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Original Research Article

Tracing of Power Using Bialek's Tracing Method

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Abstract

Transmission lines are equally as important as power generation plants for developing the energy sector of any country. In the case of electricity transmission system, economic efficiency implies promoting an optimal utilization of existing network, placing of new generations and promoting addition of loads where the maximum efficiency is envisaged and promoting transmission investments. These characteristics require that the transmission networks that pertain to each transaction must be identified and their costs properly allocated among users based on ARR (Annual Revenue Requirement). In case of developing countries like Nepal where the energy resources are yet to be utilized and huge investments are attracted to build the infrastructures for energy sectors, inviting ample investments and the cost recovery of transmission line becomes challenging. In order to evaluate the wheeling charge of the transmission line, various methodologies have been adapted in different countries. In this view tracing the flow of electricity has gain significance as its solution helps in evaluating fair and transparent tariff. Electricity tracing methods would make it possible to charge the consumers and/or generators on the base of actual transmission capacity used. This paper focuses on electricity tracing using Bialek's tracing algorithm. Case study carried out using an IEEE 14-bus with additional two bus to replicate the radial network of a transmission system.
Keywords: Transmission, power generation, tracing algorithm, radial network.

INTRODUCTION

The electricity industry has been undergoing a major transition over the past two decades. Earlier, power generation, transmission, and distribution were considered as a natural monopoly under a utility company. In a restructured environment, Genco (Generation Companies) compete to supply large users and Disco (Distribution Companies) through efficient transmission networks generally owned and operated by Transco (Transmission Companies).

Pricing of transmission services plays a crucial role in determining whether the transmission services to be provided are economically beneficial to both the transmission wheelers and its customers (transmission users). Transmission pricing should be a reasonable economic indicator used by the market to make decisions on resource allocation, system expansion and reinforcement. The competitive environment of electricity markets necessitates wide access to transmission and distribution networks that connect dispersed customers and suppliers. The following points represent the need for effective Transmission Pricing [1].

- Unbundling of the Vertically Integrated Utility.
- Separation of generation from transmission.
- Transmission owner becomes separate entity.
- Transmission owner should recover its sunk cost plus revenue for expansion.
- Open access customers make use of electrical "highway" needs to pay toll.
- How much each entity should pay towards usage of transmission network?
- Issue becomes complicated because of peculiar nature of electric power.
- Demand and supply has to be balanced out real time basis.
- Electric power cannot be routed through desired path. It obeys laws of physics.

A proper transmission pricing could meet revenue expectations, promote an efficient operation of electricity mark. A proper transmission pricing could meet revenue expectations, promote an efficient operation of electricity markets, encourage investment in optimal locations of generations and transmission lines, and adequately reimburse owners of transmission facilities. Most importantly, the pricing strategies should implement fairness among users of transmission facilities and be practical. Based on the prevailing transmission pricing philosophies, it can be classified into three paradigms: embedded cost, incremental cost, and composite [2]. The choices of adopting particular types of pricing mechanism mainly base on the degree of liberalization of the country. So, the method adopted must be simple and implementable. The Network based methods under embedded cost methods are commonly used throughout the utility industry to allocate the cost of transmission system is assumed to be one integrated facility and all costs to meet transmission system revenue requirements. (ARR in this study) are distributed across all costumers. There are generally five different pricing of wheeling method under the category " Network Based Methods" [3]. The postage stamp method, distance based MW-Mile method, MVA Mile Method and Distribution factor method are commonly adopted methods under this category. The embedded cost methods provide, in general, an adequate remuneration of transmission systems and are easy to implement. Generally, a power system consists a combination of loop and radial system. Proportional sharing is recommended as a transmission loss allocation procedure if volatility, negative losses and allocation imbalance are not desired [4]. This study focuses on the flow based Bialek's Tracing method as presented in [5] and is applied in the modified IEEE 14 bus with two additional buses.

Transmission Pricing Method

The main objective of any transmission pricing method is to recover the transmission system cost plus some profit. The transmission pricing philosophies prevailing all over the world can be classified into three paradigms embedded cost, incremental cost, and composite [3]. The degree of liberalization in the power sector of that country will influence the choice of adopting particular types of pricing. Transmission pricing methods are the overall processes of translating transmission costs into overall transmission charges. These methods are shown in Figure-1.

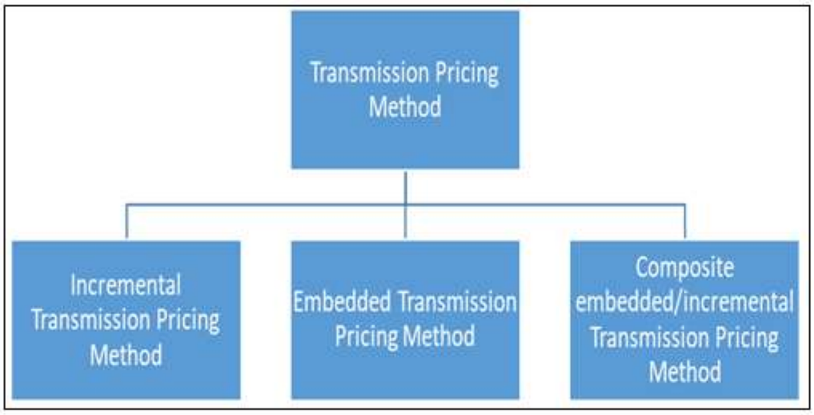

Fig-1: Transmission Pricing Methods

Incremental cost can be defined as the revenue requirements needed to pay for any new facilities that are specifically attributed to the transmission service customer. These facilities must be identified for all years across the life of the contract for transmission service.

This includes revenue requirements in years beyond the life of the contract. The transmission service customer pays the all cost for any new facilities that the transaction requires; if a new facility would have been built for other reasons at a later time, then the transmission service customer pays the cost to advance the facility's in-service date. If a facility is needed by more than one transmission service customer, then the cost of the facility can be allocated to the incremental customers by the Usage method [6].

The embedded cost methods are commonly used throughout the utility industry to allocate the cost of transmission services [7]. These pricing methods allocate the embedded system costs i.e., fixed cost among transmission system users. The embedded cost methods are further divided into network based methods and flow based methods. The network based methods depend on the structure of the transmission system but do not recognize the physical laws governing its operation. The flow based methods on the other hand, allocates the charges of each transmission facility to a wheeling transaction [2] based on the extent of use of that facility by the transaction. This is determined as a function of magnitude, the path, and the distance travelled by the transacted power. The flow based methods are Bialek tracing method and Kirschen Tracing [8].

This study however, is limited to the application of Bialek's tracing method only. Before that a brief overview on the two method as defined in [9] have been explained in this paper.

Kirschen Tracing

This method is based on a set of definitions for domains, commons and links [9]. A domain is a set of buses that obtain power from a particular generator. A common is a set of contiguous buses supplied by the same set of generators. Links are branches that interconnect commons. The rank of a common is defined as the number of generators supplying power to the buses comprising this common. It can never be lower than one or higher than the number of generators in the system. Based on these definitions, the state of a system (an acyclic state graph) is represented by a directed graph that consists of commons and links, with directed flows between commons and the corresponding data for generation/loads in commons and flows on links. The method assumes that the proportion of inflow traced to a particular generator is equal to the proportion of outflow traced to the same generator. As in Bialek tracing method, Kirschen tracing method can determine contributions from individual generators to line flows, and determine contributions of individual loads to line flows. The method is applicable to both 'alternating current (ac)' and 'direct current (dc)' load flow solutions. This traceable allocation method does not rely on a linearized model of the network and is therefore not limited to incremental changes in injections. The method starts by calculating line flows through an optimal power flow. To calculate the contribution of each generation to commons and line flows, the method calculates the inflow to each common. The inflow to common k is the sum of generation at common k and the flow to common k from other commons with a lower rank j; mathematically:

$$I_k = g_k + \sum_j F_{jk} \qquad \text{Eq. 1}$$

Where,

I_k = is the inflow of common k,

g_k = is the net generation in common k,

F_{jk} = is the flow (from j to k) in a link connecting commons j and k.

The next step is to recursively calculate relative contributions by each generator to the load and outflow of each common, starting from the root common (that has rank 1). Relative contributions are calculated based on absolute contributions to a common.

Let: R_{ij} = relative contribution of common i to the load and the outflow of common j, A_{ij} = absolute inflow contribution of common j to common i,

N_c = number of commons, F_{ki} = flow between commons 'k' and 'i'

Bialek's Tracing Method

The method was coined in [5]. Tracing methods determine the contribution of transmission users to transmission usage. Tracing methods may be used for transmission pricing and recovering fixed transmission costs. Bialek's tracing algorithm [1] is used in this study. This algorithm is basically based on the so-called proportional sharing principle. In Bialek's tracing method, it is assumed that nodal inflows are shared proportionally among nodal outflows.

This method uses either the upstream-looking algorithm or the downstream-looking algorithm.

Bialek's Up Stream Tracing Factor

In the upstream-looking algorithm, the transmission usage/supplement charge is allocated to individual generators and losses are apportioned to loads.

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 upstream distribution matrix (A_u) defined as following:

$$[A_u]_{ij} = \begin{cases} 1 \ if \ i=j \\ -\frac{|p_{ji}|}{p_j} \ if \ j \in \alpha_i^u \\ 0 \ otherwise \end{cases} \qquad \text{Eq. 2}$$

Where,

p_{ji} is the actual flow from node j in line j-i

p_j is the actual total flow through node j

α_i^u is set of buses supplying directly bus i

4. Determine topological distribution factors defined as following:

$$D_{ij,k}^{g} = \frac{p_{ij}\left[A_u^{-1}\right]_{ik}}{p_i} \qquad \text{Eq. 3}$$

5. Determine the total usage of the network by the kth generator U_{GK} defined as following:

$$U_{GK} = \sum_{i=1}^{n} \sum_{j \in \alpha_i^d} w_{ij}^g D_{ij,k}^g P_{GK} \qquad \text{Eq. 4}$$

Where

w_{ij}^g is charge per MW of each line i=j

P_{GK} is generation in node k

α_i^d is set of buses supplied directly from bus i

Bialek's Down Stream Tracing Factor

In the downstream-looking algorithm, the transmission usage/supplement charge is allocated to individual loads and losses are apportioned to generators.

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 to generators.
3. Find downstream distribution matrix (A_d) defined as following:

$$[A_d]_{ij} = \begin{cases} 1 \ if \ i=j \\ -\frac{|p_{ji}|}{p_j} \ if \ j \in \alpha_i^d \\ 0 \ otherwise \end{cases} \qquad \text{Eq. 5}$$

Where

p_{ji} is the actual flow from node *j* in line j-i

p_j is the actual total flow through node j

α_i^d is the set of nodes supplied directly from node i

4. Determine topological distribution factors defined as following:

$$D^n_{ij,k} = \frac{p_{ij}\left[A_d^{-1}\right]_{ik}}{p_i} \qquad Eq.\ 6$$

5. Determine the total usage of the network by the kth load U_{LK} defined as following:

$$U_{LK} = \sum_{i=1}^{n} \sum_{j\in\alpha_i^u} w_{ij}^g D^n_{ij,k} P_{GK} \qquad Eq.\ 7$$

Where

w_{ij}^g is charge per MW of each line i=j

P_{LK} is load in node k

The aforementioned algorithm have been developed in the Mat Lab and the load flow analysis was done with the Mat Power software.

Evaluation of Annual Required Revenue

As in [10], Transmission cost comprises mostly the Substation and Transmission Line Cost. So, the cost of the facilities have been sub-divided into two broad categories:

- Capital Cost of Substation
- Capital Cost of Transmission Line

The capital cost of the substation and the transmission line was taken from [11] by taking the average values of the data presented and the annuity of the cost was calculated using.

This cost is assumed to be present value of the network cost and annuitized for 25 years (accounting life of transmission lines) with discount rate of 10% using and the evaluated annuitized cost is considered as the required annual revenue of INPS.

$$ARR = \frac{PV_{rev}}{\frac{1-(1+r)^{-n}}{r}} \qquad Eq.\ 8$$

RESULTS AND DISCUSSIONS

IEEE 14 Bus System with certain modification to create prototype of a real system was considered as the test system to apply this technique. The Figure-2 presents the system to which bialek's tracing has been applied for the study. Two buses are added showing in blue color to replicate the radial network. Results showed that the only Generator G-16 is using the line 15-16 only to transfer its power to the desired location. After full filing the desired local load.

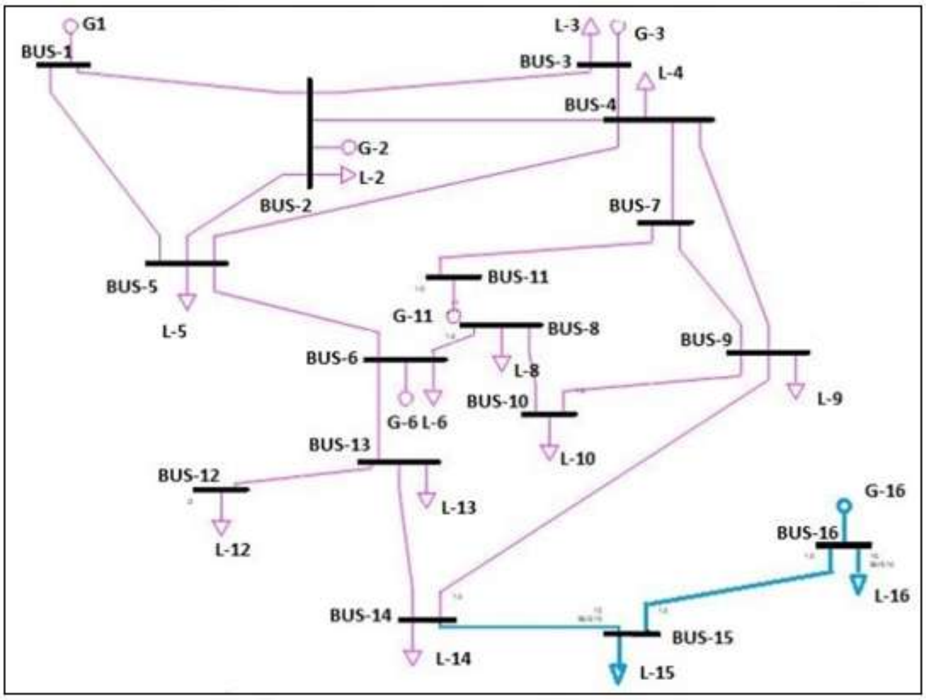

Fig-2: IEEE 14 Bus with few modification

In such scenario the load L-15 and G-16 shall bear the cost of the line i.e. the cost of the transmission line. The Figure-3 Illustrates the transmission line usage of Generators.

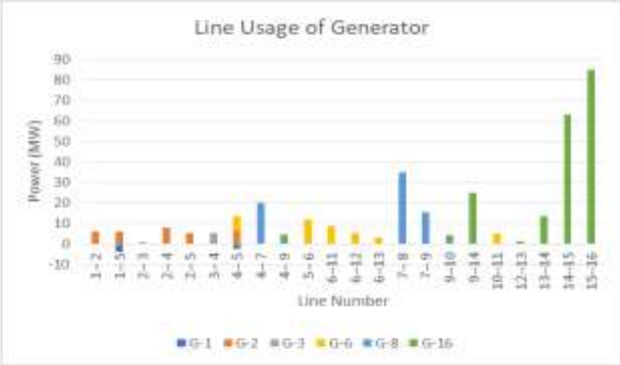

Fig-3: Transmission Line Usage by Generator

Similarly transmission line usage by load have been evaluated using the Bialek's downstream principle and the results are shown in Figure-4.

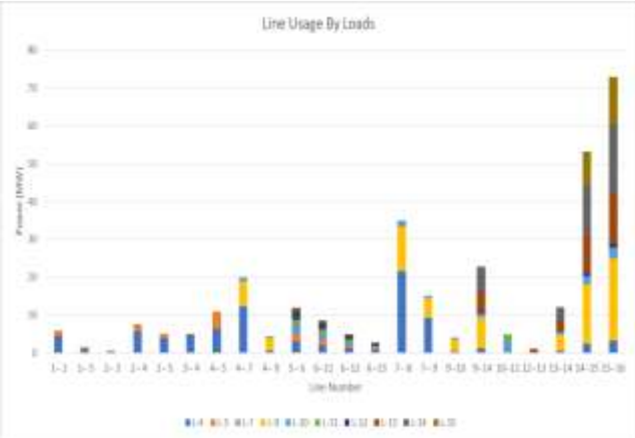

Fig-4: Transmission Line Usage by Load

Similarly, cost is also allocated to each generator and load based on the usage of the power in the transmission line network.

Considering all the transmission line network as 132 kV, the Transmission The total cost of the lines are assumed to be USD 4188.8 kUSD. Now calculating the annuity considering the discount rate of 10% and a span of 25 years we get 460.6 kUSD. Now the cost allocation have been done based on the aforementioned cost. The Figure 5 shows the sharing of the Line cost among the Generators.

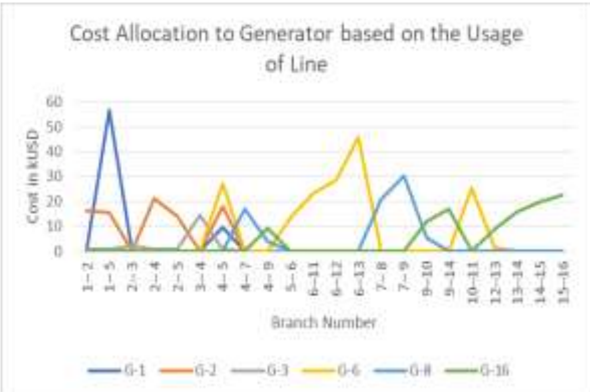

Fig-5: Cost Sharing of Line among the Generators

Similarly, cost sharing of line among loads can be calculated and the results are shown below. The total cost allocated to the Generators and Loads are 517.87 k USD and 752.87k USD respectively which showed that the cost recovery is possible using the power tracing method the Generator.

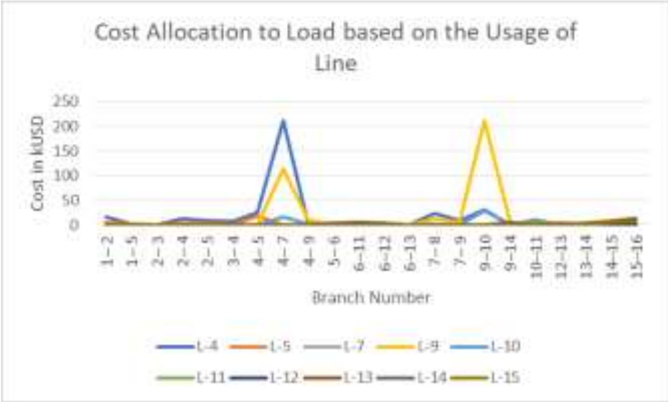

Fig-6: Cost Allocation to Load based on the Usage of Line

Table-1: Cost Allocation to Generator based on the Usage of Line

LINE	G-1 (kUSD)	G-2 (kUSD)	G-3 (kUSD)	G-6 (kUSD)	G-8 (kUSD)	G-16 (kUSD)
1-- 2	0	16.17117	0.622768	0	0	0
1-- 5	56.8744	15.45672	0.595253	0	0	0
2-- 3	0	0	2.010206	0	0	0
2-- 4	0	21.26267	0.818847	0	0	0
2-- 5	0	14.05645	0.541328	0	0	0
3-- 4	0	0	14.5335	0	0	0
4-- 5	9.51584	17.8131	0.686	26.99838	0	0
4-- 7	0	0	0	0	17.0025	0
4-- 9	0	0	0	0	3.962099	9.016501
5-- 6	0	0	0	13.34778	0	0
6--11	0	0	0	23.22819	0	0
6--12	0	0	0	28.53295	0	0
6--13	0	0	0	45.71305	0	0
7-- 8	0	0	0	0	20.93634	0
7-- 9	0	0	0	0	30.14031	0
9--10	0	0	0	0	5.328135	12.12517
9--14	0	0	0	0	0	16.88295
10--11	0	0	0	25.28921	0	0
12--13	0	0	0	1.520644	0	8.933881
13--14	0	0	0	0	0	15.777
14--15	0	0	0	0	0	19.64179
15--16	0	0	0	0	0	22.54356

Table-2: Cost Allocation to load based on the Usage of Line

LINE	L-4 (kUSD)	L-5 (kUSD)	L-7 (kUSD)	L-9 (kUSD)	L-10 (kUSD)	L-11 (kUSD)	L-12 (kUSD)	L-13 (kUSD)	L-14 (kUSD)	L-15 (kUSD)
1-- 2	16.26288	5.10305	0	0	0	0	0	0	0	0
1-- 5	2.393281	1.659871	0	0	0	0	0	0	0	0
2-- 3	0.405162	0.008016	0	0	0	0	0	0	0	0
2-- 4	12.28615	3.855212	0	0	0	0	0	0	0	0
2-- 5	9.197159	2.885932	0	0	0	0	0	0	0	0
3-- 4	6.328918	0.125223	0	0	0	0	0	0	0	0
4-- 5	25.27375	17.52873	0	0	0	0	0	0	0	0
4-- 7	211.3698	0	0	114.6601	15.69252	0	0	0	0	0
4-- 9	1.678803	0	0	11.36421	1.555319	0	0	0	0	0
5-- 6	3.348115	2.3221	0	0	2.36027	1.664642	2.457481	1.180924	0	0
6--11	5.432397	3.767664	0	0	3.829595	2.700921	3.987322	1.916077	0	0
6--12	3.545375	2.458911	0	0	2.499329	1.762717	2.602268	1.2505	0	0
6--13	0.615171	0.426655	0	0	0.433668	0.305855	0.451529	0.216979	0	0
7-- 8	22.71932	0	0	12.32437	1.686728	0	0	0	0	0
7-- 9	9.749465	0	0	5.288716	0.72382	0	0	0	0	0

9--10	31.35723	0	0	212.2645	29.05076	0	0	0	0	0
9--14	0.858752	0	0	5.813094	0.795587	0	0.305439	3.606637	4.877797	0
10--11	0	0	0	0	9.939271	7.00993	0	0	0	0
12--13	0	0	0	0	0	0	0.33432	3.947664	0	0
13--14	0.597147	0	0	4.042231	0.553224	0	0.212392	2.507935	3.391857	0
14--15	1.241942	0	0	8.406999	1.150592	0	0.441732	5.215983	7.054355	4.734467
15--16	2.073098	0	0	14.03329	1.920612	0	0.737356	8.706722	11.77541	7.902957

CONCLUSION

In this paper, tracing of the power have been done on IEEE 14 bus system with additional two buses to represent the actual power network of radial and loop system. The cost have been allocated to generators and loads based on the usage of the particular by the loads and Generators. Both the upstream and downstream algorithm have been used and results are obtained. The annual required revenue have been assumed for the system considering the uniformity in the system. It has been observed that cost recovery is possible using the power tracing system and nondiscrimination can be maintained as the loads and generators shares price based on the usage of the particular line.

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