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Assessment of energy supply and continuity of service in distribution network with renewable distributed generation

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HIGHLIGHTS

- Difficulties in assessing distribution network adequacy with DG are addressed.
- Indices are proposed to assess adequacy of energy supply and service continuity.
- Analytical methodology is developed to assess the proposed indices.
- Concept of joint probability distribution of demand and generation is applied.

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ABSTRACT

Continuity of electricity supply with renewable distributed generation (DG) is a topical issue for distribution system planning and operation, especially due to the stochastic nature of power generation and time varying load demand. The conventional adequacy and reliability analysis methods related to bulk generation systems cannot be applied directly for the evaluation of adequacy criteria such as 'energy supply' and 'continuity of service' for distribution networks embedded with renewable DG. In this paper, new indices highlighting 'available supply capacity' and 'continuity of service' are proposed for 'energy supply' and 'continuation of service' evaluation of generation-rich distribution networks, and analytical techniques are developed for their quantification. A probability based analytical method has been developed using the joint probability of the demand and generation, and probability distributions of the proposed indices have been used to evaluate the network adequacy in energy supply and service continuation. A data clustering technique has been used to evaluate the joint probability between coincidental demand and renewable generation. Time sequential Monte Carlo simulation has been used to compare the results obtained using the proposed analytical method. A standard distribution network derived from Roy Billinton test system and a practical radial distribution network have been used to test the proposed method and demonstrate the estimation of the well-being of a system for hosting renewable DG units. It is found that renewable DG systems improve the 'energy supply' and 'continuity of service' in the distribution networks. The results suggest that the consideration of the time varying demand and stochastic renewable generation output has significant impact on the 'energy supply' and 'continuity of service' in the distribution networks.

1. Introduction

Adequacy of the electricity network can be defined as the existence of the facility within the system to satisfy the customer demand [1]. Distribution network service providers are primarily responsible for designing the network to ensure the continuity and quality of the electric supply. The capacity of the distribution feeder to supply demand of the feeder is to be assessed for distribution network expansion planning [2]. Integration of renewable distributed generation (DG) has impacts on the energy supply and service continuation of the distribution networks. The time varying demand and the uncertainty in power generation from renewable DG introduces difficulties in the conventional distribution network adequacy estimation methods. Load based reliability indices and customer oriented reliability indices are estimated in the conventional distribution network adequacy analysis using either analytical approach or Monte Carlo simulation (MCS) techniques [3–15].

In [3], both analytical and MCS techniques have been applied to evaluate the probability distributions of the customer oriented reliability indices for a distribution network. In [4], MCS technique

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has been applied for the adequacy assessment of a distribution network with distribution generation (DG) systems. It uses state duration sampling approach and evaluates adequacy index from the negative marginal load of the network. In [5], distribution network adequacy evaluation methodology is developed with the aid of loss of load and system well-being indices for grid connected and islanded operation of distributed and renewable generation systems. In [6], capacity outage table is used to evaluate adequacy of the distribution network with intermittent DG supply, and new reliability indices are proposed. In [7], energy based adequacy indices are proposed and a comparative study is presented for assessing the impact of load growth and different types of generating units on the indices. In [8], the impacts of generating units, operated as peak load and base load power plants, on the generation system adequacy is analysed using the sequential MCS technique. In [9], an analytical approach using probability distribution of demand and renewable generation is proposed for the well-being assessment of an isolated power system with renewable generation units. An energy based system well-being analysis of power system is presented in [10]. In [11], well-being analysis of various generation systems involving wind generators is carried out using capacity outage table; and impact of the load and generation forecasting on reliability has been also investigated. In [12], the capacity credit of wind generation system is evaluated for isolated distribution network using the analytical method. In [13], a new reliability index composed of customer side reliability indices has been proposed to assess the contribution of the DG in improving the risk of energy supply in a distribution network. The load point reliability parameters and average load have been considered in [13,14] for evaluating the customer oriented reliability indices of the distribution networks.

The existing distribution network adequacy indices and estimation technique may not be able to provide sufficient information for assessing distribution system adequacy due to the time varying nature of load demand and stochastic power generation by renewable DG systems that exhibit in practical systems. The network aspects such as nodal voltages, power losses and power transfer capacity may also affect the hosting capacity of renewable DG units [15]. Moreover, the above mentioned network aspects are also dependent on the size, location, mode of operation, type and number of renewable DG units, and the uncertainty in generation and demand. Evaluation of the adequacy in terms of energy supply and continuity of service of the distribution networks can aid in the plan and design of distribution networks to avoid loss of continuity of the services and redundancy in the networks. Conventional adequacy indices are developed based on the system risk concept which provides the quantitative indication of load interruption due to the failure of equipment. In most of the practical distribution feeders, the total or partial load can be transferred to the neighbouring distribution feeder through closing the generally opened tie connection to ensure supply security. It is important to estimate the ability of the distribution feeder to transfer and receive load to and from the feeder connected with tie line, respectively.

It has been noted that the reported methods for adequacy analysis of distribution network can be classified into two major groups: adequacy estimation from the source of energy supply and adequacy estimation from potential contingency of the feeder equipment. The existing methods, related to estimation of the supply adequacy and continuity of service adequacy, consider constant load demand and generation. As indicated earlier, the existing methods assume the successful load transfer capacity of the distribution feeder to be constant and estimate it from the peak demand level of both the distribution feeders [1,16]. However, the peak demands of the two neighbouring distribution feeders may not coincide with each other. Moreover, the transferrable load of the distribution feeder with outage could be less and the available capacity of the neighbouring distribution feeder may become higher during the off-peak hours.

In the reported analytical methods for adequacy evaluation of the distribution network, the demand and output from renewable generation systems are considered to be independent. The coincidental occurrence of the demand and renewable generation has significant impacts on the adequacy of the distribution network. It has been observed that the reliability of the distribution network does not improve greatly after installation of DG system unless islanding operation is allowed [5,6]. However, islanding operation is not permissible by the existing standards and utilities do not allow islanding in most of the electricity networks [17–19]. As a result, new indices and methodology are required to assess the energy supply and service continuity adequacy for distribution network that can facilitate the integration of DG systems.

In this paper, issues related to the energy supply and service continuation assessment of a distribution network embedded with renewable DG units are addressed. New indices have been developed to estimate the energy supply adequacy and continuity of services adequacy which are essential to evaluate the distribution network adequacy and reliability. The adequacy assessment indices and methods of bulk generation systems are well established. Hence, it is required to develop new indices for distribution network so that existing generation adequacy assessment methodologies for bulk generation systems can be applied to the distribution network adequacy assessment incorporating renewable DG. Energy supply indices enable the distribution network planner to estimate the energy supply adequacy using the capacity credit of renewable DG and well-being analysis of the distribution network with renewable DG. The continuity of service indices proposed in this paper can incorporate the time varying demand and variable generation from renewable DG systems whereas in the conventional distribution network adequacy assessment methods peak demand and installed generation capacity of the renewable DG are considered for the purpose. A joint probability based analytical method is developed for the assessment of network adequacy in terms of energy supply and continuity of service in distribution networks embedded with DG systems. Well-being analysis has been applied to assess the energy supply and continuity of services adequacy of the distribution network with renewable DG systems using the proposed indices. Probabilities of different operating states have been evaluated and reported.

2. Indices for distribution network energy supply and service continuation evaluation

The adequacy and reliability analysis of distribution network with renewable distributed generation (DG) requires installed DG capacities, available capacity in the distribution substation and load transfer capacity of the distribution feeder on the occurrence of outage of the distribution feeder. Hence maximum renewable DG hosting capacity of the distribution feeder, energy supplied during system peak, distribution substation capacity release, transferrable load, additional available capacity to accommodate the transferrable load and successfully transferrable load are to be estimated in the adequacy and reliability analysis of distribution network with renewable DG. Distribution substation and DG are the sources of the energy for satisfying the consumer demands in a distribution network [5,6]. Supply adequacy of the distribution network depends on the feeder capacity of the line connecting the load points to the distribution substation transformers and capacity of the DG systems. On the other hand, to maintain the continuity of the supply, the distribution network should be capable of meeting load demand under all the system conditions. In this