# RENEWABLE SOURCES AND OPERATION OF DISTRIBUTION NETWORK

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## *ABSTRACT*

*Knowledge of the actual behavior and characteristics of photovoltaic plants (PVP) scattered in a larger area is important in terms of the size of the total power supplied to the network (in terms of crowding out other types of non-renewable resources due to preferential purchase) as well as the changes that affect the necessary support services and demands on the regulatory capacity of PVP. As for the support services influenced by the character of PVP production there is important not only the value but also the rate of change of power output. The paper contains an analysis, based on data from PVP and wind power plants (WPP) in operation connected to the distribution network in the territory of the Czech Republic with the installed capacity of about 2000 MW; summer minimum load of ES in the Czech Republic is less than 5000 MW.*

## INTRODUCTION

The paper describes the results of evaluation of 1098 renewable sources in operation with a total installed capacity of 1341 MW in the territory of the largest distribution network operator (DNO) in the Czech Republic. The results of this evaluation not only has compared installed and contemporary maximum power, reactive power balance for each type of renewable energy sources in the supply area of the DNO, but also the time of use of the individual types (PVP, WPP, Biogas Plant(BGP), etc.) sources in the Czech Republic.
The paper also deals with the issue of forced reduction of active power supply from photovoltaic and wind power plants in cases affecting the stability of the transmission system, and describes the chosen approach to determine the correction factors expressing the expected utilization of the installed power of photovoltaic and wind power plants at the time of application, reduction or interruption of production. These factors are then used to calculate the production losses of photovoltaic and wind power plants, whose power was forcibly limited by the TSO / DNO.

## EVALUATION OF THE OPERATION OF RES

The evaluation of the renewable energy sources (RES) involved 1341 MW sources connected to the MV and HV networks (of which 60% of PVP, 14% of WPP, 13% of hydro power plants (HPP), 6%of biomass power plants (BMP), 5%of BGP and 2% other) in the supply area of the largest electricity distributor in the Czech Republic which provides the distribution for about 3.5 million delivery points. The evaluation was based on the commercial measurements data (15 min. intervals). Rated power distribution of sources under evaluation is then shown in Fig. 1. From the rated power distribution is clear that the sources with rated power of up to 1 MW are prevailing. On the contrary, there is minimum sources with $P_{inst}$> 10MW, even though there are sources with $P_{inst}$> 20MW in the evaluated distribution network (DN) (particularly photovoltaic and wind sources).

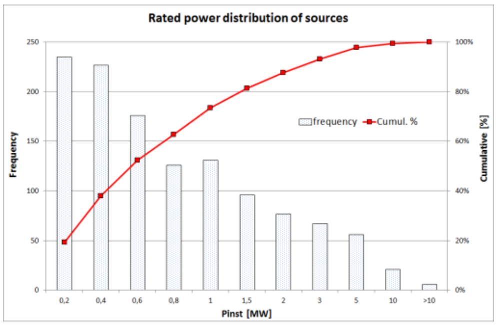


Figure 1

## Simultaneous power and time of use

The evaluation of the RES operation in the area of the largest DNO in the Czech Republic was carried out in two stages. The first stage covered 11 months of the year 2011, the second stage – the first half of the year 2012. The DNO assumes the continuation and evaluation of the period of 2012 and 2013. The Figure 2 shows the ratio of installed and contemporary power for the 1st half of 2012 of the individual types of renewable energy sources operating within the territory of this DNO. PVP ($P_{inst}$=776 MW, $P_{soud}$=632 MW, contemporary factor -simultaneity of power delivery – approx. 0.82) are clearly the dominant source type. Other important types of sources are then wind and hydropower plants. Large controllable hydropower plants (10 - 100MW) were excluded from the evaluation in order to avoid misinterpretation of the results. The evaluation was purely focused on dispersed generation of renewable energy sources.
The Figure 3 shows the time chart of the monthly maximum of simultaneous power in both periods of evaluation. It is obvious that the largest simultaneity in both periods is achieved in the months of March, April and May. It is because in the mix of sources the largest proportions of

power are the photovoltaic sources.
From the provided data for the evaluation it was possible to determine the time of use of the maximum for different types of sources. In order not to distort the presented results by using the evaluation for only half year period, we present the following Figure 4 where there is given the maximum usage time for the period from February to December 2012 (data for the month of January was not provided because of technical reasons).

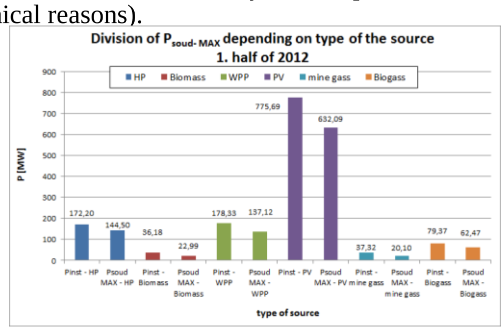


Figure 2

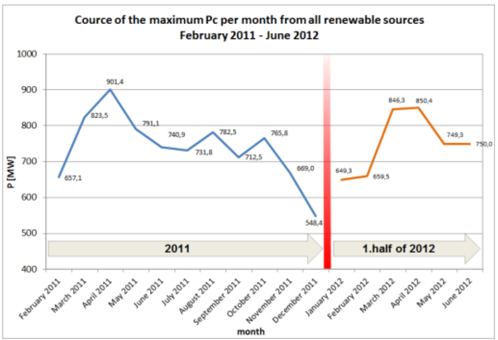


Figure 3

Due to dominant position of photovoltaic sources their time of use of the maximum was very interesting, which was in the evaluated period at about 1000 hours / year. No significant difference was observed between the individual regions of the Czech Republic. A quite interesting value is the maximum usage time of biogas resources, especially for the reason that after exhausting the potential of construction of large photovoltaic parks in the Czech Republic, investors turned their attention to the construction of biogas plants, which in case of the current purchase prices may have significant impact on the state budget and subsequently on electricity prices for final customers.

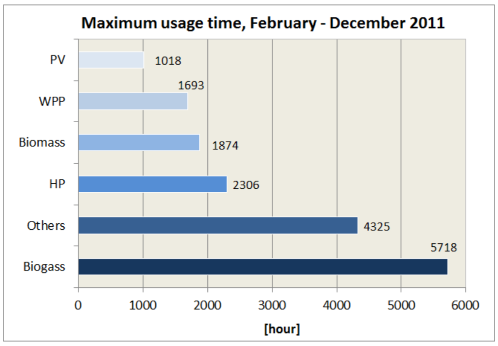


Figure 4

## Evaluation of the reactive power

In addition to evaluation of the active power supply, the production analysis was focused on the observance of allowable movement of power factor, or more precisely on supply or consumption of reactive power. We evaluated two different modes of operation:

1. Energy generation to the grid of the DNO
2. Energy consumption from the grid of the DNO

As an example we present the following figures, which clearly show a problem with the observance of the defined power factor (on the basis of a non-discriminatory recommendations of the Czech Regulatory Authority (ERU) it is, in the majority of cases, required the observance of the neutral power factor at the delivery point). The results of evaluation on the supply of active power are for PVP or for WPP shown in Fig. 5 and Fig. 6. Conditions during the active power consumption for the same types of sources are shown in Fig. 7 and Fig. 8.

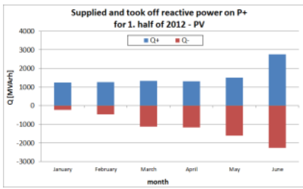


Figure 5

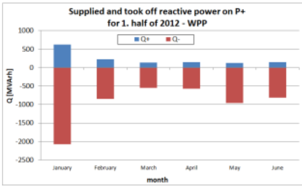


Figure 6

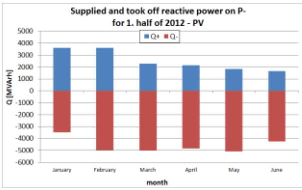


Figure 7

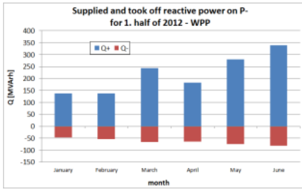


Figure 8

Not meeting the required criteria may besides other things cause voltage stability problems not only at the delivery point of the plant, but also at the delivery points between the DNO network and other customers, especially in distant parts of the network. In the Czech Republic there is penalty (a decree of the Regulation Authority) for not complying with the stated band of power factor in electricity consumption from the DN, a similar instrument is being prepared for the electricity delivery of the RES into DN.
These payments can then motivate the operators of these generating plants to install corrective measures (better management tools, decompensating reactance coil in networks with large cable lines, installations of new types of inverters with higher range of power factor, etc).

## The extent of the active power changes

In addition to billing data, the data from the dispatchers´ measurement system (one-minute cuts) was provided for 234 sources of dispersed generation (about 521MW). With that data it was possible to perform analysis focused on the size of the power changes between consecutive 1-minute intervals with a focus on photovoltaic, wind and biogas power plants. The resulting values were processed for distribution changes, meaning a decrease of active power and for active power changes increase. The resulting distribution is shown in the following Figure 9.

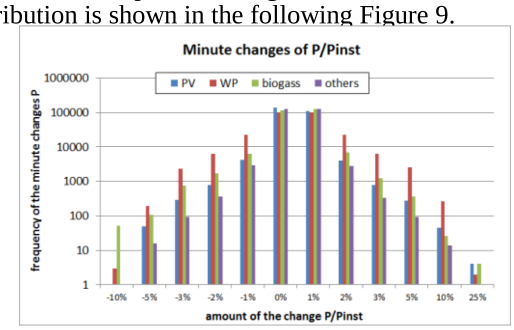


Figure 9

The values shown on the horizontal axis of the graph correspond to evaluated intervals of changes in the the active power value, for example, where a value of 10% covers the interval from 5% to 10%, the value of 25% covers the interval from 10% to 25%, etc. The graph shows that most values vary in the range from -1% to 1% of power. From the histogram it is also clear that although there were changes in the range of 10-25% of the installed capacity at some types of renewable energy sources (WPP and biogas), then changes in contemporary power that are from the perspective of network more important, varied only in the range from -5 to -3% of increase in active power and from 3-5% of decrease in active power.

## THE LOSS OF PRODUCTION DUE TO FORCED POWER REDUCTION

Installed power in the Czech Republic in WPP and PVP is more than about 2000 MW, which is relatively significant share of the total load. During operation of DN or transmission network (TN) there can appear situations which may cause a direct threat to the stability of the system. For these purposes, there is the duty for those sources of the TSO dispatching center request to reduce active power to 60%, 30%, 0% with no compensation for losses in production. For management purposes, DNO needs to be able to regulate power of at least some significant PVP and WPP also in other cases in which there is a right for compensation of production restrictions. In the Czech Republic the applicable regulations do not expect, due to the nature of production in PVP and WPP, that they will be used for support services (the relevant provisions can be found in the Distribution Network Code). For the above-mentioned purposes of active power regulation there were selected 108 significant PVP (61 sources) and WPP (47 sources) operating in the two largest regions of the DNO in the Czech Republic. The list was set up after agreement between the DNO and the TSO. To establish the conditions of compensation for the undelivered electricity during reduced production by the TSO the operation of PVP and WPP in the Czech Republic was analyzed [2], the results were used in amendment of the MIT Decree [3].
Evaluation of power output of selected RES was based on data provided by DNOs for the year 2011 and for the year 2010 in limited extent. Accuracy of provided data was checked before the evaluation
The data were then converted to contemporary hour values. With these values it is possible to determine the characteristic curves of the production of PVP and WPP in the Czech Republic, see Fig. 10, Fig. 11. There is an obvious dependence of PVP on climatic conditions during the day; with WPP this dependence is not so clear. The measured values were extrapolated by trend line to determine the curve characterizing daily production.

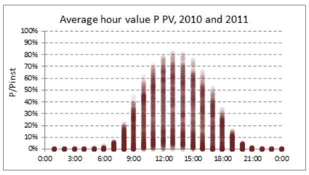


Figure 10

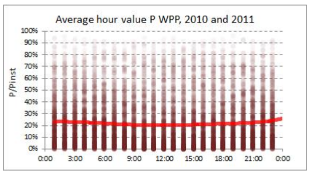


Figure 11

## Contemporary evaluation

The delivered values of measured power were summarized for each source and then contemporary power output was calculated, separately for the PVP and WPP sources. The proportional power values are always related to the current value of the installed capacity in a given period of time. The evaluation was aimed at determining the maximum and average power output value in selected time intervals.
In Figure 12 there are shown proportional maximum hour values of contemporary power output in a given month and the time measurement period (e.g. maximum for May is set from 31 contemporary hour values for each hour interval and related to $P_{inst}$). Figure 13 shows monthly maximum of contemporary hour values of contemporary power output (i.e. maximum regardless of the time interval).

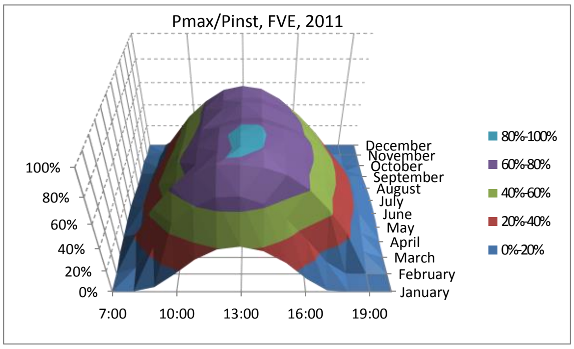


Figure 12

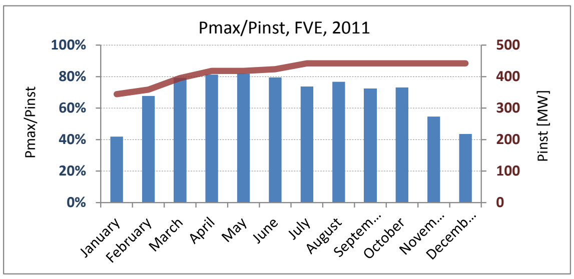


Figure 13

## THE AMOUNT OF NON-PRODUCED ENERGY DUE TO THE DISPATCHER CONTROL

Non-produced energy due to the forced power reduction is for compensation calculation based on the duration of production reduction and installed capacity of the plant multiplied by a correction factor according to the formula:

$W_{ne}=P_{inst}$ x $k_v$ x $(t_{zp} – t_{kp})$

*$W_{ne}$ non-produced energy during production interruption [MWh]*
*Pinst installed power of the plant*
*$k_v$ a correction factor to determine energy during interruption of production*
*$t_{zp}$ time at the beginning of interruption*
*$t_{kp}$ time at the end of interruption*

The main objective of this analysis was to find a simple and acceptable algorithm for calculation of correction factors representing the expected reduction of the installed capacity of renewable energy sources at the time of application of the restriction or interruption of electricity production in PVP and WPPs.
On the basis of provided data were derived equations for calculation of correction factors in the following structure (t - one hour interval, m - month, $P_c$ - contemporary power, $N_i$ - number of measuring intervals):

- PVP – summer period

$$k_{v1} = \frac{\sum_{m=3}^{10} \sum_{t=9:00}^{16:00} \frac{P(t)_{c>50\%P_{inst}}}{P_{inst(m)}}}{\sum_{m=3}^{10} \sum_{t=9:00}^{16:00} N_i(P(t)_{c>50\%P_{inst}})}$$

- PVP – winter period

$$k_v = \frac{\sum_{m=11}^{2} \sum_{t=9:00}^{16:00} \frac{P(t)_{c>50\%P_{inst}}}{P_{inst(m)}}}{\sum_{m=11}^{2} \sum_{t=9:00}^{16:00} N_i(P(t)_{c>50\%P_{inst}})}$$

- WPP

$$k_v = \frac{\sum_{m=1}^{12} \sum_{t=0:00}^{24:00} \frac{P(t)_{c>50\%P_{inst}}}{P_{inst(m)}}}{\sum_{m=1}^{12} \sum_{t=0:00}^{24:00} pni(P(t)_{c>50\%P_{inst}})}$$

### The resulting values of correction factors

General overview of the calculated correction factors defined from contemporary hourly power of evaluated types of sources is given in Tab. 1. Since these are contemporary values defined for selected sources, it is necessary to keep in mind different operating conditions of individual sources.

For PVP, two values of $k_{vPVP}$ were defined

In the months of March to October we use the value defined under the assumption $\alpha_{PVP} = 0.7$ and quantification of $k_{vPVP}$ as a weighted average respecting maximum usage time for contemporary power.

$\alpha$ = 0,70; 0,725; 0,75; 0,775, a 0,8, so

$k_{vPVP1} = 0{,}76$

In the months of November to February we use the value $\alpha_{PVP} = 0.5$ and quantification of $k_{vPVP}$ for contemporary power $\alpha$ = 0.5, 0.6, 0.65, 0.70, 0.725, 0.75, 0.775, 0.8, namely

$k_{vPVP2} = 0{,}6$

| Power limit | $k_{vPVP}$ (summer period) | $k_{vPVP}$ (winter period) | $k_{vWPP}$ | $k_{vPVP+WPP}$ (summer period) |
|---|---|---|---|---|
| Without restrictions | 0,44 | 0,15 | 0,21 | 0,36 |
| $\alpha = 0{,}5$ | 0,63 | 0,57 | 0,63 | 0,55 |
| $\alpha = 0{,}6$ | 0,68 | 0,64 | 0,69 | 0,65 |
| $\alpha = 0{,}65$ | 0,71 | 0,67 | 0,71 | 0,69 |
| $\alpha = 0{,}7$ | 0,74 | - | 0,75 | 0,72 |
| $\alpha = 0{,}725$ | 0,76 | - | 0,77 | 0,73 |
| $\alpha = 0{,}75$ | 0,78 | - | 0,79 | - |
| $\alpha = 0{,}775$ | 0,80 | - | 0,80 | - |
| $\alpha = 0{,}80$ | 0,81 | - | 0,81 | - |

Table 1

For WPP there was defined one value for all months of the year as a weighted average of the correction factors for $\alpha$ = 0.6, 0.65, 0.70, 0.725, 0.75, 0.775, 0.8, namely

$k_{vWPP} = 0{,}72$

This approach and corrective factor values were discussed with the associations of PVP and WPP producers, and are the part of the decree [3].

## CONCLUSION

From the presented results of evaluation of the operation of distributed generation of RES in the Czech Republic is clear that the installed capacity with regard to overall Czech Republic consumption achieves significant level, resulting in a change of view on these sources.

This paper points out the some risks for operation of network with a significant portion of dispersed generation sources, in particular due to power factor fluctuation at the PCC point and the active power change. Furthermore, the paper describes the use of selected higher power sources for forced power limitation of WPP and PVP and setting correction factors for calculation of compensation.

## REFERENCES

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[3] Vyhl. 388 o dispečerském řízení elektrizační soustavy a o předávání údajů pro dispečerské řízení, 2012