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Reviewing strategies for active power transmission loss allocation in power pools

R.S. Salgado[a,*,1], C.F. Moyano[a], A.D.R. Medeiros[b]

[a]Universidade Federal de Santa Catarina, CTC/EEL, Florianópolis, Santa Catarina, Brazil

[b]Operador Nacional do Sistema ONS/NRS, Florianópolis, Santa Catarina, Brazil

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Abstract

Transmission losses have a considerable effect on the active power generation cost and thus, a strategy to allocate them *fairly* among the power system agents is essential to economic efficiency of the electric energy market. The present work focuses on the allocation of the active power transmission losses among the buses of a power system operating under pool condition. Three types of approaches, based on extensions of the conventional and optimal solutions of the power network equations, are analyzed here: (1) direct use of sensitivity relationships between the transmission losses and the bus power injections; (2) use of participation factors obtained from power flow solutions; and (3) integration of sensitivity relationships mentioned in the previous item. Numerical results obtained with a 19-bus power network are used to illustrate the main aspects of the loss allocations based on the application of the selected techniques.

Keywords: Loss allocation; Power flow; Optimal power flow; Co-operative game theory; Marginal cost; Nodal participation factors

1. Introduction

One of the main features of deregulated electricity markets is that a common transmission system is shared by multiple agents providing/consuming power. In these markets, competition among generation utilities is promoted through the open access to the grid, the costs involved in the use of the transmission system being recovered from the power system agents [1].

Several costs are implicitly associated with the power supply, one of which corresponding to the losses in the transmission structure. Active power losses typically represent a fraction of the total active power generation ranging from 4 to 8%. They depend on the power flows, which are not physically traceable; that is, the active and reactive powers can flow from a generator to a load bus through a number of alternative routes.

There are at least two main reasons for adopting schemes of power loss allocation in deregulated electric power markets: the transparency of the cost recovery process and the availability of good signals to the power system agents. Two situations illustrate this statement. If, for reason of computational simplicity, the base generation dispatch and its clearing price are calculated through a suboptimal merit-order approach that initially neglects the transmission losses, the recovery of common costs with fairness requires an equitable loss division [2]. In case of optimally dispatched power networks, loss allocation methodologies provide information about the amount of power effectively supplied to each particular consumer. In both cases, the loss allocation depends only on the criterion adopted for purposes of revenue and payment reconciliation, not affecting any power system variable. However, this information can be useful to induce efficient use of the grid by participants, providing incentive to energy producers and consumers to improve their operation conditions.

Several difficulties are associated with the division of the power losses among the power system agents. The transmission losses depend on the bus power injections, being usually represented by non-linear functions of

* Corresponding author. Address: Universidade Federal de Santa Catarina, Centro Tecnologico - Depto. de Engenharia, Eletrica Caixa Postal 476, Cidade Universitária, Florianópolis 88040-900, Santa Catarina, Brazil.

E-mail address: salgado@labspot.ufsc.br (R.S. Salgado).

[1] R. Salgado is currently on sabbatical leave at the Brunel Institute of Power Systems, University of Brunel/London, UK.

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the complex bus voltages. These functions can have a single value for different power flow solutions. The loss allocation does not affect the generation levels and power flows, but modifies the distribution of revenues and payments among suppliers and consumers [2]. There is also a question concerning which power system agents must supply the active power transmission losses; that is, the losses must be allocated only to the load buses or also to generation buses? In addition, the choice of a set of generating units to supply the loss can also be seen as an arbitrary decision.

Therefore, the establishment of a transparent, practical and politically acceptable charging system, that recovers common costs with fairness while provides incentive for the efficient use of the transmission system by all agents, is a regulatory challenge [1].

A number of strategies for the transmission loss and/or loss cost allocation have been proposed in the literature, most of which are based on conventional or optimal power flow solutions. The simplest loss allocation scheme is the so-called *pro-rata*, which divides the power transmission losses proportionally to bus power injections. It does not take into account the *electrical distance* between buses and thus, buses close to or distant from the generation centers are similarly penalized. Other approaches propose the direct use of decomposed marginal costs [3] or incremental transmission loss coefficients [4] as nodal participation factors. The tracking of the transmission line power flows to determine the fractions of power flows corresponding to the generators and loads is proposed in Refs. [5–7]. Ref. [8] evaluates nodal factors based on the current injections and bus impedance matrix. In a recent past, the integration of incremental transmission loss coefficients [2] or alternatively marginal costs [1,9–11] has been proposed.

In spite of the arbitrariness (implicitly or sometimes explicitly) inherent to any loss allocation scheme, there is a number of desirable requirements, which once satisfied, increase the degree of equity of the allocation strategy. These are:

- consistency with the solution of the steady state power network equations; that is, the magnitude of the bus power or current injections should be reflected in the corresponding allocation factors [8];
- smallest possible degree of dependence of the nodal loss factors on changes in the set of generation buses responsible for loss supply;
- non-negativeness of the loss fraction attributed to each bus and non-existence of cross subsidy; that is, changes in the demand of a set of buses must be reflected basically in the corresponding nodal factors, not leading any consumer to subsidize another.

These features are also useful for comparison purposes of the various approaches proposed in the literature. For the objective of the present paper, the following types of approach were studied:

- direct use of marginal costs or sensitivity relationships between the active power transmission losses and the bus power injections;
- extension of the power flow results through bus impedance matrix;
- integration of the sensitivity relationships mentioned in the previous item.

Four techniques, based on Refs. [2,3,8,9] illustrate the analysis presented here. These strategies are relatively simple extensions of the conventional and the optimal power flow solutions, which are basic numerical tools in the power system steady state analysis. They are suitable for solving loss allocation problems in power systems operating under pool conditions. The main objective of our study is to investigate the similarities and differences between the loss allocation approaches in terms of the quality of the signal provided to power system agents. Numerical results obtained with a 19-bus network, equivalent from the Brazilian South–Southeast power system were used to illustrate the proposed study.

2. Theoretical review

The following sections summarize three types of approaches for active power transmission loss allocation, which are the basis for the study presented in this paper.

2.1. Loss allocation through direct use of sensitivity coefficients

Traditionally, many electric utilities have adopted loss allocation schemes based on incremental factors and/or marginal costs, which are relatively easy to compute. Nodal participation coefficients are obtained from a linear approximation of the power loss equation with respect to the bus active and reactive power injections. Each term of the linear approximation defines the fraction of the incremental losses allocated to the corresponding bus.

The computation of sensitivity relationships is proposed in Ref. [4] for loss allocation purposes and in Ref. [12] to assess the bus participation in the use of the transmission system. Usually, the largest incremental transmission factors are attributed to buses electrically far from the generation centers. However, although these factors are easy to compute, this type of loss allocation strategy can be arbitrary and discriminatory [2].

Ref. [3] proposes the determination of the loss nodal factors through the decomposition of the Lagrange multipliers. For this purpose, an OPF problem is solved to minimize the active power generation cost, from which the marginal costs are obtained. In order to compute the nodal loss factors, the marginal costs are decomposed into parcels corresponding to the cost of the power supply, active power transmission loss and congestion. It is supposed that