87 \text{ MW} \]
\[ P_3 = P_{13} + P_{43} + P_{G3} = 176.18 \text{ MW} + 123.82 \text{ MW} + 300 \text{ MW} \]
\[ P_4 = P_{14} + P_{24} + P_{G4} = 71.94 \text{ MW} + 251.86 \text{ MW} + 323.81 \text{ MW} \]
For downstream looking algorithm

\[ P_1 = P_{1\,2} + P_{1\,3} + P_{1\,4} + P_{L1} \]
\[ P_1 = 131.87 \text{ MW} + 71.94 \text{ MW} + 176.18 \text{ MW} = 380 \text{ MW} \]
\[ P_2 = P_{2\,4} = 251.86 \text{ MW} \]
\[ P_3 = P_{L3} = 300 \text{ MW} \]
\[ P_4 = P_{4\,3} + P_{L4} = 123.81 \text{ MW} + 200 \text{ MW} = 323.81 \text{ MW} \]

3. Determine matrix \( A_U \)

\[
[A_U]_{ij} = \begin{cases} 
1 & \text{for } i = j \\
-\frac{P_{ij}}{P_j} & \text{for } j \in \alpha_i^u \\
0 & \text{others}
\end{cases}
\]

\[ j \text{ must be a bus that supplies power to } i \]
\[ P = A_U^{-1} P_G \]

\[
[A_U] = \begin{bmatrix}
1 & 0 & 0 & 0 \\
-0.347 & 1 & 0 & 0 \\
-0.4636 & 0 & 1 & -0.3824 \\
-0.1893 & -1 & 0 & 1 \\
\end{bmatrix}
\]

4. Determine inverted matrix \( A_U^{-1} \)

\[
[A_U]_{ij}^{-1} = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0.347 & 1 & 0 & 0 \\
0.6687 & 0.3824 & 1 & 0.3824 \\
0.5363 & 1 & 0 & 1 \\
\end{bmatrix}
\]

\[ [A_U]^{-1} P_G = P \]

\[
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0.347 & 1 & 0 & 0 \\
0.6687 & 0.3824 & 1 & 0.3824 \\
0.5363 & 1 & 0 & 1 \\
\end{bmatrix} \begin{bmatrix} 380 \\ 120 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 380 \\ 251.87 \\ 300 \\ 323.81 \end{bmatrix}
\]
5. The power contribution of individual generators to each line is identified using equation 3.10.

Table 3.1: Power flow contribution of generator using Bialek method

<table>
<thead>
<tr>
<th>Generator</th>
<th>1 – 2 (MW)</th>
<th>1 – 3 (MW)</th>
<th>1 – 4 (MW)</th>
<th>2 – 4 (MW)</th>
<th>4 – 3 (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>131.87</td>
<td>176.18</td>
<td>71.94</td>
<td>131.87</td>
<td>77.93</td>
</tr>
<tr>
<td>G2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>120</td>
<td>45.89</td>
</tr>
<tr>
<td>Total (MW)</td>
<td>131.87</td>
<td>176.18</td>
<td>71.94</td>
<td>251.87</td>
<td>123.82</td>
</tr>
</tbody>
</table>

3.4 Usage Allocation through Kirschen Method (Common Method)

Kirschen’s method is the algorithm based on the solution of a load flows in series, identifying buses that are reached by the power generated in each generator. It was proposed by Daniel Kirschen, Ron Allan and Goran Strbac and publishes in IEEE in 1997 as “Contributions of Individual Generators to Loads and flows” [10]. It is necessary to define some concepts to more understand about this method principles. There are three concepts that to make easily understand the concept of Kirschen method. The three concepts are about the generator’s domain, commons and links. The three concepts of these methods are:

- Generator’s domain is defined as the group of buses that are reached by the power generated by a given generator.
- Commons is defined as a group of neighboring buses supplied by the same generators.
- Links is defined as the lines that connect two different commons.

This method, internal flows are the addition of the power injected by the generators in common buses and the imported power from others commons through the link. The external flows of the common are defined as the power exported through links to other common of higher rank [10]. A recursive method is built to solve the problems in power flows. It is difference from the Bialek method. The
recursive method used to determine the contribution for each generator supply to the loads in each common. The following relations are defined [10]:

\[ F_{ijk} = C_{ij} \cdot F_{jk} \]  
\[ I_k = \sum_j F_{jk} \]  
\[ C_{ik} = \frac{\sum_l F_{ijkl}}{I_k} \]

Where,
- \( C_{ij} \): contribution by generator i to the load and external flow of common j
- \( C_{ik} \): contribution by generator i to the load and external flow of common k
- \( F_{jk} \): flow from common j to common k through the link
- \( F_{ijk} \): flow from common j to common k through the link coming from common i
- \( I_k \): internal flow of common k

3.4.1 Numerical Example of Kirschen Method (Common Method)

Numerical example of Kirschen method is using the 4-bus system same as the Bialek method. The circuit of 4-bus system shows in figure 3.2. The steps of Kirschen method is summarized below.

1. Find the inflow of common k

\[ I_1 = F_{G1} = 380 \text{ MW} \]
\[ I_2 = F_{G2} + F_{12} = 120 \text{ MW} + 131.87 \text{ MW} = 251.87 \text{ MW} \]
\[ I_3 = F_{G3} + F_{13} + F_{43} = 176.18 \text{ MW} + 123.82 \text{ MW} = 300 \text{ MW} \]
\[ I_4 = F_{G4} + F_{14} + F_{24} = 71.94 \text{ MW} + 251.87 \text{ MW} = 323.81 \text{ MW} \]
2. Find the flow on the link between common j and k due to generator i

*Due to Generator 1*

\[ F_{112} \rightarrow \text{Flow on the link between common 1 and common 2 due to generator 1} \]

\[ C_{11} = \frac{F_{G1}}{I_1} = \frac{380 \text{ MW}}{380 \text{ MW}} = 1 \]

\[ F_{112} = C_{11} \times F_{12} = (1)(131.87 \text{ MW}) = 131.87 \text{ MW} \]

\[ F_{113} \rightarrow \text{Flow on the link between common 1 and common 3 due to generator 1} \]

\[ F_{113} = C_{11} \times F_{13} = (1)(176.18 \text{ MW}) = 176.18 \text{ MW} \]

\[ F_{114} \rightarrow \text{Flow on the link between common 1 and common 4 due to generator 1} \]

\[ F_{114} = C_{11} \times F_{14} = (1)(71.94 \text{ MW}) = 71.94 \text{ MW} \]

\[ F_{124} \rightarrow \text{Flow on the link between common 2 and common 4 due to generator 1} \]

\[ C_{12} = \frac{F_{112}}{I_2} = \frac{131.87 \text{ MW}}{251.87 \text{ MW}} = 0.5236 \]

\[ F_{124} = C_{12} \times F_{24} = (0.5236)(251.87 \text{ MW}) = 131.88 \text{ MW} \]
\[ F_{143} \rightarrow \text{Flow on the link between common 2 and common 4 due to generator 1} \]

\[ C_{14} = \frac{F_{114} + F_{124}}{I_4} = \frac{71.94 \text{ MW} + 131.88 \text{ MW}}{323.81 \text{ MW}} = 0.6294 \]

\[ F_{143} = C_{14} \times F_{43} = (0.6294)(123.82 \text{ MW}) = 77.93 \text{ MW} \]

**Due to Generator 2**

\[ F_{212} \rightarrow \text{Flow on the link between common 1 and common 2 due to generator 2} \]

\[ C_{12} = 0 \]

\[ F_{212} = C_{21} \times F_{12} = 0(131.87 \text{ MW}) = 0 \]

\[ F_{213} \rightarrow \text{Flow on the link between common 1 and common 3 due to generator 2} \]

\[ C_{21} = 0 \]

\[ F_{213} = C_{21} \times F_{13} = 0(176.18 \text{ MW}) = 0 \]

\[ F_{214} \rightarrow \text{Flow on the link between common 1 and common 4 due to generator 2} \]

\[ C_{21} = 0 \]

\[ F_{214} = C_{21} \times F_{14} = 0(71.94 \text{ MW}) = 0 \]

\[ F_{224} \rightarrow \text{Flow on the link between common 2 and common 4 due to generator 2} \]

\[ C_{22} = \frac{F_{G2}}{I_2} = \frac{120 \text{ MW}}{251.87 \text{ MW}} = 0.4746 \]

\[ F_{224} = C_{22} \times F_{24} = (0.4746)(251.87 \text{ MW}) = 120 \text{ MW} \]
REFERENCES


