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A Probability Model of PV for the Middle-Term to Long-Term Power system Analysis and Its Application

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Abstract

This paper proposes a probability model for the Photovoltaic (PV) power output which is adaptive for the middle-term to long-term power system analysis. In the first step, a discrete random time series model for the mean value of hourly solar irradiance is presented according to meteorology models. Then a Beta distribution model works to describe the stochastic vibration of the hourly solar irradiance around its mean value. The proposed model can describe the long term behavior of PV generator and has the advantages of less parameters and lower requirements on PV history data. It can also effectively reflect the correlation among PV generators and loads related to locations and life styles. An example of PV location and capacity selection on a distribution feeder is presented to illustrate the application and the feasibility of the model. The proposed model is applicable in power system planning, reliability analysis and many other power system long-term analyses with PV sources.

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Keywords: Distributed generation; Distributed probability time series; Continuous probability model; power system planning

1. Introduction

Today, sustainable development has become a global consensus under the circumstances of fossil energy shortages and environmental deterioration. Sustainable energy is the basis for sustainable economic development [1]. Not only developed countries, but also China and other developing countries are promoting the applications of renewable energy and distributed generation technologies, such as the wind power generation and the Photovoltaic (PV) generation, as the core of the 21st century energy policy.

PV, as a major type of DGs, has the characteristics of randomness, volatility and weak controllability.

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Therefore, probability models, instead of deterministic models, should be applied to describe the uncertainty of the PV power in power system analysis. However, PV power also shows significant regularity over longer time scales, which should not be ignored.

In recent years, many research on PV modeling are reported which can be divided into two categories. One is the detailed mathematical models about PV modules including PV cell array, current converter, MTTP and PV-islanding protection etc. These models are suitable for the PV operation analysis, PV control designs[2]-[5], as well as the power grid transient analysis with large-scale grid-connected PV stations. Another type of PV model is the PV power probability models for the steady state analysis of grid. A widely used one is the continuous probability density function model based on Beta distribution which was first discussed in the research findings of Z. M. Salameh[6]. Then a lot of researches adopted the model. In[7], a methodology has been proposed for optimally allocating PV units in the distribution system so as to minimize annual energy loss. With the same PV model, a meta heuristic Harmony Search Algorithm (HSA) is used to reconfigure and identify the optimal locations for PV installation[8]. However, this model only reflects the vibration of solar irradiance at a given time point, for instance at 8:00 pm of January. It doesn't reflect the time series nature of PV power in a long term, such as one day or one year. Therefore in the present studies, there is lack of effective PV model for the middle-term to long-term power system planning and analysis which can not only reflects the randomness of the PV power, but also contains the intrinsic patterns of the hour-to-hour PV power series determined by the motion of Earth.

Nomenclature

$C(m)$	a discrete random variable
$R_s(\varphi, m, d, h)$	hourly mean value of the solar irradiance at the Earth surface in sunny days
$\alpha(m)$	the irradiance attenuation coefficient in rainy days， $0 \le \alpha(m) < 1$
H_0	hourly mean value of the extraterrestrial solar irradiance
δ	deflection angle
ω_{sr}	the hour angle at sunrise
I_0	base value of extraterrestrial irradiance （Wh/m^2）
K_t	clearness index
$f_b(r)$	Beta distribution function
$\Gamma(z)$	Gamma function
α , β	parameters of the Beta distribution
μ	mean value of solar irradiance in a specific hour
P_e	PV rated power which is measured at standard solar irradiance (1000 W/m2) and 25°C
α_T	temperature coefficient of photovoltaic cells
T	working temperature

This paper innovatively proposes a hybrid stochastic PV power model applicable for the mid-term to long-term power system analysis. Both the meteorology knowledge[9]-[12] and the statistic probability model are employed and an transformation interface are set up to combine both to generate long term PV power stochastic time-series. In the double-layer model, a time series model with discrete probability is set up to calculate the mean values of the hourly solar irradiance in a year. Then the Beta distribution based model works to describe the stochastic vibration of the hourly solar irradiance around its mean