



An overview of reliability models and methods for distribution systems with renewable energy distributed generation

Carmen Lucia Tancredo Borges*

Federal University of Rio de Janeiro, P.O. Box 68504, 21941-972 Rio de Janeiro, Brazil

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ABSTRACT

This paper presents a review of reliability models and methods for estimating renewable energy resources influence on electrical generation availability. These models and methods may be used to evaluate the impacts on the distribution systems reliability of distributed generation integration, especially when they are based on renewable energy sources. For such, the paper presents the main characteristics of renewable resources models that have been developed for wind, small hydro, solar and biomass, and presents the main methods for reliability evaluation of distribution systems with such resources integrated. These evaluation methods may be based on analytical techniques, Monte Carlo simulation or hybrid approaches. The impact of distributed generation on the reliability of electric distribution systems depends mainly on the operational mode and the energy source in which it is based. The most uncertain case is related to generation based on renewable energy of intermittent nature where the generation availability depends on the availability of the energy source and the availability of the generating unit.

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1. Introduction

Distributed generation (DG) is concerned with small generating units installed in strategic points of the distribution or sub-transmission systems and close to load centers. DG can be

used in an isolated way, supplying the consumer's local demand, or in an integrated way, supplying energy to the remaining of the electric system. In distribution systems, DG can provide benefits for the consumers as well as for the utilities, especially in sites where the central generation is impracticable or where there are deficiencies in the transmission system. DG may also be named as Embedded Generation or Distributed Energy Resources (DER). The main advantages expected from the connection of DG to the electric system are:

* Tel.: +55 21 25628027; fax: +55 21 25628080.

E-mail addresses: carmen@nacad.ufrj.br, cltborges@ig.com.br

- Transmission costs reduction by allocation of generation closer to the load.
- Reduced construction time and investment cost of smaller plants.
- Adequacy to the sector deregulation and competition policy.

However, the utilities obligation of providing access to the distribution network to the Independent Producers that want to install DG units confronts with the need of controlling the network and guaranteeing appropriate security and reliability levels. The uncertainties involved in system planning and operation become larger than in the past, especially when renewable energy sources are used.

A significant increase in the use of renewable energy sources for power system generation is being observed all over the world. A number of strategic and commercial issues combined are responsible for this interest, mainly [1]:

- Reduction of greenhouse gas emission.
- Diversification of the energy sources matrix.
- Need for expansion of the generation offer to attend the forecasted growing demand.

Usually, government programs stimulate the investment in generation plants based on renewable energy, such as, wind, small hydro, solar, and biomass. Renewable sources, however, tend to have smaller energy density when compared to fossil fuels and, for that reason, the plants are smaller and geographically more distributed. When based on intermittent energy sources, they cannot be pre-dispatched by the utility but only according to the availability of the primary energy source. The large uncertainty present in this kind of generation influences strongly on the system reliability.

For that reason, intermittent energy has disadvantages as a regular energy source and is considered less reliable than conventional sources. The amount of energy daily available can vary a lot from a season to another at the same site and its use is limited only to adequate sites.

The integration of DG base on renewable energy of intermittent nature can cause positive and negative impacts to the utility distribution network. Uncertainties related to DG are due to two main aspects: the intermittent nature of the primary energy source and the possible unavailability of the unit when it is required to generate. The combination of these aspects may lead to generation deficit, which can heavily compromise the security, reliability and quality of power supply. The increase in the size and complexity of distribution systems, together with the necessity of attending the demand in an economic and reliable way, requires the assessment of the random nature of network failures and generation outages, given that such events can lead to interruptions in electricity supply. However, nowadays it is undoubted that DG is an important alternative for generation expansion planning [2].

This paper intends to address the impacts on the distribution systems reliability of distributed generation integration, especially when they are based on renewable energy sources. For such, the paper reports the evolution of some renewable resources models that have been developed (for wind, small hydro, solar and biomass) and details the general models for reliability evaluation of distribution systems with such resources integrated, based on analytical method, Monte Carlo simulation or hybrid models. In summary, it can be said that the impact of distributed generation on the reliability of electric distribution systems depends mainly on two aspects:

- The operational mode and purpose of its connection to the system.

- The energy source in which it is based, especially if renewable and intermittent.

2. Operational mode of DG and its impact on reliability

There are mainly three modes of DG connection to the network, each one with a different purpose and impact on system reliability:

1. A simple example of DG use is as generation backup, in which the unit is operated in the case of local utility supply interruptions. In a system that includes DG, load transfer to other feeders via switches operation can be performed in interruption situation in order to keep customers supply. If the DG units are correctly coordinated, they can have a positive impact on distribution system reliability [3].
2. Another DG application is the injection of the excess power of the unit generation in the distribution network that may occur when the DG capacity is higher than the necessary to attend the local loads. The energy that is injected in the network is measured and the consumer has to pay only for the difference between the energy consumed from the distribution utility and the amount injected in the network. In this case, there is no benefit for the system reliability.
3. The third mode is when the DG is operating in parallel with the main system. In this case, new considerations must be introduced for reliability modeling. The simplest alternative is to model DG as a negative power injection, independent of the system voltage at the terminal bus. To model DG units as negative loads can have a positive impact in reliability since it will represent a reduction on the load demand. However, better models need to be used in order to represent the DG, especially when they are based on intermittent renewable energy, to evaluate the influence of such units on the system reliability. That is what the next section will deal with.

3. Renewable resources modeling

The renewable energy in which the DG is based has fundamental influence on reliability. Units based on non-intermittent and storable energy sources, such as biomass, can be more easily represented, since energy can be considered available in reliability studies. The only issue usually considered for unavailability of generation is the failure of the generating unit. This kind of DG tends to be more reliable.

On the other hand, the units based on intermittent and not storable energy sources, such as wind, small hydro and solar, require a more complex model in reliability studies, where the energy availability also needs to be represented. The unavailability of generation of this kind of DG can be caused by unavailability of energy, failure of the generating unit or insufficient level of available energy. The availability model of energy normally requires an analysis of time series of measurements on the energy input (wind speed, solar radiation, etc.). Therefore, the generation availability must be modeled by the combination of the availability model of energy and the availability model of generating unit.

3.1. Wind generation

Wind energy can be considered as the renewable energy source with the most successful exploration in the world. However, wind generation has disadvantages as a regular source of energy in terms of reliability. The daily amount of energy available can vary widely and its use is limited to places of high and relatively constant winds. The connection of a growing number of wind farms to the electrical systems implies in the need to study their effects. The operating

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