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# Usage Based Allocation for Transmission Costs under Open Access

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***Abstract*—This paper analyses some issues related to the transmission cost allocation for grids with open access. Allocation methods based on electricity tracking are presented and compared with methods based on sensitivities as well as with the postage stamp rate. The main purpose is to appraise in a critical manner the practicality of these methods and their capacity to send efficient economical signals. Full and usage capacity pricing are presented in contrast. Three options for dealing with counter flows are considered and their influence on cost recovery under used capacity pricing is outlined. The pricing strategies and methodologies are depicted for a 9-bus test-system including pool, bilateral and wheeling transaction.**

***Index Terms*—Electricity tracking, Transmission cost allocation, congestion, embedded costs, used transmission capacity, counter flow, cost recovery.**

## I. Nomenclature

TC: transmission capacity
CF: Counter Flow
LIM: Load Images Method for electricity tracking
TSO: Transmission System Operator
GSDFs: Generation Shift Distribution Factors
GGDFs: Generalized Generation Distribution Factors
GLDFs: Generalized Load Distribution Factors
LUFs: Line Utilization Factors

## II. Introduction

Under open access, transmission is still recognized as natural monopoly. Every TSO manages autonomously the corresponding service over a certain area. Besides, mandatory and/or voluntary providers are called to sustain with ancillary services, [1], the undertaking of commercial transaction by maintaining the system reliability [2].

The cost of the basic transmission service corresponds mainly to the transmission capacity cost, which is a fixed cost. Different solutions were adopted for allocating this embedded cost on grid users:

- Based on *postage stamp rate*: the users are charged, for the magnitude of their transacted power, at the average existing system cost. The postage stamp charge has the advantage of simplicity but it is economically inefficient due to the lack of any geographically-differentiated signal.
- By *contract path methods*, which assume that the transacted power flow along an artificial contractual path. The users are charged for the transacted power according to the individual average rates by all the transmission operators next to the path, [3]. In reality the power flow in meshed networks accordingly to physical laws, and not along contractual paths.
- *MW-Mile* methodology: is one of the earliest solutions proposed for charging wheeling transactions. The charge for each transaction is determined as a function of the magnitude, the path and the distance traveled by the transacted power, [4].
- *Usage based methods*: allocate the transmission costs based on the "extend of use" assessed by means of:
  - Distribution factors: GSDFs, [5], GGDFs, GLDFs, [6] for DC models and LUFs, [7], for AC models;
  - Multiple power flow methods: by performing AC power flows with no/each/all transaction/s, [8], or by power flow decomposition, [9], [10].
  - Tracing methods: based on proportionality hypothesis, [11] – [13], or based on the network reduction by Kron formulation, [14], [15].

Cost allocation for ancillary services is even more complicated. Unlike to the transmissiont, the ancillary service involves various cost components. The matter of the pricing the ancillary services outshines the agenda of this paper.

In Romania the transmission tariff for the path provision is approximately 4€/MWh (postage stamp). Moreover, a zonal charge is intended to recover both short term (losses) and long term (congestion) marginal costs. The dispatching area is split in six G-zones with injection charge varying by -37%/+17% around an average value of 2€/MWh and eight L-zones with sinking charges between 1,65€/MWh and 2,92€/MWh. The payment for the ancillary services is around 3,9€/MWh.

This paper investigates the influence of the magnitude and geographical coverage of the contracts over the transmission charges under usage-based allocation. Two kinds of pricing strategies are involved: full (used + unused) capacity pricing and used capacity pricing. In case of used capacity pricing, the impact of various influence factors on the transmission cost recovery is evaluated. The controversial issue of counter-flows charging is apprised too. Numerical example is provided to compare the results.

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## III. TRACING BASED TRANSMISSION USAGE EVALUATION

Two tracing methods, [13] and [16], were proposed based on proportionality hypothesis. By introducing a supplementary principle, some non-physical equations are added to the power system model. The resulting model just shares the flows: every grid user carry power solely in the direction of the net flows. Because of this feature, the employment of proportionality tracing based methods to the usage assessment could mislead.

Tracing methods based on Kron type transfigurations can be used instead. Either mathematically possible, [14] – [15], reactive power tracking is irrelevant and confusing. The MVARs at load buses are not delivered by generators but exchanged with adjacent elements (under loaded lines, compensating devices, etc.). The reactive powers injected by the generators are absorbed by the nearest inductive element. For reactive power issues, all the inductive components (loads, TCRs, under loaded lines, etc.) are to be treated identically. Similarly, any capacitive element can be seen as a "provider" of reactive power. Thus, reactive power is neither produced nor consumed but exchanged among converse elements (inductive and capacitive) along short paths.

In this respect a tracing methodology was proposed, based on the DC power system model, [17]:

$$[P_{bus}] = -[B_{bus}]\cdot[\theta_{bus}] \quad (1)$$

If "G" denotes the generation buses and "L" is the remaining set, the DC model is to be partitioned as:

$$\begin{bmatrix}[P_G]\\ [P_L]\end{bmatrix} = -\begin{bmatrix}[B_{GG}] & [B_{GL}]\\ [B_{LG}] & [B_{LL}]\end{bmatrix}\cdot\begin{bmatrix}[\theta_G]\\ [\theta_L]\end{bmatrix} \quad (2)$$

After reducing de model to the "G" set, we get:

$$[P_G] = [P_G^{(0)}] + [\mathrm{A}^{(0)}]\cdot[P_L] \quad (3)$$

with $[P_G^{(0)}] = -[\mathrm{B}^{(0)}]\cdot[\theta_G]$ (4)

$$[\mathrm{B}^{(0)}] = [B_{GG}] - [B_{GC}]\cdot[B_{CC}]^{-1}\cdot[B_{CG}] \quad (5)$$

$[\theta_G]$ phase angles of bus voltages (column matrix)

Equation (4) outlines the loop flows within the network reduced to the "G" nodes. The more the network is meshed and stronger are disparities between the productions, the more the loop flows increases. This is why significant loop flows are to be observed in strongly meshed networks supplied by highly discrepant productions. Herein, "weighty" generators stream powers not only in a radial manner but also along paths including weaker generators buses.

It such a case, the generations from (3) are not linear combinations of consumptions. The adding up elements of $[P_G^{(0)}]$ outline the circulating flows. In order to assess the responsibilities of the producers for loop flows, the positive elements of $[P_G^{(0)}]$ are to be separated into "G" - set, while the negative ones will form the "L" - set:

$$[P_G^{(0)}] = \begin{bmatrix}[P_G^{(1)}]\\ [P_L^{(1)}]\end{bmatrix} \text{ and } [\theta_G] = \begin{bmatrix}[\theta_G^{(1)}]\\ [\theta_L^{(1)}]\end{bmatrix} \quad (6)$$

After replacing in (1) $[B_{\mathrm{bus}}]$ with $[B^{(0)}]$, $[P_{bus}]$ with $[P_G^{(0)}]$ and $[\theta_{bus}]$ with $[\theta_G]$, the procedure consisting of steps (1) – (6) is to be repeated iteratively until all elements of $[P_G^{(0)}]$, from (6), become positive. The productions transmitted by loop flows are to be outlined by forward postponing among the previous iterations. Finally we obtain the "destination" of each production as:

$$[P_G] = [\mathrm{A}]\cdot[P_L] \quad (7)$$

The "contribution" of the productions to flows is to be computed by substituting $[P_G]$ from (7) into the conventional relation between line flows and nodal powers:

$$[P_{branch}] = -[\mathrm{H}]\cdot[\mathrm{B_{bus}}]^{-1}\cdot\begin{bmatrix}[P_G]\\ [P_L]\end{bmatrix} \quad (8)$$

Thus the flows are expressed as linear combinations of productions:

$$[P_{branch}] = [\mathrm{D}]\cdot[P_G] \quad (9)$$

By replacing (7) into (9), the "responsibilities" of the consumers to flows are expressed as:

$$[P_{branch}] = [\mathrm{D}]\cdot[\mathrm{A}]\cdot[P_L] \quad (10)$$

The algorithm is simple and stable, transparent, and uses only common inputs, always available, from measurements or plans. It deals fine with counter flows, with circulating flows and with cross-border trades. All energy market structures are easily manageable herein because any kind of contract (bilateral, multilateral, wheeling trades, pools, etc.) is to be represented by the column matrix of its nodal powers. Moreover, calculations for interconnected networks can be done in a decentralized manner without involving any centralized body.

## IV. PRICING STRATEGIES

The pricing strategy for the basic transmission service is still a controversial issue. Because of the lack of consensus, practically every European country adopted a different solution for allocating i transmission cost. Such variety and heterogeneity of the transmission pricing regimes inhibits the inter-area transactions and slow down the creation of regional or global energy markets. In fact, a trader who attempts to arrange a cross-border transaction must negotiate the transfer fees with different utilities on the way. To make things even more difficult, it is not easy to determine which utilities, and to what extent, are affected by a particular cross-border trade.

For wheeling through the Romanian power system, a trader has to pay not only the transmission charge but also an additional transfer fee. This supplementary fee is about 10%

of the charge for an inner transmission along the same path (the postage-stamp transmission rate plus the sum between the average power injection fee and the average power withdrawal fee).

Another critical problem related to the transmission charging strategy is the need for pricing continuity in case of congestion. If the charging mechanism changes severely under congestion, some network users could try to force artificially the network limits in order to take profit. Such gaming could be very dangerous.

Two major *options* are available *for transmission pricing*:

- postage stamp rate;
- usage based charging.

The postage stamp rate is simple and leads to completely predictable payments. On the other hand, such tariff does not stimulate the users to search for favorable grid locations. Quite inconvenient long term effects could occur, as the arising of chaotic congestions, asking for critical network reinforcement.

Conversely, usage based transmission charging is able to send correct economic signals to the network users. Thereby convenient network loading and positive grid expansions and reinforcement are to be expected. The main disadvantages of the usage based transmission charging are: it is more complex than the postage stamp and it produces less predictable payments.

The range of available usage based solutions, either wide-ranging or custom made, is rather large. The MW-mile methodology is simple but also hard to be included in this category, because of the subjectivity in path choosing. More appropriate seem to be the transmission charging methods based on usage evaluation. These either make use of sensitivity indexes or electricity tracing methods. The tracing algorithm from section III and generalized shift factors are employed in this paper.

Two *options* are available *for transmission charging based on grid usage*: total capacity or used capacity pricing.

### A. Pricing the total capacity

The costs of the transmission facilities are charged based on their total capacity. This pricing rule ensures the full recovery of all the embedded costs because any transmission user has to pay both for the actual capacity use as well as for the unused transmission capacity. Unfortunately, a TSOs that fully recovers the transmission cost could not be motivated to use more efficiently the transmission grid. On the other hand, adequate transmission margin is required to maintain system reliability.

If by any usage evaluation method (tracing, sensibilities, etc.) a part, $P_{mn,k}$, of the flow, $P_{mn}$, on the facility "*mn*" is allocated to the network user "*k*", than it has to pay:

$$C_{U_k} = \sum_{mn} C_{mn} \frac{P_{mn,k}}{P_{mn}} \tag{11}$$

where $C_{mn}$ is the cost for the facility "*mn*".

When charging on a contract basis, the cost allocated to a bi/multi-lateral transaction involving "{T}" users is:

$$C_{\{T\}} = \sum_{U_k \in \{T\}} C_{U_k} \tag{12}$$

### B. Used capacity pricing

Transmission users pay only for the actual capacity use but not for the unscheduled capacity. Since the total flows are usually smaller than the facility capacities, the recovery of the fixed transmission costs is not guaranteed.

On the other hand the total ignorance of the reliability value of transmission margin under system contingency conditions is a main drawback. This is why the unused capacity is usually charged for reliability purposes.

In this case, the payment of the user "*k* " becomes:

$$C_{U_k} = \sum_{mn} C_{mn} \frac{P_{mn,k}}{P_{mn}^{(\max)}} \tag{13}$$

while any transaction charge is to be computed with (12).

## V. Pricing of Counter Flows

The counter flows are associated with network users carrying power in opposite direction to the main flows. One can consider the counter flow very helpful because it reduces the loading level of the facilities. Thus the losses could decrease and congestions could be avoided.

In fact, one user can generate counter flows only on few transmission facilities. This is why the beneficial impact on the network losses has to be proven and charged accordingly. Moreover, is to be outlined that counter flows are exhibited only by superposing the transactions. Otherwise any individual transaction produces no counter flows but flows throughout the grid.

If the local benefit for reducing or avoiding congestions is to be acknowledged, the counter flows are remunerated by charging the users as in (11). Conversely, those who consider that any users have to pay for carrying power, irrespective to the flow direction, argue for computing the charges with:

$$C_{U_k} = \sum_{mn} C_{mn} \frac{\left|P_{mn,k}\right|}{P_{mn}} \tag{14}$$

Another option is equally possible: to recognize some benefits related to counter flows but to avoid any related remuneration. In this case the users pay nothing for the counter flows. Thus they have to pay only for the positive flows:

$$C_{U_k} = \sum_{\substack{mn \\ P_{mn,k} > 0}} C_{mn} \frac{P_{mn,k}}{P_{mn}} \tag{15}$$

## VI. Numerical Example

The pricing strategies and methodologies from above were applied to the nine-bus test system from Fig. 1.

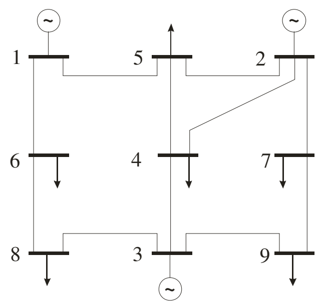


Fig. 1. 9 buses, 3 generators, 6 loads – test system

Details about related line parameters and costs are presented in Appendix – Table V..

The energy market structure for this power system is shown in Table 1. In this case, the pool covers 2/3 of the market. The remaining part corresponds to bilateral contracts implying producers G1 and G2. Two of these four contracts (40MW from bus# 1 to bus# 8 and the trade of 80MW involving buses 1 and 9) are wheeling transactions.

TABLE I
Energy Market Structure [MW]

| Bus no. | Bus Gen | Bus Load | Pool | Bilateral contracts | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1-5 | 1-8 | 1-9 | 2-4 |
| 1 | | 170 | 30 | 20 | 40 | 80 | |
| 2 | | 310 | 230 | | | | 80 |
| 3 | | 180 | 180 | | | | |
| 4 | -200 | | -120 | | | | -80 |
| 5 | -140 | | -120 | -20 | | | |
| 6 | -60 | | -60 | | | | |
| 7 | -80 | | -80 | | | | |
| 8 | -80 | | -40 | | -40 | | |
| 9 | -100 | | -20 | | | -80 | |

The contributions of producers and consumers to flows for this operating regime are computed by tracking powers with (9) and (10) - section III. The results (Fig. 7 and Fig. 8 in Appendix) outline dispersed but moderate counter flows, as is shown in Table II:

TABLE II
Responsibilities to Counter Flows]

| Line | | Network user | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| From | To | G1 | G2 | G3 | L4 | L5 | L6 | L7 | L8 | L9 |
| 1 | 5 | | yes | | | | | | | |
| 1 | 6 | | | | | | | | | |
| 2 | 4 | | | | | | | | | |
| 2 | 5 | yes | | | | | | | | |
| 2 | 7 | | | | | | | | | |
| 3 | 4 | | yes | | | | | yes | yes | yes |
| 3 | 8 | yes | | | yes | | | yes | | yes |
| 3 | 9 | | | | yes | | | | yes | |
| 5 | 4 | | | yes | | yes | | | | |
| 6 | 8 | | | yes | | | yes | | | |
| 7 | 9 | | | yes | | | | yes | | |

By dealing with counter flows as in section V and accordingly to the pricing strategies from section IV, the following options are available for charging transmission based on tracing results:

a. Full transmission capacity pricing:
   - a.1. by using the counter flows magnitude – (14)
   - a.2. by ignoring the counter flows – (15)
   - a.3. by remunerating the counter flows – (13)

b. Used transmission capacity pricing:
   - b.1. by using the counter flows magnitude – (14)
   - b.2. by ignoring the counter flows – (15)
   - b.3. by remunerating the counter flows – (13)

By the other hand, it is possible to allocate the transmission costs on:

- individual network users:
  - producers;
  - consumers;
- transactions.

If applied to producers, transmission charging for various pricing strategies leads to the results presented in Fig. 2. It is to be outlined that the payments of the greatest producer, G1, are very similar for postage stamp rating and full transmission capacity pricing. Such result is justified by the significant loop flows associated with this generation.

Moreover, smaller producers are charged less if producing acknowledged counter flows (see G3). These remarks may not be commonly valid for other cases. Further analyzes are required before concluding on the extent of counter flows influence on payments.

On the other hand, under used capacity pricing, the payments of producers are leveled down. In this case, the average value of the transmission cost recovery nears the network average loading level. The uncovered share of the transmission cost is to be priced in the framework of security and reliability.

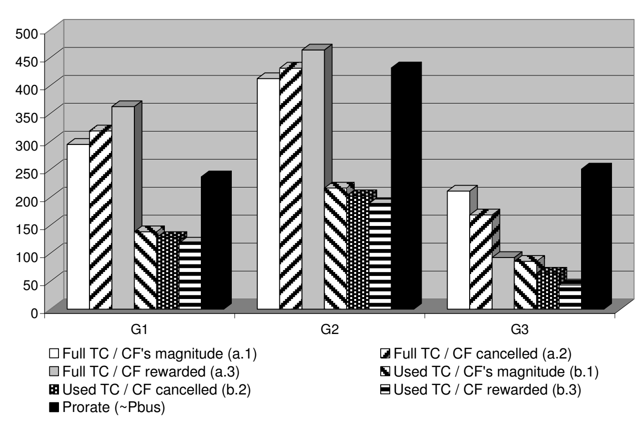


Fig. 2. Costs allocated on GENs [k€/h] by tracing & prorate

Similarly, Fig. 3 depicts the results for tracing based allocation on consumers. Under total capacity pricing, small consumers, as L6, L6, L7, can take more profit from unpaid (case a.2) or remunerated (case a.3) counter flows than the small producers. As for the producers, this advantage diminishes when charging only the used capacity.

Some of the previous remarks are easy to presume even without any computation. However, intuitive judgments could be very risky. This is the case for load L5, placed between two sources: G1 and G2. Despite such favorable network location, if it's counter flow on line $L_{5-4}$ is not remunerated, as in (14) or (15), the consumer has to pay under full capacity pricing almost as with the postage stamp rate.

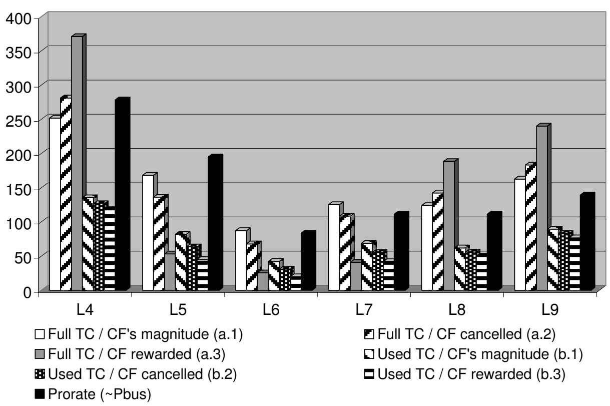


Fig. 3. Costs allocated on loads [k€/h] by tracing & prorate

Usage based pricing with unpaid counter flows recovers more of the transmission cost if applied to consumers, as can be seen in Table III.

TABLE III
TRANSMISSION COST RECOVERY FOR USAGE PRICING BY TRACING APPLIED TO INDIVIDUAL NETWORK USERS

| Case | Transmission cost recovery | |
|---|---|---|
| | On GENs | On LOADs |
| Used TC / CF's magnitude (b.1) | 0,48 | 0,52 |
| Used TC / CF cancelled (b.2) | 0,43 | 0,45 |
| Used TC / CF rewarded (b.3) | 0,38 | 0,38 |

Such pricing strategies can be applied not only to individual network users (producers or consumers) but to transactions too – (12). Any bilateral or multilateral contract can be charged either based on injections (Fig. 4) or based on consumptions (Fig. 5).

As expected, the results are very alike. For very large multilateral transactions (pool case) the related payments are quite identical. Only for minor transactions the choice can be critical. This is the case of the 20MW contract, representing 3% of the energy market and involving buses# 1 and #5. Counter flow remuneration can affect positively mainly smaller transactions.

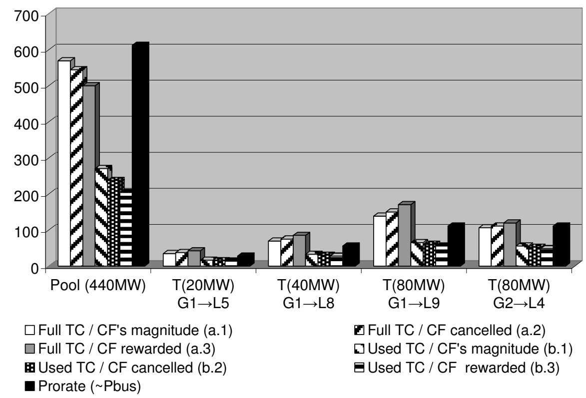


Fig. 4. Generation based contract charging [k€/h] by tracing & prorate

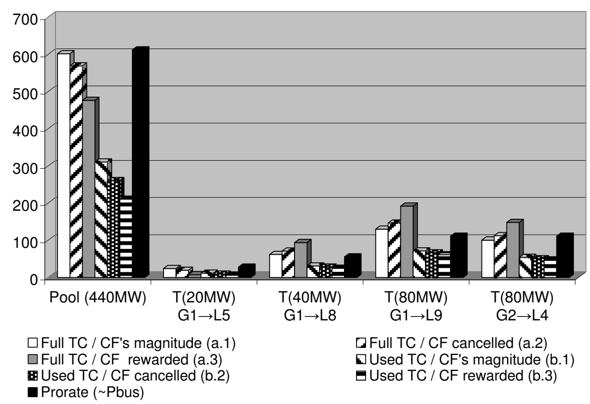


Fig. 5. Load based contract charging [k€/h] by tracing & prorate

Usage based pricing recovers the same share of the transmission cost whatever is applied to transactions or to individual consumers, as can be observed by comparing Table III and Table IV.

TABLE IV
TRANSMISSION COST RECOVERY FOR USAGE PRICING BY TRACING APPLIED TO TRANSACTIONS

| Case | Transmission cost recovery | |
|---|---|---|
| | On GENs | On LOADs |
| Used TC / CF's magnitude (b.1) | 0,48 | 0,52 |
| Used TC / CF cancelled (b.2) | 0,43 | 0,45 |
| Used TC / CF rewarded (b.3) | 0,38 | 0,38 |

The transmission can also be priced on sensitivities basis. The results obtained by employing shift factors are presented in Fig. 6. When charging just the used transmission capacity, the payments are quite similar to those issued by tracing. If pricing the full capacity, the payments migrate from the greatest portfolios towards the littlest. The influence of counter flows on this allocation is very alike to the tracing based one.

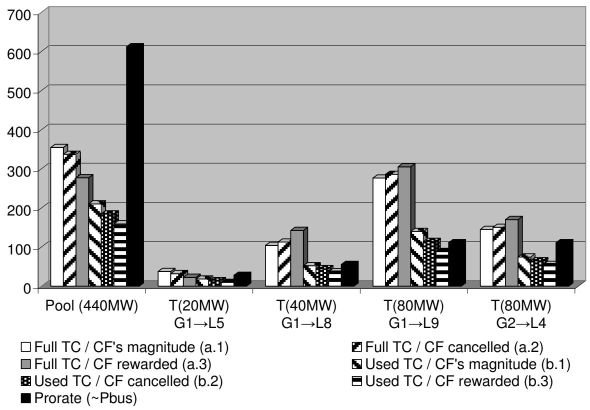


Fig. 6. Costs allocated on transactions [k€] based on general shift factors & prorate

In this case, the used capacity pricing with unpaid counter flows recovers more of the transmission cost than the tracing based methods.

TABLE V
TRANSMISSION COST RECOVERY FOR USAGE PRICING BASED ON SHIFT FACTORS

| Case | Transmission cost recovery |
|---|---|
| Used TC / CF's magnitude (b.1) | 0,54 |
| Used TC / CF cancelled (b.2) | 0,46 |
| Used TC / CF rewarded (b.3) | 0,38 |

## VII. CONCLUSIONS

The allocation of the transmission cost is a major issue under open access. Various solutions are actually used.

This paper analyzes available pricing strategies and methodologies. Transmission cost can be allocated based on usage or on postage stamp rate. For the first option, by pricing the full transmission capacity, transmission cost is recovered but the TSO is not motivated to increase the transmission efficiency. Conversely, if charging just for the used capacity, than the reliability margin has to be priced apart. Counter flow treatment can affect significantly the payments for the basic transmission service.

In a numerical example the usage was evaluated by tracing and based on shift factors. The outputs were used for computing transmission charges both for full capacity and for used capacity pricing. In both cases, the transmission costs were allocated on individual network users (producers/consumers) or on transactions. Three options were employed for dealing with counter flow: to ignore the flow direction, to exonerate or to remunerate the counter flows.

After comparing the results, the main remarks are to be summarized as follows:

- all usage based pricings distribute payments similarly;
- the charging strategy and methodology affect mainly minor network users;
- the counter flow treatment can be critical for small bilateral transactions;
- if the counter flows are not remunerated, better cost recovery is obtained when allocating the used transmission capacity on more dispersed users (loads or consumptions from portfolios;

It is to outline that the usage based pricing allows avoiding severe changes in transmission charging under congestion.

These conclusions are based on a study concerning a simple test system and a common energy market. More general conclusions require for a careful analysis involving a number of larger networks of different characteristics and a variety of market structures and volumes.

## VIII. APPENDIX

TABLE V
RELEVANT PARAMETERS OF THE LINES FROM THE TEST-SYSTEM

| From Bus | To Bus | X [pu] | B [pu] | Embedded hourly cost [€/h] |
|---|---|---|---|---|
| 1 | 5 | 0,06 | 0,03 | 96000 |
| 1 | 6 | 0,056 | 0,02 | 89600 |
| 2 | 4 | 0,065 | 0,025 | 104000 |
| 2 | 5 | 0,045 | 0,038 | 72000 |
| 2 | 7 | 0,076 | 0,01 | 121600 |
| 3 | 4 | 0,03 | 0,028 | 48000 |
| 3 | 8 | 0,036 | 0,03 | 57600 |
| 3 | 9 | 0,054 | 0,045 | 86400 |
| 4 | 5 | 0,066 | 0,03 | 105600 |
| 6 | 8 | 0,05 | 0,02 | 80000 |
| 7 | 9 | 0,036 | 0,06 | 57600 |

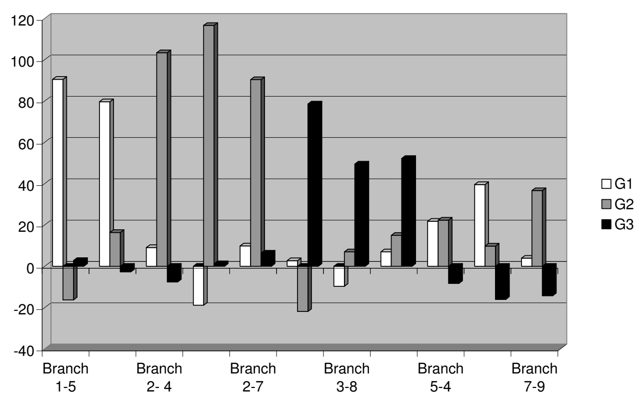


Fig. 7. Generation's contributions to flows [MW]

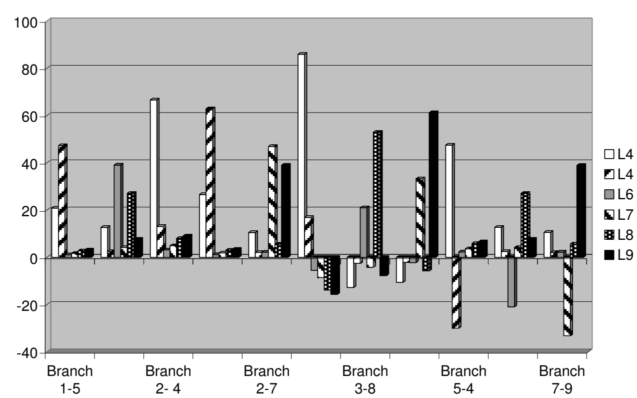


Fig. 8. Load's contributions to flows [MW]

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## X. Biographies

**Leonardo-Geo MĂNESCU** (M' 2007) graduated Electrical Engineering at the University of Craiova (Romania) in 1989. He got the Dr. Sc. in Power Systems at the same university and the Ph.D in "Génie Electrique" degree from the "Institute Nationale Polytechnique de Grenoble" (France) in 1998.

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Actually he is professor at the University of Craiova (Romania) and his main interest fields are: power system modeling, markets in electricity field, congestions and ancillary services management and virtual power plants.

**Denisa RUŞINARU** (M' 2008) was born in 1968 in Craiova, Romania. In 2002 she received the Ph.D. in Power Engineering from University "Politehnica" of Bucharest.

She is currently a Senior Lecturer at the Energy Department of the Faculty of Electrical Engineering, University of Craiova. Her research interests include automatization of distribution networks, power quality and electromagnetic compatibility.

**Paul DĂDULESCU** was borned in 1951 in Craiova (Romania). He graduated Electrical Engineering at the University of Craiova (Romania).

Since 2004 he is the Technical Director of the regional section of Craiova of the Romanian TSO "Transelectrica S.A." where he is in charged with the transmission network O&M.

**Valeria ANGHELINA** was borned in 1955 in Craiova (Romania). Owner of a Diploma in Electrical Engineering from the University of Craiova (Romania), she worked in Power System since 1980.

In 1998 she became Head of the Technical Department of the regional section of Craiova of the Romanian TSO "Transelectrica S.A.", where she manages transmission network planning and maintenance.