Allocation of Spinning Reserve Cost Amongst Customers in Deregulated Power Systems

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Abstract: In a deregulated power system, DISCOs are considered to be customers who can choose their desirable reliability levels and purchase their required reserve in an ancillary service market based on this reliability level. This paper presents a new approach for determining spinning reserve requirements considering customer's desired reliability level in a pool energy and reserve market. An approach is also developed to fairly allocate the cost associated with provision of spinning reserve amongst the customers. The effectiveness of the proposed approach is examined and the results are presented using the IEEE-RTS. [Journal of American Science 2010;6(6):129-138]. (ISSN: 1545-1003).

Key words: Power market, system risk, spinning reserve, required reliability level, reserve allocation

1. Introduction

In a vertically integrated power system, spinning reserve is principally determined by system operators to maintain the entire system reliability at a favorable level. The main assumption here is that customers connected to different load points all benefit from the same level of reliability. However, this method is not optimal in a market-based system since it does not balance the value that consumers place on not being disconnected against the cost of providing enough reserve to prevent such disconnections. Thus, it may happen that the amount of spinning reserve planned during some periods exceeds what is economically viable, whereas it may be inadequate at some other times.

The question of determination of optimal reserve in a power system is an old one. The classic approach was to adopt reserve equal to the size of the largest generating unit. Anstine et al. (1963) proposed a method whereby the forced outage rates of the generating units are also considered such that the overall system reliability never falls below a certain predetermined value. Gooi et al. (1999) described the optimum scheduling of spinning reserve by using the Lagrangian relaxation method together with probabilistic reserve assessment in a conventional power system. In a conventional system, spinning-reserve allocation amongst the generating units generally has a significant bearing on unit commitment and dispatch decisions, since it comes at a price which should be kept to a minimum. As a result, spinning reserve requirements can be fitted to different generating units to maintain the whole start-up/back-down and operating costs at a minimum [Chattopadhyay and Baldick (2002)].

Marketing gives the customers different choices regarding what to buy. In a deregulated power system customers can choose the energy and transmission providers, as well as desirable reliability levels. This means that the reliability levels provided by different customers (or DISCOs) are different. In this context, reliability is mainly expressed by the amount of generation reserve. In a power market, customers can buy the spinning reserve from generation providers. Goel et al. (2004) indicated that customers can obtain their favorable reliability level by making various reserve bilateral agreements. It is obvious that a lower cost paid for spinning reserve results in less reliable electric service, and customers have to pay more for a higher level of reliability. Bouffard and Galiana (2004) used the mixed integer linear programming method to make the system operate at less than a definite EENS or loss of load probability (LOLP) requirement. The procedure also determines a greatest value for EENS to meet a predefined system reliability requirement.

Wang et al. (2005) proposed to rely on a cost-benefit analysis to determine the optimal reserve. The benefit gained from a higher reserve can be computed from the reduction of the amount of energy not served. Motamedi and Fotuhi-Firuzabad (2007) proposed the use of a hybrid deterministic/probabilistic approach to determine the spinning reserve in restructured power systems. Qi and Ding (2009) proposed the allocation of spinning reserve cost amongst all market partners involved in power generation, transmission and consumption having risk elements. The spinning reserve's value was evaluated by using the expectation of spinning reserve's gain or loss, and allocated in proportion according to the spinning reserve's value for all the market partners. Ahmadi-Khatir et al. (2009) addressed the problem of spinning reserve procurement in a pool-based market and the associated cost allocation using well-being analysis. This paper proposes a new approach for determining spinning reserve requirements based on desired reliability level in a pool energy and reserve market. An approach is also presented to fairly allocate the cost associated with provision of spinning reserve amongst the customers. The IEEE Reliability Test System has been used to illustrate the effectiveness of the proposed method.

2. Energy and Reserve Market Model

The model of energy and reserve market that is defined in this paper is a pool model. The operating reserve market is independent of the reserve market and is cleared right after the energy market is cleared when the unit commitment problem has already been solved. As spinning reserve is provided by synchronous units, generating units only participate in the reserve market when they are accepted in the energy market. Sellers (GENCOs) send curves of energy and reserve generation price, their ramp-up rates and the amount of maximum generation capacity to ISO. DISCOs send amount of their needed demand and the desirable level of reliability to ISO. The load model in this market is inelastic with respect to price. In fact, the customers do not send any bids for price to the market for their required energy. Only generating units send their bids. The criterion used for clearing the energy market is included in the unit commitment (UC) problem. After UC, load economic dispatch is performed to determine the amount of accepted generation for each unit. The main objective in clearing the energy market is to minimize the payment to the generating units for purchasing energy. After clearing the energy market and determining the amount of generation for each unit, generation units submit the spinning reserve capacity which they can provide in ten minutes. Due to the limits imposed by ramping rate, each unit has a different capability to present for the spinning reserve market. The maximum amount of spinning reserve capability equals the minimum of ten times the ramping rate, in MW per minute, and the unit's capacity. Each unit has a limited capacity to provide spinning reserve due to its limited ramping rate [Zhu et al. (2000)]. The amount of capacity that generating units can present to the spinning reserve market is calculated as follows:

$$AC_i = MIN\ ((P_i^{MAX} - G_i), 10 \times RR_i) \qquad (1)$$

where AC_i is the actual generating capacity of unit i for presenting to the spinning reserve market; P_i^{MAX} is the maximum generation capacity of unit i; G_i is the generation of unit i; and RR_i is the ramping rate limit of generating unit i.

ISO clears the spinning reserve market considering the results obtained from the energy market, and the requested reliability levels of the customers. The proposed model assumes that load forecasts have some uncertainty. The effect of transmission and distribution networks is also ignored. The reliability model of the generating units is considered to have only two states being either available or on outage. Rapid start units and load curtailment philosophies are also not taken into consideration.

3. The Algorithm for Clearing the Reserve Market

In this section, the algorithm for clearing the reserve market is presented. Customers send their energy requirements and the desired reliability levels to ISO. After receiving and collecting the information regarding desired reliability levels of the customers plus the information related to clearing the energy market, ISO starts to clear the reserve market. The procedure for clearing the reserve market is as follows:

1- A risk level should be defined for the entire system using the desired reliability levels.

2- Reserve capacity should be purchased based on a priority list in the reserve market until the desired overall system risk level is satisfied.

3- The generation reserve should be allocated to the customers in the market after the procurement of the required reserve in the system.

The flowchart of the procedure to clear the reserve market is shown in Figure 1.

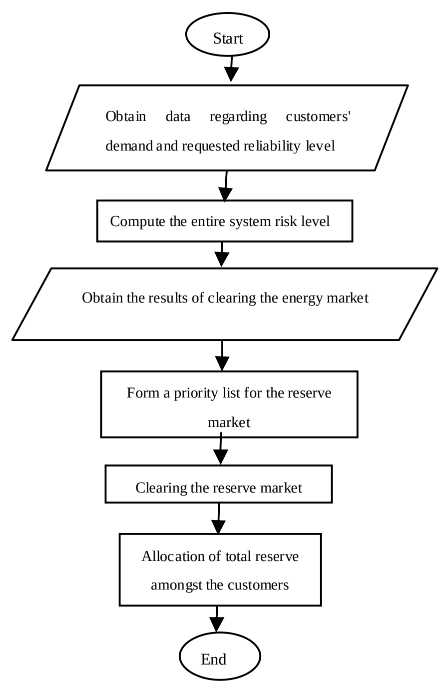

Fig. 1. The flowchart of clearing the reserve market and allocating the reserve to customers.

4. The Reliability of the Entire System

As the load level of the customers increases, the reliability level of the whole system decreases. In other words, when the load of a given customer is reduced, the load level of the whole system goes down and the risk level of the system decreases. Thus, we use the following equation for computing the risk level of the overall system using the reliability level required by customers as in (2):

$$LOLPT = 1 - \frac{\sum_{i=1}^{n} R_i (1 - LOLPL_i)}{N - \sum_{i=1}^{n} LOLPL_i} \quad (2)$$

where R_i is the desired reliability level for customer i, $LOLP_i$ is the system risk level after shedding the load of customer i, N is the number of customers in the market, and $LOLPT$ is the reliability level of the entire system. For example, if three customers A, B and C participate in the reserve market with their demand, LOLPL and requested reliability levels as shown in Table 1, then the LOLPT will be:

$$LOLPT = 1 - \frac{R_A \times (1 - LOLPL_A) + R_B \times (1 - LOLPL_B) + R_C \times (1 - LOLPL_C)}{N - LOLPL_A - LOLPL_B - LOLPL_C} = 0.01045$$

Table 1. A sample of customer information sent to ISO

customer	Customer demand (MW)	Customer desirable reliability level	LOLPL
A	1600	0.999	0.0568217
B	500	0.98	0.0196308
C	500	0.99	0.0196308

5. Reserve Allocation Mechanism

The amount of required spinning reserve in the system is found according to the load risk imposed on the system because of consumers and also the total system reliability level. As mentioned before, the overall system reliability level is calculated according to the customers (or DISCOs) requested reliability levels.

The total reserve planned in the system should be allocated to the customers. Thus, a fair and rational method of allocating the reserve amongst the customers of reserve (or DISCOs) should be used. In this study, a reserve allocation mechanism is introduced to solve the problem of reserve allocation to the customers for reserve in a fair and rational manner.

The customer' imposed risk level and the required reliability level of DISCOs are factors that should be considered when allocating the reserve amongst the reserve customers. That is, the imposed risk level of a DISCO on a system increases when the required amount of energy consumption of the DISCO is high.

Also, the required reserve for a given DISCO is more when his requested reliability level is higher. Equation (3) clearly shows the relation between the DISCO's share of reserve, the customer's imposed risk level and the requested reliability level.

$$CSFR \propto \frac{RRL}{CILR} \quad (3)$$

where $CSFR$ is the customer's share of the reserve, RRL is the requested reliability level, and $CILR$ is the customer's imposed risk level.

The proposed method of allocating reserve amongst the various customers is presented next. A coefficient is obtained for each customer according to the reliability level requested by the DISCOs. The optimal reserve is divided amongst the customers according to this coefficient. The flowchart for the implementation of the proposed method is shown in Figure 2.

Step 1: The required reliability levels which the DISCOs have requested from the ISO are sorted in an ascending manner.

Step 2: Reserve is purchased for the system to the extent that the reliability level increases from R_{i-1} to R_i.

Step 3: Allocation of the reserve which is bought (BOR) is done according to the customer's imposed risk level to customers who have asked for a reliability level equal to or higher than R_i.

Step 4: Repeat steps 2 and 3 for all N customers.

Step 5: Each customer's share of reserve in the various periods are added up as follows:

$$RE_i = \sum_{K=1}^{n} RE_{ik} \quad (4)$$

where RE_i is the customer's share, and RE_{ik} is the i[th] customer's share in period k.

The number of division steps is equal to the number of sent reliability levels to ISO. The customer with a higher level of requested reliability will participate in more periods of reserve allocation. For example, customer N (with the highest requested reliability level) participates in all periods of reserve allocation, while the first customer (with the lowest requested reliability level) participates in reserve allocation only in the first step.

Step 6: The coefficient RF_i to be used for the i[th] customer will be computed from equation (5).

$$RF_i = \frac{RE_i}{\sum_{i=1}^{n} RE_i} \quad (5)$$

Step 7: The share of each customer from the reserve is calculated based on the bids of the generating units for the reserve market such as the one shown in Table 3, and the allocation coefficients RF_i obtained above as shown in (6):

$$AR_i = RF_i \times Reserve \qquad (6)$$

where AR_i is the share of the ith customer from the reserve.

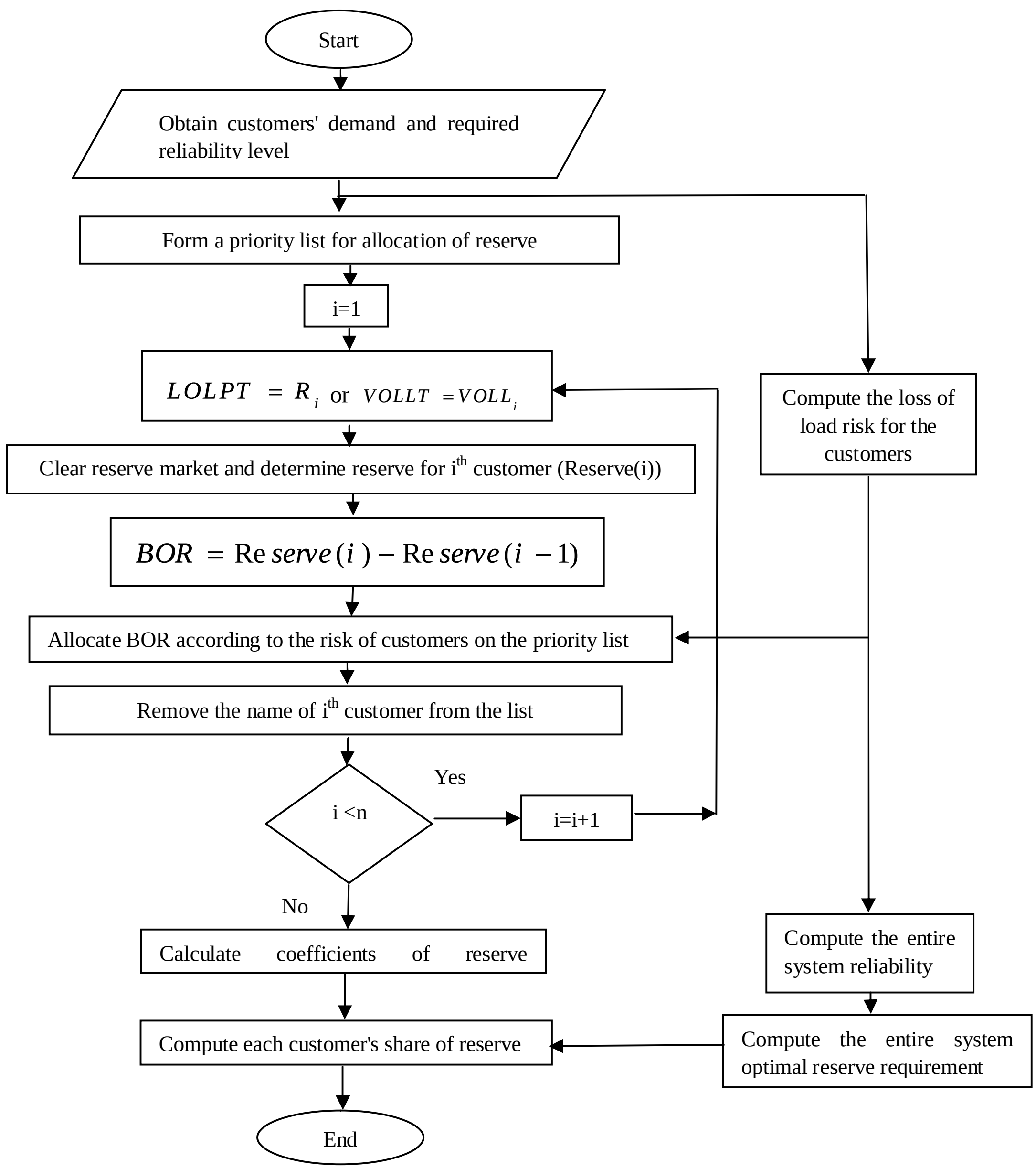

Fig 2 - The flowchart for clearing the reserve market

6. Results of Simulation

The proposed method of procurement of reserves needed for the system and the allocation of the cost of total reserve amongst the various consumers is tested on the IEEE reliability test system as presented by the Reliability Test System Task Force (1999) excluding the hydro units. Generation data for this system is shown in Table 2 and the one-line diagram is shown in Figure 3 [Reliability Test System Task Force (1999)].

The unit commitment data presented by Ouyang and Shahidehpour (1991) and Wang and Shahidehpour (1993) are used in this study. Total generation in this system is 3405MW and annual maximum load is 2850MW. For simplicity, we consider that the load buses of the system are divided into three major distribution companies. DISCO A supplies load for consumers that are connected to buses 1 to 12. DISCO B does the same for consumers that are connected to buses 15, 18, 21 and 22. DISCO C supplies the load for consumers on buses 13, 14, 19, 20 and 23 as shown in Figure 4.

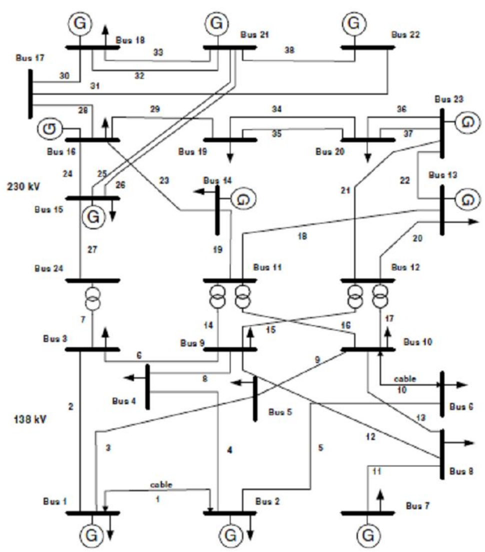

Fig 3 - The one line diagram of the IEEE-RTS system

[Reliability Test System Task Force (1999)]

By this method, the consumers in the market can request their needed energy and desired level of reliability from the ISO in order to buy their needed reserve.

Sellers (GENCOs) in the market also present their bids for selling electrical energy along with minimum and maximum production levels and ramp-up rate to ISO. It is considered that the suggested prices for energy in the power market are equal to the marginal costs of the generating units. We supposed that the GENCOs offer their bids as shown in Table 3 for the reserve market.

After clearing the energy market and defining the generation level of each unit, ISO clears the reserve market separately for each hour considering the list of priorities in the reserve market. Considering that clearing the reserve market is done on an hourly basis, the lead time of production units is equal to one.

The results obtained from the reserve market clearing for 1800MW load level are shown in the following Tables.

The total reliability level is the total risk level of system that is computed using equation (2). The information provided to ISO by the customers and the computed total risk level for the system are all shown in Table 4.

Considering the results obtained after clearing the energy market and identification of the amount of energy produced by each generating unit, we can compute the capacity that each generating units can present in the spinning reserve market by using equation (1).

Considering the expressed bids presented by sellers, as well as specifying the ability rate of generating units for participating in the reserve market, ISO uses the reserve market priority and purchases generating reserve in order to satisfy the total reliability level of the system. The result of reserve market liquidation and the total purchased reserve are shown in Table 5.

After clearing the reserve market, and procurement of total needed reserve in the system, ISO should allocate the purchased reserve to its customers using the proposed allocation mechanism. Table 6 shows the results obtained using the allocation coefficients for DISCOs as shown in Table 5. Also, the cost of this reserve is divided amongst these DISCOs using these coefficients.

Table 2 - Generation data for the IEEE-RTS system adopted from Reliability Test System Task Force (1999) excluding the hydro units

Generation Units	Unit Size (MW)	Unit Type	Bus No.	P_{min} (MW)	P_{max} (MW)
1,2	20	Oil/CT	1	6	20
3,4	76	Coal/Steam	1	25	76
5,6	20	Oil/CT	2	6	20
7,8	76	Coal/Steam	2	25	76
9,10,11	100	Oil/Steam	7	40	100
12,13,14	197	Oil/Steam	13	80	197
15,16,17, 18,19	12	Oil/Steam	15	5	12
20	155	Coal/Steam	15	3	155
21	155	Coal/Steam	16	60	155
22	400	Nuclear	18	200	400
23	400	Nuclear	21	200	155
24,25	155	Coal/Steam	23	60	155
26	350	Coal/Steam	23	150	350

7. Sensitivity Analysis

In this part, a sensitivity analysis is performed. Changes of the purchased reserve with respect to the alterations in load levels, the change in the required reliability level for DISCOs, uncertainties in load forecast and also changes in the ORR of generators are studied.

7.1 Changes in the load level

In order to study the effect of changes in load level of the DISCOs on the amount of spinning reserve required, we assumed that the requested load level ranges from 1200MW load level to2850 MW load level (peak load).

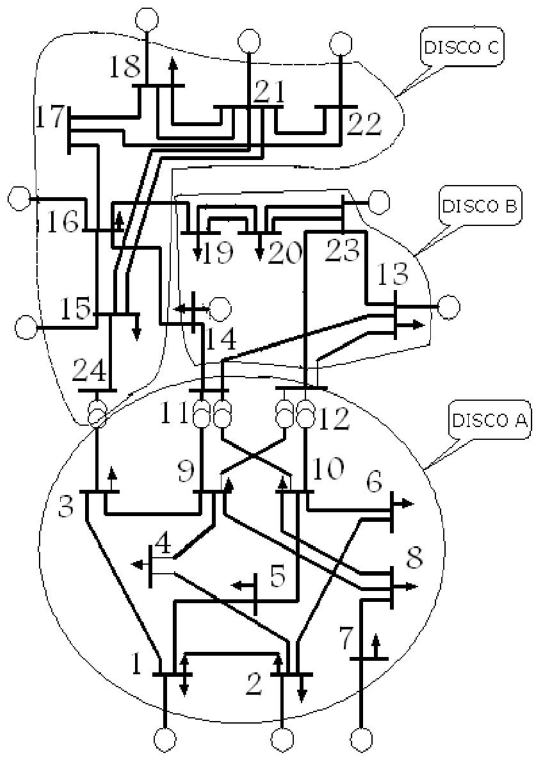

Fig 4 - The one line diagram of the IEEE-RTS system indicating how the customers are grouped into DISCO A, DISCA B and DISCO C.

The results obtained for the amount of spinning reserve as load level is changed are shown in Figure 5.

With the increase of the total purchased reserve in the system, the share of each DISCO for reserve increases as seen from Figure 6.

7.2 Changes in the required reliability level of the customers

The required reserve for the system is related to the reliability level of the system. In this part the effect of changes in the requested reliability level by the customers on the amount of reserve in the system is studied. Since the highest reliability level for the system is always less than one, the requested reliability level for DISCOs is increased from its initial value so that it is close to one.

For this purpose, the difference between one and the required reliability level for the DISCOs is calculated and a percentage of this difference is added to the requested reliability level in 25% increments. The results obtained are shown in Fig.7.

It can be seen from this Figure that the amount of needed reserve increases as a higher reliability level is requested. Moreover, as a higher amount of spinning reserve is provided, the risk of the system is decreased. We can also see from Figure 7 that when the reliability level of the customers is increased to 75%, the system risk level is reduced and as a result the purchased reserve in the system for all the load levels is fixed at about 400 megawatts.

Table 3 - Assumed bid for prices of generation units for the reserve market

U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	U14	U15	U16	U17
10	12	13	14	15	16	17	18	19	20	21	22	22	23	25	25	25

Table 4. Customer information in the market for total system load level of 1800MW

Total load of the system (MW)	The load and requested reliability level of each DISCO			Total level of system Risk(LOLP)
	DISCO	load (MW)	Requested Reliability level	
1800	A	830	0. 997	0. 006
	B	450	0. 9938	
	C	520	0. 9912	

Table 5 Spinning reserve market clearing for load level of 1800MW and system risk level

Customers	G_i Energy market	g_i reserve market	$g_i + G_i$
U1	310.5	89.5	400
U2	312.4	10.5	322.9
U3	350	0	350
U4	56	0	56
U5	101	0	101
U6	104	0	104
U7	110	0	100
U8	100	0	100
U9	100	0	100
U10	100	0	100
U11	20	0	20
U12	20	0	20
U13	20	0	20
U14	20	0	20
U15	76	0	76
	Total demand=1800MW	Total purchased reserve=100MW	
	Total System Risk (LOLP)=0.0185876		Total System Risk (LOLP)=0.005824

Table 6 - The steps of obtaining the allocation coefficients

<table>
<tr><td colspan="2">Requested reliability levels</td><td colspan="3">The share of purchased spinning reserve for customers for various courses</td><td rowspan="2">purchased reserve in each course of division</td></tr>
<tr><td>Entire system</td><td>DISCO</td><td>DISCO A</td><td>DISCO B</td><td>DISCO C</td></tr>
<tr><td rowspan="3">LOLP=0.006</td><td>0.9912</td><td>20.05</td><td>17.45</td><td>18.5</td><td>56</td></tr>
<tr><td>0. 9938</td><td>23.52</td><td>20.48</td><td>0</td><td>100</td></tr>
<tr><td>0. 997</td><td>30</td><td>0</td><td>0</td><td>130</td></tr>
<tr><td>RE_I</td><td>customer's share</td><td>73.57</td><td>37.93</td><td>18.5</td><td></td></tr>
<tr><td>RF_I</td><td>division coefficients</td><td>0.56</td><td>0.31</td><td>0.13</td><td></td></tr>
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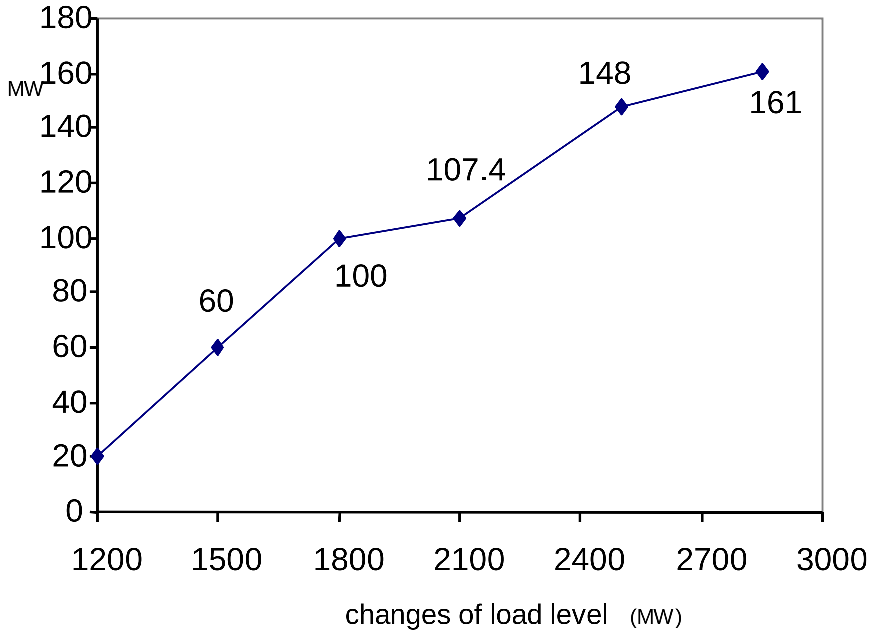

Fig 5 Changes in purchased reserve in the system with respect to the load level changes of DISCOs

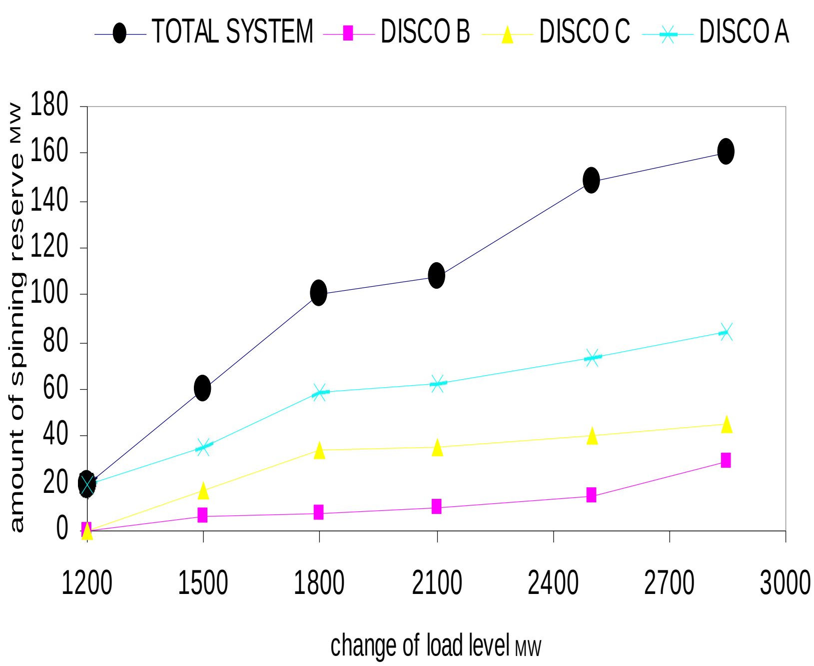

Fig 6 Change in spinning reserve and share of each DISCO from reserve

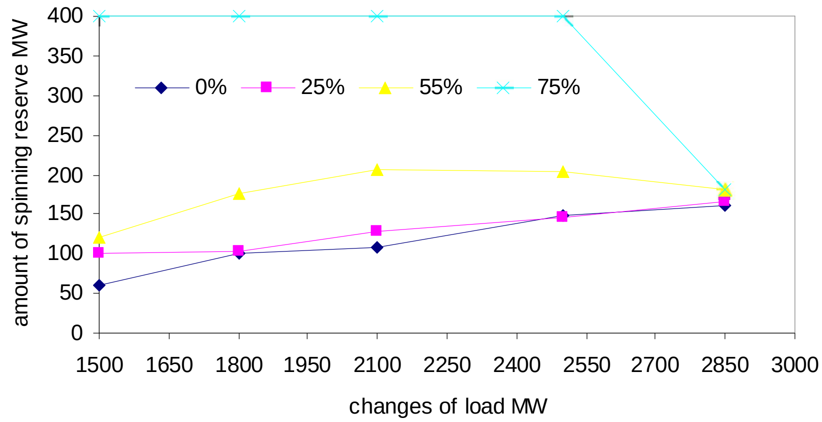

Fig 7 Change in spinning reserve with respect to risk level of the customers

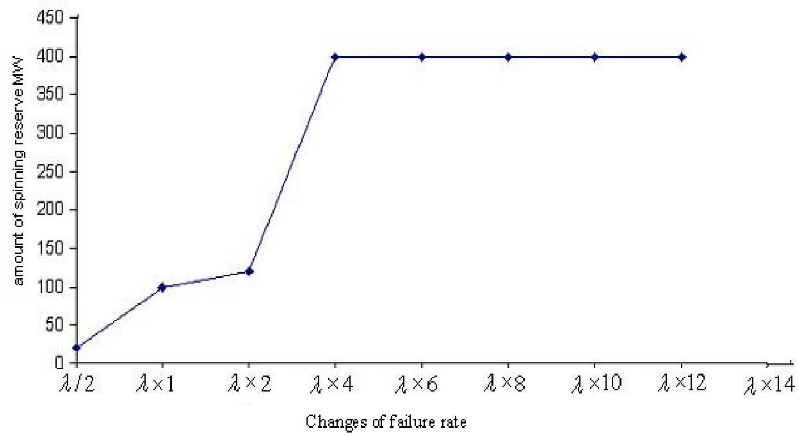

Fig 8 Changes of amount of spinning reserve with respect to changes of failure rate

7.3 Changes in the failure rate of generating units

The higher the failure rate of the generating units, the more is the risk of system and as a result system reliability level reduces. Hence ISO must consider larger amounts of reserve for system. This point is shown in Fig. 8 where the changes in the failure rate of generating units are shown up to fourteen times greater than the actual rate for a load of 1800MW.

8. Conclusions

In this paper, a new approach is proposed for clearing the reserve market and allocating the associated costs. In the proposed method, customers have the chance to choose their required risk levels. That is, the customers send their energy requirement and desired risk levels to the market. Reserve market is cleared such that the total risk level is satisfied. After clearing the reserve market, the cost of reserve is allocated amongst the various customers according to their requested reliability levels. Lower cost for spinning reserve leads to less reliable electric service whereas a higher reliability level requires that the customers pay more. All these choices are given to the customers. From the customers' perspective, the system reliability is not uniform any more. The proposed method has been applied to the IEEE-RTS and the simulation results which ascertain its effectiveness and efficiency have been presented.

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