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Determining of Optimal Capacity Reserve in a deregulated electricity market by modeling the consumers

javad norouzi
Department of Engineering
Saveh Branch, Islamic Azad University,
Saveh, Iran
norouzi_j@yahoo.com

javad nikoukar
Department of Engineering
Saveh Branch, Islamic Azad University,
Saveh, Iran
j_nikoukar@yahoo.com

***Abstract*—determining of required spinning reserve capacity of system is the most important tasks of system operator for safe and ensure operation of power systems. The spinning reserve is the unused capacity which can be activated on decision of the system operator and which is provided by devices which are synchronized to the network and able to affect the active power [1]. In this paper represented a method to determining the capacity of reserve in deregulated systems with the goal of maximizing public benefits by modeling the consumers. Objective function associated with this method, is minimizing total cost of production and expected cost of outage to consumers. Simplicity of this algorithm is the superiority of this method over other stochastic methods. Finally this algorithm was applied to 14 bus IEEE network and the result was compared with different criteria and has observed that this algorithm can easily prevent the payment of additional costs.**

***Keywords*—spinning reserve, public benefit, value of loss load, willingness to pay**

I. Introduction

The main task of the operator system is providing optimal reliability of power system which is done by ancillary services. Indeed ancillary services are responsible for supporting main commodity exchanges to exit consistently stable and reliable electricity in a power system. One of the most important of these services is reserve. Reserve is considered as ancillary services and their ultimate aims are public welfare and reduce the irreversible losses of economic and social damages which caused by outage. Extent and scope of the existing power system and variety of equipments has caused probability of failure in the system is not low, therefore system reliability decreases. Electric system reliability can be addressed by considering two basic and functional aspects of the electric system-adequacy and security [2]. **Adequacy** is the ability of the electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements [3] and **security** is the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements [3]. Usually increasing the reserve margin provides a more reliable power system but at a higher cost. Decreasing the reserve margin saves money but could mean higher likelihood of curtailment. Therefore in practically, must be find optimal dot that consider the two element that is reliability of system and economic terms [3].

II. A brief introduction to some used methods

In different articles are presented variety of methods for determining required reserve level of power systems. However, existing methods can be divided into two general techniques which are deterministic and stochastic criteria. Understanding of the deterministic criteria for planner and operator of the system is easier over stochastic indices, and this causes deterministic criteria usually used for determining reserve because of its ease and simplicity. Most power systems are run with deterministic reserve criteria which ensure that there is enough reserve on-line to cover for the loss of the largest unit (or in-feed) or that the reserve is equal to some percentage of the load or some combination of these. A commonly used deterministic criterion sets the desired amount of spinning reserve so that the system will be able to withstand the outage of any single generating unit without having to resort to load shedding and system operator orders units planned to produce extra[4].

Because behavior of system is completely random behavior, using of stochastic techniques, improves performance of system from improvement of reliability point of view and reduced cost effective. But sometimes lack necessary information to calculate the risk index, make stochastic methods difficult for using [5]. The most stochastic method for determination of reserve is based on consideration of the forced outage rate generators and lines in the issue.

1- Power systems are typically planned and operated so that, following a contingency, load will not be curtailed. This is the so-called “n-1” criterion [4].

Indeed, the system required reserve determines by considering the loss of load probability and size of lost load [6]. In reference 7 a method based on optimal load flow is provided for simultaneous dispatch energy and spinning reserve with respect to restriction network security. Reference 8 determines optimal reserve in issue on the unit commitment. Consider the stochastic nature generating units and uses cost-benefits analysis to determine the optimal reserve value in the power market is the advantage of using this method in this article. In this process, benefit from the availability of production costs measured by outage cost of consumers. Expected energy not supplied (EENS) in this reference is calculated from the capacity outage probability table. Calculating EENS from this table is a standard method in which is considered generation units in the system, outage probability and load value. In this paper to determine the required reserve for each generation bus, for optimal and safe operation of network is represented a new method based on consumer willingness to pay. Considering the vary value of lost load is the advantage of the proposed method.

III. Suggestion method

In this paper determining of reserve was measured with stochastic method and have used parameters of reliability which calls EENS and outage cost determined by modeling the consumers and is compared by cost of reserve.

A. Modeling the consumers [9]

A.1 Individual demand

Suppose that we are looking at the commodity. The number of commodity we purchase depends on their current price. There is certainly a price above which we will decide to forego our daily purchase afterward.

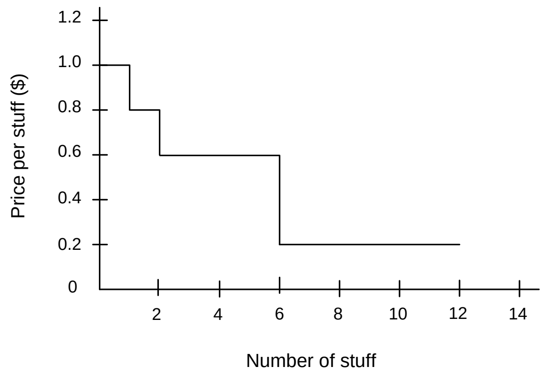


figure 1. relation between the price of commodity and the demand of a particular customer

Figure 1 summarizes how demand for commodities varies with price.

A.2 inverse demand function

It is very unlikely that all the consumers going to the market have exactly the same appetite for commodities as you do. Some of them would pay much more for the same number of commodities, while others buy commodities only when they are cheap. If we aggregate the demand characteristics of a sufficiently large number of consumers, the discontinuities introduced by the individual decisions are smoothed away, leading to a curve like the one shown in Figure 2. This curve represents the inverse demand function of the customers taken as a whole.

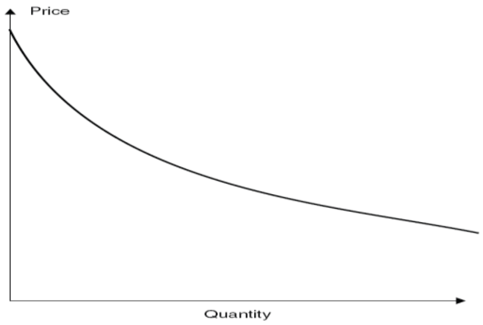


figure 2. Typical relation between the price of a commodity and the demand for this commodity by a group of consumers

The above inverse demand function has an important economic interpretation.

For a given consumption level, it measures how much money the consumers would be willing to pay to have a small additional amount of the good considered.

In other words, the demand curve gives the marginal value that consumers attach to the commodity or in other words, it shows consumer's willingness to pay when units added.

A.3 Elasticity of demand

In fact, The elasticity of the demand represent that how much increase in the price of a commodity even by a small amount will clearly decrease demand and shows with ε.

The elasticity of the demand for a commodity depends in large part on the availability of substitutes.

B. Restriction balance between supply and demand [10]

The total energy generated in a power system must be equal to the energy consumed in the system, so we have:

$$\sum_{i} P_{gi} = \sum_{k} P_{Dk} + P_{losses} \quad (1)$$

In which $\sum_k P_{Dk}$ is the total energy consumption and P_{losses} is losses of total transmission lines system.

In this paper we neglect from considering of transmission line losses.

C. Calculation of the outage cost by inverse demand function model for consumers

As previously mentioned, the model of consumer is as follows:

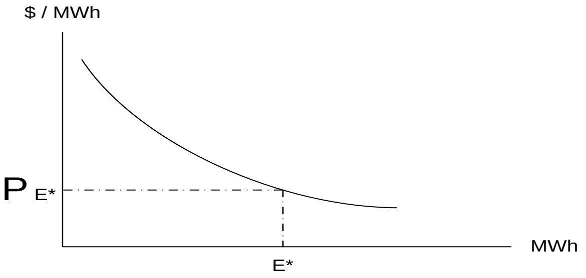


figure 3. Determination of market clearing price in modeling the consumers

In which E^* is peak value and P_{E*} is market clearing price for loading E^*, so we have:

$$D = \alpha P^{\varepsilon}\ , \qquad \alpha = E^*/(P_{E^*})^{\varepsilon}\ , \qquad \varepsilon < 0 \qquad (2)$$

ε is estimated price elasticity of demand, whereas D and P is the energy consumption in MWh and energy price in $/MWh respectively. If in consumption model, peak load quantity (E*) change to Eq, then:

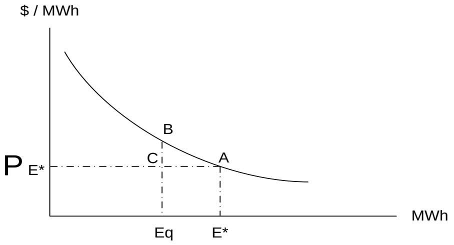


figure 4. cost outages from customer point of view

With reference to Fig.4, we can find area ABC using equation 2. The area is given by the following expression:

$$\Delta_{ABC} = \int_{E_q}^{E^*} \Big(\frac{\alpha^{\frac{1}{|\varepsilon|}}}{D^{\frac{1}{|\varepsilon|}}} - P_{E^*} \Big)\, dD \qquad (3)$$

Indeed the above formula is the outage consumers cost.

2- The difference between two values E^* and Eq, is the amount of capacity of the system which has gone out due to outage capacity.

D. Objective function [11]

Thus, the whole problem can be expressed mathematically as minimizing the sum of the operating cost ($C(r^t_d)$) and the expected cost of outages ($E(r^t_d)$).

Then:

$$\min_{r^t_d} \{\, f(r^t_d) = C(r^t_d) + E(r^t_d) \,\} \qquad (4)$$

Note that the cost of outages has the character of expected because it is not possible to know a priori which or if contingency will happen.

At the minimum, it is a necessary condition that:

$$\frac{d\, f(r^t_d)}{d\,(r^t_d)} = \frac{d\, C(r^t_d)}{d\,(r^t_d)} + \frac{d\, E(r^t_d)}{d\,(r^t_d)} = 0 \qquad (5)$$

Because the spinning reserve provision is discontinuous due to the indivisibility of the generating units, the above equation can be represented in difference form as:

$$\frac{\Delta\, C(r^t_d)}{\Delta\,(r^t_d)} + \frac{\Delta\, E(r^t_d)}{\Delta\,(r^t_d)} = 0 \qquad (6)$$

From the previous equation it must be noted that the increment in the expected cost of outages is negative for a positive increment in the spinning reserve provision (ΔR). Therefore it is favorable to procure an extra mw of spinning reserve up to the point in which the incremental cost of the expected cost of outages .That is, for the whole range of the following inequality:

$$\frac{\Delta\, C(r^t_d)}{\Delta\,(r^t_d)} \le -\frac{\Delta\, E(r^t_d)}{\Delta\,(r^t_d)} \qquad (7)$$

And:

$$E(r^t_d) = EENS_R \times VOLL_R \qquad (8)$$

$E(r^t_d)$, $EENS_R$ and $VOLL_R$ is Expected outage cost pro reserve R, Expected Energy Not Served pro reserve R and value of loss load pro reserve R respectively.

We assume market is kind of Pay As Bid, then the reserve cost is calculated from the following formula.

$$C(r^t_d) = \sum_{gen,n} (P_{Rj} \times Rj) \qquad (9)$$

P_{Rj} and R_j is proposed price for reserve unit j and amount of given reserve by their unit.

Since the value of loss load is variable for different levels of reserve, therefore:

For min f(r^t_d) :

$$\mathrm{VOLL_R} \times \frac{\partial\, \mathrm{EENS_R}}{\partial\, \mathrm{R}} + \mathrm{EENS}_{\,\mathrm{R}} \times \frac{\partial\, \mathrm{VOLL_R}}{\partial\, \mathrm{R}} + \frac{\partial\, \mathrm{C}}{\partial\, \mathrm{R}} = 0 \qquad (10)$$

E. proposed algorithm

According to the above relationship, first reserve units are ordered in ascending by proposed price. According to 7 formulas, buying reserve will be stopped when buying the extra cost of buying this energy package is equaled to the reduction of energy losses caused by reduction of energy interruption by buying this package of energy. So decision to buy for reserve unit j+1 th is with following equations.

$$\Delta\, \mathrm{C_{j+1}} = \mathrm{C}\left(\mathrm{R_{j+1}}\right) - \mathrm{C}\left(\mathrm{R_j}\right) \qquad (11)$$

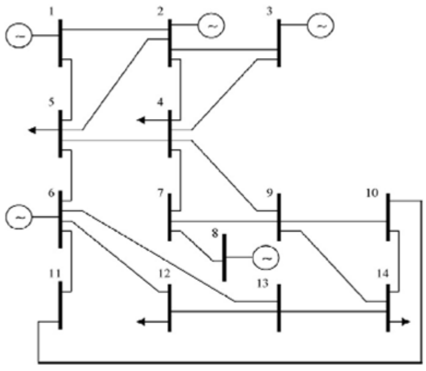
$$\Delta\, \mathrm{E\, R_{j+1}} = \mathrm{VOLL_R} \times \left(\mathrm{EENS\, R_j} - \mathrm{EENS\, R_{j+1}}\right) + \mathrm{EENS_R} \times \left(\mathrm{VOLL\, R_j} - \mathrm{VOLL\, R_{j+1}}\right) \qquad (12)$$

At the first in each step we must acquire outage cost with formula 3, and EENS parameters from Capacity Outage Probability Table (COPT) and then we calculate value of loss load with 8 formulas. After that we implement formula 11 and 12 for applying appropriate algorithm. Then we have:

If $\Delta E_{Rj+1} > \Delta C_{j+1}$, then the reserve unit will be bought, otherwise the cost of buying this reserve is more that reduction cost of interruption of energy and the buying cost is not affordable. So, in this step, buying the reserve will be stopped.

IV. Case study

14 bus IEEE network is used for testing proposed model. In figure 5 is plotted single line diagram of this network.



2. single line diagram of 14 bus IEEE network

This network consists of 5 generators, 11 buses and 20 lines of communication between the buses. Information about the generators of this network is given in Table 1.

TABLE I. information about 14 bus IEEE network

Generator	At bus	Number of Units	Capacity (MW)	Forced outage rate	Price ($)
A	1	1	100	0.01	10
B	2	4	50	0.04	12
C	3	1	80	0.03	14
D	6	3	20	0.02	20
E	8	1	100	0.02	25

V. Simulation results

The assumptions in this issue is that the market would close for an hour and generators load into system to supply total load 300 MW and their preparation cost is equal to proposed power cost.

Since D =300 MW and P = 12 $, we will have :

$$\alpha = 1040$$

First step:

For supplying 300 MW must load into the system a unit of A and four units of B. therefore with creating COPT table we will have: $\mathrm{EENS_1}$= 9 MWh.

In this step, because of ΔABC =0, consequently consumer outage cost will be equal to zero.

Second step:

At this stage, the first inexpensive unit will be loaded into system and is regarded as first reserve which in this example is C generator. The results are as follows.

$$EENS_2 = 0.728\, MWh$$

$$\Delta_{\,ABC} = \int_{220}^{300} \left(\frac{1040^{\frac{1}{|-0.5|}}}{D^{\frac{1}{|-0.5|}}} - 12\right) dD = 351.01\,\$$$

$$\mathrm{E}(\,\mathrm{r_d^t}\,) = EENS_R \times VOLL_R \rightarrow 351.01 = 0.728 \times VOLL_R \rightarrow VOLL_R = VOLL_1 = 482.14\,\$$$

$$\Delta\, L = VOLL_1 \times (\,EENS_1 - EENS_2) + EENS_2 \times (\,VOLL\, R_0 - VOLL\, R_1) = 3637.26\,\$$$

$$\Delta\, C = 80 \times 14 = 1120\,\$$$

Because ΔL is greater than ΔC, so buying will be affordable and process continues.

Third step:

First unit of D will be loaded into system which is equal to 20 MW. The results are as follows.

$$EENS_3 = 0.273\ MWh$$

$$\Delta_{ABC} = \int_{200}^{300} \left(\frac{1040^{\frac{1}{|-0.5|}}}{D^{\frac{1}{|-0.5|}}} - 12 \right) dD = 602.66\ \$$$

$$E(r_d^t) = EENS_R \times VOLL_R \rightarrow 602.66 = 0.273 \times VOLL_R \rightarrow VOLL_R = VOLL_2 = 2207.5\ \$$$

$$\Delta L = VOLL_2 \times (EENS_2 - EENS_3) + EENS_3 \times (VOLL\ R_1 - VOLL\ R_2) = 533.37\ \$$$

$$\Delta C = 20 \times 20 = 400\ \$$$

Because ΔL is greater than ΔC, so buying will be affordable and process continues.

Fourth step:

Second unit of D also will be loaded into system which is equal to 20MW. At this stage, because ΔL is smaller than ΔC buying will be stopped and process ends. Therefore total amount of required reserve with applying this algorithm will be the sum of the capacity of generator C and one unit of generator D, means it will be 100 MW.

VI. Comparison with deterministic criteria

If reserve considered according to the percentage of peak load and percentage is 10%, then amount of reserve is:

$$reserve = 10\% \times 300 = 30\ \text{MW}$$

If reserve considered according to the largest unit, then amount of reserve is: 100 MW.

In these cases, we will see that using both criteria cause consumer unreasonable pay more than outage cost, spend for reserve that this is irrational.

VII. Conclusion

As we saw, applying this algorithm can be easily prevented from unnecessary and complexity calculations, also the simplicity of this algorithm over other probability methods result superiority of this method. In addition, because most of reliability parameters are unknown, this method shows its superiority once again.

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