Electrical Power and Energy Systems 77 (2016) 395–403

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A new graph theory based loss allocation framework for bilateral power market using diakoptics

Dibya Bharti *, Mala De

Department of Electrical Engineering, National Institute of Technology, Patna, Bihar 800005, India

ARTICLE INFO

Article history:
Received 31 July 2015
Accepted 10 November 2015
Available online 11 December 2015

Keywords:
Bilateral power market
Graph theory
Loss allocation
Power flow
Diakoptics

ABSTRACT

Deregulation and privatization of power market worldwide has forced to identify the different ancillary services and the service providers so that all the services can be priced properly. Active power loss is a component that can never be avoided and constitutes a considerable part of economy. Hence, identification of the sources of active power loss is very important. In deregulated power market bilateral power trading plays a very important role where the amount of power and the flow path between the transacting generators and loads are fixed beforehand. But the power flow rarely follows contracted path, it flows according to physical property of the network. Graph theory based loss allocation methods are based on power flow paths and hence are more reliable. But proper transaction based power flow is not available and it makes graph theory based loss allocation for bilateral market a complex task. Present paper applies diakoptics algorithm to find out the loop flows that is the deviation from contracted path for each bilateral transaction which in turn allows finding out the loss allocated to any transaction. Diakoptics is a general concept in which larger problems are solved by dividing the larger problem into smaller problems and then finding out the overall solution by considering the solutions of each smaller problem together. The proposed method is applied to different test systems and results are discussed in detail.

Introduction

INITIALLY, the power sector was vertically integrated utility and was functioning in a monopolistic environment which means there was a single authority to generate, transmit, distribute and sell electrical energy. In the 1990's, the unbundling of ancillary services and deregulation in power sector has introduced several independent power players in generation and distribution of electricity while maintaining a single transmission system in an area. The objective behind deregulating the power sector is to induce competition by allowing several new power players which will make system reliable and profitable. But, this leads to complexities in power market because in between generation and consumption there are several owners with their own objectives.

When an entire power system is managed in monopolistic environment, path for electricity flow was of no concern. However, in the multi-layered interconnection it is an important factor due to ownership rights as the owner of the transmission line have to be paid for loss incurred in the line for wheeling power.

* Corresponding author.
E-mail address: dibya_minu1@rediffmail.com (D. Bharti).

http://dx.doi.org/10.1016/j.ijepes.2015.11.014
0142-0615/© 2015 Elsevier Ltd. All rights reserved.

The three fundamental power market models exist for electricity transaction [1]:

1. Poolco: In this model consumers can buy power only from the energy pool which purchases energy from competing generating companies i.e., Generators and loads communicate with each other through the pool.
2. Power exchange (PX): Similar to a monetary stock exchange, the PX constantly revises and declares the current price at which transactions are being done.
3. Bilateral exchange: In this model suppliers and consumers are allowed to arrange power transfer independently without any interference of system operator.

A transaction specifies the participants involved in trading amount of power and a particular time interval when it will take place. Sometimes, transactions can also specify a 'contract path' which is the desirable path that power should follow. The amount of power scheduled to flow through the specified sequence of transmission line is referred as 'contracted power'. All other paths except the intended contract path are called parallel paths and the corresponding flows are referred to as ''parallel flows or loop

Nomenclature

F^a	line flows for all lines present in reference frame 'a' in matrix form
Δ_a	voltage angle differences across lines present in reference frame 'a'
X_{aa}	diagonal reactance matrix of the network in reference frame 'a' of order ($\mathbf{l_a} * \mathbf{l_a}$)
C_{ab}	connection matrix that maps between reference frame 'a' and 'b'
F^{ibt}	internal bilateral transactions as column matrix
F^{ebt}	external bilateral transactions as column matrix
F^{ic}	internal loop flow matrix; number of element will be equal to number of loops present in a particular area
F^{ec}	external flow matrix; number of elements are dependent on number of single areas in a meshed network
l_a	number of lines present in reference frame 'a'

flows". The price of power exchange will be decided by the buying and selling company confidentially.

The existing loss allocation methods for both pool market and bilateral transaction based market can be broadly classified as: pro-rata method, incremental transmission loss based method, game theory based approach and graph theory approach. Graph Theory based methods like Impedance Matrix based method [2], Modified Y-bus method and Reachability Matrix based method [3] overcome drawbacks of other methods based on pro-rata methods and ITL methods and is based on physical flow of network. But, these methods are not well suited for bilateral transactions because these methods don't consider loop flows. Power tracing based methods provides allocation of transmission losses which uses proportional sharing assumption [4]. Also, load flow solution is the fundamental requirement for the application of this method. Based on power flow tracing methodology, topological generation and load distribution factors are determined in [5] through matrix inversion, with additional nodes added to represent line losses which makes system messy. In [6] new method is proposed which topologically determines the contribution of each generator and loads in transmission losses. In [7], new methodology based on complex power flow tracing is proposed in which transmission losses are decomposed into three components.

The methods based on circuit theory are simple and easy to implement. Z- bus matrix method [2] proposed by Conejo et al. presents a new procedure for allocating transmission losses to generators and loads in the view of pool structured market. In [8] method based on circuit theory and the concept of orthogonal projection for pool based electricity market is proposed. In 2009, Xie et al. [9] proposed and explained the power flow tracing algorithms founded in the extended incidence matrix considering loop flows.

Various other algorithms like breadth first search (BFS) technique [10] are applied along with graph theory for tracing but become very complicated in case of bilateral transaction.

Modern competitive power system structure works on the pool structure as well as on transactions where generators and loads deliver and receive power through bilateral contracts [1]. Loop flows and inter-area flows are very important in bilateral transactions because these constitute losses. For calculating these flows, a graph theory based new framework using diakoptics is proposed for flow allocation which gives information about for losses. The proposed framework enables explicit and network graph based modelling of bilateral transaction tracing and loop flow tracing together for flow allocation.

This paper is organised as follows: Section 'Problems associated with loss allocation for bilateral transaction' describes problems associated in loss allocation for bilateral transaction market using power tracing. In Section 'Proposed solution for bilateral transaction using new circuit theory based framework', new methodology for bilateral transaction tracing is discussed and the new framework is applied in 6-bus test system to show the applicability of the method. Section 'Calculations and results' summarizes the results and finally Section 'Conclusion' concludes the paper.

Problems associated with loss allocation for bilateral transaction

The main problem in allocating transmission loss to the loads or the generators is that allocations are based on assumptions and approximations which introduce certain degree of arbitrariness. This occurs because transmission loss is a non-separable and non-linear function [11] of active power. The loss allocation methods discussed in Section 'Introduction' have their merits and demerits which are presented below [11]:

1. The pro-rata method is not suitable for bilateral transactions as the allocation does not reflect the location of the load in the network. It is characterized by the allocation of electric losses proportionally to the power delivered by each generator and each load.
2. Allocation based on incremental loss coefficients has the following characteristics: (a) it may be positive and negative, (b) it depends on the choice of the slack generator, and (c) it typically results in over-recovery of loss (when the coefficients are applied directly).
3. ITL method proposes cross subsidies incorporating negative allocations and also presents high volatility and negative loss. Furthermore, it may present a high loss allocation imbalance between generation and demand.
4. Although the proportional sharing procedure takes into account the network, but its allocation trend uses load flow results. The load flow results are not available for transaction market.
5. Game theoretic solution, needs much more computational works; as many power flow analyses need to be performed for all possible coalitions among the participating players. Thus computationally, game theory based method is the costliest, but on the basis of desirability of the results, it satisfies all the involved players.
6. Network based loss allocation procedures like MW-mile method and MVA-mile method are power flow path dependent.

Many of these methods are based on some assumptions or produce allocations that are not comparable to physical network behaviour.

Problem with power tracing for bilateral market is that no proper transaction based power flow method is available. The existence of loop flows creates the difference between financial networks and the physical networks through which power is actually delivered.

In literature, bilateral transactions are usually modelled as point-to-point power injections without specifying contract paths and the resulting loop flows [12–15].