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INCREASING POWER SUPPLY SAFETY IN THE ASPECT OF SUPPORTING THE RENEWABLE ENERGY SOURCES BY CONVENTIONAL AND VIRTUAL POWER STORES

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ABSTRACT

This paper presents characteristics and purposefulness of supporting the renewable energy sources (OZE) by means of energy stores. The main emphasis was placed on analysis of virtual energy stores available for implementation in Polish economy conditions. A role which management of Demand Side Response (DSR) may play in balancing Polish electric power system, is discussed. Implementation of such solutions together with conventional energy stores may significantly influence power supply safety by assuring continuity of electric power supply at an acceptable price. Involvement of electric power consumers (DSR) should be one of the basic solutions for power markets in Poland and Europe.

Keywords: OZE, power market, energy stores, DSR, power supply safety, electric power system, mangement of electric power demand

MAJOR ACRONYMS USED IN THE TEXT

OZE – Renewable Energy Sources
CAES – Compressed Air Energy Storage
DSR – Demand Side Response
EOM – Energy Only Market
KSE – Polish Electric Power Network
LAES – Liquefied Air Energy Storage
MD – Point of Delivery
MC – Missing Capacity
NN/WN – Low Voltage/High Voltage
OSD – Supply Network Operator
OSP – Transmission Network Operator
PCM – Phase Change Material
PMC – Energy Phase Transition
POB – Body Responsible for Commercial Balance
SEE – Electric Power Network
SN – Intermediate Voltage
SZU – Official Energy Seller
TES – Thermal Energy Storage
TTES – Tank Thermal Energy Storage
UTES – Underground Thermal Energy Storage

INTRODUCTION

Assurance for supplying sufficient amount of energy constitutes one of the basic challenges which economies of various countries, especially those highly developed, must cope with. Risk of occurrence of breaks in electric power supply has triggered debate on effectiveness of the functioning of uniform power market. The conducted analyses show that yearly increase in electric power demand is close to 1% and in Polish conditions it amounts to 2% in recent years. In the light of EOM (Energy Only Market), the one-good power market which does not allow to return investment capital engaged by producers caused that investment decisions partly or entirely stopped. Consequently, it leads to a decrease in production capacity (Missing Capacity).

In Poland, in case of lack of appropriate economic signals, about 10 GW production capacity will be withdrawn till 2025 [21].

There is necessity of continuous development of production sources, modernization of existing high-power blocks, support for dissipated power industry as well as investment into conventional and virtual energy stores and renewable energy sources (OZE).

Profitability of investment into new production capacity is closely associated with development of OZE. Support systems, subsidies in the area of capital costs, low changeable costs of power production from OZE all that results in shortening the lifetime of conventional production units. It generates the problem of Missing Money – shortage of financial resources for covering operational and investment costs [2].

Energy from alternative power sources, though inexhaustible and commonly available, is characterized by a high changeability of occurrence and is not correlated with power demand from the system [3]. Costs of wind and solar power plants are dropping but do not guarantee supply stability without changing the functioning paradigm and way of thinking about the whole electric power system.

Development of energy storage and its capacity is one of the crucial research issues in recent years. It is necessary to assure a stable mode of operation of electric power system [4]. Storage of huge amounts of power is rather questionable due to technological limitations therefore a great emphasis is recently placed on development and application of virtual power stores based on including the demand side into balancing the power demand system (incentive programs for electric power consumers) [15].

CHANGES WHICH OCCUR IN ELECTRIC POWER SYSTEM

In recent years very dynamic changes have been observed in Polish electric power system : increasing demand for electric power, increasing share of OZE, transborder exchange, new fuels, certification systems, power effectiveness, electric driven cars, intelligent measuring systems. These are only some factors which cause greater and greater problems in balancing the system and safety assuring. Fig. 1 presents the statement of amounts of produced and consumed electric power in particular years. The year 2014 was a breakthrough with respect to electric power consumption in Poland – more power was consumed than that produced by the system (indicated by red arrows in Fig. 1).

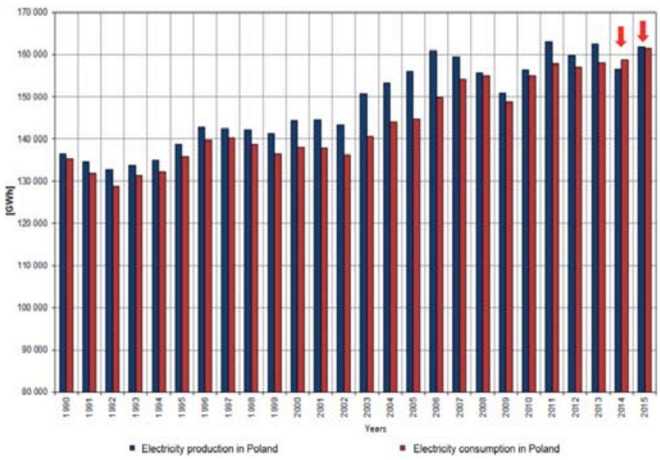

Fig. 1. Electric power production and consumption in the last years, [5]

However on 9th January 2017 the power demand in Poland exceeded 26,2 GW (this way the record of 2012 was broken). Despite 40 GW power capacity installed in the system, the events in which the available power reaches the level of only 26 GW, occur (such situation is illustrated in Fig. 2) [5]. This results due to non-availability of OZE (RES), heat and power stations, industrial electric power plants, breakdowns or repair down times.

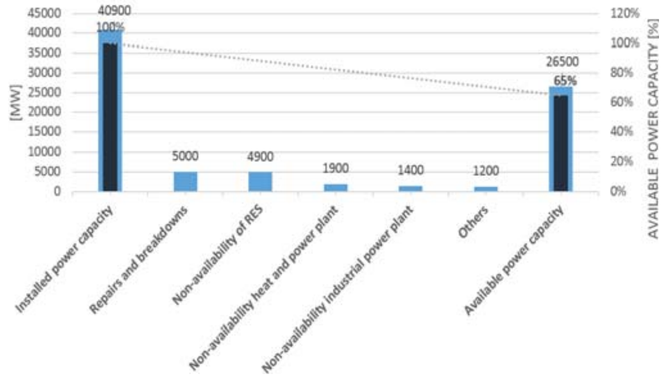

Fig. 2. Average power capacity available at the summit in September 2016. Own study based on data from [5]

A more and more serious problem for the electric power system results from the increase of the installed wind-generated power (from 1 200 MW power installed until the end of 2010 up to 4254 MW power installed until the end 2015, and up to 5 800 MW until the end of March 2017 – Fig. 3.)

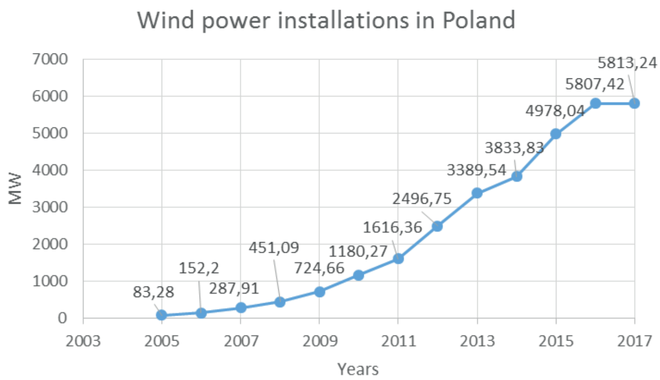

Fig. 3. Wind- generated power installed in Poland in particular years. Own study based on data from [5]

Nominal power of wind turbines is taken into account in balance of Polish electric power system however its availability depends on hard predictable atmospheric conditions (see an example given in Fig. 4.). The below given figures (Fig. 4, Fig 5) present discrepances between planned and actual amount of wind- generated electric power.

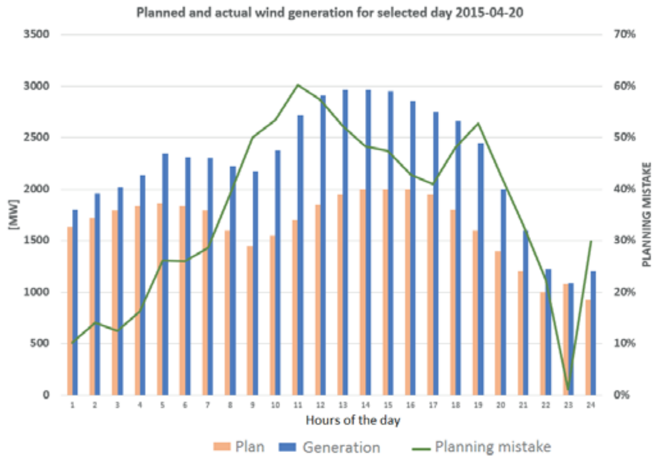

Fig. 4. Planned and actual amount of wind- generated electric power on the selected day : 2015-04-20. Own study based on data from [5]

The discrepances in daily prediction of power production from wind power sources may reach the level of over 60%, which is equivalent to the not planned emount of wind-generated power reaching more than 1000 MW in particular hours of the day.

According to Fig. 5, the difference between maximum and minimum amount of wind -generated power during about a month may exceeds 3500÷4000 MW.

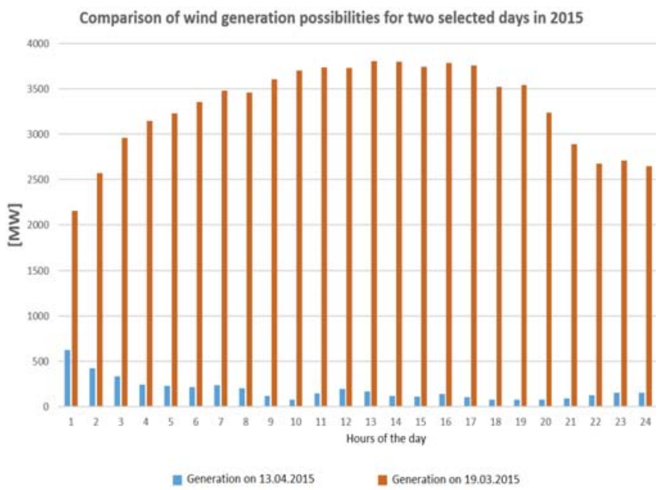

Fig. 5. Comparison of wind generation possibilities for two selected days : 19.03.2015 and 13.04.2015 . Own study based on data from [5]

In the subsequent stage of analysis of the data, a coefficient of impact or share in electric power production, which shows consequences for stability and characteristics of the electric power system, may be determined. The wind turbine impact coefficient is time-variable. On the ordered characteristics of yearly power loading it can be observed that the largest percentage of share of wind-generated power is achieved in the situations of the lowest demand for power from side of the system (Fig. 6.)

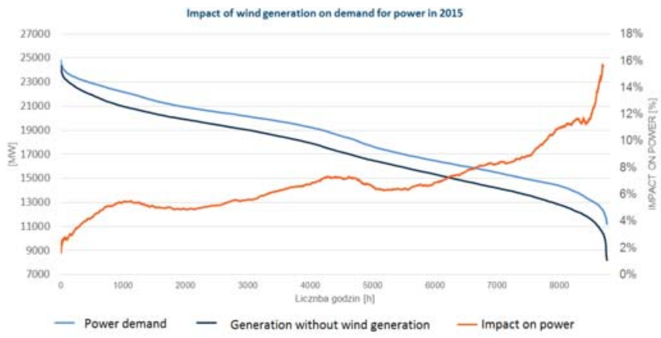

Fig. 6. Impact of wind generation on power demand in 2015. Own study based on data from [5]

The situation presented in Fig.6 results in an increase and variation of prices on the electric power market.

According to various analyses, even 4,4 GW production power capacity may be cut off in subsequent years [5, 21].

To counteract consequences of lack of peak power capacity in the system the Supply Network Operator has a few solutions at his disposal. First, he can make use of the so called Operational Power Reserve (of yearly cost of about 400 mln PLN). Secondly, he can activate the so called Intervention Cold Reserve (of yearly cost of about 170 mln PLN) which artificially supports extension of lifetime of unprofitable and non-ecological production units [5]. Thirdly, he can increase power import. Fourthly, he can optimize timetable of repair of production units being at central disposal. In spite of that the two last solutions are rationally justified their results do not yet solve any cause of shortage of peak power. It should be remembered that the highest load intervals occur in the system during 100÷150 h per year only.

The assuring of appropriate power production capacity and power reserves, hence power supply safety, requires to introduce stable and long-lasting stimulation mechanisms for investing into new production sources and energy stores. The power market which limits risk associated with long-term investment into power industry constitutes such mechanism . It also supports realization of climatic policy.

For building the power market it is necessary to develop DSR services despite future energy decisions . Examples from USA, France or Great Britain show that demand-side resources may be less expensive than building new production units [20]. In case of providing appropriate conditions as well as possible participation and equal functioning conditions on the market for DSR services they are also stable and achieve high effectiveness.

POWER MARKET

Power supply safety is conditioned by availability of fuels, an appropriate network's infrastructure which is developed by control mechanisms as well as an appropriate production capacity developed by competition mechanisms. In long-term horizon it will be possible to assure power supply safety by working out power mechanisms, i.e. implementation of a power market.

Power rewarding mechanism which functions aside power market and balancing one can be considered as an additional, transient power rewarding mechanism only after undertaking actions aimed at elimination of imperfections of the power market . It is usually introduced in the situation when evaluation of adequacy of resources, carried out in compliance with European standards, demonstrates that in the near future the relevant resources would be not fully invested which may endanger power supply safety [2].

Power resurces which make profit from support or/and public help systems (operational assistance for OZE and CHP – combined heat and power, difference contracts etc) cannot take part in the power market.

The power market is technologically neutral and forms therefore uniform competition conditions for all production technologies as well as DSR with taking into account parameters of how much particular technologies contribute in the assuring of electric power supply safety [2]. In various analyses of power markets and mechanisms a taxonomy based on their operational modes is usually implemented. The aspects of which entities determine quantity of production capacities, which are to be bought and in how big amount, are taken into account (Tab. 1). Such solutions are already under operation in France, Belgium, Great Britain, Spain and Ireland [2].

Tab. 1. Typology of power capacity markets [2, 6]

Based on quantity	**Based on price**
Auction organized by a control body (in Poland e.g. by Polish Electric Power Networks[1]) assures an appropriate level of power. Alternatively, the control body requires from retail sellers to have power certificates covering the peak demand.	Payment for power is determined by a control body and it constitutes an additional income for power producers (supplier is paid for a unit of delivered energy as well as for assurance of power delivery to the system).
Centralized	**Decentralized**
Overall domestic auction is organized to cover lacking power. The control body transfers its cost onto final consumers.	The control body requires from retail sellers to cover peak power demand appropriately. The sellers are made resposible for realization of the task.
Dedicated	**General**
Only a part of producers make profit from the mechanism, e.g. planned installations, or a part of those which fulfill criteria.	All consumers make profit from the mechanism irrespective of a used technology.

In compliance with a proposal offered in [6], on identification of all problems as well as because of lack of possibility to balance demand for power,it is planned in Polish electric power system to introduce a centralized auction for production capacities accompanied by a reform of power capacity market and system's services.

[1] The operational body of Polish Electric Power Networks is to render services of electric power transmission under condition of fulfilling required criteria for operational safety of Polish Electric Power System (KSE) [5].

In Poland a crucial aim for changes in power market should be to assure an appropriate quantity of available power in the electric power system. A standard level for power supply safety can be determined both deterministically and stochastically. In case of designing a new mechanism the two methods should be initially used, making this way it possible to verify results of stochastic approach by means of the deterministic method which is better known in Poland.

In the proposed project of power market volumes of power in MW units will be contracted in the form of the so called Dutch auction, i.e. the "dropping price" auction . In the power market DSR services will be able to participate.

European experience, especially the implementation of power market in Great Britain, Has revealed trends and specifity of functioning a two-good market.

In Great Britain in auction for the winter season 2020/2021 stores based on batteries (e.g. Li-Io ones) won about 1% of contracted power capacity (about 500 MW). However investments into new big electric power stations could not count on any support. Only small gas power plants reached contracts (3412 MW power capacity in total for 129 units which gives 25 MW per unit) [22].

Among eight winning investments into support and stabilization services of electric power system operation, five were devoted to storage systems, two to DSR (detail analysis of the solutions is given in Chapter 5 and 6 of this paper) and one to a gas power plant.

CONVENTIONAL ENERGY STORES

According to the definition of energy stores being in force in Poland, which was approved including the last amendment of the act of OZE, energy store is defined as "a separate facility or a set of facilities which serve to store energy in an arbitrary form and in the way which makes it possible to win at least some amount of it back, as well as does not cause any emission burdensome for environment".

The today applied technologies which allow to store electric energy can be divided into those for intermediate electric energy storage (with the use of converting electric energy into other kind of energy, e.g. kinetic or chemical) and those for direct storage of it (in electric or magnetic field) [19].

Undertakings aimed at application of energy storage technology make it possible [14]:
- to moderate variability in power generation from wind sources, introduced into electric power network in shorter time intervals,
- to limit the using of conventional peak sources in situations of changes in generation from wind sources,
- to shift electric power production from non-summit load hours to summit load ones.

A good enegy storage system should be characterized by [7]:
- high energy density,
- easiness of loading and unloading and a high number of their cycles,

– high energy output of the cycles,
– possibly simple conversion of energy into its other forms,
– it should reach a required economical effectiveness and do not cause any danger to the environment,
– an assumed duration time of energy storage and time of delivery it to consumers .

Tab. 2 presents the basic operational parameters for different modes of energy storage recommended by American Electric Power Research Institute, aimed at support for integration of wind electric generation plants with electric power system.

Tab. 2. Basic operational parameters of selected types of energy storage technology [1]

Lp.	Technology	Cycle efficiency %	Nominal power [MW]	Discharge time [h]
1.	Pumped-storage Hydroelectricity	80	100-1000	> 1 hour
2.	Compressed Air Energy Storage	60-75	0,1 – 1000	few hours
3.	Flywheel Energy Storage	90	0,1 – 10	0,1
4.	Conventional Batteries	60-80	0,1 – 10	0,1 … > 1
5.	Rechargeable electrochemical	70	0,1 – 20	> 1
6.	Fuel cell	50	0,1 – 1	> 1

COMPRESSED- AIR ENERGY STORAGE (CAES)

Pumped-storage power stations are commonly used for energy storage. This is a large-scale technology when taking into account that such amount of available power can be of importance from point of view of the entire electric power system. Alternative storing facilities of comparable capacity, but more profitable, are compressed air installlations [17].

The example technical solution of interaction of gas turbines and compressed air tanks is given below (Fig. 7.) There are a few systems for energy storage in compressed air. Fig. 7 presents a system which reaches the highest efficiency of over 70%. It contains in its turbine part both a combustion chamber and recuperator. Beyond the last compressor stage there is no cooler as the produced heat is stored in a tank for waste heat which can be used for heating the compressed air directed either to turbine stages (in the systems without combustion chamber) or to combustion chamber (Fig. 7.).

Such solutions are designed and tested in the countries where wind power industry is developed the most. The German project ADELE (Adiabatic Compressed-Air Energy Storage for Electricity Supply) may serve as an example of such solution. The main aim of carried out investigations is to develop air tanks as well as heat exchangers and stores recovering waste heat from compression [1, 3].

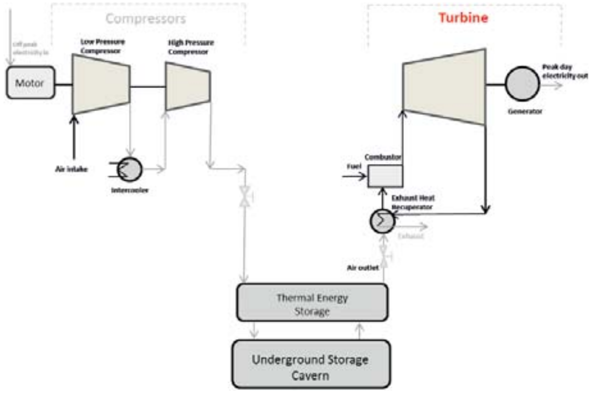

Fig. 7. A CAES system with exhaust [waste] heat storage, combustion chamber and recuperator [3]

HEAT STORAGE

Accummulation (storage) of heat takes place in the devices called Thermal Energy Storages (TES). They are split into three groups depending on a temperature range of storing medium: low-temperature (up to 120°C), intermediate-temperature (120-500°C) and high-temperature ones (over 500°C).

The following three basic heat storage systems may be distinguished:
– by using specific heat,
– by using energy phase transition (PMC),
– by using chemical heat transition.

Tab. 3 presents comparison of the three storage systems.

Tab. 3. Typical parameters of Thermal Energy Storage Systems [8, 9]

TES System	Capacity (kWh/t)	Power (MW)	Efficiency (%)	Storage period (h, d, m)	Cost (€/kWh)
Sensible (hot water)	10-50	0.001-10	50-90	d/m	0.1-10
PCM	50-150	0.001-1	75-90	h/m	10-50
Chemical reactions	120-250	0.01-1	75-100	h/d	8-100

Heat accumulators, the so called UTES (Underground Thermal Energy Storage), are able to use ground, water or gravel as a storing medium. These also may be water reservoirs, i.e. TTES (Tank Thermal Energy Storage).

LIQUEFIED –AIR ENERGY STORAGE

One of the most effective methods of surplus energy storage is storing in liquefied air (LAES method – Liquefied Air Energy Storage) [18]. Such process consists in compression of air and next cooling it until the instant of its transition from gaseous state to liquid state of matter. Consequently, the liquefied air is stored. In the periods of increased demand for energy the pressure of liquefied air is increased by pumping and as a result it starts to vapourize. The air in gaseous state (under pressure) is heated and used for production of electric power in electric power stations equipped with compressed-air turbines or gas turbines [10, 11].

VIRTUAL ENERGY STORES

One of the verified and efficient means for assuring efficiency, stability and competitiveness of dispersed energy production sources is to implement technology of virtual energy stores (called also virtual electric power plants – Virtual Power Plants). Solutions based on virtual energy stores constitute a closed controllable entity (unit) which is capable of satisfying energy needs of a single installation or it may be integrated with electric power network increasing this way its energy effectiveness.

The concepts of virtual energy stores find greater and greater industrial/commercial application in EU countries.

The notion of virtual energy storage (Virtual Energy Storage) should be meant an aggregated and accessible – on request by means of teleinformatical solutions, i.e. virtually-structure which covers controllable units (manufacturing, consuming and storing). Such structures may render system's services supporting this way operation of SEE on the level of the entire system (i.e. in aid of transmission network's operator – OSP) or locally (in aid of delivery network's operator – OSD) to optimize power purchase costs with simultaneous limiting network's losses and investments associated with short-lasting occurrence of power demand peaks.

Virtual energy stores may be also used as economic tools for POBs (Bodies Responsible for Commercial Balance) to balance elements of commercial contracts. Activity of virtual energy stores results in improvement of SEE balance conditions.

Execution of services rendered by virtual energy stores may be carried out in two ways :

– by power supply management (delivery of energy generated by managing-subjected, small disperse sources – electric generating sets, industrial/ private units) or
– by power demand management (management of power absorption – most often by shifting load towards other time of the day).

A very important aspect necessary for functioning such services are informatic and measuring tools used for verification of correct run of supporting activity directed to the electric power system.

In the worldwide existing solutions there are demand aggregators which are responsible for aggregation of energy in virtual energy stores [2]. These are bodies which are able to sell and deliver – both in quantitive and qualitative sense – energy (power) to SEE or to limit demand
(to activate the so called „ negawatts" on the market).

As services rendering bodies, i.e. those which offer power generation on call or its reduction (shifting electric power demand in time) may serve e.g. large industrial enterprises (foundries, mines, water supply networks, metalurgical works, food processing plants, manufacturing plants, collocation centres, trade centres equipped with BMS systems (Building Management Systems).

DSR SOLUTIONS

An act of electromobility has to introduce, into Polish legal order, issues associated with management of electric power demand, i.e. the so called DSR [16].

The notion of " demand management" has to be applied to "final consumer's installation whose devices make it possible to change profile of electric power absorption on call from the side of power supply system's operator, power transmission system's operator or operator a joint system which may be consisted in particular of an energy store, production installation which does not coopoerate directly with the network, or loading point".

The below given analysis presents ways of making use of DSR services (demand side management – virtual energy store management) for the puropses of participants of Polish energy market.

DSR FOR OSP

The intervention reserve is used in situation of critical load in the system. Earlier, OSP contracts power demand reduction by means of a tender/auction. Till now, OSP have announced seven tenders for rendering demand reduction services. They allowed not to contract abt. 200 MW for winter season (October-March) and 185 MW for summer season (April-September). In May 2017, PSE announced next auction to enlarge the quantities, that was a consequence of concern resulting from increasing load during summer. Appropriate contracts were signed with three big consumers and one aggregator [13].

The contracts are described by detail regulations in which requirements for the attendance, execution and accounting of services are defined. Till now, OSP has made use of the services in 4h reduction periods . Fig. 8 presents an example of such services.

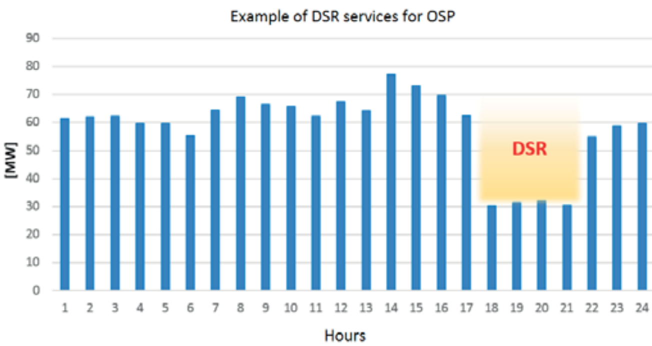

Fig. 8. Example of DSR services for OSP

According to the new conditions (available from OSP web page) OSP is going to put into operation two following programs:

– guarranteed one – services provider is to response on OSP call – the so called stand-by fee,
– current one – services provider may response on OSP call – payment for rendered services.

DSR FOR POB

Issues which are present in activity of bodies responsible for trade balancing (POB) always result from the situation which occurs on electric power markets where prices are varying within the range from 70 PLN/MWh to 1400 PLN/MWh. The variations result from three main commercial-technical factors :

- a level of electric power produced by wind turbines,
- a level of power available from centrally administered production units, and
- a service time of coal power plants put in operation only in power shortage periods.

In Poland consequences of varying prices most afflict POBs which do not have capital connections with conventional production sources but simultaneously face a high level of wind generation in the region where they operate in the role of an official seller (SZU). POBs are obliged to buy back electric energy at a price announced by the Office for Energy Control . Such price is usually higher than that contracted with final clients.

The used trade model (following-up) assuming to buy electric energy on long-term markets contributes to the bad situation.

Implementation of DSR services in regions under demand control may be greatly useful in levelling unfavourable market trends for POBs being in the above described situation. Their commercial application in reduction region (activation of demand reduction in an appropriate moment, in aid of POB) consists finally in limiting number and value of deficit transactions on the Next Day Market (optionally on the Current Day Market) as well as on the Balancing Market, indirectly. The transactions are considered to be obligatory energy purchase at a higher price than that of selling to final client with taking into account necessary price mark-ups.

Analogous situation of commecial application of DSR in generation regions consists in activation on demand clients' power generation sources (which are not centrally administered units) in hours of high electric power prices on spot markets. However in case of occurrence of low electric power prices on spot[2] markets (e.g. in the night) such application consists in limitation on demand a more expensive generation from clients' sources, this way making it possible to increase volume of cheap energy purchase from the market. In case of a lack of access to client's generation, the increasing of electric energy demand in response to low electric power prices on spot markets is a natural consequence of activation of DSR services.

DSR FOR OSD

Problems which appear for operators of supply systems (OSD) consist first of all in the over-dimensioning of network infrastructure to cope with short-lasting rises of demand for electric power. It leads to higher investment costs and is directly associated with maintainance and operation costs of electric power supply produced by means of an infrastructure not adjusted to needs.

The earlier discussed problems of OZE and the increasing share of dispersed generation affect character of network operation. It generates additional losses and forces not only decision on new infrastructural investments but also a change in view on rendering supply services. Present business model does not consider to apply an active demand – supply management on the OSD level but it is only focused on maintaining distribution capability of the network. The situation results from a stiff structure of tariff building process which does not take into account changes in market situation.

Today, OSDs assure power level in OSP's network. In case of OSP, payment operations are made on the basis of an average value taken from maximum amounts of total power absorbed by OSDs. In order to assure power level in the assumed account model, amount of contracted power is over-dimensioned against usual needs. This is associated with generation of additional costs which are entirely transferred onto electric energy consumers.

Commercial application of DSR services on the level of OSD may be made in analogous regions as in the case of POB. When dynamics and characteristics of power demand in the Polish electric power system is analyzed the demand peaks which occur in very short-lasting periods can be observed.

Potential profits for OSD which may arise from implementation of system services rendered by producers wired into intermediate voltage (SN) network, are analyzed in Tab. 4,[4].

Tab. 4. Profits from implementation of system services rendered for OSD

Action	Profit	Alternative
Active power control	Frequency control (fast control), overload mitigation (slow control), substitutivity of network investments or possible shifting system's extension investments in time, possible voltage control, lowering tariff payments for contracted power in NN/WN (the highest voltage / high voltage) stations	System generators, absorption control, energy dispensers, investments
Passive power control	Voltage control, optimization of losses, lack of necessity of passive power transmission over large distances, limitation of use of already installed passive power (Q) sources as well as transformers	Passive power sources,, WN/SN (intermediate/ low voltage) transformers, control of sources connected to 110 kV switching stations
Island operation (+blackstart)	Lowering breaks in power supply (lowering SAIDI and SAIFI coefficients), lowering danger of occurrence of system failures, lowering probability of loss of a part of generation, resulting from disturbances	Multi-side supply, electric generating set

Services for OSD may be also rendered by sources incapable of regular increasing generation in peak demand periods

[2] Cash market – in this case the Next Day Market.

but able to increase power during a dozen or so hours per year (i.e. heat and power stations, over-dimensioned power sources).

To render services it is necessary for a producer to have a permanent margin of power to be produced over that delivered to network. The increasing of generation is executed on OSD's demand immediately Just after stating a risk of exceeding an assumed level of hourly average power absorption in a given MD. Determination of power amonut contracted by OSP consists in averaging five (out of seven) highest hourly average measurements taken at NN/WN station. Duration of time during which the increased level of generation has to be maintained should be determined on the basis of statistical data about flow of maximum power amounts into particular power delivery points (MD).

CONCLUSIONS

The analysis presented in this paper illustrates a number of changes which occur in the field of electric energy . New solutions and mechanisms are compulsory in this area. It is essential to abandon the one-good model of electric energy market in aid of a two-good market. In the new model, a power market, i.e. mechanism of rewarding production capacities which store electric energy indispensable for assuring power supply safety for the country should function in parallel to the electric energy market.

The power market is a mechanism in which resources of both supply side and demand side (i.e. production sources and consumers of electric energy) may take part. Virtual stores which make use of DSR (demand side management) can effectively lower cost of maintaining stable electric energy supply to consumers making this way possible to balance KSE . Integration of technological systems making use of OZE with traditional electric energy system imposes necessity of searching for more useful forms of energy which may be consumed in any time.

This became a motivation for searching for and developing new forms of energy storage. Flywheels, fuel cells, CAES, LAES, supercondensers, electrochemical cells represent only some of conventional technological solutions of energy stores, which are under permanent development and improvement.

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