

## Transmission loss allocation using combined game theory and artificial neural network

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### ARTICLE INFO

#### Article history:

Received 8 January 2010

Received in revised form 10 May 2012

Accepted 14 May 2012

Available online 7 July 2012

#### Keywords:

Transmission loss allocation

Game theory

Shapley value

Artificial neural network

### ABSTRACT

An artificial neural network based method is suggested for allocation of transmission loss in a deregulated power system involving bilateral contract based power transactions between power suppliers and the distribution companies. The proposed method allocates transmission losses to operating transactions on the basis of Shapley value game theoretic approach. For this, bilateral transactions for power system are simulated and corresponding losses are obtained through load flow analysis. Shapley value approach is used to calculate the loss allocations. A large number of such simulation cases are generated and a large data pool stores these possible bilateral transactions and the corresponding loss allocations following Shapley value approach. For allocating losses to the transactions of an operating system environment the required neural network is developed online. A simple filtering technique is used to extract the suitable training data that are close enough to the actual operating condition from the generated data pool and neural network is trained online. The performance of such a network when tested on standard power networks has been found to be very encouraging.

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### 1. Introduction

During the last two decades the electric power industry had to face major changes due to deregulation and restructuring. These changes on one hand have introduced operational independence and flexibility, but on the other, have incorporated complexity in economic and functional decision making. Transmission loss is one of such issues currently being discussed with great concern. Transmission losses accounts for 4–8% of the total power generated in a power system [1]. These losses annually cost large sum of money and thus should be allocated among the network users. Loss allocation should be fair and acceptable to all market players (or participants), transparent and easy to compute and also revenue adequate. Transmission loss bears a quadratic relationship with the current flowing through a line and is a non-separable quantity. The issue of transmission loss allocation thus remains an open problem. Hence, the objective of this work is to propose a method of determining the sharing of transmission losses among all participants of the network.

In recent years, a number of methods have been proposed to allocate the system losses to generators and/or loads in a pool based market or to individual transactions in a bilateral contract market [2]. In absence of a closed form solution, different utilities

use different methods for transmission loss allocation. With *pro rata* methods, losses are first divided equally between generators and demands, and then an allocation within each category is made based on the level of power or current injection [3]. The class of proportional sharing methods requires the application of a linear proportional sharing principle [4,5] and the results of a power flow solution. Sensitivity methods allocate losses according to network sensitivities, or partial derivatives [6]. Procedures based on incremental principles allocate losses to network participant through assigning a coefficient known as ITLs to each one that represent the total network losses sensitivity to that particular user injection [7,8]. Expression analysis methods express losses as a function of some system variables and allocate losses to the market participants by analyzing the characteristics of the expression. Transmission losses are expressed as function of transaction MW powers and allocate interaction terms by geometric means [9]. Z-bus allocation methods use the network parameters and system loss formula and compute losses using complex current injections [10]. Electricity tracing methods [11] and based on the same principle using graph theory [12] transmission losses is also allocated for a deregulated environment. Again, power flow based methods [13,14] and optimal compensation of transmission losses [15] also uses power flow solutions to allocate losses for multiple transactions in a power market. Summarizing, network based methods use network solution techniques along with rational reasoning and/or heuristics to allocate system losses. Though all the above solution techniques have established theoretical background, they

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lack of solid economical foundation for the allocation of losses. In recent years, different allocation schemes have been formulated based on the natural economic use of the transmission system [16].

Game theory provides well-behaved solution mechanisms for resolving the conflicts among players in a competitive environment [17]. In particular, cooperative game theory is a very convenient tool to solve cost allocation problem [16,18,19]. Game theory is used for solving different deregulated power system problems in the literature [20–23]. Popular game theoretic approaches used in power engineering problems are negotiation set, core, the kernel, nucleolus, Shapley values, Aumann–Shapley value, etc. [24,25]. Among these methods, the Shapley value approach proposed by Shapley [26] is very straight forward, easy to implement and thus seems to be more appealing to the power engineering professionals. The major problem with any game theory based allocation method is the volume of data (and hence the computational requirement) needed to arrive at a solution making it a difficult approach for real time implementation. Thus, loss allocation problem can be categorized as a problem that is difficult to solve. Artificial intelligence methods, more specifically, the artificial neural network are appropriate tool for handling such problem.

The motivation of this work is to offer an alternative scheme of loss allocation using solved load flow methods with game theoretic approach and artificial neural network (ANN) and which will allocate losses with an economically viable situation. The proposed method is presented briefly in the next section, followed by the details of methodology used for Shapley values and ANN. Section 3 presents the system description of the networks where the proposed methods are tested and loss allocation results obtained using IEEE standard bus system are presented in Section 4.

## 2. Methodology

### 2.1. The loss allocation problem

Electrically, transmission loss is given by the current squared times resistance of the power flow path. In a power system as shown in Fig. 1 where a common transmission path of resistance  $R$  is utilized by several generators/loads having associated currents  $I_1, I_2, \dots, I_n$ , the total power loss is given by  $(I_1 + I_2 + \dots + I_n)^2 \times R$ . The problem of loss allocation is to determine the contribution of a participant's current  $I_i$  on the total current's square. The above approach is the circuit theoretic approach of formulating and solving the loss allocation problem. Circuit theoretic approach, however, leads to an inconclusive situation because the square of the sum of the component currents results in cross terms, e.g.

$$S_{loss} = (I_1 + I_2 + \dots + I_n)^2 \times R$$

$$= (I_1^2 + I_2^2 + \dots + I_n^2) \times R + 2R(I_1I_2 + I_1I_3 + \dots + I_iI_j + \dots) \quad (1)$$

While the responsibility of the squares of identical component currents is obvious, it is very difficult to determine the share of the mutual terms like  $2I_iI_jR$ .

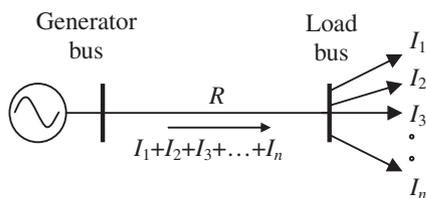


Fig. 1. A common transmission path is shared by several loads.

Transmission loss may also be expressed in a different way as the difference between the power generation and the total power consumption by the loads. Considering a power market having  $G$  number of generation companies,  $D$  number of distribution companies, making  $T$  transactions, the problem of loss allocation is to allocate  $S_{loss}$  to the participants, where

$$S_{loss} = \sum_G S_{Gi} - \sum_D S_{Tk} \quad (2)$$

where  $S_{loss}$  is the transmission loss,  $S_{Gi}$  is the generation of  $i$ th generating company,  $S_{Tk}$  is the power drawn by  $k$ th transaction,  $S_{ai}$  is the loss allocated to  $i$ th transaction,  $S_{aj}$  is the loss allocated to  $j$ th transaction, and  $S_{Ti}$  and  $S_{Tj}$  is the  $i$ th and  $j$ th transaction quantities.

The problem in loss allocation is to allocate this loss into participating parties such that  $S_{loss} = \sum_k S_{ai}$ , where  $S_{ai}$  is the allocation to  $i$ th participant. As a closed form of solution of the problem does not exist, a number of non-circuit theoretic solutions have been proposed. These approaches are based on some rational relations between the power transactions and the allocated losses and in some way or the other aimed at the satisfaction of the participating parties on the allocated losses. Allocation decisions in these methods are such that  $S_{ai} > S_{aj}$  if  $S_{Ti} > S_{Tj}$ .

### 2.2. The proposed method

We propose a game theory combined with artificial neural network (ANN) based loss allocation technique in the present paper. The reasons for proposing the ANN for solving the transmission loss allocation problem are the following:

1. Loss allocation problem is a highly nonlinear problem lacking any definite closed form of solution.
2. Of all the loss allocation techniques available in literature, Game theory based allocation possesses established theoretical background.
3. Game theoretical solutions need exhaustive information that is difficult to process in real time.

ANN can learn the relation hidden in a set of input and output data used to train the network. As the training is completed, the ANN architecture represented by the neurons and the weights connecting them are tuned optimally such that when a new set of inputs are presented to the network, it can generate the desired solution following the rules it has learned during the training process. The proposed neural network may be trained to follow any method of loss allocation proposed in literature. But in the present work we have used the Shapley value based Game theoretic approach as the allocation rule because of the fact that unlike other methods Game theory based method generate solutions that are having some theoretical background. Moreover, game theory attempts to generate allocations that are satisfactory solutions to all the participants [27,28]. As the Shapley value is the basis of loss allocation we attempt to generate, one may raise a doubt regarding the utility of ANN as an additional component in the allocation process. It may be stated in this connection that the implementation of Shapley value needs huge simulation and computations which is an obstacle in its real time implementation. But, simulation cases may be run to generate the operational scenarios in the offline. The neural network trained using these simulated data can be used to produce allocation results in real time. Fig. 2 shows the organization of the proposed model of simulation and detailed discussion and the necessary implementation of various issues related to the proposed tool are presented in the subsequent section.

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