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Reliability modeling of demand response considering uncertainty of customer behavior

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HIGHLIGHTS

- Reliability model of demand resource is constructed considering customer behavior.
- Reliability model has simple two-state model, and is generalized by a multi-state.
- Integrated power market includes conventional generation and demand response (DR).
- Aggregated demand resources are represented by an equivalent multi-state DR.
- The reliability indices of the system and load point with DR are evaluated using OPF.

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ABSTRACT

Demand response (DR) has been considered as a generation alternative to improve the reliability indices of the system and load point. However, when the demand resources scheduled in the DR market fail to result in demand reductions, it can potentially bring new problems associated with maintaining a reliable supply. In this paper, a reliability model of the demand resource is constructed considering customers' behaviors in the same form as conventional generation units, where the availability and unavailability are associated with the simple two-state model. The reliability model is generalized by a multi-state model. In the integrated power market with DR, market players provide the demand reduction and generation, which are represented by an equivalent multi-state demand response and generation, respectively. The reliability indices of the system and load point are evaluated using the optimal power flow by minimizing the summation of load curtailments with various constraints.

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1. Introduction

Due to the restrictions for utilizing conventional generation resources, the power system operators have been trying to find alternatives to expansion of the conventional generation. Then the system operators accepted demand response (DR) as one of the alternatives in order to improve the system reliability, prevent rolling blackouts, and lower electric price [1–2]. DR can be defined as the changes in the electric usage by the end-user from their normal consumption patterns [1]. DR can reduce the system peak load, and thus, the system risk of being exposed to forced outages and electricity interruption. As a consequence, the operator will have more options and resources to maintain the system reliability. Recently, some technical papers have been published from the viewpoint of reliability enhancement relevant to DR program. Analytic hierarchy process has been proposed as a decision-support tool to implement the reliability indices by customer-oriented DR programs [3]. The reliability enhancement considering DR has been presented with the concepts of nodal prices and nodal reliability indices by re-dispatching generation based on a load response model [4,5]. It has been shown that DR can improve the reliability of power system, with the advent of new electronic devices in the grid [6], or with an optimal mix of integrated resources such as renewables and storage [7]. DR can be utilized as system reliability resources in order to maintain the system reliability due to the advantages of geographic locations close to loads and the fast response time to system disturbances [8]. In addition, DR is procured as spinning reserve resources for system reliability enhancement [8,9]. However, all these studies have assumed that demand resources scheduled in DR market never fail to reduce their loads for DR events. Actually loads often fail to reduce when requested due to some external factors such as DR event duration, natural human inertia and external temperature [10]. The previous studies have overlooked that customer behavior is unstable, changeable and unpredictable. Even though the historical data about customer behavior can be collected, there is still another possibility that the customers may change their consumption patterns unexpectedly. This paper is motivated by the necessity of study on the system reliability problems caused by failed demand resources.

In this paper, a reliability model of the demand resource is first developed to represent the customer behavior by two-state of demand reduction and its failure, which is the same form of conventional generation unit reliability model [11,12]. It is also extended to a multi-state model for demand resources due to the variety of loads in contrast to the typical two-state model for the generation units. The reduction of the demand resources can be considered as the addition of the conventional generation resources. The conventional generations usually are modeled by an equivalent multi-state generation provider (EMGP) [13–16], and with a form similar to that of EMGP, demand resources also are modeled by an equivalent multi-state demand response provider (EMDRP). The parameters of EMDRP and EMGP are separately calculated using the available capacity probability table (ACPT) [11], and then the reliability indices of the whole power system are determined by using OPF and conventional reliability evaluation techniques [17,18].

2. Reliability model for demand resources

Demand reductions can be treated as equivalent generation resources. In this sense, the negative quantity of the demand that has been reduced from the load can be converted to a positive quantity as the available capacity provided to its customer. In a practical power system with DR, the generation resource can be replaced with the demand resource that has a lower marginal cost than the marginal cost of the electricity power [19]. However, with a higher probability that customers will unexpectedly change their consumption patterns, the amount of demand reduction according to customer behavior is not as stable as that of conventional

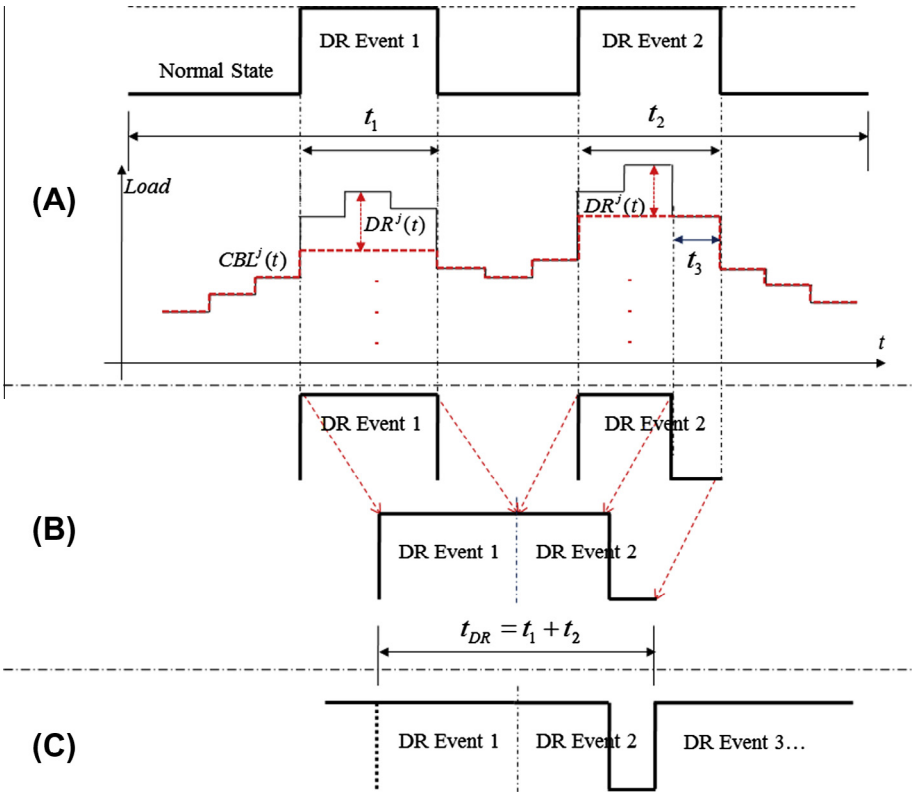

Fig. 1. DR unavailability and availability.