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The course of renewable resources production

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***Abstract*— The article analyses the deviation caused by renewable energy sources and looks for solutions to minimize them. It analyses the size of the deviation caused by renewable sources from the available data. The work compares daily, monthly and yearly courses of renewable sources supply. It also mentions the regulatory properties of individual renewable sources and seeks options for the usage of renewable resources in support services of the electrical network. Based on the measured data it models the size of the control power to minimize deviations. The work also studies economically effective solutions to minimize the purchase price of electricity generated from renewable sources.**

Keywords—renewable resources; production prediction; deviation of electrical network; purchase of electricity; power regulation

I. Introduction

Electrical energy is one of the most valuable types of energy that peole use. Its high usage is based on the fact that it can be directly turned into other types of energy by simple means with high efficiency. However the disadvantage of this type of energy is that we can only produce a small amount of it with direct transformation and even that not efficiently. That is why thermal power plants prevail, where the energy bound in the chemical bonds of molecules, atoms and nuclei (nuclear bonds) into thermal energy and in turn this energy is turned into electrical energy through steam turbines. This way we can the highest efficiency of transformation in thermal power plant achieve approximately 41.6% [1]. The problem is that these power plants mainly burn fossil fuels and emit large amounts of CO_2 (about 500 - 1 000 gCO_2/kWh [2]). Renewable energy sources (RES) produce 100 or less gCO_2/kWh [2]. Another characteristic of RES is that they are renewed either naturally or with human activity; they are inexhaustible in this way.

There are two primary reasons that are related, because of which these sources do not fully replace power plants using fossil fuels. Electrical energy on its own cannot be stored. The produced electrical energy can be stored only if it is converted into another type of energy. Because of that reason every moment it is necessary to produce an amount of electrical energy that is needed. That means that the sources connected into the electrical network must be adjustable to some control. Therefore the first reason is that renewable sources like wind, solar (photovoltaic), the plants making use of the movement of rivers and oceans and the others do not have the capability of storing their primary energy source. They can only lower their power during operational hours, but if there is not enough wind, solar radiation or movement in the water, they cannot raise their output. Another reason why renewable sources do not replace commercial power plants is that their technology is financially demanding. Without financial support their return value is questionable, and for that reason their operators run these facilities such that they make as much electrical energy as they can. Their goal is to make profit, and so they are not motivated to regulate their power output. The RES production requires other resources, that must be controlled by other means (in most cases by plants using fossil fuels) [3]. This article works out the extent of adjustment these renewable sources must have, and how they affect the load-energy diagram of Slovakian electrical system (ES). In this analysis we will look at the diagrams of supply for these sources and their usage in the production of electrical energy in the energy-mix of the Slovak Republic. We will also include some options for regulating renewable sources working for the Slovakian ES and the economic aspects of the return value problem.

II. Renewable energy sources in electricity production in Slovakia

The annual consumption of electrical energy in Slovakia in 2018 was 30,950 GWh [4]. That year Slovakia produced 27,150 GWh**.** Out of the entire used electric energy only 8.8% was provided with RES (not counting the big hydroelectric power plants).

Almost half (49.4%) of the electrical energy produce from RES was produced by power plants burning biomass. Beside biomass they also used biogas, which contributes a quarter (24.9%) of the RES production in Slovakia. Using these methodes they produce 1,774 GWh of electrical energy from biomass and biogas in 2018 [4]. However the full technical potential of energy made from biomass can be even 36,384 GWh [5], which is just about the amount of electrical energy consumed in Slovakia. Approximately one quarter of this potential is in agricultural biomass (23.8%), 14.1% in forest biomass and about 6% in both biofuels and in biogas (5.8% and 5.7%). The remaining 50.6% are made up of other types of biomass (landfill gases, gases from waste water cleaners, some organic cycles etc.)

The currently installed power in photovoltaic power plants (PVPP) is 531 MW, with an annual output of 585 GWh of electrical energy [6]. A major share of this energy was generated by big photovoltaic power plants built on the ground. Although the technical potential of electrical energy produced with photovoltaic systems can even be 5,200 GWh every year [7]. From that about 283 - 354 GWh [8] produce by photovoltaic systems placed on rooftops (with an 800 to 1,000 kWh/kW annual output).

In terms of the entire production of electrical energy in Slovakia the rest of the RES are negligible. On the other hand there is great potential in other types of RES:

- Wind - there is a technical potential of 600 GWh [9] annually, from which only 6 GWh [10] is realised (an installed power output of approximately 3.14 MW). However almost 178 MW of wind power plants is already projected [10].
- The technical potential of hydroelectric power plants (6,700 GWh [11]) is exhausted to about 58.5% and the construction of a hydroelectric power plant with an installed power capacity bigger than 10 MW is practically impossible. The construction of smaller hydroelectric power plants with an installed capacity of less than 10 MW (small hydro power plant - SHPP) is stopped due to ecological reasons [12].
- In Slovakia there is an identified technical potential in geothermal energy of about 6,300 GWh, from which about 5.4% is put to use [9]. The construction of facilities that produce electrical energy from geothermal heat is financially very difficult and in a lot of cases unprofitable. It is not popular between investors and operator alike for that reason. Currently there are plans for construction of a geothermal power plant in the district Žiar nad Hronom with a power capacity of 12.6 - 13 MW [13].

III. Operation of RES

In principle we distinguish between local and systemic influences of RES on the operation of the ES. By the term local influences we mean how it influences voltage, short-circuit outputs, losses on the conductors, the supply of harmonic current and the influence on facilities of mass remote control, flicker and so on. These effects can be eliminated only to some extent, because their full removal is technologically and financially difficult. The basic indicators that must be kept can be found in the standard STN EN 50 160. Characteristics of the voltage of electrical energy provided from a public distribution network (DS). For that reason operators of distribution systems put out a document titled “Technical demands of the operator of the distribution system of the company”. Based on that document the option of connecting the RES to the network is assessed.

We can include into the systemic influences of RES on the operation of ES for example the effect on the stability and the problems with working in RES into the daily load-energy diagram of the ES. In other words it is a negative effect on the increase of the deviation of the system. The next crucial systemic influence is the overloading of the network. Overloading the network in the confines of DS occurs only in special situations (e.g. when the lines are turned off due to maintenance or repair), since when submitting an application concerning the connection of a source it is necessary to analyse its effect on the system. In favourable conditions can RES make close to its installed output on a bigger area, which can cause an overload on local lines not only on a distribution level, but also by overflowing into the transmission system (TS) on national or international profiles. The TS is overloaded in the event when the produced electrical energy from RES is not all spent in the DS and the active power overflows into the transmission system. In the transmission system this overflow can cause an increase in transmitted power to an extent that the system will no longer satisfy criterion N-1. If the network is configured in appropriately, so called circular flows can occur that overload the lines even beside the source of the problem.

The load-energy diagram depicts the course of the load on the system. Since demand is constantly changing, supply must adjust to it. For that reason in energetics we divide sources into basic (main nuclear and other thermal power plants), semipeak (some thermal, hydroelectric and some gas power plants), peak (pumping hydroelectric, gas and diesel power plants) and sources regulating the frequency of the network (every source that provides support for the operators of the transmission system). This division can be seen on the load-energy diagram in the maximal load days (Fig. 1) and the minimal load days (Fig. 2) for the system of the Slovak Republic in 2018.

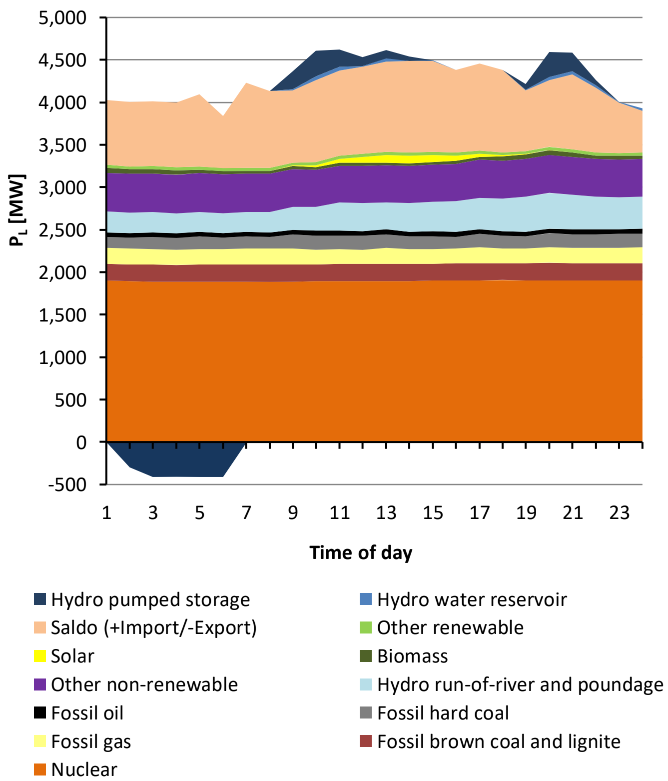

Fig. 1. Load-energy diagram of the Slovakian power system in the day of maximal network load (27.2.2018) [6]

In the maximal network load diagram (Fig. 1) the production from photovoltaic power plants is fairly insignificant, but it does fall into the load-energy diagram, it helps the supply of power during the biggest load of the day. Other renewables, especially production from biomass can be categorised as a basic source, because the power supply from these sources changes throughout the day only minimally. If we compare the production of this source to the summer minimal load (Fig. 2) we can see that it is significantly lower during the smallest load on the network. We can also see that during the maximal network load the production from fossil fuels is substantially higher than during the minimal network load. This can be caused by lesser heat reduction in these power plants. We can also observe a slight fluctuation of the power output in flow oriented hydroelectric power plants on the minimal load diagram. This fluctuation is caused by a water shortage in the waterflow. Throughout the day of the highest load and also the day of the lowest load, the electrical energy made in nuclear power plants is supplied into the basic load of the system without much change throughout the year.

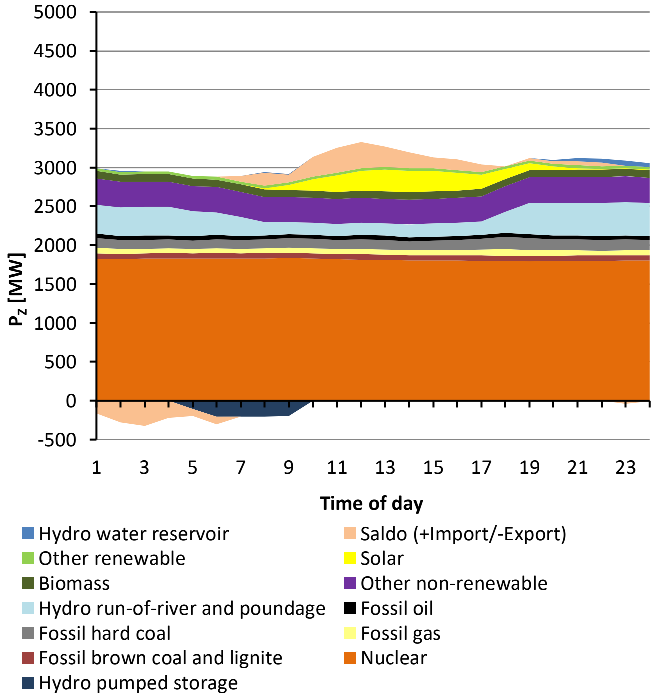

Fig. 2. Load-energy diagram of the Slovakian power system in the day of minimal network load (29.7.2018) [6]

As it was mentioned above, the source itself that produce electrical energy from renewable primary fuels is not profitable on the electricity market; therefore the price must be artificially raised – supported. Beside the price support, in Slovakia, RES is supported by not being held accountable for the deviation they cause on the electricity market. Each producer, consumer or other company that wants to sell the produced electrical energy must beforehand market their electrical energy by the stated conditions, and then proceed to make it and add it into the network precisely in 15 minute intervals (15 minute integrals of power). If the producer does not supply the agreed amount of electrical energy (supplies less or more), he must pay a penalty for the caused deviation. Due to the fact that the producers from RES are exempt from this duty, the deviation penalty is paid by the purchaser or the national purchaser, who buys the energy produced with these resources. Following this the purchaser also markets the produced amount of electrical energy. That means that the purchaser takes on the responsibility for the deviations caused by the RES.

Although on the electricity market it is necessary to hold the supplied or consumed amount of purchased electrical energy in the window of the 15 minute intervals, the provider of the transmission system must balance the power balance at hole time.

A. Biogas and biomass

As we have discussed, most of the electrical energy that is produced from RES comes from biogas and biomass. They make up 74.3% of the entire annual electrical energy production from RES (for 2018). In most cases with facilities that produced from biomass or biogas the supply of active power comes from generators connected to gas or steam turbines. That means that the supply of active power produced from biomass is largely dependent on the primary resource. That is why we can assume that the substantial increase in the supplied energy during summer months is caused by the more than sufficient amount of primary resource (biomass). Information about the installation of new facilities, or information about facilities that have been classified into this category during the year are not available.

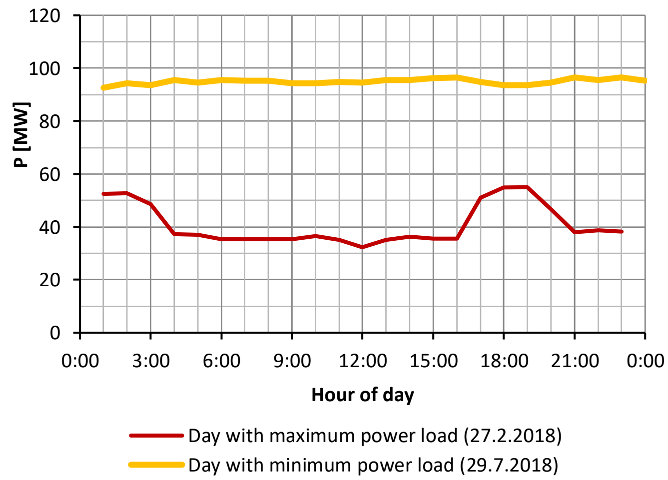

Fig. 3. The course of supplied active power made from biomass on the day of maximal and minimal power load [14]

As it can be seen on the diagram (Fig. 3), the production of electrical energy made from biomass and biogas fluctuates only a bit throughout the day, which means it is a safe and viable source of electrical energy for the ES. Its production is easily predictable and the mistakes of the prediction can be attributed to the imprecise estimation for the production of primary resources (biogas or biomass), which are mostly storable.

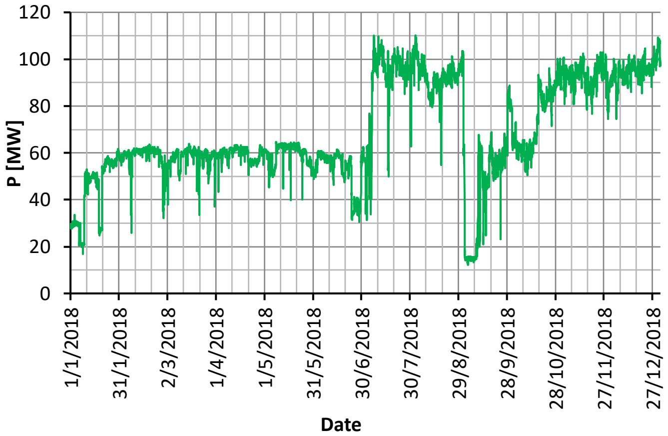

Fig. 4. The course of supplied active power made from biomass in 2018 [14]

It is clear from the diagram that the production of electrical energy from biomass is seasonal. We can observe a significant rise in power during summer days, which could have been caused by an increase in primary resources, but we cannot rule out the possibility of the deployment of new resources either.

The production of electrical energy from biogas is produced with the help of gas turbines or with a gas turbine within a congregational unit. Its primary resource is biogas, the production of which is reliant on plant remains or animal excrement. This gas is stored in gas pouches under atmospheric pressure. For better predictability and adjustability for the production of electrical energy in these power plants, it is better to store them in pressurised containers. From the viewpoint of regulation of power the gas turbines are some of the most easily adjustable machines with a fast start-up time and a wide interval of regulated level of supplied power.

Power plants processing solid biomass use steam turbines to turn the mechanical energy of steam into electrical energy. Solid biomass is economically less difficult store than biogas. However, these power plants work effectively only if they have a supply of 50-100% of the installed power. The technical options for the regulation of the power output in power plants making electrical energy from biomass and biogas are good enough, but there is not enough financial motivation for them to become fully-fledged resources in the system.

B. Photovoltaic power plants in Slovakia

The next significant RES producing electrical energy into the Slovakian ES are the photovoltaic power plants (PVPPs). These power plants produce electrical energy based on weather conditions, making their supplied power remarkably fluctuating. Meteorological predictions can make an estimate about the production accurate to about 15 minutes to an hour, but the supplied power of PVPP is constantly changing. On a sunny day if a couple of small clouds pass above an PVPP, the power output can drop by 30% of the installed power over 1 second, as you can see on the diagram below (Fig. 5). During this particular day the maximal positive change in power (increase) was 29.94% of the installed capacity and 36.66% was the maximal negative change (decrease).

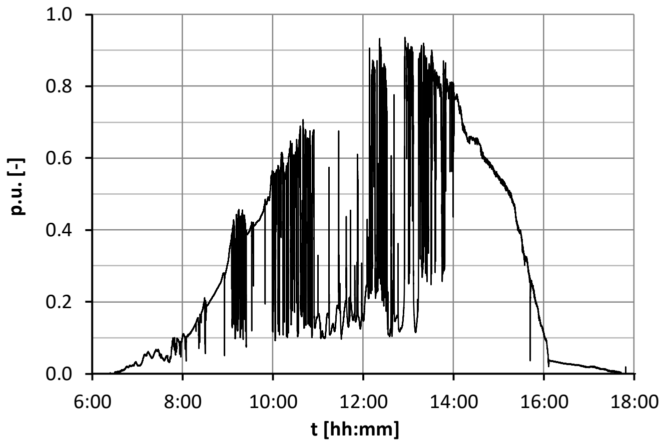

Fig. 5. Supplied power of a small photovoltaic power plant with an installed power output smaller than 20 kW calculated per a unit of installed power [15]

The bigger area the power plant covers, the bigger cloud necessary to overcast it and the slower it is overcast. This means that bigger power plants will be significantly less affected. On the basis of available measurements (in 15 minute intervals) we can get the conclusion; distributed out PVPPs in a regulated region prevent substantial changes in the supplied power in said regulated region, and the fluctuations of power will only have local effects. We can see this fact in the following diagrams (Figures 6 and 7).

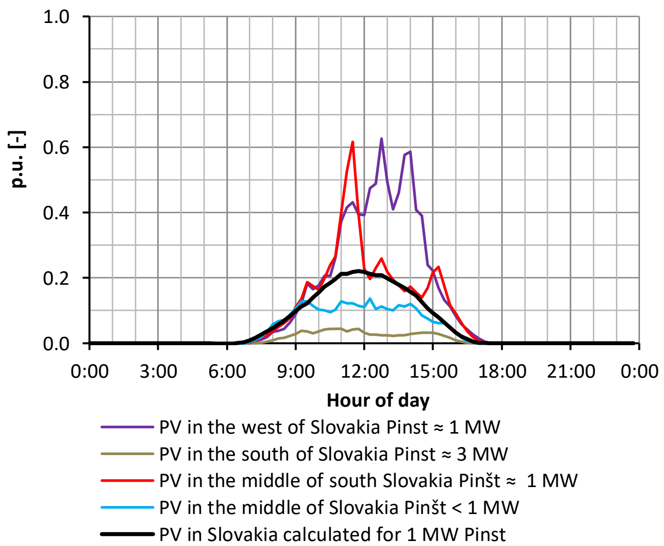

Fig. 6. Supplied active power throughout the day of maximal network load (27.2) in some PVPPs placed cross the Slovakia calculated per unit of installed capacity [14]

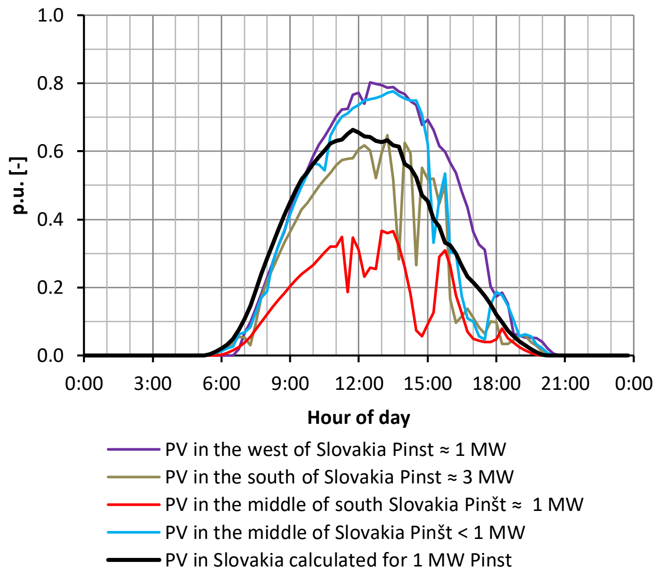

Fig. 7. Supplied active power throughout the day of minimal network load (29.7) in some PVPPs placed cross the Slovakia calculated per unit of installed capacity [14]

From Fig. 8 we can see that the areal distribution of PVPPs in Slovakia is fairly even. A distinctly higher density of PVPP is only in the towns Lučenec and Tornaľa. 24.9% (130 MW) of the installed power of all Slovakian PVPPs is located in these regions. The next locations with a high density of PVPPs are the regions around Hurbanovo and Dunajská Streda, where there are about 23 MW of PVPPs installed.

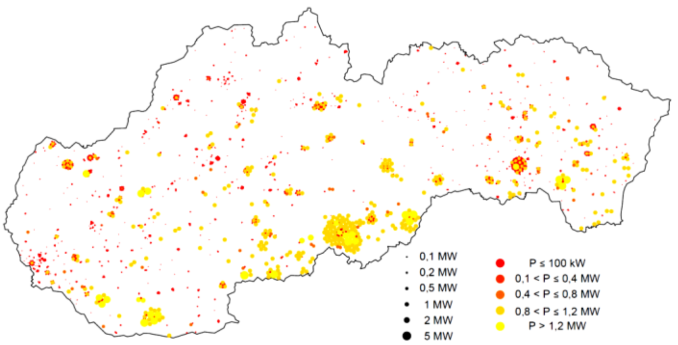

Fig. 8. Distribution of PVPPs in Slovakia [16]

The effect of the placement of the PVPP in Slovakia is best seen in the diagrams below (Figures 9 and 10). These diagrams show that in western region of Slovakia there is 132.06 MWp; in middle Slovakia there is 233.62 MWp and in eastern Slovakia there is 155.40 MWp of installed PVPPs. Basically both diagrams (Figures 9 and 10) show that the shift in the rise and fall of production of PVPP electrical energy is minimal from east to west through Slovakia. Throughout the day of maximal network load (a day that is partially cloudy – Fig. 10) we cannot recognize the influence of the placement of the PVPPs in Slovakia. Yet throughout the day of minimal network load (a day mostly unclouded – Fig. 9) we can observe that the course of the full production of electrical energy from PVPP is approaching the numbers of the production found in middle Slovakia.

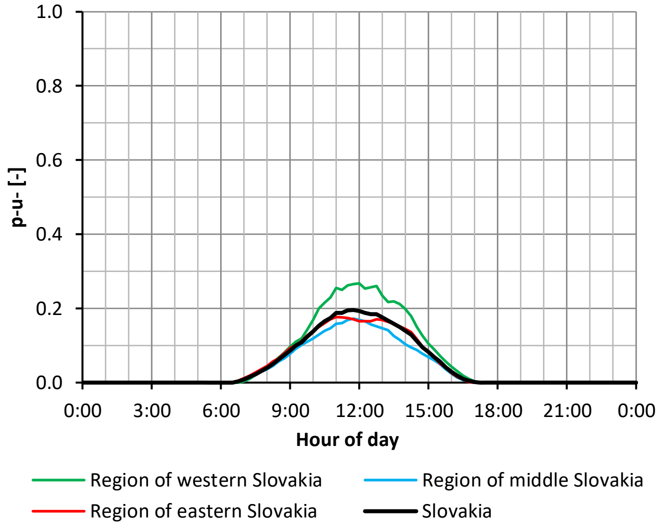

Fig. 9. : Supplied active power throughout the day of maximal network load (27.2) from PVPPs placed in various regions in Slovakia calculated per unit of installed power [14]

Another conclusion we can deduce is that in regional distribution systems the production from PVPPs is less fluctuating in comparison to the course of production from a single PVPP (Figures 6 and 7).

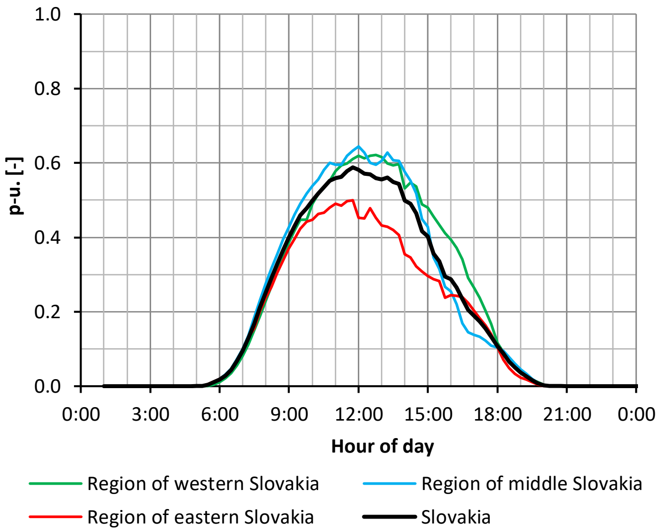

Fig. 10. : Supplied active power throughout the day of minimal network load (29.7) from PVPPs placed in various regions in Slovakia calculated per unit of installed power [14]

Direct information about the deviations caused by PVPP on the electrical market are not available (business secrets). The experience of the operator is, that two power plants that work next to each other, on the same day, can produce electrical energy with a difference of 30%. On the scale of a month from PVPP to PVPP this Fig. drops to ±25%, and throughout the year it is about ±10%. Capable sources in the ES must be capable of self-regulation. PVPPs tend to operate at maximum capacity, and that means they can only regulate themselves by decreasing their power output. Another possibility is the creation of virtual blocks (connecting two or more power plants). For example by connecting an PVPP plant with an accumulation system with 25% of the installed power of the plant and an accumulative capability of 50% of the maximal hourly supply we can decrease the positive deviations (production surpassing predicted power) by 94% and negative deviations by 35% with a predicted daily inaccuracy of production of +20%. If an opposite inaccuracy of -20% occurs (the prediction is 20% lower than real production), it is possible to lower the deviations both positive and negative by more than 30% using the above mentioned virtual block [17]. Modern control units are capable of such regulation, but the operators of the facilities are not financially motivated to predict their power output with the highest accuracy or not to cause deviations or at least cause minimal deviations in production.

C. *Wind power plants*

In this part we will pay more attention to wind power plants (WPPs). Although in Slovakia there is only 3.14 MW of installed WPPs, there are future plans of construction for wind turbines with a full installed power of about 178 MW. Since we have so little WPP in Slovakia it is almost impossible to accurately estimate the deviations they would cause in the Slovakian ES. Similarly to PVPP, we can predict the production of WPP from meteorological forecast in hourly or 15 minute intervals; however the supplied power from WPP changes every second, as we can see on the diagram below (Fig. 11). On this diagram one can see the production of a WPP during one day in one second intervals. Through to WPPs are rotating machines and have their own inertia and rotational inertia, the maximal change in their power output throughout 2 weeks of measurement is a little above ±14% of the installed power per second.

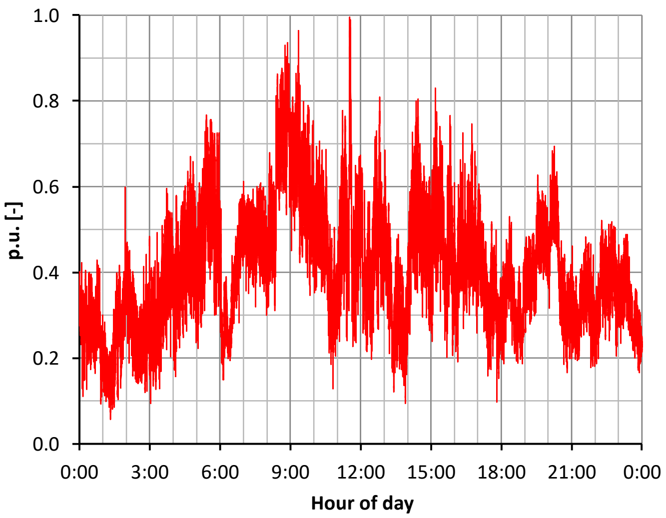

Fig. 11. : The course of supplied power of a WPP on a chosen day calculated per unit of installed power [18]

Another thing PVPPs and WPPs have in common is that they can only be regulated by decreasing their output power. Contemporary technology allows the turning of the blades of the turbine, and that is a way of regulating its output. Because the electricity from WPPs is cheaper, in some cases it favours the purchaser (who is responsible for the deviations it causes) to lower the power of the WPP rather than to pay for the caused deviations [17]. However these traders of the electrical market have other units in their portfolio of sources with which it is more advantageous to lower their power output.

Another option for giving stable power and significantly lower power deviations is the use of virtual blocks connected to WPP with another source (e.g. an accumulative facility with an inverter). With the help of virtual power plant models it was found out that in a virtual block with WPP and a supporting facility with a power output of about 2% of the WPPs and an accumulative capacity of about 2% of the electric energy produced with the installed power we can reduce positive deviation (production exceeding prediction) by 20% with an inaccuracy of prediction of +1 m/s of wind speed and reduce negative deviations by 41% with an inaccuracy of prediction of -1 m/s of wind speed [17].

D. *Small hydroelectrical power plants*

Small hydroelectrical power plants (SHPPs) also supported with the purchaser taking responsibility for the deviations, but thanks to the relatively decent prediction of production they do not affect the balance of power in the network negatively. The reason is the accurate forecast of the state of the waters, which is calculated from the amount of water flowing upstream of a said river. Although a short term forecast can be made very accurately, long term predictions can be of by 60% (less water) or 30% (more water), even in a months time. Since these flow oriented hydroelectrical power plants are dependent on the state of the waters, their maximal supplied power is limited. The accumulative capability of these power plants is minimal, it can be used only to correct small deviations in the confines of the balance group of the trader (the subject of penalty) in the electricity market. However with idle draining we can make a certain power reserve for an occasional raise of power on command. In some cases these SHPPs directly serve as facilities providing regulatory services for their purchasers.

E. *Other RES*

Other facilities sharing in the production of electrical energy from renewable resources make up only 2% of electricity produced from renewable, only 0,234% of the entire electrical energy production of Slovakia. These are the power plants converting landfill gases from communal waste into electrical energy, plants using gases attained from waste water cleaners and so on. In principle they are of similar fashion than the facilities making electricity out of biogas and biomass.

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