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Allocation of the costs of transmission losses

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Abstract

An analysis of the performance of six major methods of loss allocation for generators and demands was conducted, based on pro-rata (two), on incremental factors (two), on proportional sharing (PS) (one), and on electric circuit theory (one). Using relatively simple examples which can easily be checked, the advantages and disadvantages of each were ascertained and the results confirmed using a larger sample system (IEEE-118). The discussion considers the location and size of generators and demands, as well as the merits of the location of these agents for each configuration based on an analysis of the effect of various network modifications. Furthermore, an application in the South-Southeastern Brazilian Systems is performed. Conclusions and recommendations are presented.

Keywords: Loss allocation; Energy market; Transmission networks; Power flow

1. Introduction

In the present economic environment, electric energy transmission companies must deal with significant changes, and various new challenges have arisen. One of these is the need to determine the optimal available transfer capacities, and another is the determination of the responsibility for energy loss in relation to generators and demands. This paper deals with the determination of the loss allocation for generators and demands starting with the most prominent methods in practical applications and the ones with higher future potentials.

Since energy losses originate from the power injection in various buses and they are non-linear functions, the analysis of these phenomena should consider various options. The allocation of the cost of these losses certainly does not affect directly the functioning of the existing electrical systems, since the calculation of the costs is computed after the dispatch of the demand. However, the size and the location of generators and demands does influence these losses, some more than others. This piece of information can thus be a determining factor in the definition of the most adequate location for the insertion of new generators in a system, as well as in the decision regarding the expansion.

Loss allocation methods are designed to evenly distribute the responsibility of transmission losses between generators and loads. Various factors must be considered for an equitable allocation, including the injection of power at each bus, the relative location of each bus in the transmission network, consistency of the power flow solution, stability in relation to alterations in network parameters, and effectiveness of calculation of financial incentives to individual generators and demands as a function of its relative location in the network and of its magnitude.

The present paper was oriented towards presenting an analysis of the performance of the major methods used in the allocation of losses to generators and demands. After using simple examples which are easy to check for advantages and disadvantages, the results were checked on larger systems. The results presented and discussed in this article consider the location and size of generators and the demands involved, as well as the merits of these locations in the network configuration. The sensitivity of the methods to alterations in the electric network was also investigated in an attempt to provide effective alternatives for the solution of a problem expansion transmission planning.

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The methods discussed are the following:

- Z-bus (a method based on circuit theory using a Z-bus matrix);
- Incremental transmission loss (ITL), including negative allocation (compensation for efficiency) and without such allocation (U-ITL);
- Proportional sharing (PS);
- Pro-rata method (P) based on active power injection, and (I) based on the current injection.

The analysis of energy losses is essential since losses can involve an amount of hundreds of millions of dollars per year. For instance, the power losses in the South-Southeastern Transmission Brazilian System can reach up to 2200 MW during the peak load period.

2. Loss allocation methods

Various proposals for the allocation of transmission and distribution losses in electrical networks have arisen in recent years. The major emphasis has been on problems of transmission due to the large sums involved, as well as to the large numbers of agents with free access to transmission networks. An overview of the methods of loss allocation that will be herein discussed is presented in this section.

2.1. Circuit theory-based method

The Z-bus method [1] is able to exploit equations of electrical circuits without simplification. The rationale is to distribute loss throughout the "n" buses of the system (P_{loss}), starting with the solution of the following power flow equation:

$$P_{\text{loss}} = \sum_{k=1}^{n} L_k \tag{1}$$

where L_k is the percentage/fraction of the losses attributed to bus k. The solution of this equation involves an admittance matrix ($Y = G + \text{j}B$) and a complex voltage vector (V) or an impedance matrix ($Z = R + \text{j}X$) and a complex vector of the current injection (I). Solving this initial loss equation gives the following:

$$P_{\text{loss}} = \Re \left\{ \sum_{k=1}^{n} V_k I_k^* \right\} \tag{2}$$

where $\Re$ indicates that the term refers to the real part from the sum. The loss associated with bus k can be expressed as follows [1]:

$$L_k = \Re \left\{ I_k^* \left(\sum_{j=1}^{n} R_{kj} I_j \right) \right\} \tag{3}$$

where R_{kj} represents the real part of the Z-bus matrix which reflects the link between bus k and all the other buses in the system. L_k refers to the loss, considering the "n" terms which represents the connection between current injection at all "n" buses with the injection of current at bus k.

2.2. Methods of loss allocation utilizing incremental procedures

Allocation procedures based on incremental principles allocate losses to generators and demands on the basis of ITL factors [2,3] obtained from the solution of the power flow. The ITL factors of a given bus are the result of changes in total loss arising from the incremental variation of the power injection at each bus. The use of these ITL factors can allocate negative loss to certain generators and demands, providing useful information for analyzing where problems are located. These factors can also be modified, thus giving rise to a U-ITL (unsubsidized marginal allocation), a method designed to attribute losses to generators and demands in which the negative losses are avoided [1].

2.3. Method of loss allocation utilizing proportional sharing

The class of proportional sharing methods requires the application of a linear proportional sharing principle [4–6], and the results of a power flow solution. The procedure from [4] is used in this paper, and it needs the active power flow, the losses in every line and the power generations and demands in every bus.

2.4. Pro-rata methods

With pro-rata methods, losses are first divided (generally half and half) between generators and demands, then an allocation within each category is made based on the level of power or current injections [7]. Hence, the demands at a bus will have a loss allocation corresponding to the percentage of total energy consumption involved. The same principle is applied to generation buses. An example of the use of these methods is presented in [8]. Losses can thus be attributed on the basis of active power injection at the buses (P) or on the current injection (I).

3. Tests, results and discussions

An analysis on the performance of methods of loss allocation considering different situations and obtaining results with more than a method is presented. All of the tested methods allocate zero losses for buses that have neither generators nor demands. The methods P, I, PS and U-ITL always allocate a part of the loss to buses with generators and demands, which means all generators and demands shall "pay" for power losses. Moreover, the ITL and Z-bus methods attribute both positive and negative allocation of losses, resulting in a situation where generators and demands may either