Evaluation of Transmission Cost Allocation Methods using a Specially Designed Software Application

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Abstract: – The current paper presents an evaluation of transmission cost allocation methods. The case study used is represented by the power system based on the South-West side of the Romanian National Power System. The evaluation is carried-out using a software tool specially designed for this purpose. It was elaborated at “Politehnica” University of Timisoara, within the Power Engineering Department. The algorithm is implemented in Matlab software. Two operating regimes are evaluated. The base case for the power system mentioned previously and a congested regime, for the same power system, is analyzed from the transmission cost allocation mechanism point of view. There are evaluated three transmission cost allocation methods: zonal allocation method, postage stamp method and locational marginal prince method. The algorithm of the software and the obtained results are presented and analyzed.

Key-Words: – power system, cost allocation method, tool, software, generating unit, load, power flow, marginal cost.

1 Introduction. Deregulation process context

Historically, the electricity industry was a monopoly industry with a vertical structure.

In a vertically integrated environment, enterprises were responsible for the generation, transmission and distribution of electrical power in a given geographical area. Such companies could be state owned as well as private.

The last two decades, and especially during the 1990s, the electricity supply service has been undergoing a drastic reform all over the world. The old monopolist power markets are replaced with deregulated electricity markets open to the competition. Different forces have driven the power market towards the deregulation. Not all of them are behind the reform in all these countries. Furthermore, in each different country the same reason has to be studied taking into consideration the local circumstances. However, it is possible to categorize all these various causes in technical, economical and political [1].

The technological development of high voltage networks during the 1960s and 1970s made possible transmission of bulk power over long distances. This is a necessary condition in order the power market to be opened to producers that are located far from the main customers [1]. Despite this achievement the electricity industry remained a monopoly for the next twenty years.

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So, there is another technical factor which has given a stronger impulse towards the deregulation. This factor is the improved power generation technologies. The decisions of generation expansion could be taken only by a monopolist utility so as to make the necessary investments. Besides the reduction in the investment cost, the construction time of such power plants is essentially shorter than it was before. Hence, it is now possible the generation expansion decisions to be taken by smaller enterprises [3].

Another mixed technical-ecological cause is the inclination of modern society for an increase in power produced by renewable sources. The emerging of independent producers who operate, mostly, wind power units gives a further competitive character to the power industry despite the fact that such producers survive still due to the subsidies.

The key economical idea, which led to the deregulation, was that a well operated competitive market can guarantee both cost minimization and average energy prices hold at a minimum level [2].

The economists believe that an open market provides stronger incentives to the supplier in order to apply cost-minimizing procedures than a regulated market. The second positive characteristic of a competitive market is its ability to drive the prices towards the marginal costs. In order this advantage to appear the market has to be well designed.

The second part of the paper describes the deregulation process in Europe. The 3rd section is presenting the objectives of the current work. The 4th part deals with the evaluation of the transmission cost allocation methods. The 5th section illustrates the power system used as a study case. The application developed is presented within the 6th section. The 7th section provides the numerical results and their discussion. Section 8 contains the concluding remarks.

2 The deregulation process in Europe

In European continent, England started up the procedure of electricity industry restructuring process.

At the same time, the second country next to England, which restructured its electricity market towards deregu-lation, is Norway. The beginning of deregulation was in 1990 by adopting the Energy Act. In 1995, the Swedish market was also reformed and together with the Norwegian electricity market established the Nord Pool which launched in early 1996 [6].

Finland became a member of Nord Pool in 1998 followed by West Denmark in 1999 and finally the East Denmark in 2000. The performance of Nord Pool brings it among the most successful paradigms of electricity sector deregulation.

In Russia public discussions about the power sector reform have started in the last years. The coordination of Russian giant network in a deregulated environment by itself represents a real challenge.

In the European Union, with the exception of United Kingdom, the deregulation of electricity industry has been launched in 1996 by the adoption of Electricity Directive 96 / 92 / EC [7]. This was the result of many years' negotiations between the member countries.

The directive sets some thresholds for the progressive opening of the power sector. The final deadline is July 2007 when the electricity markets of all current member countries have to be fully deregulated. However, the directive does not define a common guideline for the electricity industry reform. Therefore, the restructure process has followed many different paths between the member countries.

In Germany, the adoption of Electrical Economy Right New Regulation Law signalled the power sector deregulation, in 1998. The German market was fully opened, in 100 %, i.e. the end-consumers are able to choose their supplier. A particular characteristic of German electricity market is the absence of a regulator authority. The Cartel Office replaces some of the functions that a regulator would have. Taking the price reduction as criterion, one may describe the electricity industry deregulation as successful because both industrial and residential consumers have faced essential price reductions after the market opening.

In contrast to Germany, the power sector of France remains regulated and dominated in a high degree by the state-owned Electricité de France. In summer 2003 only a 35 % of market volume was opened to competition.

The situation in the rest countries of the European Union is a mirror of the two above paradigms. From the one side is Greece where the electricity market is opened up to 35%, while the power market in Spain is already fully deregulated.

Despite the different forms that the deregulation has taken in member countries, the final aim of European Union is to build up the Internal Market of Electricity (IEM) as a Pan European single market for the commodity of electricity [8].

The IEM will contribute to the achievement of the aims that European Union has set concerning the electricity industry. The first aim is the increase of competitiveness by better service for consumers. The second aim, persuaded by the European Union, is a better environmental protection and ultimately greater security for power supplies.

In order to deal with the task of setting up the Internal Market, European Union has founded the Florence Regulatory Forum [9]. The Florence Forum focuses on three regulatory issues that are necessary for the development of IEM. The first point is the definition of a framework for the cross-border power trade. Furthermore, the Florence Forum has to set up rules for the use of transmission capacity in case of congestions. Finally, the development of procedures, which will lead to the increase of interconnections' capacity, is another important task of Florence Forum.

3 Objectives of the paper

The scope of this work is the analysis of the costs that are associated with the power transfer as well as the conception of new tools concerning the computing and the allocation of these costs.

The power transmission costs, which are charged to the market participants, are a central issue of the new deregulated electricity markets. The increased requirement for fair and transparent pricing in the competitive environment as well as the complexity introduced by unbundling the services point out why this issue is of great importance [4].

Basically, the costs associated with the power transfer may be categorized as follows:

- Cost associated with the power losses;
- Cost caused by system congestion;
- Fixed cost of the power system;
- Cost of ancillary services.

In the deregulated electricity market, the participants are obliged to cover the power losses either by providing the necessary power or paying for the losses. The second category comprises the costs that are emerged when some technical features of the network reach their operational limits. The costs associated with this deviation are known as congestion costs. The fixed cost refers to the networks' investment and maintenance cost which is collected by the Independent System Operator (ISO). The last category comprises the expenditures for the appropriate power system performance. In order to operate the network in a proper way, the ISO has to ensure the procurement of the ancillary services.

The largest part of power transmission cost consists of charges in order to recover the network fixed cost. The congestion cost may also be significant part of the power transmission cost depending on the nature of congestion.

The revenue generated from transmission tariffs for the system's ability to serve load can be used to determine the economic value of a transmission system. The economic value of the transmission system generated from tariffs is affected by the ability to serve load, which depends on certain characteristics of the system, such as thermal, voltage, and stability limits.

4 Evaluation of the transmission cost allocation methods

The term fixed costs, generally, embraces the capital invested to build the network as well as the network maintenance costs. In a monopoly market, the utility covers those costs through the tariff policy. In the modern deregulated electricity markets, the network operation is the responsibility of the ISO. However, the company which is the network owner must still be compensated for those fixed costs. Hence, the ISO has to charge the market participants so as to collect the necessary amount.

In the liberalized power markets, the issue of charging the participants, regarding the fixed costs, is of great significance. The reason is that the fixed costs make up the largest part of transmission charges. Hence, it is easy to explain the demand for a fair and effective allocation of those costs to the market participants.

4.1 The Postage Stamp Method

One of the traditional methods is the postage stamp method (PS), also known as the rolled-in method [5].

According to this method, the network usage from the side of a transaction is measured by the magnitude of the transaction P_i, without taking into account how the transaction affects the power flows over the various lines in the network. The amount to be paid by transaction i is:

$$PS_i = K \cdot \frac{P_i}{\sum_{j=1}^{n} P_j} \qquad (1)$$

where: K represents the total cost to be covered by the market participants; PS_i represents the amount charged to participant i according to the postage stamp method.

This method does not require power flow calculations and is independent of the transmission distance and network con-figuration. It is widely implemented because of its simplicity.

4.2 Locational Marginal Price (LMP)

LMP is the marginal cost of supplying the next increment of electric energy at a specific bus considering the generation marginal cost and the physical aspects of the transmission system. LMP is given as:

LMP = generation marginal cost + congestion cost + cost of marginal losses

Mathematically, LMP represents the additional cost for providing one additional MW at a certain bus.

Using LMP, buyers and sellers experience the actual price of delivering energy to locations on the transmission systems. The difference in LMPs appears when lines are constrained. If the line flow constraints are not included in the optimization problem or if the line flow limits are assumed to be very large, LMPs will be the same for all the buses. In this case no congestion charges apply. If any line is constrained, LMPs will vary from bus to bus or from zone to zone, which may cause possible congestion charges.

4.3 Zonal transmission cost allocation method

Currently, in Romania, the zonal transmission cost allocation method is applied.

In this case, the power system analyzed is divided into 8 load zones and 6 generation zones. Each power system has two zones (generation and load). But the number of the sub-zones is imposed by the regulatory authority.

The buses within the power system are divided into 6 generating zones, taking into consideration the static stability of the power system. Each of the areas created has to include completely at least one tariff zone.

Regarding the load zones, the P-Q buses within the power system are divided, based on the administrative regulations borders of the power delivery and supply subsidiaries.

Every bus belongs to one zone, knowing the consumed power and the generated one. Each of these zones has a different price (€ / MWh), as described in Table 1. We have calculated a zonal load cost and a zonal generation cost, corresponding to each of the zones mentioned above. In the following, a load charge and a generation charge has been established.

Table 1. Zonal costs for the power system analyzed

Zone	€ / MWh
1L	3.50
2L	2.90
3L	2.60
4L	2.50
5L	3.30
6L	4.10
7L	4.60
8L	2.90
1G	2.90
2G	2.00
3G	3.20
4G	3.70
5G	2.30
6G	2.70

Finally it has been established the total income applying this method.

The transport tariff, as a cost element of the electric power sector, represents a delicate issue because of the following two reasons:

- it has to be reduced, not affecting the tariffs at the final customers;
- it has to provide the necessary revenue to allow the Transmission System Operator to ensure high quality services and the secure and stable operation of the power system. Also it has to be viable from economic point of view.

5 Description of the power system analyzed

The power system used as a study case (Fig. 1) is developed based on the West and South-West side of the National Romanian Power System.

It has 88 buses and 107 branches. The 35 P-U buses are divided in 17 real generating units and 18 equivalent P-U buses, obtained by extracting the analyzed part from the National Power System. The system has a number of 42 P-Q buses. All the buses belong to the same area.

Within the power system the buses at medium voltage, 220 kV, 400 kV are represented. At 110 kV voltage level, only the generated and consumed powers are represented.

It is designed in Powerworld version 8 software. It is used as a background for the software application created in Matlab.

6 Description of the application developed

The flowchart of the software tool developed is presented in Fig. 2. The software was elaborated in Matlab. It has a user friendly interface, specific to Windows applications. The application created uses the power system designed in Powerworld software, together with the related data too. It can be used by any Transmission System Operator (TSO). It is very easy to operate with, having a suggestive graphical user interface. The tool allows the final results to be printed and also the intermediary ones, if the user wishes.

The application created uses a script file. It is a special type of file which provides the link between Matlab environment and Powerworld software. It loads the base case of the power system analyzed in Powerworld and allows the user to automatically extract the necessary data from it. These data are represented by:

- all the buses within the power system;
- the active generated power;
- the active consumed power;
- the P-U buses;
- the P-Q buses;
- he branches of the power system analyzed;
- the power flows on the system branches;
- the marginal costs.

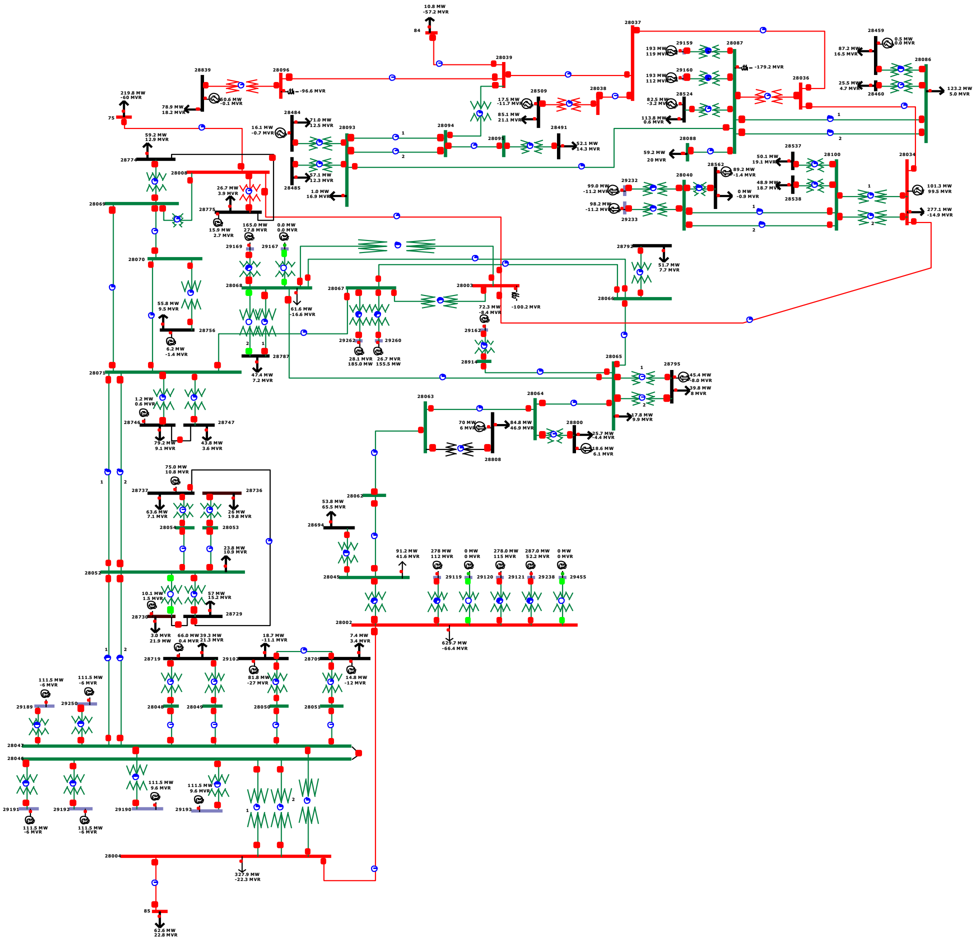

Fig. 1. The configuration of the power system analyzed.

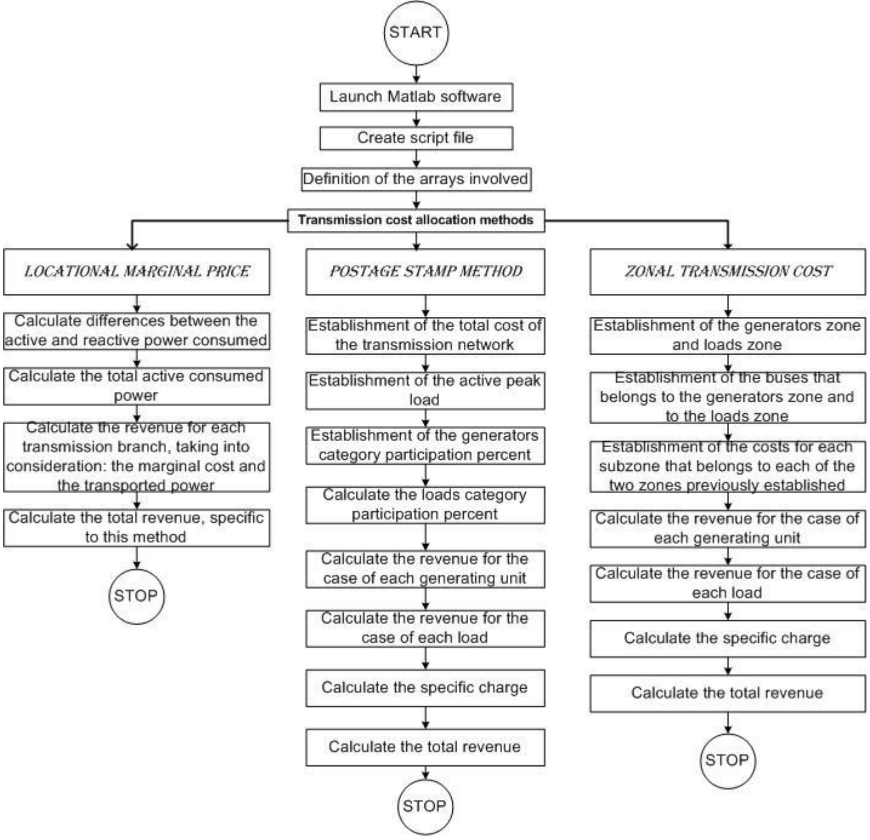

Fig. 2. The diagram of the software tool developed.

The main window of the application is presented in Fig. 3. For the beginning the user is requested to create the script file (previously discussed). Once this file is created, it has to be run in Powerworld software, Powerworld being operated in script mode. The necessary data are extracted from Powerworld in individual text files. Based on these files, the arrays necessary within the computing process, are defined (*File* menu, *Arrays definition* option).

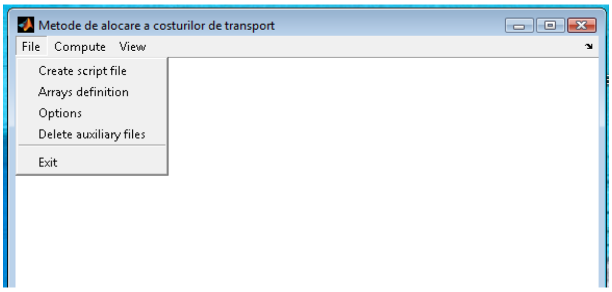

Fig. 3. The main window of the application

Once the necessary arrays have been defined, the cost allocation computing mechanism, within the power system, can be started. Selecting *Compute* menu, *Computing process* (Fig. 4), the user can chose between the three transmission cost allocation methods implemented within the software application created.

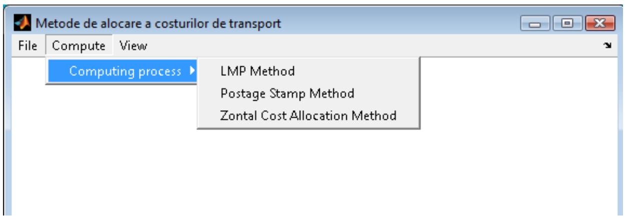

Fig. 4. The transmission cost allocation methods implemented within the software application

The obtained results can be viewed selecting *View* menu and the option corresponding to the desired transmission cost allocation method.

7 Analysis of the obtained results

7.1. Analysis of the base case

Using our instrument we have obtained the following results, for the three transmission cost allocation methods:

- Locational Marginal Price: 3187.4 € / h;
- Postage Stamp 18719.7 € / h;
- Zonal allocation cost: 19609.6 € / h.

Currently the *zonal transmission cost allocation method* is applied within the Romanian National Power System.

Taking into consideration the results obtained applying our tool the highest total revenue is highlighted for the zonal transmission cost allocation method.

The values for the two components of the total revenue are the following ones:

- total income corresponding to the P-Q buses: 9188.78 € / h;
- total income corresponding to the P-U buses: 10420.76 € / h.

In case of the current method the power transported on the system branches is not taken into consideration.

Knowing the total active consumed and generated powers and the two components of the total revenue, the specific charge for this method is calculated: 5.76 € / MWh.

Applying a charging system differentiated on zones ensures the following advantages:

- an economic signal is transmitted more efficiently for all the market participants, having as the main goal to incorporate the new customers or producers on a trend, that can provide the optimal transmission network development;
- the different tariff on load and generating zones, is sustained by the fact that, within a certain system zone the effort is clearly different depending on the nature of the provided service (the evacuation of the produced power or a consumer supply).

In case of the *postage stamp method*, the total revenue obtained is characterized by a reduced value, compared with the last method analyzed.

The value obtained corresponds to a so-called “stamp”, which represents a value applied to the active consumed / generated power. The “stamp” is represented by the ratio between the total cost of the transmission network and the active power at the peak load.

If the operating regime analyzed corresponds to the peak load, then the total revenue obtained applying this method, must be equal with the total cost of the transmission network. This is not the case of the current paper. The operating regime analyzed is not equal to the peak load.

The values for the two components of the total revenue, for the current method, are the following ones:

- total income corresponding to the P-Q buses: 9287.30 € / h;
- total income corresponding to the P-U buses: 9432.36 € / h.

In Fig. 5 is presented the situation of transmission cost allocation mechanism in case of each bus, within the power system. The contribution of each bus, depending of its type, is pointed out.

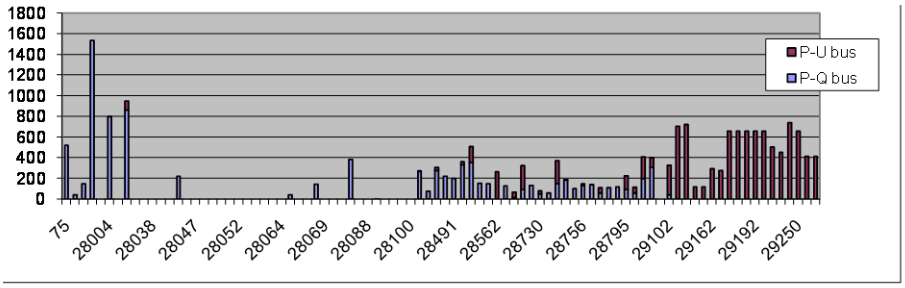

Fig. 5. Transmission cost allocation mechanism according to the zonal method

Knowing the total active consumed and generated powers and the two components of the total revenue, the specific charge for this method is calculated: 5.5 € / MWh.

Among the factors involved at establishment of the transmission cost allocation (using the current method), the main role is played by the loads category and generators category. A specific element, characteristic to the postage stamp method is represented by the participation percent of the generators category within the cost allocation process.

Using our software tool, when the user selects the transmission cost allocation using the postage stamp method, he is invited to enter a numeric value for the percent mentioned previously (Fig. 6). At this moment it is worth to highlight that the participation percent of the loads category could be also considered as an input data within our software, instead of the generators category.

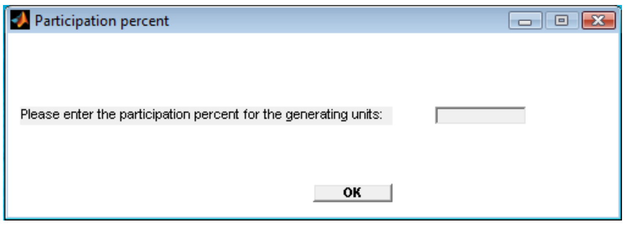

Fig. 6. The postage stamp method

Once the participation percent of the generators category is established, the software determines the participation percent of the loads category. Within the current practices, regarding the values of these two percents, there are multiple theories. It can be considered that the generators and the loads category are participating in the same percent at the transmission cost allocation process. In this case the two values are equals (to 1). Or, just the generating units participate at the transmission cost allocation process, case that leads to a value equal to 1 for each generator and another one equal to 0, for each P-Q bus.

In the current paper, the results presented (for the case of the postage stamp method), were obtained for a fifty-fifty participation percent between the generators and the loads.

In Fig. 7 is presented the situation of transmission cost allocation mechanism in case of each bus, within the power system. The contribution of each bus, depending of its type, is pointed out.

The postage stamp method also does not take into account the power transported on the system branches.

The smallest value regarding the total revenue was obtained applying the *LMP transmission cost allocation method*.

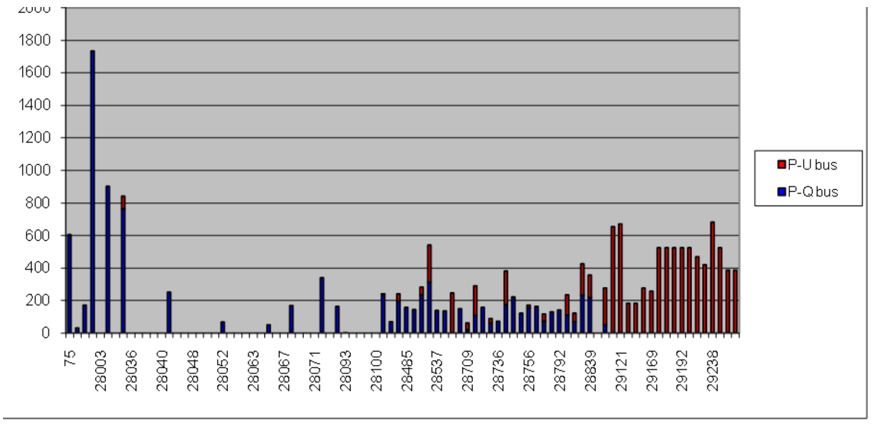

Fig. 7. Transmission cost allocation mechanism according to the postage stamp method

This method uses the active power consumed / generated and the marginal cost. Regarding the values of the marginal cost, all the values are ranging between 32 and 39 € / MWh (Fig.8). The fact that these costs do not have a high variation, leads us to the conclusion that this operating regime is a normal one, without any congestions or branches loaded at limit.

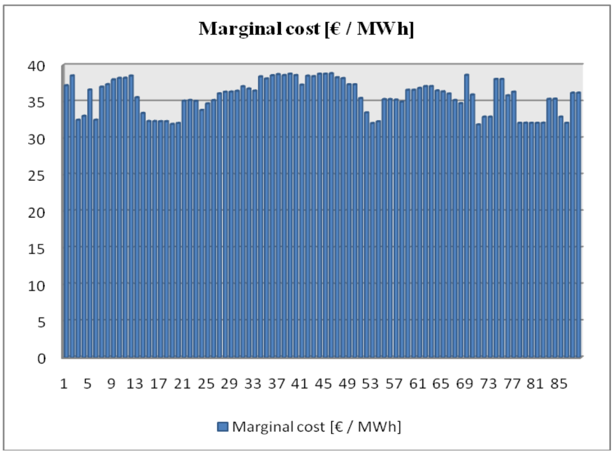

Fig. 8. Marginal cost for the system buses (base case)

In addition, against the other two methods presented, this one is taking into account the active power transported within the power system analyzed.

Based on this power and knowing the values of the marginal cost for the two end buses, which belongs to a certain branch, the revenue of each branch can be determined.

The total revenue is represented by the sum of the individual revenues previously calculated in the manner presented.

Knowing the total active consumed power and the differences between the active consumed and generated powers, multiplied by the marginal cost for each bus, the specific charge for this method is calculated: 0.38 € / MWh.

7.2. Analysis of an additional case

The base case of the power system analyzed is loaded and an additional consumer of 100 MW and 25 MVAr is considered in bus number 28070. The power flow is calculated.

The previous change from the base case can be fully accepted because it corresponds to a future extension of the West side of the power system analysed. This new operating regime is compared with the base case, regarding only (for the case of the current paper) the transmission cost allocation mechanism.

Analyzing the values of the marginal costs, high deviations between the values are highlighted. There are buses having a marginal cost equal to 15 € / MWh and other buses having 43 € / MWh (Fig. 9).

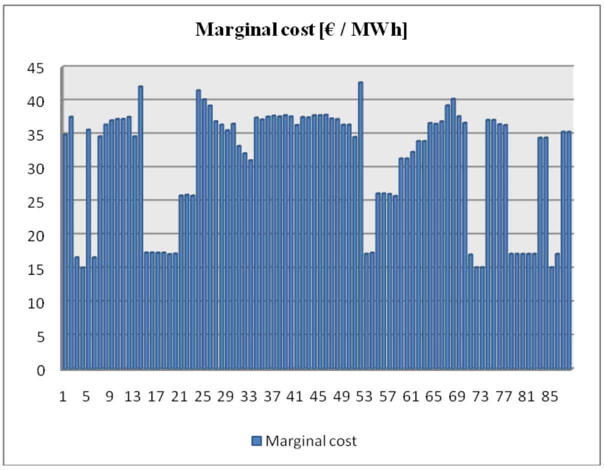

Fig. 9. Marginal cost for the system buses (2nd regime)

These values are noticing about the presence of congestions within the power system. And if we are analysing the new operating regime obtained the interesting cases are presented in Table 2.

The congestion situations initially presented in the current operating regime have been solved by the OPF mechanism, based on redispatching. In this situation the congestions are no longer presented, but there are a few branches loaded at limit or having a very high loading percent (such as the ones presented in Table 2).

Table 2. Interesting information regarding the branches

Number	**Branch**	**Marginal cost at the two end buses**
1	28045 – 28002	42.06-15.11 € / MWh
2	28052 – 28047	25.82-17.35 11 € / MWh
3	28040 – 29232	34.65-34.44 € / MWh

This operating regime, which we are analyzing at this moment, is subjected to congestions and branches which are loaded at limit.

Using our software tool we had obtained the following results, for the three transmission cost allocation methods evaluated:

- Locational Marginal Price: 22583.6 € / h;
- Postage Stamp 19430.1 € / h;
- Zonal allocation cost: 20861.4 € / h.

Analysing the three values obtained (corresponding to the total revenue), the highest value is highlighted by the LMP transmission cost allocation method.

Among the three analyzed methods, the LMP transmission cost allocation method is very suitable to be applied in case of congestion regimes. This method is highlighting very well the presence of the congestions in the system, by its increased value. In opposite if it is applied for the base case. This conclusion is very well illustrated in Fig. 10.

The remaining two methods, in case of this congested operating regime, lead to higher values that the ones obtained for the base case. But the difference is not very significant. Only for the LMP method a very significant difference is noticed. And the maximum revenue, in case of a congested operating regime, can be obtained applying this method.

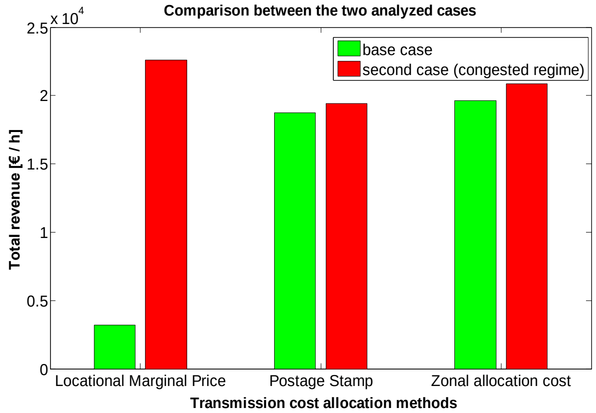

Fig. 10. Comparison between the transmission cost allocation methods in the two cases analyzed.

8 Conclusions

In the current competitive environment the problem of transmission cost allocation is a complex process. There are necessary powerful tools for carrying this task.

The software tool developed proves to be very useful for evaluating the transmission cost allocation mechanism. It determines the total revenue in case of the three allocation methods evaluated. But it also allows viewing the costs' allocation on each element (generating unit, load, or branch) which is involved in the transactions established.

In case of the normal operating regimes, the zonal transmission cost allocation method is recommended to be applied. The single step that might be time consuming is represented by the grouping of the system buses into the subzones that belongs to the load and generator zones.

In opposite, in case of the congested regimes, the LMP method is very suitable for this purpose. The LMPs are playing an important role in analyzing a congested regime.

Also the LMP method transmits the right locational price signal suitable for consumers and generators too (Table 2).

All the work carried out within the current paper, was effectuated for the deterministic case. Regarding the future work, the authors are focusing on implementing the transmission cost allocation mechanism into the probabilistic power flow tool.

The evaluation of the transmission cost allocation methods represents a necessary tool largely applied for power system analysis. In the current paper the transmission cost allocation mechanism has been investigated for the case of a real power system, operated by a real TSO. As a future research direction, the probabilistic transmission cost allocation mechanism is identified.

The TSO from our country is interested in developing a software toolbox necessary for power system analysis. The analysis is focusing on congestions management, uncertainties and risk management. The software application created is intended to be implemented within the TSO.

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