IMPACT OF ENTSO-E RECOMMENDATION ON REFITTING OF PV FREQUENCY RELAYS IN CZECH REPUBLIC

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ABSTRACT

Aim of the paper is assessing of variants of the implementation of the recommendations ENTSO-E "Dispersed Generation impact on Continental Europe region security", dated 15 November 2014, concerning the readjustment of frequency protection behaviour (retrofit) of photovoltaic power plants in the Czech Republic. It highlights the particularity of technologies used in the Czech Republic and which should be respected during readjustment of frequency protections of the photovoltaic power plants. As the significant power of photovoltaic plants operated in the Czech Republic (2,040 MW in about 28,666 installations), improper approach could lead to significant increase of retrofitting costs.

INTRODUCTION

The paper analyses the impact of the ENTSO-E [1] recommendations for ensuring safe operation of PVPs with requested performance in wider frequency range 47,5 to 51,5 Hz in the Czech Republic and highlights specific features, necessary to respect when applying this recommendation. In the region of the Czech Republic distribution companies operated at the end of the year 2015 totally 28,437 of photovoltaic power plants, which were mostly connected to the grid before the end of 2010 and use the technology, which in most cases does not meet current requirements [7]. Therefore, we consider as necessary to adapt the current setting of frequency inverters and protections of PVPs with respect to the structure of the PVPs and their technology, and to assess how the cost of the retrofit depends on gradually increased power of retrofitted power plants, and also to seek the optimal approach and timeframe for retrofitting. This paper brings the possible aspects arising from the specific conditions of the Czech Republic. On one side it will not result in 100% compliance with the requirements of ENTSO-E, on the other side it will lead to reduced costs, simplifying the process of retrofitting, with acceptable deviation from the original requirements of ENTSO-E. As the main aspects it is possible to consider:

- Distribution of electric power from PV plants in the different voltage levels
- Organization and technical equipment of PV plants

ENTSO-E REQUIREMENTS FOR CR

ENTSO-E [1] recommendation prescribes settings and features of PV plants, connected to the grid (wider frequency band, supplementing or activating the P(f)) function. For each of the European countries, the recommendation [1] specifies up to which output power the PV plant will not be affected by this recommendation. For the Czech Republic, the following applies:

Country TSO	49 .. 50 Hz	50 .. 50,2 Hz
CZ ČEPS	81 MW	257 MW
$P_{lim/plant}$	**8,6 kW**	**40 kW**
Number	16 676 ks	26 163 ks
Number $/_{CR}$	28 437	
$P_{inst\_PV\_CR}$	2040 MW	

Table 1 – Recommendation for the Czech Republic

From the Table 1 it is clear that the process of retrofitting will not concern about 16767 photovoltaic power plants with an unit power lower than 8,6 kW for the underfrequency and 26,163 photovoltaic power plants with unit power below 40 kW for overfrequency.

SPECIFICS OF CR

Despite the requirements set out in the recommendations of ENTSO-E [1], the process of retrofitting should respect the specifics of the area in which it should be performed. The Czech Republic and its structure of PVPs belong to specific countries, not only in terms of the power mix, the manner of their connections but also in other aspects. In the Czech Republic, these are mainly the specifics below.

Output power structure of PV plants

With respect to substantial financial support during the solar boom, i.e. in 2009 and 2010, most of the connected power of the PVPs was realised with higher power per one PVP. More than 60% of PVP power is realised by units with installed power higher than 1MW.

Distribution of output power of PV plants among voltage levels

Distribution of output power of PV plants among voltage levels follows the previous point. Due to such unit structure, most of the PV plants are connected to MV voltage level. About 78% of the total power of photovoltaic power plants operated in the Czech Republic are connected to the medium voltage level. The distribution of output power among different voltage levels is shown in the following Figure1.

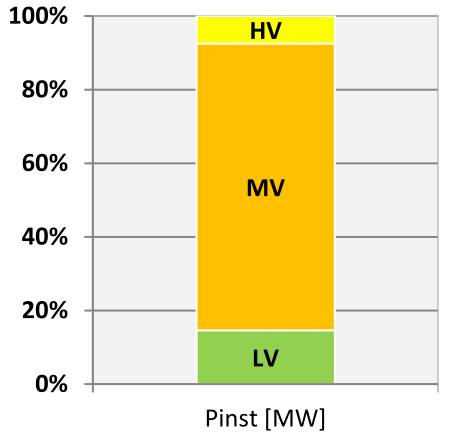

Figure 1: Distribution of output power

PVP arrangement

Very important specific, which could negatively affect the retrofitting process is the fact that a lot of PV plants with total output of 1 MW and more is composed of small decentralized inverters with an output of tens of kW.

Technical facilities of PV plants

Due to the spontaneity of the process of construction of photovoltaic power plants during 2009-2010, a number of photovoltaic power plants are equipped with outdated technology. In many cases, it was an outdated technology already in the year of installation, because in those years was a general lack of technology for the construction of PV plants and thus outdated technology was installed in need to meet the deadline for granting high state support for the construction and operation of this type of generation.

RETROFIT SETTINGS

As mentioned in the previous section, the Czech Republic belongs to specific regions and the retrofit cost will be sensitive to a number of marginal conditions which may not apply in other EU countries.

It is obvious that the greater is the number of PV plants will enter the retrofit, the higher is the cost of its implementation. From sensitivity analysis, it is clear that increasing the unit output of PV plants, entering the process of the retrofitting will cause the slight decline in the total retrofitted output power. In the case of the PVPs with lower output power, the decline is significantly steeper (Figure 2). From the figure it is clear that a properly chosen unit output power of PV plant, entering the retrofit process will have a significantly positive effect on the number of PV plants entering the retrofit process and hence the total cost.

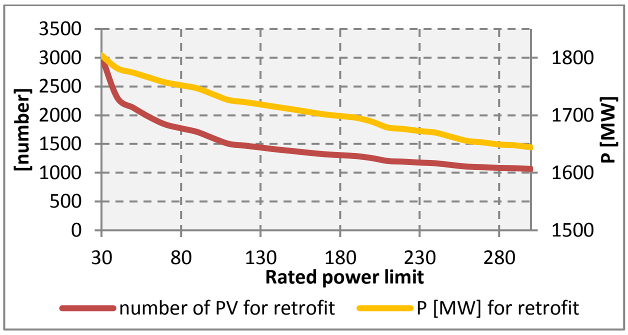

Figure 2: The number and output power of PV plants depending on the rated power limits for the retrofit

If converting the above result of the sensitivity analysis on particular categories of the unit output power of PV plants (Figure 3 and 4), it can be stated that the largest number of PV plants is in lower power ranges, that have negligible total output, compared to the total power of higher output series with unit capacity of 30 or 100kW and more.

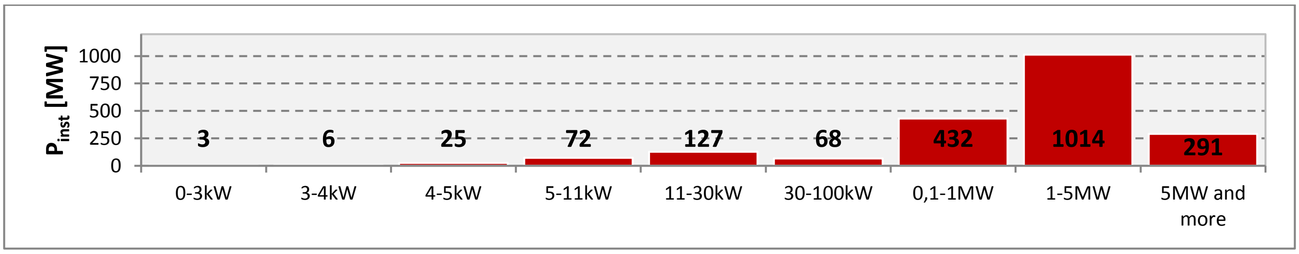

Figure 3: Result of the sensitivity analysis - P_{inst}

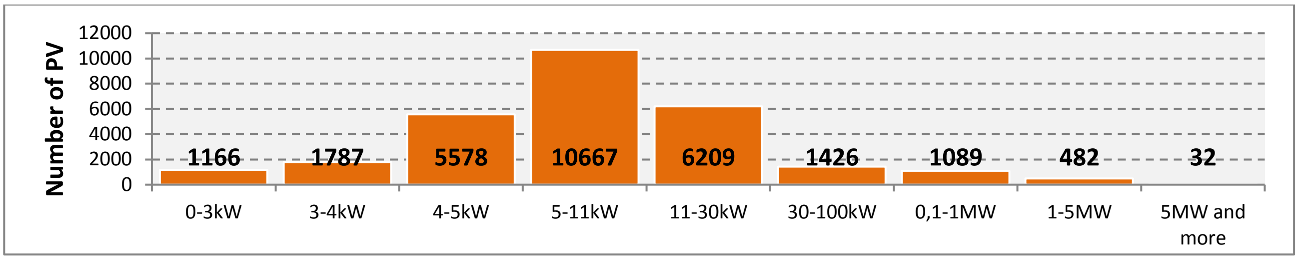

Figure 4: Result of the sensitivity analysis – number of PV

From the pictures above is evident, that dominant sources are categories 4-5kW, 5-11kW, 11-30kW.These three categories represent nearly 79% of the total number of connected PV plants, but it is only about 14% of the total installed capacity of PVPs.

If we compare the selected threshold of a unit power of PV plants, from which the retrofit would take place, with the recommendation of ENTSO-E [1], we can determine deviation the overall retrofit output from this recommendation. For example, when the threshold of unit output 100kW is selected, the following Figure 5, respectively 6 show the impact on retrofit output power in case of underfrequency (Figure 5) or overfrequency (Figure 6)

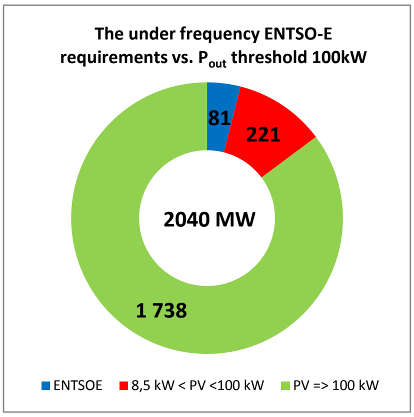

Figure 5: Underfrequency requirements

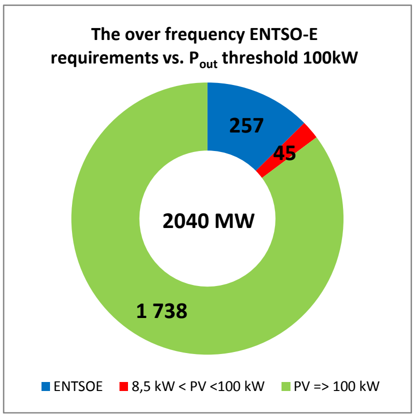

Figure 6: Overfrequency requirements

Considering the distribution of the number of sources shown in Figure 4 it is apparent that even minimal output power deviation from the recommendations of ENTSO-E can lead to a significant reduction of number of PV plants, entering the process of retrofit and hence a significant reduction in overall cost of the frequency protections readjustment.

PROBLEM OF SETTING THE FREQUENCY BAND FROM 47.5 TO 51.5 Hz

Recommendation ENTSO-E [1] requests readjusting of inverters on 47,5Hz for underfrequency and on 51.5 Hz for overfrequency. Readjustment, according to this recommendation, is necessary for existing technologies which are already in use. When considering the data listed in Table 1, in the Czech Republic this requirement will affect 11,760 of PV plants for underfrequency and 2,273 of PV plants for overfrequency. The recommended frequency band of inverters is quite broad and some of the installed technology does not comply with this requirement. To fulfil the desired ENTSO-E [1] recommendations, it would be necessary to adapt hardware or completely replace inverters, which could significantly affect the cost of retrofitting (Readjusting the frequency protection and adding the function P (f)).

Commission Regulation (EU) 2016/631 [3] states in Article 13 requirements for frequency settings for newly installed sources. Parameters related to Continental Europe are given in Table 2.

Synchronous area	Frequency range	Time period for operation
Continental Europe	47,5 Hz - 48,5 Hz	To be specified by each TSO, but not less than 30 minutes
	48,5 Hz - 49,0 Hz	To be specified by each TSO, but not less than the period for 47,5 Hz - 48,5 Hz
	49,0 Hz - 51,0 Hz	Unlimited
	51,0 Hz - 51,5 Hz	30 minutes

Table 2: Parameters related to Continental Europe

From the values of frequencies required for Continental Europe, it is clear that the limits on frequency 51,5 Hz and 47,5 Hz comply with the ENTSO-E [1] recommendations. The table shows that the frequency range 47,5 - 49 Hz, or 51 - 51,5 Hz is defined for significant frequency deviation, which may be caused by larger disturbances in the system. For the normal operating state, the [2] defines the frequency range

49-51Hz.
We recommend therefore for the group with narrower frequency band, 49-51Hz for unlimited operation not to insist on the full frequency band 47,5Hz – 51,5 Hz according to [1].This way enables achieving large cost reduction.
The advantage of the readjusting the selected technologies only on a narrower frequency range 49-51 Hz (and avoiding HW modification) is evident from the following Figures 7 and 8. Due to the positive impact of this step, the output power of unsuitable technology, (in terms of setting the frequency protections) decreases from 27% to 10%.

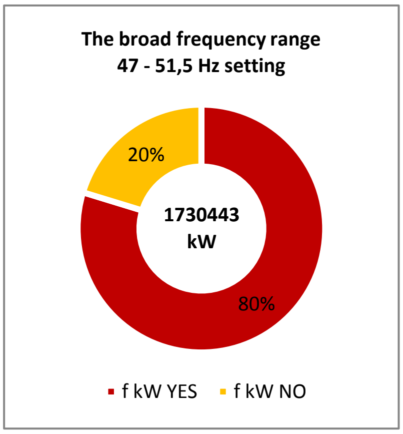

Figure 7: 47 – 51,5 Hz setting

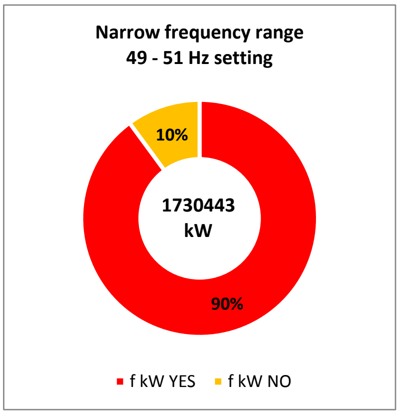

Figure 8: 49 – 51 Hz setting

ADDITIONAL FUNCTION P (f)

In the Czech Republic there are PV plants, with technology which allows setting the whole desired frequency range according to ENTSO-E [1], or the narrower band described in this article, but they cannot implement a function of active power dependency on frequency, shown in following Figure 9.

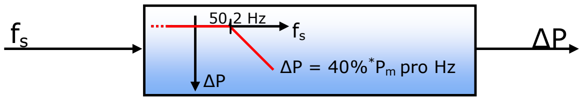

Figure 9: Active power reduction in case of overfrequency

Adding this feature may in some cases require hardware changes or a complete replacement of the inverter.
In order to meet the requirements defined by ENTSO-E, while considering the costs, we propose an alternative method for bigger photovoltaic plants consisting of dividing of PVPs into several sections with different setting of frequency protection. It enables shedding of individual PVP sections at different frequency levels. PVPs of this type will follow the desired curve of active power dependence on frequency at the delivery point. Behaviour of these PVPs plant will match PVPs with implemented function P (f).
Following recommendation was put together in cooperation with our TSO. Individual frequency limits and assigned output powers (P_{out}) are shown in Table 3, the resulting curve is then presented in the Figure 10.

St.	Frequency	Disconnected output power
1.	50,2 Hz	10%
2.	50,5 Hz	12%
3.	50,8 Hz	12%
4.	51,1 Hz	16%
5.	51,5 Hz	50%

Table 3 Individual f limits and assigned P_{out}

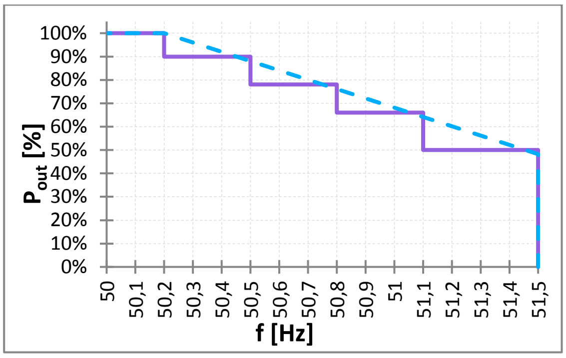

Figure 10: Frequency limits and assigned P_{out}

POSSIBILITIES OF READJUSTMENT OF PHOTOVOLTAIC POWER PLANTS

For proper readjustment of frequency protections of PV plants and adding the function P (f), a close cooperation with manufacturers of inverters is necessary. Unfortunately, the situation in the Czech Republic in this area is rather complicated. CR is not currently among the countries strongly supporting the construction of new

photovoltaic plants, so many manufacturers of inverters closed their local representation (e.g. SMA). Despite of the expected next expansion of photovoltaic plants in Europe, several companies that produce or produced technologies, associated with solar energy joined, in some cases even ended up their activities. It is not easy to obtain credible information for analysing the possibility of the frequency protections readjustment based on the recommendations of ENTSO-E in such large-scale.
For the readjustment process of PV plants frequency protections, it is possible in principle to consider three scenarios.

One step action
From the perspective of all stakeholders (producers, DSO or TSO), this scenario is the fastest, but the most expensive option. When readjustments the frequency protections of photovoltaic plants were separate actions, it would not be possible to combine it with renewal or maintenance of the equipment. It will lead to significantly higher costs not only concerning technical costs but especially the costs associated with human resources.

Natural replacement after the end of technology lifetime
The most elegant from these scenarios. It would be based on a ten-year replacement cycle of technology. The first replacement time would then be achieved around 2020. The technical lifetime of inverters ranges between 20-30 years, so it significantly shifts the horizon of the possible replacement to the year 2030. For that reason, this is unrealistic option.

The step-by-step process of frequency protections readjustment
As a further variant of the global readjustment of the frequency protections, a step-by-step process of readjustment, using scheduled service inspections of the PV plants can be considered. It can be used especially in the case of central inverters where an annual inspection of the technical state of the inverters can be expected. This variant thus will reduce the costs, since there is a synergy effect of service organizations activities. Especially the personal costs will be significantly lower.

From the above scenarios of a retrofitting variants, it is possible to conclude that the most reasonable option seems to be the step-by-step process of readjusting the frequency protections. Of course, even in this case, it will be necessary to determine the acceptable time schedule, from the view point of TSO and ENTSO-E.

CONCLUSION

The aim of this paper is to discuss problematic of global readjustment of the frequency protections of photovoltaic power plants and adding function P (f) in the Czech Republic, arising from the recommendations of ENTSO-E [1].
It describes a number of specific features associated with the installation of photovoltaic sources operated in the Czech Republic, which is necessary to respect when selecting the final variant, and the extent of global PVP protections readjustment. The paper deals not only with the description of the selected issues related to the implementation of retrofit, but also demonstrates the importance of proper choice of the output power of PV plant units taking part on the global retrofit process.
Optimizing the choice of the unit output power of PV plant has the significant influence on the total number of retrofitted PV plants and their total output power, which will significantly affect the difficulty of the process of retrofitting and the overall associated costs.

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