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Reliability assessment of distribution system with the integration of renewable distributed generation

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HIGHLIGHTS

- Addresses impacts of renewable DG on the reliability of the distribution system.
- Multi-objective formulation for maximizing the cost saving with integration of DG.
- Uses Markov model to study the stochastic characteristics of the major components.
- The investigation is done using modified RBTS bus test distribution system.
- Proposed approach is useful for electric utilities to enhance the reliability.

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ABSTRACT

Recent studies have shown that renewable energy resources will contribute substantially to future energy generation owing to the rapid depletion of fossil fuels. Wind and solar energy resources are major sources of renewable energy that have the ability to reduce the energy crisis and the greenhouse gases emitted by the conventional power plants. Reliability assessment is one of the key indicators to measure the impact of the renewable distributed generation (DG) units in the distribution networks and to minimize the cost that is associated with power outage. This paper presents a comprehensive reliability assessment of the distribution system that satisfies the consumer load requirements with the penetration of wind turbine generator (WTG), electric storage system (ESS) and photovoltaic (PV). A Markov model is proposed to access the stochastic characteristics of the major components of the renewable DG resources as well as their influence on the reliability of a conventional distribution system. The results obtained from the case studies have demonstrated the effectiveness of using WTG, ESS and PV to enhance the reliability of the conventional distribution system.

1. Introduction

The main function of a power system is to supply electricity to its customers at optimal operating costs with the assurance of a reasonable quality and continuity at all times [1]. Reliability is the probability that a power system will perform its functions adequately without any failure within a stipulated period of time when subjected to normal operating conditions [2]. The reliability study can be utilized to assess the performance of the distribution system based on the availability of suitable input component data and the configuration of the system. The reliability assessment can also be used to identify the malfunctional components that need urgent replacement in the distribution system as well as recommending the numbers of new components that should be incorporated in order to improve the reliability of the networks [3]. Owing to these technical and economic attributes, the reliability technique has been accepted as a benchmark for power system design and operation at all phases of the power system, i.e. conceptual, design, planning and operational phases [4].

The power system is in a significant phase of shifting from a conventional distribution system to the smart grid system with the integration of renewable energy resources (RER) [5–7]. This allows more intelligent state of the art technologies and renewable DG units to be integrated into the transmission and distribution (T&D) systems as a measure to improve the reliability of the system. The integration of renewable DG units and more intelligent technologies into a power system will reduce the outage duration and the interruption cost and also increase the revenue of the utilities owing to quick power restoration and the improved utilization of the distribution system capacity. Power utilities have encouraged the integration of RERs into their networks having ana-

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lyzed the environmental, technical and economic impacts of using these resources to enhance the reliability of the distribution system. The integration of renewable DG units into a conventional distribution system depends on the power output of the DG units, availability of wind speed and solar irradiance based on the specifications of the original equipment manufacturers (OEM), repair time, configuration of the network, consumer load demand, etc. The performance of the WTG and PV can be analyzed by using the historical meteorological data of the sites where the units are to be installed, so that it will be very easy to predict the availability of the local renewable energy resources on an hourly basis.

This research work is aimed at exploring renewable energy resources to ameliorate the reliability of the distribution system and to reduce the cost that is associated with the power outage. Renewable DG units have the potential to enhance the reliability of the distribution system, to optimize greenhouse gas emissions and the fuel consumption cost of the conventional power systems [7–9]. This work focuses on developing a reliability evaluation framework for a conventional power system in the presence of WTG, ESS and PV to the reduce power outage which is one of the challenges of the distribution system. The main objective of this work is achieved by integrating renewable energy system, which consists of WTG, ESS and PV units, into a conventional distribution system at a number of bus bars within the network. The distributed energy resources (DER) at the respective bus bars are designed in such a way that their operations depend on the availability of the local RERs. This paper presents a methodology that allows multiple renewable DG and ESS units at various states to be integrated into a conventional distribution system.

It has been reported in many literatures that the distribution system contributes the greatest percentage of power outage at the consumer load points owing to the radial nature of the networks [4]. Therefore, the reliability assessment of the distribution system in the presence of WTG, ESS and PV has drawn the attention of many researchers. The impact of renewable DG and battery storage units on the reliability of a conventional distribution system has been studied in [10,11]. Arifujjaman et al. [12] have explored the characteristics of the ESS to optimize power system losses, efficiency, reliability and energy cost. Bhandari et al. [13] have presented the economical hybridization methods to estimate the impacts of PV, wind and micro hydro units on the environmental sustainability. Ogunjuyigbe et al. [14] have proposed a Genetic Algorithm (GA) to optimize the dump energy, life cycle cost and CO_2 emissions of a power system that consists of PV-wind-diesel-battery hybrid energy systems. They have explored the characteristics of the renewable energy resources to minimize the objective function of the proposed power system. Ahadi et al. [15] have presented a new approach for optimal combination of renewable energy sources in stand-alone systems with the main objective of minimizing the total cost of the system.

Duan et al. [16] have presented a network reconfiguration method to improve the reliability indices of a conventional distribution system. The method, however, depends on the availability of a power supply from the utilities and the capacity of the power system components. Souza et al. [17] have presented a pseudo-dynamic planning approach to estimate the impact of reliability assessment on the distribution system. The technique is tested on a 54-bus distribution network and the results obtained from the technique have demonstrated the effectiveness of the pseudo-dynamic planning method on a conventional distribution network. Abbasi et al. [18] have proposed distribution system expansion planning to improve the reliability of a conventional distribution system. This approach is aimed at optimizing the system's reliability indices, power system investment and operating costs. The method has demonstrated that it can be effectively used to improve the reliability of a power system. Locatelli et al. [19] have proposed an optimal switch allocation in a conventional distribution system for reliability improvement. This technique minimizes the cost that is associated with energy not supplied in a power system. Ghajar et al. [20] have presented different methods for evaluating the reliability worth and the cost of the power system. These techniques are based on customer damage functions (CDF) and the interrupted energy assessment rates for each load point in the network. The proposed model is illustrated by an interruption cost data of the IEEE-reliability test system (IEEE-RTS). The work is aimed at optimizing the costs and benefits of using DG units to reduce power system interruption.

Monte Carlo simulation is one of the techniques for calculating the reliability indices of a conventional distribution system with the integration of the renewable DG and ESS units [21–26]. The techniques present the stochastic characteristics of the RERs and their impact on the system reliability. The simulated results from the Monte Carlo simulation methods illustrate the fact that the stochastic behaviour of the renewable energy technologies plays an important role in determining the reliability indices of the distribution system. The Monte Carlo simulation technique presented in [21–26], can be very effective in giving approximate solutions to the power system problems. The results are, however, not accurate when compared with other techniques. The computational time is lengthy, and it is not easy to implement when applied to the large electrical power networks that contain multi-objective functions. Owing to the computational time, it can be used only in small electrical systems.

The reliability indices of a conventional distribution system can also be estimated based on the analytical method that can handle numerous generating units [27]. The analytical method for estimating the reliability indices of a conventional distribution system in the presence of DG units is adopted to carry out a reliability assessment of a power system [27]. This technique is based on the fact that the conventional DG units will supply the load demand in a situation where there is a power outage from the utilities. The analytical technique can be used only to estimate the reliability indices of the generating units that have non-intermittent output power. Analytical models can be utilized only for the reliability evaluation of a small-scale power system [28]. It can provide accurate results or solutions when applied to a small-scale power system with a smaller computational effort than Monte Carlo simulation. The results obtained with the analytical technique demonstrate its effectiveness in a power system. These benefits are, however, limited to the failure of the technique to be used for stochastic characteristics of the major components of a power system at different operating states.

To achieve an accurate solution of the multi-objective functions and a more realistic reliability assessment of the distribution systems, a multi-state model that describes the stochastic characteristics of different components of the WTG, ESS and PV units in their respective states has been introduced. It is a powerful model that can be used to describe multi-states of various components of the renewable DG units [29–32]. This method yields more information on the load points and system reliability indices when compared to the analytical and Monte Carlo simulation methods. The methodology proposed in this paper aims to reduce the frequency and duration of power interruption at the consumers' load points during the grid connected mode. Many approaches have been employed to improve the reliability assessment of a conventional distribution system. Nevertheless, the stochastic characteristics of the major components of the renewable DG and ESS units, as well as their economic impact on the reliability assessment of a power system, have not been fully addressed. In view of this shortcoming, this paper addresses the reliability improvement of a conventional distribution system with the integration of WTG, ESS and PV units.