Transmission Pricing Using Accounting Rate of Return and MW-km Methods

Surender Reddy Salkuti

Abstract*: *This paper presents a realistic and transparent approach to determine transmission cost for the transmission lines of a power system network by allocating the costs to all the participating generating units and load demands. There is a requirement for developing an appropriate transmission pricing mechanism which can give economic and technical information to the participants of the market, i.e., customers, generation and transmission companies. This paper proposes a methodology to allocate the cost of transmission in power system network. In this paper, accounting rate of return (ARR) and MW-km approaches have been used to evaluate the cost of transmission in the system. Simulation results are presented on standard IEEE 14 bus system.

Index Terms*: *MW-km method, postage stamp method, power flow tracing, transmission cost, transmission losses.

I. INTRODUCTION

In the recent restructured electrical power markets, proper allocation of transmission pricing is very important for the open access of transmission system. Therefore, there is a requirement for developing an appropriate transmission pricing mechanism which can give economic and technical information to the participants of the market, i.e., customers, generation and transmission companies. After the introduction of deregulated/restructured power systems, various issues/challenges are raised such as transmission pricing, market power, bidding strategies, congestion management, ancillary services management and optimal market clearing. Among them, fair transmission pricing is a challenging issue. To solve this issue, several methodologies have been proposed by the researchers [1]. Types of embedded transmission pricing approaches include roll-in methods, network based approaches and flow based methods. The roll-in methods classified into contract path method and postage stamp method. The network based methods are classified into MW-mile/MW-km method and MVA-mile method. The flow-based methods are classified into proportional sharing principle based methods and circuit theory based methods.

Reference [2] proposes an approach to divide the cost of transmission lines of power network to all participating generating units and load demands. Power tracing based methods, i.e., Bialek's and Kirschen's methods are considered in Reference [3] for determining the optimal transmission pricing. An overview of transmission pricing focusing on the techniques of cost of transmission is presented in [4]. The analysis of wheeling charges for different transactions by implementing static synchronous series compensator (SSSC) in the power system is proposed in [5]. A comprehensive review of various costs incurred and the types of transmission transaction, and transmission pricing approaches is presented in [6]. Transmission pricing by using improved MVA-km approach based on impedance bus and MVA-km approaches are proposed in [7]. An overview of various approaches and algorithms based on the principle of power flow tracing is presented in Reference [8]. A power flow tracing approach by using the genetic algorithms for transmission pricing is proposed in [9].

An overview and comparison of 3 transmission cost allocation methods, i.e., Wangensteen method, optimal power flow based method and Hogan method is presented in [10]. Reference [11] presents a transmission pricing method based on power flow tracing method by taking into account the generator fixed cost, transmission loss and congestion costs. A transmission pricing approach in an economic way based on users' benefits is proposed in [12]. A survey on various transmission cost allocation methodologies and their evaluation on respective properties across several dimensions is proposed in [13].

There are several transmission cost allocation approaches are available in literature, some of them include postage stamp rate method, contract path method, proportional sharing principle based methods, MW-km/MW-mile method, MVA-km/MVA-mile method, and unused transmission capacity methods. From the literature survey, it is clear that there is a pressing need for an efficient, realistic and transparent transmission pricing mechanism which can recover all the transmission costs by properly allocating the costs to power network users. This paper proposes an approach to allocate the cost of transmission in the power system network. In this paper, accounting rate of return (ARR) and MW-km approaches are utilized to find the cost of transmission in the system.

The remainder of this paper is organized as follows: Section II presents the description of accounting rate of return method and MW-km approach. Section III presents simulation results and discussion. Section IV summarizes contributions of this paper.

II. PROPOSED METHODOLOGY

As mentioned earlier, the postage stamp approach is the simplest of all available transmission pricing methods. A fixed price is charged per unit energy for transferring a prescribed amount of energy over electrical grid. In the present paper, accounting rate of return (ARR) approach is used which falls into the category of postage stamp method.

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A. Accounting Rate of Return (ARR) Approach

Different pricing methods available in the postage stamp approach include the ARR approach and energy division approach. In this work, the ARR approach is used. The step-by-step procedure of this method is presented next:

- Step 1: Read the test system data, such as line data, bus data, slack/reference bus, line length and cost per MW.
- Step 2: Run the Newton Raphson's load flow and then determine power flow and line losses in transmission lines, total losses in the system and slack/reference bus power.
- Step 3: Update slack/reference bus powers from unknowns to found values.
- Step 4: Using the amount of power injection at each bus, determine the transmission charges at all buses using,

  Transmission charge = P_{inj} × cost per MW (1)
- Step 5: Determine the charges for generator and load buses using,
  (i). If transmission charge at a bus > 0 then it is a generator bus
  (ii). If transmission charge at a bus < 0 then it is a load demand bus
  (iii). Total transmission charge = Total loss × (cost per MW + salvage cost)
- Step 6: Determine the charges for each demand bus by dividing the charge for total loss by number of demand buses.
- Step 7: Determine the sum of generator and load demand buses charges for the transmission.

MW-Km Method

This method uses the proportional sharing principle approach evaluates the contribution of transmission users to transmission usage. This approach is used for the pricing of transmission and also for recovering the fixed costs of transmission [14]. However, the wheeling charges depends on the power that is moved through a particular transmission line. Let us consider a power network has n buses and m transmission lines. Let P, P_G and P_D as $(n \times 1)$ vectors of nodal flows, power generations and load demands respectively. F is a $(m \times 1)$ vector of line flows and these are evaluated from the DC power flow model. The incidence matrix (E) of size $(m \times n)$ is formed by considering '-1' for receiving end node and '+1' for sending end node, respectively. This incidence matrix (E) can be split into downstream incidence matrix (E_d) consisting of +1's and upstream incidence matrix (E_u) consisting of -1's.

The branch flow matrix (F_d) of size $(n \times n)$ is formulated, in such a way that its (ij) element is equal to the flow in the transmission line (i-j) towards bus j (i.e., downstream). F_d can be represented by using,

$$F_d = -E_d^T diag(F) E_u \qquad (2)$$

Upstream allocation matrix (A_u) can be represented by using [15],

$$A_u = I + E_u^T diag(F) E_d [diag(P)]^{-1} \qquad (3)$$

Downstream allocation matrix (A_d) can be represented by using,

$$A_d = I + E_d^T diag(F) E_u [diag(P)]^{-1} \qquad (4)$$

Allocation of Networks to Line Flows

Proportional sharing principle allows to express the line flows as sum of components supplied from individual generating units or to load demands. By using the downstream algorithm, the allocation of generators to line flows can be expressed using,

$$P_m^k = \frac{P_{ij}}{P_i} \sum_{k=1}^{n} \left[A_{u(i,k)}\right]^{-1} P_G^k \quad \forall j \in \beta_i^d \qquad (5)$$

where k represents the index for generator buses. P_{ij} is the power flow in a line, where i represents upstream and j represents downstream. By using the upstream algorithm, the allocation of loads to line flows can be expressed using,

$$P_m^k = \frac{P_{ij}}{P_i} \sum_{k=1}^{n} \left[A_{d(i,k)}\right]^{-1} P_D^k \quad \forall j \in \beta_i^u \qquad (6)$$

where k represents the index for load bus. P_{ij} is the power flow in a line, where j represents the upstream and i represents the downstream [16].

Algorithm for MW-Km Method

The algorithm of proposed MW-km approach is as follows:

- Step 1: Read the test system data, such as line data, bus data, slack/reference bus, line length and cost per MW.
- Step 2: Run the DC power flow and calculate the power flows in each transmission line.
- Step 3: Form the branch incidence matrixes (E) for the network under study. And also, form E_u and E_d.
- Step 4: Evaluate adjacency matrix (D) and branch flow matrix (F_d).
- Step 5: Evaluate the vector of nodal powers (P), then the A_u and A_d.
- Step 6: Find the allocations of generation and demand networks to branch flows.
- Step 7: Calculate the transmission cost using MW-Km method for both upstream and downstream power flow tracing approaches.

The flow chart of proposed MW-km method is depicted in Figure 1.

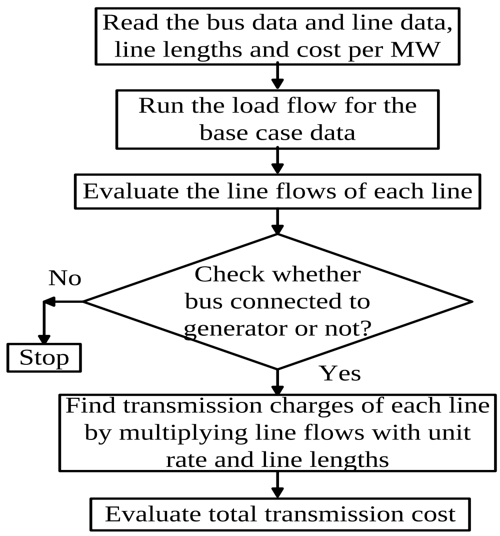

Figure 1: Flow chart of MW-km approach.

III. RESULTS AND DISCUSSION

In this paper, the simulation results are performed on a standard IEEE 14 bus system [17]. This test system has 14 buses, among them 5 are the generator buses, and it has 20 transmission lines. Bus number 1 is considered as slack/reference bus. This test system has 11 loads located at the bus numbers 2, 3, 4, 5, 6, 9, 10, 11, 12, 13 and 14; 2 generators located at buses 1 and 2, along with local load demands; and 3 synchronous compensators located at buses 3, 6 and 8. In this work, it is assumed that the length of line is proportional to line reactance (x). The length of transmission line for IEEE 14 bus test system is not readily available in the literature. Hence, in this work, the transmission line length is calculated by multiplying the line reactance (x) with the multiplication factor (i.e., 1000 km). The single line diagram of IEEE 14 bus system is depicted in Figure 2.

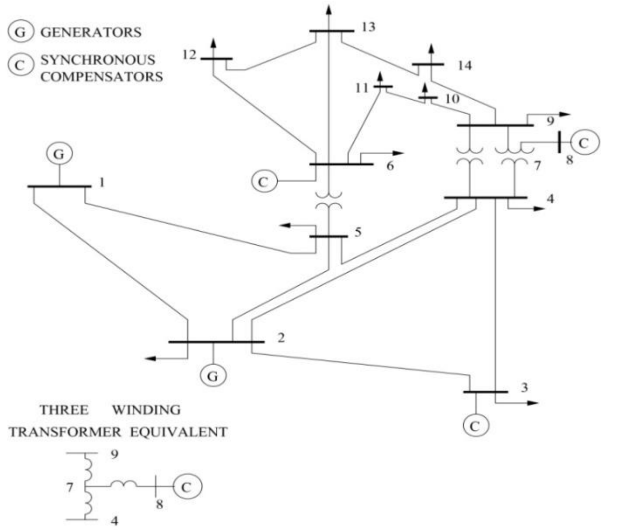

Figure 2: Single line diagram of IEEE 14 bus system.

Power flow is performed on this system to know the power flows in each line. In this paper, it is considered transmission cost per MW is 0.4 $. As mentioned earlier, in this section the simulation results obtained from ARR approach and the power flow tracing based MW-Km approach based on upstream and downstream approaches are presented.

A. Transmission pricing using ARR approach

In this subsection, the ARR approach is applied on IEEE 14 bus system. The total transmission cost obtained in this method is the sum of transmission cost and the energy cost. The detailed algorithm of this method is presented in Section 2.1. The total transmission cost obtained using this approach is 20,024.9 $/hr, which is the sum of transmission cost of 19,519.7 $/h and the energy loss cost of 505.2 $/h. Figure 3 depicts the obtained transmission cost by using this approach.

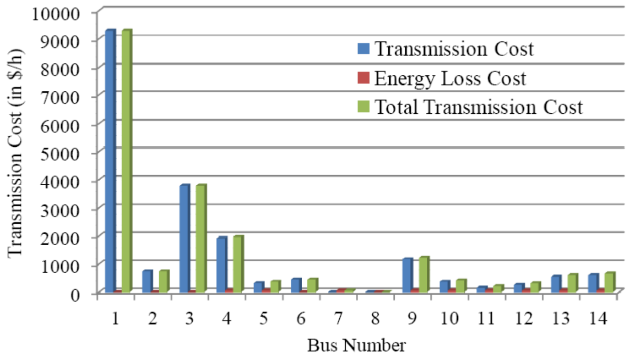

Figure 3: Transmission cost using accounting rate of return (ARR) method.

From the obtained simulation results, it is clear that the charges for energy loss are same for all the distribution companies irrespective of their cost of transmission.

B. MW-Km Method (downstream)

Here, power flow tracing based MW-km approach (downstream tracing approach) is used to determine the transmission pricing. Figure 4 depicts the power contribution of generating units to transmission lines by using the power flow tracing based MW-km approach (downstream).

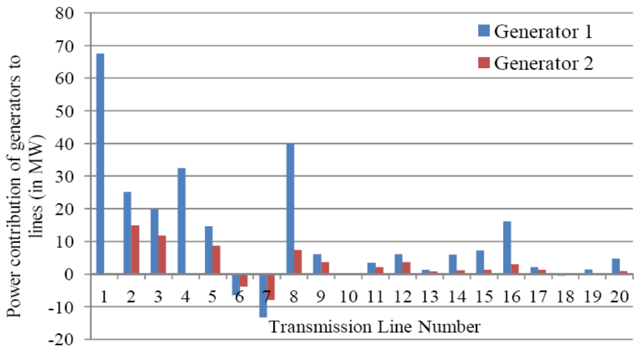

Figure 4: Power contribution of generating units to transmission lines by using MW-Km approach (downstream).

Total wheeling charges by using the power flow tracing based MW-Km approach (downstream) is equal to the power wheeling pricing of generator 1 (i.e., 28908 $/h) and the power wheeling pricing of generator 2 (i.e., 4560.4 $/h), which is equal to 33468.4 $/h. Figure 5 depicts the power wheeling cost by using the MW-km approach (downstream).

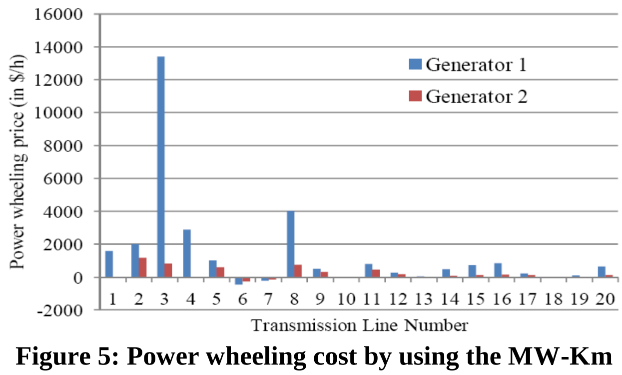

Figure 5: Power wheeling cost by using the MW-Km approach (downstream).

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C. MW-Km Method (upstream)

Here, the power flow tracing based MW-km approach (upstream tracing approach) is used to determine the transmission pricing. Figure 6 depicts the power extraction of load flows from transmission lines by using MW-km approach (upstream tracing approach).

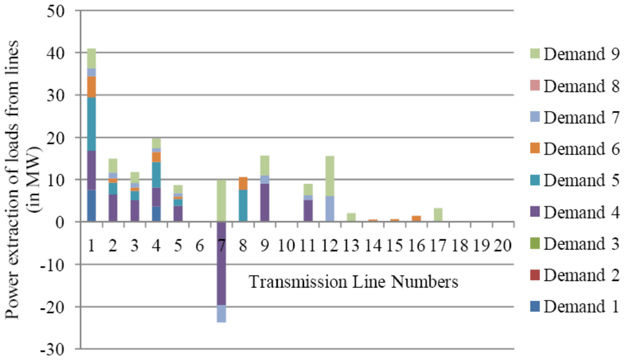

Figure 6: Power extraction of load demands from transmission lines by using MW-Km approach (upstream).

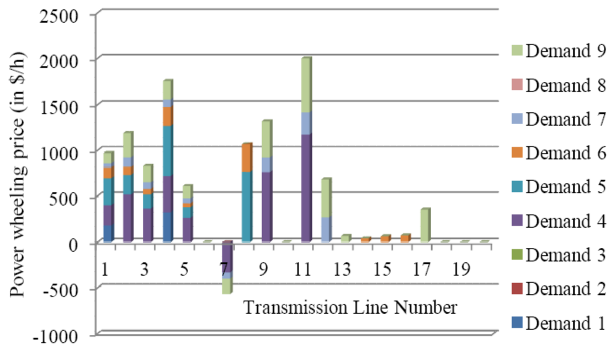

Figure 7: Power wheeling cost by using MW-Km approach (upstream).

Figure 7 depicts the power wheeling cost by using the MW-km approach (upstream).Total wheeling charges by using power flow tracing based MW-Km approach (upstream) is equal to 10,448 $/h.

IV. CONCLUSIONS

Proper allocation of transmission pricing is very important for the open access of transmission system. After the deregulation of electrical systems, there is a pressing requirement for an efficient, realistic and transparent transmission pricing mechanism which can recover all the transmission costs by properly allocating the costs to power network users. This paper proposes an approach to allocate the cost of transmission in the power system network. In this paper, accounting rate of return (ARR) and MW-km approaches are used to find transmission pricing in the system. Simulations results on IEEE 14 bus system shows the effectiveness of proposed transmission pricing approaches.

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REFERENCES

1. Ch.Vani, J.K. Kishore, “Transmission Cost Allocation Schemes Considering Security Under Deregulated Power System”, *International Journal of Electrical and Electronics Engineering*, vol. 2, no. 5, pp. 11-20, Oct. 2015.
2. Ch. V.V. Reddy, G.R. Reddy, V. Anjaneyulu, “Allocation of Transmission Cost Using Power Flow Tracing Methods”, *International Journal of Engineering Research and Application*, vol. 6, no. 10, pp. 17-22, Oct. 2016.
3. K.Hema Lalitha, I.Kranthi Kiran, “Comparison of Wheeling Cost using Power Flow Tracing Methods in Deregulated Electric Power Industry”, *International Journal of Engineering Technology, Management and Applied Sciences*, vol. 5, no. 6, pp. 861-870, Jun. 2017.
4. K. Paul, N. Kumar, “Power System Transmission Pricing-A Review”, *International Journal of Engineering Research & Technology*, vol. 5, no. 1, pp. 437-441, Jan. 2016.
5. P. Vidhya, R. Ashok Kumar, K. Asokan, “A Novel MVA – Mile Method Based Cost Allocation Scheme for Competitive Power System by Employing SSSC Controller”, *Middle-East Journal of Scientific Research*, vol. 24, no. 10, pp. 3230-3242, 2016.
6. M. Murali, M.S. Kumari, M. Sydulu, “An Overview of Transmission Pricing Methods in a Pool Based Power Market”, *International Journal of Advances in Science Engineering and Technology*, vol. 1, no. 2, pp. 58-63, Oct. 2013.
7. A. Mokhtarizade, A. Sedaghati, “Transmission Cost Allocation Using Improved MVA-km Method by Optimal Power Flow”, *Journal of Information Sciences and Computing Technologies*, vol. 5, no. 1, pp. 386-398.
8. B. Khan, G. Agnihotri, “A Comprehensive Review of Embedded Transmission Pricing Methods Based on Power Flow Tracing Techniques”, *Hindawi Publishing Corporation, Chinese Journal of Engineering*, pp. 1-13, 2013.
9. B. Naresh, S. Kumari M and M. Sydulu, “Transmission cost allocation using power flow tracing and Genetic Algorithm”, *5th IEEE International Conference Intelligent Systems*, London, 2010, pp. 432-437.
10. T. Kristiansen, “Comparison of transmission pricing models”, *International Journal of Electrical Power & Energy Systems*, vol. 33, no. 4, pp. 947-953, May 2011.
11. S. Chellam, S. Kalyani, “Power flow tracing based transmission congestion pricing in deregulated power markets”, *International Journal of Electrical Power & Energy Systems*, vol. 83, pp. 570-584, Dec. 2016.
12. M. Roustaei, M.K. Sheikh-El-Eslami, H. Seifi, “Transmission cost allocation based on the users’ benefits”, *International Journal of Electrical Power & Energy Systems*, vol. 61, pp. 547-552, Oct. 2014.
13. “A Survey of Transmission Cost Allocation Issues, Methods and Practices”, *Technical Report*, March 2010.
14. D. Avinash, B. Chalapathi, “MW-Mile method considering the cost of loss allocation for transmission pricing”, *Conference on Power, Control, Communication and Computational Technologies for Sustainable Growth (PCCCTSG)*, Kurnool, 2015, pp. 128-131.
15. S.R. Vaishya, V. Sarkar, “Integrated energy and transmission pricing”, *IEEE Annual India Conference (INDICON)*, Bangalore, 2016, pp. 1-6.
16. J. Nikoukar, M.R. Haghifam, “Transmission pricing and recovery of investment costs in the deregulated power system based on optimal circuit prices”, *Journal of Zhejiang University SCIENCE C*, vol. 13, no. 1, pp. 48-57, Jan. 2012.
17. Available. [Online]: https://al-roomi.org/power-flow/14-bus-system

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