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Active power estimation of photovoltaic generators for distribution network planning based on correlation models

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ABSTRACT

For the last years, PV (photovoltaic) generation has been having an important impact on LV (low voltage) and MV (medium voltage) grids in Spain, due to the increasing number of installations. As power monitoring of the generation is in most cases not required, utilities are forced to make assumptions on PV power generation in order to perform network planning studies for both peak demand and contingency analysis. These assumptions increase errors committed during the analysis, as the number of PV installations increases. This paper presents a methodology for estimating PV active power generation values for planning purposes in MV and LV power systems, from historic generation data, based on the development of correlation models. This methodology is applied to three different examples, using predictors based on real registered data. The methodology was also applied in a typical grid study and it's error was determined.

1. Introduction

Global energy security and environmental concerns have caused several governments to encourage electrical production from renewable energy sources [1]. This is especially true for PV (photovoltaic) generation systems, which have experienced an important increase in the last years [2,3] in power systems. Unlike wind power, which normally has a plant size of tens of MW and therefore feeds into the transmission system, PV generation is usually small sized and connected to the distribution system at MV (medium voltage) and LV (low voltage) levels [4,5]. This type of generation is also known as distributed generation (DG) [6,7] and has several environmental and energy security benefits [7] and is supported by energy policy measures.

But also as a consequence, this integration modifies grid planning strategies. Literature exists for determining limits of distributed generation when planning distribution grids [8] and its connection requirements [9,10].

Power generation from PV systems is highly variable because of its dependence on meteorological conditions [11]. This leads to the need for methodologies in order to predict the production of PV generation [12,13] from a predictor variable, like irradiation [14], and to generate a simulation model of such generation.

Models for wind generators from a predictor located on earth's surface were developed by Refs. [15–17], focusing on non-normal distribution dependence between stochastic generators applying the copula theory, instead of focusing on the modeling of the system load uncertainty, in a usual time-dependent stochasticity. The authors show that the assumptions of independence and normality can lead to misleading conclusions when used for the modeling of stochastic generation.

The present paper applies to the PV generation the idea [15] that it is necessary to take into account that outputs of stochastic generators are coupled due to their common dependence on their prime mover and that power outputs of stochastic generators situated in a

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relatively small geographic area that use the same generation technology are expected to be strongly coupled, i.e. their power outputs are expected to follow similar fluctuations. Analogously, non-normal distribution dependence between stochastic generators is applied in the present paper to a different type of generator, in particular PV generation, and using the Spearman correlation instead of copula theory.

Modeling the variation of global terrestrial solar radiation on the earths' surface was proposed by Refs. [18]; another possible predictor for PV production as solar radiation data has been studied in Ref. [12]. Models to calculate solar irradiation on the earth's surface from irradiation outside the atmosphere are presented in Refs. [19], and a simple model to determine five PV power production parameters from different solar irradiance intensities and module temperatures is given by Ref. [20].

The contribution of this paper is a methodology to develop correlation models of the time series of PV active power generation for planning purposes in distribution power systems from a single earth surface predictor. This methodology has been applied to three different earth surface predictors:

- Global solar irradiation on the earth's surface
- Active power PV generation from fixed installed arrays
- Active power PV generation from arrays with sun tracker systems

The purpose of this paper is to predict the electrical power generated in discrete time intervals of PV generators in a certain area, while many publications [21–23] treat the accumulated electrical energy production in a certain period.

For distribution grid planning the hourly electrical power prediction is more useful to get a more accurate planning result [24]. This paper extents the approach of [15,16] to wind generation for the model development of PV generation. The developed models are based on data measurement of the PV power generation and meteorological conditions in a region of Spain.

2. Statistical relation between nearby stochastic generators

As it is defined in Refs. [15,16], a stochastic generator is an energy conversion system that converts an uncontrollable primary energy source (wind-, solar-, hydro-, etc.) into electrical power supplied to the power system.

The power output of a stochastic generator is defined by two factors:

- Stochastic Prime Mover: the type of primary energy source used for electrical power generation. Due to their geographical dispersion, the stochastic behavior of similar prime movers differs at different sites in a system. According to the probabilistic approach, the prime mover activity is modeled as a random variable (r.v.) following a specific statistical distribution.
- Energy Conversion System: according to the converter technology, the power output of the generator for each input value of the prime mover can be defined by a deterministic relationship. According to the system analysis to be performed (steady state, dynamic/transient stability, etc.), an appropriate converter model should be utilized.

These two factors determine the power output of a single stochastic generator. However, more information is necessary for the definition of the contribution of the stochastic generators to the system; the coupling between the respective prime movers should be taken into account, i.e. the behavior of each prime mover respective to the other. In particular, the power output of stochastic generators situated in a small geographic area show similar fluctuations due to their mutual dependence on the same prime mover, which is not the case for stochastic generators situated in remote areas. This is the most cumbersome problem in the modeling procedure which is often underestimated in power system modeling.

It is showed also in Refs. [15,16] examples about WTGs (wind turbine generators) that the coupling between the prime movers should be taken into account, i.e. the wind speed (W1, W2) on one site conditional to the other. A general practice in power system modeling is to consider the r.v. W1 and W2 to be independent. This may however be a non-realistic assumption [25,26]. In practice, especially in cases of WTGs situated in a relatively small geographic area, where similar weather conditions prevail, the wind activity in the two sites is expected to be positively correlated. The notion of independence implies that knowing the wind speed in one location does not change our belief about the wind speed in the other location, which contradicts reality; when a high (low) wind speed occurs in site 1, most likely a high (low) wind speed occurs in site 2, in a relatively small geographic area.

This paper argues that it is also applicable to other stochastic generator technologies, as for example power output produced by solar PV generators situated in a small geographic area, related to their common prime mover, solar irradiation, based in real data examples.

3. Problem statement of distribution network planning with PV generation

At the end of 2011, of 60,077 renewable generators connected to the grid in Spain, 56,830 where PV, as much as 94.6% of the total number [27], and PV has a share of 4104 MW of the installed power of a total of 35,080 MW of renewable generators. In Spain, in 2011, the total installed generation capacity was about 100 GW [27]. PV generators have been having an important impact on LV and MV networks in Spain, due to a high number of such installations, and because their average power is only 72 kW, in contrast to wind installations, that have 17.6 MW at the end of 2011 in Spain Ref. [27]. PV generation covers a maximum of 4% of the total annual energy demand in the country's electrical system, but its geographic distribution is very irregular, reaching values up to 15% of the energy generation in the Extremadura region, with peaks of up to 25% in summer.

As measurement equipment is not required for all PV installations due to the high cost of instrumentation and its communication infrastructure, such installations do not provide real time generation measurements to the utility [28]. In most cases, only the energy produced in a period is provided, for economic billing purposes. Due to the lack of this data, utilities have to make assumptions on this generation in order to perform network planning for demand peak or contingency analysis.

In the case of conventional generation, generic models can be used [29] in order to estimate the power production. This is not the case if renewable energy resources are connected to the distribution grid, and this can increase the difficulty of distribution grid planning tasks [30].

Regarding medium voltage distribution grids, utilities usually have access to the measurements at the origin of the feeder [31]. This measurement is given by

$$P_f = P_{\text{load}} + P_{\text{loss}} - P_{\text{DG}} \quad (1)$$

where P_f is the power measurement at the feeder origin, P_{load} is the sum of all load power connected to the feeder, P_{loss} are the losses in such feeder, and P_{DG} is the sum of the power generated from DG connected to the feeder.