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Impact of correlation on reserve requirements of high wind-penetrated power systems

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ABSTRACT

This paper investigates the effects of two important factors, i.e., correlation of wind farms output with load and wind speed coincidence in determining the required static reserve in a high wind-penetrated power system. To this end, it suggests an analytical approach to involve the effects of these two factors in probabilistic analytical multi-state models of wind farms output generation. Based on an optimization framework with the objective of reaching the desirable level of correlation, the key idea is to calculate some joint probabilities for equivalent models of wind farms. As a result, these models become compatible with the ones for conventional generation units in adequacy studies of power systems. The proposed analytical approach, then, continues with evaluating the reliability level of power systems exactly and also practically employing these multi-state models once dealing with wind farms at multiple locations. The proposed analytical approach is applied to the modified IEEE-RTS and the obtained results and discussions offered demonstrate the unavoidable effects of these important factors (load and wind speed coincidence) in real world applications.

Introduction

IND energy as a promising alternative for power generation is expected to make a significant contribution in future power systems. Facing with environmental and energy security concerns, many countries around the world are employing supportive policies aimed to increase the share of wind power in generation sector of power systems. Consequent upon these supportive policies, wind power installed capacity reached 282.5GW in 2012 [1]. In fact, 2012 was also a record-breaking year for worldwide wind power installations, with 44,000 MW installed and total capacity exceeding 280,000 MW. As a result, more than 80 countries now receive a portion of their electricity from wind power [1].

This environmentally-friendly source of energy, however, owns an unpredictable and intermittent nature which in turn results some impacts on technical and financial aspects of power systems. To properly investigate the pros and cons of wind energy utilization in power systems, there has been significant activities in the literature addressing these various issues [2–4]. Among them, reliability assessment of power systems including wind farms has widely been studied (see [4,5] as examples). Once the contribution of wind energy in generation sector of power system increases, many new factors needs to be considered in reliability evaluation of power systems including the wind power penetration level, the installed capacity of wind farms, the correlation between output generation of wind farms with the others and also load and wind farms output generation coincidence. This paper focuses on the impacts of wind farms output correlation with the other ones and also load and wind farms output coincidence in reliability studies of power systems.

In this regard, at first, we need to develop an appropriate model for wind farms output generation. Employing this model, power system planners should be able to easily consider the effects of correlation in adequacy assessment of power systems. Sequential Monte Carlo simulation (SMCS) approach has been used to model wind farms output generation in adequacy analysis of wind-penetrated power systems [4,6]. This method is the most accurate one to evaluate adequacy studies of power systems incorporating wind energy. The computational burden of this method and a long history of hourly wind speed data requirement, however, threaten its practicality, specially, when applied to large-scale systems [7].

In response, some authors in [4,5] tried to preset an analytical model for wind farm output generation similar to the ones introduced for conventional units. These models can easily lend the

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system planners a hand to apply the available methods in adequacy studies of wind-penetrated power systems. The analytic approach overcomes the difficulties of computational burden and volume of data needed in simulation-based methods. Based on these discussions, a multi-state analytical method proposed in past works of the authors has been used in this paper to efficiently model the variations in output generation of wind farms [8].

In compare with the other essential factors, a few papers have seriously considered and studied the effects of correlation in reliability studies of wind-penetrated power systems. Ref. [9] investigates the impact of wind speed correlation between two wind farms on the system reliability indices using the SMCS approach based on the auto-regressive moving average (ARMA) time-series model. The wind farms correlation within different regions are studied in [10]. In both of these two papers the authors come to this conclusion that as long as the correlation of two wind farms is low, there would be significant enhancement in system reliability. Wind speed coincidence in different zones using the multivariate time-series approach was hired in [11] with regards to actual wind speed data of UK Met-Office. It was concluded that considering wind speed correlation between wind farms in different zones allows accurate studies to be done for power systems with presence of significant wind energy. Authors in [12] examined the genetic algorithm (GA) method capabilities in adjusting the ARMA wind speed models with the main goal of simulating hourly wind speeds based on the correlation level between multiple wind sites.

The coincidence of load and wind patterns in reliability studies was investigated in [5]. The authors in this paper examine that what would be the outcome of reliability studies defining various scenarios, i.e., wind speed is high and the load demand is low as the first scenario; and when the load demand is high, wind speed is low as the second one. The authors came to this conclusion that the wind speed and load pattern coincidence can result in considerable effects on the accuracy of reliability indices.

All the above-introduced works are unable to present an effective as well as practical strategy in which the operating conditions of these renewable-based units being involved, i.e., wind farms output correlation with the other ones and load coincidence. In complementary to the past works, this paper investigates the impacts of correlation as an effective factor on adequacy assessment of power systems including large-scale wind farms. First, a probabilistic multi-state model is borrowed to properly as well as practically consider the effects of both wind farms correlation and load coincidence. A novel analytical approach is, then, presented to correlate wind farms output together and also with load levels of a system. Afterward, an optimization procedure is introduced to optimally find joint probability distribution of the correlated wind farms. Aimed to investigate effectiveness of the proposed method, it has been implemented on the IEEE-RTS and the reliability studies of this test system at generating reliability assessment Hierarchical Level 1 (HLI) are reported. The results show that utilization of the proposed method makes the adequacy studies of wind-penetrated power systems more accurate. Furthermore, this method can efficiently be utilized in future power system planning studies with less computational burden and data needed. As a notification, this paper focuses on long-term impacts of wind farms on power system adequacy studies.

Wind farms generation output modeling procedure

The wind farms output generation at each time follows a nonlinear relation with wind speed. As a result, to obtain an accurate model for output levels of wind farms, the wind speed model at first should be investigated. This section briefly explains wind farm output modeling procedure.

Wind speed characteristics

The historical data of Manjil and Lotak, respectively in North and Southeast part of Iran, measured and recorded by Renewable Energy Organization of Iran, are used in wind farm modeling procedure [13]. The hourly wind speed data of one year (2008) in Manjil and Lotak are utilized for reliability analysis. Wind speed is assumed to be constant within an hour.

As the generators hubs of wind turbines are usually placed at a position different from where the wind speed is measured, the historical data should be transformed to the desired height. In this regard, the relation shown in (1) can be employed which shows the nonlinear relation of wind speed with the height.

$$v_{\omega}(h) = v_{10} \cdot \left(\frac{h}{h_{10}}\right)^{\alpha} \ (\mathrm{m/s}) \tag{1}$$

here $v_{\omega}(h)$, v_{10} and α respectively denote the wind speed at height h, the wind speed at height 10 m and the Hellman exponent. The Hellman exponent is a function of the coastal location, the shape of the terrain on the ground, and the stability of the air [14].

In this paper, the understudied wind farms are comprised of some two MW V90 turbine type manufactured by "Vestas Wind Systems". The hub height of these turbines is 105 m [15]. According to [14], Hellman exponent of Manjil and Lotak site was respectively assessed equal to 0.12 and 0.16. As the historical wind speed data of Manjil and Lotak sites were measured at height of 40 m, these data are transformed to the desired height, i.e., 105 m via (1). The variations of hourly wind speed in Manjil at height of 105 m are depicted in Fig. 1.

Wind turbine output model

The wind turbine output generation in each time follows a nonlinear relation with the wind speed as shown in (2).

$$P_t = \begin{cases} 0 & 0 \leqslant V < V_{ci} \\ (A + B \times V + C \times V^2)P_r & V_{ci} \leqslant V < V_r \\ P_r & V_r \leqslant V \leqslant V_{co} \\ 0 & V_{co} < V \end{cases} \tag{2}$$

here V_{ci}, V_r, V_{co} and P_r respectively stand for the cut-in speed, the rated speed, the cut-out speed and the rated power of the turbine. The parameters A, B and C are presented in [16]. Based on [15], the cut-in, rated, and cut-out speeds of V90-2MW are considered to be 4, 12, and 25 m/s, respectively. Taking into account the nonlinear relation of wind turbine output-speed shown in (2), the output

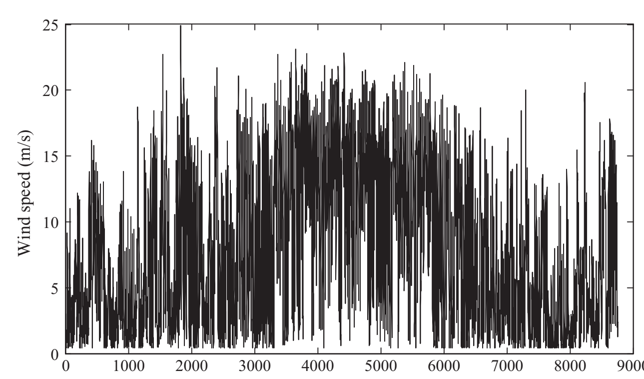

Fig. 1. Manjil hourly wind speed variations at 105 m-height in 2008.