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Wind generation impact on electricity generation adequacy and nuclear safety

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ABSTRACT

This paper presents the results of the analysis of the generating adequacy in the power system considering the introduction of wind generating power units. The Loss of load probability is the measure utilized for the evaluation of the electricity generation adequacy. The uncertainty of the wind generators output power and power system peak load uncertainty are considered in the analysis. The implication of the substitution of nuclear power plants with wind generating units on the risk of the remaining operational nuclear power plants within the analysed power system is evaluated.

The obtained results show that the introduction of wind generating units in the power system results in the change of the Loss of load probability. The obtained Loss of load probability depends on the uncertainty of the peak load size and the wind speed shape parameters. The increase of the share of the wind generation in the power system results in increased Loss of load probability. The change of the generation adequacy results in the change of the risk of the nuclear power plants. Substitution of the nuclear power plants with wind generating units results in small decrease of overall risk within the analysed power system.

1. Introduction

The main function of the power system is to provide electrical energy to the customers as economically as possible with an acceptable degree of continuity and quality, known as reliability. The two constraints of economics and reliability are competitive since increased reliability of supply generally requires increased capital investment. These two constraints are balanced in many different ways in different countries and by different utilities and they are all based on various sets of deterministic criteria [1].

The power system reliability evaluations are categorized in three main hierarchical levels depending on the level of the analysis and the considered facilities and elements of the power system [2]. The hierarchical level I (HLI) considers only the generation facilities extended in HLII with the transmission network and in HLIII, in addition to the generation and transmission, with the distribution system.

A wide range of power system reliability indices are determined using the probability theory [3]. The power system reliability evaluation techniques can be divided into analytical analyses and simulations. Analytical techniques represent the system by a mathematical model and evaluate the indices using mathematical solutions. Monte Carlo simulation methods estimate the indices by simulating the actual process and random behaviour of the system [4]. The Monte Carlo simulation requires a large amount of computing time and is not used extensively if alternative analytical methods are available. Combinations of both analytical analyses and Monte Carlo simulations have been developed [5]. The obtained indices depend on the model derived for the system, the appropriateness of the evaluation technique and the quality of the input data used in the models and techniques [6].

The power system reliability evaluation on HLI examines the available power in the system in order to determine the adequacy to meet the power system loads. This evaluation is termed "generating capacity reliability evaluation". The transmission system and its ability to transmit the generated energy to the consumer load points are ignored in the HLI studies.

The Loss of load probability (LOLP) method is the most widely used probabilistic technique for evaluating the adequacy of a given generation configuration [1,7,8]. The LOLP is the average number of days on which the daily peak load is expected to exceed the available generating capacity.

The LOLP consists of two segments in which the generating unit unavailability is characterized by the random outage rate (forced) and the scheduled outage rate. The effect of random outages is evaluated probabilistically, while that of scheduled outages is evaluated deterministically.

The application of LOLP in the power system analysis is limited to HLI and the estimation of the generation adequacy without the

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consideration of the transmission system capacity or reliability.

The EU directive on the promotion of renewable energy sources sets the share of renewable energy to 20% in the final energy consumption by the year 2020 [9]. This overall target is broken down into binding national targets for all EU member states [10]. The share of the renewable sources in the final energy consumption depends on country policy [11].

The renewable sources include photovoltaic and wind generating power units that have an intermittent power output resulting from the power output dependency from the local weather conditions. The overall generated power within the power system should be adequate to meet the system loads and to maintain stable operation [12]. The load-frequency control with the technical reserves and the corresponding control performances maintain the required balance of power within the system and compensate for planned and unplanned power deviations. The power deviations include the sudden loss of the generation capacity or load-shedding and loss of load with the largest deviation, known as reference incident, of 3000 MW for the Continental European synchronously operated transmission grid [12].

The precise planning of the power units output is essential for the load-frequency control resulting in the utilization of the advance wind speed forecast models and the forecast of the power output of the wind generating power units [13–15]. An error in the prognosis can result in a large and sudden loss of the generation capacity. Fig. 1 shows the forecasted and actual power output of wind farms in Germany [16] on the given dates in the year 2009 with the difference between the production and prognosis, representing the error in the prognosis, given in Fig. 2. Figs. 1 and 2 show that the largest difference was on 4.11.2009, the error is in the range of 2000 MW in both directions (overestimation and underestimation of the predicted power output) and occurs quickly. Fig. 2 shows that on 4.11.2009 the change of the wind power error in the prognosis is larger than 300 MW/h.

The energy and reliability consequences of the introduction of the wind energy conversion systems have been analysed in previous studies [17], including the reliability evaluation using the time-shifting technique [18,19], and generation adequacy evaluations [4,20,21]. The analysis of the uncertainties affecting an electric transmission network with wind power generation and their impact on its reliability has been investigated for small example systems [17,23].

The goal of this paper is to analyse and assess the implications of the introduction of the wind generating power units as intermittent power sources on LOLP of the analysed power system with a size of a real power system. The obtained results are utilized for the assessment of the implications of the substitution of nuclear power plants with wind generators on the safety of the nuclear power plants. The Monte Carlo sampling approach is applied for the assessment of the implications of the uncertainties of the wind generation and peak load on the obtained results.

The probabilistic safety assessment (PSA) model of the nuclear

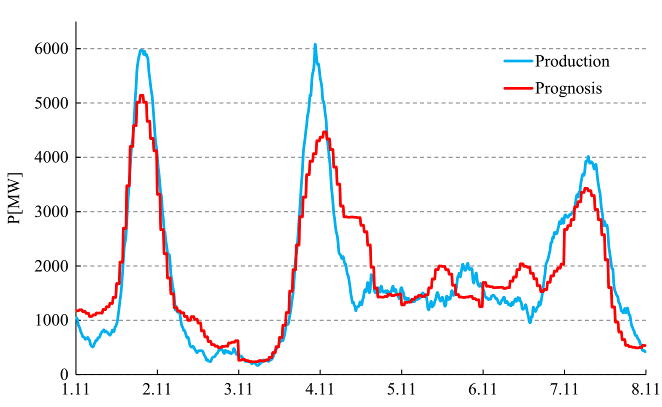

Fig. 1. Prognosis and actual production of wind generators in Germany on given dates.

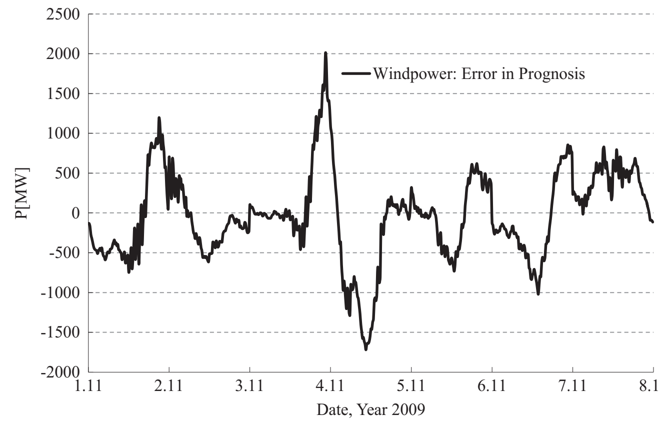

Fig. 2. Error in prognosis of wind energy production in Germany on given dates.

power plant is used for the assessment of the nuclear power plant safety.

2. Method description

The description of the LOLP assessment method is given in Section 2.1. The models of the wind generating units output power and load uncertainties are given in Section 2.2. The description of the Monte Carlo sampling and integration in the developed method is given in Section 2.3.

2.1. LOLP assessment method

The probability of finding the generator in the forced outage at a distant time in the future represents the basic parameter used in the static capacity evaluation for the modelling of the generating unit reliability. This probability is defined as the unit unavailability (U) and in power system applications it is known as the unit forced outage rate (FOR), defined as:

$$U = FOR = \frac{\lambda}{\lambda + \mu} \tag{1}$$

where λ is the expected failure rate and μ is the expected repair rate.

The unavailability (FOR), calculated with Eq. (1), for a generating unit with relatively long operating cycles, is an adequate estimator of the probability that the unit under similar conditions will not be available for service in the future [1].

The capacity outage probability table is an array of the capacity levels, or the corresponding capacity out of service and the associated probabilities of existence. The associated probability of existence is the probability of the indicated amount of capacity being out of service. For the capacity model the cumulative probability of existence is used and it is equal to the sum of the probabilities corresponding to the capacity on outage equal to or greater than the indicated amount. The probability for an outage of power X (MW) or more can be directly assessed from the capacity outage probability table.

The capacity model can be created using a convolution algorithm [1,24,25], which is a recursive algorithm of adding or removing units in the model and calculating the cumulative probability of a particular capacity outage state. The convolution algorithm applied in the method is given in [26], with a brief description given here.

In case of two state units, the cumulative probability of a particular capacity outage state of X (MW), after a unit of capacity C (MW) and a forced outage rate U are added, is given by:

$$P(X) = (1 - U)P'(X) + (U)P'(X - C), \tag{2}$$

where *P′(X)* is the cumulative probability of the capacity outage state of X (MW) before the unit is added; *P(X)* is the cumulative probability of