Combined Pool / Bilateral Loss Allocation in Electricity Market Using Game Theory

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Abstract: This paper presents a new and practical method for the loss allocation in the deregulation systems. The restructured markets sell the electricity in two main categories; bilateral exchanges and pool based. In reference 1, the losses in bilateral market using game theory has been assigned to each player [1]. The method which is used in this paper investigates the loss allocation in both markets. The deregulated systems are not under control of one person but there are other players such as generators and loads at which every one of such players has to pay the cost for some parts of system loss. The method used in this paper is to be fair the loss allocation. This method is consisted of two different categories; one finding the losses and the other is loss allocation using Game Theory. To test this method, IEEE 14 buses system is put in use. This paper takes the allocation of losses in the hybrid market (Combined Pool / bilateral).

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1. Introduction

Upon the deregulation practice in electricity market, many of its rules have changed. Such a change requires organizing and setting new rules by the ISO1 to maintain system stability, balance, economic operation and safety [2]. A problem that would be revealed after restructuring is the loss allocation [3].

Importance of this problem would be clearer considering to the fact that the range of these losses is expressed at 4 to 8% of the total product in different references, for instance for Brazil where such losses cost only half of a billion dollars [3].

Different methods have been used to investigate the loss allocation, which here are the most important ones:

- Pro Rata Method [2]
- Proportional Sharing [3]
- Z-bus Method [4].
- Modified Z-bus Method [5]
- Marginal Allocation Method

This method uses ITL coefficients for the loss allocation in which the coefficients are equal to the change of the entire losses made by change of power injection to a specific bus [6]. In this paper the Game theory is used for loss allocation in pool / bilateral market. Although Game Theory does not have a long term history in science, due to its high capability and applicability, the use of this theory is increasing in different branches. The applications of Game Theory can be investigated in two completely distinguished categories such as anticipation and the other is fair sharing and finding the shares of other players in the game. The first use of Game Theory is to determining the market price and suggested price for the generators [7, 8, and 9] and the second is to allocate transmission cost [10, 11]. The principle of Game Theory use can be found in reference 12 in which Shapley Value method is used to find power consumption.

In this paper the method for losses calculation, which is the same as AC Load Flow has been explained, then for the cooperation games Shapley Value method has been described finally and in simulation part, the results of proposed method, which is applied on IEEE 14 bus Standard Network, has been shown. Must be noted that loss allocation does not mean finding losses, but it is a economic mechanism after load flow [6].

2. Loss Finding Method

AC load distribution has been used for finding the cost and Newton-Raphson Method has been used for solving [14]. Load distribution or power distribution problem means presenting a solution to find voltages, power flow in lines, generators reactive power, line cost, etc; these computations would be performed in Steady state. To solve the load distribution problem following equation must be used:

$$p_i - jq_i = v_i^* \sum_{j=1}^{n} y_{ij} \; v_j \qquad (1)$$

Solving the load distribution problem, the bus voltages could be founded. Then, using following relations the loss will be founded:

$$p_{ij} + jq_{ij} = v_i \left[\frac{v_i - v_j}{z_k} + \frac{1}{2} y_k v_j\right]^* \quad (2)$$

$$p_{ji} + jq_{ij} = v_j \left[\frac{v_j - v_i}{z_k} + \frac{1}{2} y_k v_i\right]^* \quad (3)$$

$$\Delta p_{ij} = \Delta p_{ji} = |p_{ij} + p_{ji}| \quad (4)$$

$$\Delta q_{ij} = \Delta q_{ji} = |q_{ij} + q_{ji}| \quad (5)$$

To find losses in coalitions, first the flowing power of lines must be calculated for every player and according to any coalition; the answer provided for every line must be summed together.

3. Using Cooperative Game Theory

Cooperative Game theory is a method in which each player's share could be obtained from total factor [11]. Game theory in power system has been also applied to transmission costs allocation [10, 11]. The Game theory has different branches and methods, however; Shapley Value method, a method for cooperative games, has been used in this study. In this method, first the players are introduced, since the market is a bilateral market, so; any equivalent bilateral exchanges ought to be considered as a player. In Pool based market because it is not clear which of generator, what does feeding the load, Therefore, the assumption used in the previous case cannot be used. Here we want divide each load to Generators The victorious in power market. For divide this load between generators, Production of each generator must first find from total production and then multiply in size of the load. After characterizing the players, variety of coalitions should be formed. After finding variety of coalitions, share of each player from total loss could be found using following relation [10, 11].

$$x_i = \sum_{\forall s \,|\, i \notin s} p_n(s)[v(s \cup \{i\} - v(s)] \quad (6)$$

$$p_n(s) = (|s|!\,(n - |s| - 1)!)/n! \quad (7)$$

In which i= number of the players, S = coalition, |s| = number of the S coalition players, n = number of total players, V(s) = loss in S coalition and V(s-{i}) = loss in the S coalition without the i players.

4. Case Study

14 bus systems were used to test the results of the case study. Test system and results are as follows.

4.1. Case study for IEEE 14 bus network

A 14 bus system is illustrated in figure 1. 14 bus system which is meant to be used for surveying the capability of this method at putting in practice in larger systems.

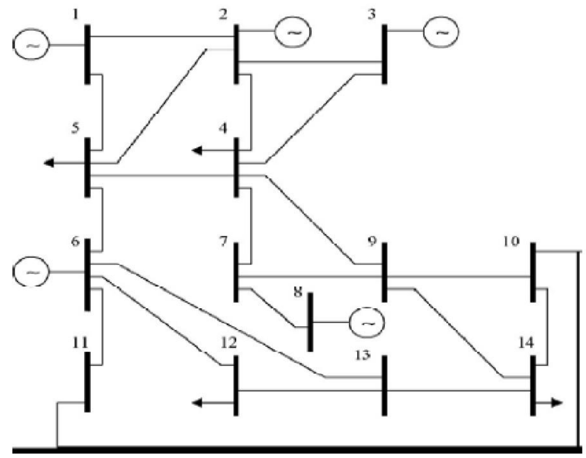

Figure 1: One line diagram of IEEE 14 bus system

Specification Lines of the IEEE 14 Bus System

The specification lines of the IEEE 14 bus system is mentioned in Table 1.

Table 1: Information about 14 bus network

B	x	R	To bus	From bus	Line#
0.0528	0.0592	0.0194	2	1	1
0.0528	0.2230	0.054	5	1	2
0.0438	0.1980	0.047	3	2	3
0.0374	0.1763	0.0581	4	2	4
0.0340	0.1739	0.057	5	2	5
0.0346	0.1710	0.067	4	3	6
0.0128	0.0421	0.0134	5	4	7
0.0000	0.2091	0.0001	7	4	8
0.0000	0.5562	0.0001	9	4	9
0.0000	0.2520	0.0001	6	5	10
0.0000	0.1989	0.095	11	6	11
0.0000	0.2558	0.1229	12	6	12
0.0000	0.1303	0.0662	13	6	13
0.0000	0.1762	0.0001	8	7	14
0.0000	0.1100	0.0001	9	7	15
0.0000	0.0845	0.0318	10	9	16
0.0000	0.2704	0.1271	14	9	17
0.0000	0.1921	0.082	11	10	18
0.0000	0.1999	0.2209	13	12	19
0.0000	0.3480	0.1709	14	13	20

Player's Introduction

In bilateral exchange each contract as a player of the game will consider. Therefore by having two bilateral contracts we also have two players are as follows:

Table 2: bilateral contract table

Number	Gen		Load	
	Bus	P gen	Bus	P load
1	3	50	4	50
2	6	50	12	50

After identifying bilateral contract players, we examined the pool market. Due to existence of two loads in pool market will have two players:

Table 3: pool type players table

Number	Load		Gen	
	Bus	P load	Bus	P gen
3	5	50	1	8
			2	21
			8	21
4	14	50	1	8
			2	21
			8	21

In next step with revealing players will be to form coalitions and found losses in any coalition. In next step, losses will be allocated to the players of the game using Shapley value. After finding share of each player this share should be divided between generators and loads of each player. This rate for bilateral contract has as 50 to 50. But for pool players According to the load supply factor was a must operate

Table 4: Loss in coalitions

Number	Player	Loss
1	0	0
2	1	1.614
3	2	2.663
4	3	0.74
5	4	2.554
6	1-2	3.814
7	1-3	2.039
8	1-4	3.970
9	2-3	2.899
10	2-4	2.867
11	3-4	3.073
12	1-2-3	4.06
13	1-2-4	4.17
14	1-3-4	4.666
15	2-3-4	5.594
16	1-2-3-4	7.214

Table 5: Allocated loss to the players

Player	P loss
1	1.4688
2	2.0873
3	1.3501
4	2.3079

Table 6: Loss allocated to each player

Player	P loss	Gen		load	
		Bus	Ploss allocation	Bus	Ploss allocation
1	1.4688	3	0.7344	4	0.7314
2	2.0873	6	0.3672	12	0.3672
3	1.3501	1	0.1032	5	0.6451
		2	0.2709		
		8	0.2709		
4	2.3079	1	0.2142	14	1.1534
		2	0.6104		
		8	0.6104		

Now losses must be add together which related to generators that exist in several player and found total losses allocated to them.

Table 7: loss allocated to Gens and Loads

bus	P loss allocated
1	0.317
2	0.880
3	0.734
4	0.731
5	0.645
6	0.367
7	0
8	0.880
9	0
10	0
11	0
12	0.367
13	0
14	1.153

5. Conclusion

According to the change in electricity market from traditional to deregulation, loss allocation is necessarily unavoidable. The importance comes from the matter that the nonlinear functional loss of the power, therefore a method should be used which considers both the players (generators and loads) and network's features. Restructuring electrical energy markets, the share determination for each load and generator from total loss has been unavoidable. It should be performed honestly and all loads and generators should participate. The method has been used in this paper is based on cooperating Game Theory. This method has been applied on 14 bus IEEE system. The advantage of this approach rather than the previous ones is that, this method does not need the inverted matrix, which also includes the active and reactive losses. Both factors consider the network's feature and support decreasing losses.

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