Efficient Transmission Pricing using Power Flow Tracing

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***Abstract* - The evolution of transmission pricing philosophies in deregulated power markets has introduced various techniques for efficient and accurate cost estimation of power exchanges. Earlier methods of postage stamp cost estimation failed to provide accurate cost signals. Point of Connection (POC) method is a technique through which a considerable sunk cost can be recovered but is still inefficient if applied alone. In addition to this, the POC method along with the marginal cost method does not provide an accurate price signal. To overcome the above lacunae, the POC tariff method is employed with the recent Power tracing framework, employed for Active power flow methodologies.**

***Keywords – distributed energy resources(DER), point of connection, locational transmission pricing, tariff method, cost estimation, postage stamp methods, Load Flow Analysis(LFA)***

1. INTRODUCTION

A high voltage transmission network provides, a large number of routes through which transfer of electrical power can take place from source (commonly referred to as Generators) towards sinks (commonly referred to as Load side, or, grid supply points). Generally, a Load flow program is used for finding the different flows, in different lines when considering a complex mesh structure. However, it is difficult for the Load flow program, to trace the connections, ass any change in demand or generation at any node, will directly affect the generation coming from a marginal plant. Hence, conventional methodologies suggest that, it is unattainable to trace electricity from one particular generation point/bus, towards one particular supplier or demand side point/bus.

With conventional LFA, it is possible to determine a relation between generators and transmission line flows by the virtue of sensitivity analysis. While sensitivity analysis can determine a relation between generator and line flows, it is unable to determine how changing a nodal generation or demand can change line flows. In recent times, modern power systems are adapting to more and more Information and Communication Technologies (ICTs), along with the integration of Distributed Energy Resources (DERs) as they provide stability and reliability to the power system. Recent micro-grids that are being set up utilize a number of additional elements, hence, these provide a more reliable and uninterrupted power supply. Undoubtedly, a number of deregulation have been introduced which have pushed the advancement of the energy market.

In[1], author has proposed an innovative methodology for tracing of power from the generation side to the demand side. This work includes two algorithms based on matrices, which considers either the outflows from a node or inflows into a node, making it feasible for the tracing of Active power and to accurately assess the contribution of particular generators to particular loads. In[2][12], author has proposed a methodology of absorption of power at a particular load point and power utilization of the generation end. This topological based power flow tracing solves the problem with the counter flows. Also, in [3], the authors have incorporated both active and reactive powers into consideration while performing the power flow tracing. The advantage of this methodology is that it is unaffected by incremental changes. Many of the cost related problem and accurate analysis of transparency in a transmission network can be estimated by this method. The author in [4], transmission line power flow, in which real power flow is considered while analyzing the contribution of each generator unit is done by a new algorithm based method, i.e. by using VESPO algorithm. This method considers the contribution of particular generation units to particular load units, while taking the contribution of generator to line power injections into consideration. This method considers the not so popular constraints of the generator such as, thermal limits and prohibited operating zone. In[5], author conveys the idea of a bi-directional tracing method based on the separation of power supply paths in power grid. Under the premise of known power flow in an AC section and in consideration of the line-to-ground capacitance, this method conducts an equivalent conversion on the system’s intrinsic parameters, which cannot merely form the single-power multi-load networks, the single-power single-load networks and the single-load multi-power networks, and can further realize the bi-directional tracing in multi-power multi-load loop networks. Coordinating this method with economic accounting, the profit distribution of the power grid can be computed and revealed. In[6], the author presents a transmission pricing scheme using a power flow tracing method to determine the transmission service, congestion and loss cost. The goal is to trace the actual contributions of generators (loads) to each line flow and loss using tracing method, and then the transmission cost can be calculated and allocated based on these contributions.

1. POWER FLOW TRACING AND LOCATIONAL TRANSMISSION PRICING

Some inventive work in the field of power tracing. Two versions of algorithms have been proposed to find out either the inflows or outflows of a node[1]. The main advantage of this is parting of transmission losses in to particular generator or load. This will always give the positive charges which always not possible with the traditional marginal cost-based methodology. By this method of power tracing the active and reactive power flow in each line due to each generator and each load can be find out. With the availability of modern tracing framework, we are able to find proper contributions of particular generators towards particular loads, resulting in an efficient manner of load flow allocation and which also becomes the foundation of our cost estimation methodology[13]. Power tracing based on the topological generation load flow remove the problem of counter flow occurs by another power flow tracing techniques. Tracing of electricity is basically a mathematical procedure of finding out the contribution of each generator towards each load, along with the path the electricity took while flowing from some Generator A to some Load A.

The fundamental principle behind the power flow tracing technique is the Proportional sharing principle. The basis of this can be explained through a simple junction diagram shown in Fig.1.



 Fig.1. Proportional sharing principle

The figure shows that the line *j-i* is carrying power 80W, thus, it can be depicted as, Pj-i  = 80MW ; Pk-i= 120MW ; Pi-m = 140MW ; Pi-l = 60MW. Now, incoming power to ith node will be, Pi = 80 + 120 = 200 MW, the contribution of line j-i to the node ith contribution is 40% and the contribution of k-i line to node ith is 60%, which is visible from the simple concept of proportional sharing. Now, the outflows from node i, is independent of voltage gradient and impedance of line[14]. Thus, the outflow of line i-m 140MW will consist the contribution from the lines, j-i and k-i in the same proportionality, which is,

Contribution of line j-i to line i-m = 140(80/200) = 56MW

Contribution of line k-i to line i-m = 140(120/200) = 84MW

Similarly, the contribution of line i-l will be due to lines, j-i and k-i in the same proportion, which is,

Contribution of line j-i to line i-l = 60(80/200) = 24MW

Contribution of line k-i to line i-l = 60(120/200) = 36MW

The concept of locational transmission pricing (LTP), comes from the core of Point of Connection (POC) tariff scheme. POC scheme provides the operators access to whole energy system network, at one point, that is, the entire market place is accessible through one point of connection[15]. The main advantage of 24 using this pricing scheme is that, the charges applied or recovered from the users is done through a MW proportional injection or demands, which is independent of path followed and thus pancaking of costs doesn’t takes place, as a result of which, both power exchange and bilateral trades can be employed.

Let us define some variables as,

Name of Line = Lm

Cost of line per MW per unit = clm

Length of line = Llm

Thus C`lm = clm . Llm Now, a load is using Plm power from the corresponding line, thus, the total network usage cost for that particular line will be[9],

Total Cost = Σ∀ lm C`lm. Plm

By the virtue of real power tracing it is possible to assign this cost accurately among different participants of the network[10]. Thus, Plm = Σi=1to n (yi lm . Pli) Here, y i lm is the fraction of load the line lm is carrying towards the fulfillment of load i Now, the final expression for LTP is given by,

LTPi = Σ∀ lm(yi lm . C`lm) Rs/MW

The result of the above equation when applied, is expected to show higher cost for farther loads[11].



 Fig. 2. Locational Transmission Pricing

1. METHODOLOGY

In this paper, we have used a 4-Bus system for the execution of our code and to tally the results so as to check the authenticity of the code, so that, implementation on a 13-Bus system and 30-Bus system could be done. First, the implementation on the 4-Bus system is done. The 4-Bus system is shown.

There are two forms of algorithms which can be used to find the tracing or flow of electricity from generator to load[7]. These two are namely, Upstream looking algorithm and Downstream looking algorithm. The upstream looking algorithm will focus on the nodal balance of the inflows, while the Downstream looking algorithm will focus on the nodal balance of the outflows.

Overall flow Pi through the node i can be expressed as sum of all the inflows as,

Pi = Σj ϵ ɑ(u)i |Pi-j| + PGi for, i = 1, 2 ,…...k (1)

Here, ɑ(u) is a set of all nodes supplying node numbered i , since, line is lossless, thus,

|Pj-i| = |Pi-j|

Also, the nodal power Pi can be expressed as,

Pi = (Σjϵ ɑ(u)i cji .Pj)+ PGi (2)

Now, rearranging the above equations, this will lead to a new expression namely,

Pi – (Σjϵɑ(u)i cji . Pj ) = PGi (3i)

Alternatively, Eqn. (3) can be written in the form of matrice notation as, Au . P = PG (3ii)

Here, Au is a distribution matrix of order (n x n), also known as, Upstream Distribution Matrix, P in the Eqn. (3ii) depicts a nodal-through flows, while, PG is the vector of nodal 22 generations. Any element of the matrix Au with position indices as (i, j) is estimated via the below given conditions into consideration.

$\left\{\begin{array}{c}\left[Au\right]ij=1;fori=j\\-cji={-\left(Pj-i\right)}/{Pj};forjϵɑ\left(u\right)j\end{array}\right\}$ (4)

Pi = Σq=1 to n [Au-1]iq . PGq for i = 1, 2, ……. k (5)

The above mentioned set of equations depicts the offering of a q th generator to i th node power equal to the expression [Au-1 ]iq . PG [8].

It should be noted that this same Pi is equal to summation of the load demands corresponding to the note i . The estimation of Load Demand PLi , is depicted as, as function of Pi ,

PLi = (PLi / Pi) (Σq=1 to n [Au] -1 iq . PGq) for i = 1,2,3,4,5………..n (6)

The above equation depicts the contribution of q th generator unit towards the i th load unit. Thus, the expression,

(PLi / Pi ) (Σq=1 to n [Au] -1 iq . Pgq)

is used to trace the power from a generator to a load unit.

According to the above mentioned conditions and equations, we obtain Au , Upstream Distribution Matrix as,

Au =$\begin{matrix}1&0&0&0\\-0.1508&1&0&0\\-0.5614&0&1&0.2889\\-0.2877&-1&0&1\end{matrix}$

Similarly, [Au]-1 = $\begin{matrix}1&0&0&0\\0.1508&1&0&0\\0.6882&0.289&1&0.289\\0.4385&1&0&1\end{matrix}$

TABLE 1. GENERATOR TO LOAD CONTRIBUTION IN 4-BUS SYSTEM

|  |  |  |  |
| --- | --- | --- | --- |
| LOAD | Generator 1 | Generator 2 | Total |
| Load3 | 271.5 | 32.5 | 304 |
| Load4 | 123 | 80 | 203 |
| Total | 394.5 | 112.5 | 507 |

 Fig. 2. 4-Bus lossless system

We have considered Cost per unit length, clm to be 100 units. Now, applying the concept of LTP in this 4-Bus system, we get the following result,

TABLE 2. COST OF LOADS BY USING LTP

|  |  |
| --- | --- |
| LOAD NO. | COSTING(Rs/MW) |
| 1 | 0 |
| 2 | 0 |
| 3 | 6150 |
| 4 | 12709 |

1. RESULTS AND OBSERVATION

Now, the analysis is done on a 13-Bus system as well as on a 30-Bus system. The 13-Bus system consists of two generator buses, namely, Bus no. 4 and Bus no. 10, while two other buses are redundant buses namely Bus no. 2 and Bus no. 5. Now, Applying the concept of power tracing and LTP to 13 Bus system, we get results as,

TABLE 3. LINE FLOWS OF 13-BUS SYSTEM

|  |  |  |  |
| --- | --- | --- | --- |
| From Bus | To Bus | Flow | Line No. |
| 1 | 3 | 0.1429 | 1 |
| 2 | 5 | 0.0811 | 2 |
| 3 | 5 | 0.0949 | 3 |
| 3 | 6 | 0.2288 | 4 |
| 3 | 11 | 0.0564 | 5 |
| 3 | 12 | 0.0329 | 6 |
| 4 | 1 | 0.1657 | 7 |
| 5 | 2 | 0.0819 | 8 |
| 5 | 11 | 0.0114 | 9 |
| 7 | 9 | 0.0104 | 10 |
| 9 | 11 | 0.0314 | 11 |
| 10 | 7 | 0.0406 | 12 |
| 10 | 8 | 0.1527 | 13 |
| 10 | 9 | 0.0512 | 14 |
| 12 | 13 | 0.0225 | 15 |
| 13 | 11 | 0.0025 | 16 |

TABLE 4. POWER TRACING FOR 13-BUS SYSTEM

|  |  |
| --- | --- |
| LOAD | GENERATOR |
| GENERATOR 4 | GENERATOR 10 |
| Load 1 | 0.2 | 0 |
| Load 3 | 0.0134 | 0.0314 |
| Load 6 | 0.0718 | 0.2389 |
| Load 7 | 0.0023 | 0.0279 |
| Load 8 | 0.01159 | 0.1411 |
| Load 9 | 0.0023 | 0.0279 |
| Load 11 | 0.0743 | 0.0290 |
| Load 12 | 0.00326 | 0.00714 |
| Load 13 | 0.00628 | 0.01372 |

The LTP result for the 13-Bus system is given below. Since, there is no load attached to the Bus no. 2 and 5, thus, there is no cost bearing value obtained for the same buses.

TABLE 5. LTP FOR 13-BUS SYSTEM

|  |  |
| --- | --- |
| LOAD BUS No. | COSTING(Rs/MW) |
| Load 1 | 1429 |
| Load 3 | 3140 |
| Load 6 | 7389 |
| Load 7 | 2413 |
| Load 8 | 11599 |
| Load 9 | 2793 |
| Load 11 | 1678 |
| Load 12 | 1298 |
| Load 13 | 3045 |

For a 30-Bus system, there are two generator buses, namely, Bus no. 1 and Bus no. 2, while others being the load buses. Since, we are performing Active Power analysis for this system, we have some buses which are not involved in power flow analysis.

Bus no. 9, 11 and 13 do not contribute towards the Active power flow tracing of the Bus system, hence, Generator contribution is zero for them.

TABLE 6. POWER TRACING FOR 30-BUS SYSTEM

|  |  |
| --- | --- |
| LOAD | GENERATOR |
| GENERATOR 1 | GENERATOR 2 |
| LOAD 3 | 3.985 | 0 |
| LOAD 4 | 9.1321 | 0.1229 |
| LOAD 5 | 92.0974 | 3.4626 |
| LOAD 6 | 1.5264 | 0.0386 |
| LOAD 7 | 22.7008 | 0.5742 |
| LOAD 8 | 29.3135 | 0.7415 |
| LOAD 9 | 0 | 0 |
| LOAD 10 | 5.9739 | 0.1511 |
| LOAD 11 | 0 | 0 |
| LOAD 12 | 11.0217 | 0.1483 |
| LOAD 13 | 0 | 0 |
| LOAD 14 | 5.9598 | 0.0802 |
| LOAD 15 | 8.0418 | 0.1082 |
| LOAD 16 | 3.9765 | 0.0535 |
| LOAD 17 | 8.8299 | 0.1801 |
| LOAD 18 | 2.9799 | 0.0401 |
| LOAD 19 | 8.8180 | 0.1920 |
| LOAD 20 | 1.9891 | 0.0503 |
| LOAD 21 | 16.6342 | 0.4208 |
| LOAD 22 | 0.0488 | 0.0012 |
| LOAD 23 | 2.9799 | 0.0401 |
| LOAD 24 | 8.8334 | 0.2016 |
| LOAD 25 | 0.0341 | 0.0009 |
| LOAD 26 | 3.9208 | 0.0992 |
| LOAD 27 | 0.1317 | 0.0033 |
| LOAD 28 | 0.0293 | 0.0007 |
| LOAD 29 | 2.0093 | 0.0508 |
| LOAD 30 | 10.8213 | 0.2737 |

The power flow through each line is known through the N-R method, but, through power tracing we know the contribution of each generator to the line flows, thus, making it more efficient for the production of pricing signals.

TABLE 7. GENERATOR CONTRIBUTION TOWARDS LINE FLOWS

|  |  |
| --- | --- |
| LINE  | GENERATOR |
| GENERATOR 1 | GENERATOR 2 |
| LINE 1 | 173.2 | 0 |
| LINE 2 | 87.7 | 0 |
| LINE 3 | 41.9296 | 1.6704 |
| LINE 4 | 79.2431 | 3.1569 |
| LINE 5 | 57.9898 | 2.3102 |
| LINE 6 | 82.2 | 0 |
| LINE 7 | 71.2413 | 0.9587 |
| LINE 8 | 43.6131 | 0.5869 |
| LINE 9 | 37.16 | 0.94 |
| LINE 10 | 28.8697 | 0.7303 |
| LINE 11 | 27.0166 | 0.6834 |
| LINE 12 | 15.4102 | 0.3898 |
| LINE 13 | 18.2387 | 0.4613 |
| LINE 14 | 14.4349 | 0.3651 |
| LINE 15 | 0.4877 | 0.0123 |
| LINE 16 | 27.0166 | 0.6834 |
| LINE 17 | 0 | 0 |
| LINE 18 | 5.1692 | 0.1308 |
| LINE 19 | 8.7780 | 0.2220 |
| LINE 20 | 15.4102 | 0.3898 |
| LINE 21 | 7.4125 | 0.1875 |
| LINE 22 | 0 | 0 |
| LINE 23 | 7.7951 | 0.1049 |
| LINE 24 | 17.6623 | 0.2377 |
| LINE 25 | 7.1044 | 0.0956 |
| LINE 26 | 1.5788 | 0.0212 |
| LINE 27 | 5.9203 | 0.0797 |
| LINE 28 | 4.9336 | 0.0664 |
| LINE 29 | 3.6509 | 0.0491 |
| LINE 30 | 2.7628 | 0.0372 |
| LINE 31 | 6.5345 | 0.1653 |
| LINE 32 | 1.7556 | 0.0444 |
| LINE 33 | 5.5594 | 0.1406 |
| LINE 34 | 1.7761 | 0.0239 |
| LINE 35 | 1.1704 | 0.0296 |
| LINE 36 | 3.4137 | 0.0863 |
| LINE 37 | 4.6816 | 0.1184 |
| LINE 38 | 17.6535 | 0.4465 |
| LINE 39 | 6.047 | 0.1530 |
| LINE 40 | 6.9248 | 0.1752 |
| LINE 41 | 3.6087 | 0.0913 |

The overall cost estimation of the load is mentioned, here, we can observe that bus no. 22 and 17 do not participate in the Active power flow tracing of the 30-Bus system, hence, the LTP result would also show zero values for the same.

TABLE 8. LTP RESULT FOR 30-BUS

|  |  |
| --- | --- |
| LOAD  | COST(Rs / MW)(x106) |
| LOAD 3 | 0.1291 |
| LOAD 4 | 0.0309 |
| LOAD 5 | 0.7321 |
| LOAD 6 | 0.3135 |
| LOAD 7 | 0.7981 |
| LOAD 8 | 0.0886 |
| LOAD 9 | 0.0354 |
| LOAD 10 | 0.2286 |
| LOAD 11 | 0.0356 |
| LOAD 12 | 0.0070 |
| LOAD 13 | 1.1843 |
| LOAD 14 | 0.0035 |
| LOAD 15 | 0.0070 |
| LOAD 16 | 0.0448 |
| LOAD 17 | 0 |
| LOAD 18 | 0.0022 |
| LOAD 19 | 0.1840 |
| LOAD 20 | 0.0060 |
| LOAD 21 | 4.3624 |
| LOAD 22 | 0 |
| LOAD 23 | 0.0177 |
| LOAD 24 | 0.0418 |
| LOAD 25 | 0.0023 |
| LOAD 26 | 0.0381 |
| LOAD 27 | 0.0273 |
| LOAD 28 | 0.0098 |
| LOAD 29 | 0.0085 |
| LOAD 30 | 0.0096 |

1. CONCLUSION

The results obtained through the application of the above methodologies, can be summarized as,

* The power tracing result confirms the establishment of tracing technique being adopted for the Active power analysis.
* The farther load utilizes more transmission line and hence, the LTP for the same is taken into consideration.
* It is not necessary that the LTP of farther load will always be more, the costing depends upon the power consumed and also the length of transmission line being used.
* The costing results shown are thus, accurate as well as adequate for the pricing scheme to be setup.  In comparison of other methods for transmission pricing the LTP method gave a more detailed result, thus helps in establishing better and efficient pricing signals.
* Further, comparison of results suggest that, ethically, the costing should be distributed equally among the Generator and Demand side, but, since the sunk cost contribution of generator has already been invested, thus, one half of the costing can be charged to the demand side. This will allow for a lesser burden on the consumer side, when rural areas are to be considered.

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