Proceedings of the Fourth IASTED International Conference
POWER AND ENERGY SYSTEMS (AsiaPES 2008)
April 2-4, 2008 Langkawi, Malaysia
ISBN CD: 978-0-88986-732-1

SECURITY COST ALLOCATION UNDER COMBINED BILATERAL-POOL MARKET DISPATCH

M.P. Abdullah, M.Y. Hassan, and F. Hussin
Department of Power Engineering
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
Malaysia
pauzi@fke.utm.my

ABSTRACT

This paper proposes a security cost allocation method in a combined- bilateral-pool market structure. The security cost presented here is the cost of congestion relief. It is suggested that the pool market does any generation adjustments for congestion relief but the incurred security costs are shared between bilateral and pool market. The costs allocated to the bilateral market are further allocated to each bilateral transaction based on their contribution to security problem. This paper begins by discussing the congestion management and security cost allocation in a pool market model and the concept of bilateral market. Then the proposed security cost allocation strategy of the combined bilateral-pool market is presented. Case studies using IEEE-14 bus system are presented to test the proposed method.

KEY WORDS

System operator, pool market, bilateral market, congestion, security cost allocation

1. Introduction

Prior deregulation, power system generation, transmission and distribution were owned and operated by one utility. The system operator is part of the utility, is responsible in maintaining security and reliability of the system. When security problem occurs in a system, the SO would reschedule the generators output at minimum cost. The incurred cost due to generators rescheduling is already included in the cost of electricity service to all customers in electricity tariff.

Deregulation has resulted in the breakdown of the big power utility into generation, transmission and distribution services. The SO is no longer part of the big utility but still responsible for maintaining security of the system. Energy trading does not take security cost into consideration. Thus, when congestion occurs in power system operation, the incurred cost due to generation re-dispatch must be recovered from market participants. This is done through security cost allocation to assign each market participant its share of security costs. Many congestion management methods have been applied or proposed for pool-based and bilateral-based electricity market [1-4]. In the case of pool market, congestion problem is handled similar to the traditional power system, where the problem is relieved by re-dispatching generators output. However, the generation costs are replaced by energy bid prices in which each generator indicates the price it is willing to accept in order to increase its output. The security cost is allocated to the loads using uniform pricing or nodal pricing method. Uniform pricing allocates the security cost uniformly to all loads disrespect of their location in the system. In other words, all loads equally share the security cost disregarding their impact on security problem. Nodal pricing on the other hand reflects the loads location in the system. However the method introduces merchandising surplus problem [5]. For bilateral based electricity market, congestion problem is managed differently as the system operator doesn't have control on generators output and does not have price information of the bilateral contracts. The main reason is that in bilateral market the generators are normally self-dispatched. The easiest way to solve security problem in this type of market is to curtail the bilateral contracts [6].

In practice, most of electricity markets in the world are combination of bilateral and pool market such as NordPool and NYPOOL [7, 8]. In these models, market participants not only bid into the Pool but may also make bilateral contracts with each other. In this paper the security cost allocation in a combined bilateral-pool market model is considered.

2. Pool and Bilateral Market

The operation of the Pool typically includes two distinct stages [4] ie. Market dispatch and congestion-constrained dispatch. During the market dispatch, generators are placed in an ascending order according to their bid prices. A sufficient number of the least expensive generators are then selected to meet system predicted demands and the market-clearing price is determined by the most expensive bid that has been accepted. The System

Marginal Price (SMP) is determined by the point of intersection of supply and load curves in the bid price vs generator power output graph as shown in figure 1. (ie. $SMP = \alpha_{G3}$). The SMP is the marginal cost of the marginal unit in the absence of transmission constraints. That is, the SMP is only determined from the generators bids but independent of system physical constraints. Next, the SO will evaluate if transmission constraints would occur under the unconstrained dispatch. If there is no congestion, the dispatch obtained from the market dispatch stage is executed and the clearing price is published. If there are constraint violations, the SO would execute a congestion-constrained dispatch. If the price elasticity effects are neglected, the market dispatch algorithm in the absence of system losses and constraints may be stated as an optimization problem of:

$$\min \sum_{i=1}^{N_G} \alpha_{Gi} P_{Gi} \tag{1}$$

$$\text{subject to: } \sum_{i=1}^{N_G} P_{Gi} = \sum_{i=1}^{N_D} P_{Di} \tag{2}$$

$$0 \le P_{Gi} \le P_{Gi}^{\max} \tag{3}$$

where:

N_{Gi} : number of generator bus

N_{Di} : number of load bus

α_{Gi} : bid price of generator *i*

P_{Gi} : power output of generator *i*

P_{Gi}^{0} : initial power output of generator *i*

$P_{Gi}^{\max}$: maximum power output of generator *i*

P_{Gi}^{adj} : final adjustment on power output of generator *i*

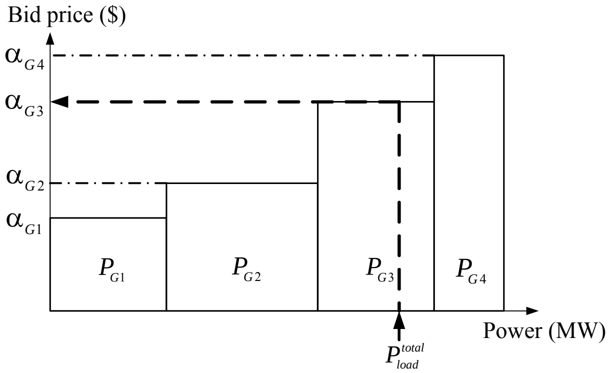

Figure 1. The aggregate supply curve from submitted bids

If the initial generator dispatch cause congestion to the system (line overload), the ISO will implement congestion constrained dispatch. This is done by adding the following inequality constraint to the optimization function:

$$P_{kl} \le P_{kl}^{\max} \tag{4}$$

$$P_{kl} = P_{kl}^{0} + \sum_{i=1}^{N_G} a_{kl,i} \left(P_{Gi}^{adj} - P_{Gi}^{0} \right) \tag{5}$$

where:

P_{kl}^{0} : initial power flow on line k-l

$P_{kl}^{\max}$: maximum power flow on line k-l

$a_{kl,i}$: DC-Power Transfer Distribution Factor, the sensitivity of the flow on line k-l due to a change in generation bus i [9]

By solving the optimization problem, equation (1)-(5), the optimal market dispatch and congestion-constrained dispatch for the generators can be determined. The difference between the total generation cost in optimal market dispatch and congestion-constrained dispatch gives the security cost of the system.

In the old E&W pool market, this cost is regarded as part of system uplift [4]. It is allocated equally to the loads disregarding their actual contribution to security problem by using the following equation;

Security Cost allocated to load *i*,

$$SC_{load\ i} = \left(\frac{total\ security\ cost}{total\ system\ load} \right) \times \left(MW\ demand\ of\ load\ i \right) \tag{6}$$

In bilateral-based market, a load is free to purchase electrical energy from any generator. The energy purchasing is done through bilateral contract between a load and its chosen generator, which specifies the amount of contractual energy and the time period that the energy would be delivered. Once bilateral contract has been agreed, the participants inform their quantities to the SO. The SO task is either accept or reject the submitted contract given by the participant. It is generator and load responsibility to ensure that the agreed contract does not violate system security and physical constraints or risking rejection from the SO.

3. Proposed Security Cost Allocation Method

The formulations used here adopt the mixed pool/bilateral dispatch presented in [10]. However, the equations have been simplified into a set of real power equations. The reason is to make the DC-based sensitivity factor applicable to the equations.

3.1 Market operation

The market participants are firstly traded in bilateral market. The participants that not settle in bilateral market will enter pool market by submitting their bid energy volume and bid price to the ISO. It is noted that the bid energy volume submitted in pool market must not include the amount of energy that has been traded in bilateral market. The optimization problem of the pool section of the combined bilateral-pool market dispatch is given by:

$$\min \quad \sum_{i=1}^{N_G} \alpha_{Gi} P_{Gi}^{pool} \tag{7}$$

$$\text{subject to} \quad \sum_{i=1}^{N_G} P_{Gi}^{pool} = \sum_{i=1}^{N_D} P_{Di}^{pool} \tag{8}$$

$$P_{Di}^{pool} = P_{Di}^{total} - P_{Di}^{bil} \tag{9}$$

The congestion-constrained dispatch:

$$P_{kl}^{pool} \le P_{kl}^{\max} - \sum_{all\, T_p} P_{kl,T_p}^{bil} \tag{10}$$

$$P_{kl}^{pool} = \sum_{i=1}^{N_G} a_{kl,i} \left(P_{Gi}^{pool} - P_{Gi}^{bil} \right) \tag{11}$$

3.2 Security cost calculation

The total security cost of the combined bilateral-pool system comes from the pool market. The calculation of security cost is given by:

$$SC^{total} = \left\{ \min \sum_{i=1}^{N_G} \alpha_{Gi} P_{Gi}^{pool} \right\}_{\substack{congestion- \\ constrained}} - \left\{ \min \sum_{i=1}^{N_G} \alpha_{Gi} P_{Gi}^{pool} \right\}_{\substack{market \\ dispatch}} \tag{12}$$

3.3 Security cost allocation

Basically the paper adopts the cost allocation method proposed in [11] for a pure bilateral market model. The method consists of two steps. The first step is to allocate the cost of congestion relief (security cost) to the congested line. The marginal and incremental cost of relieving each congested line is calculated, and then the average of these two costs is assigned to the line as an aggregated cost. In the second step, the cost allocated to each line is further allocated to the transactions that contribute to the flow in the line. However certain modification has been made for our proposed combined bilateral/pool market dispatch. Instead of allocating the cost to the transactions only, the cost is also allocated to the pool. Therefore the security cost is shared by both pool and bilateral market.

The main steps of the security cost allocation method are as follows:

1) Step 0: With all constraint are respected, the total security cost (rescheduling cost) of the combined pool-bilateral market dispatch is determined, SC^{total}.

2) Step 1: The flow in each line is represented by equation (10). If the equation is bounded, the line is congested and hence contributing to security cost. All bounded equations (ie. lines; *l* = 1, 2,… L) are determined.

- Consider only the congested line, *l* and determine the rescheduling cost that makes the line comply with security criterion SC_l^{mg}. This is the marginal cost associated with line *l*.
- Consider all lines except the congested line, *l* and determine the rescheduling cost that makes the line comply with security criterion, SC_l^{L-l}. The incremental cost associated with line *l* is then $SC_l^{in} = SC^{total} - SC_l^{L-l}$. Calculate the aggregated security cost allocated to line *l* as $SC_l = \frac{1}{2}\left(SC_l^{mg} - SC_l^{in} \right)$

3) Step 2: Distribute the cost allocated to each line to the appropriate bilateral transactions and the pool, based on their contribution to the flow of the congested line. A clear source and sink of bilateral transaction contract makes the tracing of power flow due to each transaction possible. This is great advantage in determining the contribution of each transaction to the flow of each line. Consider that a generator m and load n signed a bilateral contract T_p, the power flow of line k-l (line *l*) with respect to bilateral transaction T_p (with ΔP_{mn} energy contract) is given by:

$$P_{l,T_p}^{bil} = \left(a_{kl,m} - a_{kl,n} \right) \Delta P_{mn} \tag{13}$$

Correspondingly, the power flow in line *l* due to pool market is:

$$P_l^{pool} = P_l^{total} - \sum_{all\, T_p} P_{l,T_p}^{bil} \tag{14}$$

Therefore the contribution of each bilateral transaction and pool market to the power flow in security violated line, *l* is given by:

$$Ctrb_{l,T_p}^{bil} = \frac{P_{l,T_p}^{bil}}{P_l^{total}} \tag{15}$$

$$Ctrb_l^{pool} = \frac{P_l^{pool}}{P_l^{total}} \tag{16}$$

$$\text{where:} \quad P_l^{total} = \sum_{all\, T_p} P_{l,T_p}^{bil} + P_l^{pool} \tag{17}$$

Neglecting counterflow: To neglect the contribution of counterflow, the negative $P_{l,Tp}$ gained from equation (13) is replaced by zero.

Finally, the security cost allocated to the pool market and each transaction of the bilateral market are given by:

$$SC^{pool} = \sum_{all\, l} Ctrb_l^{pool} P_l^{total} \times SC_l^{total} \tag{18}$$

$$SC_{T_p}^{bil} = \sum_{all\, l} Ctrb_{l,T_p}^{bil} P_l^{total} \times SC_l^{total} \tag{19}$$

For each transaction, the allocated security cost is shared between generator and load based on the agreed percentage in their bilateral contract. For the allocation form the pool market, the proposed method adopts uniform pricing (as practiced in the old E&W market) strategy rather than nodal pricing to prevent merchandising surplus problem.

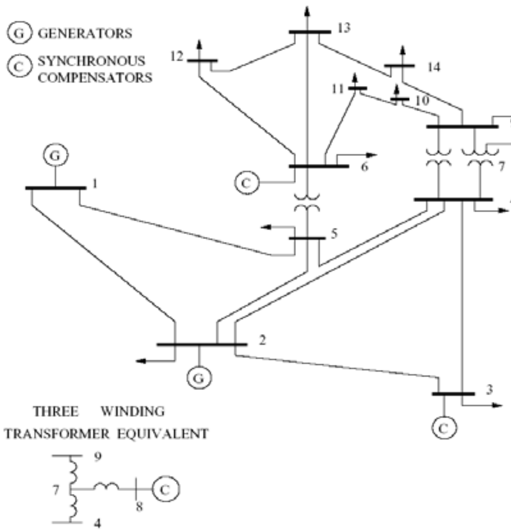

Figure 2. The IEEE-14 bus system

4. Test System

The proposed security cost allocation strategy is tested on the IEEE-14 bus system shown in Figure 2. The condenser at bus 3, 6 and 8, are replaced by generators. The system consists of five generators and 11 loads. The maximum output of each generator is 200MW, while the energy demand of each load is 60MW. The line limit of each line is 200MW except for line 5-6 which is 100MW. 50% of energy demand of each load is bought through bilateral market while the remaining is bought through pool market.

4.1 Case study 1

In this case study, the bilateral contracts between the generators and the loads are given in Table 1 (e.g. T1 represents a bilateral transaction between generator 1 and load 2 of 30MW). In pool market, the bid price of the generators are: Gen 1=$20/MW, Gen 2=$27/MW, Gen 3=$35/MW, Gen 6=$45/MW, Gen 8=$50/MW. Under market dispatch through equation (7)-(9), the resulted flow in line 5-6 is 136.22MW, which exceeds the line 5-6 limit of 100MW (i.e. congested). The line is secured through congestion re-dispatch at a cost of $614.98. By using the proposed method, the flow contribution of each market to the flow in the congested line (line 5-6) is given in Table 2, in which the resulted flow in the combined-market is divided between bilateral and pool market. For bilateral market, the flow contribution of each transaction to the congested line is shown in Table 3 (e.g. T6 contributes 8.1690MW of flow to the congested line). Assume that the allocated security cost of each transaction is burden to the load and the pool allocated security cost is further allocated uniformly to pool market participants. The total security cost allocated to each load from bilateral and pool market is shown in Figure 3. The results show that load 6 is allocated with the highest security costs. This is expected as load 6 has a bilateral contract with generator 3, which clearly contributes to the flow in the congested line (line 5-6) as shown in Table 2. Load 5, 10, 12 and 13 are allocated with minimum cost as their transaction in bilateral market cause counterflow to the congested line. The proposed method rewards these transactions by allocating them with zero security cost from bilateral market. Thus, only security costs from the pool market are allocated to them. For comparison, the method where all security cost is allocated to the pool alone is also shown in Figure 3. It is observed that the method allocates the security cost uniformly to all loads without reflecting their contribution to security problem.

Table 1
Designated bilateral contracts between generators and loads

Trans	Gen.	Load	Quantity (MW)
T1	1	2	30
T2	1	3	30
T3	2	4	30
T4	2	5	30
T5	3	6	30
T6	3	9	30
T7	6	10	30
T8	8	11	30
T9	6	12	30
T10	6	13	30
T11	8	14	30

4.2 Case study 2

This case study investigates the security cost allocations when the loads trading strategy changes. Load 6 is now bought 30MW from generator 6 instead of generator 3 while load 10 bought 30MW from generator 3 instead of generator 6. As mentioned, the proposed method reflects the bilateral market participants' contribution to security problem. Thus when their trading partner changes, their flow contribution to the congested line changes and thus the allocated security cost will also changes. Figure 4 shows that the allocated security cost to load 6 has reduced, as its transaction no longer contributes to the flow in the congested line. The bilateral transaction of load 10 is now contributing more flow to the congested line and hence its security cost allocation has increased. This characteristic encourages participants to adjust their transaction so that congestion can be prevented in future trading.

Table 2
Power flow contribution of each market to the congested line (line 5-6)

	Power flow contribution to line 5-6 (MW)
Bilateral Market	32.59
Pool Market	103.63
Combined-Bilateral-Pool Market	136.22

Table 3
Power flow contribution of each transaction (of the bilateral market) to the congested line (line 5-6)

Transaction	Power flow contribution to line 5-6 (MW)
T1	0.1350
T2	0.5220
T3	0.7230
T4	-0.6480
T5	19.2300
T6	8.1690
T7	-9.0960
T8	9.1320
T9	-0.8760
T10	-1.5570
T11	6.8550
Total	32.59

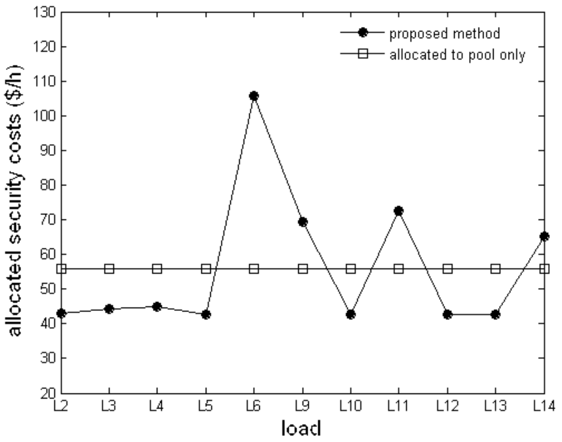

Figure 3. Security cost allocation using the proposed method

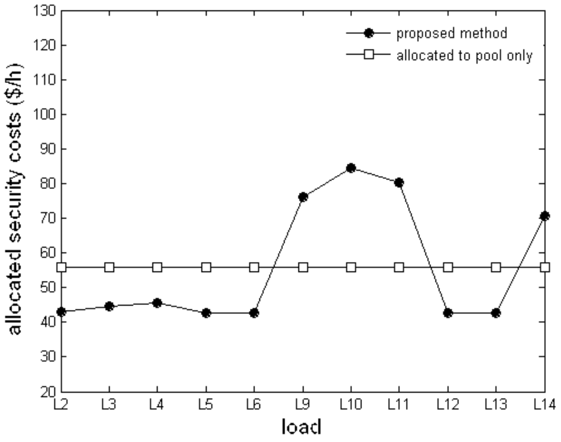

Figure 4. Security cost allocation with adjusted bilateral contract

5. Conclusion

A proposed security cost allocation strategy of a combined bilateral-pool market design is presented in this paper. The basic idea is to divide the incurred security cost due to congestion relief into pool and bilateral market based on their flow contribution to the congested line. Using the proposed method, it is showed that the security cost is allocated to market participants at different price which reflecting the load contribution to the security problem. This solves the problem of the uniform security cost allocation in a pure pool market system (with uniform pricing) and provides proper security signal to market participants.

References

[1] M. Bjørndal, K. Jörnsten, and V. Pignon, Congestion management in the Nordic power market: counter purchases and zonal pricing. A discussion paper, Department of Finance and Management Science, Norwegian School of Economics and Business Administration, 2002.

[2] A. K. David and R. S. Fang, Congestion management of electric power systems under open transmission access, *IEE Conference Publications*, *1997*, 1997, 469-474.

[3] M. Lommerdal and L. Soder, Combination of two methods for congestion management, *Proceedings of the 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies,* 2004.

[4] K. L. Lo, *Lecture notes*: *Power System Economics* (Glasgow: Strathclyde University, 2002).

[5] J. W. Bialek, Elimination of merchandise surplus due to spot pricing of electricity, *IEE Proceedings - Generation, Transmission and Distribution*, *144*, 1997, 399-405.

[6] R. S. Fang and A. K. David, Transmission congestion management in an electricity market, *IEEE Transactions on Power Systems*, *14*, 1999, 877-883.

[7] R. D. Christie and I. Wangensteen, The energy market in Norway and Sweden: the spot and futures markets, *IEEE Power Engineering Review, 18*, 1998, 55-56.

[8] B. Kranz, R. Pike, and E. Hirst, Integrated Electricity Markets in New York, *The Electricity Journal*, *16*, 2003, 54-65.

[9] A. J. Wood, *Power Generation Operation and Control* (New York: John Wiley & Sons, Inc., 1996).

[10] F. D. Galiana, I. Kockar, and P. C. Franco, Combined pool/bilateral dispatch. I. Performance of trading strategies, *IEEE Transactions on Power Systems, 17*, 2002, 92-99.

[11] M. E. Baran, V. Banunarayanan, and K. E. Garren, Equitable allocation of congestion relief cost to transactions, *IEEE Transactions on Power Systems,* 15, 2000, 579-585.