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A fuzzy membership filtering aided neural network based transmission loss allocation scheme using game theory

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ABSTRACT

The present paper proposes development of a transmission loss allocation scheme in a deregulated environment using fuzzy memberships and supervised neural networks. This method can be effectively utilized in online applications where game theory based solutions, which otherwise produce acceptable results, cannot be utilized for prohibitive computation load. We propose a fuzzy membership based approach to filter data from a global database and create a local relevant database, for each transaction detail online, each time. A neural network is trained for each such local database formed and utilized for estimating loss allocations among players, for the transaction detail under consideration. The proposed method has been employed for an IEEE 14 bus system and the results of our proposed method have been shown to be sufficiently accurate, when compared to results obtained by using game theoretic approach.

1. Introduction

The electric power industry is experiencing important changes brought about by the deregulation and restructuring. These changes, on one hand, have introduced operational independence and flexibility, but, on the other hand, have also incorporated complexity in economic and functional decision making. Many technical and financial issues, which were very obvious in the vertically integrated system, have now become major issues of debate in the disintegrated non-monopolistic system. Transmission loss is one such issue which is currently discussed with great concern. In the vertically integrated utility companies, before the deregulated era, where the available generations were centrally dispatched, transmission losses were used to be treated as an extra load or burden. Since generation, transmission and distribution now belong to distinctly separate bodies/companies, the question of 'who and how much should pay for losses' arises. The complexity of the problem gets multiplied by the fact that the power loss caused by the change in the power supply or consumption of a generator or load is dependent upon the current supplied by the other participant in the network. The issue of transmission loss allocation thus remains an open problem. Hence, the objective of this work is to find out an acceptable strategy of sharing of transmission losses among all market participants.

Transmission losses account for 3–8% of the total power generated (Belati & da Costa, 2008). These losses annually cost a large sum that should be properly allocated among network users. The loss allocation should be fair and acceptable to all market players (or participants), transparent and easy to compute and also revenue adequate. In absence of a closed form solution, different utilities use different methods for transmission loss allocation.

According to the ways to deal with the problem of loss allocation, most schemes fall into the following broad categories: circuit theory based methods and heuristic methods. The first one generally deals with circuit laws like incremental transmission loss (ITL) methods, expression analysis, loss formula based methods and the heuristics based methods are mostly based on *pro-rata* and proportional sharing methods. The procedures based on incremental principles allocate losses to network participants by assigning coefficients known as ITLs, obtained from the solution of the power flow (Galiana, Conejo, & Kockar, 2002; Leite da Silva & Guilherme de Carvalho Costa, 2003). Expression analysis methods (Ding & Abur, 2006; Jing, Duan, & He, 2002), express losses as functions of variables, such as complex valued node currents, complex valued generator currents and transaction MW powers, and allocate losses to the market participants by analyzing the expression. In Exposito, Santos, Garcia, and Velasco (2000), transmission losses are expressed as functions of transaction MW powers and allocate interaction terms by computing geometric means. Loss formula based allocation methods, like Z-bus allocation methods (Conejo & Galiana, 2001), use the network parameters and system loss formula and compute losses using complex current injections. Sensitivity methods allocate losses according to different

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variations of sensitivities or partial derivatives (Menezes & da Silva, 2006). On the other hand, with pro rata methods (Ilic, Galiana, & Fink, 1988), the losses are first divided equally among the generators and demands, and then an allocation within each category is made based on the level of power or current injection (Hsich, 2006). The class of proportional sharing methods requires the application of a linear proportional sharing principle (Bialek, 1996, 1997; Kirschen & Strbac, 1999) and the results of a power flow solution (Abdelkader, 2009; Lim, McDonald, & Saha, 2005; Teng, 2005). In a nutshell, network based methods use network solution techniques, along with rational reasoning and/or heuristics, to allocate system losses. Different view points and approaches may result in different results and most of the models and methods, presented till now, are constrained by the fact that they lack economic foundations. In addition to the different loss allocation methods discussed above, few other natural economics based methods are also proposed in the literature for loss allocation. In recent years, game theory based methods have found prominence which are based on the natural economic use of the transmission system (Zolezzi & Rudnick, 2002). Game theory provides interesting concepts, methods and models and well-behaved solution mechanisms for assessing the interaction of different participants in competitive markets and resolving the conflicts among players (Bierman & Fernandes, 1998). In particular, cooperative game theory is a very convenient tool to solve allocation problems (Hu, Chen, Gan, & Chattopadhyay, 2006; Molina, Prada, & Saavedra, 2007; Zolezzi & Rudnick, 2002). Game theory has been used for different deregulated power system problems in the literature (Hsich, 2006; Lima, Contreras, & Feltrin, 2008; Lo & Al-Turki 2004; Songuai, Xinghue, Lu, & Hui, 2006). The solution mechanisms of cooperative game theory apply well in terms of fairness, efficiency, stability and qualities required for the correct allocation of transmission losses. Popular game theoretic approaches used in power engineering problems are negotiation set, core, the kernel, the nucleolus, Shapley values, Aumann–Shapley values, etc. Among these methods, the Shapley value approach, proposed by Shapley (1953), is quite 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 associated computational burden) needed to arrive at a solution. Thus, loss allocation problem can be categorized as a problem that is difficult to solve.

The motivation of the present work arises in the context of developing a suitable method that can overcome the constraint of significant computational burden involved in employing game theory for loss allocation problems online. The solution proposes to use an alternate scheme of creating a database, offline, of loss allocation data using solved load flow methods in conjunction with game theoretic approach. At first supervised neural networks are utilized to train a hyper-dimensional, non-linear, mathematical mapping for a *J*-Transaction-*K*-Loss_Allocation database. Once these neural networks are trained offline, their structure and parameter information can be kept stored and they can be utilized to determine individual loss allocation among participants, once the system is presented with a new transaction detail. In literature, artificial neural network is used to solve different problems in deregulated power system (Catalao, Mariano, Mendes, & Ferreira, 2007; Charytoniuk et al., 2000; Mustafa, Khalid, Shareef, & Khairuddin, 2008; Pao, 2007). An approach to allocate transmission losses using artificial neural network is also attempted (Haque & Chowdhury, 2005) and in that work a simple ANN is used and results were compared with incremental load flow approach. In Arunachalam, Ramesh Babu, Mohanadasse, and Ramamoorthy (2006), feed forward ANN is used to allocate losses based on *Z*-bus loss allocation methods. However, when we utilized our trained supervised neural network in our before mentioned method, the system could not achieve the desired accuracy. A possible logical reasoning behind this can be that a single ANN is not sufficient to learn such high degrees of non-linearities involved in the entire hyper-dimensional space under consideration.

In our bid to increase accuracy, we propose to consider each transaction detail as an operating point in a *J*-dimensional space and create a local *J*-dimensional subspace around this operating point. For each transaction detail under consideration, we extract only those transactions from the global database that fall within the local subspace and create a local database. The supervised ANN is then trained using exemplars in the local subspace and then the transaction detail is used as a testing exemplar for this trained ANN to estimate loss allocation. As the creation of the local subspace, and hence the local database, will vary with the operating point, both the training and the testing procedure of the ANN have to be carried out online for each transaction detail under consideration. Since the size of the local database created will be significantly small compared to the global database maintained online, the computation time involved in this entire exercise, for each transaction, will be sufficiently small. Now, to determine the local subspace for each transaction, we propose to utilize a fuzzy membership (Ross, 1997) based approach. For each operating point in a *J*-dimensional space, we consider one Gaussian fuzzy membership function (MF) for each dimension. The mean of the Gaussian MF in the *j*th dimension corresponds to the value of the operating point in the *j*th dimension. Then the overall membership value (MV) of each transaction detail in the global database is calculated based on the product of individual MVs of the transaction in each dimension. A higher value of the overall MV of a transaction indicates that it is in closer proximity to the operating point in the *J*-dimensional space and hence a better candidate for inclusion in the local database. Once the overall MVs are evaluated for all transaction details in the global database, they can be sorted to form the local database, on the basis of a threshold.

The rest of the manuscript is organized as follows. Section 2 presents the methodology involved in solving the loss allocation problem employing game theoretic approach. Section 3 presents the hybridization of game theory approach and supervised neural networks, proposed here for the loss allocation problem. Section 4 presents the fuzzy membership approach employed for creation of the filtered local database for each transaction detail. Section 5 presents the performance evaluation for the proposed scheme. Conclusions are presented in Section 6.

2. Methodology

2.1. The loss allocation problem

In a power market, as shown in Fig. 1, having *G* number of generation companies, *D* number of distribution companies, making *J*

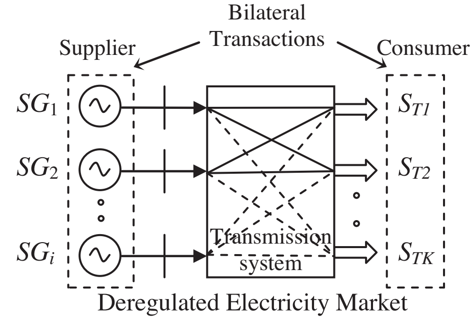

Fig. 1. Structure of a deregulated power system having bilateral transaction.