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Optimal Transmission Pricing Scheme with Consideration of System Reliability

by

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ABSTRACT

The power industry has become an essential driver of economic progress in our country. Over the past couple of decades, the electricity market has experienced significant transformations in its structure, primarily due to deregulation, which has fostered competition among power generators. However, this deregulation has presented several challenges, including the allocation of transmission embedded costs, effective management of losses, and addressing congestion issues within the integrated market. Within this framework, the cost of transmitting electricity imposed on consumers assumes a critical role as it serves as a variable that can be controlled within the power system. This variable provides valuable signals to generator owners in making decisions about the location, type, and timing of their installations. Moreover, it plays a crucial role in defining the overall efficiency of the market. The primary objective of transmission pricing methodologies is to ensure fair competition within the electricity sector and offer reliable economic indicators. As part of this process, users are required to pay fees for network access and usage to the entity responsible for the network. Various methodologies exist for determining the pricing of transmission usage and access, each serving its purpose in promoting a robust and equitable electricity market.

In this thesis work, we have concerned about the usages allocation of generator and load to the line. Also transmission reliability margin (TRM) based on the matrix methodology & transmission cost allocation at base capacity condition and based on the Line outage condition considering the factor (LOIF). The proposed approach involves the development of a Kirchhoff matrix to allocate the usage of generators and loads. This matrix serves as a tool for accurately assigning the utilization of power generation and consumption within the system. For the optimal transmission usages and cost allocation under outage condition i.e. N-1 contingency condition. For allocating the transmission usages cost under contingency condition, line outage impact factor (LOIF) is calculated at maximum flow. These indices play a crucial role for recovering the transmission usage cost from the users. For the cost allocation under contingency condition Modified MW-mile methods is used. In our thesis work, the usages allocation to generator/load, transmission reliability margin allocation to the generator and/or load and cost allocation to the generator and load on the basis of sharing or usages of network is three independent objectives. For the evaluation of methodology considering IEEE 6 bus, system consists

of 3 generator and 3 loads. Also IEEE 14 bus, system consists 5 generator and 12 loads. Transmission usages allocation, transmission reliability margin and cost allocation to each generator are obtained at base capacity case scenario and contingency condition.

For the IEEE 6 bus test system, usage cost allocated to generator G1 308.483 Rs/MWh where as the cost allocated to the generator after considering LOIF is 726.354 Rs/MWh similarly for the generator G2 103.546 Rs/MWh, where as the cost allocation to generator after considering LOIF is 305.874 Rs/MWh and for the generator G3 cost allocation at base case is 91.610 Rs/MWh, where as the cost allocation to generator after considering LOIF is 206.924 Rs/MWh. Furthermore, in the case of the 14 bus system, the allocation of usage costs for generator G1 during outage conditions, taking into account the Line Outage Impact Factor (LOIF), is approximately 1.97 times higher compared to the base capacity scenario. Similarly, for generator G2, the usage cost allocation during outage conditions using LOIF is approximately 2 times higher than that of the base capacity scenario.

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LIST OF SYMBOLS/ ABBREVIATIONS

C_a	Cost of Line
IEEE	Institute of Electrical and Electronic Engineering
$F_{opt,k}$	Optimal Capacity of Transmission line
K	Set of Lines
L_k	Length of Line
LOIF	Line Outage Impact Factor
P_{GG}	Diagonal generator Matrix
Pline	Max. Power Flow
P_{peak}	System Peak
SFM	Supply Factor Matrix
T	Set of Transaction
TC	Total Transmission Cost

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CHAPTER 1 : INTRODUCTION

1.1 Background

The electricity market has experienced substantial organizational transformations during the last two decades as a result of deregulation in the vertically integrated electricity market. The implementation of competition among generators and the establishment of appropriate regulations and market conditions have been recognized as important step to towards reducing cost associated with generation, transmission and distribution. However, deregulation has also given rise to various new challenges including the allocation of transmission embedded costs, loss allocation and congestion management. Because of the transmission system it is considered as natural monopoly, it must be regulated to guarantee, this service will ensure equitable provision to all customers and therefore to promote the economical efficiency of the whole system.

Regulation in the transmission system should cover the following issue,

i) Transmission system expansion planning.
ii) Connection of new agent/generator.
iii) Tariff structure and fees.

Under this framework, the transmission access & usage cost charged to the customers becomes an important parameter because it can be considered the control variable in electricity system. This variable gives the proper signals to the owners of the generator to takes the necessary decision about location, type and time for installing their units, beyond that, it would be one of the key parameters that would define the efficiency of the whole electricity market.

The transmission sector plays a crucial role in the power industry, making the issue of transmission pricing highly significant. The primary objective of transmission pricing methods is to foster fair competition within the electricity sector and offer efficient cost signals. In a deregulated market, generators are accountable for their respective loads and their share of transmission losses, necessitating payment for network access and usage to the relevant network entity. Two key transmission pricing methodologies are embedded cost and incremental pricing. Some countries opt for the long run marginal cost (LRMC) approach due to its ease of implementation, while others employ the marginal participation method. Power flow tracing provides a comprehensive understanding of the usage allocation problem, which is crucial for the allocation of transmission costs to generators and loads. Following topics are studies in this thesis:

i) Principle and background of transmission pricing.
ii) Methods for allocating contribution.
iii) Cost allocations.

There are four type of embedded cost methods which are widely used to allocate the transmission transaction cost namely; postage stamp method, contract path method, distance based MW-Mile method and power flow based MW-Mile method [1]. In the postage stamp method, transmission usage charge are allocated based on the average embedded cost and magnitude of transacted power. This method is simple but it ignores the actual power flow. Contract path method is based on the assumption that transaction is conformed along the specified/particular path through the wheeling company system. So disadvantage of this method is that transaction is not only through specified path but outside the stated path also. As a result it affect the cost of transmission system outside the path. The distance based MW-Mile method allocates the charge based on magnitude of transacted power. This methods has found incorrect economic indication to the wheeling participants because air distance does not gives actual transmission facilities involve in transaction.

Power flow based MW-Mile method is widely used from the time when it has been shown to be more reflective of actual usage of transmission system to allocating the transmission cost. This method allocate the charge in the extent of transmission usage.

Bialek et al [2] conducted the initial endeavor to trace power flows, where they elucidated the techniques employed for tracking generator output. They introduced straightforward topological approaches for tracing the movement of real and reactive power within the transmission network [3]. In 2009, Xie et al [4] put forth and expounded upon power flow tracing algorithms that rely on the extended incidence matrix.

This thesis introduces a model for the distribution of generator shares and usage, as well as the allocation of transmission reliability margins (TRM) using a matrix-based methodology. Additionally, it proposes a cost allocation method for transmission usage based on the base capacity and outage conditions, specifically considering the impact factor of line outages (LOIF). In 2008, H. Monsef [5] presented methods for allocating transmission costs based on the reliability contingency condition of the system. The proposed approach involves the development of a modified Kirchhoff matrix to allocate transmission usage, incorporating (N-1) reliability criteria to calculate the maximum flow of transmission lines. Subsequently, the allocation of transmission reliability margins (TRM) to generators is performed using the modified Kirchhoff matrix. Finally, transmission usage costs are allocated to each generator.

1.2 Problem Statement

A basic characteristic of a transmission system is that it may have a certain degree of redundancy. This mean that in its normal state, the transmission capacity exceeds the necessary capacity, whether unintentional or intentional.

Unintended redundancy occurs at the component level and the usual result of transmission project individuality. Intended redundancy occurs at system level and results from the application of the N-1 reliability criterion.

The outcome of transmission redundancy is the impression that there is surplus transmission capacity may lead to undervaluation of many circuits, both marginal based cost and MW-Mile based methodologies. A common solution to this difficulty is to add a corresponding term to recover the total circuit investment.

1.3 Objectives

The main Objective of this thesis work is to analyze and find out network optimal transmission pricing of the system.

In order to achieve main objectives, following specific objectives are set.

1) To find the transmission usages allocation: this objective gives the sharing of transmission usages by system user i.e. Generator/Load while delivering the power to load or while extracted the power form generator by load. And gives the correct signal of generation and demand; use of the network by system user and operation by transmission operator.
2) To find the reliability margin allocation: for any transmission company, this objective is paramount, company have no interest in taking on risk which means they mainly concerned with recovering all the costs incurred in building and operation the network.
3) To develop the model for efficient regulation: since most transmission system are natural monopolies, they need to be regulated efficient regulation should minimum-cost by means which keep intervention of the operator to a minimum.
4) To develop the cost allocation scheme for the pricing to Generator or Load for the access and usage of transmission network.

Also there is other objectives for transmission price such as stable price a commitment to provide equitable for access, and other social objectives which affect prices.

1.4 Scope and Limitations

The study is considered on the optimal transmission pricing of the system. The transmission pricing is evaluated on the basis of how generator share the load on line in the rated capacity of line and on the outage condition i.e. considering the line outage impact factor (LOIF). It doesn't explore this methods is absolutely suitable for all condition. It also doesn't consider the loads are responsible for the transmission charges i.e. only generators are responsible for transmission charges. Depending on the entity they may apply different methods for the recovery of the investment and fair competition in between different generator. It only gives the pricing methods that i.e. less recovery time as compare to other methods. The optimal transmission pricing is done to recuperate the transmission cost from generator or Load. It has not considered all the objective at once. The system has studies under the IEEE standard bus. It has not studied under the real-life system.

1.5 Outlines of Thesis

The remainder of the thesis is prepared as follows:

Chapter 2: It includes detail description on Sharing of Generator to load/Sharing of line to load Literature review, the power flow tracing in the transmission line and evaluation of system loss. It gives the understanding of the cost allocation method for the pricing.

Chapter 3: Way to evaluate the system, evaluation matrix methodology, power flow tracing method, Transmission reliability margin and usages cost allocation.

Chapter 4: It includes the result of the used method and is applied to obtain the transmission pricing/usages cost allocation.

Chapter 5: Conclude the study achievement and contribution of the study and future scope of possibility.

CHAPTER 2 : LITERATURE REVIEW

2.1 Background

In competitive markets, the transmission network plays a crucial role, even though transmission charges account for a small portion of utilities' operating overheads. In a restructured power system, the transmission network serves as the platform for generators to supply electricity to both large users and distribution companies. Consequently, transmission pricing serves as a valuable economic indicator that the market should utilize when making decisions regarding resource allocation, system expansion, and reinforcement.

For the competitive surroundings of electricity markets requires of easy and wide access to the transmission and distribution networks that connect dispersed customers and suppliers. As power flow effect transmission charges, transmission pricing may not only determine the right of entry but also inspire efficiencies in electricity markets. Appropriate transmission pricing scheme that considers transmission constraints or congestion could encourage financiers to build new transmission or generating capacity for improving the efficiency of the electricity system. In a competitive environment, the implementation of suitable transmission pricing can fulfill revenue requirements and facilitate the efficient operation and regulation of electricity markets. It can also encourage investments in optimal locations for generation and transmission lines while adequately compensating transmission asset owners. It is crucial for the pricing scheme to prioritize fairness and practicality. In 1997, Kirschen [6] elucidated power flow tracing methods that rely on the assumption of proportional sharing. This approach introduced the concepts of domains, commons, and links. In 2007, Conjeo [7] presented a network cost allocation technique based on the Z-bus matrix.

In the year 2000, P. N. Biskas [8] employed a solution known as security constrained optimal power flow (SC-OPF) to track the extent of user involvement in the line flow within the network. This allowed for the allocation of usage and transmission reliability margins (TRM). Additionally, in 1998 silva [9] proposed various methods to allocate reliability contribution to market participants. In june, 2010, V. Vijay [10] proposed the novel probabilistic transmission pricing methodologies with consideration of transmission reliability margin.

2.2 The transmission usages cost allocation methods:

An effective transmission pricing should recover transmission costs by allocating the costs to transmission network users in a proper way. The transmission costs may include:

- Running costs.
- Capital investment.
- Ongoing investment for future expansion.

Consequently, over the investment recovery period, transmission charges for embedded cost recovery would largely exceed running costs, even though running costs are small compared with capital investment.

Regardless of the market structure, precisely determining transmission usage is important in order to implement usage based cost allocation [11] [12] However, due to the nonlinear nature of power flow, this is very difficult. Thus, it is requires to the use of approximate models, sensitivity indices, or tracing algorithms to determine the contributions to the network flows from individual users/transactions [6]. The selection of these algorithms is mostly dependent on the study objectives & market structures.

2.3 Postage-Stamp Rate Method:

Electric utilities commonly utilize the postage-stamp rate method to allocate the fixed transmission cost among users of the transmission service. This method, also referred to as the rolled-in embedded method, is an embedded cost approach. Notably, this method does not rely on power flow calculations and is unaffected by variables such as the distance of the transmission line, supply and sending points, or the charges imposed on specific transmission facilities involved in the transaction. The fundamental assumption of this method is that the entire transmission system is utilized, regardless of the specific facilities responsible for transmitting the transmission service.

The formula is employed to calculate the transmission charges:

$$TC_t = TC \times \frac{P_t}{P_{peak}} \tag{2.1}$$

Where,

TC_t = Cost allocated to the generator t.

TC = Total transmission cost.

P_t = Power generated by generator t, at the time of system peak

P_{peak} = System peak generation

2.4 Contract Path Methods:

This methods is also traditionally used by electric utilities to allocate/charge the fixed transmission cost. Additionally, power flow calculations are not necessary for cost allocation in this method. The underlying assumption is that transmission services can be represented by the transmission power flows along specific predefined paths within the transmission network. This approach disregards power flows in facilities that are not part of the designated paths. Once the contract paths have been established, transmission charges are assigned using the postage-stamp rate method.

2.5 MW-Mile Method:

The MW-mile method, also known as the line-by-line method, is an embedded cost approach that takes into account calculations, changes in MW transmission flows, and the lengths of transmission lines (in miles). This method calculates charges associated with each wheeling transaction based on factors such as transmission capacity, magnitude of transacted power, the route taken by the transacted power, and the distance traveled by the transacted power. Power flow calculations are required for this method. The MW-mile method was the first pricing approach proposed for recovering fixed costs of transmission lines based on the actual utilization of the transmission network. This method ensures the complete recovery of fixed transmission costs and accurately reflects the usage of transmission systems.

To estimate the usage of transmission services for wheeling transactions, the MW-mile method utilizes the following algorithm:

1. For each transaction (t) :
   - Calculate the transaction-related flows on all network using an approximate power flow model, considering the utilization of nodal power injections involved in the transaction.
   - Multiply the magnitude of MW flow on each line by its length (in miles) and the cost per MW per unit length of the line ($/MW-mile).
   - Sum the results obtained from multiplying the MW flow and line length for all lines involved in the transaction.

2. The contribution of transaction t to the transmission capacity cost is calculated as follows:

$$TC_t = TC \times \frac{\sum_{k \in K} C_k L_k MW_{t,k}}{\sum_{t \in} \sum_{k \in} C_k L_k MW_{t,k}} \quad (2.2)$$

Where,

TC_t	=	Cost allocated to transaction.
TC	=	Total cost of lines in $.
L_k	=	Length of line k in mile k.
C_k	=	Cost per MW per unit length of line k,
$MW_{t,k}$	=	Flow in line k, due to transaction t
T	=	Set of transactions
K	=	Set of lines

2.6 Unused Transmission Capacity Method:

The difference between the capacity of a facility and the actual flow on that facility is referred to as the unused (unscheduled) transmission capacity. To guarantee the complete recovery of all embedded costs, it is presumed that all transmission users bear responsibility for paying both the utilized capacity and the unused transmission capacity. The MW-mile pricing methods employ the following general expression:

$$TC_t = \sum_{k \in} C_k \frac{|F_{t,k}|}{\sum_{t \in T} |F_{t,k}|} \quad (2.3)$$

Where,

TC_t	=	Transaction cost allocated to t
C_k	=	Embedded cost of facility k,
$\lvert F \rvert_{t,k}$	=	flow on facility k, caused by transaction t
T	=	set of transactions
K	=	set of transmission lines

One drawback of this method is that it fails to incentivize efficient utilization of the transmission network system. To address this limitation, a suggestion has been made to charge transmission users based on the percentage utilization of the facility capacity [13], rather than simply aggregating the flows contributed by all users.

Following equation gives the revised MW-mile rule:

$$TC_1 = \sum_{k \in K} C_k \frac{|F_{t,k}|}{F_k} \quad (2.4)$$

Where,

F_k -capacity of facility k.

2.7 Evaluation of Power Tracing Method:

Tracing methods determine the contribution of transmission users to transmission usage [14]. For the recovery of the transmission fixed cost and for transmission pricing this tracing methods can be used. The following are two well-known tracing methods: Bialek's tracing method and Kirschen's tracing method.

2.8 Bialek's tracing Method:

Bialek's tracing method operates under the assumption that nodal inflows are distributed proportionally across nodal outflows. By employing a topological approach, this method calculate topological distribution factor to determine the contribution of individual generators or loads to line flows. It is capable of handling both dc power flow and AC power flows, enabling the identification of contributions from both active and reactive power flows. Bialek's tracing method takes into account.

- Two flows in each line, one entering the line and the other exiting the line (to consider losses in line).
- Generation and load at each bus.

The dominant methodology used for power tracing relies on the principle of proportional sharing. This method employs two algorithms. In the downstream-looking algorithm, the transmission usage charge is assigned to individual loads.

2.9 Kirschen's tracing Method:

Kirschen's tracing method is founded on a defined set of domains, commons, and links. The method utilizes a recursive procedure to calculate the contribution of generators (or loads) to commons, links, loads (or generators), and line flows within each common. Within a particular common, the method assumes that the proportion of inflow traced to a specific generator is equal to the proportion of outflow traced back to that same generator.

Kirschen's tracing method is a topological technique designed to answer the question of how much active or reactive power flow in a branch can be attributed to each generator. This method is applicable to both AC and DC load flow solutions.

$$I_k = g_k + \sum_j F_{jk} \tag{2.5}$$

Where,

I_k = inflow of common k

g_k = generation of common k

F_{jk} = flow in a link connecting common j and k

CHAPTER 3 : METHODOLOGY

Objective of the this research study is to allocate the cost to the generator according to network access and usage as well as transmission reliability margin of each transmission line and usage allocation to the generator & load will be evaluated. To achieve the main objective, methodology starts with literature review of various related topics, case studies, review of existing practices and study of the available related standards. This research methodology that will be applied to achieve the specific as well as main objective of the research work adopted in this research work is listed below.

1. Load flow analysis of the IEEE 6 bus and 14 bus system.
2. Determination of power flow matrix of both system.
3. Modification of the power flow matrix based on the Kirchhoff's matrix.
4. Allocation of network usage to each generator to line.
5. Determination of the transmission reliability margin.
6. Analyzing and finding the Line outage condition (LOIF) of the each line.

These steps are elaborated in the respective section below.

3.1 Power-flow analysis in Transmission Network.

AC Power flow

The commonly used methods for load flow analysis are Gauss Seidel method and Newtons-Raphson Method. The problem formulation in the gauss seidel is comparatively simple for each iteration, however the convergence rate is slow. Thus, much iteration is required to reach convergence. Newtons-Raphson method is used is comparatively much faster than Gauss-seidel, and each iteration require comparative much computation though. Hence, Due to high convergence rate, Newtons Raphson Method is taken in this thesis work.

In Power System load flow analysis, bus is categorized as the three type of bus: load bus, generator bus, and swing bus.

Load bus: the bus where the active power and reactive power injection is predefined.

Generator bus: the bus where the active power injection is predefined and magnitude of generator Voltage determines the reactive injection and the Voltage angle.

Swing bus: where neither active power is predefined nor reactive power. It compensates the shortage or excess of power. Voltage angle of this bus act as reference angle to determine for the Voltage angle for other bus. Voltage magnitude participate the reactive power injection of other bus, Technically Voltage of reference bus also plays role on reactive power dispatch

In Newtons-Raphson's Method the load flow is done as;

- Initially, Guess Voltage Magnitude of load bus is assumed as 1, and Voltage angle as zero. The Voltage magnitude of Generator bus kept constant over the iteration as the given value and the angle is assumed 0 initially
- The reference bus Voltage magnitude and angle are taken as given.
- The Y_{bus} is calculated for the given network.
- With initial guess the power flow at each load bus and the generator active power dispatch is calculated from load flow equation

$$s_i^* = V_i^* \left(\sum_{1}^{nbus} Y_{ik} * \mathrm{V}_k\right)$$

- The Jacobian Matrix is calculated for the given Voltage solution.
- The mismatch of active and reactive power is calculated for load bus and mismatch active power is calculated for Voltage bus.
- The correction factor for Voltage Magnitude and Angle is calculated from jacobian and mismatch power matrix.
- The Voltage magnitude and Angle is corrected and the process is repeated from point (iv) until the convergence is achieved.
- If final power flow violated the reactive power flow limit of generator, that bus is made to load bus limiting the reactive power flow at boundary

3.2 Proposed matrices methodology:

In this thesis, we employ a power flow tracing technique [4] utilizing Modified Kirchhoff matrices. The power flow tracing method is commonly used in many literature to compute the utilization of branches in a power system. The underlying principle of the flow tracing method is the assumption of proportional sharing. The power flow tracing method calculates the transmission usage and cost by analyzing the distribution of power injections across transmission lines based on the nodes. According to this method, there exists a direct relationship between the power injected and extracted at each bus. Two algorithms have been proposed to allocate the power: There are two algorithms utilized in this context: the upstream-looking algorithm, where the usage is allocated to generators, and the downstream-looking algorithm, where the usage is assigned to loads. Both of these allocations are based on the proportional sharing principle, as depicted in Figure 3.2-1.

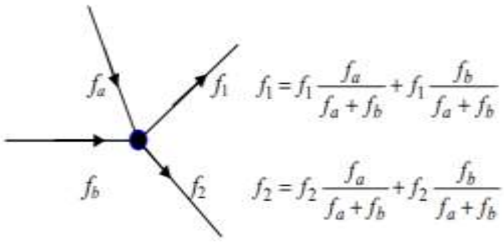

Figure 3.2- 1: Illustration of Proportional Sharing.

The proportional sharing method depends on crucial data, including the proportion of branch inflow and the proportion of branch outflow at a specific node. Branch inflow represents the flow of the branch entering a node, while branch outflow represents the flow of the branch exiting a node. Let's consider a simple directed graph G, as illustrated in Figure 2.

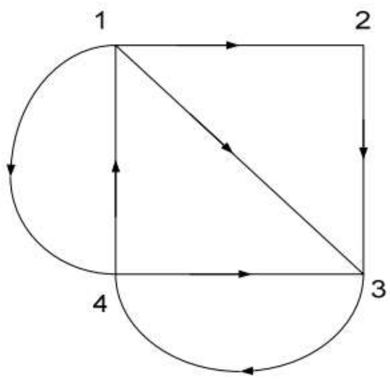

Figure 3.2- 2: Simple Diagraph G.

The Kirchhoff matrix of above diagraph is given by

$$K(G) = \begin{bmatrix} 1 & -1 & -1 & -1 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & -1 & -1 \\ -1 & 0 & -1 & 2 \end{bmatrix}$$

From above example this is a simple diagraph G of n vertices and n*n matrix call the Kirchhoff matrix $K(G)$ or $k = [k_{ij}]$ is defined as;

$$f(x) = \begin{cases} d^{-}(V_i) & for\ i = j \\ -X_{ij} & for\ i \neq j \end{cases} \quad (3.1)$$

Where,

$d^{-}(V_i) =$ In-degree of the i^{th} vertex

$-X_{ij} = (i,j)^{th}$ Entry in the adjacency matrix.

This matrix offers a comprehensive depiction of power flow and loss flow throughout the system. It is created by considering the interconnections between nodes within the system. The diagonal elements of the matrix indicate the net flows at each node, while the off-diagonal elements represent the actual flow and counter flows taking place within the system.From the Newton-Raphson load flow power flow matrix constructed and defined as; active power in branch i from bus i to bus j as $p_{ij} > 0$ and total inflow in bus i as

$$pf_{ij} = \begin{cases} -p_{ij} & for\ i \neq j\ and\ p_{ij} > 0 \\ p_{ij} & for\ i \neq j\ and\ p_{ij} > 0 \\ p_{Ti} & for\ i = j \end{cases} \quad (3.2)$$

Where,

P_{Ti} = Net flows on the nodes

$p_{ij} =$ Active power flow in branch i - j,

Now Using equation (3.1), the Modified Kirchhoff matrix is constructed based on the aforementioned information

Let's denote the Modified Kirchhoff matrix as M for a Power network as $K_m = ({K_{ij}}^m)_{n\times n}$

$$K_{ij}^m = \begin{cases} -p_{ij} & for\quad i \neq j\ and\ p_{ij} > 0 \\ p_{Ti} & for\ i = j \\ 0 & otherwise \end{cases} \quad (3.3)$$

Now from the above Modified Kirchhoff matrix, Kirchhoff loss matrix can be formed as follows;

$$kl_{ij} = \begin{cases} p_{ij}^{|} & for\ i \neq j\ and\ p_{ij} > p_{ji}\ and\ p_{ji} < 0 < p_{ij} \\ p_{ji}^{|} & for\ i \neq j\ and\ p_{ji} > p_{ij}\ and\ p_{ij} < 0 < p_{ji} \\ 0 & otherwise \end{cases} \quad (3.4)$$

Where,

$p^{|}_{ij} = p_{ij} + p_{ji}$ and $p^{|}_{ji} = p_{ji} + p_{ij}$

$p^{|}_{ij}$ = Transmission loss in line i - j in actual direction

$p^{|}_{ji}$ = Transmission loss in line i - j in counter direction

3.3 Procedure for Tracing Power Flow:

In this thesis work, we utilized the tracing methodology proposed in [15]. However, we have made modification to this tracing algorithm specially for the purpose of allocating transmission loss.

3.4 Model for Power Flow Tracing:

Let In =1.....................n represents the total number of lines in the system. M=1 ....m is the total number of generators and D = 1 ....d is the total number of loads in the system.

Again let $P_{GG} =$ diag (P_{G1} P_{G2} P_{G3} ... ... P_{Gm}) represents the number of generators in the diagonal matrix. Therefore, it signifies the count of generators within the system.

$$\mathrm{I}^T P_{G1} = P_G{}^T \; or \; P_G = P_{GG} \, I \qquad (3.5)$$

$$P_G = P_{GG} \, P_m^{-1} \, P_L$$

Where, matrix $P_{GG} \, P_m^{-1}$ is named supply factor matrix (SFM) and denoted by $T = (t_{ij})$

$$T = P_{GG} \, K_m^{-1} \qquad (3.6)$$

And from (9)

$$P_{Gi} = \sum_{j=i}^{n} t_{ij} \, P_{Lj} \qquad (3.7)$$

Where, $t_{ij} \, p_{Lj}$ denotes the active power distribution of generator output.

$$t_{i \to j} = t_{ij} \, P_{Lj} \qquad (3.8)$$

This Eq. (8) gives generator share to load in the system

In order to determine the allocation of generators' share to the line flow, we have introduced adjustments to equation (3.8) by replacing the load power with the line flows, as shown in equation (3.9). This modification assumes that 100 percent of the transmission usage is assigned to the generators.

$$t_{i \to j-t} = t_{ij}\, P_{st} a_g \quad (3.9)$$

Therefore, equations (3.8) and (3.9) provide the distribution of generators' share in both load and line flows. Similarly, to determine the allocation of usage to a load, considering the utilization of all lines, the variables can be modified usinga_l, instead of a_g .

$$P_{LL} = P_{LL}\,(K_m^{-1})^T\, P_G \quad (3.10)$$

Where the diagonal matrix $P_{LL} =$ diag $(P_{L1}\, P_{L2}\, P_{L3} \ldots\ldots\ldots\ldots P_{LD})$ and $R = P_{LL}\,(K_m^{-1})^T$ this is now as the supply factor matrix of loads from the generators.

The calculation of the loads’ contribution to power generation and lines flows is determined by utilizing a supply factor matrix.

3.5 Transmission Reliability Margin (TRM) Allocation:

To allocate the transmission reliability margin (TRM) to generators and the transmission reliability margin (TRM) to loads, specific procedures need to be followed. These procedures involve assessing the performance and reliability of the transmission network, as well as determining the impact of each generator and load on the overall system.

For the allocation of TRM to generators, factors such as generator capacity, availability, and contribution to system stability and reliability are taken into account. A proportional allocation approach may be used, where the TRM is distributed among generators based on their individual contributions to the overall system's reliability.

Similarly, for the allocation of TRM to loads, the criticality of each load, its impact on system stability, and its significance in maintaining the overall reliability of the transmission network are considered. The TRM can be assigned to loads based on their importance and sensitivity to power interruptions or disturbances.

The specific methodology and calculations involved in the TRM allocation process can vary depending on the system's characteristics, reliability criteria, and regulatory requirements.

Transmission reliability margin (TRM) = Maximum capacity of the line in p.u. – usage of the line in (pu).

$$TRM_{ij} = 1 - pf_{ij} \quad (3.11)$$

For specific line, the calculation of transmission reliability margin (TRM) takes into account the max. Capacity of the line, which is considered as 1 pu.
In the aforementioned equation, the line flows are substituted with the transmission reliability margins (TRM) in lines, which are derived from the elements of TRMij. This replacement allows for the consideration of the TRM values specifically associated with each line, enabling a more accurate assessment of the transmission reliability and the allocation of resources.

Therefore, the transmission reliability margin of line s-b assigned to the generator situated at bus i is expressed as follows:

$$TRM^{I}_{i-s\rightarrow b} = t_{is} trm^{I}_{sb} \quad (3.12)$$

Similarly transmission reliability margin of line s - b allocated to load situated at bus i is given by the following expression:

$$TRM^{I}_{j-s\rightarrow b} = r_{js} trm^{I}_{sb} \quad (3.13)$$

3.6 Transmission Usage Cost Allocation:

The MW-Mile method determines charges by considering the MW-Miles of the network utilized by individual users. It does not take into account the direction of power flow on the circuit. Instead, it focuses solely on the magnitude of power flow and the distance traveled by the transmitted power. This approach allows for a simplified calculation of charges based on the overall usage of the transmission network by users, disregarding the specific directional aspects of power flow [16].

The capacity of each line is determined as the optimal, representing the most favorable capacity, and is expressed as follows:

$$pline f_{k,m} = pline f_k + LOIF_{k,m} . pline_m \qquad (3.14)$$

$$LOIF_{K,m} = \begin{cases} \frac{Pl_{k,m} - Pl_m}{Pl_j} & pl_{k,m} > pl_m \\ 0 & otherwise \end{cases} \qquad (3.15)$$

Where,

$pl_{k,m}$ And pl_m - both are power flow and loss of the line $i - j$ under outage condition.

$pline f_{k,m}$ - Power flow on link K after an outage on line M,

$pline_k$ - The power flow on line under normal operation and

$LOIF_{k,m}$ - Represents the unhealthy line on healthy line with respect to healthy line

$$F_{opt,k} = \max(|pline f_{k,1}|, |fpline_{k,2}| \dots \dots \dots |fpline_{k,k}|). \frac{F_{k,\ max}}{F^c_{k,\ max}} \qquad (3.16)$$

Where $F_{opt,k}$the optimal capacity of transmission is line k and $F^c_{k,\ max}$ is the short term emergency rating of line.

$$TC_t = \sum_{k \varepsilon K} C_a * \frac{|F_{t,k}|}{F_{opt,k}} \qquad (3.17)$$

Where,

C_a - Cost of line k is,

$F_{t,k}$ - Power flow of line k caused by user t and,

$F_{k,\ max}$ - is the capacity of link$k$.

The following are the different step for the proposed method:

1) First, Calculate users' (generator/load) contribution to each transmission line for each load scenario by using the supply (SFM) factors (3.6) and (3.10).

2) second, considering the outage condition and calculate the post contingency power flows for each transmission lines for all the LS load scenarios using (3.12), (3.13).

3) For each transmission facility, find the optimal capacity for each load scenario using (14).

4) For every transmission facility, determine the maximum optimal capacity across all load scenarios using (3.16). Identify the specific load scenario that correspond to this maximum capacity value.

5) Compute the transmission usage charges for each user of the network using MW-Mile pricing methods (3.17). This calculation involves utilizing the optimal capacities and relative load scenarios for transmission facility.

3.7 Project Implementation Features.

3.7.1 Test Bus

The thesis study is done on the IEEE 6 and IEEE 14 test bus. The features of IEEE 6 and IEEE bus are

- 6 bus
- 3 loads
- 3 nos. of generator

For the IEEE 14 bus system

- 14 bus
- 12 loads
- 5 nos. of generator

3.8 Tools and software.

MATLAB (matpower 4.1 version) tools is used for the Simulation and programming. This optimization problem has to be solved for the objective of transmission usages allocation, transmission reliability margin and for the usages cost allocation. For the power flow tracing and TRM allocation and for usages cost allocation programming is done with the MATLAB software, because for the complex mathematical computation is required to evaluate the required result.

CHAPTER 4 : RESULT AND DISCUSSION

4.1 General:

The IEEE 6 test bus and IEEE 14 test bus is taken as the study case for this thesis work. Fig. 1. Illustrates the bus diagram of a sample 6-bus system, which comprise 3 generator buses and 3 load buses. Additionally fig 4.5 B-1 presents the bus diagram oa a 14- bus system, consisting of five generator buses and twelve load buses. The power flow solution for both system is obtained through the application of Newton-Raphson load flow method. In MATLAB mathematical model is done. The Line and Data value of the network is tabulated in the ANNEX 1 and ANNEX 2.

A. Sample 6 bus system.

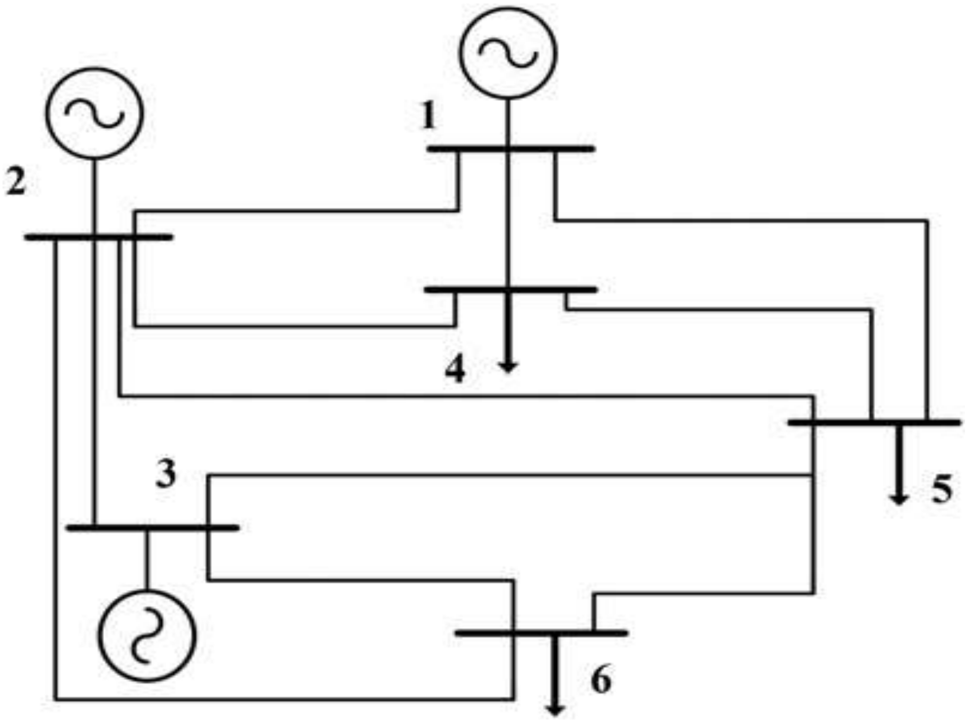

Figure 4.1- 1: IEEE 6 bus system.

4.2 Transmission Usage Allocation for 6 Bus System:

The proposed methodology is demonstrated using a sample 6-bus power system.As seen in table-1, display the maximum power transmitted through a transmission line under various load levels. Which is determined using Newton-Raphson load flow method. After calculating supply factor matric (SFM), the generator share to line flows are computed using by using Eq. (8) generator shares to line flows is calculated. Table 4.2-1 and Table 4.2-2 give the usage allocation to generators and loads respectively

Transferred Power Allocated to Generators for 6-bus System.

Table 4.2- 1: The transferred Power Allocated to Generators for 6 Bus System

Line	Generator Usage Allocation					
	Starting Bus	Ending bus	Power supplied by G1 (MW)	Power supplied by G2 (MW)	Power supplied By G3 (MW)	Total Flow (MW)
1	1	2	25.964	0.000	0.000	25.964
2	1	4	41.204	0.000	0.000	41.204
3	1	5	32.832	0.000	0.000	32.832
4	2	3	0.761	1.465	0.000	2.226
5	2	4	11.167	21.505	0.000	32.672
6	2	5	5.562	10.711	0.000	16.273
7	2	6	8.474	16.319	0.000	24.794
8	3	5	0.209	0.402	16.473	17.084
9	3	6	0.552	1.063	43.527	45.141
10	4	5	2.747	1.128	0.000	3.876
11	5	6	0.038	0.011	0.015	0.065

Table 4.2-1: shows the transferred power allocated to generator for the system in which only generator G1 transferred the power for line 1, 2 & 3 for the line 1 to 7 generator G1 and G2 transferred the power. For rest of the line all three generator are involved for transferred the power. This table shows the usage allocation of generator for each line.

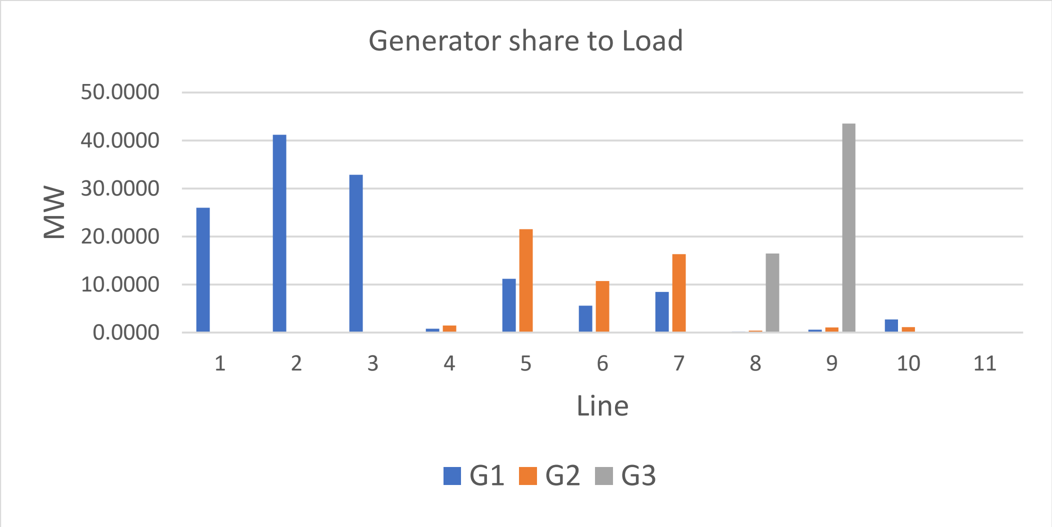

Figure 4.2- 1: Generator share to Load at IEEE 6 bus

Figgure 4.2-1 shows the generator share to the load on each line. For line 1, 2, 3 only Generator G1 is supplying, whereas for line 4, 5, 6, 7 and 10 generator G1 and generator G2 sharing the load. For line 8, 9 and 11 all three generator share the load.

Table 4.2-2, shows the power extracted by the load as follows;

Table 4.2- 2: The extracted Power Allocated to Load for 6-bus System

Line	**Power Extracted by Loads**					
	Starting Bus	**Ending bus**	**Power extracted By L4 (MW)**	**Power extracted By L5 (MW)**	**Power extracted By L6 (MW)**	**Total power Flow (MW)**
1	1	2	10.581	6.350	9.032	25.964
2	1	4	39.042	2.159	0.002	41.204
3	1	5	0.000	32.801	0.030	32.831
4	2	3	0.000	0.610	1.615	2.225
5	2	4	30.957	1.712	0.001	32.671
6	2	5	0.000	16.257	0.015	16.272
7	2	6	0.000	0.000	24.793	24.793
8	3	5	0.000	17.068	0.015	17.084
9	3	6	0.000	0.000	45.141	45.141
10	4	5	0.000	3.872	0.003	3.875
11	5	6	0.000	0.000	0.064	0.064

From table 4.2-2 it shows that power extracted by loads, for each load how much power is extracted by each load. Load L4 extracted the power from the line 1, 2 and 5. Similarly power extracted by L5 through line 1, 2, 3, 6, 8 and 10. And L5 through all the lines.

4.3 Transmission Reliability Margin Allocation (TRM):

The allocation of transmission reliability margin (TRM) to generators and loads is determined using equations (3.12) and (3.13). By referencing Table 4.3-1, it can be observed that generators that contribute a higher amount of power to line flows receive a greater allocation of TRM. The table serves as an overview of the TRM allocation, providing insights into the distribution of TRM among different generators.

Table 4.3- 1: The transmission Reliability Margin (TRM) Allocation for Sample 6-bus system

Line	Transmission Reliability Margin Allocation by Proposed Method			
	G1 (pu)	G2 (pu)	G3 (pu)	Total
1	0.740	0.000	0.000	0.740
2	0.588	0.000	0.000	0.588
3	0.671	0.000	0.000	0.671
4	0.334	0.643	0.000	0.977
5	0.230	0.443	0.000	0.673
6	0.286	0.551	0.000	0.837
7	0.257	0.495	0.000	0.752
8	0.010	0.019	0.799	0.829
9	0.006	0.012	0.529	0.548
10	0.681	0.279	0.000	0.961
11	0.589	0.174	0.235	0.999

Table 4.3-1 shows the allocation of transmission reliability margin (TRM) to each generator in per unit (pu). The table highlights that generators with higher transmission reliability margins are those contributing more power to the system.

Table 4.3- 2: Transmission Reliability Margin Allocation for proposed method at load

Line	Transmission Reliability Margin Allocation by Proposed Method			
	L4(p.u)	L5(p.u)	L5(p.u)	Total
1	0.740	0.000	0.000	0.740
2	0.588	0.000	0.000	0.588
3	0.671	0.000	0.000	0.671
4	0.334	0.643	0.000	0.977
5	0.230	0.443	0.000	0.673
6	0.286	0.551	0.000	0.837
7	0.257	0.495	0.000	0.752
8	0.010	0.019	0.799	0.829
9	0.006	0.012	0.529	0.548
10	0.681	0.279	0.000	0.961
11	0.589	0.174	0.235	0.999

4.4 Transmission uses cost Allocation for 6 Bus system.

Table 4.4 displays the outcomes of the optimal power flow analysis for the peak load scenario of the IEEE 6 bus system. The optimal capacity of the system during peak load is determined using Equation (3.14), considering the outages in each line. In Table 4.4-2, the cost allocated to different lines based on the MW-Mile method is presented. This allocation takes into account the rated capacity and outage condition, considering the line outage impact factor (LOIF). It is noteworthy that the cost allocated due to LOIF is higher compared to the base cost.

Table 4.4- 1: Maximum and Optimal Capacity of 6 bus system.

Line/network	Starting Bus	Ending bus	Power Flow At Peak Load	Maximum Capacity (pu)	Optimal Capacity At Peak Load
1	1	2	0.438	1	0.526
2	1	4	0.507	1	0.608

3	1	5	0.394	1	0.473
4	2	3	0.184	1	0.220
5	2	4	0.537	1	0.644
6	2	5	0.224	1	0.269
7	2	6	0.428	1	0.513
8	3	5	0.316	1	0.379
9	3	6	0.510	1	0.613
10	4	5	0.107	1	0.129
11	5	6	0.155	1	0.186

Table 4.4-1 shows that power flow in each line at peak load and optimal capacity of line at peak load. Considering the max. Capacity of the line is 1 in pu. System.

Table 4.4- 2: Usage Cost Allocation at Base Case and due to LOIF

Line	**Usage Cost Allocation due to LOIF (Rs/MWhr.)**						
	Cost	**G1 at base case**	**G1 after LOIF**	**G2 at base case**	**G2 after LOIF**	**G3 at base case**	**G3 after LOIF**
1	223.61	58.058	115.801	0.000	0.000	0.000	0.000
2	206.16	84.946	146.552	0.000	0.000	0.000	0.000
3	310.49	101.940	226.021	0.000	0.000	0.000	0.000
4	254.95	1.939	9.221	3.735	17.757	0.000	0.000
5	111.8	12.485	20.342	24.042	39.173	0.000	0.000
6	316.23	17.589	68.565	33.871	132.038	0.000	0.000
7	211.9	17.957	36.690	34.581	70.654	0.000	0.000
8	286.36	0.598	1.656	1.152	3.189	47.173	130.635
9	101.98	0.563	0.964	1.084	1.856	44.389	76.016
10	447.21	12.287	99.860	5.045	41.005	0.000	0.000
11	316.23	0.121	0.683	0.036	0.202	0.048	0.272

Table 4.4-2: highlights that the cost of network usage in base case, or under normal conditions, is lower compared to the incurred during contingency cases. It is almost double than that the normal cases. Furthermore, in certain cases /line it is greater than the

base case. It is important to note that this cost allocation also influenced by the capital cost of the respective transmission line.

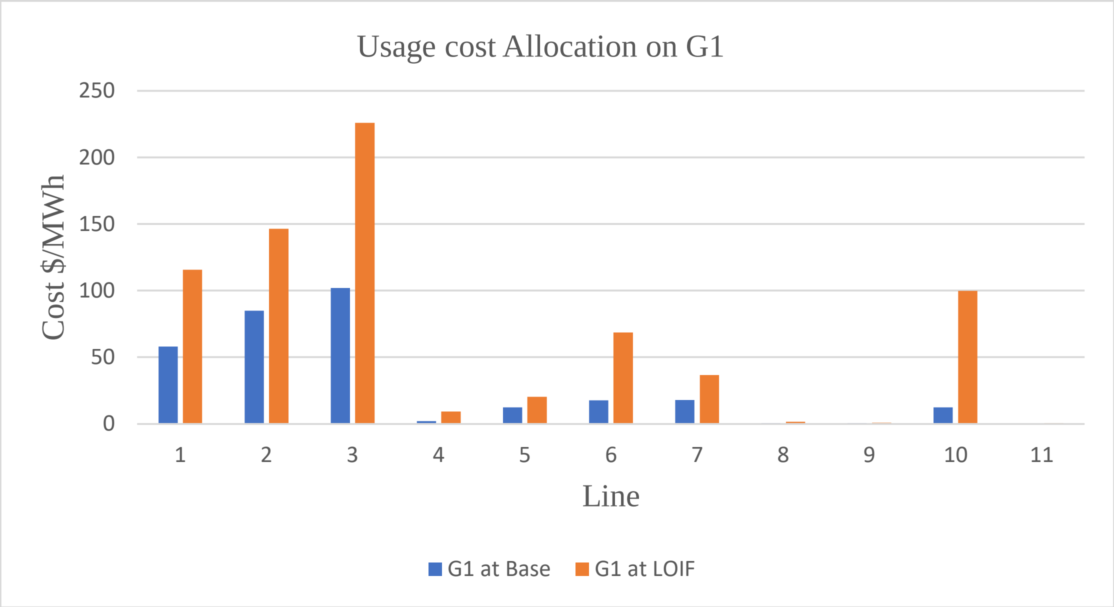

Figure 4.3- 1 : Usage Cost Allocation for G1 at different Line for IEEE 6 bus

Figure 4.3-1 illustrate the allocation of usage generator G1 to different line in the 6-bus system. The allocation is based on the rated capacity of each line and takes into account the outage factor i.e. (LOIF). It shows that cots of usage allocation at normal case is lesser than that after considering outage condition. Also figure 4.3-2 displays the usage cost allocation for generator G2 at different lines in the system, considering the rated capacity and LOIF. Similarly figure 4.3-3 shows the usage cost allocation for generator G3. Additionally, Figure 4.3-5 provides an overview of the total usage cost allocation foe all generators in the system.

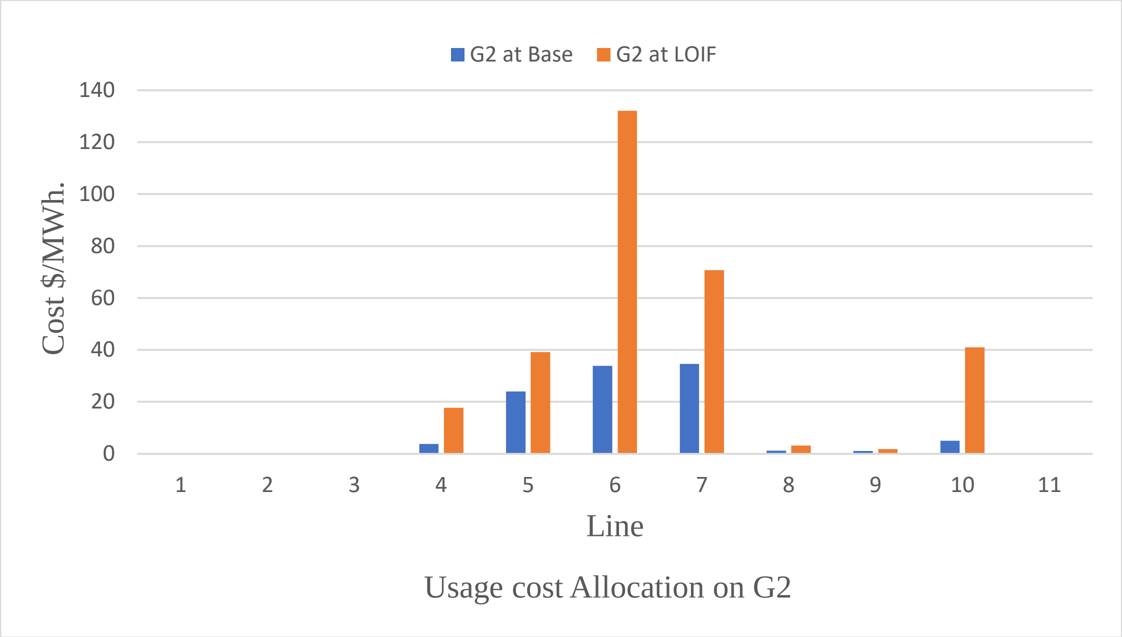

Figure 4.3- 2: Usage Cost Allocation for G2 at different Line for IEEE 6 bus

Figure 4.3-2 depicts the usage cost allocation at generator G2 to different line in the 6-bus system. The allocation is based on the rated capacity of each line and takes into account the outage factor, represented as LOIF. It shows that cots of usage allocation at normal case is lesser than that after considering outage condition.

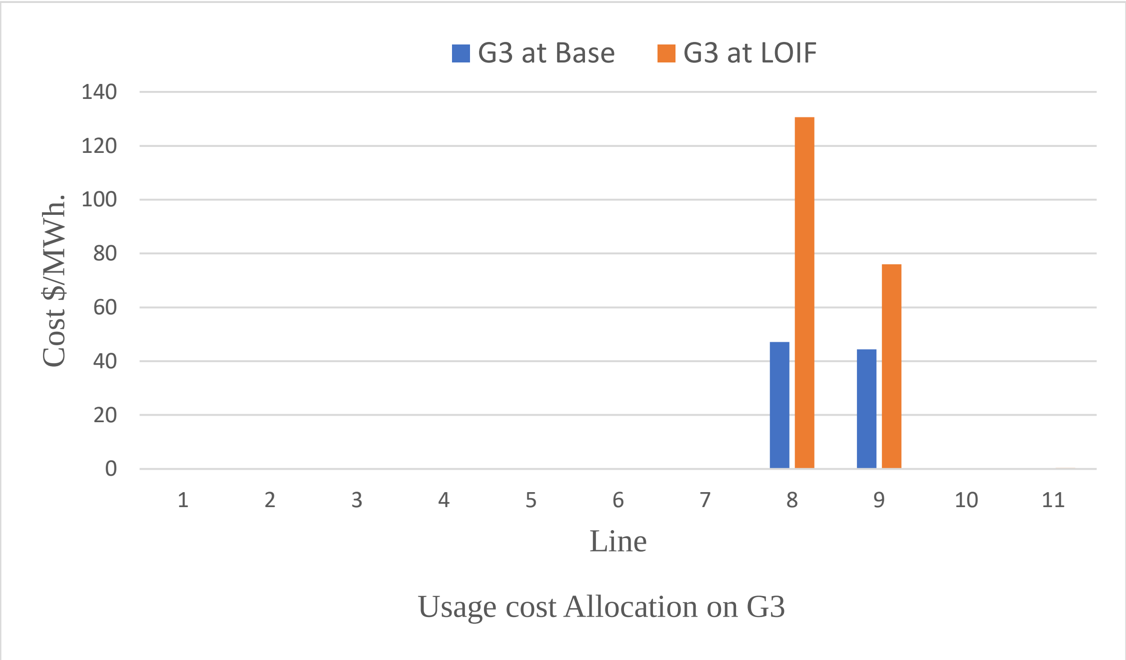

Figure 4.3- 3: Usage Cost Allocation for G3 at different Line for IEEE 6 bus

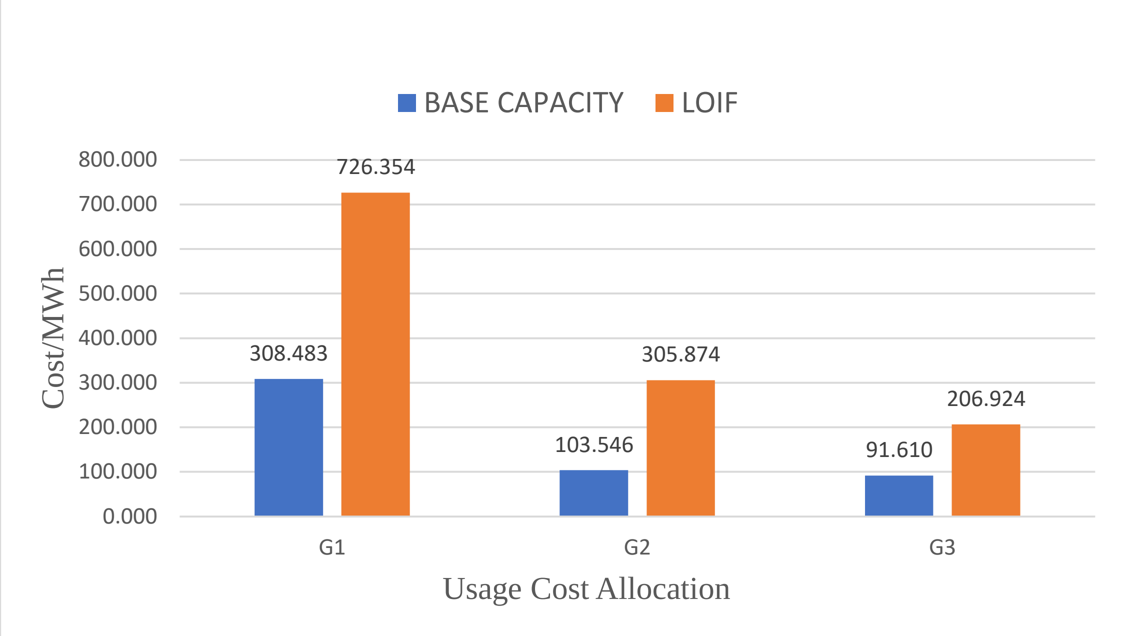

Figure 4.3- 4: Generator Cost Allocation at Base Case and LOIF for IEEE 6 bus

Figure 4.3-4 shows the usage cost allocation at generator G1, G2 and G3 for the network at base capacity and after considering outage condition ie. Line outage impact factor i.e. (LOIF) for 6 bus system. It shows that cots/Mwh of the each generator at normal/base case is lesser. After considering outage condition or considering line outage impact factor (LOIF) cots should be pay by each generator is greater.

B. Case Study for IEEE 14 Bus system

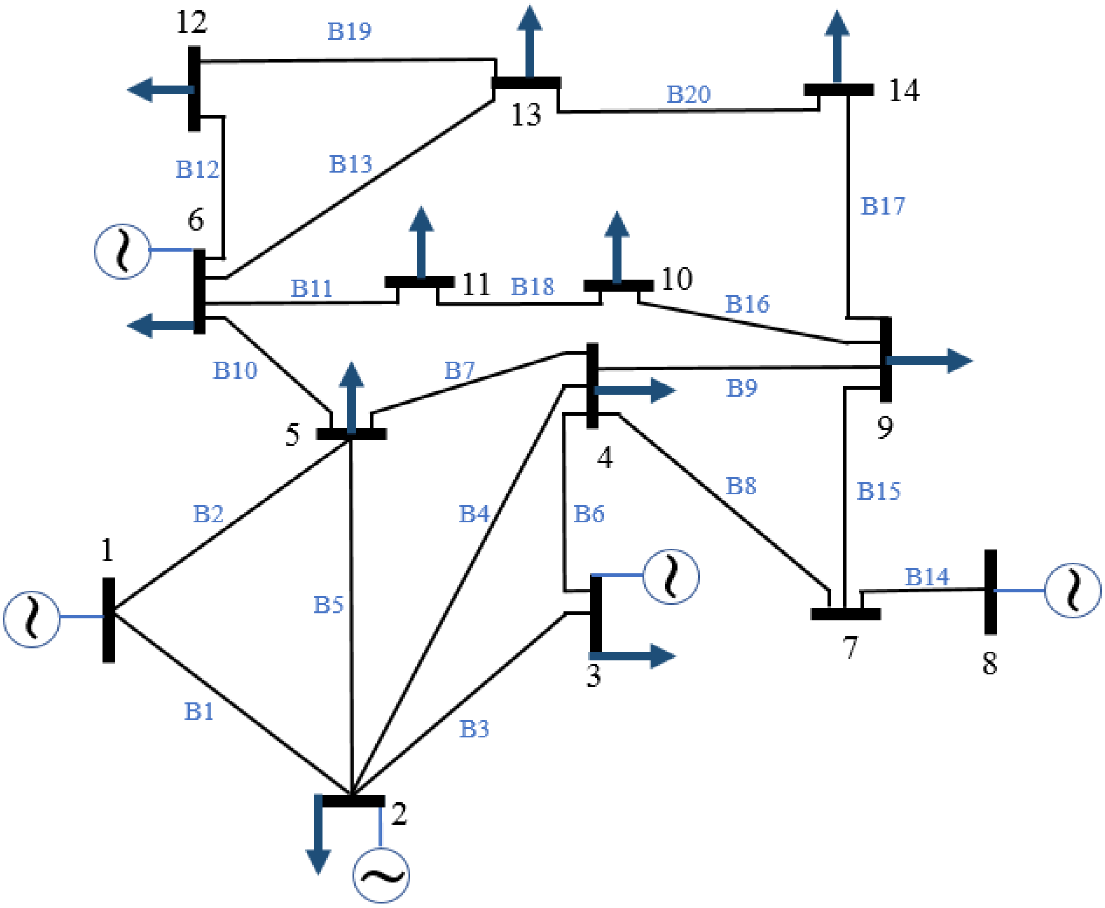

Figure 4.5 B- 1 : IEEE 14 Bus system

4.5 Transmission Usage Allocation for 14 Bus System:

The proposed methodology is applied to analyze the sample 14-bus power system. Table 4.5-1 provides information on the contributions of generators to line flows within the system. The maximum power transmission capacity of each transmission line, considering various load levels, is determined using the Newton-Raphson load flow method. This analysis helps in understanding the capabilities and limitations of the transmission lines under different operating conditions.

The Transferred Power Allocated to Generators for 14-bus System.

Table 4.5- 1: Transferred Power Allocated to Generators for 14 Bus System

Line	Generator Usage Allocation							
	From Bus	To bus	Supplied By G1 (MW)	Supplied By G2 (MW)	Supplied By G3 (MW)	Supplied By G3 (MW)	Supplied By G3(MW)	Flow (MW)
1	1	2	155.166	0.000	0.000	0.000	0.000	155.166
2	1	5	74.834	0.000	0.000	0.000	0.000	74.834
3	2	3	56.587	14.587	0.000	0.000	0.000	71.175
4	2	4	46.737	12.048	0.000	0.000	0.000	58.785
5	2	5	34.590	8.917	0.000	0.000	0.000	43.507
6	3	4	0.000	0.000	0.000	0.000	0.000	-23.025
7	4	5	0.000	0.000	0.000	0.000	0.000	-65.670
8	4	7	30.619	4.843	0.000	0.000	0.000	35.462
9	4	9	15.687	2.481	0.000	0.000	0.000	18.168
10	5	6	41.674	3.396	0.000	0.000	0.000	45.070
11	6	11	7.504	0.611	0.000	0.000	0.000	8.115
12	6	12	7.220	0.588	0.000	0.000	0.000	7.809
13	6	13	16.594	1.352	0.000	0.000	0.000	17.946
14	7	8	9.498	1.502	0.000	0.000	0.000	11.000
15	7	9	21.121	3.341	0.000	0.000	0.000	24.462
16	9	10	3.786	0.599	0.000	0.000	0.000	4.385
17	9	14	7.551	1.194	0.000	0.000	0.000	8.745
18	10	11	0.000	-0.485	0.000	0.000	0.000	-4.615
19	12	13	1.580	0.129	0.000	0.000	0.000	1.709
20	13	14	5.691	0.464	0.000	0.000	0.000	6.155

Table 4.5-1: shows the transferred power allocated to generator for the system in which only generator G1 transferred the power for line 1& 2 for the rest of line, generator G1 and G2 transferred the power. This table shows the usage allocation of generator for each line.

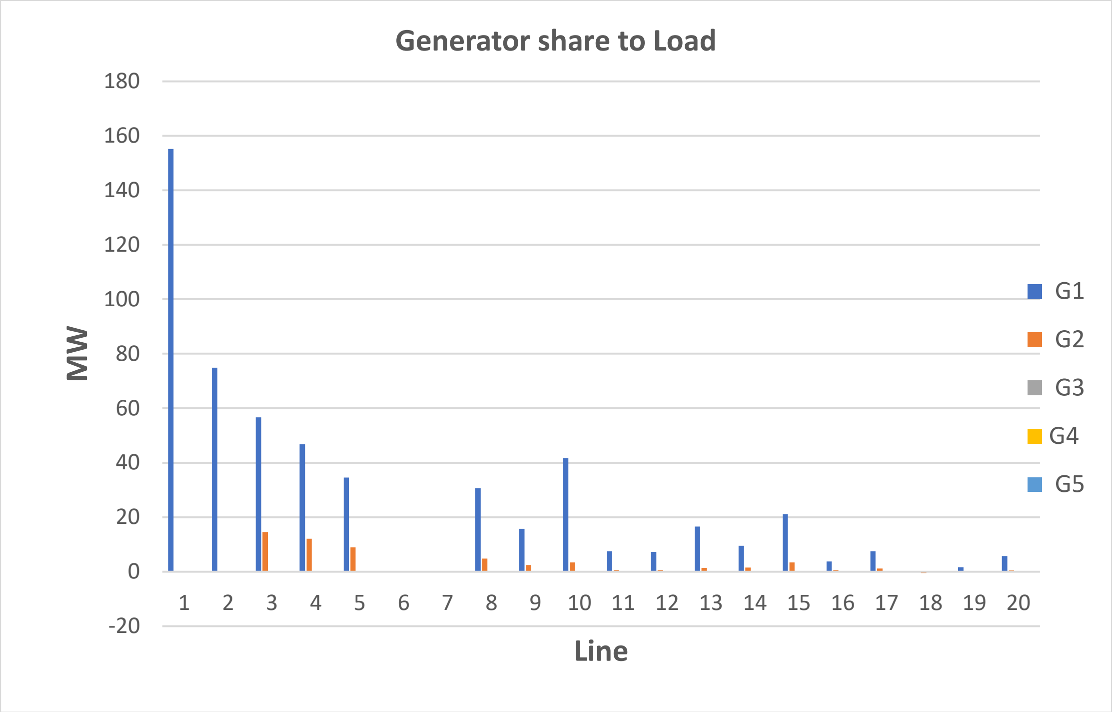

Figure 4.4- 1: Generator share to Load for IEEE 14 bus

Fig. 4.4-1 shows the generator share to the load on each line. For line 1, 2, only Generator G1 is supplying, whereas for the rest of line both generator G1 and generator G2 sharing the load.

4.6 Transmission Reliability Margin Allocation (TRM) for 14 Bus system:

The allocation of transmission reliability margin (TRM) to generators and loads is carried out using equations (12) and (13). Based on the information presented in Table 4.6-1, it is evident that generators that contribute a larger amount of power to line flows receive a higher allocation of TRM. The table provides a detailed overview of the TRM allocation, illustrating the distribution of TRM among different generators.

Table 4.6- 1: Transmission Reliability Margin Allocation for Sample 14 bus

Line	Transmission Reliability Margin Allocation by Proposed Method					
	G1(p.u)	G2(p.u)	G3(p.u)	G4(p.u)	G5(p.u)	Total
1	0.552	0.000	0	0	0	0.552
2	0.252	0.000	0	0	0	0.252
3	0.229	0.059	0	0	0	0.288

4	0.328	0.084	0	0	0	0.412
5	0.449	0.116	0	0	0	0.565
6	0.625	0.145	0	0	0	0.770
7	0.296	0.047	0	0	0	0.343
8	0.557	0.088	0	0	0	0.645
9	0.707	0.112	0	0	0	0.818
10	0.508	0.041	0	0	0	0.549
11	0.850	0.069	0	0	0	0.919
12	0.852	0.069	0	0	0	0.922
13	0.759	0.062	0	0	0	0.821
14	0.768	0.122	0	0	0	0.890
15	0.652	0.103	0	0	0	0.755
16	0.826	0.131	0	0	0	0.956
17	0.788	0.125	0	0	0	0.913
18	0.854	0.100	0	0	0	0.954
19	0.909	0.074	0	0	0	0.983
20	0.868	0.071	0	0	0	0.938

Table 4.6-1 shows the transmission reliability margin allocation to each generator. This indicated that which generator have more transmission reliability margin that contributes the more power to the system.

4.7 Transmission uses cost Allocation for 14 Bus system.

Table 4.7-1 presents the result of optimal power flow for the peak load scenario for IEEE 14 bus system. Table shows the optimal capacity of the system at peak load with considering outage in each line. Also cost allocated to different line is shown in table 4.7-2 based on the rated capacity and due to line outage impact factor (LOIF). It can be seen that cost allocated due to LOIF is more compare to base.

Table 4.7- 1: Maximum and Optimal Capacity of 14 bus system.

network	Staring Bus	Ending bus	Power Flow on Peak Load	Max Capacity (pu)	Optimal Capacity At Peak Load
1	1	2	2.190	1	2.300
2	1	5	2.190	1	2.300
3	2	3	0.897	1	0.942
4	2	4	0.882	1	0.926
5	2	5	0.755	1	0.792
6	3	4	0.897	1	0.942
7	4	5	1.344	1	1.411
8	4	7	0.611	1	0.641
9	4	9	0.344	1	0.362
10	5	6	0.596	1	0.625
11	6	11	0.182	1	0.191
12	6	12	0.186	1	0.195
13	6	13	0.236	1	0.247
14	7	8	0.105	1	0.110
15	7	9	0.506	1	0.531
16	9	10	0.301	1	0.316
17	9	14	0.253	1	0.266
18	10	11	0.216	1	0.226
19	12	13	0.128	1	0.134
20	13	14	0.142	1	0.149

Table 4.7- 2: Usages cost allocation for IEEE 14 bus system

Line	Usage Cost Allocation due to LOIF (Rs/MWhr.)				
	Cost	G1 at base case	G1 after LOIF	G2 at base case	G2 after LOIF
1	62.26	96.606	44.103	0.000	0.000
2	229.49	171.737	78.401	0.000	0.000
3	203.47	115.138	128.338	29.681	33.084
4	185.65	86.767	98.406	22.367	25.368
5	182.97	63.289	83.876	16.315	21.622
6	183.69	-34.334	38.270	-7.962	8.874
7	44.18	-25.051	18.646	-3.962	2.949
8	209.12	64.031	104.850	10.128	16.584
9	556.18	87.246	253.270	13.799	40.059
10	252.02	105.028	176.362	8.559	14.372
11	220.41	16.539	90.742	1.348	7.394
12	283.81	20.492	110.210	1.670	8.981
13	146.10	24.244	102.876	1.976	8.383
14	176.15	16.730	159.699	2.646	25.259
15	110.01	23.236	45.927	3.675	7.264
16	90.29	3.418	11.345	0.541	1.794
17	298.77	22.559	89.177	3.568	14.105
18	208.86	-8.626	40.008	-1.014	4.702
19	297.92	4.707	36.818	0.384	3.000
20	387.73	22.067	155.503	1.798	12.672

Table 4.7-1 highlights that the cost of network usage in the base case or under normal conditions is lower compared to considering contingency cases. The network analysis and cost allocation to the generator are based on the transmission line cost provided in reference [17]. It is observed that the cost of usage allocation is greater than that in the normal cases, and in some instances, it surpasses the base case. This cost allocation is influenced by the capital cost of the transmission line, as it plays a significant role in determining the overall cost allocation within the network.

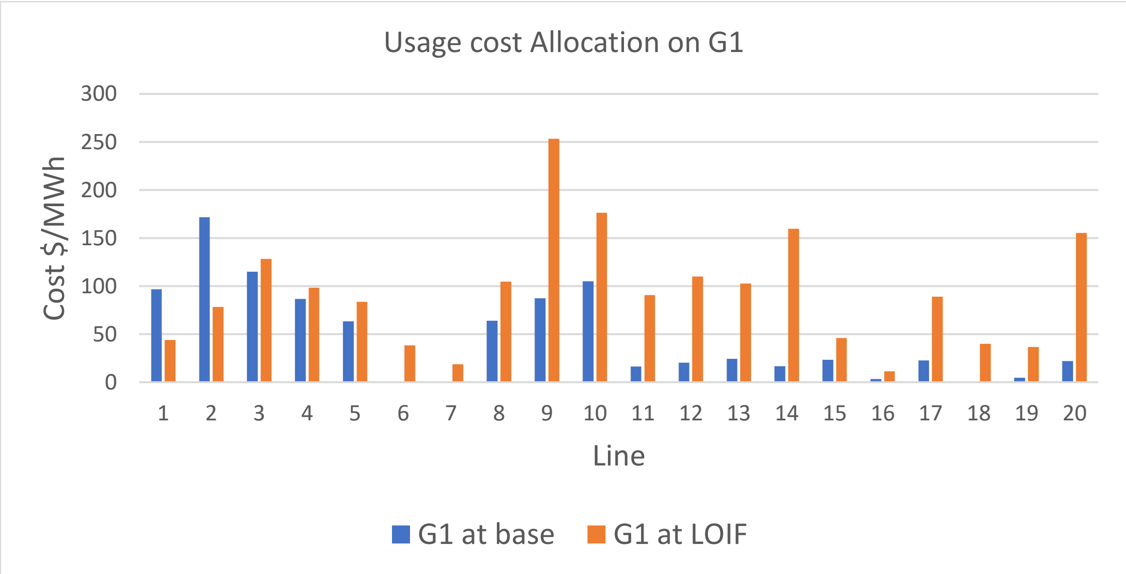

Figure 4.7- 1 : Usage Cost Allocation for G1 at different Line for IEEE 14 bus

Figure 4.7-1 shows the usage cost allocation at generator G1 to different line with rated capacity and after considering outage factor i.e. (LOIF) for 14 bus system. Also usage cost allocation for generator G2 is shown in figure 4.7-2 and total usage cost allocation for all generator is shown in figure 4.7 -2.

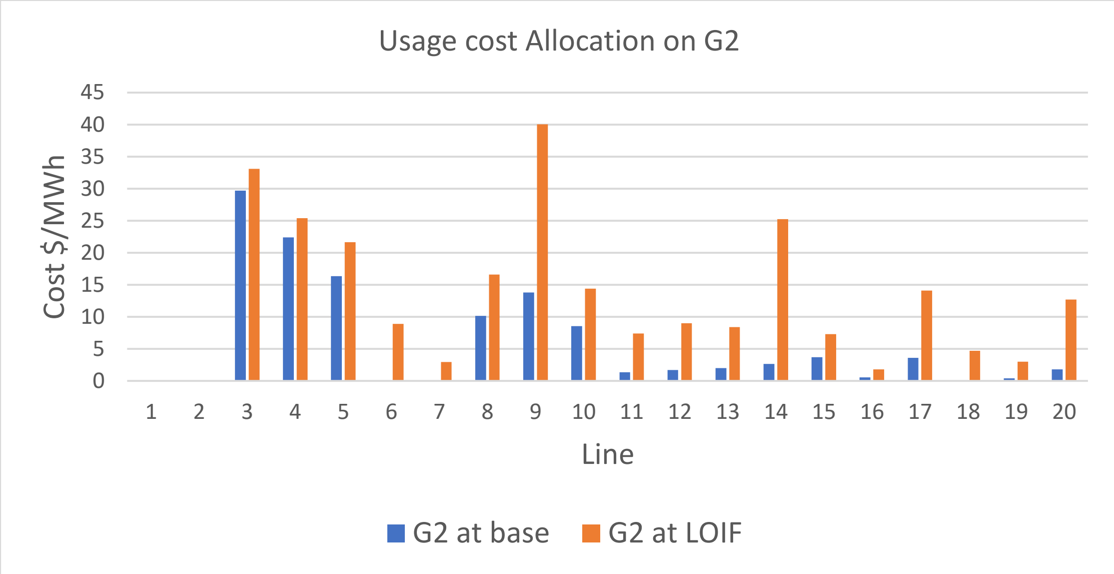

Figure 4.7- 2 : Usage Cost Allocation for G2 at different Line for IEEE 14 bus

Figure 4.7-1 illustrates the allocation of usage cost at generator G2 to different lines within the 14-bus system. This allocation is based on the rated capacity of the lines and takes into account the outage factor, also known as the Line Outage Impact Factor (LOIF). It can be observed that the line usage cost allocated to generator G2 varies for different lines and is generally higher than the cost in the base case or under normal operating conditions, particularly when considering outage conditions. This highlights the impact of line outages on the cost allocation and underscores the need to account for such factors in determining the usage cost for each line.

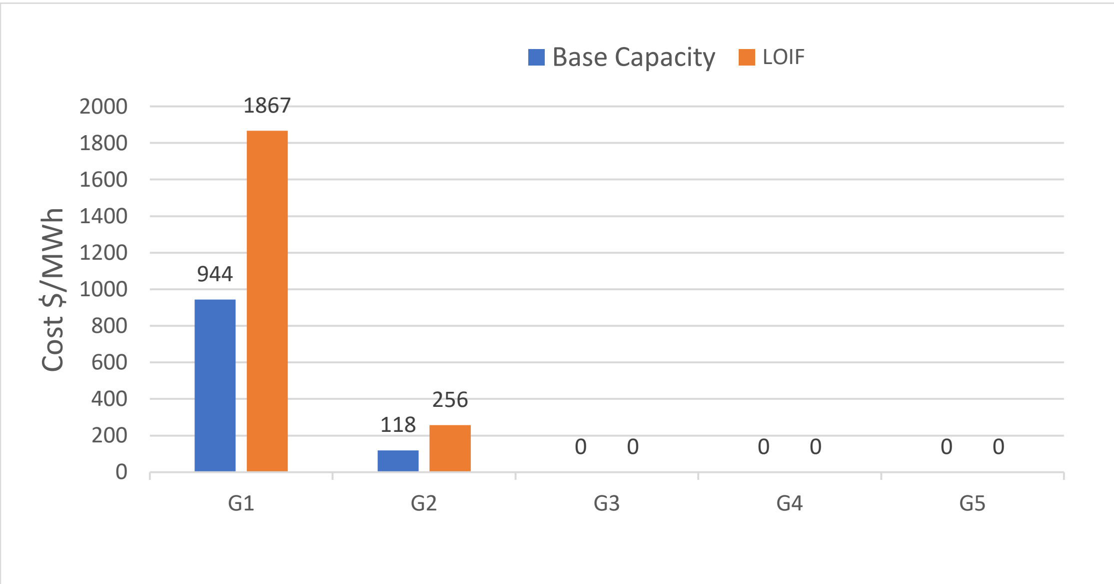

Figure 4.7- 3 : Generator Cost Allocation at Base Case and LOIF for IEEE 14 bus

Figure 4.7-3 shows the usage cost allocation at generator G1 and G2 for the network at base capacity and after considering outage condition ie. Line outage impact factor i.e. (LOIF) for 14 bus system. It shows that cots/Mwh of the each generator at normal/base case is lesser. After considering outage condition or considering line outage impact factor (LOIF) cots should be pay by each generator is greater.

CHAPTER 5 : CONCLUSION.

5.1 Conclusion

In a deregulated environment, transmission usages costs and access cost play a significant role in driving transmission investments. Therefore, it is crucial for transmission use of system charges to accurately reflect the actual usage of the transmission system and allocate a substantial portion of the fixed transmission costs through power flow-based methods. Pricing solely based on the peak load condition can help minimize the need for additional transmission capacity and costly peak generation. However, it may not incentivize increased efficiency or provide accurate signals for locating new demand and generation. In this paper, we propose combined methodology foe the allocation of transmission usage and reliability margins. This methodology is based on a modified Kirchhoff matrix scheme, where the allocation of transmission usage Costs is determined by proportion of usage. The proposed MW-Mile methods, regardless of counter-flow pricing, have been tested on IEEE 6-bus reliability test system. These pricing methods implicitly consider the N-1 security criterion, which is crucial for transmission planning and power system operation. They allocate a portion or the entirty of the reliability capacity cost of a transmission facility to network users. The allocation of transmission usage cost under base condition is optimized using the proposed method. Additionally, new indices are introduced to account for contingency conditions, resulting in increased transmission usage cost allocation compare to the base capacity. This demonstrates the efficiency of the proposed method. The Paper also presents a comprehensive model for the allocation of transmission usage cost, both in terms of full and partial recovery. Moreover, the method allows for direct allocation of transmission reliability margin since the necessary calculation have been performed for usage calculation. The result of applying the proposed method are demonstrated using the sample 6-bus system and IEEE 14-bus system.

Table 4.2.1 shows the usages allocation of generators to load where as table 4.2.2 shows the usage by load to line in the IEEE 6 bus system. Similarly Table 4.3.1 shows the transmission reliability margin. Figure 4.3.1 to Table 4.3.3 shows the result of usages cost allocation to individual generator to line and Table 4.3.4 shows the cost allocation of generator at base case and LOIF case. Its shows that cost allocation on generator G1 at base case is 308.457 Rs/MWh whereas cost allocation considering line outage condition is 726.354 Rs/MWh similarly for the generator G2 cost allocation at base case is 103.547 Rs/MWh and at outage condition cost allocation is 305.8774 Rs/MWh and for the generator G3 cost allocation at base case is 91.60 Rs/MWh and at outage condition cost allocation is 206.92 Rs/MWh It clearly reflect that the cost allocation at generator at considering LOIF is greater then base case. For the IEEE 14 bus system, table 4.5 show the generator share and table 4.7 show the usage cost allocation on each generator for different line. For the cost allocation on the generator G1 at outage condition is 1.9 times greater then base case as well as for the generator G2 is 2 times greater then the base case. There should be higher cost allocation for faster cost recovery when considering line outage.

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ANNEX 1: Bus Data, Line Data of IEEE 6 Bus Test System

Table A: Bus Data of IEEE 6 Bus Test System

Base MVA=100

Bus	Bus Type	Voltage Magnitude	Voltage Angle	P Gen	Q Gen	P Load	Q Load	Bs
1	3	1.05	0	100	36.46			
2	2	1.05	-2.709	50	63.52			
3	2	1.07	-3.081	60	85.94			
4	1	1.004	-4.343	0	0	70	70	
5	1	1.003	-5.561	0	0	70	70	
6	2	1.018	-5.453	0	0.8	70	70	

Table B: Line Data of IEEE 6 Bus Test Systems

From Bus	To Bus	R (p.u.)	X (p.u.)	B(p.u.)	Ratio
1	2	0.1	0.20	0.04	
1	4	0.05	0.20	0.04	
1	5	0.08	0.30	0.06	
2	3	0.05	0.25	0.06	
2	4	0.05	0.10	0.02	
2	5	0.1	0.30	0.04	
2	6	0.07	0.20	0.05	
3	5	0.12	0.26	0.05	
3	6	0.02	0.10	0.02	
4	5	0.2	0.40	0.08	
5	6	0.1	0.30	0.06	

ANNEX 2: Bus Data, Line Data of IEEE 14 Bus Test System

Table A: Bus Data of IEEE 14 Bus Test System

Base MVA=100

Bus	Bus Type	Voltage Magnitude	Voltage Angle	P Gen	Q Gen	P Load	Q Load
1	3	1.06	0	230	46.75	-	-
2	2	1.045	-4.760	40	26.51	21.7	12.70
3	2	1.010	-12.448	0	-9.96	94.20	19
4	1	1.033	-10.298	-	-	47.80	-3.90
5	1	1.032	-8.758	0	-	7.60	1.6
6	2	1.070	-13.924	-	5.07	11.20	7.5
7	1	1.073	-14.235	0	-	-	-
8	1	1.101	-15.174	-	17.40	11	0
9	1	1.067	-15.677	-	-	29.5	16.6
10	1	1.062	-16.062	-	-	9	5.80
11	1	1.067	-14.274	-	-	3.5	1.80
12	1	1.064	-14.983	-	-	6.10	1.60
13	1	1.062	-15.198	-	-	13.50	5.80
14	1	1.057	-16.622	-	-	14.90	5

Table: Line Data of IEEE 14 Bus Test Systems

From Bus	To Bus	R (p.u.)	X (p.u.)	B(p.u.)	Ratio
1	2	0.01938	0.0592	0.0528	
1	5	0.05403	0.2230	0.0492	
2	3	0.04699	0.1980	0.0438	
2	4	0.05811	0.1763	0.0340	
2	5	0.05695	0.1739	0.0346	
3	4	0.06701	0.1710	0.0128	
4	5	0.01335	0.0421	0.0000	
4	7	0	0.2091	0.0000	

4	9	0	0.5562	0.0000	
5	6	0	0.2520	0.0000	
6	11	0.09498	0.1989	0.0000	
6	12	0.12291	0.2558	0.0000	
6	13	0.06615	0.1303	0.0000	
7	8	0	0.1762	0.0000	
7	9	0	0.1100	0.0000	
9	10	0.03181	0.0845	0.0000	
9	14	0.12711	0.2704	0.0000	
10	11	0.08205	0.1921	0.0000	
12	13	0.22092	0.1999	0.0000	
13	14	0.17093	0.3480	0.0000	

ANNEX 3: PROPERTY OF MATRIX

Property 1: the sum of all elements in the row j of a Modified Kirchhoff matrix equals the active load power at bus j

$$K_m I = P_L$$

Property 2: the sum of all elements in the column j of a Modified Kirchhoff matrix equals the total active power of generators at bus j

$$I^T K_m = {P_G}^T$$

The above Eq. can be rewrite as follows;

$${K_m}^T I = P_G$$

From Eq ( ) and ( )

$$I = {K_m}^T P_I \quad \text{And} \quad I = ({K_m}^T)^{-1} P_G$$

From above ,

$$I = ({K_m}^T)^{-1} P_G$$

From this matrix inverse of modified Kirchhoff matrix is obtained which is used for power flow tracing and transmission allocation.

MATLAB CODING

```
clear all
clc
%name=input('typename: \ncase6 , \ncase14,\ncase30\n ');
%temp=loadcase(name);
temp=loadcase('case6');
%ls=input('type 1 if loss less');
%if ls==1


   temp.branch(:,3)=0;

%end




res=runpf(temp);
nbus=length(temp.bus(:,1));
v=res.bus(:,8);
d=res.bus(:,9);
d=deg2rad(d);
[rl im]=pol2cart(d,v);
V=complex(rl,im);
ybus=ybus_cal(data_branch(temp));
S=cal_power(V,ybus);
%input('wait');
P = real(S);

nbranch=length(temp.branch(:,1));
ngen=length(res.gen(:,1));
pp=zeros(nbus);
ll=zeros(nbus);
for o=1:ngen

   rg=res.gen(o,1);
   pp(rg, rg)=res.gen(o,2)/100;

end

   for o=1:nbus

    for j=1:nbus
        if o~=j
            flag=0;

            for k=1:nbranch

                    if (o==temp.branch(k,1)&j==temp.branch(k,2))
                        rw=k;
                        flag=1;
                    end
                    if(o==temp.branch(k,2)&j==temp.branch(k,1))
                        rw=k;
                        flag=2;
                    end

            end
```

```
            if(flag==1)
                if(res.branch(rw,14)>0)
                    pp(o,j)=res.branch(rw,14)/100;

ll(o,j)=abs(res.branch(rw,14)/100+res.branch(rw,16)/100);
                else
                   % pp(o,j)=res.branch(rw,16)/100;
                    pp(o,j)=res.branch(rw,14)/100;

ll(o,j)=abs(res.branch(rw,14)/100+res.branch(rw,16)/100);

                end


            end
             if(flag==2)
                 if(res.branch(rw,16)>0)
                  pp(o,j)=res.branch(rw,16)/100;

ll(o,j)=abs(res.branch(rw,14)/100+res.branch(rw,16)/100);
                 else
                     % pp(o,j)=res.branch(rw,14)/100;
                      pp(o,j)=res.branch(rw,16)/100;

ll(o,j)=abs(res.branch(rw,14)/100+res.branch(rw,16)/100);

                 end


              %  pp(o,j)=0;
            end

        end
    end
   end


%{for o=1:nbus

   % for j=1:nbus
        %if o~=j
            %flag=0;

            %for k=1:nbranch

                   % if (o==temp.branch(k,1)&j==temp.branch(k,2))
                  %       rw=k;
                 %        flag=1;
                %     end
               %      if(o==temp.branch(k,2)&j==temp.branch(k,1))
              %          rw=k;
             %           flag=2;
            %        end
           %
          %  end
         %   if(flag==1)
               % pp(o,j)=res.branch(rw,14)/100;
        %    end
```

```
        %       if(flag==2)
                 % pp(o,j)=res.branch(rw,16)/100;
       %       end

      %   end

     %end
     %end
PGG=zeros(nbus);
PLL=zeros(nbus);




for o=1:ngen

   rg=res.gen(o,1);
   kk(rg, rg)=res.gen(o,2)/100;
   PGG(rg,rg)=res.gen(o,2)/100;
end
for o=1:nbus

   rg=res.bus(o,1);

   PLL(rg,rg)=res.bus(o,3)/100;
end


    pp;
    %for o=1:nbus

      %      for j=1:nbus

        %       if (o==j)
         %              if (P(o)>0)
          %             kk(o,o)= (P(o));
           %           else
            %                kk(o,o)=0;
             %           end

              %end
             %end
    %end




    for o=1:nbus

    for j=1:nbus
        if o~=j
            flag=0;

            for k=1:nbranch

                    if (o==temp.branch(k,1)&j==temp.branch(k,2))
                        rw=k;
                        flag=1;
```

```
                    end
                    if(o==temp.branch(k,2)&j==temp.branch(k,1))
                        rw=k;
                        flag=2;
                    end

            end
            if(flag==1)
                if(res.branch(rw,14)>0)
                    kk(o,j)=-res.branch(rw,14)/100;
                else
                    kk(o,j)=0;
                    kk(o,o)=kk(o,o)-res.branch(rw,14)/100;
                end


            end
             if(flag==2)
                 if(res.branch(rw,16)>0)
                  kk(o,j)=-res.branch(rw,16)/100;
                 else
                      kk(o,j)=0;
                      kk(o,o)=kk(o,o)-res.branch(rw,16)/100;
                 end


              %  pp(o,j)=0;
            end

        end

    end
    end

    kk;
    K=zeros(nbus);
for o=1:nbus
    for j=1:nbus
        if kk(o,j)~=0
            K(o,j)=kk(o,j)+ll(o,j);
        end
    end
end

I=zeros(nbus,1);
I(:,1)=1;


    SFM=PGG*inv(kk);


    nbranch=length(res.branch(:,1));
    gen=res.gen(:,1);
    SH=zeros(nbranch,ngen+3);
    for o=1:nbranch

        st=res.branch(o,1);
        ft=res.branch(o,2);
```

```
        SH(o,1)=st;
        SH(o,2)=ft;
        for j=3:(ngen+2)
            SH(o,j)=SFM(gen(j-2),st)*res.branch(o,14);
            SH(o,ngen+3)=res.branch(o,14);
        end


    end

    PL=temp.bus(:,3);

     for o=1:nbus
         SL(o,1)=temp.bus(o,3);
         for j=2:(ngen+1)
             SL(o,j)=SFM(gen(j-1),o)*SL(o,1);
         end
     end
     LLF=PLL*transpose(inv(K));



     SK=zeros(nbranch,nbus+3);
     bus=temp.bus(:,1);
    for o=1:nbranch

        st=res.branch(o,1);
        ft=res.branch(o,2);

        SK(o,1)=st;
        SK(o,2)=ft;
        for j=3:(nbus+2)
            SK(o,j)=LLF(j-2,ft)*res.branch(o,14);
            SK(o,nbus+3)=res.branch(o,14);
        end


    end

        for o=1:ngen
         SG(o,1)=res.gen(o,2);
         rg=gen(o);
         for j=2:(nbus+1)
             SG(o,j)=LLF((j-1),rg)*SG(o,1);
         end
     end



                    %SH sharing of branch flow with individual
generation
                    %SL sharing of load with Generator

                    %SK Sharing of branch flow ith individual load
                    %SG sharing of Generation with load
```

```
%


for o=1:nbranch

        st=res.branch(o,1);
        ft=res.branch(o,2);

        TRMG(o,1)=st;
        TRMG(o,2)=ft;
        for j=3:(ngen+2)
            TRMG(o,j)=SFM(gen(j-2),st)*(1-abs(res.branch(o,14)/100));
            TRMG(o,ngen+3)=(1-abs(res.branch(o,14)/100));
        end


    end

for o=1:nbranch

        st=res.branch(o,1);
        ft=res.branch(o,2);

        TRML(o,1)=st;
        TRML(o,2)=ft;
        for j=3:(nbus+2)
            TRML(o,j)=LLF(j-2,ft)*(1-abs(res.branch(o,14)/100));
            TRML(o,nbus+3)=(1-abs(res.branch(o,14)/100));

        end


end

max_Pline=zeros(1,nbranch);
LOIF=zeros(nbranch,nbranch);
for o=1:nbranch

    maxflow=0;


   for j=1:nbranch

       if o~=j
           fnormk=abs(res.branch(o,14));
           fnormm=abs(res.branch(j,14));
           temp.branch(j,11)=0;
           res=runpf(temp);
           flow=abs(res.branch(o,14));
          LOIF (o,j)= (flow-fnormk)/fnormm;
           temp.branch(j,11)=1;
           if maxflow<flow;
               maxflow=flow
           end
       end
   end
```

```
   mflow(o)=maxflow/100;
   Fopt(o)=mflow(o)/1.05;

end
Fopt=Fopt';
npq=find(temp.bus==2);
nload=length(npq);
userflow(:,1:ngen)=SH(:,3:(ngen+2))/100;

 for o =1:nbranch
        for k=1:ngen

        Costratio(o,k)=abs(userflow(o,k))./Fopt(o);
        end
  end
userflow1(:,1:nload)=SK(:,ngen+3:nload+ngen+2)/100;

 for o =1:nbranch
        for k=1:nload

        Costratio1(o,k)=abs(userflow1(o,k))./Fopt(o);
        end
  end
```

Optimal Transmission Pricing Scheme with Consideration of System Reliabilityy

By Hikmat B.C

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