조류계산에 기초한 탁송요금 계산

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A Load Flow Based Approach to Transaction Cost Allocation in Transmission Network

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Abstract : This paper describes a novel approach for allocating transmission costs among users of transmission services. In the suggested approach, the cost share of each participant is proportional to amount of its line flow. To develop individual user's impact, the line utilization factors of each participant are derived by power flow equations of all nodes (i.e., load-flow equations). To deal with the slack bus problem inherent in the conventional load-flow analysis more practically, a additional power supply/demand balance equation is incorporated. Although the developed allocation rule is basically similar to the existing MW-mile method in the aspect of embedded cost allocation, it does not require to get load flow solutions of each wheeling transaction when multiple transmission transactions are considered.

I. INTRODUCTION

Electric utilities all of the world are confronted with the trend of a decentralization, deregulation, privatization and the introduction of competition in electric power markets. These world-out electricity reforms are seen as necessary conditions to increase efficiency of electric energy production, transportation and distribution and to offer a lower price, higher quality and more secure product to customers.

Traditionally, Korea has maintained a monopolistic policy in the electricity sector. That is, a government-owned monopolistic electric utility has owned and operated the vertically integrated power system. However, recent changes in the surrounding environments have spurred the Korea's government to introduce independent power producers (IPPs) in the generation sector from the year of 2001.

The changing environment for electric power utilities has resulted in the unbundling services provided by these utilities. Wheeling of the electrical energy (transmission services) is one of the most prevailing unbundled services provided by electric power utilities. Pricing of transmission services plays a crucial rule in determining whether providing transmission services is economically beneficial to both the wheeling utility and the wheeling customers.

To evaluate the cost of transmission capacity, many salient methods have been used and suggested. These methods are divided into the following two main categories; embedded cost and marginal cost approach. The former approaches include the postage stamp, the contract path, the distance based MW-mile, power-flow based MW-mile method and their variations. In these methods, all system costs (unrecovered investment and operating & maintenance costs of existing system) are allocated among the users proportional to their "extent of use" of the transmission resources. The latter approaches which are based on the solutions of optimal power flow are divided into short-run and long-run marginal cost methods. The short-run marginal cost (SRMC) methodologies of wheeling measure the change in costs due to infinitesimal changes in wheeling. The long-run marginal cost (LRMC) methodologies consider both the changes in investment costs and the changes in operating costs.

II. OVERVIEW OF EMBEDDED COST METHODS

1.Postage stamp method

This transmission pricing method allocates transmission charges based on the magnitude of the transacted power. The magnitude of the transacted power for a particular transmission transaction is usually measured at the time of system peak load condition. This approach has advantage of simplicity, but it ignores the actual system operation. Especially the concept of wheeling distance is not considered in transmission pricing.

2.Contract path method

In this method a specific path between the points of delivery and receipt is selected for a wheeling transaction. Without performing a power flow the "contract path" is selected to identify the transmission facilities that are actually involved in the transaction. A portion or all charges associated with transmission facilities in the contract path is then allocated to the wheeling customer. The majority of the transacted power may actually flow on transmission facilities outside the contracted path and even on neighboring utilities' transmission systems. Since so-called "parallel flow" affect the price of the transmission systems outside the contract path, uneconomic transaction may take place.

3.Power flow based MW-mile method

The power flow based MW-mile method allocates the charges for each transmission facility to transmission transactions based on the extent of use of that facility by these transactions. This method overcomes some limitations of other embedded cost methods, but has been criticized as having on obvious grounding on economic theory. However, considering some simplifying assumptions this method can be interpreted as a solution to the optimal transmission planning problem from a static point of view.

III. THE SUGGESTED METHOD

Responding to increasing global competition, Korea's government passed laws paving the way for sweeping deregulation of its electricity industry. The laws permit IPPs to penetrate into the Korea's generation market from the year 2001. In this regard, the existing generators and transmission facilities are owned by the vertically integrated electric utility. Therefore, we need a new framework to charge transmission service against new-coming IPPs. This paper offers a novel guideline for wheeling costs to cope with aforementioned situations.

The derived cost allocation rule, in this paper, is based on the following basic assumption. That is, the ratio of each bus's load is constant and given in advance. In addition, the ratio does not change during the variations of load levels.

$$k_i = \frac{P_{L,i}}{P_{L,total}} = Const \quad , \; for \;\; i = 1,2,\cdots,n \quad \text{.............................(1)}$$

where,

$P_{L,i}$: load demand at bus i

$P_{L,total}$: total demand

n : number of buses.

The suggested method calculates the incremental flow on each transmission line caused by the introduction of a new wheeling participant based on a power flow model. Costs to the user of transmission service are then allocated in proportion to the ratio of incremental line flow due to a transaction and line flow after a transaction.

$$R(k) = \sum_{all\, i,j} C_{ij} \frac{\left|u_k^{ij}\right| \Delta P_{Gk}}{\left|P_{ij}\right| + \left|u_k^{ij}\right| \Delta P_{Gk}} \quad \text{..............................(2)}$$

where,

$R(k)$: allocated costs to a transaction wheeler at bus k

C_{ij} : costs of transmission line from i-th bus to j-th bus

P_{ij} : line flow from i-th bus to j-th bus before considering a wheeling transaction

ΔP_{Gk} : injected transaction power at bus k to a network

u_k^{ij} : incremental line flow from i-th bus to j-th bus when a unit power is increasing at bus k

When multiple transmission services are considered, wheeling charges for each transaction are allocated based on the generic formulation.

$$(Total\ Wheeling\ Costs) = \sum_{all\, i,j} C_{ij} \frac{\sum_{k\in\Omega} \left|u_k^{ij}\right| \Delta P_{Gk}}{\left|P_{ij}\right| + \sum_{k\in\Omega} \left|u_k^{ij}\right| \Delta P_{Gk}} \quad \text{............(3)}$$

Then for each participant, the allocated cost can be obtained :

$$R(l) = \sum_{all\, i,j} C_{ij} \frac{\sum_{k\in\Omega} \left|u_k^{ij}\right| \Delta P_{Gk}}{\left|P_{ij}\right| + \sum_{k\in\Omega} \left|u_k^{ij}\right| \Delta P_{Gk}} \times \frac{\left|u_l^{ij}\right| \Delta P_{Gl}}{\sum_{k\in\Omega} \left|u_k^{ij}\right| \Delta P_{Gk}} \quad \text{.............(4)}$$

where,

Ω : the set of all wheeling transaction participants.

The coefficients u_k^{ij} implies the impact of an individual generation increment to the line flow from i-th bus to j-th bus j. These coefficients called Line Utilization Factor (LUF) can be expressed as follow;

$$\Delta P_{ij} = u_1^{ij} \Delta P_{G1} + u_2^{ij} \Delta P_{G2} + \ldots + u_{n-1}^{ij} \Delta P_{G,n-1} + u_n^{ij} \Delta P_{G,n} \quad \text{..........(5)}$$

The detail procedure to determine their values is presented in Appendix A.

IV. SIMULATION RESULTS

The methodology was applied to a sample system with 5 buses, 7 transmission lines and 2 generators. The corresponding data of the system are given in Appendix B.

We evaluated the charges associated with 2 wheeling transactions.

T1. Injection of 5 MW at bus 1 and removal at bus 5

T2. Injection of 5 MW at bus 4 and removal at bus 2

As shown in figure 1, the transaction T1 is in the same direction of the main flow, while T2 is in the counterdirection of the main flow. Table 1 summarizes the transaction charges of the developed allocation method, and compared with the conventional MW-mile based Modulus Method (MM)[8]. The principle of MM is to replace the circuit capacities of conventional MW-mile method by the sum of absolute power flows caused by all transactions. The suggested method is very similar to the MM in its formula except for using sensitivity factor (LUF). The main advantage of our method is that it can deal with multiple transactions simultaneously, which does not require a set of load-flow solutions.

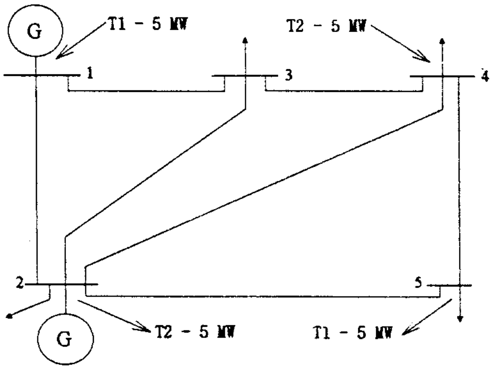

Figure 1. Wheeling Transactions in 5-bus system

As we can see in table 1, the charges of transaction T2 is cheaper than that of T1 since T2 is in the counterdirection of the main flows. Also, solutions of the suggested method is close to those of the conventional MM.

Table 1. Transaction Charges (US$/MWh)

Transactions	Conventional MM	Suggested Method
T1	5.0205	4.9977
T2	4.5547	4.6434
T1+T2	4.6188 / 4.1256	4.6003 / 4.1884

Table 2 shows that the line flows are nearly same in both method. The line flows provided by the load flow solutions are used in the conventional MM, while line flows provided by the suggested algorithm are used in our allocation rules.

Table 2. Line Flows by Load Flow and Suggested Method

Line	Line Flow (MW) before T1 Transaction (Solution by Load Flow)	Line Flow (MW) after T1 Transaction (Solution by Load Flow)	Line Flow (MW) after T1 Transaction (Solution by Suggested Algorithm)
1-2	89.33	93.56	93.55
1-3	41.79	42.95	42.94
2-3	24.47	24.61	24.58
2-4	27.71	28.05	28.01
2-5	54.66	58.30	58.29
3-4	19.39	20.60	20.58
4-5	6.60	8.14	8.15

IV. CONCLUSIONS

In the suggested approach, the cost share of each participant is proportional to amount of its line flow. To develop individual user's impact, the line utilization factors of each participant are derived by power flow equations of all nodes (i.e., load-flow equations). To deal with the slack bus problem inherent in the conventional load-flow analysis more practically, an additional power supply/demand balance equation is incorporated. Throughout the case studies simulation, we can see the transaction costs are very close to those of the conventional modulus method. The main advantage of the developed method is that it does not require to get load flow solutions of each wheeling transaction when considering multiple transmission transactions.

V. REFERENCES

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VI. APPENDIX

A. Procedure to Derive Line Utilization Factors (LUFs)

Considering the power flow from i-th bus to j-th bus,

$$P_{ij} = f(\theta_i, \theta_j, V_i, V_j) \text{ ....}(1)$$

If it is assumed that $\Delta V = 0$, then incremental value of P_{ij}, ΔP_{ij} can be expressed as

$$\Delta P_{ij} = \frac{\partial f}{\partial \theta_i}\Delta\theta_i + \frac{\partial f}{\partial \theta_j}\Delta\theta_j$$

$$= \begin{bmatrix} 0 & \cdots & 0 & \frac{\partial f}{\partial \theta_i} & 0 & \cdots & 0 & \frac{\partial f}{\partial \theta_j} & 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} \Delta\theta_1 \\ \Delta\theta_2 \\ \vdots \\ \Delta\theta_{n-1} \end{bmatrix} \quad (2)$$

According to the Newton-Raphson method to the solution of the power-flow equations, the relationship between real power injections and bus voltage angles can be described as

$$\Delta P = J_{P\theta}\, \Delta\theta \text{ ....}(3)$$

where, $J_{P\theta}$ is submatrix of Jacobian representing $\frac{\partial P}{\partial \theta}$,

$\Delta P = [\Delta P_1 \;\; \Delta P_2 \;\; \cdots \;\; \Delta P_{n-1}]^T$ and $\Delta\theta = [\Delta\theta_1 \;\; \Delta\theta_2 \;\; \cdots \;\; \Delta\theta_{n-1}]^T$.

From Eq. (3)

$$\Delta\theta = J_{P\theta}^{-1}\, \Delta P \text{ ....}(4)$$

In order to compute line flows at all buses including slack bus, in a similar way to Eq. (3),

$$\Delta P_{slack} = J_{slack,\theta}\, \Delta\theta = J_{slack,\theta}\, J_{P\theta}^{-1}\, \Delta P \text{ ....}(5)$$

where, ΔP_{slack} is the incremental value of active power at slack bus and $J_{slack,\theta}$ represents $\frac{\partial P_{slack}}{\partial \theta}$.

And from Eq.(5), we obtain a linear combination as follows

$$\begin{bmatrix} -J_{slack,\theta}\, J_{P\theta}^{-1} & 1 \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta P_{slack} \end{bmatrix} = 0 \text{ ....}(6)$$

Let $\begin{bmatrix} -J_{slack,\theta}\, J_{P\theta}^{-1} & 1 \end{bmatrix}$ be linear combination factors $[q_1, q_2, \ldots, q_{n-1}, q_n]$,

$$[q_1, q_2, \cdots, q_{n-1}, q_n] \begin{bmatrix} \Delta P \\ \Delta P_{slack} \end{bmatrix} = 0 \text{ ....}(7)$$

After solving power flow equations, then $\Delta P = \Delta P_G - \Delta P_L$, where, ΔP_G, ΔP_L are vectors which represent incrementals of real power at generation buses and incrementals of real power at load buses respectively. And applying the assumption that the ratio of each bus's load is constant and given in advance,

$$\begin{bmatrix} \Delta P_{L1} & P_{L2} & \cdots & \Delta P_{L,n-1} & \Delta P_{L,n} \end{bmatrix}^T = \begin{bmatrix} k_1 & k_2 & \cdots & k_{n-1} & k_n \end{bmatrix}^T \Delta P_{L,total} \; (8)$$

where, $\Delta P_{L,total}$ is a total demand.

And hence Power Supply-Demand Balance Equation (PSDBE) including slack bus is

$$\Delta P_{L,total} = \frac{1}{r}[q_1, q_2, \cdots, q_{n-1}, q_n] \begin{bmatrix} \Delta P_{G1} \\ \Delta P_{G2} \\ \vdots \\ \Delta P_{G,n-1} \\ \Delta P_{G,n} \end{bmatrix} \text{ ....}(9)$$

where, $r = [q_1, q_2, \cdots, q_{n-1}, q_n]\begin{bmatrix} k_1 & k_2 & \cdots & k_{n-1} & k_n \end{bmatrix}^T \Delta P_{L,total}$.

Using Eq.(2), Eq.(4), $\Delta P = \Delta P_G - \Delta P_L$ and Eq.(9),

$$\Delta P_{ij} = \begin{bmatrix} 0 & \cdots & 0 & \frac{\partial f}{\partial \theta_i} & 0 & \cdots & 0 & \frac{\partial f}{\partial \theta_j} & 0 & \cdots & 0 \end{bmatrix} J_{P\theta}^{-1} \begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \vdots \\ \Delta P_{n-1} \end{bmatrix}$$

$$= \begin{bmatrix} u_1^{ij} & u_2^{ij} & \cdots & u_n^{ij} \end{bmatrix} \begin{bmatrix} \Delta P_{G1} \\ \Delta P_{G2} \\ \vdots \\ \Delta P_{G,n} \end{bmatrix} = \sum_{k=1}^{n} u_k^{ij}\, \Delta P_{G,k} \text{ ....}(10)$$

B. Input Data for Simulation

Parameters of the transmission lines in the 5-bus system

BUS I	BUS j	RESISTANCE (p.u.)	REACTANCE (p.u.)	COST OF TRANSMISSION (Million $)
1	2	0.02	0.06	0.1863
1	3	0.08	0.24	0.8250
2	3	0.06	0.18	0.5499
2	4	0.06	0.18	0.5499
2	5	0.04	0.12	0.2809
3	4	0.01	0.03	0.0978
4	5	0.08	0.24	0.8250