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Problems related to balancing peak power on the example of the Polish National Power System

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Abstract: The article discusses issues related to ensuring secure operation of the National Power System. The tasks of transmission system operators in that scope were presented and the power demand of the Polish National Power System on critical days in terms of power generation and demand was characterized. The article also presents the causes and course of events which took place in August 2015 when there was a critical imbalance in the Polish National Power System leading to the introduction of limitations. Then, the possibilities and types of costs connected with the possibilities of balancing the system in the periods of peak loads were characterized. The summary of the article contains the presentation of conclusions related to power balancing in the power system and reduction of related costs.

Key words: cost of energy deliver failure, peak demand of system, system services, power grids

1. Tasks of transmission system operators in the scope of power balancing

One of the basic tasks of transmission system operators (TSOs) is to ensure secure operation of power systems (PSs) managed by them. For this purpose, TSOs undertake a number of actions, including e.g.:

a) the preparation of periodic (current, daily, monthly, annual) coordination plans,
b) the provision of transmission capacities for the cross-border commercial exchange,
c) the conclusion of agreements in the scope of system services for power balancing,
d) the acquisition of cold intervention reserve services, availability of capacities of generating units that are not subject to the central management carried out by TSOs,
e) the conclusion of agreements for demand reduction services at the request of TSOs,
f) the conclusion of agreements with operators from neighboring countries, including agreements for emergency power supplies,
g) the preparation of procedures in case of threats to secure operation of PSs.

Apart from TSOs, entities participating in the performance of the above-mentioned activities are generators, customers and electricity distribution system operators (DSOs) with devices, installations or networks connected directly to the closed grid. TSOs and DSOs operating in the hierarchical order as well as dispatch operation services of the power plants and customers ensure secure operation of the power system. The cooperation between TSOs and transmission system operators from neighboring countries in the scope of the current operation of the grid takes place in accordance with the principles described in the Continental Europe Operation Handbook, i.e. in the document of ENTSO-E, the organization of TSOs from the Continental Europe [1] and the terms and conditions provided in bilateral agreements.

Coordination planning conducted in cooperation with other users of the system is the basic tool used by TSOs to ensure the coherence of activities undertaken by entities participating in the current operation of the grid with safety requirements of the power system. Power balances of the power system presenting its generating capacities, power demand and power surplus necessary for obtaining the required operating reserve as well as the amount of power possible to be provided for the purposes of the cross-border exchange with neighboring PSs, is the basic element of coordination plans. The provision of transmission capacities for the purposes of the cross-border interconnection exchange is an important element affecting the possibilities of covering customers' demands for power and electricity.

The basic task of the Polish TSO – the entity responsible for ensuring secure operation of the Polish National Power System (PNPS) is to balance power. The control of the sufficiency of national generation resources to cover the power demand is provided by power balances prepared by the Polish TSO for different time horizons. They include expected national demand, scheduled power outages and transmission capacities available for the cross-border commercial exchange.

Annual and monthly balances are prepared to determine power surplus available to TSOs for daily peak power demand on working days respectively for specific months of the next year and days of the next month. Daily and current balances are more detailed due to the fact that they are prepared using the Load Distribution Algorithm and based on the commercial and technical data contained in balancing offers, taking system limitations and necessary operating capacity reserve of a given system as well as balances of foreign trade into account.

Coordination plans, apart from the part related to the power balance, also contain shutdown plans for particular components of the closed grid which are prepared, taking overhauls of generating units connected to this grid into consideration. TSOs also identify transmission limitations arising out of applicable criteria for reliable operation of the system and specify the resulting requirements related to the minimum and maximum possible number of generating units in specific nodes of the grid for the entire period covered by the plan.

Detailed arrangements concerning power balancing in the PS are included in internal procedures of the TSO in the form of planning and dispatching instructions. They specify, for instance, resources and the order in which such resources are used for ongoing balancing of the system. The sufficiency of generation capacities occurring in the area of this TSO to cover the demand is of essential importance for the secure operation of the PS in the adopted planing prospects. The criteria for the assessment of the sufficiency of generation capacities in the

Polish National Power System are defined in the Instruction of Transmission System Operation and Maintenance (Instrukcja Ruchu i Eksploatacji Sieci Przesyłowej, IRiESP) [2]. Pursuant to this document, the required power surplus available to the Polish TSO in relation to the demand to be covered by national power plants, i.e. taking the balance of exchanged power into account, should amount to at least 18% of the planned demand to be covered by national power plant for the annual planning horizon, 17% for the monthly planning horizon and not less than 9% for the daily planning horizon.

The requirements in the scope of the management of minimum capacity reserves applicable in the area of ENTSO-E were defined in the documents of this organization applicable in this respect.

2. Characteristics of the power demand in the PNPS

The analysis of the power demand in power systems shows that this demand is different at each hour of the day as well as on each day and in each month of the year. This variability results from the needs of electricity customers which, in turn, depend on a number of other factors, including economic factors such as: conditions of their functioning in the economy of a given country and conditions connected with the time of the year, the day of the week (working days, weekends, bank holidays) and the time of the day (night, intermediate loads, peak loads).

In order to illustrate this phenomenon, Figs. 1-3 present the most important data concerning the variability of the demand in the PNPS in 2014 prepared on the basis of data published in annual reports on the functioning of the PNPS [11] by PSE S.A., performing the role of Polish TSO. Fig. 1 presents the daily demand in the PNPS on days when there was the minimum and maximum power demand.

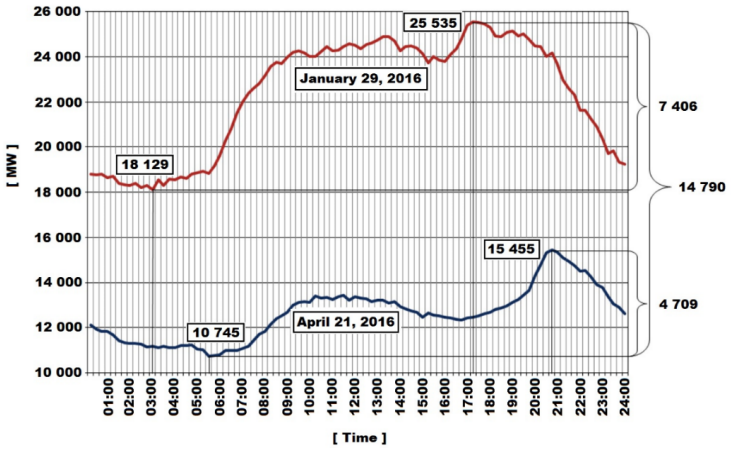

Fig. 1. Power demand on days when there was the minimum and maximum national power demand in the PNPS in 2014

During this period, the maximum power demand in the PNPS occurred on 29 January and amounted to 25 535 MW. The minimum national power demand occurred on 21 April and amounted to 10 745 MW. The difference between the maximum and minimum power demand in the analysed period was 14 790 MW, i.e. approx. 57.9% of the peak demand. The high variability of the power demand was also observed at specific hours of the day. On the day on which the maximum power demand was recorded it changed from 18 129 MW to 25 535 MW. On the day on which the minimum power demand in 2014 was recorded it fluctuated from 10 745 MW to 15 455 MW.

Figs. 2 and 3 present the partial coverage of power demand on days when there was the maximum and minimum power demand in 2014. The demand for power on 29 January 2014 was covered by the generation of electricity in lignite-fired power plants ranging from 5 136 MWh to 7 851 MWh, the generation of electricity in coal-fired utility power plants ranging from 9 938 MWh to 13 510 MWh and the generation of electricity in industrial power plants which was quite stable at all times of the day and which was maintained at the level of approx. 1 300 MWh. Hydro and gas-fired power plants also participated in meeting the power demand - electricity generated by small hydro power plants was low and amounted to approx. 80 MWh on average, and electricity generated by gas-fired power plants amounted to approx. 430 MWh. Electricity generated by wind farms or other renewable energy sources amounted to approx. 2 000 MWh on average. Pumped-storage power plants were started to supply additional electricity during the morning and evening load peak.

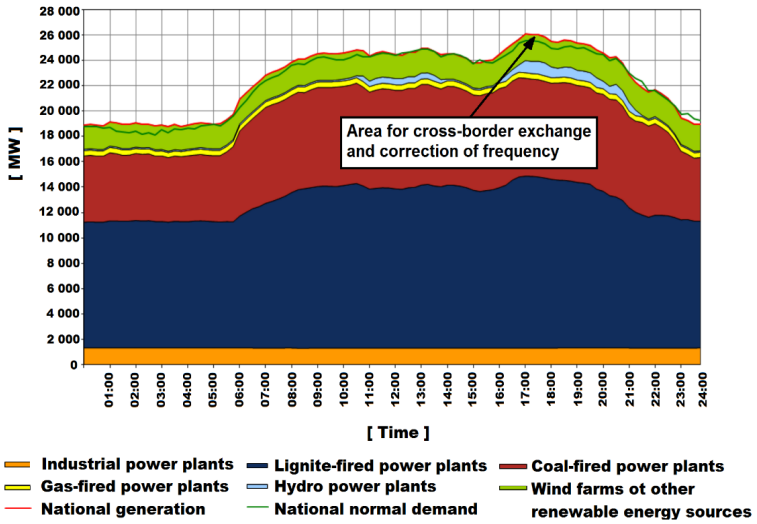

Fig. 2. Power demand in the PNPS on the day on which the maximum national power demand in 2014 was recorded and ways of meeting this demand

On 21 April 2014, electricity generated in industrial power plants was quite stable at all times of the day and amounted to approx. 970 MWh. Electricity generated in lignite-fired utility power plants fluctuated from 3 330 MWh to 5 375 MWh, and in coal-fired utility power

plants from 5 501 MWh to 6 480 MWh. Small hydro power plants generating approx. 100 MWh on average, gas-fired power plants generating approx. 330 MWh and pumped-storage power plants working at the time of peak demand supported the power balance of the PNPS. The total electricity generated by wind farms and other renewable energy sources amounted to approx. 600 MWh per hour on average.

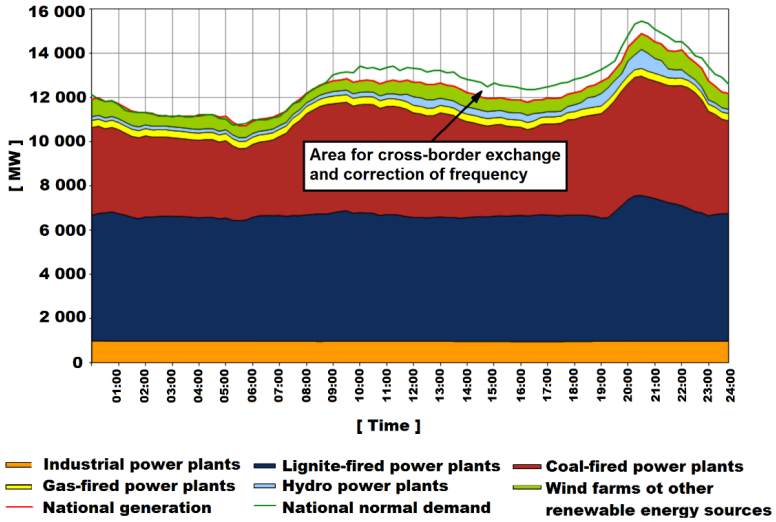

Fig. 3. Power demand in the PNPS on the day on which the minimum national demand in 2014 was recorded and ways of meeting this demand

3. Introduction of limitations of the supply and consumption of electricity in the PNPS in August 2015

In the operational practice concerning issues related to power balancing in the PS, there are a number of examples of occurrence of limitations of the supply of electricity to customers. In 2015, the total amount of electricity not supplied to customers of the PNPS amounted to approx. 95 000 MWh, which constituted approx. 0.06% of the energy consumption in Poland [13]. Such situations are the result of many events, such as e.g.:

a) technical failures in generation, transmission or distribution subsectors [9],
b) extreme weather conditions that cause significant limitations of the operation of key components of the power system or generate extreme increases in the power demand,
c) improperly prepared or too slowly implemented power system development plans leading to the periodic lack of capacity to meet the power demand [3].

In case of possible difficulties with power balancing in the PS, in order to maintain expected supplies to the customers, operators of the PS should undertake all possible activities, such as e.g.: emergency import of electricity from other PSs, overloading of operating generating units, commissioning of emergency units, reduction of voltage in the power supply grid of

a certain group of customers, suspension of works conducted in these parts of the PS which lead to the limitation of the available capacity.

If all possible preventive measures turn out to be insufficient, the TSO is obliged to use other measures, including to implement the limitation of the supply and consumption of electricity, in order to ensure safe and stable operation of the PS. Such limitations are introduced according to the plan previously prepared for this purpose, starting from scheduled limitations and ending, if needed, with emergency limitations.

The heat wave which took place in August 2015, when the air temperature in the afternoon exceeded 35ºC in the entire country, caused a drastic deterioration of power balancing conditions in the PNPS. The average temperature in the country as much higher compared to the previous year, indicated temperature differences reached even 10ºC. These temperatures significantly differed from average long-term temperatures. A strong correlation between the increase in the air temperature and the maximum power demand in the PNPS resulting from the use of cooling equipment on a large scale has been observed for years. As a result, the power demand in the PNPS on 7 August reached its historical maximum level for the summer period amounting to 22 186 MW. High temperatures led to the gradual increase in power outages in centrally dispatched generating units (CDGUs). The reasons for such limitations varied. There were very high emergency outages which reached approx. 3 000 MW on 10 August. This situation was associated with very difficult conditions of operation and cooling of basic and auxiliary equipment forming part of generating units, especially those that have been operated for a very long time. The second group of outages occurring at generating units with open cooling water systems included hydrological limitations. They were caused by low water levels in rivers and exceeded limits of cooling water temperatures during discharges. The most difficult hydrological situation was recorded in the following rivers: Vistula, San and Narew. These outages reached the maximum value of 1 200 MW. High temperatures also led to limitations of the operation of specific systems, for example flue gas desulphurization installation. This resulted in the occurrence of so-called operational outages which reached about 800 MW in the described period. High temperatures resulted in the systematic decrease in the permissible load of 110 kV lines forming part of the distribution grid. This decrease led to limitations of power evacuated from power plants reaching even 1 000 MW. As a result, the total power outages in the analyzed period, caused by the above-mentioned limitations amounted to 4 900 MW.

At the same time, due to technical conditions arising out of unscheduled power flows through the PNPS (so-called loop flows), it was not possible to offer transmission capacities for the purposes of electricity import from neighboring market areas. In spite of using all operational preventive measures available at the planning stage by the Polish TSO, such as:

a) postponement of scheduled overhauls of several units,
b) use of emergency power supplies from neighboring power systems in the Czech Republic and Slovakia,
c) commissioning of available non-centrally dispatched generating units (nCDGUs),
d) reduction of power (DSR).

On 10 August 2015 the expected shortage of generating capacities necessary for balancing the demand of customers of the PNPS reached the value clearly indicating the occurrence of the state of threat to the security of the supply of electricity to customers.

In this situation, the Polish TSO, exercising its statutory rights, made the decision to impose limitations of the supply and consumption of electricity on 10 August from 10:00 am to 09:00 pm and announced applicable power supply levels on a statutory basis. The decision concerning the choice of the power supply level for specific periods was made on the basis of current forecasts of the balance of the PNPS and analyses of consequences of introducing further limitation levels. On their basis it was stated that for the actual conditions of the functioning of the PNPS it is possible to obtain the effect of power reduction for power supply levels above the 16th level; the maximum possible reduction of power consumption is 750 MW for the 17th level, up to 3 360 MW for the 20th level.

Statutory rights authorize the Polish TSO to impose limitations of the supply and consumption of electricity on this basis for the maximum period of 72 hours. Therefore, on 10 August 2015, acting on the basis of article 11c section 3 of the Energy Law Act, the Polish TSO notified the Minister of Economy and the President of the Energy Regulatory Office of the occurrence of threat to the security of the supply of electricity, the measures taken in order to remove this threat and prevent its negative effects. At the same time, the Polish TSO also informed the Minister of Economy that due to forecasted weather conditions, the introduction of limitations of the supply and consumption of electricity at the request of the Polish TSO for the period of 72 hours may be insufficient. Moreover, it informed the Minister that in order to maintain the proper functioning of the NPS, it would be necessary to introduce limitations on the basis of article 11 section 7 of the Energy Law Act, i.e. on the basis of the Regulation of the Council of Ministers. The Polish TSO indicated the 20th level as the maximum requested level of limitations in accordance with § 4 section 3 of the Regulation on the detailed rules and procedures for introducing limitations in the above-mentioned notification. The Polish TSO determined the maximum value of requested limitations of the supply and consumption of electricity at 7 651 MW, indicating at the same time the period from 10 August 2015 to 31 August 2015 as the duration of limitations of the supply and consumption of electricity. On 11 August 2015 the Council of Ministers adopted the Regulation on the introduction of limitations of the supply and consumption of electricity (Journal of Laws of year 2015, item 1136). Pursuant to this Regulation, the limitations of the supply and consumption of electricity were introduced from 11 August 2015 from 00:00 am to 31 August 2015 to 00:00 am on the territory of the Republic of Poland for customers with contracted capacity above 300 kW.

Expected and covered power demand in the PNPS on critical days from 10 to 13 August in the context of introduced power supply levels is presented in Fig. 4 [12].

Power consumption was reduced not only by customers obligated by law, but also by customers not covered by the limitation plan. This was the result of their voluntary response to the TSO's call for the reduction of power consumption by means of mass media. As a result, it changed the daily national power demand in the following way:

a) the effect of the demand reduction started earlier and also lasted after lifting a given power supply level,

b) the full potential of limitations arising out of the 20th power supply level was not revealed on 10 August 2015. As expected, on the first day of limitations a part of customers did not manage to adapt to new conditions (the effect of the power reduction was bigger on 11 August of 2015 when the 19th power supply level was announced),
c) the effect of limitations was also visible on 13 August 2015 despite the fact that the 11th power supply level was announced in which customers may consume electricity up to the level of contracted capacity, which in practice means no limitations.

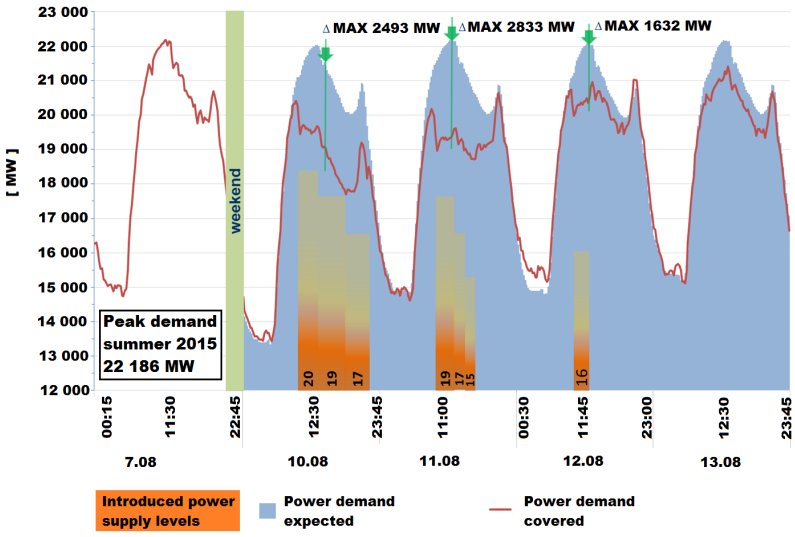

Fig. 4. Expected and covered power demand in the PNPS from 10 to 13 August 2015

The next stabilization of conditions of power balancing in the PNPS was caused by the significant reduction of emergency outages of power generators and hydrological outages in connection with implemented extraordinary measures related to weirs in rivers. It made it possible to prevent the implementation of power supply levels (above the 11th level) on the next days of the month for which the Polish TSO obtained relevant authorizations from the Council of Ministers. The amount of electricity not supplied due to the limitations imposed in the described period was calculated. The difference between the forecasted power demand assumed in daily plans and the actual demand stood at about 55 000 MWh [13], which amounted to 60% of the total electricity not supplied to customers in 2015. On this basis, the total cost of electricity not supplied due to the implementation of planned limitations and other reasons, for example those connected with failures of distribution grids, can be evaluated. For this purposes, the level of unit costs of not supplied electricity should be assumed appropriately to the reason.

Taking the type of measure taken to reduce the power consumption and high uncertainty of possible effects into consideration, implemented power supply levels should be deemed to be properly chosen. It was confirmed by the opinion prepared by the President of the Energy

Regulatory Office on the basis of the report of the Polish TSO. The decisions taken and their efficient implementation at the level of operational activities allowed for safe and stable operation of the PNPS. It was possible to avoid the introduction of emergency limitations, the economic and social consequences of which would be much more serious or, in fact, disastrous.

4. Possibilities of meeting peak power demand of customers

As described above, each power system may experience periodic problems with ensuring safe margin of power balance, which in extreme cases may lead to the implementation of mechanisms of limitations of the supply and consumption of electricity. The probability of the occurrence of such undesirable situations is much higher in the periods of peak loads of the PS which are relatively short. Statistical data collected for the last few years of the operation of the PNPS show that the demand for the last 500 MW of the peak power only lasted about 20 hours and, accordingly, for the last 1 000 MW about 100 hours per year. Such data indicate the assumptions that should be taken into account in the economic analysis presenting different possibilities of covering power demand in the system, including the justification of the feasibility of building peak-load sources. Due to the fact that peak demand lasts for short periods of time, the search for alternative solutions to the construction of generating units designed for peak operation is fully justified. The development of the model allowing for the determination of unit costs of system services for power demand balancing of the system for various variants of possible solutions is very useful for this purpose. It is possible to compare them and identify the optimum solution on the basis of this model.

Available collected data concerning solutions used in the PNPS on the basis of which the comparative analyses were carried out are presented below. Possible solutions were chosen in such a way that they could be used as a model for similar analyses for other power systems. For this purpose, the calculations for the system services available in the PNPS (items 1-5) and potential services in the scope of emergency operation provided by generating sources designed for peak operation (item 6) were made. The following system services were included:

1. overload operation of centrally dispatched generating units (UPP),
2. availability of non-centrally dispatched generating units (GWS),
3. import of electricity by the operator from Sweden (OIs) and synchronous intercomnections (OIps),
4. system service of cold intervention reserve – the result of two public tenders (IRZ1, IRZ2),
5. power consumption reduction at the request of the Polish TSO (DSR – Demand Side Response),
6. intervention operation provided by used (ZISuo, ZISug) and new (ZISno, ZISng) oil- or gas-fired generating sources designed for peak operation.

The following assumptions were taken into account in the above comparative analysis:

a) unit cost were determined on the basis of data published in public tenders or assumed as values estimated on the basis of other source data,

b) determined costs of power balancing services include all costs of the provision of services, i.e. fixed and variable costs [4],
c) all calculated costs were presented in current prices in 2015,
d) analyzed fuel (coal, oil, gas) prices are based on market data applicable in 2015 so significant differences, especially in the area of the calculation of unit variable costs of compared variants should be taken into account,
e) in the case of a new unit, capital expenditures per unit in the amount of 600 000 EUR/MW were assumed for the analysis of costs of peak-load intervention sources. The weighted average cost of the capital was assumed in the amount of 10% and annual operating costs in the amount of 2% of capital expenditures in the entire 30-year period of operation. Data for used generating units were assumed on the basis of the analysis of a rich market offer. The use of open circuits without the use of waste heat was assumed for the calculation of variable costs per unit. Moreover, the use of oil and LPG was assumed, thus maintaining the independence from the operation of gas transmission and distribution grids,
f) electricity is supplied to the PNPS as part of the services acquired by the Polish TSO, referred to in points 1-5, which is then sold on the Balancing Market (BM). The revenue from the sale of electricity is deducted from the purchase cost of these services (the rounded average selling price of electricity on the BM from year 2014, i.e. 160 PLN/MWh was assumed),
g) unit costs of overload operation were calculated on the basis of published data concerning prices on the energy market and increased by the cost increase rate associated with the decrease in the efficiency of the generating unit caused by the mode of operation,
h) unit purchase costs of GWS services were estimated on the basis of variable costs of these sources, taking their structure in the national market into account,
i) unit costs of import of electricity by the operator were established on the basis of the average taken from several years according to the emergency energy exchange mechanism. According to this mechanism, these costs are established on the basis of available electricity prices applicable in markets in which TSOs purchase electricity for the purposes of their neighboring operators (for example spot prices on the Nordpool stock exchange),
j) the same time of using system services, 200 hours per year, was assumed in the calculation of unit costs presented in Table 1. In the case of the reduction of power demand at the request of the Polish TSO (DSR), 60 hours were assumed according to the terms and conditions of concluded agreements, which corresponds to the limitations resulting from technological and organizational conditions of service providers.

Unit costs of system services for power balancing calculated in this way (*jkubm*) are presented in Table 1. They were prepared in two variants: the gross variant including all incurred costs ($jkubm_b$) and the so-called net variant ($jkubm_n$), i.e. the variant in which revenues from the sale of electricity supplied as part of the service provided in the BM are deducted from the costs of system services and avoided costs of purchase of operating capacity reserve were included in the cold intervention reserve service.

Table 1. Unit costs of system services for power balancing of the PNPS in 2015

No.	Type of service	Unit cost of power balancing services		Unit cost of power balancing services	
		fixed [PLN/MWh]	variable [PLN/MWh]	gross [PLN/MWh]	net [PLN/MWh]
1	Overload operation service (UPP)	–	200	200	40
2	Reliability Must Run (GWS)	–	300	300	140
3	Electricity import from Sweden by the operator (OIs)	–	250	250	90
4	Electricity import using synchronous connections (OIps)	–	520	520	360
5	Cold intervention reserve (IRZ1)	770	300	1 070	480
6	Cold intervention reserve (IRZ2)	880	300	1 180	590
7	Reduction of power demand at the request of the Polish TSO (DSR)	–	1 160	1 160	1 160
8	Used oil-fired peak-load intervention source (ZISuo)	1 570	650	2 220	2 060
9	Used gas-fired peak-load intervention source (ZISug)	1 570	940	2 510	2 350
10	New oil-fired peak-load intervention source (ZISno)	2 060	650	2 710	2 550
11	New gas-fired peak-load intervention source (ZISng)	2 060	940	3 000	2 840
12	Unit cost of electricity not supplied due to scheduled limitations ($jknee_{pp}$) – unscheduled limitations ($jknee_{np}$)			7 500-13 500	

Taking the actual conditions of the functioning of the power system into account, the actual time of using specific system services for power balancing in each year is different. For this reason, in the case of optimisation analyses it is useful to prepare the graph presenting the relationship between net unit costs of system services for power balancing of the PS and the time of using such services. The relevant graph for the PNPS and data from Table 1 is presented in Fig. 5.

In spite of unified assumptions, presented unit costs are not fully comparable due to the technical characteristics of specific services. In the case of conventional sources providing the cold intervention reserve service and being peak-load intervention sources (the same also applies to pumped-storage hydro power plants), it is necessary to incur fixed costs of their operation and the actual total unit cost, indeed, depends on the actual time of using such sources.

In the case of services such as: overload operation, use of GWS services, reduction of power demand at the request of the Polish TSO or electricity import by the operator, according to the adopted model of settlement with service providers, fixed costs do not have to be settled with service providers. As a result, the total unit cost does not depend on the actual time of using these services. For reasons given above, it is worth using the unit capacity cost indicator expressed in PLN/MW/year in the process of comparison of costs of various options of obtaining power for the purposes of balancing the PS. To ensure the comparability of various possible solutions, the indicator determined in such a way was calculated on the basis of the

assumption that each of the analysed services will be provided with the same available capacity. Obtained results are presented in Table 2.

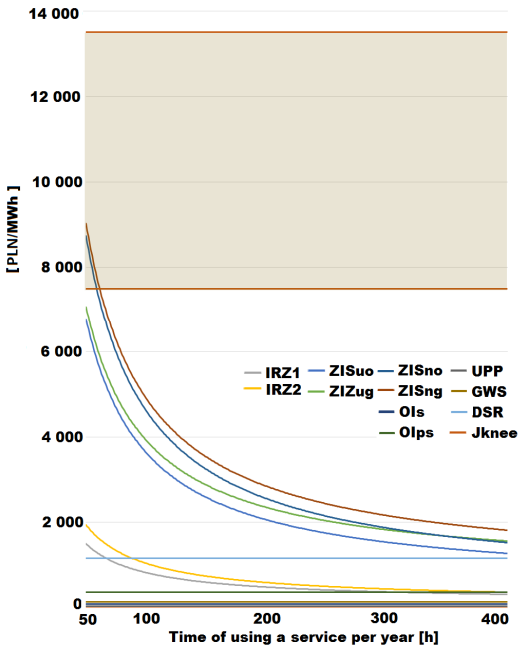

Fig. 5. Relationship between the net unit costs of power balancing services in the PNPS ($jkubm_n$) and the time of using services in the year

Table 2. Unit capacity costs of system services for power balancing of the PNPS in 2015

No.	Type of service	Power to be used by the Polish TSO	Unit capacity cost
		[MW]	[‘000 PLN/MW/year]
1	Cold intervention reserve (IRZ1)	200	154
2	Cold intervention reserve (IRZ2)		176
3	Reduction of power demand at the request of the Polish TSO (DSR)		5.3
4	Used oil-fired peak-load intervention source (ZISuo)		314
5	Used gas-fired peak-load intervention source (ZISug)		314
6	New oil-fired peak-load intervention source (ZISno)		412
7	New gas-fired peak-load intervention source (ZISng)		412

Services provided by sources of cold intervention reserve and the reduction of power demand at the request of the Polish TSO were included in the group of services presented in Table 2 due to the periodic tests of this service generating fixed costs of its provision. The last four items constitute various variants of peak-load intervention sources. It is assumed that these sources would be built for the purposes of the provision of system services for the Polish TSO and not on the basis of their functioning in the electricity market.

The service of intervention operation provided by pumped-storage sources which has not been published in relation to the costs of its provision is also included in the group of services contracted by the Polish TSO. It was assumed that the revenues from the sale of generated electricity in the BM balance variable costs of purchase of electricity in the BM for the purposes of pumping water and costs of the variable component of the distribution fee. However, the nature of this service does not differ much from cold intervention reserve services and does not change the general conclusion regarding the evaluation of the grounds for the purchase of system services for power balancing during peak loads.

Another possible comparison consists in the breakdown of annual costs of purchase of system services for the purposes of power balancing, which however requires making certain assumptions concerning the time of using such services in the analysed period of cost balancing. Costs determined in such a way are reduced by revenues from the sale of generated electricity in the balancing market and in the case of the cold intervention reserve (IRZ) by the avoided costs of purchase of operating capacity reserve services. The breakdown of annual costs is helpful in the calculation of costs of the licensed activity carried out by the TSO, and the choice and purchase of the appropriate service should be the basis for its optimization.

It should also be emphasised that both volumes of available capacity within specific services and the possible time of using such services by the Polish TSO differ much and are not comparable to services the provision of which does not generate fixed costs. For example, capacity available within the overload operation service depending on a given generating unit can be available only for several hours. Also, the volume of available import of electricity by the operator depends on the grid and balancing situation of other TSOs and the duration and frequency of possible reductions are different in case of different providers of this service. Therefore, all these factors should be appropriately taken into account and evaluated in the final comparison and choice of services ensuring the coverage of peak demand for power and electricity.

5. Summary

1. One of the basic tasks of transmission system operators is to ensure the security of operation of power systems managed by them, including power balancing. The analysis of power demand in power systems shows that it is different at different hours of the day as well as on different days of specific months of each year. This variability depends on a number of factors, including conditions of the functioning of customers in the economy of a given country, conditions resulting from the time of the year, week or day – night, intermediate load zones, peak loads.
2. The task of power balancing is particularly difficult in periods of peak loads when the risk on non-supplying electricity to customers is relatively higher than in other periods. The control of the sufficiency of generation resources to cover the demand for power is ensured, for example, by power balances prepared by TSOs for different time horizons.
3. A lot of examples of occurrence of limitations of the supply of electricity to customers were recorded all over the world in the operational practice related to the balancing of power in the PS. The analysis of financial consequences of selected cases of limitations of the

supply and consumption of electricity for customers connected to the PNPS shows that the unit costs of not supplied electricity amounted to 7 500-13 500 PLN/MWh. The amount of these costs in future events will depend on a number of factors such as the nature of limitations – scheduled or emergency limitations, their duration or frequency, ability to foresee them and ability to report possible limitations well in advance, ability to undertake developed preventive measures.

4. The analysis of both direct and indirect financial consequences of limitations of the supply and consumption of electricity for customers clearly shows that possible preventive measures taken well in advance have less serious, economic and social consequences. Appropriate preparation and implementation of measures minimizing the probability of the introduction of limitations is justified.
5. Covering peak power demand by means of generating units designed for peak operation is one of the mechanisms of balancing peak loads. They are characterized by low unit capital expenditures, high availability, short commissioning periods and high flexibility of operation. Fixed costs of such sources and forecasted costs of fuels used by them determine the choice of the optimum technology. However, they do not have a significant impact on the economic calculation determining their construction as an alternative solutions to possible limitations imposed on customers. However, taking into account the fact that peak demand does not last long, the search for alternative solutions to the construction of generating units designed for peak operation is necessary and well-grounded in spite of using cheaper used sources available in the market. It is determined by both technical and economic aspects. For this purpose, it is very helpful to develop the model allowing for the determination of unit costs of system services for power balancing for different variants of possible solutions so that it could be possible to compare them and choose the optimum solution on the basis of this model.
6. The analysis of unit costs of system services for power balancing in the PS from the time of using them shows that the following alternative solutions are more favorable than the construction of generating units designed for peak operation:
   a) possibility of overloading generating units designed for basic and intermediate peak operation, functioning in the market,
   b) use of the possibility of providing system services for power balancing by distributed generation units by TSOs,
   c) system services provided by pumped-storage power plants functioning in the market,
   d) intervention import of electricity from other power systems on the basis of separate interconnection agreements,
   e) temporary use of the intervention operation of old generating units intended for liquidation,
   f) use of the possibilities offered by diversified mechanisms of demand side response (DSR) [6, 8, 10],
   g) use of the electricity storage installations [5, 7].

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