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Determination of optimum reserve based on wind energy in power systems

Serdal Atic*[1], Ercan İzgi[2], Mehmet Rida Tur [1]

[1]Batman University, Electricity and Energy Department, Türkiye, serdal.atic@batman.edu.tr; mrida.tur@batman.edu.tr
[2]Yildiz Technical University, Department of Electrical Engineering, Türkiye, izgi@yildiz.edu.tr

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Abstract

In power systems, unforeseen imbalances between load and generation may occur due to sudden interruptions of generation units, errors in load forecasting, or deviations of generation units from the planned schedule. Spinning reserve (SR) allows system operators to compensate for these imbalances. Today, the share of wind farms in the power system is increasing rapidly. This makes it even more difficult to accurately estimate the total amount of power in the power system. This uncertainty due to wind energy estimation should be taken into account in determining the SR. This study is not only about the production cuts in determining the reserve; It focuses on determining the optimum reserve amount for the case where the error in the wind forecast is also taken into account.

Introduction

Wind energy is one of the important renewable resources used to generate electrical energy. In recent years, electricity generation with wind energy has been increasing rapidly around the world. The high penetration of wind energy generation in the power system also negatively affects the distribution of energy from conventional generation units. However, uncertainty in wind energy also negatively affects power system reliability. Therefore, an appropriate amount of SR must be provided to restore reliability in power systems with large amounts of wind power.

The nature of the wind is uncertain and variable, which causes wind energy to be unpredictable. Therefore, the significant increase in the rate of power generated from wind poses planning and management challenges for the power system. The uncertainty in wind power generation also increases the uncertainty on the demand that must be met by conventional generation plants [1]. This increased uncertainty needs to be taken into account when determining the SR, as the SR system is intended to protect against unforeseen events such as generation interruptions, sudden load changes, or a combination of both. Therefore, it can be expected that large-scale penetration of wind generation in the power system may require a significant increase in the SR requirement.

However, SR has a cost that cannot be neglected. If higher amounts of SR are required due to higher wind energy penetration, more conventional generation units in the power system will need to be included in the planning. This will continue until the expected downtime costs are less than the cost of providing the SR. Therefore, determining the optimum amount of SR considering the system conditions is an important and current issue. However, SR has a cost that cannot be neglected. If higher amounts of SR are required due to higher wind energy penetration, more conventional generation units in the power system will need to be included in the planning. This will continue until the expected downtime costs are less than the cost of providing the SR. Therefore, determining the optimum amount of SR considering the system conditions is an important and current issue [2].

It should be ensured that the optimum amount of SR and the cost of the extra reserve are equal to the benefit provided by this reserve. Here is the benefit; can be expressed as a reduction in the expected downtime cost. Ideally, the energy and SR quantities should be optimized simultaneously. There are two problems in solving this problem. First, net demand is stochastic due to demand and wind forecast errors. The second problem is that there is no direct way to include in the optimization procedure the probability distribution of current capacity cuts. It should be ensured that the optimum amount of SR and the cost of the extra reserve are equal to the benefit provided by this reserve. Here is the benefit; can be expressed as a reduction in the expected downtime cost.

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In the study of Doherty and O'Malley [4]; He proposed a method in which the SR requirement is adjusted such that the system reliability criterion is equal to or better than a predetermined target, taking into account the installed wind capacity. However, since the reliability criteria are not comparable for the systems, there is no way to predetermine the reliability target of the system. In addition, determining a single level of reliability in all phases of the optimization process will result in inappropriate solutions. Because the cost and benefit of SR; It varies for each period depending on the demand, wind generation and the committed generation units. In [1] and [5], the wind forecast uncertainty was considered in the study by Black et al. In the study, the SR requirements are set as the product of the standard deviation of the difference between net demand and wind forecast error, and a constant λ. This semi-fixed approach does not consider the probability and extent of system contingencies. In this case, larger quantities of SR will be supplied with the increase of wind power generation and installed capacity. In the study of Bouffard and Galiana [5], a method formulated as a stochastic optimization problem in which the net estimated demand error is modeled as a normally distributed random variable is proposed. The disadvantage of this study is that the number of scenarios to be considered increases rapidly during the optimization process. This study proposes estimation of SR requirements by taking into account wind power generation forecast and load forecast errors.

Problem Formulation

This study deals with a unit allocation problem that takes into account the uncertainty of wind energy. In the proposed method; Along with the unit status and optimum production output, the SR provisioning status of the committed generation units are also given. The SR considered in this formulation consists of two parts, traditional SR due to load forecast uncertainty and SR due to wind energy uncertainty. The SR for each hour can be calculated as a fixed percentage of the system hourly load. The SR resulting from wind energy uncertainty is determined by a reliability criterion known as the Expected Energy Not Served (EENS) [6, 7]. The objective function of this problem is to minimize the total cost (TC), which consists of the operating cost (OC), the total SR cost (CSR) of the conventional generating units, and the Undelivered Energy Expectation cost (Cwfe) due to wind energy uncertainty as shown in equation (1). The operating cost consists of the operating costs of the committed production units. The EENS cost is the cost related to the load losses obtained by multiplying the EENS criterion, which is the Lost Load Value (VOLL) over the entire period, and the wind energy uncertainty. k production units cost to provide SR; m_k is the cost of SR provided due to load uncertainty; $SR_{l,k}^t$ is the cost of SR provided due to load uncertainty; $C_{SR,lu}$ is written as.

$$C_{SR,lu} = \sum_{t=1}^{T} \sum_{k=1}^{G} \left(m_k SR_{l,k}^t\right) \tag{1}$$

SR from k generation units due to wind energy uncertainty; $SR_{w,k}^t$ is the cost of SR provided due to wind energy uncertainty; $C_{SR,wu}$ is written as follows.

$$C_{SR,wu} = \sum_{t=1}^{T} \sum_{k=1}^{G} \left(m_k SR_{w,k}^t\right) \tag{2}$$

Undelivered energy expectation due to wind energy forecast error; $EENS_{wfe}$ is the energy cost that cannot be provided due to wind forecast error; C_{wfe} is written as follows.

$$C_{wfe} = VOLLxEENS_{wfe} \tag{3}$$
$$k = 1, \ldots, G; t = 1, \ldots, T$$

fuel cost of k conventional production units; C_k, Power supplied by k generating units during t; $P_{G,k}^t$, working status for unit k; u_k^t (u_k^t =0 ya da u_k^t =1) is the objective function; $minTC$ is written as follows.

$$minTC = \left\{\left(\sum_{t=1}^{T} \sum_{k=1}^{G} C_k\left(P_{G,k}^t\right)u_k^t\right) + C_{SR,lu} + C_{SR,wu} + C_{wfe}\right\} \tag{4}$$

where G is the number of production units and T is the planning time. Estimated wind power output during t; P_{wf}^t, Estimated wind power output during t; P_l^t, k maximum power capacity of k generating units; $P_{max,k}$, the total number of sections of the normal distribution curve for the wind energy output; P, is the wind power output of the section p during t; $P_{wf,p}^t$ and maximum undelivered energy expectation; The constraints for the optimization problem $EENS_{max}$ are given by the following equations

$$\sum_{k=1}^{G} P_{G,k}^t u_k^t + P_{wf}^t = P_l^t; \quad t = 1, \ldots, T \tag{5}$$

$$P_{G,k}^t + SR_{l,k}^t + SR_{w,k}^t \leq P_{max,k} u_k^t; \quad k = 1, \dots, G; \ t = 1, \dots, T \tag{6}$$

$$EENS_w = \sum_{t=1}^{T} \sum_{p=1}^{P} \left(P_l^t - \left(\sum_{k=1}^{G} \left(P_{G,k}^t + SR_{w,k}^t\right) u_k^t\right) - P_{wf,p}^t\right) Pb_p \, AS_p^t \tag{7}$$

$$AS_p^t = \begin{cases} 1; \left(\sum_{k=1}^{G} \left(P_{G,k}^t + SR_{w,k}^t\right) u_k^t\right) + P_{wf,p}^t < P_l^t \\ 0; \left(\sum_{k=1}^{G} \left(P_{G,k}^t + SR_{w,k}^t\right) u_k^t\right) + P_{wf,p}^t \geq P_l^t \end{cases}; \quad p = 1, \dots, P; t = 1, \dots, T \tag{8}$$

$$0 \leq EENS_w \leq EENS_{max} \tag{9}$$

The production output of conventional generation units is given by the power equation (5) related to wind energy and system load. The sum of the production output from each unit and the SR from the unit should not exceed the maximum limit as expressed in equation (6). To calculate $EENS_w$'yi in Equation (7), the normal distribution curve is divided into seven parts (P=7) with their calculated probabilities (Pb_p). A normal distribution curve representing the wind power uncertainty was applied to the wind power output at each time t. At each time t $EENS_w$, is the sum over all parts of the division probability multiplied by the amount of lost load due to wind power uncertainty. The amount of lost load is calculated from the system load at time t by subtracting the sum of the generation output from the committed units, including the SR and the wind power output in the p section. ($P_{wf,p}^t$) value is the mean value of each part of the normal distribution curve, which is the mean value; μ and standard deviation; Calculated from σ. If there is no load loss, the adequacy status is taken as zero as written in equation (8). Total undelivered energy expectation calculated over the entire planning period; $EENS_w$, is constrained by $EENS_{max}$ as shown in equation (9).

For load uncertainty, hourly SR is assumed to be 9% of hourly load. Four cases will be considered to examine the relationship between SR and EENS resulting from wind energy uncertainty. Case 1 is when there is no wind energy in the system. In this case, the loads are provided by conventional generation units, which are stable. Case 2 is when there is wind energy in the system. The energy expectation that could not be provided for this situation did not reach the maximum limit. Case 3 is when there is wind energy in the system. In this case $EENS_{max}$, is set from Case 2 to 50% of EENS. Case 4 is the case where there is wind energy in the system. In this case $EENS_{max}$ is set to zero.

Conclusion

In this study, an approach that incorporates load and wind energy uncertainties into the optimization problem is proposed. SR reserve capacities to be provided due to load and wind uncertainties in the approach are added to the objective function to minimize the total energy cost. Simulation studies to be carried out in future studies will show how power system reliability, total cost and reserve provision are affected by the inclusion of wind energy in the system. The main contributions of this study are to develop an approach that incorporates the total SR to be provided as a result of load and wind uncertainty into the objective function, and to determine the optimum reserve for different situations, taking into account the undelivered energy expectation resulting from the wind forecast error.

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