

A transaction-based method for allocation of transmission grid cost and losses

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Abstract

The problem of grid cost and losses allocation may be divided into independent subproblems: allocation of branch flow and losses to transactions, definition of these transactions and cost allocation to transactions. From this final allocation, the charges to participants in transactions may be made straightforwardly. A differential, slack-invariant method for the allocation of flow and losses to transactions that makes use of the AC load flow equation is presented here. The definition of transactions must be addressed using a non-discriminatory rule in pool systems. There are many possible options for this definition, and the choice made has great influence on the results. Cost allocation, on the other hand, may be made in different ways, as well. The paper presents an allocation process that addresses all these issues. Results for the IEEE-RTS96 test system are obtained and discussed.

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1. Introduction

Transmission cost and losses allocation are different though related problems in deregulated electricity markets. The chosen allocation procedures for both problems must provide locational signals and incentives in order to encourage efficient use of the transmission facilities. They must also be based on actual grid use. The proposed methods in technical literature for solving these problems share several points.

Transmission cost allocation methods must comply with some conditions, namely to avoid cross-subsidies, to be transparent and easy to implement, to ensure cost recovery, to provide adequate economic signals and to have continuity with time [1]. The proposed methods could be classified as embedded cost and marginal cost methods. The latter, however, do not guarantee cost recovering in real networks [2]. Embedded cost methods, on the other hand, allocate the transmission costs according to the extent of use of generators and consumers. Several methods of this kind have been proposed and are in use in different systems. They can be divided into rolled-in methods and load

flow-based methods. Rolled-in methods charge a fixed amount per energy unit, and their main drawback is that they ignore actual network use and that they do not send adequate economic signals to grid users. Flow-based methods, on the other hand, charge the users in proportion to the use they make of grid facilities. Some proposed methods of this kind may be classified as proportional [3] or differential methods [4].

Loss allocation methods may also be classified as proportional [3], differential [5–8], circuit-based [9,10] and others [11]. It must be outlined that this problem has no unique solution, due to its non-linearity, and some assumptions have to be made for any possible allocation. Among the proposed methods, the proportional method has several advantages: it is simple to understand and provides several results such as loss allocation, grid use and load sharing among generators. However, although it begins from a solved load flow, it does not follow the Voltage Kirchhoff Law in the allocation process, ignores the counterflows, and the results seem to be too volatile [4]. Differential (or incremental) methods are, on the other hand, well known in literature and are based on the Incremental Loss Coefficients [12]. These coefficients, however, depend on the choice of the slack bus in the studied case, and, therefore, there is a part of arbitrariness in the allocation. Several proposals have been made to overcome this difficulty. In [7], a fictitious slack bus is cho-

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sen; in [5,6], the property of invariance of the allocation for a transaction is applied, claiming a total invariance of the slack bus choice.

Another method for overcoming this difficulty, but applied to the transmission cost allocation method for bilateral exchanges, is given in [4]. This method allocates transmission costs among transactions, obtaining participation factors in the transmission network for each one of these transactions, and assuming that the generator node is a slack bus in each transaction. It is only applied to lossless systems and uses DC load flow equations.

In this paper, the problems of transmission grid cost and losses allocation to transactions are divided into three subproblems that can be addressed independently. First, the definition of grid users. Second, the allocation of power flows through branches and losses to each grid user, and finally, the cost allocation to the already allocated flow and losses. Different solutions can be given to all of them.

The grid users to whom grid use and losses are allocated is a very important question. In this paper, the allocation is made to transactions (generation–load couples), in order to make it invariant from the slack bus choice of the initial load flow. It must be recalled that when using differential methods for direct allocation to nodes (for instance, with Incremental Loss Coefficient), a transaction is tacitly assumed between each node and the slack node.

The definition of the transactions is straightforward for markets based on bilateral contracts, but in pool organized markets a definition of transaction must be made. This definition has a great influence on the results, as will be shown in this paper. Two principles for defining these transactions in a pool-based system that have been proposed in literature are examined in this paper. These methods are the Proportional Sharing Principle (PSP) and the Equivalent Bilateral Exchanges (EBE). The consequences of this choice have been analyzed.

The grid use and loss allocation problems are solved in this paper using a differential method for the allocation of branch flows and losses to transactions. The method is slack invariant that is to say that the results do not depend on the choice of the slack bus of the system in the initial load flow. AC load flow equations are used, allowing to solve both (power flow and losses) allocation problems with the same method. The use of AC load flow equations involves more theoretical complexity in the formulation, but does not imply a significative increase in computation time. Also, by using the AC load flow equations, a greater accuracy can be expected.

The cost allocation problem has also been addressed, and different solutions have been considered. A further decision must be taken about the percentage of costs allocated to generation and load. In non-slack-invariant methods, this choice is taken by choosing a slack node close to the generation or load centers. However, the fact that the costs are allocated to transactions, and from this to users, allows more flexibility.

The main contributions of this paper are intended to be the following:

- The split of the whole problem into three subproblems: transaction definition, use of grid and losses allocation, and cost

allocation, with different possible solutions for each of them. This division allows to make choices for each subproblem being aware of their consequences.

- The proposal of a method for flow allocation to transactions that is differential and slack invariant (DSI method). This method makes use of the AC load flow equations.
- A method (parallel to the previous one) for loss allocation that is also slack invariant.
- A study about the consequences of the definition of transactions in pool systems, together with a proposal of the choices that could be considered more reasonable.

The paper is organized as follows. Section 2 exposes the differential, slack-invariant (DSI) method of flow and losses allocation to transactions. Section 3 deals with the problem of cost allocation to transactions, while in Section 4 the subject of transaction definition choice is addressed. In Section 5, the numerical results of the application of the method to the IEEE 24 nodes Reliability Test System [16] are given and commented.

2. Flows and losses allocation

2.1. General formulation

The method begins from the results of a solved AC load flow in a system with a given load and generation. This solution is used as a start point.

The average power flow and losses in branch r are given by Eqs. (1) and (2). All the symbols are explained in Appendix B.

$$F_r = \frac{1}{2} g_{km} (u_k^2 - u_m^2) - b_{km} u_k u_m \sin(\delta_k - \delta_m) \quad (1)$$

$$L_r = g_{km} [u_k^2 + u_m^2 - 2u_k u_m \cos(\delta_k - \delta_m)] \quad (2)$$

Let us define T_{ij} as the transaction t of a power P_{ij} between the generation node j and the demand node i . Differential methods allocate these losses and power flow to transactions from the value of sensitivities of average flow (ϕ_{rt}) and losses (λ_{rt}) to a differential increase in each transaction t , T_{ij} . These sensitivities will be obtained in Section 2.2. Hence, the increment of average flow of branch r , dF_{rt} , and the increment in losses, dL_{rt} , due to the differential transaction t , could be found as (3).

$$\begin{aligned} dF_{rt} &= \phi_{rt} dT_{ij} \\ dL_{rt} &= \lambda_{rt} dT_{ij} \end{aligned} \quad (3)$$

These equations are only valid for differential variations in transactions. In order to obtain the allocation of the flow to a transaction, it would be necessary to integrate them somehow. The integration process requires an initial point, to define an integration path I_P , and to know the value of the sensitivities along this path, $\phi_{rt}(T_{ij})$, $\lambda_{rt}(T_{ij})$. A discussion about this point will be given in Section 2.3.

If all these aspects are defined in some way, the flow in branch r due to transaction t , F_{rt} , along the integration path I_P , could be

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