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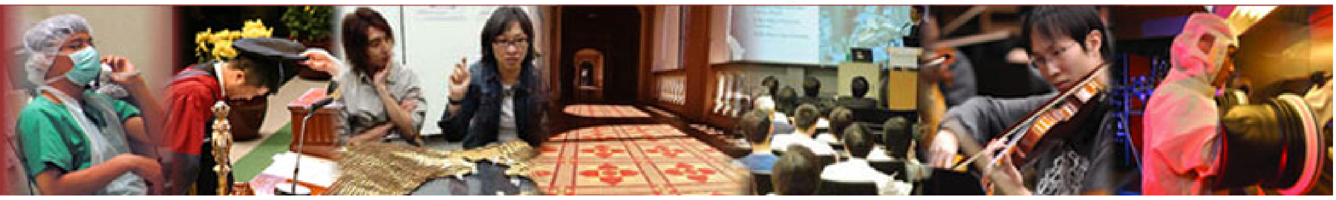

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The concept and algorithm of "conductor renting" and its application in transmission losses allocation

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***Abstract*--The cost of transmission losses represents an important part of transmission costs. In the context of competitive electricity marketplace, the costs caused by transmission losses should be reasonably allocated to various market participants, but the nonlinearity of the transmission losses function makes the allocation very difficult. In this paper, the concept of "conductor renting" is proposed for the first time and is used to solve transmission losses allocation problem. The analysis indicates that the active power losses caused by different current components are in proportion to the conductor section acreage and the corresponding conductance used by the current components, and the reactive power losses caused by current components have similar characteristics. Based on the concept of conductor renting, it is easy to solve the losses allocation problem, and the interaction effect of the transactions is eliminated.**

***Index Terms*--electricity market; transmission pricing; transmission losses allocation**

I. INTRODUCTION

IN the context of competitive electricity marketplaces, the cost of the transmission losses, which presents an important component of transmission costs, should be compensated through certain way. Since the compensation method may have unneglectable impact on profit and decision-making of market participants and economic efficiency of the electricity markets, it must be carefully designed to provide correct economic signals.

Basically, there are two clusters of losses compensation methods. One is the marginal cost based methods, which can lead to the optimal social benefit and nodal price, with the loss price explicitly appeared as Lagrangian multiplier and included in nodal price. The drawbacks of methods of this category include the dependency of reference bus selection, the complexity of the calculation and over charge in losses costs.

Even though the cost of transmission losses only presents a small portion of the transmission costs, the accumulative effect cannot be ignored. This gives rise to another category of losses cost recovery methods, that is, the various loss allocation methods. But for the nonlinearity of the losses functions, the allocation is very difficult. Many methods have been developed to solve the problem of nonlinearity, but none has been widely adopted.

The post-stamp method, which allocates losses to transactions in proportion to quantities of the power transmitting, is the simplest allocation method but cannot provide correct economic signals. Both [1] and [2] propose a shared-terms based allocation method, in which each of the standalone term, which is caused by a single transaction, is allocated to the corresponding transaction and each of the shared term, which is caused by at least two transactions, is allocated to the corresponding multiple transactions. Reference [3] proposes an aggregative comparison method, in which losses are allocated to transactions by comparing losses under different operation conditions. In [4-5], calculous method is adopted. All transactions are assumed to increase at the same rate and the loss increment between each two steps is allocated to the transactions in proportion to sensitivities of the loss to the transactions. Reference [6] proposed a Z-bus based allocation method, in which loss is expressed as a function of Z-bus matrix and current injection vector and then allocated based on this function. In [7-8], under the DC assumptions, the transmission loss is expressed as a function of multiple variables, each of which corresponding to a separate transaction, and allocated to the transactions in proportion to sensitivities of the loss to the variables. In [8], different transactions can select different generations as losses providers. There are many other allocation methods, although most of them can allocate total losses to all transactions, none of them can be proved correct.

In this paper, the concept and arithmetic of "conductor renting" is proposed for the first time and is used to analyze transmission losses allocation problem. It properly solves the problem of interaction impact of different trnasctions on the transmission losses.

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II. MATHEMATICAL MODAL OF LOSS ALLOCATION OF A SINGLE CONDUCTOR

In this section, a single conductor is taken as an example to illustrate the basic concept and arithmetic of conductor renting. DC conductor, which refers to pure resistance conductor, is firstly analyzed, then AC conductor, which refers to conductor with both resistance and reactance, is analyzed.

A. Loss on a DC conductor

Suppose that there is a DC conductor and the current on it is composed of two components, say, 1A and 3A. The total current on the conductor is 4A. In steady state, since current densities are equal in the different section of the conductor, it can be regarded that the 1A current uses 1/4 section acreage of the conductor and the 3A current uses 3/4 section acreage of the conductor. The corresponding conductance is 1 unit and 3 units respectively. The losses on the two sections can be written as

$$P_{L1} = I_1^2 / G_1 = 1^2 / 1 = 1\,\mathrm{W}$$

$$P_{L2} = I_2^2 / G_2 = 3^2 / 3 = 3\,\mathrm{W}$$

We can get from the above formulas that the losses caused by the two current components are in proportion to magnitudes of the currents.

Generally, if the current, conductor and section acreage of a conductor are I, G and S respectively, the loss on the conductor can be expressed as $P_L = I^{\,2} / G$. Suppose that current I is composed of N current components, that is, I_1, $I_2 \cdots I_N$. Denoting K_i that I_i constitute proportion of the total current I, S_i section acreage used by I_i and G_i the corresponding conductance, we would get

$$K_i = \frac{I_i}{\sum_{j=1}^{n} I_j} = \frac{I_i}{I}$$

$$S_i = K_i S\,,\quad G_i = K_i G$$

$$P_{L,i} = I_i^2 / G_i = K_i^2 I^2 / K_i G = K_i P_L$$

$$\frac{P_{L,i}}{P_{L,j}} = \frac{S_i}{S_j} = \frac{G_i}{G_j} = \frac{I_i}{I_j} \tag{1}$$

where $P_{L,i}$ is the loss caused by current component I_i.

Equation (1) indicates that losses caused by current components in a single DC conductor are in proportion to their current magnitudes, section acreage they used and the corresponding conductances. They have linear relationship.

B. The loss on an AC conductor

Denoting g_l, b_l, I_l, V_l, $S_{l,g}$, and $S_{l,b}$ the conductance, susceptance, current, voltage, apparent conductor section acreage of an AC conductor. We could get:

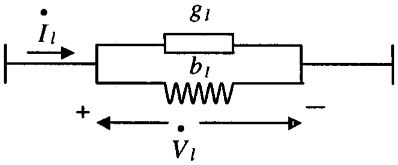

Fig. 1 AC conductor

$$\dot{V}_l = \dot{I}_l \left(g_l + j b_l \right) 。$$

$$P_{Ll} + jQ_{Ll} = \dot{V}_l \overset{*}{I}_l = VI\left(\cos\varphi_l + j \sin\varphi_l \right)$$

$$= \frac{I_l^2}{g_l + j b_l} = \frac{g I_l^2}{g_l^2 + b_l^2} - j\frac{b I_l^2}{g_l^2 + b_l^2} \tag{2}$$

where $\dot{V}_l$ is the voltage drop on the conductor, P_{Ll} + jQ_{Ll} is the power loss on the conductor and φ_l is the angle of the current phasor lagging the voltage phasor.

For convenience, we make a coordinate circumvolve: take the direction of voltage drop $\dot{V}_l$ as the active power axis (P axis) and take the direction leading $\dot{V}_l$ 90° as the reactive power axis (Q axis). Denoting symbols with subscript p variables of P axis and symbols with subscript q variables of Q axis, we could get from (2) that:

$$V_{l,p} = V_l\,,\quad V_{l,q} = 0$$

$$I_{l,p} = I_l \cos\varphi_l\,,\; I_{l,q} = -I_l \sin\varphi_l \; \frac{I_{l,p}}{I_{l,q}} = -\frac{\cos\varphi_l}{\sin\varphi_l} = -\frac{g_l}{b_l}$$

$$\frac{I_{l,p}}{g_l} = -\frac{I_{l,q}}{b_l}$$

$$\frac{I_{l,p}^2}{g_l^2} = \frac{I_{l,q}^2}{b_l^2} = \frac{I_{l,p}^2 + I_{l,q}^2}{g_l^2 + b_l^2} = \frac{I_l^2}{g_l^2 + b_l^2}$$

$$\begin{cases} P_{Ll} = \dfrac{g_l I_l^2}{g_l^2 + b_l^2} = \dfrac{g_l I_{l,p}^2}{g_l^2} = \dfrac{I_{l,p}^2}{g_l} \\ Q_{Ll} = \dfrac{b_l I_l^2}{g_l^2 + b_l^2} = \dfrac{b_l I_{l,q}^2}{b_l^2} = \dfrac{I_{l,q}^2}{b_l} \end{cases} \tag{3}$$

Formula (3) indicates that active power loss is in direct ratio to the current active component (component that has the same phase angle with voltage drop $\dot{V}_l$) and in inverse ratio to the conductance. There are similar rules for reactive power loss.

Supposing that the current on the conductor is composed of N components (caused by N transactions), we could get

$$I_{l,p}^{(t)} = I_l^{(t)} \cos\varphi_l^{(t)}$$

$$I_{l,q}^{(t)} = -I_l^{(t)} \sin\varphi_l^{(t)}$$

where $I_l^{(t)}$ is the magnitude of the t^{th} current component,

$\varphi_l^{(t)}$ is the angle of the t^{th} current component lagging the conductor voltage drop, $I_{l,p}^{(t)}$ and $I_{l,q}^{(t)}$ are the active and reactive component of the t^{th} current component respectively.

Based on the concept of conductor renting, we could get:

$$\begin{cases} k_{l,p}^{(t)} = \dfrac{I_{l,p}^{(t)}}{I_{l,p}} = \dfrac{I_l^{(t)} \cos \varphi_l^{(t)}}{I_{l,p} \cos \varphi_l} \\ k_{l,q}^{(t)} = \dfrac{I_{l,q}^{(t)}}{I_{l,q}} = \dfrac{I_l^{(t)} \sin \varphi_l^{(t)}}{I_{l,p} \sin \varphi_l} \end{cases} \tag{4}$$

$$\begin{cases} S_{l,g}^{(t)} = k_{l,p}^{(t)} S_{l,g}, & S_{l,b}^{(t)} = k_{l,q}^{(t)} S_{l,b} \\ g_l^{(t)} = k_{l,p}^{(t)} g_l, & b_l^{(t)} = k_{l,q}^{(t)} b_l \end{cases} \tag{5}$$

$$P_{Ll}^{(t)} = \frac{g_l^{(t)} \left(I_l^{(t)}\right)^2}{\left(g_l^{(t)}\right)^2 + \left(b_l^{(t)}\right)^2} = \frac{g_l^{(t)} \left(\left(I_{l,p}^{(t)}\right)^2 + \left(I_{l,q}^{(t)}\right)^2 \right)}{\left(g_l^{(t)}\right)^2 + \left(b_l^{(t)}\right)^2}$$
$$= \frac{g_l^{(t)} \left(I_{l,p}^2 + I_{l,q}^2\right)}{g_l^2 + b_l^2} = \frac{g_l^{(t)} I_{l,p}^2}{g_l^2} = \frac{k_{l,p}^{(t)} I_{l,p}^2}{g_l} = k_{l,p}^{(t)} P_l \tag{6}$$

$$\frac{P_{Ll}^{(i)}}{P_{Ll}^{(j)}} = \frac{k_{l,p}^{(i)}}{k_{l,p}^{(j)}} = \frac{I_{l,p}^{(i)}}{I_{l,p}^{(j)}} = \frac{S_{l,g}^{(i)}}{S_{l,g}^{(j)}} = \frac{g_l^{(i)}}{g_l^{(j)}} \tag{7}$$

$$Q_l^{(t)} = k_{l,q}^{(t)} Q_l \tag{8}$$

$$\frac{Q_{Ll}^{(i)}}{Q_{Ll}^{(j)}} = \frac{k_{l,q}^{(i)}}{k_{l,q}^{(j)}} = \frac{I_{l,q}^{(i)}}{I_{l,q}^{(j)}} = \frac{S_{l,b}^{(i)}}{S_{l,b}^{(j)}} = \frac{b_l^{(i)}}{b_l^{(j)}} \tag{9}$$

$k_{l,p}^{(t)}$: usage ratio of $I_{l,p}^{(t)}$ to the conductor conductance;

$k_{l,q}^{(t)}$: usage ratio of $I_{l,q}^{(t)}$ to the conductor susceptance;

$S_{l,p}^{(t)}, S_{l,q}^{(t)}$: apparent conductor conductance and susceptance section acreage used by current component t;

$g_l^{(t)}, b_l^{(t)}$: conductor conductance and susceptance used by current component t.

$P_{Ll}^{(t)}$, $Q_{Ll}^{(t)}$: active and reactive loss caused by current component t.

We could get from (6)-(9) that active losses caused by the transactions (equ. (7)) are in proportion to their P-axis current components, apparent conductor conductance section acreages and the corresponding conductance; reactive losses caused by the transactions (equ. (9)) are in proportion to their Q-axis current components, the apparent conductor sesceptance section acreages and the corresponding susceptance. They all have linear relationship.

III. TRANSMISSION LOSSES ALLOCATION BASED ON CONDUCTOR RENTING CONCEPT

From the former sections we can conclude that the active and reactive losses on a single conductor caused by the current components corresponding to multiple transactions are in proportion to the conductance and susceptance they used, which is the theory foundation of "conductor renting". The conductor-renting based losses allocation method regards that each transaction rents a portion of the conductor admittance, or a portion of the section acreage, and the total losses are allocated among the transactions in proportion to the corresponding admittance and the losses on the sections. In this method, the shared terms do not appear in the analysis and calculation, which makes the allocation simple. The losses can be allocated to transactions accurately and the transmission owner could be break-even. What's more, both active and reactive losses can be allocated.

In actual transmission network, there is always a great deal of branches. If contribution of each transaction to current on each branch is gotten, loss on each branch can be allocated to the transactions according to the concept of conductor renting. Summing the losses allocated to a transaction on all branches will get the total losses allocated to the transaction.

A. To determine the contribution of transactions to branch currents according to superposition principle

The bus voltage function of N-bus network can be written as

$$\boldsymbol{Z I} = \boldsymbol{V}$$
$$\boldsymbol{I} = (I_1, I_2, \cdots, I_n, \cdots, I_N)^{\mathrm{T}}$$
$$\boldsymbol{V} = (V_1, V_2 \cdots, V_n \cdots, V_N)^{\mathrm{T}}$$

where $\boldsymbol{I}$ is the complex bus current vector, $\boldsymbol{V}$ is the complex bus voltage vector and $\boldsymbol{Z}$ is the bus resistance matrix.

The node current injection of transaction k (k = 1, 2, $\cdots K$) can be expressed as

$$\boldsymbol{I}^{(k)} = \left[I_1^{(k)}, I_2^{(k)}, \cdots, I_N^{(k)}\right]^{\mathrm{T}}$$

where $$I_i^{(k)} = \frac{P_i^{(k)} + jQ_i^{(k)}}{V_i}, \quad \boldsymbol{I} = \sum_{k=1}^{K} \boldsymbol{I}^{(k)}$$

$P_i^{(k)}$, $Q_i^{(k)}$ are the active and reactive power injection of transaction k at bus i respectively.

According to superposition principle, we could get:

$$\boldsymbol{V}^{(k)} = \boldsymbol{Z} \boldsymbol{I}^{(k)}$$
$$\boldsymbol{V}_b^{(k)} = \boldsymbol{M}^T \boldsymbol{V}^{(k)}$$
$$\boldsymbol{I}_b^{(k)} = diag(\boldsymbol{Y}_b) \boldsymbol{V}_b^{(k)} = diag(\boldsymbol{Y}_b) \boldsymbol{M}^T \boldsymbol{V}^{(k)}$$
$$= diag(\boldsymbol{Y}_b) \boldsymbol{M}^T \boldsymbol{Z} \boldsymbol{I}^{(k)} \tag{10}$$

where $\boldsymbol{V}^{(k)}$ is the vector of the node voltage caused by transaction k; $\boldsymbol{V}_b^{(k)}$ and $\boldsymbol{I}_b^{(k)}$ are the vectors of voltage drops and currents on the branches caused by transaction k; $\boldsymbol{M}_{N \times B}$ is the bus-branch incidence matrix; B is the number of branches; $diag(\boldsymbol{Y}_b)$ is the diagonal matrix of branch acceptance.

Getting the currents on each branch caused by the transactions, losses of branches can be allocated to the transactions based on conductor renting concept and formula developed in the former section.

B. Discussion on counter flows

The fact that directions of flows on a branch caused by different transactions may be different results in the problem of "counter flow", where the term counter flow refers to the flow that has the different direction with the net flow. The counter flow problem exists in both active and reactive losses allocation. For simplicity, only that in active losses allocation is analyzed here.

If the active power flow on a branch caused by a transaction is counter flow, according to the formulas, the rented conductor section acreage, the used conductor acceptance and the allocated losses corresponding to the transaction will be negative. The fact that the conductor section acreage rented by a transaction is negative means that the existence of the transaction increases the acting acreage and then decreases the total losses. That is to say, the transactions causing counter flows decrease the branch losses. From the viewpoint of providing correct economic signals and promoting the economic operation of the power systems, it is reasonable that the losses allocated to these transactions are negative.

IV. EXAMPLE

In this section, the IEEE-30 network, which has 30 nodes and 41 branches, is used as an example to illustrate the allocation method proposed in this paper. Regarding the injection at each node as a market participant, table 1 lists the node injections and the losses allocation result. The columns in the table are node number, node voltage magtitude, node voltage angle, generation active power, generation reactive power, load active power, load reactive power, node active losses (active losses allocated to node injections) and node reactive losses(reactive losses allocated to node injections) respectively. The last line is the sum of the above lines. The sum of losses allocated to all nodes equal to total losses of the system, which validates the correctness of this method. Negative numbers in the last two columns indicate that the corresponding nodes result in counter flows on some branches.

TABLE 1
THE BUS DATA AND RESULT OF THE IEEE-30 NETWORK

node(i)	v(pu)	ang(°)	Pg(pu)	Qg(pu)	Pl(pu)	Ql(pu)	$P_{L,i}$(pu)	$Q_{L,i}$(pu)
1	1.0500	5.6948	0.7920	0.0703	0	0	0.7920	0.0703
2	1.0400	4.3638	0.8000	0.1940	0.2170	0.1270	0.5830	0.0670
3	1.0265	2.5018	0	0	0.0240	0.0120	-0.0240	-0.0120
4	1.0210	1.8891	0	0	0.0760	0.0160	-0.0760	-0.0160
5	1.0100	-0.0662	0.5000	0.1853	0.9420	0.1900	-0.4420	-0.0047
6	1.0166	1.2989	0	0	-0.0000	-0.0000	0.0000	0.0000
7	1.0055	0.2168	0	0	0.2280	0.1090	-0.2280	-0.1090
8	1.0100	1.1622	0.2000	0.2083	0.3000	0.3000	-0.1000	-0.0917
9	1.0111	0.0177	0	0	0.0000	-0.0000	-0.0000	0.0000
10	0.9969	-1.9347	0	0	0.0580	0.0200	-0.0580	-0.0200
11	1.0500	2.2633	0.2000	0.2002	0	0	0.2000	0.2002
12	1.0183	-1.4134	0	0	0.1120	0.0750	-0.1120	-0.0750
13	1.0500	0	0.1884	0.2402	0	0	0.1884	0.2402
14	1.0000	-2.1885	-0.0000	-0.0312	0.0620	0.0160	-0.0620	-0.0472
15	1.0000	-2.4294	-0.0000	-0.0644	0.0820	0.0250	-0.0820	-0.0894
16	1.0000	-1.8719	-0.0000	-0.0554	0.0350	0.0180	-0.0350	-0.0734
17	1.0000	-2.3169	-0.0000	0.1317	0.0900	0.0580	-0.0900	0.0737
18	1.0000	-3.3699	-0.0000	0.0252	0.0320	0.0090	-0.0320	0.0162
19	1.0000	-3.6308	-0.0000	0.0817	0.0950	0.0340	-0.0950	0.0477
20	1.0000	-3.3055	-0.0000	0.0300	0.0220	0.0070	-0.0220	0.0230
21	1.0000	-2.7225	-0.0000	0.2378	0.1750	0.1120	-0.1750	0.1258
22	1.0000	-2.6535	0.0000	0.0185	0	0	0.0000	0.0185
23	1.0000	-2.9011	-0.0000	0.0320	0.0320	0.0160	-0.0320	0.0160
24	1.0000	-2.9138	-0.0000	0.1195	0.0870	0.0670	-0.0870	0.0525
25	1.0000	-1.1856	0.0000	-0.0048	0	0	0.0000	-0.0048
26	1.0000	-2.2965	-0.0000	0.0469	0.0350	0.0230	-0.0350	0.0239
27	1.0000	0.4271	0.2000	0.0401	0	0	0.2000	0.0401
28	1.0000	1.3994	0.0000	-0.4794	0	0	0.0000	-0.4794
29	1.0000	-1.4540	-0.0000	0.0235	0.0240	0.0090	-0.0240	0.0145
30	1.0000	-2.6841	-0.0000	0.0782	0.1060	0.0190	-0.1060	0.0592
sum	——	——	$2.8804^{(a)}$	$1.3283^{(b)}$	$2.8340^{(c)}$	$1.2620^{(d)}$	$0.0464^{(e)}$	$0.0663^{(f)}$

note : $(e) = (a) - (c) = \sum_i P_{L,i}$ $(f) = (b) - (d) = \sum_i Q_{L,i}$

V. CONCLUSION

Transmission losses allocation is an important problem in the context of competitive electricity market. But due to the nonlinearity of loss function, it is difficult to reasonably allocate the losses among market participants. The concept of "conductor renting", which is proposed for the first time in this paper, properly solves the losses allocation problem. The single conductor is firstly taken as an example to prove the conclusions that active losses caused by the current components are in proportion to the apparent conductor conductance section acreage they used and the corresponding conductance, the reactive loses caused by the current components are in proportion to the apparent conductor susceptance section acreage they used and the corresponding susceptance. The losses allocation method based on this concept solves the problem of interaction of different transactions on transmission losses. The digital example proves the validity and correctness of the method. This losses allocation method, which is easy to understand and apply and has high transparency, is expected to be applied in large-scale power systems.

APPENDIX: THE BRANCH DATA OF IEEE-30 NETWORK

TABLE 2
THE BRANCH DATA OF IEEE-30 NETWORK

From bus	To bus	r	x	b	ratio
1	2	0.0192	0.0575	0.0264	0
1	3	0.0452	0.1852	0.0204	0
2	4	0.0570	0.1737	0.0184	0
3	4	0.0132	0.0379	0.0042	0
2	5	0.0472	0.1983	0.0209	0
2	6	0.0581	0.1763	0.0187	0
4	6	0.0119	0.0414	0.0045	0
5	7	0.0460	0.1160	0.0102	0
6	7	0.0267	0.0820	0.0085	0
6	8	0.0120	0.0420	0.0045	0
6	9	0	0.2080	0	1.0780
6	10	0	0.5560	0	1.0690
9	11	0	0.2080	0	0
9	10	0	0.1100	0	1.0320
4	12	0	0.2560	0	0
12	13	0	0.1400	0	0
12	14	0.1231	0.2559	0	0
12	15	0.0662	0.1304	0	0
12	16	0.0945	0.1987	0	0
14	15	0.2210	0.1997	0	0
16	17	0.0824	0.1932	0	0
15	18	0.1070	0.2185	0	0
18	19	0.0639	0.1292	0	0
19	20	0.0340	0.0680	0	0
10	20	0.0936	0.2090	0	0
10	17	0.0324	0.0845	0	0
10	21	0.0348	0.0749	0	0
10	22	0.0727	0.1499	0	0
21	22	0.0116	0.0236	0	0
15	23	0.1000	0.2020	0	0
22	24	0.1150	0.1790	0	0
23	24	0.1320	0.2700	0	0
24	25	0.1885	0.3292	0	0
25	26	0.2544	0.3800	0	0
25	27	0.1093	0.2087	0	0
28	27	0	0.3960	0	1.0680
27	29	0.2198	0.4153	0	0
27	30	0.3202	0.6027	0	0
29	30	0.2399	0.4533	0	0
8	28	0.0636	0.2000	0.0214	0
6	28	0.0169	0.0599	0.0065	0

VI. REFERENCES

[1] A.G. Exposito, J.M.R. Santos, T.G. Garcia *et al*, "Fair allocation of transmission power losses," *IEEE Transactions on Power Systems*, vol. 15, no. 1, pp.184-188, Feb. 2001.

[2] Z. Yu, "The proposed CLP method for allocating real power losses of multiple flows," *IEEE Power Engineering Review*, vol. 21, no. 11, pp. 45-47, Nov. 2001.

[3] M.E. Baran, V. Banunarayanan and K.E. Garren, "A transaction assessment method for allocation of transmission services," *IEEE Transactions on Power Systems*, vol. 14, no. 3, pp.920-928, Aug. 1999.

[4] Z.Q. Wu, "Contribution factor theory on variables to the nonlinear function value and its applications," *Automation of Electric Power Systems*, vol. 24, no. 22, pp 32-34, Nov. 2000.

[5] A. Fradi, S.Brignone and B.F.Wollenber, "Calculation of Energy Transaction Allocation Factors," *IEEE Transactions on Power Systems*, vol. 16, no. 2, pp.266-272, May 2001.

[6] A.G. Conejo, F.D. Galiana and I. Kockar, "Z-Bus loss allocation," *IEEE Transactions on Power Systems*, vol. 16, no. 1, pp. 105-110, Feb. 2001.

[7] G. Gross and S. Tao, "A physical-flow-based approach to allocating transmission losses in a transaction framework, " *IEEE Transactions on Power Systems*, vol. 15, no. 2, pp. 631-637, May 2000.

[8] S. Tao and G. Gross, "Transmission loss compensation in multiple transaction networks, " *IEEE Transactions on Power Systems*, vol. 15, no. 3, pp. 909-915, Aug. 2000.

VII. BIOGRAPHIES

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