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A survey of reliability assessment techniques for modern distribution networks

Alberto Escalera[a,c,*], Barry Hayes[a,b], Milan Prodanović[a]

[a] IMDEA Energy, Avda. Ramón de la Sagra 23, Móstoles 28935, Madrid, Spain
[b] NUI Galway, University Road, Galway, Ireland
[c] University Carlos III de Madrid, Avda. Universidad 30, 28911 Leganés, Madrid, Spain

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ABSTRACT

Reliability assessment tools are of crucial importance for planning and modernisation of distribution power systems. In recent years there has been an increased deployment of renewable energy, distributed generation, energy storage, electric vehicle, protection device automation and demand response schemes in the distribution networks. All these technologies contribute in their own way to network reliability. The objective of this paper is to provide a critical survey of the reliability assessment techniques used for the evaluation of distribution networks, emphasising the importance of an increased penetration of distributed energy resources and a more widespread application of control, protection and communication technologies. A detailed analysis and a comparison between different techniques and models used for the reliability assessment will be provided for each technology along with the guidelines for their application. A case study will be used to demonstrate the properties and the modelling procedure of the reliability assessment tools for modern distribution networks.

1. Introduction

Reliability of power supplied to a customer can be measured by the impact interruptions cause to customers and distribution companies under network fault conditions [1]. Consequently, specific reliability levels are set by the regulators and penalties introduced for distribution network operators failing to comply with them. Also, an adequate reliability level during the distribution network planning stage has to be considered.

Traditional solutions to provide an adequate level of reliability in distribution networks are the following: meshed grids (components in parallel, alternative feeders to restore the supply, etc.), improved maintenance of the assets, application of more reliable components and installation of additional protection devices. The evolution of distribution networks towards Smart Grids and more sustainable energy systems has created a new set of opportunities for further improvement of the reliability of supply [2,3].

For example, during a fault in the distribution network an aggregation of both conventional and renewable DG can provide sufficient power to supply those interrupted areas that cannot be otherwise supplied by primary substations. Energy storage technologies can be used to mitigate the fluctuations of renewable generation and extend their contribution to supply restoration. Automation of the protection devices can be used to reduce the time response necessary for the network reconfigurations in presence of fault conditions. Also, the application of Demand Response (DR) techniques can help decrease the peak demand selectively and preserve the security of supply under emergency conditions.

The impact of all these technologies on the reliability of supply has to be properly addressed in order to support planning decisions in distribution networks [4]. Therefore, the techniques that are commonly used to assess the impact of different network technologies on the reliability of supply are of a particular interest. The critical review of techniques will help identify the most suitable ones for any given network scenario and, in this way, help guarantee the reliability of future distribution networks.

Several publications have addressed the state of the art in reliability assessment techniques applied to distribution networks. The most relevant probabilistic methods applied to reliability evaluation of power systems from 1964 to 1999 were presented in [5–10] and some of them addressed distribution networks. EPRI white paper in [11] presented definitions, concepts, practices and regulatory issues with respect to reliability in distribution networks and a dedicated chapter addressed the principal techniques and the software used. In year 2000, a review of the reliability evaluation techniques applied to distribution networks was published in [12]. In this paper it was explained how the

* Corresponding auhtor at: IMDEA Energy, Avda. Ramón de la Sagra 23, Móstoles 28935, Madrid, Spain.
E-mail addresses: alberto.escalera@imdea.org (A. Escalera), barry.hayes@nuigalway.ie (B. Hayes), milan.prodanovic@imdea.org (M. Prodanović).

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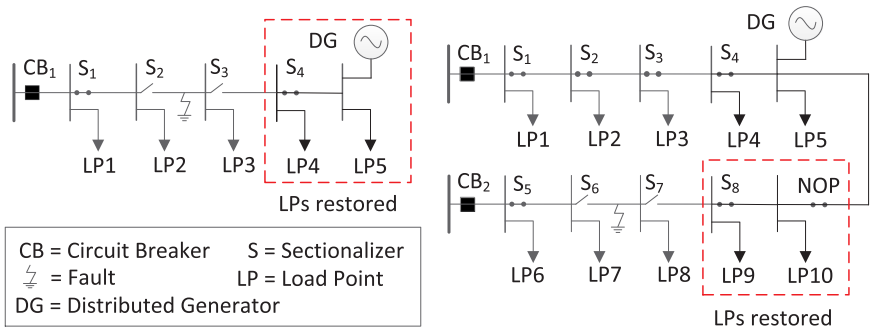

Fig. 1. DG operating modes for improvement of reliability of supply: islanded mode (left) and grid-connected mode (right).

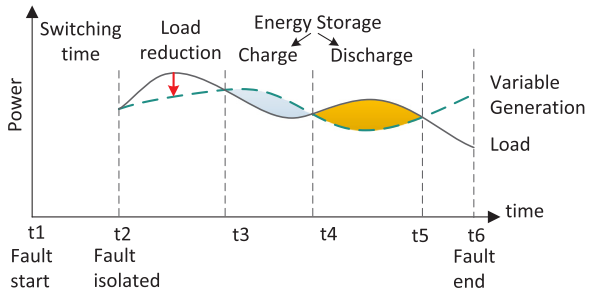

Fig. 2. Contribution of energy storage and demand response to improve the reliability of supply.

techniques can be used (or adapted) to suit the competitive nature of modern power systems along with the additional modelling requirements for generation resources in distribution networks. In [13], the reliability assessment techniques for distribution networks were classified by methodology, reliability indices used and inclusion of Distributed Generation (DG). The models and algorithms applied to reliability evaluation of power systems with wind generation were found in [14]. A review of the models used for the evaluation of the impact of renewable energy sources on the reliability of distribution networks was included in [15]. Although some of those reviews assessed the reliability impacts of conventional and renewable DG on distribution networks, a critical and complete comparison of the applied methodologies has not been found in the existing scientific literature. Moreover, techniques for reliability assessment of modern distribution networks with energy storage, microgrids, electric vehicle, DR and protection devices have not been adequately addressed.

This paper provides a literature review of the most relevant techniques used for reliability assessment of modern distribution networks. The principles and the methodologies proposed for the reliability evaluation of the above-mentioned technologies will be firstly introduced and then critically reviewed. The features and shortcomings of the reliability assessment tools and the technology models applied will be discussed. A case study will be presented to illustrate how the survey of the methodologies and the comparison of the results can be used to model the most appropriate techniques for reliability assessment.

The objectives of the survey are: a) to provide a state-or-the-art in the topic to researchers and practitioners in the field, b) support in modelling the appropriate reliability assessment techniques for modern distribution networks with specific requirements and technologies c) identify opportunities for future research in the field.

The paper is organized as follows: Section 2 describes how the new technologies in Smart Grids can further improve the reliability of supply, Section 3 briefly introduces the methodology for the reliability assessment of conventional distribution networks, Section 4 provides a critical analysis of the techniques proposed for the reliability evaluation of DG, energy storage, microgrids, electric vehicle, DR, protection devices automation and communication technologies. In Section 5 a case study is used to illustrate how the survey can be applied to model the appropriate tools for reliability assessment. Finally, concluding remarks including the main findings and future research are summarised in Section 6.

2. Reliability in modern distribution networks

The development of the Smart Grids implicitly creates new opportunities for improving reliability of modern distribution networks [3] and they will be described in this section.

2.1. Distributed generation

Installed Distributed Generation (DG) capacity can be used to improve reliability of distribution systems [16]. Under fault conditions in a distribution network, the power supply to some areas of the network can be interrupted. The DG installed in these areas can be used then to supply the interrupted power and improve the reliability.

DG units can be found operating in two modes: islanded mode and grid-connected mode [17] (see Fig. 1). Both modes can be used to improve the reliability of supply. The islanded mode refers to the areas isolated from the primary substation under fault conditions. In this case, the DG units located within isolated areas are used to provide energy that is not supplied by the primary substation. The grid-connected refers to the areas of the network equipped with Normally-Open Points (NOPs) that have a limited capacity to transfer power from adjacent feeders. In such a case, the DG can be used to increase that transfer capacity as shown in Fig. 1.

2.2. Energy storage

A significant part of the DG will be from variable renewable sources exposed to fluctuations and energy storage systems are installed in networks mainly to support their operation. Capabilities of variable DG to restore the interrupted supply are extended by using energy storage as Fig. 2 shows. Consequently, energy storage can be used to improve the reliability of distribution networks.

DG and energy storage location, capacity, availability and operation are the principal factors that affect the network reliability. The impact of these factors is necessary to be evaluated during the planning stage.

2.3. Demand response

One of the roles of Demand Response (DR) is to reduce the load under fault conditions by disconnecting or shifting less critical loads. The load reduction may allow DG to restore the supply in both operating modes of the distribution network, islanded and grid-connected (see Fig. 2).