DETERMINATION OF SPINNING RESERVE IN RESTRUCTURED POWER SYSTEMS USING A HYBRID DETERMINISTIC/PROBABILISTIC APPROACH

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ABSTRACT

Effective control of spinning reserve can provide substantial cost reductions in large power systems. Most of the current research on operating reserve markets assumes that the required capacity is predetermined, which means that the demand of spinning reserve capacity is inelastic. This paper proposes an approach which tightly integrates a hybrid deterministic/probabilistic reserve assessment with the unit commitment function. Based on the reliability evaluation of the generation system and calculating of acceptable risk level one new method is proposed to determine the optimal reserve capacity. Indeed, the proposed method in this paper obtains the acceptable overall risk level of power system using a new simple method based on committing or de-committing of the marginal units. Therefore, the proposed method results in lower computational burden in comparison with other probabilistic approaches. Case studies for reliability test system (RTS96) demonstrate the usefulness and efficiency of the proposed model.

NOMENCLATURE

UC	Unit Commitment
ND	Number of DisCos
$LOLP$	Loss of load probability
L_{dci}	Demand of Disco i
U_i	availability of unit i
L_s	System load (MW)
$p_{gi}^{\max}$	Maximum output of unit i (MW)
P_{gi}	power output of generating unit i (MW)
R_{gi}	spinning reserve contributed by unit i (in megawatt).
u_i	1 if unit i is on and available and 0 otherwise
σ_i	1 if forced outage of unit i cause some loss of load and 0 otherwise
$\sigma_{i....k}$	1 if forced outage of unit i to k cause some loss of load and 0 otherwise
MU_i	Minimum up time of unit i
MD_i	Minimum down time of unit i
n	Number of generators
$LOLP_i$	Desired risk level of Disco i

I. INTRODUCTION

Scheduling sufficient reserve capacity helps power systems to overcome unexpected generator outages and major load forecasting errors without load shedding. Most utilities have adopted deterministic criteria for the spinning reserve requirements. Their operating rules require the spinning reserve to be greater than the capacity of the largest online generator or a fraction of the load, or equal to some combination of both of these [1]. While deterministic criteria are easy to implement, they do not match the stochastic nature of the problem and do not take into consideration the intrinsic reliability of each scheduled generator [2].

Operating reserve provides an electric power system with the ability to respond to unforeseen load changes and sudden generation outages, and a wide range of techniques have been used to determine operating reserve requirements. An assigned amount of the operating reserve must be available within a given period of time in the event of a sudden loss of generating capacity, unforeseen changes in the system load or any other contingency which results in loss of capacity [3].

A probabilistic approach generally bases the design and operating constraints on the criterion that the risk of certain events must not exceed pre-selected limits. Utilization of probabilistic techniques will permit the capture of the random nature of system components and load behavior in a consistent manner. Despite the obvious disadvantages of deterministic approaches, deterministic criteria are still in wide use by many utility companies and there is considerable reluctance to apply probabilistic techniques to assess spinning reserve requirements. The reason for this is that these criteria are easier for system planners and operators to understand and apply than probabilistic approaches. This reluctance dictates a need to create a bridge between the deterministic methods and the prevalent probabilistic techniques [4].

In recent years considerable work has been done on determination of spinning reserve based on probabilistic methods. Gooi in [2] has shown that how probabilistic reserve assessment can be used in short term generation scheduling to drive spinning reserve requirement which is appropriate for the individual failure rate of the committed units. Wang and his colleagues in [5] consider that operating reserve capacity in a power system is flexible and one should optimize it by cost-benefit analysis. Developing a novel pool-based market-clearing algorithm for application in electricity markets that includes the scheduling of spinning reserve according to a probabilistic reliability criterion has been discussed in [6].

Probabilistic reserve criteria can be implemented to make the system operate under a uniform system reliability level. Loss of load probability (LOLP) is the likelihood index that the system would suffer load cut in the generation dispatch. In [7], an approximation method was implemented to estimate the LOLP. Bouffard and Galiana in [6] incorporated the LOLP constraints into the market clearing process through the mixed-integer linear programming.

This presents an approach which tightly integrates a hybrid deterministic/probabilistic reserve assessment with the unit commitment problem. In this paper, spinning reserve capacity in a power system is considered to be flexible and should be optimized by a hybrid deterministic/probabilistic approach. Based on the reliability evaluation of the generation system and calculation of acceptable risk level by collection the desired reliability levels of GenCos one new method is proposed to determine the optimal reserve capacity. Unit commitment is done based on deterministic reserve criteria (capacity of the largest unit). After that, by reliability evaluation of the generation system, the risk level of the system can be obtained. The proposed method of this paper is to obtain the acceptable risk level by reforming the unit commitment based on a new algorithm. Case studies for the IEEE reliability test system (RTS96) demonstrate the usefulness and efficiency of the proposed model.

II. SYSTEM LOLP AND ITS COMPUTATION

The system LOLP refers to the likelihood index that the sum of the generation and system available reserve falls below the system load demand. The value of system LOLP is strongly related to the reliability levels of the selected generators and system operation. In the classic way, LOLP is evaluated by obtaining the COPT as fallow:

$$LOLP = \text{probability } of \left[\sum_{i=1}^{n} u_i \left(P_{gi} + R_{gi}\right) \le L_s\right] \tag{1}$$

In other words, LOLP is the probability that the available generation, including spinning reserve, cannot meet the system load.

An approach for evaluating the LOLP is discussed in [6]. This paper uses this approach because of its fast computational ability. For the sake simplicity, the load demand is assumed to be equal to the sum of all generation. For the first order outages, a set of binary variables σ_i, i=1,..., n, is used to represent whether an energy deficiency has occurred when unit i is lost.

$$\frac{L_s - \sum\limits_{\substack{j=1 \\ j \ne i}}^{n} \left(P_{gi} + R_{gi}\right)}{\sum\limits_{i=1}^{n} P_{gi}^{\max}} \le \sigma_i \le 1 + \frac{L_s - \sum\limits_{\substack{j=1 \\ j \ne i}}^{n} \left(P_{gi} + R_{gi}\right)}{\sum\limits_{i=1}^{n} P_{gi}^{\max}} \tag{2}$$

These binary σ_i variables model the presence or absence of some loss of load due to the single-outage random events in an explicit manner. From the above relation, σ_i takes the value 1 if unavailability of generating unit j causes any loss of load, otherwise is equal to 0. To explain this, consider the event for which loss of load is occurs, which is where:

$$L_s - \sum_{\substack{i=1 \\ i \ne j}}^{n} \left(P_{gi} + R_{gi}\right) \ge 0 \tag{3}$$

The lower bound of (2) must be strictly greater than zero and less than 1, while the upper bound is greater than 1. Since σ_i is a binary variable, then under loss of load, it must be equal to 1 [6]. A similar argument applies when there is no loss of load and σ_i is zero. Similar binary variables can be defined for higher-order outage combinations. The general formula for σ can be expressed as blow:

$$\frac{L_s - \sum\limits_{\substack{i=1 \\ i \ne j \text{ to} k}}^{n} \left(P_{gi} + R_{gi}\right)}{\sum\limits_{i=1}^{n} P_{gi}^{\max}} \le \sigma_{j..k} \le 1 + \frac{L_s - \sum\limits_{\substack{i=1 \\ i \ne j \text{ to} k}}^{n} \left(P_{gi} + R_{gi}\right)}{\sum\limits_{i=1}^{n} P_{gi}^{\max}} \tag{4}$$

The LOLP can be evaluated in term of these binary variables as (5). Using this equation to obtain LOLP has considerable merits from the computational time point of view. For the sake of simplicity, maximum simultaneous outages of two generators are considered in this paper.

$$LOLP = \sum_{j=1}^{n} \sigma_j \left[u_j U_j \prod_{\substack{i=1 \\ i \neq j}}^{n} \left(1 - u_i U_i\right) \right] + \sum_{j=1}^{n} \sum_{k \geq j}^{n} \sigma_{jk} \left[u_j u_k U_j U_k \prod_{\substack{i=1 \\ i \neq j,k}}^{n} \left(1 - u_i U_i\right) \right] + \ldots \qquad (5)$$

III. DETERMINATION OF THE OVERAL SYSTEM RELIABILITY

In the competitive utility environment, DisCos have the full right to choose their desired reliability level. For a given DisCo, a specific risk level must be satisfied. Using the demand of each DisCo and its associated reliability level, the overall desired system reliability level is determined. Accordingly, the overall desired system risk is calculated as follows:

$$LOLP = \frac{\sum_{i=1}^{ND} (LOLP_i \times L_{dci})}{\sum_{i=1}^{ND} L_{dci}} \qquad (6)$$

From the probabilistic point of view, sufficient spinning reserve must be purchased in order to satisfy this risk level.

IV. DESCRIPTION OF THE PROPOSED METHOD

Figure 1 shows an overview of the method. This hybrid deterministic/probabilistic reserve assessment method enables correct level of reserve to be set considering the reliability of the individual scheduled units. In the proposed approach, this assessment takes place in two stages between the deterministic and probabilistic assessment of reserve.

The two stages concern the evaluation of the unit commitment risk and the adjustment of the reserve requirement. At first, using the demand of each DisCo and its associated reliability level, the overall desired reliability level is determined. Then, unit commitment is performed using deterministic reserve criteria. This paper assumes that this deterministic criterion is the capacity of the largest unit. The overall system LOLP can be calculated using Equation 5.

From the probabilistic point of view, the obtained LOLP from the deterministic unit commitment must be lower than the desired probabilistic risk level. If this risk level isn't satisfied, the marginal unit must be committed. This procedure must be continued until the risk level is satisfied.

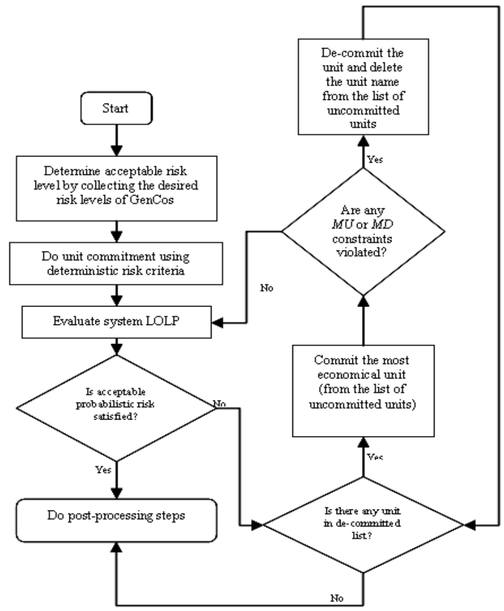

Figure 1. Unit commitment with deterministic/probabilistic reserve criteria

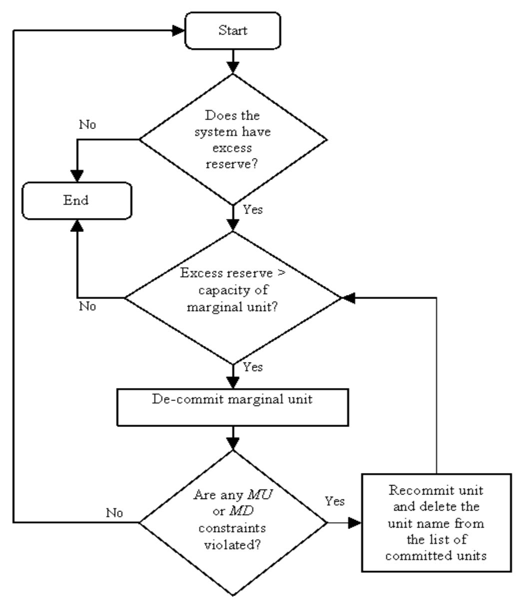

Figure 2. Post-processing procedure for reduction the excess reserve

There is another possible situation for which the system has excess reserve. For solving this problem, the post-processing process must be done. Figure 2 shows the procedure associated with the post-processing block in the flowchart of Figure 1. As Figure 2 shows, this post-processing procedure consists of de-committing of marginal units for reduction of excess reserve. It is very important to note that committing and de-committing of units must be within the minimum up and minimum down constraints, as shown in Figure 2.

V. CASE STUDY

The proposed probabilistic reserve assessment is applied to a 26-generator system that derived from IEEE-RTS. The unit commitment data was obtained from [9],[10]. Extra data for probabilistic reserve assessment was taken from [11]. The demand curve model in all cases is shown in Fig. 3. The unit commitment time interval is assumed to be 1 hour. The load demand is assumed to be constant within each hour.

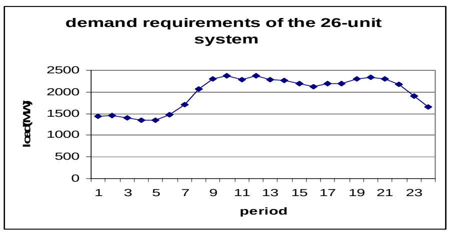

Figure 3. Demand levels for 24 hours

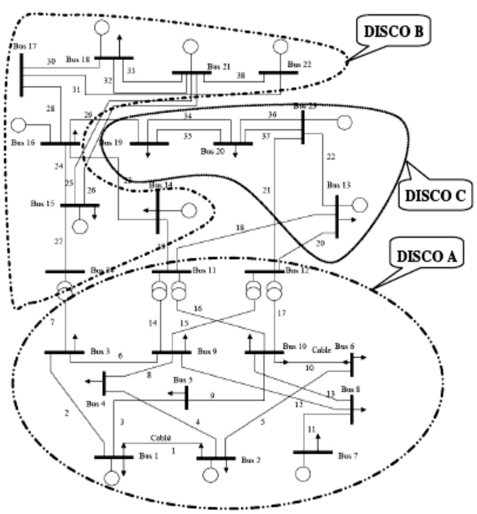

Figure 4. Single line diagram of the IEEE-RTS

All the load buses of the system are divided into three Discos as shown in the single-line diagram of the IEEE-RTS depicted in Fig. 4. Assume that DisCos submit their load and desired risk levels for a given hour to ISO as shown Table I. It can be seen from this table that the desired LOLP must be satisfied for each DisCo in which acceptable risk levels for DisCos A, B and C are respectively 0.01, 0.05 and 0.0025. As this table shows, the overall acceptable risk is 0.00586. Figure 3 shows the load levels for 24 hours.

The deterministic unit commitment of our approach has been solved using a hybrid dynamic programming and Lagrange relaxation method. Furthermore, the LOLP in our method has been calculated using Eq. (5), and whole of our method and its algorithms have been simulated using MATLAB software.

This paper uses a unit commitment with capacity of largest unit as reserve for the unit commitment with deterministic reserve criteria. Table II shows the units minimum up and minimum down time information. Table III shows the units status for 24 hour based on unit commitment with deterministic reserve criteria [12]. By reforming this unit commitment based on the proposed method of this paper, Table IV is obtained. This table shows status of units based on unit commitment with deterministic/probabilistic proposed method. The marked numbers in this table shows the changes with respect to table III. As shown in this table, in all hours the system has excess reserve.

Table I. DisCo's information

Load and reliability level of each Disco			LOLP
DisCo	% of overall load	LOLP	
A	33.75	0.01	0.00586
B	33.12	0.005	
C	33.12	0.0025	

Based on deterministic reserve criteria, the system has excess reserve in all 24 hours and it isn't economical. We use the proposed algorithm of figure 2 for reducing this excess reserve. Figure 5 shows the risk levels for the 24 hours based on the proposed method. This figure shows that in all hours, the risk level is less than 0.0058. Table V shows generation cost comparison between deterministic reserve approach and hybrid approach for one day period. This table shows that based on the proposed method, we have 0.91% saving.

Table II. Unit's characteristics

unit group	U12	U20	U76	U100	U155	U197	U350	U400
min. up time(hour)	0	0	3	4	5	5	8	8
min. down time(hour)	0	0	2	2	3	4	5	5

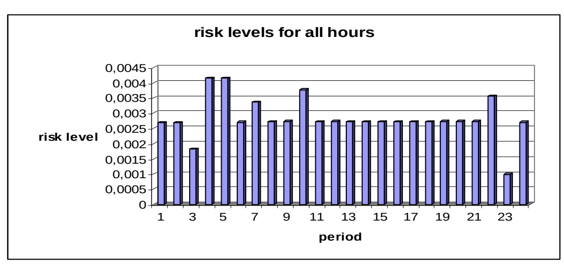

Figure 5. risk levels in 24 hours, using the proposed method

Table III. Unit commitment with deterministic reserve criteria

unit	Status for hour 0 to 24																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
U12a	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0	0	1	0	0
U12b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0
U12c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
U12d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U12e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U20a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U20b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U20c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U20d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U76a	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U76b	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U76c	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U76d	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U100a	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
U100b	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
U100c	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
U155a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U155b	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U155c	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U155d	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U197a	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
U197b	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0
U197c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U350a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U400a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U400b	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table IV. Reforming the unit commitment based on proposed method

unit	Status for hour 0 to 24																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
U12a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U12b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U12c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U12d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U12e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U20a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U20b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U20c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U20d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U76a	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U76b	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
U76c	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
U76d	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
U100a	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
U100b	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
U100c	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
U155a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U155b	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U155c	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U155d	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U197a	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0
U197b	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U197c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U350a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U400a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U400b	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table V. Generation cost comparison

cost of one day period with deterministic reserve criteria	584,649$
cost of one day period with probabilistic reserve criteria	579,334$
saving	5314.4$
saving=0.91%	

VI. CONCLUSION

This paper presents a new technique to determine the spinning reserve requirements at each period of the optimization horizon. The proposed approach in this paper is to determine spinning reserve requirements in competitive energy and reserve markets considering overall acceptable risk level of power system. Based on the reliability evaluation of the generation system and calculation of acceptable risk level by collection the desired reliability levels of GenCos one new method is proposed to determine the optimal reserve capacity. Firstly, Unit commitment is done based on deterministic reserve criteria (capacity of the largest unit). After that, by reliability evaluation of the generation system, the risk level of the system can be obtained. The proposed method of this paper is to obtain the acceptable risk level by reforming the unit commitment based on a new algorithm. Indeed, the proposed method in this paper obtains the acceptable overall risk level of power system using a new simple method based on committing or de-committing of the marginal units. Furthermore, the proposed method results in lower computational burden in comparison with other probabilistic approaches. Case studies for the IEEE reliability test system (RTS96) demonstrate the usefulness and efficiency of the proposed model.

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