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Generation Adequacy of Isolated Small Power System

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***Abstract*—Adequacy of the power system is described as an ability of power system to maintain safe operation in different operational modes. The technical properties of the generating unit and physical properties of the primary mover are evaluated in order to achieve adequacy conditions for small power systems. Operation regimes are specific for every source of electrical power. Adequacy requirements should be maintained in small power system during the all operating conditions. Meeting adequacy requirements always means reliable power supply. Isolated operation of the Baltic power system is investigated in this paper. Hourly power balances of the characteristic seasonal weeks of the year 2016 and 2020 are provided.**

***Index Terms*—Power system reliability, power system adequacy assessment, power system frequency control.**

I. INTRODUCTION

Electrical energy should be consumed at the same time when it is produced. Electrical energy should be produced in the same amount as it is needed – not more or less. In operating power system the balance between electrical energy production and consumption should always be maintained otherwise it is difficult to ensure the stability and reliability of power system supply. The main peculiarity of the power system is inability to accumulate energy directly.

The sufficient condition for the power system to function is the balance between power generation and consumption. However, the condition is not sufficient to achieve a reliable operation of the power system. The operation of the power system is continuously encountering variations of load and generation, faults of power system elements, routine maintenance, variations of the power system network configuration, etc., which may lead to the unbalance between power generation and consumption. Adequacy requirements are essential for the secure operation of any power system [1], [7]. The adequacy requirements describe the ability of the power system to operate in all available operating regimes. In order to reach the adequacy requirements in a small power system, it is necessary to evaluate every power generation source and to determine available operating regimes. Usually, the adequacy requirements in large power systems are easy to reach due to the variety of low power generation sources and loads compared to the total system power as well as the larger primary and secondary reserves.

There are numerous methods for the power system reliability assessment [7], [8]. Though these methods are commonly used for their possibility to evaluate multiple scenarios but in this article we used simplified approach to evaluate adequacy of the Baltic power system (PS).

The establishment of the adequacy requirements in a small power system is complicated due to relatively larger frequency regulation reserves. Relatively larger reserves are necessary to compensate relatively larger generation or loads that could be switched off during the faults. A small power system is sensitive to minor disturbances because generating units and load power values are relatively high and even small failure may lead to the unbalance between the generation and consumption and can cause large frequency deviations.

The Baltic PS is comprised of Lithuanian PS, Latvian PS, Estonian PS and Kaliningrad PS and while operating without any connections with neighboring power systems (without connections with IPS/UPS and ENTSOE) could serve as an example of a small power system with large generating units. The implementation of adequacy requirements in such a system is a difficult task due to large generation units and relatively small loads. Nevertheless, the research of generation adequacy in the Baltic joint power system was performed and the result analysis is one of the main goals of this paper.

II. ADEQUACY RESEARCH SCENARIOS

There are two adequacy scenarios (scenario A and scenario B) analysed in the paper to describe the power system operation in long-term perspective and to evaluate possible risks of power supply [1].

Scenario A is conservative and evaluates possible unbalance situations without additional investment to power generation development, describes the required investment during the analysed period to ensure a reliable operation of the power system. Scenario A estimates the existing power stations, newly connected and commissioned power plants during the analysed period.

Scenario B is when the list of power stations mentioned in scenario A are appended with prospective power station according to future grid development plans, government

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directives and other available technical and public information.

The study mostly relies on research of A scenario. The analysis of the critical conditions in power systems are the main goal of this research. The power system adequacy in scenario B shows better results as it is evaluating the development of the grid, the more power units and power lines are in use the higher positive effect on power system adequacy will be made.

The power evaluation methodology including scenarios from adequacy analysis is as follows [1]:

1. Net generating capacity – station's power in normal operation mode, there is a difference between maximum available unit's power and auxiliary equipment loads and losses in the main power stations transformer.

2. Unavailable capacity – the part of the net generating capacity which cannot be reliably used by the operator.

3. Reliably available capacity – it is a difference between net generating capacity and the unavailable capacity. This power can cover system's load on particular moment.

4. Remaining margin – it is a difference between reliably available capacity and the load. Remaining power is the part of the net generating capacity which can cover sudden load variation and unplanned generator outages.

5. Margin against peak load – it is a difference between maximal load of particular season and the researched regime load.

6. Remaining margin – it is difference between remaining capacity and margin against peak load.

7. Spare capacity – it is a part of net generating capacity which is activated in order to maintain security of supply in majority cases.

8. Adequacy reference margin – it is a part of net generating capacity which always should be available in order to ensure power supply.

Net generating capacity for thermal power plants is determined by considering ambience conditions (climate, temperature etc.) for hydro and wind power plants evaluating water and wind conditions. Net generating capacity share for every generating unit is distributed according to primary energy sources – nuclear, hydro or renewable (non-traditional power generating units).

Unavailable capacity is the power that cannot be used by the operator's decision to limit generating unit power (closed and disconnected, but can be turned on; restricted by local authorities; power plants whose commissioning is delayed due to modernization or any other issues), unintentional temporal restriction, when all power cannot be used due to transmission disturbance, due to permanent or overhaul maintenance, unplanned outage and due to system reserves limitations i.e. primary, secondary and tertiary reserves.

Remaining margin should be forecasted taking into account the load control [4], [6].

Margins against peak load are selected for every season separately in regard of seasonal maximum load. Margins against appropriate season peak loads are calculated by calculating hourly power balances.

According to ENTSO-E requirements power generating adequacy is established for reference points due to remaining margin. If remaining margin is positive, e.g. more than zero, it means that under normal operation conditions there is enough generating power and if remaining margin is negative, there is a shortage in a power system and power demand could not be satisfied. Usually, seasonal adequacy forecasting is performed by comparing remaining margin and adequacy reference margin. Recommended spare capacity is 5 % – 10 % of net generating capacity. Adequacy reference margin is equal to spare capacity plus margin against seasonal peak load.

III. THE ADEQUACY RESEARCH CONDITIONS OF THE BALTIC PS

Load forecasting scenario "B" was used to estimate Baltic PS generation adequacy, taken into account the possible generation insertion and was performed according to the week hourly balance, in respect to seasonal and daily load variation and extreme isolated operating conditions. The main system adequacy evaluation parameters net generating capacity, auxiliary service power, wasted (unused) power and maintenance power were calculated by summing up appropriate parameters of Lithuanian and Baltic power systems.

Auxiliary needs for thermal plants was estimated as 5 % of their nominal power, while the hydro power plants was set for 1 % and only for Narva power plants (where oil shale used as a fuel) in Estonian PS a 28,5 % value was determined. Thermal power plants are often operating at low rates and auxiliary needs for thermal power plants were set more accurately – classical characteristic were taken for representation, considering constant power component

$$P_{\text{an}} = \left(0,4 + 0,6 \cdot \frac{P_{\text{G}}}{P_{\text{GN}}}\right) \cdot P_{\text{anN}} = \left(0,4 + 0,6 \cdot P_{\text{G*N}}\right) \cdot P_{an\text{N}}, \quad (1)$$

where P_{G} is the actual power of the unit in p. u., P_{GN} is the rated power of the unit in p. u., P_{anN} is the nominal power of auxiliary needs.

Net generating capacity is determined subtracting power for auxiliary needs from installed capacity.

Maintenance repair is not planned for winter operating conditions, but the running maintenance repair is possible for the units that are not switched off and are not included into secondary and tertiary regulating reserves: in Lithuanian PS the unit G8 at Lithuanian power plant (thermal power plant, G1-G8 are thermal units, G9 is gas turbine unit), unit G1 – Kruonis PPSP, in Latvian PS – units G1, G2 and G3, unit G5 at Plavinas HPP, while there are no such units in Estonian PS and Kaliningrad PS in 2016 and 2020.

Unavailable capacity in Baltic PS consists of unused power in Baltic PS, power outage for maintenance, unplanned (unscheduled) outage and power for system services. Unscheduled power outage was evaluated as the power of the largest unit or the largest power of several units connected to a single bus and estimated equal to primary regulating reserve. Non-usable and maintenance power were determined by summing appropriate values of particular power systems. Reliable power in Baltic PS is designed to cover load power and determined by subtracting non-usable power (capacity) from net generating capacity.

Remaining margin in Baltic PS is determined by non-usable capacity subtracting from reliable capacity.

Margin against seasonal peak load are estimated approximately according to load data of 2010.

Margins against seasonal peak load estimation for 2016 are performed by appropriate load multiplying by a factor that describes margin against appropriate season peak load in per units.

Calculating of the margins against seasonal peak load the schedule of weekly peak load is analogous and appropriate hour demand multiplied by a factor that describes particular hour power reserve in per units.

System regulating reserves – primary, secondary, tertiary control reserves are calculated for all Baltic PS. The largest generating power of the unit or the group of units that are connected to one switchgear bus is estimated by the available primary reserve and is calculated by summing up appropriate hour's primary reserves of appropriate power system.

N-1 principle is applied for Baltic PS generating adequacy evaluation. It examines Baltic PS ability of reliable power supply for the consumers at the loss of the biggest generating power and sufficiency of reserve power for frequency control. It means that at Baltic PS power balancing examination post fault generating capacities and control reserve power must be examined.

Wind power generation variation and load forecasting are considered as independent events in the calculation of the required secondary control reserve.

Evaluation of isolated PS generation adequacy and frequency control possibilities is based on PS power balances calculation and frequency control possibilities analysis.

Generating power of the isolated power system (PS) must cover load power P_L and power losses ΔP in the network

$$P_{\mathrm{L}} + \Delta P_{\mathrm{L}} = \sum_{i=1}^{n}\left(P_{\mathrm{G},i} + P_{\mathrm{aux},i} - \Delta P_{\mathrm{T},i}\right), \tag{2}$$

where n, $P_{\mathrm{G},i}$, $P_{\mathrm{aux},i}$, $\Delta P_{\mathrm{T},i}$ are the number of generating units, it's generating and auxiliaries power and power losses in the main transformers.

Generation powers $P_{\mathrm{G},i}$ of individual units are restricted by its nominal and minimal permissible power ($P_{\mathrm{GN},i}$ and $P_{\mathrm{G\,min},i}$), control reserve power $P_{\mathrm{CR},i}$ of the unit and available primary control reserve of the system P_{PCR}

$$P_{\mathrm{G},i} \le P_{\mathrm{GN},i} - P_{\mathrm{CR},i}, \tag{3}$$

$$P_{\mathrm{CR},i} = P_{\mathrm{PCR},i} + P_{\mathrm{SCR},i} + P_{\mathrm{TCR},i}, \tag{4}$$

$$P_{\mathrm{G},i} \ge P_{\mathrm{G\,min},i} + P_{\mathrm{CR},i}, \tag{5}$$

$$P_{\mathrm{G},i} \le P_{\mathrm{PCR}}, \tag{6}$$

$$P_{\mathrm{PCR}} = \sum_{i=1}^{k} P_{\mathrm{CR},i}, \tag{7}$$

where k is the number of the units, participating in primary frequency control.

Power balancing of the system is analysed considering frequency control requirements [2], [4], seasonal, weekly and hourly load changes and irregularity of generating power of renewable energy sources. Secondary and tertiary control power reserve must cover possibly lost power, possible deviation of load power and generating power of renewable power sources [3]. As the biggest power units in the small PS are operating partially loaded, at load power equal or less the existing primary control reserve power, secondary and tertiary control reserve power (P_{SCR} and P_{TCR}) of the isolated small PS may be expressed as follows:

$$P_{\mathrm{SCR}} \ge P_{\mathrm{PCR}} + \Delta P_{\mathrm{L+RES}}, \tag{8}$$

$$P_{\mathrm{TCR}} \ge P_{\mathrm{PCR}} + \Delta P_{\mathrm{L+RES,T}}, \tag{9}$$

where $\Delta P_{\mathrm{L+RES}}$, $\Delta P_{\mathrm{L+RES,T}}$ are load and renewable energy sources maximal hourly and 15 minutes power deviations.

Kruonis Pumped Storage Power Plant (PSPP) generating power is restricted by the permissible water level of the upper reservoir, i.e. disposable quantity of the accumulated energy. Disposable energy reserve of Kruonis PSPP is about 8500 MWh. Usually water is pumped to the upper reservoir during the lowest loads at the weekdays during night time for about 5–7 hours and at the weekend days during night and morning time for about 10 hours.

Minimum power of Kaunas HPP is restricted by the minimum sanitarian water yield, which may not be reduced at dry season time. It corresponds to 21.6 MW generating power at the nominal water level of upper reservoir and 19.4 MW at the lowest minimum permissible level.

IV. Characteristic Weekly Load Graphs Of The Baltic Power Systems

The largest loads of the Baltic power systems according to the latest forecast, which assessed growth decline [4], are presented in Table I.

TABLE I. THE MAXIMUM FORECASTED LOADS OF BALTIC POWER SYSTEMS, MW.

Power system	2016	2020
Lithuanian PS	2100	2340
Latvian PS	1410	1590
Estonian PS	1590	1780
Kaliningrad region PS	830	900

Load graph of the Baltic power systems for the year 2016 and 2020 were composed on the retrospective analysis of the load graphs of the systems at the third weeks of January, April and July. Ratios of margins against seasonal peak loads and minimum loads of the systems were considered.

V. Baltic Power System Adequacy Investigation

The main parameters of Baltic JPS adequacy evaluation were calculated for each hour of the characteristic weeks of 2016 and 2020. The data were given only for B scenario as it was more comprehensive and more important scenario in terms of the adequacy and reliability research.

At the design of hourly power balances there were assessed available and required values of primary, secondary and tertiary control power reserve. The biggest primary control reserve will be 476 MW at 2020 winter operating conditions and the smallest – 222 MW at 2016 spring flood time. Insufficient primary control reserve power will limit utilization of 455 MW unit of

Lithuanian PP at spring flood time of 2016.

It was defined that wind generation power must be limited in all characteristic operating conditions of isolated Baltic JPS. In terms of adequacy the worst case emerges Thursday and Friday of the 3rd week spring flood and windless period of 2016. At this time, as it shown in Fig. 1, the value of the margin against peak load reaches the value of the adequacy reference margin but still is larger.

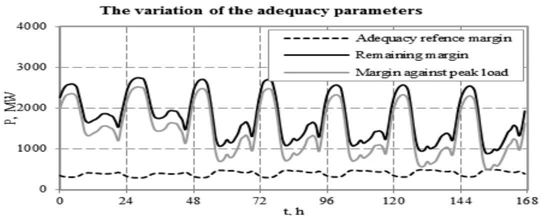

Fig. 1. Weekly change of adequacy parameters of Baltic JPS at spring flood and windless 3rd week of April 2016.

Minimum adequacy margins for other operating regimes are at cold winter seasons, when wind power plants are off. Variation of Baltic PS generating adequacy parameters at extremely cold winter weeks of 2016 are presented in Table II and graphs of some parameters – in Fig. 2.

TABLE II. RANGES OF CHANGE OF BALTIC PS GENERATING ADEQUACY PARAMETERS AT EXTREMELY COLD WINTER WEEK OF 2016 WITHOUT WINDPOWER, MW.

Parameters	Max.	Min.
Net generating capacity, MW	11291	11224
Unavailable capacity, MW	3832	3719
Reliably available capacity, MW	7977	7864
Remaining margin, MW	4283	1708
Margin against peak load, MW	3953	1153
Adequacy reference margin, MW	695	423
Load, MW	6169	3666

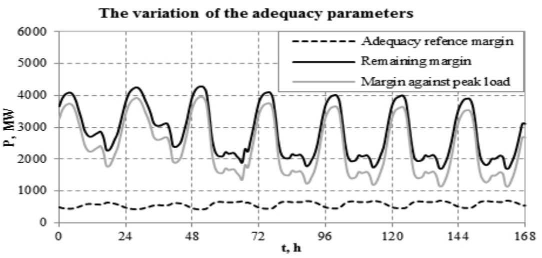

Fig. 2. Weekly change of adequacy parameters of Baltic JPS at extremely cold and windless 3rd week of January 2016.

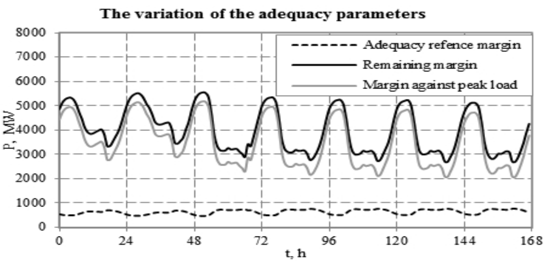

Fig. 3. Weekly change of adequacy parameters of Baltic JPS at extreemly cold and windless 3rd week of January 2020.

While the margin against peak load reaches adequacy reference margin in Fig. 1 thus showing difficult situation in 2016 – Fig. 3 and Fig. 4 shows good adequacy and reliability results of Baltic JPS in 2020.

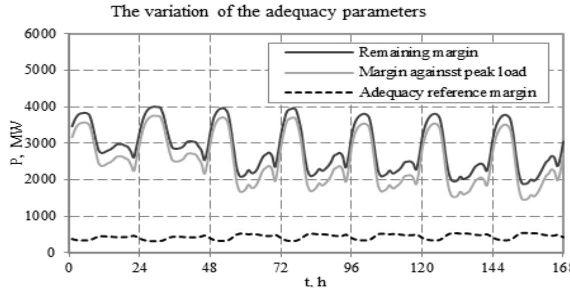

Fig. 4. Weekly change of adequacy parameters of Baltic JPS at spring flood and windless 3rd week of April 2020.

VI. CONCLUSIONS

The research of the isolated Baltic power system adequacy indicated that the adequacy of all typical week hourly regimes is not affected i.e. remaining margin is larger than adequacy reference margin. During the isolated Baltic power system operation due to lack of the primary power reserve power generators used to operate in uneconomical operating conditions. Wind power should be set to zero in order to satisfy the adequacy conditions during the summer low load and spring melting period operating conditions.

The satisfied adequacy conditions during the typical operating conditions prove that Baltic power system is able to operate in isolated conditions. Investigation of generation adequacy of Baltic JPS showed good results remaining margin is higher the adequacy reference margin.

REFERENCES

[1] *System Adequacy Methodology*, January 30th 2009. [Online]. Available: https://www.entsoe.eu/fileadmin/user_upload/_library/publications/ce/UCTE_System_Adequacy_Methodology.pdf

[2] *Operational handbook. ENTSO-E. Policy 1. Load-frequency control and performance.* [Online]. Available: http://www.entsoe.eu/index.php?id=57

[3] M. Azubalis, V. Azubalis, D. Slusnys, "Estimation of the feasible wind power in a small power system", *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering*), no. 1, pp. 79–82, 2011.

[4] V. Radziukynas, A. Morkvenas, "Investigation of maximum unit power in Lithuanian power system – Final report", Kaunas, 2009.

[5] V. Adomavicius, C. Ramonas, V. Kepalas, "Control of wind turbine's load in order to maximize energy output", *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering*), no. 8, pp. 71–76, 2008.

[6] R. Karki, R. Billinton "Reliability/cost implications of PV and wind energy utilization in small isolated power system", *IEEE Trans. Energy Conversion*, vol. 16, no. 4, pp. 368–373, 2001. [Online]. Available: http://dx.doi.org/10.1109/60.969477

[7] T. K. Vrana, E. Johansson, "Overview of power system reliability assessment techniques", *CIGRE 2011*, pp. 51–62.

[8] A M. Rei, M Th. Schilling, A. Melo, "Monte Carlo Ssimulation and contingency enumeration in bulk power systems reliability assessment", *9th Int. Conf. Probabilistic Methods Applied to Power Systems*, Stockholm, 2008.