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A combination method for modeling wind power plants in power systems reliability evaluation ☆

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ABSTRACT

The production of wind energy often involves uncertainties due to the stochastic nature of wind speeds and the variation of the power curve. In this study, a method for modeling wind power plant in power systems reliability evaluation is proposed. This method is a combination of analytical and simulation methods. Initially, the mechanical behavior of each wind turbine generator (WTG) is modeled through sequential Monte Carlo method. Then, considering the wind speed of the area, the Markov model is used for modeling the power output of wind farm. The combination method is compared with the Auto Regressive Moving Average (ARMA) time series method and some other techniques such as Weibull and normal distribution methods in wind speed modeling. Also in this study, the effects of different parameters, such as failure, repair rate and number of output power levels of WTG on the system reliability are analyzed.

1. Introduction

Due to enhanced public concern for adverse environmental impacts and reduction of fossil fuel resources, renewable energy, especially wind energy for electricity production has been increasing rapidly. However, the variable and intermittent nature of wind energy creates difficulties in power system planning and operation. Hence, it becomes increasingly more important to evaluate the impact of wind power generation on power system reliability security.

Reliability assessment of power system integrated with wind energy is a complex process. An important step in reliability evaluation of power systems including wind power is wind speed modeling to determine the power output of a WTG. There are different methods for modeling the wind speed. However, these methods require historical wind speed data collected over a number years related to a specific site in order to determine the necessary parameters of the wind speed model. The wind speed time series can usually be represented by many distributions, including Weibull distribution [1] and normal distribution [2,3].

Refs. [3–5] use an ARMA time series to simulate the hourly wind speed in order to create wind speed model. This model should be combined with power curve of a WTG to create power output of a wind farm model. Therefore, this model can be used in reliability evaluation of power system integrated with wind power.

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Another important method which has received remarkable attention in recent years is known as Markov approach. A Markov process with a discrete index set is called a Markov chain. Since each value of time of wind speed can be associated to a random value, the Markov chain can be used in wind speed modeling. Each WTG of a wind farm is modeled as a two state Markov process and thus the amount of output power state of a wind farm and computing time increase [6]. Several publications provide guidelines to reduce the numerical difficulties associated with the stochastic transitional probability matrix of a large system obtained from its Markov chain model. Refs. [7–9] discuss the use of Markov chain Monte Carlo (MCMC) methods as an appropriate representation of wind speed and power.

Generally, there are two different techniques in reliability evaluation of power systems. One technique is based on analytical method and the other on simulation method [10,11]. In this paper, two mentioned methods are combined to evaluate the reliability of power system inclusion of a large amount of wind energy located in Swift Current wind farm. Sequential Monte Carlo simulation (state duration sampling) method is utilized to model mechanical behavior of power system components and load in chronological order. The Markov model is also used in the proposed method to model the power output of the wind farm.

Unlike MCMC method which uses non-sequential Monte Carlo simulation, we proposed utilizing the sequential Monte Carlo simulation approach in Markov model of a wind farm in order to generate time series of wind power. The sequential Monte Carlo simulation approach according to its characteristics can provide frequency and duration of each state of the Markov model. Therefore, the sequential simulation can incorporate the chronological characteristics of wind speed and mechanical behavior of the system components simultaneously, while the non-sequential method involves non-chronological system state considerations when utilizing the non-sequential simulation approach.

By considering power curve of a WTG, in the zero and nominal power regions, wind speed data become independent in the wind power domain. Therefore in this study, instead of constructing Markov model of a wind farm by means of wind speed data which leads to complicated Markov chain models, wind power domain of wind farm is used, a simpler model of which may be achieved by reduction of Markov model states.

In order to illustrate and compare the results of the proposed, ARMA time series, Weibull and normal distribution methods with actual data, the RTS system is used [12]. In this study, it is shown that, using the proposed method the total number of output power states of the wind farm reduces. Also, the appropriate number of states in multistate WTG model is determined when mechanical behavior of WTG changes.

The remainder of the paper is organized as follows: Section 2 provides a general description of the WTG model. Section 3 presents a case study and some performance reliability indices which are used in reliability evaluation. Section 4 describes the two conventional methods in wind speed modeling (i.e. ARMA time series and Markov model). Section 5 gives the procedure for the design of the proposed method. Section 6 presents the numerical results obtained by the proposed model. Finally, some concluding remarks are made in Section 7.

2. Wind turbine generator model

The power output of a WTG can be obtained from its power curve which is a mapping of the wind speed into power output of wind resources. A typical power curve of the WTG is shown in Fig. 1. It can be seen that the power output of a WTG is equal to zero when the wind speed is lower than cut-in speed. The WTG generates rated power when wind speed is between the rated speed and cut-out speed, and for safety reasons at cut-out speed the WTG is shutdown.

The mathematical expression for a typical WTG is as follows:

$$P_{WTG} = \begin{cases} 0 & x < V_{ci} \\ (A + Bx + Cx^2) \cdot P_r & V_{ci} \le x < V_r \\ P_r & V_r \le x < V_{co} \\ 0 & x > V_{co} \end{cases} \tag{1}$$

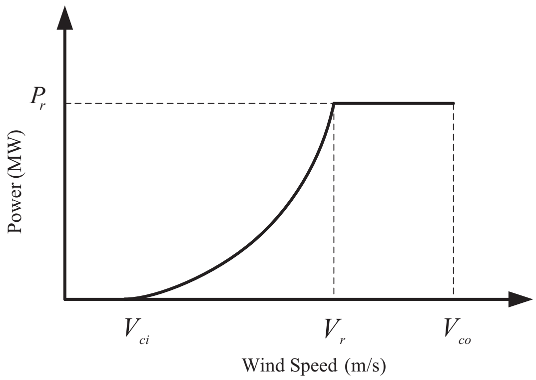

Fig. 1. Power curve of a WTG.