HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL & COMPUTER ENGINEERING

Assessment & Allocation of Transmission Losses & Costs under N-1 Contingency Condition

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In

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By

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Declaration

I, the undersigned, hereby declare that this thesis, submitted for the Master of Electrical Engineering to the Hawassa University, is my own work and has not previously been submitted as a thesis for a degree to any other college or university. All sources of materials and researches used for the thesis are duly acknowledged.

Signature___________________________ date______________________

Dedicated To My Mother Alemitu Ashango

ABSTRACT

Traditionally electricity supply industry (ESI) was monopolistic in nature with generation; transmission and distribution owned by government. Now in all over the world electricity market is restructured. All the three major areas i.e. generation, transmission and distribution are now working as separate companies namely Generating Companies (GENCO), Transmission Companies (TRANSCO) and Distribution Companies (DISCOMs). Under this environment the question of loss allocation is also very much important because no one want to bear this loss. Contingency conditions are normal practices in real power system and this brings transmission reliability margin into the picture. Further under contingency the value of losses in certain lines is increased due to extra flows in these lines. Hence transmission loss assessments, allocation and pricing with consideration of contingency are significant issues in restructured electricity market. Due to this reason a methodology for transmission loss assessment, allocation and pricing with consideration of N-1 contingent maximum flow condition has been developed. For finding contingent loss novel reliability factors is introduced. By using this factor optimal losses are calculated. After calculating these losses by using Bialek's tracing these losses are allocated to generators and loads. After that by using MW-cost methodology transmission loss cost is allocated to the generators and demands. Sample 6 bus and IEEE 14 bus system are used for showing the feasibility of this method.

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LIST OF ABBREVIATIONS

Acronyms

Amount of Transmission System Usage	ATSU
Distribution Company	DISCOs
Electricity Supply Industry	ESI
Failure Modes and Effects Analysis	FMEA
Generation Company	GENCOs
Independent System Operator	ISO
Institute of Electrical and Electronics Engineers	IEEE
Outage Transfer Loss Impact Factor	OTLIF
Outage Transfer Loss Distribution Factor	OTLDF
Static Synchronous Compensator	STATCOM
System Operator	SO
Transmission Company	TRANSCOs

Symbol

$pl_{i,out\ j}$	Transmission losses in line i when line j is out
pl_i	Transmission losses in line i in normal operating condition
pl_j	Transmission losses in line j in normal operating condition

CHAPTER ONE

1 INTRODUCTION

1.1 Background

Electric Power utilities throughout the world are currently undergoing major restructuring process and are adopting the deregulated market operation. Competition has been introduced in power systems around the world based on the promise that it will increase the efficiency of the industrial sector and reduce the cost of electrical energy of all customers. Electrical energy could not be stored in large quantities. Continuity of supply is sought as more important than the cost of the electrical energy. To meet the growing power demand, electric power industry has to adopt the deregulated structure. For integrated operation of deregulated system, regulating agencies such as pool operator or system operator have to be formulated

The power system deregulation is expected to offer the benefit of lower electricity price, better consumer service and improved system efficiency. However, it poses several technical challenges with respect to its conceptualization and integrated operation. Basic issues of ensuring economical, secured and stable operation of the power system, which can deliver the power at desired quality, has to be addressed carefully in a deregulated market.

Transmission loss allocation is important in restructured electricity markets. Since generators and demands are all connected to the same network, actions by one participant can have significant effects on others making it difficult to investigate the cost, each participant is responsible for [24]. It is difficult to achieve an efficient transmission loss allocation scheme that could fit all market structures in different locations. The ongoing research on transmission pricing indicates that there is no generalized agreement on pricing methodology. In practice, each restructuring model has chosen a method that is based on a particular characteristic of its network [25].

Fair allocation of transmission loss among market participants is essential in the present restructured electricity markets. This paper proposes a direct method to find the loss and cost allocation of the transmission line under N-1 contingent condition.

1.2 Statement of the Problem (Motivation)

The worldwide deregulation of the electrical sector has changed the electricity business from a centralized and vertically integrated industry to a segmented industry based on competition among participants. Transmission loss assessment and usage cost allocation is one of the significant issues in restructured electricity market. Due to this reason a methodology for transmission loss assessment, allocation and pricing with consideration of N-1 contingent maximum flow condition has been developed because under this condition the pattern of transmission usage depends on the questions that how much the power flows under outage condition and which generator supplied it.

The study of this paper is to compare transmission usage and cost allocation scheme to loads (and/or generators) based on power flow tracing method. Modified Kirchhoff matrix is used for power flow tracing. A case study based on sample 6 bus and 14 bus system power systems is applied to check the feasibility and reliability of the proposed usage and cost allocation methodology.

1.3 Objectives

1.3.1 General Objective

The general objective of this project work is to assessment & allocation of transmission losses & Costs under N-1 Contingency Condition

1.3.2 Specific Objective

The specific objective of this thesis is to develop a reliability indexes for assessment of transmission loss and cost allocation under N-1 contingency condition. Hence an outage transfer loss distribution factor and outage transfer loss impact factor is developed to calculate the transmission losses and cost allocation in contingent environment.

1.4 Literature review

The literature relevant to the issues investigated in this thesis. It reviews various transmission usage, loss and transmission reliability margin allocation methodologies. Along with all allocation methodologies various pricing mechanisms are also reviewed. Each methodology has its own strengths and limitations. Moreover a single pricing methodology is not able to use in all situations. From the utility point of view, adopted pricing methodology is depended on properties of utility structure. The main aim of deregulation is to achieve lower rates to consumers by introducing competition in the market structure.

A fair transmission pricing methodology should recover all the cost of the transmission system and provide profit to the transmission utility. So many methodologies have developed in past years for transmission cost allocation in transmission system.

Based on the argument that it is always possible to compute the exact loss allocation corresponding to an infinitesimal bilateral transaction in this paper F.D. Galiana et al. presented a set of governing differential equations whose solution yields the loss allocation for contracts of any size [1]. A physical-flow-based approach to allocate transmission losses is presented by G. Gross et al. [2] in a multiple-transaction system environment. The allocation scheme is developed using a framework in which the transactions are explicitly represented. For instance, the participation of generating utilities in losses caused in a specific line. A proportional sharing principle was used by many authors to elaborate a power-flow tracking algorithm. In [11] R. Reta et al. developed a new method to assess the power output flowing from a specific generator to a specific load. The justification of the method is based on concepts of electric circuit theory. Its practical implementation requires only computing a load flow and solving a linear equation system. As a result of deregulation, energy transfers increase in both volume and geographical span. Parallel flows begin to exert serious operational and economic effects. In system loss allocation calculation, it is desirable to match the calculation results and actual power flows as closely as possible. Hence in [3] Y.C. Chang et al. presented three bus-oriented schemes, based on generalized generation distribution factors (GGDFs) and generalized load distribution factors (GLDFs) to allocate the transmission losses to market participants. In [4] A.J. Conejo et al.

presented transmission loss allocation procedures and provides a detailed comparison of four alternative algorithms: (1) pro rata (PR); (2) marginal allocation; (3) unsubsidized marginal allocation; and (4) proportional sharing. Again in [12] A.J. Conejo et al. provided a procedure for the allocation of the cost of transmission losses that is based on deriving a radial network that is fully equivalent to the original one. In [5] Armando M. Leite da Silva et al. presented a new methodology for allocating transmission losses to the participants of a single energy market. The proposed approach is based on the incremental transmission loss concept and is implemented through two models: basic and extended. In the basic model, the total system losses are estimated through the linear dc load flow equations, while the extended model uses the exact ac formulation. Further Leite da Silva et al. [6] presented a new methodology based on the incremental transmission loss concept for allocating electric losses to generators and loads, participating in multiple interconnected energy markets. The main objective is to generalize the formulation proposed in the companion paper, Part I, in order to identify through a decomposition technique, the amount of losses that each participant in the market causes on all system areas. Transmission losses have a considerable effect on the active power generation cost and thus, a strategy to allocate them fairly among the power system agents is essential to economic efficiency of the electric energy market. In [7] R.S. Salgado et al. developed three types of approaches for allocation transmission losses to buses: (1) direct use of sensitivity relationships between the transmission losses and the bus power injections; (2) use of participation factors obtained from power flow solutions; and (3) integration of sensitivity relationships mentioned in the previous item. Transmission pricing of cross-border trades is a critical issue. In [50] Bialek et al. presented a tracing methodology which address cross border trades problem by taking loss allocation as example. A methodology to allocate the active power transmission loss among agents of a power pool is proposed in [8]. In this approach J. S. Daniel, include admittances equivalent to bus power injections in the bus admittance matrix. For a given power-flow solution, the relationship between the branch currents and the load/generator current injections is determined using a modified bus admittance matrix. In [9] Du Songhuai et al. proposed a nucleolus theory based loss allocation methodology under bilateral transaction environment. Further the results are compared with Shapley value. In [10] Julio Usaola addressed the problem of grid cost and losses allocation by dividing it into various sub problems: allocation of branch flow and losses to transactions, definition of these transactions and cost allocation to transactions. From this final allocation, the charges to participants in transactions may be made straightforwardly. Further a differential, slack-invariant method for the allocation of flow and losses to transactions that makes use of the AC load flow equation is also presented.

Fundamentally transmission cost allocation methodologies have been classified into three basic categories, embedded cost based pricing methods, marginal/incremental cost based pricing methods and combination of embedded with incremental cost based pricing methods

The application of marginal cost in pricing the transmission services has shown not effective mainly due to revenue reconciliation problems. In this paper J.W.M. Lima [14] derived a set of other methods from the MW-mile rule to allocate transmission fixed costs. This paper compares such methods known as embedded cost methods in a centralized transmission network environment. C. W. Yu et al. [13] suggested an approach which distinguishes between operating and embedded costs and developed separate methods in respect of each of these components. Capacity use as well as reliability benefits derived by different users are taken into account in the disbursement of charges for investment recovery. Considerable change is occurring in the structure and operation of electric power systems throughout the world. In Silva, E.L. et al. [16] considered that the revenue of each circuit is obtained in two parts: one part associates the system use under normal state and the second part belongs to the system use under contingency conditions.

1.5 Research Methodology

For calculating transmission loss under contingency condition loss factor is used. After calculating these factors, optimal losses in transmission line are obtained. This factor is defined as follows:

Outage transfer Loss Impact Factor (OTLIF) represents the impact of an outage on loss of any line has on the post contingency loss of any line. OTLIF is represented as follow:

$$OTLIF_{i,j} = \left\{ \begin{matrix} \dfrac{P_{Li,j} - P_{Lj}}{P_{Li}}, & P_{Li,j} > P_{Lj} \\ 0, & otherwise \end{matrix} \right\} \quad \textbf{(1)}$$

Thus, $OTLIF_{i,j}$ is described as the ratio of difference of the real loss in the line i after an outage in the line j and the normal loss in the line j to that of normal loss in the line i. Outage Transfer Loss Distribution Factor (OTLDF) is defined as the redistribution of the particular generation loss after an outage. OTLDF is represented as follow:

$$\mathrm{PL}_{\mathrm{k,out\,m}} = \mathrm{pl}_{\mathrm{k}} + \mathrm{OTLIF}_{\mathrm{k,m}} * \mathrm{pl}_{\mathrm{m}} \qquad (2)$$

Where

$PL_{k,out\,m}$ Power Loss in line k when line m is out

Thus, $OTLDF_{i,j}$ is described as the ratio of difference of the real loss in the line i after an outage in the line j and the normal loss in the line j to that of normal loss in the line j.Now by using above described factor optimal transmission line loss is calculated by using the equation (2).

The loss on a line after an outage condition can be approximately calculated by using aforementioned four factors are as follows:

$$P_{Li,j} = P_{Li} + OTLIF_{i,j} \times P_{Lj}$$

$$P_{Li,j} = P_{Li} + OTLDF_{i,j} \times P_{Lj}$$

In this work the method presented in [8] is modified for finding transmission loss under N-1 contingency condition. For this purpose developed loss index is used.

1.6 Thesis Outline

This thesis contains a total of five chapters. Chapter one is general introduction of the thesis, which highlights the basic idea and gives an insight or a direction to the body of the thesis. Chapter two reviews literatures of previous works which are related to the Allocation of Transmission Losses and Costs under N-1 Contingency Condition. Chapter three presents basics of transmission loss and cost allocation under base and N-1 contingency condition, contingency analysis. Chapter four presents simulation, analysis of the model and result of the thesis. Chapter five concludes the thesis after providing suggesting for future works scope

CHAPTER TWO

2 DEREGULATED ELECTRICITY MARKET UTILITIES

Initially utilities were not regulated. Early utilities would often compete for the same customers including building duplicate distribution systems. Naturally, competition was greatest in urban areas. It was cheaper to compete in densely populated areas & wealthy customers more likely to use power.

The deregulation of the electric utility industry allows many independent power producers (IPP) to be connected across the transmission system. This situation also calls for effective methods to ensure the transmission system reliability, while the power is transferred through the network.

In a deregulated environment, there are many simultaneous bilateral and multilateral transactions in addition to power pooling. Therefore, it is very much important that sellers and buyers of electricity need to find the cost allocation to their wheeling transactions. Independent System Operator (ISO), a supreme entity for the control of transmission system, also needs to know such costs in order to make correct economic and engineering decisions on upgrading the transmission facilities. So wheeling is currently a high priority problem in both regulated and deregulated power industries.

The process of removing Restrictions and Regulation to achieve competitive wholesale prices without compromising

- Security
- Adequacy
- System Reliability

However, it is quite hard to introduce competition in the transmission sector due to its monopolistic nature. It is impossible to build a separate transmission line for every generation and demand facility. Hence these issues are very complicated in the deregulated environment. Therefore, establishment of rules for operating transmission network (technical issues) and for pricing transmission services (economic issues) is the real challenge

Traditionally electricity supply industry (ESI) was monopolistic in nature with generation; transmission and distribution owned by government. The main advantage of this model was the reliability of power supply and low prices of electricity as government provided subsidy to consumers. Also at initial stage, this model was very necessary for the development and expansion of electricity industry. As every system has its pros and cons, this system has also brought inefficiency and corruption due to policies and regulations. Many state owned unities are financially in loss because of theft and less recovery of tariff. Further in this model it was technically difficult to identify various cost factors therefore charging was done at an average rate. Thus vertically integrated industry proved to be ineffective due to lack of technical innovations and managerial inefficiency. In order to remove adversities, reformation of ESI has taken place all over the world. Eventually it is causing tremendous changes in ESI around the world. The main aim behind restructuring is to introduce competition and improve efficiency to maintain quality of electricity supply

The deregulation process has faced many difficulties, further many problematic areas still being explored and developed. Among them, one of the most critical ones has been the unbiased open access of transmission network. From the transmission sector point of view, restructuring consists of various new aspects such as transmission usage cost allocation, loss allocation, congestion management etc. These crucial issues raise problems and challenges in front of transmission utilities because it is quite hard to introduce competition in the transmission sector due to its monopolistic nature. So cost allocation among the different market agents frequently at the heart of deregulation problems as it is complex in nature.

The transmission pricing system and user-cost allocation must preserve an adequate resource allocation among market agents. It is desired that transmission prices and payment do not affect decisions for new generation investment. Also this must be carried out in a simple and fair way. The model of deregulation for each country is varying with the characteristics of its transmission system.

In vertically integrated model to obtain minimum loss and cost of generation, all the generators are optimally scheduled. Further generation, transmission and distribution are governed by single authority hence there is no question of security, reliability and competition for them. But in deregulated environment all the entities are separate players and accordingly the generation schedules are made. Additionally there is a competition between them to achieve more benefits. Every entity tries to obtain more benefits by receiving energy from cheaper source. These all the activities lead to congestion and overloading in transmission system which may also come in the form of system collapse. Hence there is a requirement of external body which keep control on such activities to maintain the system security. In deregulated environment system operator (SO) does this work. It provides open access to all participants in fair and equitable manner and manages transmission network within their security and reliability limits. Since the transmission network is used by all the entities, for equally charge allocation there is a need to know about the usage by each entity and the system status. Thus induction of deregulation in electricity supply industry motivates new participants into picture and developed new models to achieve fair and equitable open access at every level of deregulation.

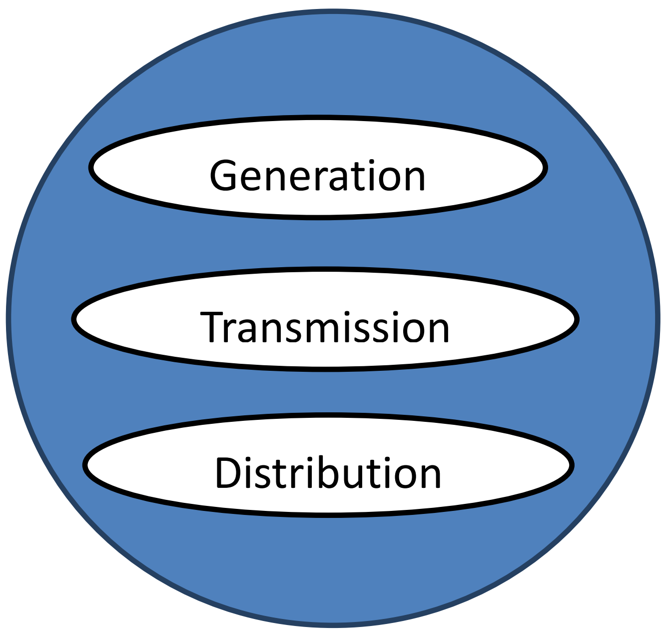

Fig. 2.1: Vertically integrated power system

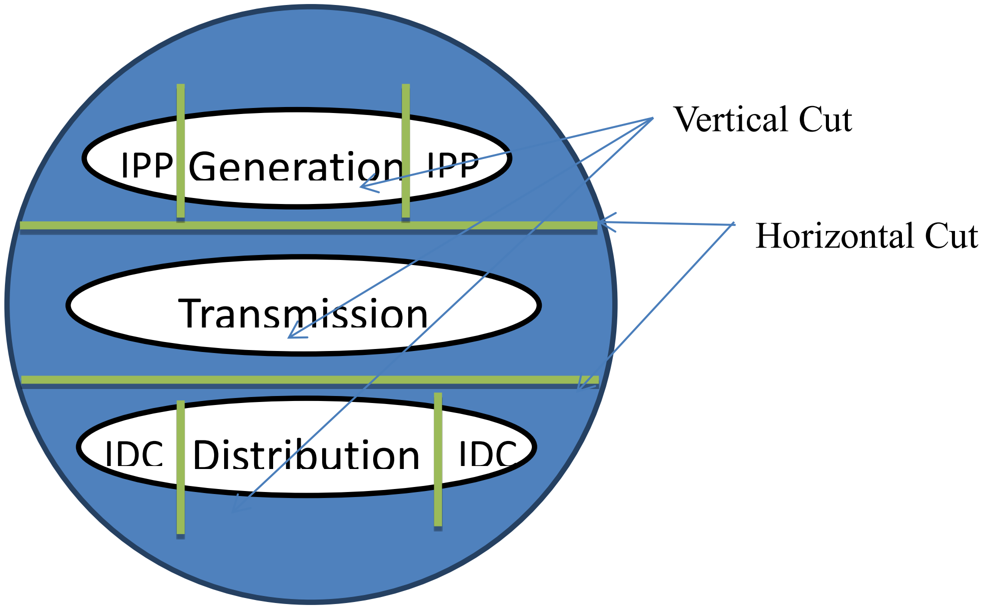

Fig. 2.2: Vertically unbundled power system

Until recently, utility procurement has been fairly simple. First, the local utility sets a price, called a rate or tariff. Next, it meters the energy used and sends the customer a bill based on the rate. Finally, the customer pays the bill. Although most local utilities work with facility staff to better manage energy use, there is little a facility manager can currently do to reduce the cost of the energy commodity or it delivery. Facility managers can participate (or intervene to use utility jargon) in the regulatory process through which rates are set, but individual consumers have little influence over final prices.

Now, however, this structure is undergoing a profound change. The energy industry is in the midst of a metamorphosis that will affect all electricity and natural gas consumers. State legislators and utility regulators are letting consumers choose among a variety of new energy suppliers on the basis of competitive prices and products this trend, called deregulation or restructuring.

Structure of the Traditional Utility

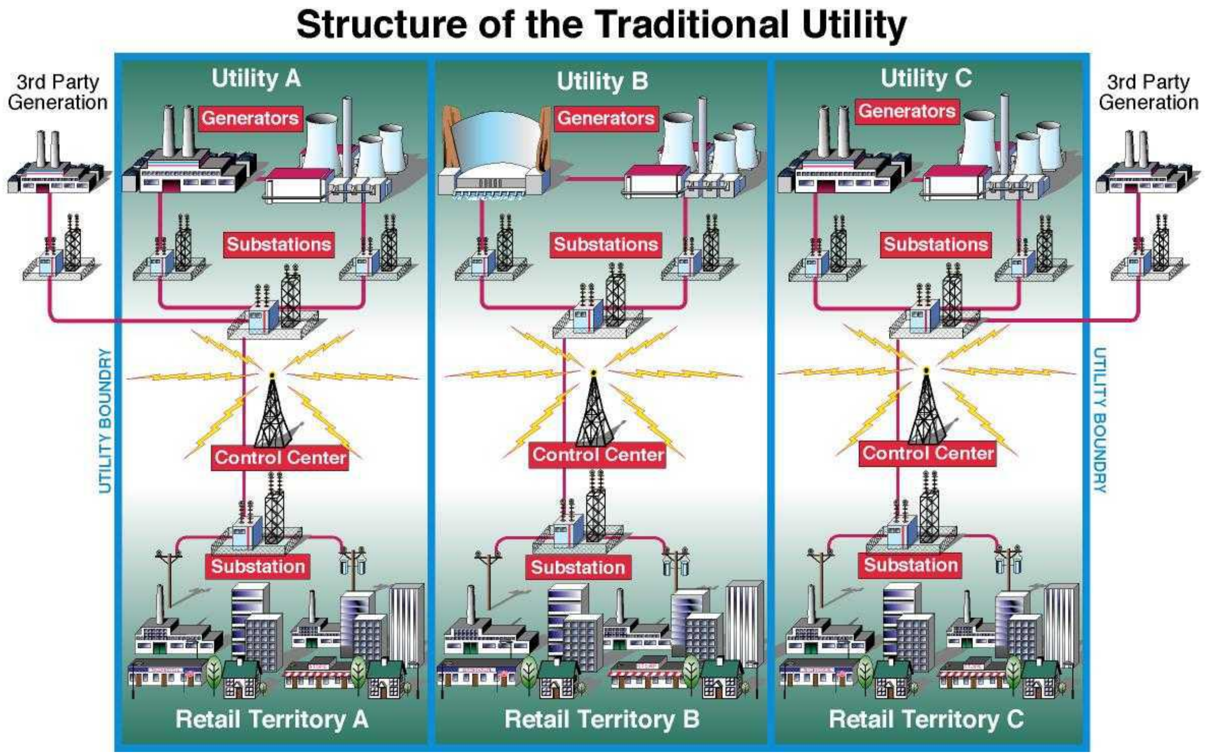

Figure 2.3 The image of a traditional utility

The image of a traditional utility is one that owns all of the generation resources it needs and controls all of its own transmission to meet the needs of its customers. In reality, even in a regulated environment, most utilities buy power from generation and transmission utilities and rely on power wheeled across the transmission grid. This transmission is usually controlled by control centers operated by major regional utilities.

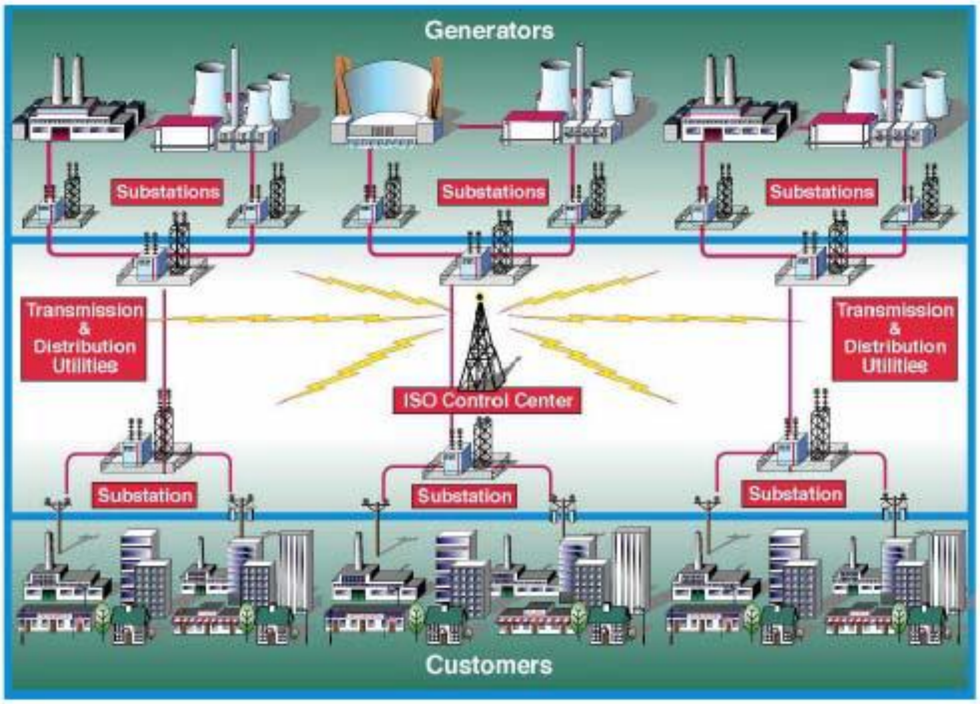

Fig.2.4 Structure of the Deregulated Electric Supply System

The restructuring of electricity industry change the role of various traditional entities and also introduces new entities to control the operation of deregulated market. A brief introduction to various markets entities are given below:

2.1 Generating Companies (GENCOs)

Generating electricity has been the primary function of electric utilities since their creation. Electricity can be generated through a wide variety of processes, although far and away the most common is by the rotation of a generator shaft, or rotor, through opposing magnetic fields. Shaft rotation induces the flow of electricity in the generator. Power can be either direct or alternating current (DC or AC). Power is delivered to consumers in the United States as alternating current, so shaft rotation literally turns an alternator rather than a generator

The generation sector in monopolistic model is made separate entity and called generation company (GENCOs). It generates and sells electricity. The generators can be classified either their rated capacity or their contracts to the market. In the pool market they submit their bid with their capacity.

2.2 Transmission Companies (TRANSCOs)

When most people think of an electric utility they envision a company, typically associated with a major metropolitan region, that owns generating plants located far away from most of its customers. A large concentration of customers, like a metropolitan area, is called a load center. Power from remotely located generators travels to load centers along high-voltage transmission lines. The linkage between power plants and load centers via transmission lines is familiar to most people due to the wide swath of land associated with transmission corridors. Less obvious is that transmission lines also connect to each other forming a network, called the transmission grid. The combination of generation and the transmission network is referred to as a power grid or power system.

Transmission sector of vertically regulated market is converted into transmission company (TRANSCOs) which own the whole transmission network. It provides the path for both GENCOs and DISCOs to sell and buy their energy and demand respectively. For this facility TRANSCOs levy the transmission tariff on various entities. It also provides open access by making transmission network available to all participants.

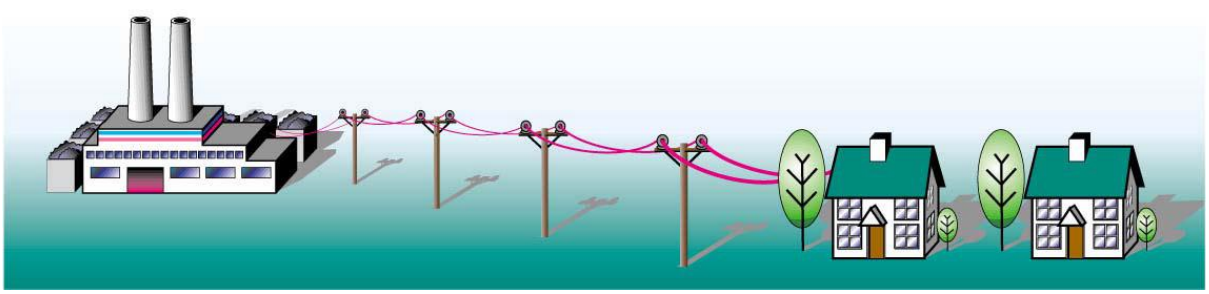

Figure 2.5 Power plants have almost always been located away from the loads they serve. Transmission lines tied the generation and the loads together.

2.3 Distribution Companies (DISCOs)

People tend to be more familiar with the distribution lines in their neighborhoods than with high-voltage transmission lines. Typically, transmission lines are located in remote areas so they can run for long distances in a straight line, as it is much cheaper to build that way. In contrast, distribution lines have to be close to the customer consequently, they are more numerous. In general, distribution lines are radial, or run away from the transmission lines to a dead end.

Power typically flows from a generator, along the transmission grid to a substation where it is transformed, or stepped down, to a lower voltage for distribution. The voltage reduction allows the utility to use smaller wires and shorter poles for distributing power to consumers. Power on the distribution line flows to customer homes and businesses, but it gets stepped down again as it comes off the distribution lines. Those large, rounds, black transformers that are mounted on the top of power poles outside homes do this transformation. If the home or business is served with underground wires, the transformer is mounted on the ground in a housing of some sort.

Distribution field of ESI is transformed into Distribution Company and termed as DISCOs. It owned the distribution network. They buy electricity either directly to the pool market or by GENCOs or IPPs and sell it to their customers.

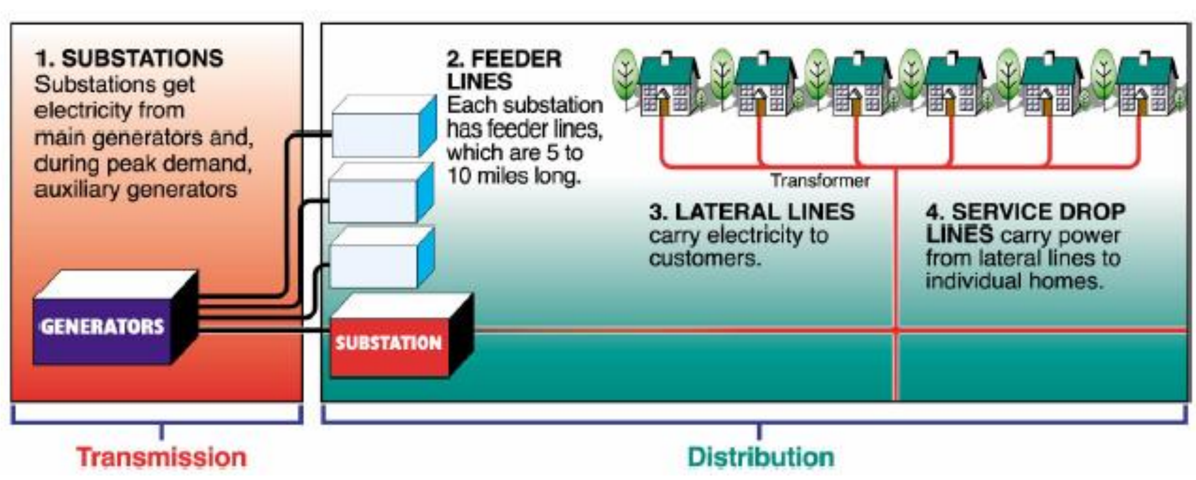

Fig.2.6 The transmission grid moves wholesale power from generators to distributors. The distribution system moves retail power from distributors to customers.

2.4 Customers

When consumers think about reliability, they generally think in terms of power outages, but reliability is much more complex than that. Transmission and generation work together. Given the roles each performs, they are effectively substitutes for one another. In other words, power can be transmitted from a remote power plant to a customer, or it can be generated locally, near the customer. In the first instance, transmission substitutes for near-by generation. In the second, generation substitutes for transmission capacity.

The benefit of an extensive transmission system is that it provides access to generation across a much broader area. This allows power purchasers to hunt for lower cost power than might be available locally and for distant generators to perhaps sell their low-cost power for a higher profit. It also allows utilities to diversify the source of their purchases. However, an extensive transmission system also has costs, in addition to the expense of construction and maintenance. Reliance on power from distant power plants delivered over long transmission lines leaves a utility vulnerable to disruptions on the power lines. This has to be taken into account when the utility plans its generating reserve margins, lest it find itself with power supply contracts in hand, and no power deliveries to back them up. These are the kinds of issues that utilities must include in their generation and transmission planning and operations.

Reliability is actually composed of two elements, adequacy of generation and transmission capacity and reliability of transmission and distribution system performance. In other words, is there enough power and transmission capacity and can it be used to get power to all customers when they need it?

When consumers have a power outage, they tend to blame “the power system” or “the utility.” In fact, less than 10% of consumer outages are the result of failures of the main power grid (the generation and bulk power transmission system). About 10% are due to substation failures. The remaining 80% of outages occur in the local distribution system, caused by falling tree limbs or other vegetation, animals getting into the power lines, automobile accidents, and lightning strikes or other severe weather.

Typically, distribution outages are localized. In other words, only a small area of the utility system is out of power. Major storms can knock out power to larger areas without actually bringing down the entire power grid. This is because transmission lines are built to be above or away from trees that can interfere with them, while distribution lines tend to follow along tree-lined streets in cities and towns.

A costumer is the end user connected to DISCOMs. Domestic customer has less electricity requirement hence it is connected to the distribution company while industrial customers connected directly to the transmission company due to bulk power requirement. In deregulated market customer has a choice to connect either directly to DISCOMs or to any other retailers.

2.5 System Operator

In the deregulated market environment the primary function of the system operators is to maintain system security and reliability at all system conditions. It does not take participate into trading. In some contingency condition it provides some emergency services like emergency reserve to maintain the system reliability. It is also called independent system operator (ISO).

Competitive generation & transmission markets merge in the ISO, despite the fact that the markets themselves operate independently. A central point of control is necessary to ensure system reliability. ISOs became the heart of the new competitive electricity industry & are required to be .broadly representative of all market participants, not just transmission owners.

Due to deregulation, the reliability margins of transmission lines are reduced because the number of participates on electric grid are increased. Also, under fault condition reliability margins are decreased. So the transmission embedded cost allocation methodologies should take into account transmission reliability margin in their calculation. Hence a factor related to transmission reliability margin should be added in transmission pricing mechanism to address this issue.

2.6 Models Based On the Function of Energy Trading

Historically, the cost of generating power declined as utilities built ever-larger power plants, which increased efficiency and reduced production costs. Increased electric demand required more & larger plants, which reduced costs further as well as increasing the utility rate base. This era was a win for everyone. Consumers had abundant, low cost power; regulators oversaw declining rates, increased electrification, & economic growth; & utilities & stockholders gained financially. These models are based on the function of energy trading.

2.6.1 Single purchase agent model

This deregulated electricity market model permitted independent power producer (IPPs) along with generating companies (GENCOs) to sell their power to power pool. In the next step distribution company (DISCOMs) buy this power from the power pool which is a purchasing company. This model introduced competition in generation not in distribution because DISCOMs are bound to buy their power from power pool.

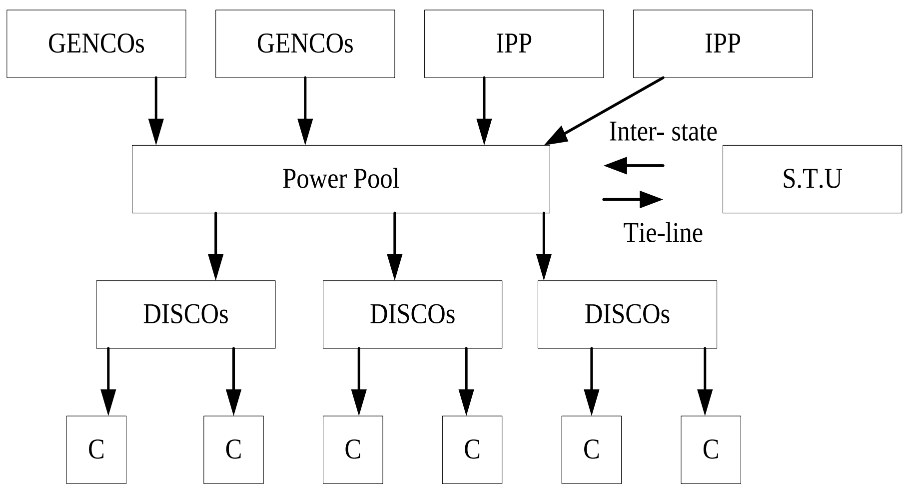

Figure 2.7: Single Purchase Agent Model [3]

2.6.2 Wholesale competition model

In this model GENCOs and IPPs are free to sell their power directly to DISCOMs. Hence this model provides competition both in generation and distribution sector. The main requirement for this model is the complete open access of the transmission network. Because every participants (GENCOs and IPPs) use the same transmission network for sell of their power to DISCOMs.

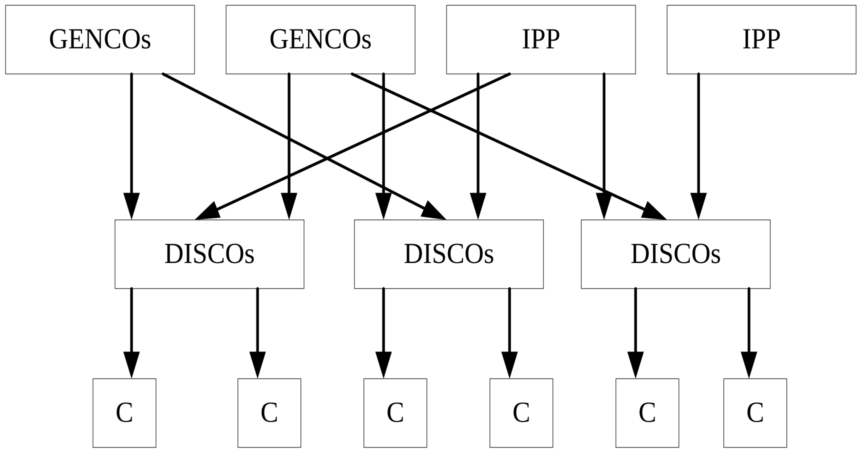

Figure 2.8: Wholesale Competition Model [3]

2.6.3 Retail competition model

In this model all customers have access to generators (GENCOs and IPPs) either directly or through retailers. Hence this model provides complete open access at generation, transmission and distribution level.

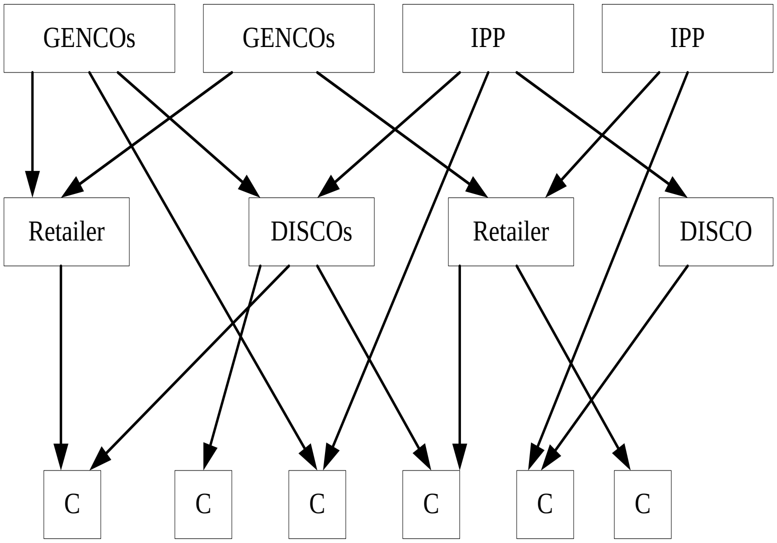

Figure 2.9: Retail Competition Model

CHAPTER THREE

3 TRANSMISSION LOSS AND COST ALLOCATION UNDER BASE AND N-1 CONTINGENCY CONDITION

3.1 INTRODUCTION

In the deregulated power system, transmission pricing has become a very important task because it is necessary to develop an efficient, feasible and reliable pricing scheme that can generate the useful economic signals to network users such as generating companies, transmission companies, distribution companies and customers.

Typically, bulk transmission system loss account for approximately 4% of total electrical energy produced. How to allocate these losses becomes a major concern for all market players. Loss allocation is a procedure for subdividing the system transmission losses into fractions. The costs of which then becomes the responsibility of individual users of the power system (Genco.'s, Disco.'s, Marketer's). Loss allocation does not affect generation levels or power flows. However it does modify the distribution of revenues and payments at the network buses among suppliers and consumers.

3.1 TRANSMISSION LOSS AND COST ALLOCATION UNDER BASE CONDITION

Transmission loss of a line can be obtained from power flow. This loss is then allocated to different generators and loads of the power system. For transmission loss allocations to generator Bialek tracing is used which is as follows:

3.1.1 Topological Generation Distribution factors based Power flow tracing (Bialek Tracing)

This algorithm works on lossless flows when the flows at the beginning and end of each line are the same. The tracing of electricity is done by upstream looking algorithm and downstream looking tracing algorithm.

Downstream Looking Algorithm

(FLOW TRACING FROM A GENERATOR TO LOAD)

In downstream looking algorithm the transmission usage/supplement charge is allocated to individual loads and losses are allocated to generators. Downstream tracing provides the information about the amount of load power shared by the transmission line and the generator. When the distribution of the power flows has been assigned, starting from the generator, according to the paths of the generator's output and the contribution factor of each node, the relationship between the generator output and line power flow or load can be determined, as well as branch loss that each generator should allocate[13-16][17].

The total flow, the inflow to the Pi bus, is the sum of all the inflows through the lines connected to the bus and the local bus injection. The nodal power Pi is expressed as the sum of the outflows

$$P_i = \sum_{l\in\alpha_i^{\{d\}}} |P_{i-l}| + P_{L_i} = \sum_{l\in\alpha_i^{\{d\}}} c_{l_i} P_l + P_{L_i} \qquad (2.1)$$

for $\mathrm{i} = 1,2,3 \ldots .\mathrm{n}$

Where $\alpha_i^{\{d\}}$ is the set of nodes supplied directly from nodei, P_{i-l} is the line flow in line$i - l$, P_{L_i} is the load at node i and$c_{l_i} = |P_{l-i}|/P_l$. This equation can be written as

$$P_i - \sum_{l\epsilon\alpha_i^{\{d\}}} c_{l_i} P_l = P_{L_i} or\ A_d P = P_L \qquad (2.2)$$

WhereA_d, is the (n x n) downstream distribution matrix and P_L is the vector of nodal demands. The (i, l) element ofA_d, is equal to

$$[A_d]_{il} = \begin{cases} 1 & for\ i = l \\ -c_{l_i} = -|P_{l-i}\ |/P_i\ for\ l \in \alpha_i^{\{d\}} \\ 0 & otherwise \end{cases} \quad (2.3)$$

Note that A_d is also sparse and non-symmetric. If A_d^{-1} exists then $P = A_d^{-1}P_L$ and its i^{th} element is equal to

$$P_i = \sum_{k=1}^{n} [A_d^{-1}]_{ik} P_{Lk} i = 1,2 \ldots . n \quad (2.4)$$

This equation shows how the nodal power P_i distributed between all the loads in the system. On the other hand, the same P_i is equal to the sum of the generation of node iand all the inflows in lines entering the node. Hence the inflow to node ifrom line $i - j$can be calculated using the proportional sharing principle as

$$|P_{i-j}| = \frac{|P_{i-j}|}{P_i} P_i = \frac{|P_{i-j}|}{P_i} \sum_{k=1}^{n} [A_d^{-1}]_{ik} P_{Lk} \quad (2.5)$$

$$= \sum_{k=1}^{n} D_{i-j,k}^{L} P_{LK} \quad for\ all\ j \in \alpha_i^{\{u\}} \quad (2.6)$$

Where $D_{i-j,k}^{L} = |P_{i-j}|[A_d^{-1}]_{ik}/P_i$ is the topological load distribution factor that is the portion of k^{th} load demand that flows in line $i - j$.

The generation at a node is also an inflow and can be calculated using the proportional sharing principle as

$$P_{Gi} = \frac{P_{Gi}}{P_i} P_i = \frac{P_{Gi}}{P_i} \sum_{k=1}^{n} [A_d^{-1}]_{ik} P_{LK}\ for\ i = 1,2 \ldots . n \quad (2.7)$$

This equation shows that the share of the output of the i^{th} generator used to supply the k^{th} load demand is equal to $P_{Gi}P_{Lk}[A_d^{-1}]_{ik}/P_i$ can be used to trace where the power of a particular generator goes to. This method of loss allocation is said to be direct because all the calculation is already done for usage allocation. Thus, transmission loss cost under base condition is given by:-

$$LC_{i,j} = \sum_{Gi}^{N_G} LC_{Li,j} \times \frac{P_{LGi}}{P_{Li,j}} \quad \text{Or} \quad LC_{i,j} = \sum_{Li}^{N_L} LC_{Li,j} \times \frac{P_{LLi}}{P_{Li,j}} \tag{2.8}$$

The method can be summarized as follows:

1. Solve power flow (either ac or dc) and define line flows (inflows and outflows).
2. If losses exist, allocate each line‘s loss as additional loads to both ends of the line.
3. Find matrix ***Ad***
4. Define generation vector ***PG***
5. Invert matrix ***Ad*** (i.e. $[A_d^{-1}]$)
6. Find nodal power ***Pg*** using ***Pg*** = $[A_d^{-1}]$***PG.*** The nodal power at node *i* is given as

$$P_i^g = \sum_{k=1}^{n} [A_d^{-1}]_{ik} P_{GK}$$

7. The nodal outflow of line *i–j*, using the proportional sharing principle, is given

$$P_i^g = \frac{P_{ij}^g}{P_i^g} P_i^g = \frac{P_{ij}^g}{P_i^g} [A_d^{-1}]_{ik} P_{GK}$$

Algorithm for bialek method

Step1: Run the AC load flow for base case data.

Step2: Evaluate the line flows of each line and slack bus power in the given power system.

Step3: Read the line lengths in miles of the system.

Step4: Fix the unit rate i.e.,$/MVA/hr

Step6: Evaluate the tracing of line flow of each line with Bialek method.

Step8: Evaluate total cost of each generator.

Step9: Evaluate the transaction cost for each generator.

$$transactioncost\ (\$) = \frac{\text{totaltransmisioncostofeachgenerator}}{\text{totaltransmissioncostofallgenerators}} * \text{total line cost}$$

Step10: Calculate cost (Br/MW) for each generator.

$$per\ unitcost\ \text{Br}/MW = \frac{\text{each transaction cost}}{power\ generation\ cost}$$

3.2 DEVELOPED LOSS IMPACT AND LOSS DISTRIBUTION FACTORS

Outage transfer Loss Impact Factor (OTLIF) represents the impact of an outage on loss of any line has on the post contingency loss of any line. OTLIF is represented as follow:

$$OTLIF_{i,j} = \begin{Bmatrix} \frac{P_{Li,j} - P_{Lj}}{P_{Li}}, & P_{Li,j} > P_{Lj} \\ 0, & otherwise \end{Bmatrix} \tag{2.9}$$

Thus, $OTLIF_{i,j}$ is described as the ratio of difference of the real loss in the line i after an outage in the line j and the normal loss in the line j to that of normal loss in the line i. Outage Transfer Loss Distribution Factor (OTLDF) is defined as the redistribution of the particular generation loss after an outage. OTLDF is represented as follow:

$$OTLDF_{i,j} = \begin{Bmatrix} \frac{P_{Li,j} - P_{Lj}}{P_{Lj}}, & P_{Li,j} > P_{Lj} \\ 0, & otherwise \end{Bmatrix} \tag{2.10}$$

Thus, $OTLDF_{i,j}$ is described as the ratio of difference of the real loss in the line i after an outage in the line j and the normal loss in the line j to that of normal loss in the line j.

3.3 Transmission loss and cost allocation under N-1 contingency condition

The loss on a line after an outage condition can be approximately calculated by using aforementioned four factors are as follows:

$$P_{Li,j} = P_{Li} + OTLIF_{i,j} \times P_{Lj} \tag{2.11}$$

$$P_{Li,j} = P_{Li} + OTLDF_{i,j} \times P_{Lj} \tag{2.12}$$

The maximum loss of each line for each factor is expressed as:

$$F_{Li,M} = \max\left(P_{Li,1}, P_{Li,2} \ldots\ldots\ldots\ldots P_{Li,M}\right) \qquad (2.13)$$

Under contingency operation, the transmission loss cost is expressed as:

$$LC_{i,j} = LC_{Li,j} \times \frac{F_{Lg}}{F_{Li,M}} \qquad (2.14)$$

A MATLAB code is developed for calculating these factors and then maximum loss of the line.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

To check the feasibility and the reliability of the methodology two test systems are considered namely: sample 6 bus system, IEEE 14 bus system.

The 6-bus system is simulated in power world simulator which involves different transaction locations. The power flow tracing method directly provides the contribution of each generator to the corresponding line. This resulting in lesser number of generators participating in the process of rescheduling is to reduce the transmission pricing as well as provide fair and fixed transparent tariff to the consumer and generators. The proportional sharing approach via downstream algorithm has been tested on 6-bus system using MATLAB programing. Power flow tracing algorithm gives better optimal solution and results and the loss allocation of individual generator and individual loads are tabulated.

4.1 Sample 6 Bus Power Systems

Figure 4.1 depicts a 6 bus test system [11], which is composed of three loads and three generators. The system data is given in Table. In an open access transmission system, it is supposed that three independent generators Gen 1, Gen 2 and Gen 3 sell their electricity to three loads Load 4, Load 5 and Load 6. In the deregulated market System Operator (SO) is responsible for providing the required transmission service and allocating the cost incurred to the loads involved in the service [10]. It is assumed here that the cost for all the transmission lines is equivalent to its impedance of the lines. Table 4.1 shows the transaction details of the 6 bus power system.

Table 4.1. Transaction Details of the 6 Bus System

Transactions	Gen _Bus	Load _Bus	P_l(MW)	Q_l(MVAr)
1	1	5	100	100
2	2	4	100	100
3	3	6	100	100

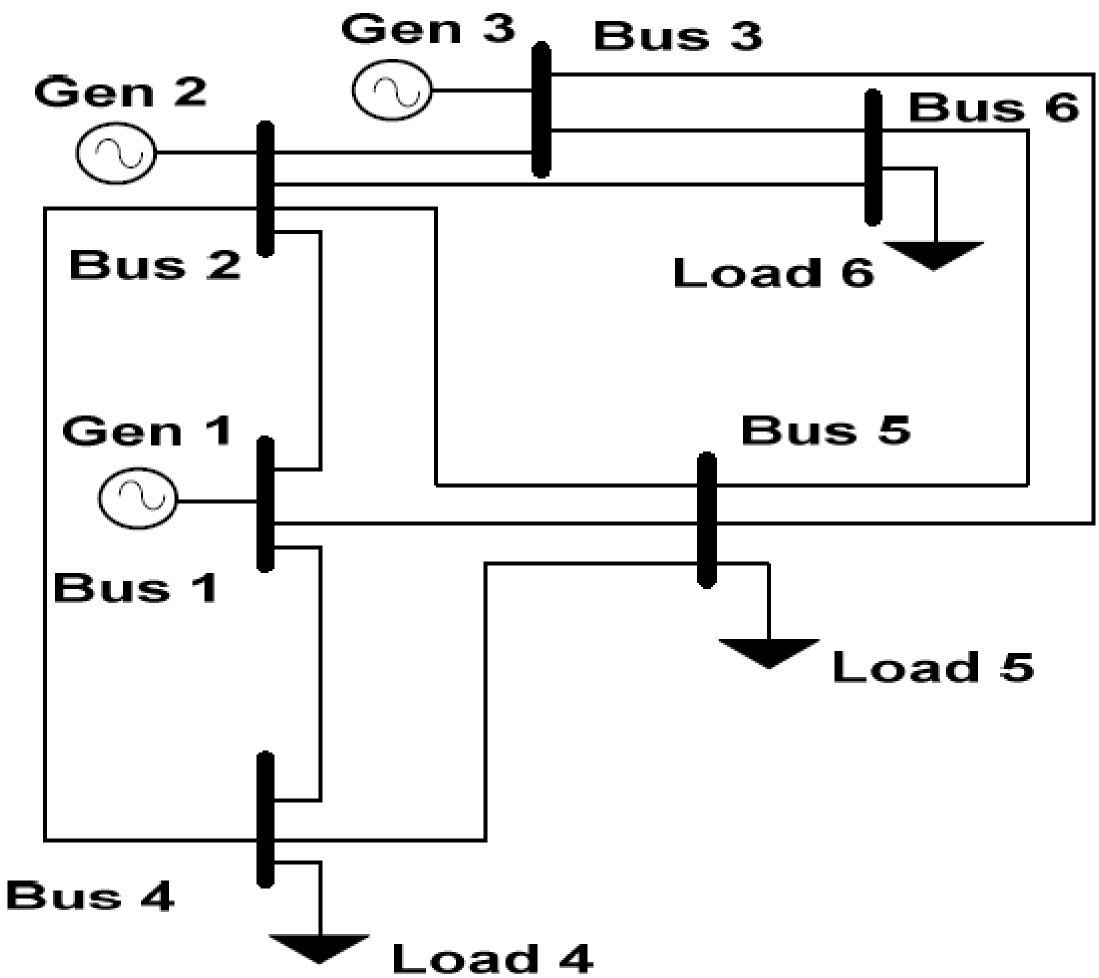

Figure 4.1 Sample 6 Bus System

Table.4.2 shows the loss cost allocation to generators under base condition to sample 6 bus systems. Loss cost of the line is taken 7% of the total cost of the line. Fig. 4.2 shows the percentage loss cost allocated to generators. It is clear that G1 shares more cost than others.

Table 4.2 Cost Allocated under Base condition for Sample 6 Bus System

Line	Loss (p.u.)	Loss Cost (Br/MWhr)	Loss Cost Allocated under Base Condition (Br/MWhr)		
			G1	G2	G3
1	0.0094	0.720	0.733	0.000	0.000
2	0.0113	0.664	0.664	0.000	0.000
3	0.0112	1.000	1.009	0.000	0.000
4	0.0004	0.821	0.000	0.893	0.000
5	0.0164	0.360	0.133	0.229	0.000
6	0.0056	1.019	0.395	0.633	0.000
7	0.0062	0.682	0.239	0.430	0.000
8	0.0123	0.922	0.032	0.032	0.880
9	0.0108	0.328	0.000	0.013	0.317
10	0.0004	1.441	1.566	0.000	0.000
11	0.0006	1.019	0.960	0.000	0.000

The cost paid by load *i* , for using transmission system by power flow tracing method can be calculated using Eq. (2.14).

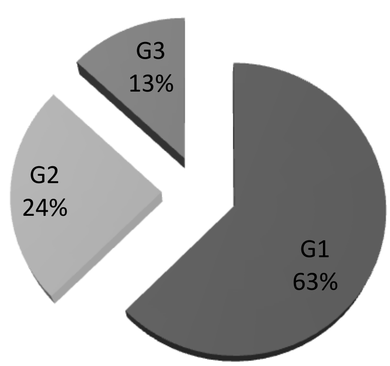

Fig. 4.2 Loss Cost allocated to generators under base condition for sample 6 bus system

Table 4.2 shows the maximum loss capacity due to various factors. Table 4.3 shows the loss cost allocation to generators under contingency condition to sample 6 bus system. Fig. 4.2 shows the percentage loss cost allocation under contingency condition due to OTLIF and OTLDF. Again, it is clear that loss cost allocated to G1 is more than that of others generator. Same procedure can be applied for allocating the loss cost to loads.

Table 4.3 Maximum Loss for Sample 6 Bus System

Line	Power Flow due to OTLIF (p.u.)	Power Flow due to OTLDF (p.u.)
1	0.0440	0.039
2	0.0548	0.042
3	0.0228	0.023
4	0.0004	0.002
5	0.0356	0.045
6	0.0193	0.012
7	0.0839	0.05
8	0.0246	0.026
9	0.0148	0.018
10	0.0004	0.006
11	0.1179	0.007

Table 4.4 Transmission Loss Cost Allocation to Generators Using OTLIF and OTLDF for Sample 6 Bus System

Line	Loss Cost (Br/MWhr)	Loss Cost Allocated due to OTLIF (Br/MWhr)			Loss Cost Allocated due to OTLDF (Br/MWhr)		
		G1	G2	G3	G1	G2	G3
1	0.720	0.156	0.000	0.000	0.176	0.000	0.000
2	0.664	0.137	0.000	0.000	0.178	0.000	0.000
3	1.000	0.496	0.000	0.000	0.491	0.000	0.000
4	0.821	0.000	0.893	0.000	0.000	0.178	0.000
5	0.360	0.061	0.105	0.000	0.048	0.083	0.000
6	1.019	0.114	0.183	0.000	0.184	0.295	0.000
7	0.682	0.017	0.031	0.000	0.029	0.053	0.000
8	0.922	0.016	0.016	0.441	0.015	0.015	0.416
9	0.328	0.000	0.009	0.231	0.000	0.007	0.190
10	1.441	1.566	0.000	0.000	0.104	0.000	0.000

11	1.019	0.004	0.000	0.000	0.082	0.000	0.000

The transmission loss cost allocation to can be calculated using Eq. (2.11 and 2.12 respectively).

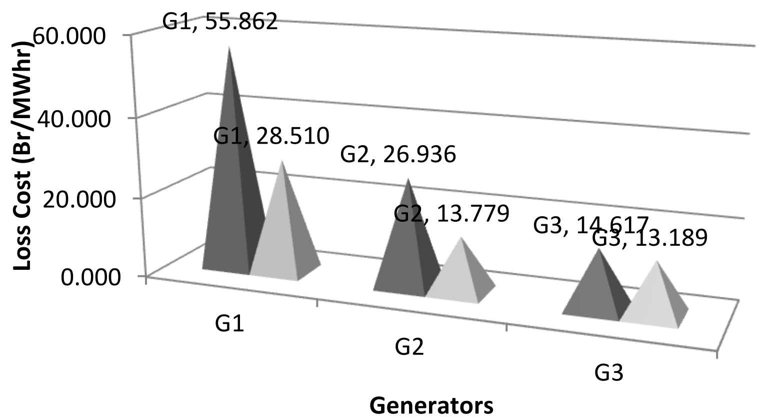

Fig. 4.3 Loss Cost allocated to Generators under Contingency condition for Sample 6 Bus System

4.2 IEEE 14 Bus Power System

Table.4.4 shows the loss cost allocation to generators under base condition to IEEE 14 bus system. Fig. 4.3 shows the percentage loss cost allocated to generators. Again, it is clear that G1 shares more cost than G2 since the loss allocation to G1 is more.

Table 4.5 Cost Allocated under Base condition for IEEE 14 Bus System

Line	Loss (MW)	Loss Cost (Br/MWhr)	Loss Cost Allocated under Base Condition (Br/MWhr)	
			G1	G2
1	4.1760	0.2	0.2	0.000
2	3.2975	0.74	0.739	0.000
3	2.9839	0.655	0.524	0.151
4	2.2550	0.598	0.478	0.137
5	1.3142	0.589	0.472	0.136
6	0.4354	0.591	0.532	0.094

7	0.5393	0.142	0.000	0.000
8	0.0000	0.674	0.000	0.000
9	0.0000	1.792	0.000	0.000
10	0.0000	0.812	0.000	0.000
11	0.1061	0.71	0.669	0.058
12	0.0996	0.914	0.878	0.079
13	0.3016	0.471	0.454	0.041
14	0.0000	0.567	0.000	0.000
15	0.0000	0.354	0.000	0.000
16	0.0108	0.291	0.233	0.000
17	0.1368	0.962	0.856	0.152
18	0.0341	0.673	0.687	0.085
19	0.0110	0.960	0.756	0.000
20	0.0971	1.249	1.230	0.112

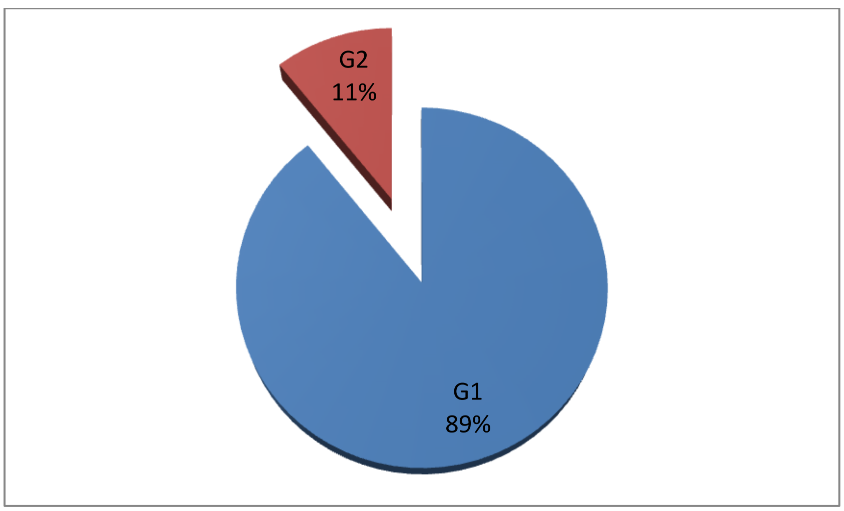

Fig. 4.4 Loss Cost allocated to various generators under base condition for IEEE 14 bus system

Table 4.5 shows the maximum loss capacity due to various factors. Table 4.6 shows the loss cost allocation to generators under contingency condition to IEEE 14 bus system. Fig. 4.4 shows the percentage loss cost allocation under contingency condition due to OTLIF and OTLDF. Again, it is clear that loss cost allocated to G1 is more than that of others generator.

Table 4.6 Maximum Loss for IEEE 14 Bus Systems

Line	Power Flow due to OTLIF (MW)	Power Flow due to OTLDF (MW)
1	13.8111	16.3781
2	97.3685	77.5799
3	13.1082	18.7889
4	21.2954	16.6442
5	18.3085	8.7991
6	185.1403	27.3868
7	37.8798	5.3611
8	0.0000	5.6838
9	0.0000	5.6042
10	0.0000	7.5025
11	0.6044	2.1716
12	3.8535	1.0255
13	2.6661	1.3988
14	0.0000	0.0000
15	0.0000	4.6385
16	61.7391	2.2869
17	16.6555	5.0508
18	0.9283	2.8265
19	11.5658	0.4339
20	1.9049	1.5207

Table 4.7 Transmission Loss Cost Allocation to Generators Using OTLIF and OTLDF for IEEE 14 Bus System

Line	Cost (Br/MWhr)	Cost Allocated due to OTLIF (Br/MWhr)		Cost Allocated due to OTLDF (Br/MWhr)	
		G1	G2	G1	G2
1	4.358	1.317	0.000	1.111	0.000
2	16.064	0.544	0.000	0.682	0.000
3	14.243	2.594	0.746	1.809	0.521
4	12.996	1.101	0.316	1.409	0.404
5	12.808	0.736	0.213	1.532	0.443
6	12.858	0.027	0.005	0.184	0.033
7	3.093	0.000	0.000	0.000	0.000
8	14.638	0.000	0.000	0.000	0.000

9	38.933	0.000	0.000	3.594	0.332
10	17.641	0.000	0.000	0.000	0.000
11	15.429	2.553	0.222	0.710	0.062
12	19.867	0.493	0.045	1.853	0.168
13	10.227	1.117	0.100	2.130	0.191
14	12.331	0.000	0.000	0.000	0.000
15	7.701	0.000	0.000	0.000	0.000
16	6.320	0.001	0.000	0.024	0.000
17	20.914	0.153	0.027	0.504	0.090
18	14.620	0.548	0.068	0.180	0.022
19	20.854	0.016	0.000	0.418	0.000
20	27.141	1.363	0.124	1.707	0.155

Fig. 4.5 Loss Cost allocated to Generators under Contingency condition for IEEE 14 Bus System

CHAPTER FIVE

5 Conclusion and Future Scope

The Electric Supply Industries (ESI) in all over the world is undergoing a phase of restructuring process. Existing long term bilateral contracts, short term trading, emergence of power exchange and transmission open access have paved the way for creation of a hybrid type of electricity market structure. Wholesale competition has been introduced at the supplier end. Retail competition, at consumer end, is yet to be started and the transmission business has remained a natural monopoly. A new approach for allocating the loss cost to network under N-1 contingency condition is presented. The new pricing mechanism provides a movement from opaque to transparent system and it rational and economic logic to the generator for siting generation with respect to load. This work is aimed to suggest a cost effective transmission pricing technique under contingency condition. In this thesis, real loss is considered only. For transmission loss allocation, Bialek's methodology is used.

In this paper, starting from a converged load flow solution, contribution factors of each complex power injection at a bus to the complex line loss in each of the transmission line are found out. At the same time, contributions of each of the transmission lines to the complex power injection at a bus are determined. These contributions allow allocation of loss among the buses based on the usage. The loss allocation factors are derived, starting from a converged load flow solution without any assumptions. In this paper a real power loss allocation methodology based on the contribution factors is established. Another significant feature of the pro-posed methodology is that, effect of reactive power generation and load can be easily established using the proposed methodology. Since the contribution factors derived does not involve any assumptions, there is every chance that these factors can play a vital role in the determination of Locational Marginal Prices in the present day electricity markets.

5.1 SUMMARY OF IMPORTANT FINDINGS

In this work the procedures have been done for allocating the line loss and cost of the systems. Loss allocation and loss cost allocation have been done for two different test systems. With the help of various developed loss impact and loss distribution factor i.e. OTLIF, and OTLDF, loss cost allocations under contingency condition have been done. From the test results obtained on various test systems, following main conclusions are drawn:

- The proposed technique can be applied easily on small system as well as large system as presented in this thesis.
- Simulation studies have demonstrated that by considering maximum capacity of the line, more cost of the line is allocated.
- Proposed method is simple to understand, easy to implement in any power system.
- It can be argued that the mathematical rigor involved in this methodology is high but it is not time taking process due to sparse impact factor for some cases.
- Results have been presented for sample 6 and IEEE 14 bus system

5.2 SCOPE FOR FUTURE RESEARCH

In this thesis, only real loss has been considered, reactive power loss can be allocated under "N-1" contingency condition.

5.3 RECOMMENDATIONS

In our country Ethiopia the three utilities are working integrally for the last decays. But know a day they start to work independently. As we know now a days the service of electricity in our county is becoming problem.so to improve/reduce this problem the restructuring of utilities is important for the deregulation of the market and also help the customers would be able to choose their electricity supplier. The deregulations improve the quality of people's lives by lowering the cost of a critical commodity

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APPENDIX A

SAMPLE 6 BUS SYSTEM DATA

In this appendix, the data of test system namely Sample 6 Bus System used in the proposed work is given. The single line diagram of the sample 6 bus system is shown in Fig. A.1. It contains 3 generator buses and 3 load buses. The data is at 100 MVA base and taken from Table A.1 and Table A.2 show the line data and bus data of the sample 6 bus system.

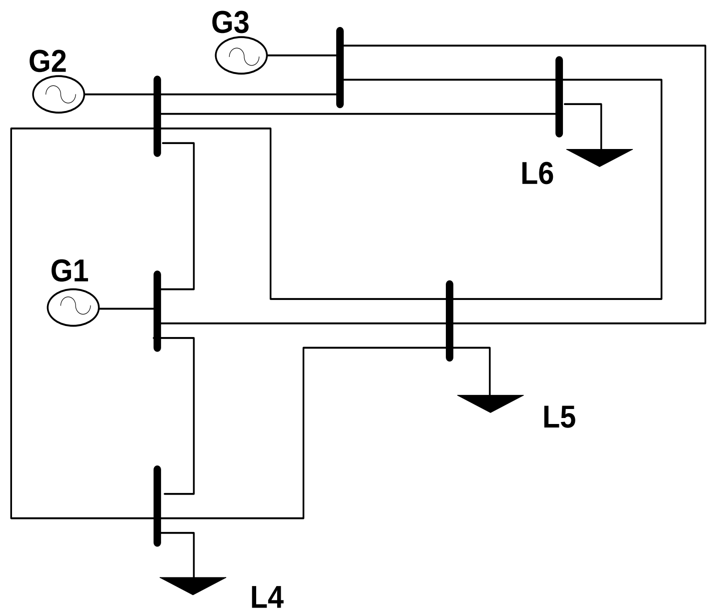

Fig. A.1 Single line diagram of Sample 6 Bus System

Table A.1 Line Data of Sample 6 Bus System (in p.u.)

Line No.	From Bus	To Bus	Resistance	Reactance	Susceptance
1	1	2	0.1	0.2	0.02
2	1	4	0.05	0.2	0.02
3	1	5	0.08	0.3	0.03
4	2	3	0.05	0.25	0.03
5	2	4	0.05	0.1	0.01
6	2	5	0.1	0.3	0.02
7	2	6	0.07	0.2	0.025
8	3	5	0.12	0.26	0.025
9	3	6	0.02	0.1	0.01
10	4	5	0.2	0.4	0.04
11	5	6	0.1	0.3	0.03

Table A.2 Bus Data of Sample 6 Bus System

Bus No	Bus Type	Vol (p.u.)	Angle (rad)	P_L (p.u.)	Q_L (p.u.)	P_G (p.u.)	Q_G (p.u.)
1	1	1.05	0	0	0	0	0
2	2	1.05	0	0	0	0.5	0
3	2	1.07	0	0	0	0.6	0
4	0	1	0	0.7	0.7	0	0
5	0	1	0	0.7	0.7	0	0
6	0	1	0	0.7	0.7	0	0

APPENDIX B

IEEE 14 BUS SYSTEM DATA

In this appendix, the data of test system namely IEEE 14 Bus System used in the proposed work is given. The single line diagram of the IEEE 14 bus system is shown in Fig. B.1. It contains 2 generator buses and 12 load buses. The data is at 100 MVA base and taken from Table B.1 and Table B.2 show the line data and bus data of the IEEE 14 bus system.

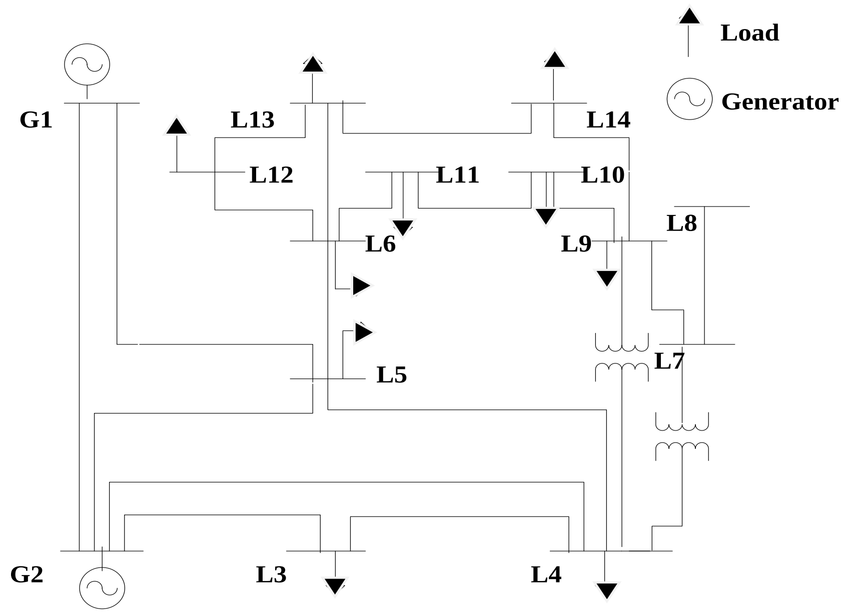

Fig. B.1 Single line diagram of IEEE 14 Bus System

Table B.1 Line Data of IEEE 14 Bus System (in p.u.)

Line No2.	From Bus	To Bus	Resistance	Reactance	Susceptance
1	1	2	0.01938	0.05917	0.026
2	1	5	0.05403	0.22304	0.025
3	2	3	0.04699	0.19797	0.022
4	2	4	0.05811	0.17632	0.019
5	2	5	0.05695	0.17388	0.017
6	3	4	0.06701	0.17103	0.017
7	4	5	0.01335	0.04211	0.006
8	4	7	0	0.20912	0
9	4	9	0	0.55618	0
10	5	6	0	0.25202	0
11	6	11	0.09498	0.1989	0
12	6	12	0.12291	0.25581	0
13	6	13	0.06615	0.13027	0
14	7	8	0	0.17615	0
15	7	9	0	0.11001	0
16	9	10	0.03181	0.0845	0
17	9	14	0.12711	0.27038	0
18	10	11	0.08205	0.19207	0
19	12	13	0.22092	0.19988	0
20	13	14	0.17093	0.34802	0

Table B.2 Bus Data of IEEE 14 Bus Systems

Bus No	Bus Type	Vol (p.u.)	Angle (rad)	P_L (p.u.)	Q_L (p.u.)	P_G (p.u.)	Q_G (p.u.)
1	1	1.06	0	0	0	0	0
2	2	1.045	0	0	0	40	0
3	0	1.01	0	94.2	19	0	0
4	0	1.019	0	47.8	-3.9	0	0
5	0	1.02	0	7.6	1.6	0	0
6	0	1.07	0	11.2	7.5	0	0
7	0	1.062	0	0	0	0	0
8	0	1.09	0	0	0	0	0
9	0	1.056	0	29.5	16.6	0	0
10	0	1.051	0	9	5.8	0	0
11	0	1.057	0	3.5	1.8	0	0
12	0	1.055	0	6.1	1.6	0	0
13	0	1.05	0	13.5	5.8	0	0
14	0	1.036	0	14.9	5	0	0

APPENDIX C

MATLAB CODE

```
%   Power flow solution by Newton-Raphson method
clear all;
clc;
%-----------------------------------
basemva=1.0; accuracy = 0.001; maxiter = 100; accel=1.8;
%----------------------------------
ns=0; ng=0; Vm=0; delta=0; yload=0; deltad=0;
%----------------------
busdata=dlmread('busdata.m');
[r1 c1]=size(busdata);
%-----------------------
nbus = length(busdata(:,1));
kb=[];Vm=[]; delta=[]; Pd=[]; Qd=[]; Pg=[]; Qg=[]; Qmin=[]; Qmax=[];  %
Added (6-8-00)
Pk=[]; P=[]; Qk=[]; Q=[]; S=[]; V=[]; % Added (6-8-00)
for k=1:nbus
n=busdata(k,1);
kb(n)=busdata(k,2); Vm(n)=busdata(k,3); delta(n)=busdata(k, 4);
Pd(n)=busdata(k,5); Qd(n)=busdata(k,6); Pg(n)=busdata(k,7); Qg(n) =
busdata(k,8);
Qmin(n)=busdata(k, 9); Qmax(n)=busdata(k, 10);
Qsh(n)=busdata(k, 11);
    if Vm(n) <= 0  Vm(n) = 1.0; V(n) = 1 + j*0;
    else delta(n) = pi/180*delta(n);
         V(n) = Vm(n)*(cos(delta(n)) + j*sin(delta(n)));
         P(n)=(Pg(n)-Pd(n))/basemva;
         Q(n)=(Qg(n)-Qd(n)+ Qsh(n))/basemva;
         S(n) = P(n) + j*Q(n);
    end
end
for k=1:nbus
if kb(k) == 1, ns = ns+1; else, end
if kb(k) == 2 ng = ng+1; else, end
ngs(k) = ng;
nss(k) = ns;
end
%-------------------
Lfybus
%-----------------
Ym=abs(Ybus); t = angle(Ybus);
m=2*nbus-ng-2*ns;
maxerror = 1; converge=1;
iter = 0;
%%%% added for parallel lines (Aug. 99)
mline=ones(nbr,1);
for k=1:nbr
```

```
      for m=k+1:nbr
         if((nl(k)==nl(m)) & (nr(k)==nr(m)));
            mline(m)=2;
         elseif ((nl(k)==nr(m)) & (nr(k)==nl(m)));
         mline(m)=2;
         else, end
      end
   end
%%%   end of statements for parallel lines (Aug. 99)

% Start of iterations
clear A  DC   J  DX
while maxerror >= accuracy & iter <= maxiter % Test for max. power
mismatch
for ii=1:m
for k=1:m
   A(ii,k)=0;      %Initializing Jacobian matrix
end, end
iter = iter+1;
for n=1:nbus
nn=n-nss(n);
lm=nbus+n-ngs(n)-nss(n)-ns;
J11=0; J22=0; J33=0; J44=0;
   for ii=1:nbr
      if mline(ii)==1   % Added to include parallel lines (Aug. 99)
           if nl(ii) == n | nr(ii) == n
           if nl(ii) == n ,  l = nr(ii); end
           if nr(ii) == n , l = nl(ii); end
         J11=J11+ Vm(n)*Vm(l)*Ym(n,l)*sin(t(n,l)- delta(n) + delta(l));
         J33=J33+ Vm(n)*Vm(l)*Ym(n,l)*cos(t(n,l)- delta(n) + delta(l));
                 if kb(n)~=1
                 J22=J22+ Vm(l)*Ym(n,l)*cos(t(n,l)- delta(n) + delta(l));
                 J44=J44+ Vm(l)*Ym(n,l)*sin(t(n,l)- delta(n) + delta(l));
                 else, end
                 if kb(n) ~= 1  & kb(l) ~=1
                       lk = nbus+l-ngs(l)-nss(l)-ns;
                       ll = l -nss(l);
                       % off diagonalelements of J1
                       A(nn, ll) =-Vm(n)*Vm(l)*Ym(n,l)*sin(t(n,l)-
delta(n) + delta(l));
                       if kb(l) == 0  % off diagonal elements of J2
                       A(nn, lk) =Vm(n)*Ym(n,l)*cos(t(n,l)- delta(n) +
delta(l));end
                       if kb(n) == 0  % off diagonal elements of J3
                       A(lm, ll) =-Vm(n)*Vm(l)*Ym(n,l)*cos(t(n,l)-
delta(n)+delta(l)); end
                       if kb(n) == 0 & kb(l) == 0  % off diagonal elements
of  J4
                       A(lm, lk) =-Vm(n)*Ym(n,l)*sin(t(n,l)- delta(n) +
delta(l));end
              else end
           else , end
      else, end
   end
```

```
   Pk = Vm(n)^2*Ym(n,n)*cos(t(n,n))+J33;
   Qk = -Vm(n)^2*Ym(n,n)*sin(t(n,n))-J11;
   if kb(n) == 1 P(n)=Pk; Q(n) = Qk; end   % Swing bus P
     if kb(n) == 2  Q(n)=Qk;
         if Qmax(n) ~= 0
           Qgc = Q(n)*basemva + Qd(n) - Qsh(n);
           if iter <= 7                  % Between the 2th & 6th
iterations
              if iter > 2                % the Mvar of generator buses are
                if Qgc  < Qmin(n),       % tested. If not within limits
Vm(n)
                Vm(n) = Vm(n) + 0.01;    % is changed in steps of 0.01 pu
to
                elseif Qgc  > Qmax(n),   % bring the generator Mvar within
                Vm(n) = Vm(n) - 0.01;end % the specified limits.
              else, end
           else,end
         else,end
     end
   if kb(n) ~= 1
     A(nn,nn) = J11;  %diagonal elements of J1
     DC(nn) = P(n)-Pk;
   end
   if kb(n) == 0
     A(nn,lm) = 2*Vm(n)*Ym(n,n)*cos(t(n,n))+J22;  %diagonal elements of J2
     A(lm,nn)= J33;        %diagonal elements of J3
     A(lm,lm) =-2*Vm(n)*Ym(n,n)*sin(t(n,n))-J44;  %diagonal of elements of
J4
     DC(lm) = Q(n)-Qk;
   end
end
DX=A\DC';
for n=1:nbus
  nn=n-nss(n);
  lm=nbus+n-ngs(n)-nss(n)-ns;
    if kb(n) ~= 1
    delta(n) = delta(n)+DX(nn); end
    if kb(n) == 0
    Vm(n)=Vm(n)+DX(lm); end
 end
  maxerror=max(abs(DC));
     if iter == maxiter & maxerror > accuracy
   fprintf('\nWARNING: Iterative solution did not converged after ')
   fprintf('%g', iter), fprintf(' iterations.\n\n')
   fprintf('Press Enter to terminate the iterations and print the results
\n')
   converge = 0; pause, else, end

end

if converge ~= 1
   tech= ('                      ITERATIVE SOLUTION DID NOT CONVERGE');
else,
```

```
   tech=('                    Power Flow Solution by Newton-Raphson
Method');
end
V = Vm.*cos(delta)+j*Vm.*sin(delta);
deltad=180/pi*delta;
i=sqrt(-1);
k=0;
for n = 1:nbus
     if kb(n) == 1
     k=k+1;
     S(n)= P(n)+j*Q(n);
     Pg(n) = P(n)*basemva + Pd(n);
     Qg(n) = Q(n)*basemva + Qd(n) - Qsh(n);
     Pgg(k)=Pg(n);
     Qgg(k)=Qg(n);     %june 97
     elseif  kb(n) ==2
     k=k+1;
     S(n)=P(n)+j*Q(n);
     Qg(n) = Q(n)*basemva + Qd(n) - Qsh(n);
     Pgg(k)=Pg(n);
     Qgg(k)=Qg(n);  % June 1997
  end
yload(n) = (Pd(n)- j*Qd(n)+j*Qsh(n))/(basemva*Vm(n)^2);
end
busdata(:,3)=Vm'; busdata(:,4)=deltad';
Pgt = sum(Pg);  Qgt = sum(Qg); Pdt = sum(Pd); Qdt = sum(Qd); Qsht =
sum(Qsh);
nbus
Busout
Lineflow
% clear A DC DX  J11 J22 J33 J44 Qk delta lk ll lm
% clear A DC DX  J11 J22 J33  Qk delta lk ll lm
```

```
%  This program obtains th Bus Admittance Matrix for power flow solution

linedata=dlmread('linedata.m');
%----------------------
j=sqrt(-1); i = sqrt(-1);
nl = linedata(:,1); nr = linedata(:,2); R = linedata(:,3);
X = linedata(:,4); Bc = j*linedata(:,5)/2; a = linedata(:, 6);
nbr=length(linedata(:,1)); nbus = max(max(nl), max(nr));
Z = R + j*X; y= ones(nbr,1)./Z;        %branch admittance
for n = 1:nbr
if a(n) <= 0
    y(n)=0;
    a(n) = 1; else end
Ybus=zeros(nbus,nbus);     % initialize Ybus to zero
               % formation of the off diagonal elements
for k=1:nbr;
       Ybus(nl(k),nr(k))=Ybus(nl(k),nr(k))-y(k)/a(k);
       Ybus(nr(k),nl(k))=Ybus(nl(k),nr(k));
    end
end
              % formation of the diagonal elements
for  n=1:nbus
     for k=1:nbr
         if nl(k)==n
         Ybus(n,n) = Ybus(n,n)+y(k)/(a(k)^2) + Bc(k);
         elseif nr(k)==n
         Ybus(n,n) = Ybus(n,n)+y(k) +Bc(k);
         else, end
     end
end
clear Pgg
```

```
%  This program is used in conjunction with lfgauss or lf Newton
%  for the computation of line flow and line losses.
SLT = 0;
fprintf('\n')
fprintf('                           Line Flow and Losses \n\n')
fprintf('     --Line--  Power at bus & line flow    --Line loss--
Transformer\n')
fprintf('     from  to    MW      Mvar     MVA       MW      Mvar
tap\n')
%a(9)=0;
for n = 1:nbus
busprt = 0;
   for L = 1:nbr;
       if busprt == 0
       fprintf('   \n'), fprintf('%6g', n), fprintf('      %9.3f',
P(n)*basemva)
       fprintf('%9.3f', Q(n)*basemva), fprintf('%9.3f\n',
abs(S(n)*basemva))

       busprt = 1;
       else, end
       if nl(L)==n      k = nr(L);
       In(L) = (V(n) - a(L)*V(k))*y(L)/a(L)^2 + Bc(L)/a(L)^2*V(n);
       Ik(L) = (V(k) - V(n)/a(L))*y(L) + Bc(L)*V(k);
       Snk(L) = V(n)*conj(In(L))*basemva;
       Skn(L) = V(k)*conj(Ik(L))*basemva;
       SL(L)  = Snk(L) + Skn(L);
       SLT = SLT + SL(L);
       elseif nr(L)==n  k = nl(L);
       In(L) = (V(n) - V(k)/a(L))*y(L) + Bc(L)*V(n);
       Ik(L) = (V(k) - a(L)*V(n))*y(L)/a(L)^2 + Bc(L)/a(L)^2*V(k);
       Snk(L) = V(n)*conj(In(L))*basemva;
       Skn(L) = V(k)*conj(Ik(L))*basemva;
       SL(L)  = Snk(L) + Skn(L);
       SLT = SLT + SL(L);
       else, end
         if nl(L)==n | nr(L)==n
         fprintf('%12g', k),
         fprintf('%9.3f', real(Snk(L))), fprintf('%9.3f', imag(Snk(L)))
         fprintf('%9.3f', abs(Snk(L))),
         fprintf('%9.3f', real(SL(L))),
             if nl(L) ==n & a(L) ~= 1
             fprintf('%9.3f', imag(SL(n))), fprintf('%9.3f\n', a(L))
             else, fprintf('%9.3f\n', imag(SL(L)))
             end
         else, end
  end
end
SLT = SLT/2;
fprintf('   \n'), fprintf('    Total loss                          ')
fprintf('%9.3f', real(SLT)), fprintf('%9.3f\n', imag(SLT))
% clear Ik In SL SLT Skn(n) Snk(n)
```

```
%  This program prints the power flow solution in a tabulated form

%clc
disp(tech)
fprintf('                      Maximum Power Mismatch = %g \n', maxerror)
fprintf('                             No. of Iterations = %g \n\n', iter)
head =['    Bus  Voltage  Angle    ------Load------    ---Generation---
Injected'
       '    No.  Mag.     Degree     MW       Mvar       MW       Mvar
Mvar '
       '
'];
disp(head)
for n=1:nbus
     fprintf(' %5g', n), fprintf(' %7.3f', Vm(n)),
     fprintf(' %8.3f', deltad(n)), fprintf(' %9.3f', Pd(n)),
     fprintf(' %9.3f', Qd(n)),  fprintf(' %9.3f', Pg(n)),
     fprintf(' %9.3f ', Qg(n)), fprintf(' %8.3f\n', Qsh(n))
end
    fprintf('      \n'), fprintf('    Total              ')
    fprintf(' %9.3f', Pdt), fprintf(' %9.3f', Qdt),
    fprintf(' %9.3f', Pgt), fprintf(' %9.3f', Qgt), fprintf(' %9.3f\n\n',
Qsht)
```