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Estimation of the Feasible Wind Power in a Small Power System

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Introduction

The number of wind power plants is growing rapidly in most countries around the world [1–3]. The biggest advantage of the wind energy in power industry is that wind power does not increase pollution and reduces dependence on imported fuel [2, 4]. However, the wind variability and difficult forecasting raise some issues for the reliable power system's operation. The development of wind power plants creates control problems for power systems due to its unpredictable nature therefore the balance between power generation and consumption is aggravated. Growing influence of wind power generation to the operation of the power system can only be controlled by imposing requirements to the connection of wind power plants thus determining the biggest feasible wind power value. Another option is to integrate wind power production into power system operation planning. This article concentrates on particularities of the small power systems. The main factors that are crucial to determine appropriate installed wind power without commercial risk are presented.

Particularities of small power system

Large generating units have to operate under adverse conditions in a small power system. A big power frequency deviation occurs when a large power unit is tripped, therefore it is difficult to restore frequency. Though load shedding devices are operating, maintenance of voltage stability is complicated task thus power system barely fulfills power quality requirements for the large power system.

The primary reserve is very small and it is complicated for the small power system to keep frequency stability in autonomous regimes. Dynamic stability and line overloads are the main issues during synchronous operation with large power system.

The design accident power is determined according to the possible lost of largest generating power.

In a small power system with large generating units, the primary reserve may be insufficient and it may not cover all the design accident power. In this case, frequency will fall below permissible value and load shedding will follow, otherwise frequency cannot be restored to the frequency of permissible quasi-stable regime.

Lithuanian power system (PS) and Baltic joint power system (JPS), which comprises Lithuanian, Latvian, Estonian and Kaliningrad power systems, are small power systems with large generating units.

Limits of wind power

The power of the wind power plant can vary rapidly in short period of time. Secondary frequency control usually compensates all power changes and imbalances [4].

Considering the wind power operating specifics there are two major factors that limit total power of the wind power - power reserves and capability of power network. These factors are characterized with plenty of critical and physical parameters, which directly affect the total wind power:

1. Total PS load power;
2. The quantity and nominal power of operating units;
3. The quantity and nominal power of the units that are involved in frequency regulation;
4. The quantity and nominal power of the primary reserve units;
5. The quantity and nominal power of the secondary reserve units;
6. The power of import – export;
7. The capability of the power lines and transformers.

The power system should have available primary reserve, which corresponds to the largest unit power or to the power that is switched off during the emergency situations. The secondary power reserve should be capable to restore primary reserve and ensure compensation of the wind power plants and loads variation. Tertiary power reserve should ensure the restoration of the primary and secondary power reserves.

The research of the largest available wind power was carried out for the winter peak load and summer low load operating regimes. Lithuanian power system and Baltic joint power system power reserves were considered for the analysis of the available wind power. The wind power among the power systems of Baltic JPS is distributed according to the forecast.

Wind power regulating reserves

Geographical distribution of the wind power parks (WP) decreases the wind power generation variation because the wind power plants are distributed over the large area.

The load following as well as generation and load balance are complex tasks, so that both the load and wind power fluctuates during the time. This fluctuation should be forecasted. While load forecasting is well researched and appropriate accuracy is reached, however wind power forecasting is still under investigation and forecasting systems are still at the development stage.

Additional regulating power reserve is needed for the compensation of WP plants forecasting errors. The reserve depends on the wind generation penetration level.

Wind power varies in time and operating wind power plants compensates those which are not operating, thus the required primary reserve adjustment increase is very small. Installed power of any wind park usually is smaller the design accident power and does not change the required primary reserve power. Available wind power is limited by primary reserve; therefore the largest generating power should be smaller than the primary reserve power of the PS. Small power system largest generating units must operate at low power, close to the minimal power. It increases number of operating units and decreases the remaining load power, which can be covered by wind power.

Power generation and regulated power reserves are forecasted during the exploitation of the PS. Though the wind power generation forecasting systems attracts more attention, prognosis still remains not enough accurate. The spread of wind power plants determines the complexity forecasting. Composing the power system balance, the load variation, wind power generation and forecasting of the wind power generation can be regarded an independent processes. Then, root mean square deviation, the standard deviation of the generation and load power balance will be calculated as

$$\sigma_{\Sigma} = \sqrt{\sigma_{L}^{2} + \sigma_{fWP}^{2} + \sigma_{WP}^{2}}\ ; \tag{1}$$

here σ_L, σ_{fWP}, σ_{WP} are the power load, power forecasted of the wind power generation, hourly wind power change of the wind power parks standard deviations.

The value of the secondary regulation power reserve $P_{ON\Sigma}$, could be evaluated by the statistical method and total deviation of the power balance σ_{Σ} may be evaluated as follows

$$P_{ON\Sigma} = 3 \cdot \sigma_{\Sigma}\ . \tag{2}$$

Secondary regulation for load balancing $P_{L,ON}$ can be evaluated according to the expression provided by ENTSO-E or IPS/UPS recommendations [5]

$$P_{L,ON} = \sqrt{a \cdot P_{L\,max} + b^{2}} - b\ ; \tag{3}$$

here $P_{L\,max}$ is the peak load power, MW; a=10 MW, b=150 MW are the empirical parameters values.

Standard deviation of load power balancing may be evaluated according to

$$\sigma_{L} = \frac{P_{L,ON}}{3}\ . \tag{4}$$

The wind power variation and forecasting errors are differently explained in literature.

In the International power agency study [6] the research results on the power balancing shows, considering the hourly wind power variation and wind power penetration of 10 %, it requires about 4 % (of total installed wind power) of additional secondary power balancing reserve. If day before forecasting errors are compensated with secondary regulating power reserve, then secondary regulating power reserve should be close to 10 % of total installed wind power.

Modern wind power forecasting systems uses digital wind forecasting considering more local factors, that influences wind speed, and they forecast for two or three days. PREVENTO, the forecasting software, was used in Germany for eight months [6] including the most stormy year periods. 24-hour-period wind power forecasts' root mean square error value was 3.8 % of total installed wind power capacity, day before forecasts was 5.8 % value and two days before – 9.5 % of total installed wind power capacity. Therefore, day ahead forecast root mean square error in Lithuanian PS and Baltic JPS can be estimated as $0.06 \cdot P_{WP\Sigma}$ of total installed wind power.

The minute variation in wind power was investigated in Danish PS [7]. According to the investigation of wind power minute variation results, standard deviation in Lithuanian PS was evaluated as $0.04 \cdot P_{W\Sigma L}$ (4 % of total installed wind power in Lithuanian PS) and $0.028 P_{W\Sigma B}$ in the Baltic JPS (2.8 % of total installed wind power in Baltic JPS). Secondary reserve balancing power values in Lithuanian PS and Baltic JP are presented in Table 1.

Tertiary regulating power reserve should be planned according to hourly wind power variation. Usually, operating regimes are planned on hour basis and during the emergency situation secondary power reserve is overtaken by tertiary power reserve in 15 minutes.

The largest available wind power within the hour highly depends on wind power distribution in the area [7].

When the area reaches 200×200 km^2, the biggest change in wind power is about ±30 % of total installed wind power and when the area is about 400×400 km^2 – about ±20 %.

Considering that biggest wind power parks in Lithuanian PS and Baltic JPS will situate in western part of the area, the biggest available hour wind power variation is estimated by ±30 % and ±20 % respectively, and average rms values – ±10 % and ±6.7 % of total installed capacity. The necessary amount of tertiary power reserve balancing power in Lithuanian PS and Baltic JPS is presented in Table 2.

Increase of secondary and tertiary reserves balancing power depends on the total installed wind power. Percent of total installed wind power is shown in Fig. 1 and Fig. 2.

Table 1. Total amount of the secondary reserve balancing power in Lithuanian PS and Baltic JPS, MW

$P_{WP\Sigma}$, MW	2012 m.	2016 m.	2020 m.
Lithuanian PS			
100	61	66	71
200	80	84	88
500	159	161	163
1000	305	306	307
2000	602	603	603
Baltic JPS			
200	136	146	157
500	182	190	198
1000	292	297	302
2000	543	545	548
2500	672	674	676

Table 2. Total amount of tertiary power reserve balancing power in Lithuanian PS and Baltic JPS, MW

$P_{WP\Sigma}$, MW	2012 m.	2016 m.	2020 m.
Lithuanian PS			
100	72	76	80
200	110	112	115
500	246	247	248
1000	483	484	484
2000	961	962	962
Baltic JPS			
200	146	156	166
500	228	234	241
1000	400	404	408
2000	770	772	774
2500	958	960	962

Investigative scenarios

The investigation scenarios were determined according to installation, commissioning and decommissioning history of the generating units:

1. Three investigated regimes – 2012, 2016, 2020.
2. Investigated load regimes:
   a. Summer low load;
   b. Summer peak load;
   c. Winter low load;
   d. Winter peak load.
3. Autonomous operation without synchronous interconnection links.
4. Autonomous operation with asynchronous interconnections.

In 2012, third and fourth units of the Lithuanian PP supposed to be closed. In 2012 and 2016 Lithuanian PS will be operating without nuclear power plant. It is supposed that 1300 MW nuclear power unit will be built in 2020. Synchronous link with Polish PS (UCTE) is included in 2020 operating regimes.

Power reserve investigation shows, that the largest export and import power through asynchronous links with neighboring power systems changes available regulating power reserve.

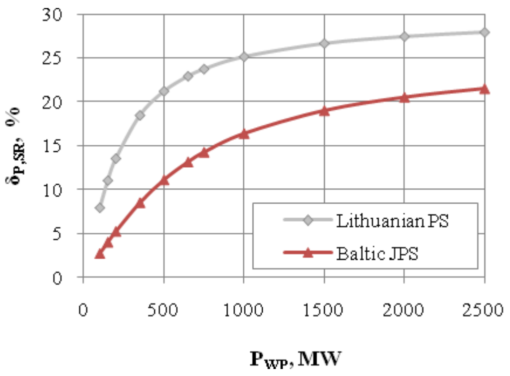

Fig. 1. The increase of secondary reserve balancing power

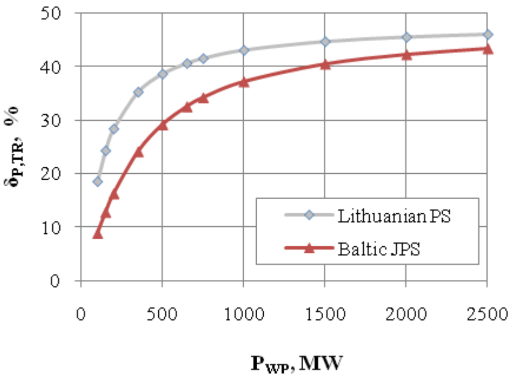

Fig. 2. The increase of tertiary reserve balancing power

The case of power import is significant for decreased number of generating units as well as regulating power reserve, especially primary reserve in autonomous operating conditions of Baltic JPS. The case of the largest power import is particularly important in summer low load conditions when the smallest number of generating units is in operation.

The case of the largest power export is significant in winter peak load conditions, when a big number of generating units is in operation. The power system elements are loaded at their highest rates and power lines overload by transit power flows is very likely. The power export should be less available capacity of PS elements and system must not loose ability to interchange with regulating power reserves.

The largest forecasted Baltic JPS loads according to the latest forecast, which assessed growth decline, are presented in Table 3.

Table 3. The maximum forecasted loads of Lithuanian PS and Baltic JPS, MW

Power system	2012	2016	2020
Lithuanian PS	1870	2100	2340
Baltic JPS	5310	5930	6600

The lowest load in Baltic JPS is about one third of peak load ($P_{L\ min}=0.33\cdot P_{L\ maks}$). That load ratio of the peak and low load power supposed to common in this work.

Balancing algorithm is determined by composing imported and generated power with power of export, load and losses of the analyzed system.

Thus, the wind power in small power system is expressed as follows

$$P_W = P_L + P_E + \Delta P - P_{CHP} - \\ -P_{HP} - P_{Treg} - P_{Hreg} - P_I ; \qquad (5)$$

here P_L, P_E, ΔP are the load and export power, and power losses in the power system, P_{CHP}, P_{HP} are the constant power of combine heat and power and hydro power plants; $P_{T\,reg}$, $P_{H\,reg}$ are the regulated power of thermal and hydro power and hydro power plants, P_I - import power.

From the analysis of power balancing of all mentioned characteristic scenarios it is seen, that the biggest available wind power in autonomous Baltic JPS in 2012 should not exceed 373 MW, in 2016 – 1050 MW, in Lithuanian PS – 123 MW and 248 MW respectively.

New nuclear power plant in 2020 cannot operate together with wind power plants in case of autonomous Baltic JPS with Estlink (1000 MW) as well as in case with no external links. In the cases of NordBalt (700 MW) and LitPol (1000 MW) asynchronous links new nuclear power plant could operate, but in the biggest part of regimes power would be reduced.

Small primary power reserve determines generating units' operating in low load power regimes in autonomous Baltic JPS. It is useful to implement asynchronized hydro units at Kruonis PPSP that would extend primary power reserve.

The secondary regulating power reserve of the Baltic JPS is sufficient in all investigated autonomous regimes with new nuclear power plant. The shortage of the online tertiary regulating power reserve is observed, but after redistribution of the secondary and tertiary reserves of the thermal power plants this problem is solved.

Conclusions

Feasible wind power for small power systems with big generating units is limited by primary reserve.

In order to make up primary reserve all generating power units are scheduled to operate at lowest possible power and thus, wind power is excluded from the balance of power system.

Asynchronous links with neighboring power systems can signitificantly change available regulating power reserve. Available wind power in autonomous Lithuanian PS in 2012 should not exceed 123 MW, in 2016 – 248 MW.

New nuclear power plant in 2020 can operate together with wind power plants in autonomous regime of Baltic JPS only if asynchronous links Estlink (1000 MW), NordBalt (700 MW) or Estlink (1000 MW), NordBalt (700 MW) and LitPol (1000 MW) are switched on.

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Due to wind variability and difficult forecasting, the maintenance of the balance between generation and demand of the electric power systems is complicated, especially in small power systems with large generating units. This article analyses evaluation of the feasible wind power in small system without investment. Feasible wind power is limited by primary reserve. During critical operation conditions, majority of units operates at lowest permissible value, thus decreasing wind power share in power system balance. Asynchronous links can significantly change available regulating power reserve. The regulating power reserves, feasible wind power of the Lithuanian power system and algorithms for regulating power reserves evaluation were set in this article. Ill. 2, bibl. 7, tabl. 3 (in English; abstracts in English and Lithuanian).

M. Ažubalis, V. Ažubalis, D. Slušnys. Galimos vėjo elektrinių galios įvertinimas mažoje elektros energetikos sistemoje // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 1(107). – P. 79–82.

Vėjo nepastovumas ir jo kitimo prognozavimo problemos elektros energetikos sistemose apsunkina generavimo ir apkrovų galių balansavimą, ypač mažose sistemose su didelės galios agregatais. Šiame straipsnyje nagrinėjamas tikslingos vėjo elektrinių galios nustatymas mažoje sistemoje, kai neplanuojamos investicijos. Sudaromi algoritmai reguliavimo rezervams įvertinti. Nustatyta, kad galimą vėjo elektrinių galią lemia pirminio reguliavimo rezervo galia. Kritiniais režimais dauguma agregatų turi dirbti mažiausia leistina galia ir taip sumažinti vėjo elektrinių galią sistemos galių balanse. Reguliavimo rezervų galias gali gerokai pakeisti asinchroniniai tarpsisteminiai ryšiai. Įvertinta galima Lietuvos elektros energetikos sistemos vėjo elektrinių suminė galia, reguliavimo rezervai. Il. 2, bibl. 7, lent. 3 (anglų kalba; santraukos anglų ir lietuvių k.).