Energy and Reserve Market Clearing to Consider Interruptible Loads

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Received 13 October 2015; accepted 29 November 2015

Abstract

This paper demonstrates a method to how reserve capacity and cost allocation could be determined in a pool-based and disaggregated market model. The method considers both the spinning reserve and interruptible loads as the operating reserve services. In the proposed market, generators and consumers (including participation of interruptible loads) submit offers and bids to the independent system operator. Firstly, the energy market is cleared according to GENCOs' offers and customers' energy requirements. To make; the more competitive market, interruptible customers participate in reserve market and supply operating reserve. It is assumed that the operating reserve market structure cleared in two-stages. Based on the reliability evaluation of the generators, market operator (MO) clears the reserve market. According to the contribution of generation units to the system expected energy not supplied, reserve cost of this level is allocated among them. In the second section of the reserve market clearing, customers can choose their desired reliability requirements. The independent system operator is cleared reserve market such that the required reliability levels of the customers are met. Reserve cost associated with this part is allocated among customers that are willing to have a higher reliability level than the standard level. To determine the share of each consumer from a shortage in the real time operation, Deficiency Factor is introduced. Finally, numerical results are presented to illustrate the impact of the reserve cost allocation and effectiveness of participations' demand side on the operating reserve market.

Keywords: disaggregated Energy and Reserve Market, Interruptible Load, operating Reserve, Expected Energy Not Supplied (EENS).

1. Introduction

Ancillary service is providing from a market auction in restructured power market. When power system encounters unexpected generation outage, ancillary services are important commodities to control and satisfy the system reliability and security [1]. In a competitive electricity market, consumers buy energy and they should pay ancillary service price, transmission and distribution price too [2]. Ancillary services are an important commodity in power market and it includes interruptible loads, spinning reserve (SR) and non-spinning reserve and etc. [3].

Demand-side management (DSM) is used in Ref. [4]. Such that optimal power flows (OPF) evaluates benefits of it. The effect of location demand load is investigated. Variation of characteristics of loads is demonstrated too.

Reference [5] refers to integrated spinning reserve market. Total payment of energy and spinning reserve are minimized in this model.

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In Ref. [6], in a deregulated electricity system consumers can choose their desired reliability level and they can buy reserve directly. The effect of reserve purchase is investigated in this paper.

In Ref. [7], the flexibility of operating reserve capacity is referred. Optimum reserve capacity evaluated based on the reliability of power system. Unit commitment (UC) program and reliability are used to determine the reserve capacity [8, 9]. In Ref. [10], priority list (PL) is used to solve the Unit commitment (UC) by a system operator.

Schedule generating units are investigated in Ref. [11]. The risk indices are used to present. The cost-benefit analysis estimates the optimal value of risk indices.

Ref. [12, 13] presents participation of demand side in simultaneous energy and reserve markets. The interruptible load is one of the subclasses of the demand side. IL use for satisfying the reliability of power system when event occurs. IL reduces system operation cost.

Interruptible loads (IL) participation in energy and reserve markets demonstrate in this approach. All of the constraints are neglected [14].

In [15], demand side uses totally. A perfect mechanism of demand response has been presented in this study. Shift able demand bids are demonstrated in the energy market.

Hierarchical level II (HLII) is used to estimate the reliability. On the other hand, an influence of interruptible loads' position in the power system is considered [16]. Stochastic Security Constrained Unit Commitment (SCUC) program has been presented in [17]. Spinning reserve and the demand side reserve are modeled as Emergency Demand Response Program (EDRP).

Changes of demand side and load by ISO have been presented with a usage of Emergency Demand Response Program and Time-of-Use [18–19].

System operator and demand side use a short notice time without consideration of interruption time. The interruptible load is formed in this time by system operator [20].

In the present paper, we propose a new model for reserve capacity determination and reserve cost allocation and analyse a reserve market model in which both generating units and customers are participants in it. In this auction, the cost of reserve allocates among generators and customers. On the other hand, it is shown that the interruptible loads will be effective on the energy and reserve market and operation price. Modified IEEE reliability test system is used to present the effectiveness of the proposed mechanism.

Article’s structure is organized as follows: In Section 2, generating unit and interruptible load models is presented. Section 3 details the objective function. A numerical study is presented in Section 4. Finally, the conclusion of the analysis is given in Section 5.

2. Generating Unit and Interruptible Load Models

Operating reserve can be generally divided into two classes of unit reserve and system reserve. The unit reserve is provided by generating units and it can be in the form of spinning and stand-by units. System reserve refers to an interruptible load, automatic load shedding, and under frequency relaying [23]. In this article, Spinning reserve and interruptible load are used.

Ideally, an interruptible load may be treated as a participant that never fails to function. However, in the real system, the interruptible load can reject the request or fail to perform when the system demands [25]. When an interruptible load is assumed to be available with a probability of unity (fully reliable), it can be modeled as an equivalent generating unit with zero failure rate or considered as a load variation [23]. Figures1 and 2 show these two models.

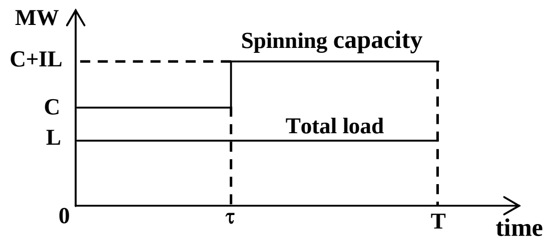

Fig. 1. Equivalent unit approach model for interruptible load

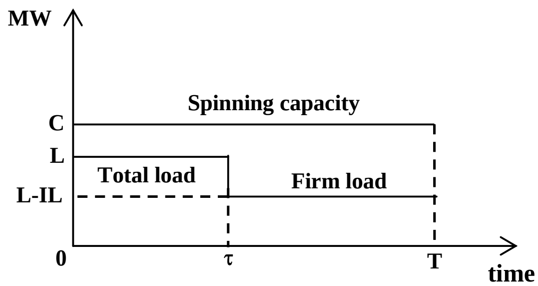

Fig. 2. Load variation approach model for interruptible load

When interruptible load fails to comply, after reserve requirement notification, it can be modelled using two approaches. The first one is the equivalent unit approach with a nonzero failure rate and the second one is the load variation approach accompanied with conditional probability concepts [29]. In this study, load variation approach is used for the purposed mechanism.

3. The Objective Function

3.1. Energy and Reserve Market Model

In this article, producers and consumers participate in a pool-based and disaggregated market structure by submitting offers to sell and bids to buy to a market operator. Independent system operator (ISO) analyse a market model in which both generators and loads are participants in an energy and reserve auction.

Note that the generating units may not produce sufficient capacity to meet the reserve requirement. In this condition, the available reserve in the reserve auction is less than the system reserve requirements to provide the security of the power system in the emergency events. In this paper, interruptible loads (IL) have been considered as one the system reserve resources. In order to obtain this purpose, a part of loads interrupt voluntarily by customers in response to ISO emergency hours.

In the proposed method, expected energy not supplied (EENS) index is used for reserve market clearing. After clearing the energy market, ISO declares the standard expected energy not supplied (SEENS) and then determines the share of each generating unit in EENS. In order to satisfy the SEENS, ISO procures reserve from operating reserve market (including spinning reserve and demand side). To enhance the reliability of the generators, reserve cost of this level allocates among producers, according to the participation of them to the need for provided reserve. Obviously, Generating companies which are unreliable should pay the price more than other units.

To prevent the cost increase of electrical energy by generating units, the price of this part of supplying the reserve should be divided among the unreliable generators. Section 3.2 details the EENS cost allocation of reserve among generators.

To improve the operation of the markets, the participation of the customers should be more actively and effectively in electricity markets. In this article, customers can choose their required reliability level, therefore, the customers are willing to have a lower portion of the power system shortage should pay more cost than others. It is assumed that there are N customers who declare N desired EENS to ISO. This means that ISO arranges them according to their reliability requirements and procure the reserve such that their desired expected energy not supplied (DEENS) are met.

In this paper, deficiency factor is introduced for the first time. When in the real time operation, power system encounters with Tripp of generating units, ISO uses deficiency factor as remedial action. Deficiency factor index calculates the share of each consumer from the remedial action. Based on customers' deficiency factors, associated cost divide between them.

The proposed method is also similar to an insurance theory [21] in which customers pay to the ISO. This theory increases the market efficiency, social welfare, and benefits all participants [26].

3.2. Satisfying Standard Expected Energy not supplied in Reserve Market Clearance

At first, the energy market is cleared according to systems' offers by ISO. It must be pointed out that the principle of clearing energy market is under the pay-as-bid mode. In this step, the energy market price is allocated among customers. Then, according to forced outage rate of producers in the energy market, the reserve is provided by committed generators and demand side such that the EENS is satisfied. Producers are forced to pay the EENS cost on the basis of their contribution to the provided reserve.

Our proposed algorithm for satisfying the EENS will briefly introduce the solution process in Fig.3 with the following:

1. Scheduling the units with consideration of generating unit offered cost and customer energy requirements. In the restructured power system, the main function of the independent system operator is to minimize the cost of energy production and maximize the social welfare. In order to obtain this objective, market clearance function can be formulated as follows:

$$Min\sum_{i=1}^{N_g} GC_i(P_{gi}) \qquad (1)$$

Here, GC_i is the energy production cost of *i*-th generator. P_{gi} is the generation of *i*- th generator and N_g is the number of generating units.

For the sake of simplicity, market operator clears the energy market for one hour and the constraints for the objective function are given by

- System power balance

$$\sum_{i=1}^{N_g} P_{gi} = \sum_{j=1}^{N_c} L_j \qquad (2)$$

- Unit generation output limits

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad (3)$$

Where

L_j The load of *j*-th customer;

$P_{gi}^{\min}$ Lower limit of power output of *i*- th generator;

$P_{gi}^{\max}$ Upper limit of power output of *i*- th generator;

N_c Number of consumers

2. Scheduling spinning reserve of committed units and considering the participation of interruptible loads as an emergency reserve in the reserve market.

3. Determining system reserve requirements (PR_1, set $PR_1 = 0$).

4. Calculating the share of each generating unit in expected energy not supplied. $EENS_i^g$ is computed by Eq. (5) in Section 3.3.

5. Forming the capacity outage probability table (COPT) and calculating the system expected energy not supplied ($EENS_{sys}$) by COPT.

6. Providing required reserve from the auction such that $EENS_{sys} \le SEENS$.

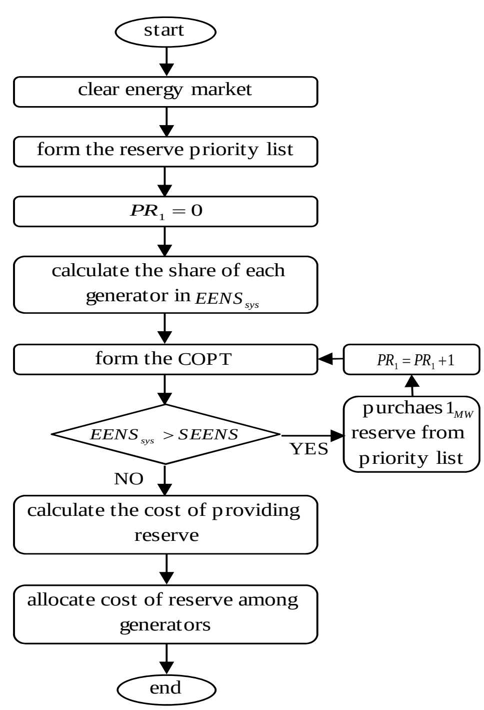

Fig. 3. Energy and reserve market clearing for satisfying SEENS

7. Calculating the reserve commodity cost associated with generators. This part of reserve cost is named as RC_1 .

8. Allocating RC_1 among producers, according to generators participation to the need for a reserve. This method is described in Section 3.4.

3.3. Determining the Expected Energy not Supplied

This section describes the details of the evaluation process of EENS. As mentioned before, based on the reliability evaluation of the generating companies, the reserve cost for satisfying the EENS, should be shared among the generators. Hence, the expected energy not supplied by each generating unit and the system expected energy not supplied should be calculated. The amount of $EENS_{sys}$ can be defined as:

$$EENS_{sys} = \sum_{i=1}^{N_g} EENS_i^g \tag{4}$$

Here, $EENS_i^g$ is the expected energy not supplied of i -th generator.

For calculating expected energy deficit attributable to generator *i*, the impact of generator outage probability due to first- , second-order and other should be determined as follows:

$$EENS_i^g = portion_i^1 . EENS_i^1 + \sum_{j=1, j\neq i}^{N_g} portion_i^2(i, j).EENS_{i,j}^2 + \sum_{j=1, j\neq i}^{N_g} \sum_{k>j, k\neq i}^{N_g} portion_i^3(i, j, k).EENS_{i,j,k}^3 + ... \tag{5}$$

Where

$$EENS_i^1 = (P_{gi} + R_{gi} - r).q_i \times \prod_{u=1, u\neq i}^{N_g} (1 - p_u) \tag{6}$$

$$EENS_{i,j}^2 = (P_{gi} + R_{gi} + P_{gj} + R_{gj} - r).q_i q_j \times \prod_{u=1, u\neq i,j}^{N_g} (1 - p_u) \tag{7}$$

$$EENS_{i,j,k}^3 = (P_{gi} + R_{gi} + P_{gj} + R_{gj} + P_{gk} + R_{gk} - r).q_i q_j q_k \times \prod_{u=1, u\neq i,j,k}^{N_g} (1 - p_u) \tag{8}$$

Where

$EENS_i^1$ Energy deficit following an outage of i -th generator;

$EENS_{i,j}^2$ Energy deficit following simultaneous outages of i -th and j -th generator;

$EENS_{i,j,k}^3$ Energy deficit following simultaneous outages of i -th and j -th and k-th generator;

$portion_i^1$ Deficit contribution parameter;

r Required amount of reserve;

p_u Outage replacement rate of all other units are not outage;

q_k Outage replacement rate of unit k ;

R_{gi} Spinning reserve amount contributed by generator i ;

If the provided reserve is not sufficient to cover the loss of the generator i , the energy shortage is given as $(P_{gi} + R_{gi} - r)$. This amount of shortage related to a single unit failure. Therefore, this unit is responsible for expected energy not supplied and the shortage portion parameter $portion_i^1$ is equal to 1. On the other hand, if two random generating companies are outaged at the same time, energy deficit increase. The second-order outage event is equal to $\frac{N_g \times (N_g - 1)}{2}$ and the shortage portion parameters in 1st and 2nd order, $portion_i^2(i, j)$ and $portion_i^3(i, j, k)$ are used as follows:

$$portion_i^1 = 1$$

$$portion_i^2(i, j) = \frac{(P_{gi} + R_{gi})q_i}{(P_{gi} + R_{gi})q_i + (P_{gj} + R_{gj})q_j} \tag{9}$$

$$portion_i^3(i, j, k) = \frac{(P_{gi} + R_{gi})q_i}{(P_{gi} + R_{gi})q_i + (P_{gj} + R_{gj})q_j + (P_{gk} + R_{gk})q_k}$$

After defining the expected energy not supplied, the EENS cost of this part allocates among generators corresponding to the described method in Section 3.4.

3.4. Operating Reserve Cost Allocation among Generating Companies

As mentioned before, corresponding to system reserve requirements, ISO purchase reserve from the auction (including spinning reserve and demand side) such that the SEENS is satisfied. Provided reserve cost that is called RC_1, allocates between generators according to their share of EENS. Share of the reserve cost of each generating unit is defined as below:

$$RC_i = RC_1 \times \frac{EENS_i^g}{EENS_{sys}} \quad (10)$$

$$RC_1 = \sum_{i=1}^{N_g} (R_{gi} \times RC_{gi}) + \sum_{k=1}^{N_c} (ILP_k \times IL_k) \quad (11)$$

Where

RC_1 Reserve commodity cost associated to the reserve market clearing;

ILP_k Interruptible load price of customer k ;

IL_k Interruptible load k contributed as emergency reserve;

RC_{gi} Bidding price for spinning reserve offered by generating unit i ;

RC_i Share of ***i***-th generating unit in the reserve cost.

Reserve cost related to the reserve market clearing is called RC_1 and RC_i is the share of ***i***-th generator in the reserve cost for satisfying the SEENS. According to Eq. (11), it is clear that a highly reliable unit is paying a smaller part of the reserve cost than an unreliable one.

3.5. Providing Reserve to Satisfy the Desired Reliability of Customers

This section of the proposed model describes how ISO provides a reserve for satisfying the customers' reliability level.

In this study, consumers can choose their desired reliability requirements and declare to ISO. Choice of higher reliability level than the standard reliability of the system leads to smaller blackout when the system encounters with an event.

It is assumed that k consumers declare their desired EENS to ISO. Market operator determines the customers which want to have reliability, higher than the standard level. Then MO classifies them corresponding to Table 1 and arrange in a descending order such that

$$DRC_M \le DRC_M \le \ldots \le DRC_2 \le DRC_1 \quad (12)$$

Table 1

Customers' classification

Class	Customer Number		Desired Reliability Coefficient
	From	To	
1	1	K_1	DRC_1
2	K_1+1	K_2	DRC_2
.	.	.	.
.	.	.	.
.	.	.	.
$M-1$	$K_{M-2}+1$	K_{M-1}	DRC_{M-1}
M	$K_{M-1}+1$	K_M	DRC_M

DRC_j is the ***j***-th customers' desired reliability level and can be calculated as follows:

$$DRC_j = \frac{DEENS_j}{RL_j} \quad j = 1 \text{ to } N_c \quad (13)$$

$DEENS_j$ is the desired expected energy not supplied of ***j***-th customer and RL_j is the required load of ***j***-th customer.

ISO determines the Average Desired Reliability Coefficient (ADRC). It is formulated as follows:

$$ADRC = \frac{SEENS}{\sum_{j=1}^{N_c} RL_j} \quad (14)$$

Where $SEENS$ is the standard expected energy not supplied. Corresponding to EENS of each class, ISO purchase reserve for satisfying the DEENS of customers, therefore $EENS_d$ which is the expected energy not supplied of each class should be calculated as follows:

$$EENS_d = P_L.ADRC + \sum_{j=1}^{d-1}(P_j.ADRC_j) + (\sum_{j=d}^{P} P_j).ADRC_d \tag{15}$$

P_L is a summation of loads. This parameter related to customers who have the higher reliability factor than ADRC.

If the system expected energy not supplied to be larger than the expected energy not supplied of each class, ISO provides reserve from reserve market. This part of the reserve cost allocates between loads that are willing to have high-reliability level. Share of reserve cost of customers is computed as in:

$$RC_d^H = L_H \times \frac{RC_d}{\sum_{J=1}^{M} L_j} \tag{16}$$

Here, RC_d is the cost of provided reserve and RC_d^H is the *H*-th costumers' portion in the reserve cost and L_H is the amount of load of *H*-th costumers.

When the power system encounters with the outage and the power output of GENCOs is less than the required load of the system, Deficiency factor (DF) is used by the system operator in real time operation as follows:

$$DF_M = \frac{DRC_M}{\sum_{i=1}^{M} DRC_i} \tag{17}$$

DF_M is the deficiency factor related to the *M*-th class.

Using the proposed deficiency factor, the deficit is divided between different customers according to their desired reliability level. Suppose that an unforeseen event occurs system operator has to interrupt customers load and balance market. In order to determine the portion of each customer from the remedial action, deficiency is calculated using the following equations:

$$shortage = Load\ of\ system - real\ generation$$
$$share_d = DF_d \times shortage \tag{18}$$

$share_d$ is the portion of the *d*-th class in megawatt.

Obviously, a customer with high desired reliability level has a lower share of shortage. This method increases the social welfare of all consumers in electricity markets. The proposed method is also similar to an insurance theory [21] in which customers pay to the ISO.

4. Simulation Results

The proposed formulations and model are tested on the modified Roy Billinton test system [22]. In this paper, MATLAB software and Simulink with its toolboxes have been utilized to illustrate simulation. For simplicity's sake, the market auction is cleared for one hour without network considerations such as congestion or losses and the principle of the clearing electricity market is under the pay-as-bid mode. The modified IEEE-RTS comprises 2 thermal and 7 hydro generators (ranging from 5 MW to 40 MW) and 5 loads that shown in Fig. 4. The annual system peak load is 185 MW and this is constant at all time of one year. Total installed capacity is 190MW.

The basic data about total generators is presented in Table 2. It should be noted, the value of failure rate per year have been determined by ISO from the historical data. Corresponding to lead time (equal to 1 h), outage replacement rate (ORR) is calculated.

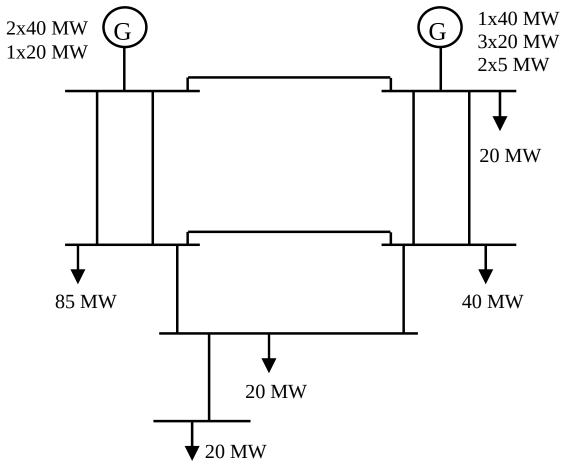

Fig. 4. Single line diagram of 6-bus system

At first, generating units and customers declare their power output offers and load requirements to ISO. This information is given in Table 3 and Table 4.

In the present paper, customers can determine and declare their desired reliability level to the market operator. The third column of Table 4 shows DEENS of each load. According to DEENS, ISO calculates customers' desired reliability coefficients. The amounts of DRC are given in Table 4.

Corresponding to the fourth column of Table 4, the loads that choose higher reliability level have a lower DRC. On the other hand, the amounts of DRC show that we have five levels of reliability. Hence, ISO classifies them into five classes.

To make a market more competitive, both generating units and interruptible customers are given the opportunity to participate in the electricity market. Customer participation in the market can improve system security and reduce reserve cost. In order to illustrate this effect on the market, this paper considers the participation of interruptible loads. Demand side submits bid to ISO according to Table 5. The bidding data of interruptible customers are chosen to make appropriate system operation condition for the proposed approach. We can see in Table 5 that the demand side changes from 5% up to 20% of the load.

For the purpose of studying the scheme proposed, for the first instance, the energy market is cleared under the PAB mode. This is shown in the third column of Table 6.

To clear the reserve market, ISO should determine the system expected energy not supplied. According to the formulation proposed for the EENS calculation, the $EENS_{sys}$ value is computed by ISO that is equal to 662 MWh/yr. Next, market operator determines the share of each generator in $EENS_{sys}$.

The fourth column of Table 6 shows results. It can be observed from the last column of this Table that, the EENS difference related to units 1, 2 and 5 are positive. It means that these units have more contribution in system energy deficit.

Table 2

Generating unit reliability data

unit number	unit size (MW)	type	Failure rate per year	ORR	Availability
1	40	Thermal	6	0.0006849	0.9993151
2	20	Thermal	6	0.0006849	0.9993151
3	5	Hydro	2	0.0002283	0.9997717
4	5	Hydro	2	0.0002283	0.9997717
5	40	Hydro	3	0.0003425	0.9996575
6	20	Hydro	2.4	0.000274	0.999726
7	20	Hydro	2.4	0.000274	0.999726
8	20	Hydro	2.4	0.000274	0.999726
9	20	Hydro	2.4	0.000274	0.999726

Table 3

Generating unit cost data

Unit number	Unit size (MW)	Energy cost($/mwh)			Reserve cost ($/mwh)
		Fuel cost	Operate cost	Total cost	
1	40	9.5	2.5	12	4.8
2	20	9.5	2.5	12	4.8
3	5	0.45	0.05	0.5	0.2
4	5	0.45	0.05	0.5	0.2
5	40	0.45	0.05	0.5	0.2
6	20	0.45	0.05	0.5	0.2
7	20	0.45	0.05	0.5	0.2
8	20	0.45	0.05	0.5	0.2
9	20	0.45	0.05	0.5	0.2

Table 4

Load demand data

Load number	Load size (MW)	Desired EENS (MWh/yr)	DRC
1	85	255	3
2	20	52	2.6
3	20	40	2
4	20	28	1.4
5	40	40	1

Table 5

Interruptible load data

Load number	Interruptible load cost ($/mwh)			
	%5	%10	%15	%20
1	27	30	33	35
2	15	20	25	30
3	–	–	–	–
4	–	–	–	–
5	17	21	30	33

On the other hand, the amount of is greater than the standard value. Hence, ISO purchase reserve from the reserve market such that SEENS is satisfied. Table 7 presents the process of calculating required reserve.

As it can be seen from Table 7, for providing the security of power system, 11 MW reserve should buy by ISO. Note that the GENCOs may not generate sufficient capacity to meet the system reserve requirement. In this condition, ISO considers to ILs as one the system reserve resources. Corresponding to results of energy market clearing, only unit 2 with 5 capacities can participate in the reserve market. Therefore, ISO contributes the interruptible customers in the auction. Reserve cost associated with this level is equal to sum of spinning reserve price and demand side cost that is equal to 222$.

The generators' share in reserve cost is given in Table 8. Clearly, the generating units with the lower reliability level have the highest energy deficit and energy loss.

In next step, customers declare their desired reliability to ISO. Corresponding to the fourth column of Table 4, units 3, 4 and 5 have lower reliability level than the standard level. These customers are willing to improve their reliability level.

In order to satisfy the desired reliability of customers, the $EENS_d$ values compute via the formulation of (15).

In this section $EENS_1$ that is equal to 412 MWh/yr should be satisfied. Therefore, ISO has to purchase 2 MW more reserve from reserve market. The cost of providing this amount of reserve divides between the consumers 3, 4 and 5.

In next stage, for satisfying $EENS_2$ that is equal to 376 MWh/yr, ISO provides 2 MW more reserve from the auction. Purchasing price of this reservation should be paid by the consumers 4 and 5.

Finally, one MW more reserve is necessary for satisfying $EENS_3$ that is equal to 360 MWh/yr. Customer 5 should pay the cost of this reserve level. The numerical results of cost calculations are presented in Table 9. As expected, the reserve cost increases with the level of reliability. It can be seen from the comparison of the payment between units that, the reserve cost of unit 5 is the highest because it wants the large amount of reserve to obtain the high reliability.

When an unforeseen event occurs, ISO has to interrupt loads and balance market. In order to determine the share of each customer from the remedial auction, ISO uses the deficiency factor.

Table 6

EENS share of each generator

unit number	unit size (MW)	Clearance of energy market	EENS share	Standard EENS	EENS difference
1	40	40	239.1	96	143.1
2	20	15	89.8	36	53.8
3	5	5	10	12	-2
4	5	5	10	12	-2
5	40	40	119.5	96	23.5
6	20	20	47.8	48	-0.2
7	20	20	47.8	48	-0.2
8	20	20	47.8	48	-0.2
9	20	20	47.8	48	-0.2

Table 7

Variation of $EENS_{sys}$ by provided reserve variation

Provided reserve (MW)	0	1	2	3	4	5	6	7	8	9	10	11
EENS(MWH/YR)	662	639	617	594	572	549	531	512	493	475	456	438

Table 8

Generators share in reserve cost

unit number	Failure rate per year	Provided reserve cost ($/h)
1	6	143.87
2	6	53.79
5	3	24.34

Suppose that the amount of operating reserve is not sufficient to cover the energy lost. For instance, unit 5 failures, therefore, the system energy deficit will be 24 MW. This generation lost allocate among customers as follows:

$$share_1 = (3/10) \times 24^{MW} = 7.2^{MW}$$

$$share_2 = (2.6/10) \times 24^{MW} = 6.24^{MW}$$

$$share_3 = (2/10) \times 24^{MW} = 4.8^{MW}$$

$$share_4 = (1.4/10) \times 24^{MW} = 3.36^{MW}$$

$$share_5 = (1/10) \times 24^{MW} = 2.4^{MW}$$

From the above analysis, it can be concluded that, loads with low reliability will contribute more to energy lost and the payments. Obviously, the lower portion of this shortage belongs to load 5 because it wanted greater reliability and paid more cost.

Table 9

Loads share in reserve cost

Load number	First stage ($/h)	Second stage ($/h)	Third stage ($/h)	Reserve cost share ($/h)
1	_	_	_	_
2	_	_	_	_
3	16.5	_	_	16.5
4	16.5	16.7	_	33.2
5	33	33.3	25	91.3

5. Conclusion

A new approach for allocating the reserve cost in the electricity market has been proposed in this paper. The market model includes demand side reserve offers and spinning reserve and energy. Based on standard expected energy not supplied, Independent System Operator clears the reserve market in two stages. In the first level, according to the share of each generator in EENS, the cost of reserve allocates among generating units. The main purpose of this stage is to improve the reliability of the generators. In level two, customers can choose their desired reliability and EENS. In order to satisfy the customers' reliability level, ISO procures reserves. The customers, who are willing to have the reliability level better than the standard level, should pay the supplying reserve cost of this part.

In this paper, spinning reserve and interruptible loads are considered. The customers participating in an energy and reserve market can reduce the market-clearing price and the price of reserve market. Participation of the demand side in electricity market increases the social welfare and makes real competitive markets.

A number of case studies ascertain the efficiency of the interruptible loads participating in the reserve market and the effectiveness of the proposed model.

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