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Customer choice of reliability in spinning reserve procurement and cost allocation using well-being analysis

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ABSTRACT

A novel pool-based market-clearing algorithm for spinning reserve (SR) procurement and the cost allocation associated with provision of spinning reserve among customers (DisCos) is developed in this paper. Rational buyer market model is used to clear energy and spinning reserve markets in the proposed algorithm. This market model gives DisCos the opportunity to declare their own energy requirement together with their desired reliability levels to the ISO and also they can participate in the SR market as a interruptible load. The DisCos' desired reliability levels are selected from a hybrid deterministic/probabilistic framework designated as the system well-being model. Using the demand of each DisCo and its associated desired reliability level, the overall desired system reliability level is determined. The market operator then purchases spinning reserve commodity from the associated market such that the overall desired system reliability level is satisfied. A methodology is developed in this paper to fairly allocate the cost associated with providing spinning reserve among DisCos based on their demands and desired reliability levels. An algorithm is also presented in this paper for implementing the proposed approach. The effectiveness of the proposed technique is examined using the IEEE-RTS.

1. Introduction

Power system operators must maintain a certain amount of spinning reserve at all times to account for sudden loss of generating capacity or system load fluctuation [1,2]. In a traditional power system, the decision for providing the required spinning reserve is made centrally and the cost associated with the provided spinning reserve is allocated among customers based on their load levels. Since the past decade, power industries worldwide have been going through a process of restructuring in order to introduce commercial incentives in generation, transmission and distribution. The reforms are achieved through a clear separation between production and sale of electricity, and network operations [3]. A key point in the competitive environment for the power industry is that the customer must be at the center of any business strategy. Deregulation has made it possible for consumers to select their suppliers based on cost effectiveness. In a mature market they must also have a say in reliability matter, mostly by making decisions on the reliability level of supply for which they want to receive and are willing to pay [4,5]. Therefore, not only can the consumers bid their load levels and prices, but also they can declare their desired reliability levels for the supply they receive [4].

Both deterministic and probabilistic approaches can be used to establish spinning reserve requirements. The essential disadvantage of the deterministic criteria is that they do not respond to the many factors that influence the actual risk in the system. Utilization of probabilistic techniques enables the random nature of system components and load behavior to be included in a consistent manner. Ref. [6] presents a probabilistic technique to determine the required spinning reserve in a traditional power system using the loss of load probability (LOLP) index. A probabilistic pool-based market-clearing algorithm is presented in Ref. [7] for application in electricity markets where generation scheduling is performed based not only on the prices of energy and reserve, but also on the reliabilities of generating units.

In order to incorporate practical security considerations in operating reserve assessment and to alleviate the dilemma associated with the lack of sufficient information provided by probabilistic indices including difficulties in interpreting the risk index, a bridge was created between the deterministic methods and the prevalent probabilistic techniques using a system well-being model [8–11]. A hybrid probabilistic/deterministic method is presented in Refs. [8,9] using the well-being model to provide the requisite spinning reserve and its allocation in traditional power systems. Ref. [11] extends the application of the well-being framework to adequacy evaluation of composite systems in the competitive environment. Goel et al. [12] extended the well-being technique to determine

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the customer spinning reserve requirements based on desired reliability levels in a bilateral market model. A number of bulk load point indices are introduced in Ref. [12] for customers to recognize their reliability levels.

A novel pool-based market-clearing algorithm for spinning reserve procurement and the cost allocation associated with providing spinning reserve among DisCos is developed in this paper using the well-being model. Rational buyer market model [3] is used to clear energy and spinning reserve markets in the proposed algorithm. In such a market, DisCos declare their desired reliability levels and purchase their requisite reserve in an ancillary services market based on pre-selected (desired) reliability levels. A methodology is developed to determine how each user (DisCo) contributes to the use of the procured spinning reserve. Once the contribution of different users is determined, the next step is to fairly implement provided spinning reserve among users based on their demands and desired reliability levels. The IEEE Reliability Test System (RTS) [13] is used to examine the effectiveness and applicability of the proposed algorithm and the results are presented and discussed.

2. System well-being model

In order to incorporate practical security considerations in operating reserve assessment, the system performance can be divided into operating states classified in terms of the degree to which the security constraints are satisfied. For this purpose, the system well-being framework was first introduced by Billinton et al. [8]. This framework provides the opportunity for system operators to consider both deterministic and probabilistic approaches, and to appreciate the weaknesses associated with using only the deterministic approach or a single risk index in a probabilistic technique. The system well-being is described by a set of mutually exclusive, exhaustive operating states designated as healthy, marginal and at risk. The system operates within the specified limits in both the healthy and marginal states. In the healthy state, all the equipment and security constraints are within limits while supplying the total system demand. In this state, there is sufficient reserve margin such that acceptable deterministic criterion, such as any single contingency, can be tolerated without violating the limits. In the marginal state, the operating constraints are within limits, but some specific single contingencies will result in a limit being violated due to insufficient reserve margin. The system is, therefore, on the edge of being in trouble when in this state. The operating constraints are violated in the risk state and the system is required to shed load. Detailed definition of the operating states can be found in Refs. [8–11].

3. Reliability criteria

3.1. Developed indices of well-being analysis for DisCos

The system well-being model utilized in traditional power systems is extended in this paper to DisCos in a pool market. The performance of a given DisCo is expressed by well-being indices in the form of the DisCo's healthy, marginal and risk state probabilities. The approaches and methodologies used in [11] can be generalized for calculating well-being indices associated with DisCos.

A particular DisCo is considered to be in the healthy state, if the DisCo's contribution to the total procured spinning reserve is such that the associated share of loss of all single generating units is made up by the contributed spinning reserve. In the marginal state, however, the DisCo's contribution to the usage of the procured spinning reserve is not enough to respond to the associated share of some or all single unit outages.

3.2. Determination of the overall desired system reliability criteria

The probability of the system being in the healthy state together with the conventional risk index can be used as the system operating criteria. A single criterion or multiple criteria can be considered as the desired reliability level. The selection of specific values for the healthy state probability or risk depends on the desired degree of system well-being and the conditions under which the system is being operated. It is a managerial decision and depends largely on the degree to which the reliability level is required. For the case of a single criterion, normally, a single risk criterion must be satisfied similar to the conventional probabilistic technique. In this case, the calculated risk must be less than or equal to a specified value as expressed below:

$$\mathrm{CSR} \le S_{\mathrm{risk}} \tag{1}$$

Once the system risk is satisfied, the well-being indices are calculated. Depending on the desired risk level, the system may or may not tolerate single component outages.

The system health probability is an additional index which reflects the degree of system well-being. The concept of satisfying multiple criteria provides a more comprehensive appraisal of the system well-being and therefore more comfort for the system operator who has to make the required decisions. The multiple criteria can be expressed as below:

$$\mathrm{CSR} \le S_{\mathrm{risk}} \quad \text{and} \quad \mathrm{CSH} \ge S_{\mathrm{health}} \tag{2}$$

It can be seen from (2) that in addition to the specified risk level, an acceptable level of health needs to be maintained. As noted earlier, the performance of a particular DisCo can be expressed by the well-being indices. In this paper, DisCos' desired reliability levels are declared from one or two of the well-being indices. Once the desired reliability levels associated with all DisCos are declared, the overall desired system reliability criterion/criteria are determined. This implies that DisCos consequently contribute to the overall system desired reliability levels by choosing their own preferred reliability levels. Accordingly, the overall desired system risk and health levels are calculated as follows:

$$\mathrm{ODSRL} = \frac{\sum_{i=1}^{\mathrm{ND}} DR_{\mathrm{d}ci} \times L_{\mathrm{d}ci}}{\sum_{i=1}^{\mathrm{ND}} L_{\mathrm{d}ci}} \tag{3}$$

$$\mathrm{ODSHL} = \frac{\sum_{i=1}^{\mathrm{ND}} DH_{\mathrm{d}ci} \times L_{\mathrm{d}ci}}{\sum_{i=1}^{\mathrm{ND}} L_{\mathrm{d}ci}} \tag{4}$$

4. Market clearing—proposed method

4.1. Energy and spinning reserve market model

The market structure used in this paper is assumed to be a Pool Model which the independent system operator (ISO) responds to system operation, planning and power market management. In the proposed market structure, energy and spinning reserve markets are based on rational buyer model such that GenCos concurrently submit their offer curve for energy and reserve along with ramping rates and maximum available unit capacities to the market. Simultaneously, customers or DisCos declare their own energy and desired reliability levels to the ISO, and also they participate in the reserve market as interruptible load. The reliability level specified by a DisCo could be in the form of a single risk criterion or multiple criteria (health/risk). It has to be noted that in order to prevent market gaming, DisCos do not have information about each other. The proposed algorithm for spinning reserve procurement in a pool power market model is a bottom-top process as shown in Fig. 1.