PARTICIPATION OF PHOTOVOLTAIC SYSTEMS IN CONTROL RESERVE MARKETS

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ABSTRACT

Photovoltaic (PV) systems have not provided control reserve until now in Germany although the installed capacity is increasing constantly. This paper will give an overview of how PV systems could deliver control reserve to the system. A new proof method for the offering of control reserve provision is presented.

Results show an economic opportunity for PV systems if they opt to offer negative control reserves. The cost saving potentials under realistic conditions can reach up to 6.5 % in the tertiary control reserve market and up to 3.9 % in the secondary control reserve market.

INTRODUCTION

For the secure system operation transmission system operator (TSO) procure ancillary services such as control reserve, which is needed to maintain the frequency of 50 Hz within operational limits of ±200 mHz [1]. Currently this service is provided mainly by conventional generation such as thermal power plants.

The installed capacity of PV systems in Germany has reached 30 GW [2] by the end of 2012 which means that PV systems are supplying increasingly large shares of the electricity. During off-peak hours this will lead to situations where PV systems become the main electricity supplier. System stability is endangered in the future if it depends solely on the use of conventional generation for the provision of control reserve. Therefore the provision of control reserve by PV systems should strongly be encouraged. Otherwise PV systems will experience more curtailment as the conventional generation needs to stay connected as must-run units.

Changes in the legislation that came into force by the 1st of January 2012 introduced an "optional market premium" that enables generation from renewable energy sources (RES) to participate in different market schemes [3]. This led to the successful integration of RES in energy exchanges. By now PV systems have not participated in control reserve markets until now. This is due to the lack of proper regulations.

PROOF METHOD FOR THE DELIVERY OF CONTROL RESERVE

State of the Art

Currently the proof for the delivery of control reserve is performed by considering the schedule of a generator as a reference value for comparison. For thermal generation it is assumed that this schedule is equal to the actual power production. The difference from this schedule that occurs when the plant changes its output in order to deliver energy from control reserve is interpreted as the proof that the plant actually delivered the contracted service. The difference has to match the contracted control reserve power. This method is applicable to conventional generation as it is for controllable RES generation such as biogas plants. In the following chapters this method will be called "balance control" (BC).

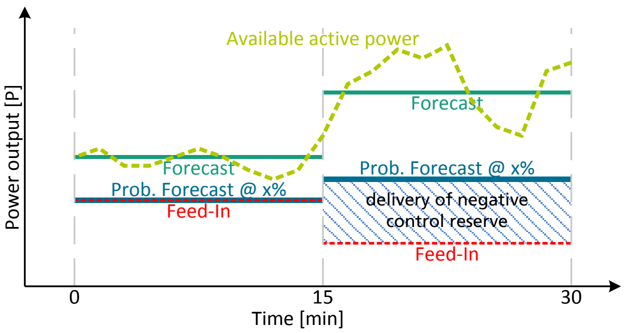

Figure 1: Proof of control reserve under the schedule mechanism, according to [4]

Figure 1 shows the operating principle during a dispatch of control reserve. The PV systems will be down regulated to a schedule that guarantees the reliability that was offered. Without dispatch the PV system will be curtailed in order to comply with the schedule. Solar energy will be spilled. In the time of the dispatch the PV system will be down regulated by the offered amount in reference to the scheduled power output.

An application of this method to PV systems would force them to announce a schedule in advance and comply with it during the hour of operation. This would then be realized by down-regulating PV systems or balancing them with storages. Both solutions are neither economic nor ecologic [5]. This method is currently applied for wind turbines in Denmark [6] as well as in research projects like the TWENTIES project [7].

Available active power

Another possibility to prove the dispatch of control reserve is to compare the so called "available active power" with the real power production. The available active power is the power that would have been produced if the PV system had not been down-regulated. This method is developed for wind turbines in the project "Regelenergie durch Windkraftanlagen" [8].

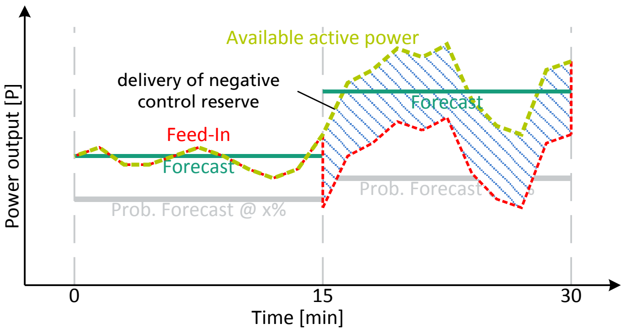

Figure 2: Proof of control reserve under the available active power mechanism, according to [4]

Due to the fact that PV systems have similar characteristics as wind farms, the proof mechanism shown in Figure 2 is transferred to PV systems. This method is advantageous for PV systems. They will not be curtailed more than absolutely necessary when reserve is made available. On dispatch they only will be curtailed by the contracted power.

Calculation of the available active power

The determination of the available active power for the latter proof method can be done by introducing meteorological data. A physical model which was originally developed for crystalline solar cells is used for the calculation of the available active power [9].

Parameters were changed to take into account the different characteristics of thin-film solar cells. The power curve of the inverter was derived from this data. The available active power was determined with a time resolution of one second.

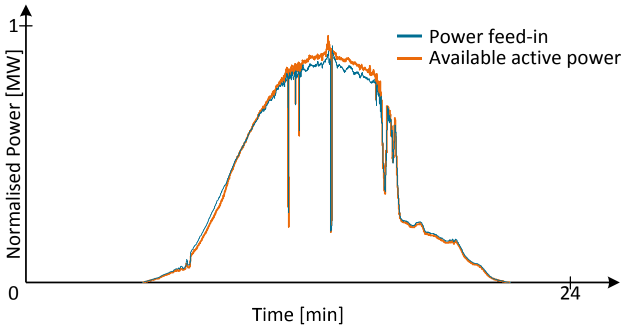

Figure 3: Comparison available active power with actual feed-in

Figure 3 shows the results from this approach for one day. The blue line indicates the measured power feed-in and the orange line the available active power. The result shows a good match of the two lines. Nevertheless further research is necessary with a more accurate model to calculate the available active power. The data was taken from a single PV system equipped with sensor to measure solar radiation and the systems parameters. For the assessment it was assumed that the available active power is equal to the power feed-in.

OFFER

Due to the characteristics of PV systems energy and control reserve cannot be offered the same way as it is offered by conventional generation [4]. The power output of PV systems is predictable to a certain degree with a forecast that inherits a forecast error. Due to this fact the forecast involves a certain level of insecurity which makes it impossible to offer with a reliability of 100 %. In the project “Regelenergie durch Windkraftanlagen” the security level of 99.994 % was agreed upon. This security level amongst others will be applied to this assessment.

In order to calculate an offer for the control reserve market a probabilistic forecast is created. These forecasts are given on a defined security level and are based on statistical data. A security level of 99% means that with a probability of 99% the real power production is equal or higher than the forecast. In this specific case a kernel-density estimator (KDE) was used for the calculation. The bandwidth is essential for the quality of the results from the KDE. The principles as well as the approach to calculate the bandwidth was taken from Bowman et al. [10]. The assessment will consider different security levels from 95 % to 99.999 %. Figure 4 shows the probabilistic day-ahead forecast, the 1h-intraday forecast, the corresponding offers with a product length of 1 hour and the feed-in for the German PV portfolio. The offer is created based on the results from the KDE. The offerable amount (day-ahead) is significantly lower than the measured feed in.

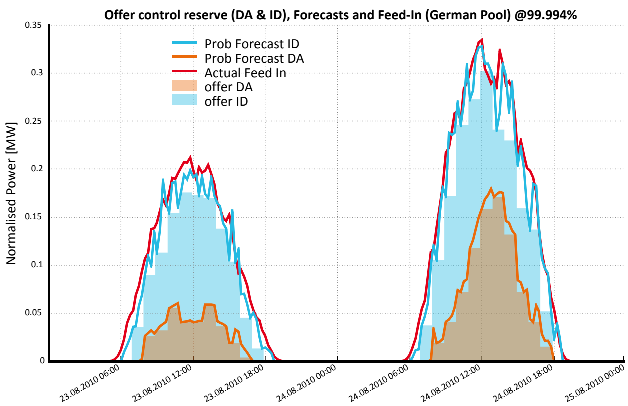

Figure 4: Day-ahead and intraday forecast at 99.994%, corresponding offers for control reserve and measured feed-in of the German PV portfolio

COST REDUTION POTENTIAL

The impact of the participation of PV systems on control reserve markets is assessed based on historical data for German energy system.

Data

July 2010 to December 2010 is the time period selected for the assessment. The PV systems data was obtained from the homepages of the TSOs.

EPEX Spot market data for day-ahead and intraday products [11] is used. PV systems participate under the current RES support schemes [3] on the markets, trading day-ahead and intraday products on the EPEX Spot Market.

Market data of the secondary and tertiary reserve market [12] is used. Each set contains merit-order lists and dispatch time series for the respective control reserve type. The dispatch of minute reserve is available at the homepages of the TSOs. Detailed secondary reserve dispatch data can be obtained on demand from the TSOs.

Model

The first step of the model creates a bid for the control reserve market from all German PV systems. The economic impact is assessed by placing the offer in the control reserve markets. The bids created by the PV systems are compared to those that are already in the merit-order lists for each product type in the control reserve market.

The assessment is performed for secondary and tertiary reserve control markets and assumes daily tendering. This is an adjustment for the secondary control which anticipates changes in tendering conditions in the near future [13]. By now this market is tendered on a weekly basis. In the case of tertiary control daily tendering is already implemented.

The assessment will be performed within the legislative framework of the German Renewable Energies Act (EEG) with exception of the new way to offer control reserve and the method to proof the delivery. Input parameters are varied in the assessment. The reliability levels of the offer of control reserve power will change the prices of bids placed by the PV. For the assessment security levels from 95 % to 99.999 % are considered. The product lengths used in the model are 1, 4 and 8 hours for both reserve types. Another assessment evaluates the influence of the proof method. A more detailed description of the model can be seen in [14].

Results

Potential for control reserve of PV systems

The offerable amount of control reserve from PV systems depends on the product length and security level. Figure 5 shows the results for the potentials of PV systems.

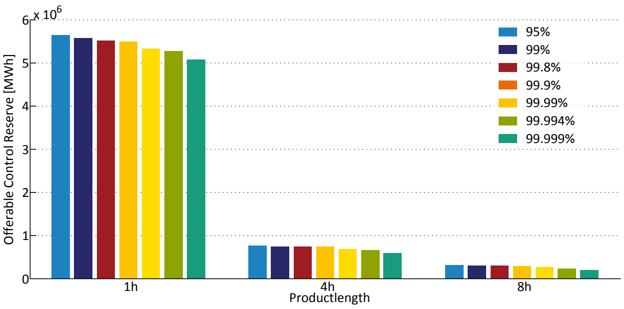

Figure 5: Energetic potential for control reserve of PV systems in the second half of 2010

The PV system operator is free to offer this energy potential to positive and/or negative control reserve markets. At any time the tendered amount was larger than the offerable amount. The whole potential could have been integrated in the control reserve market.

The theoretical potential at a security level of 99.994 % and a product length of one hour is 5.27 TWh. This potential is the offer times the product length. With a product length of four hours the potential would be 0.66 TWh and with a product length of 8 hours the potential would be 0.24 TWh.

Economic potential of the entire German PV portfolio

In Figure 6 the results for secondary control reserve can be seen. The costs of tertiary control reserves are significantly lower than the costs for secondary control reserve. Due to this reason and for the sake of brevity cost saving potential in tertiary control market will not be displayed in this paper. By comparing the original dispatch costs with the scenarios relevant cost reductions can be identified. The upper lines in each graph reflect the maximum saving potential and the lower line is the minimum saving potentials. For details see [14].

Results show that only bids placed in negative control reserve markets are accepted. Bidding for positive control reserve markets currently is not a beneficial business case for PV systems.

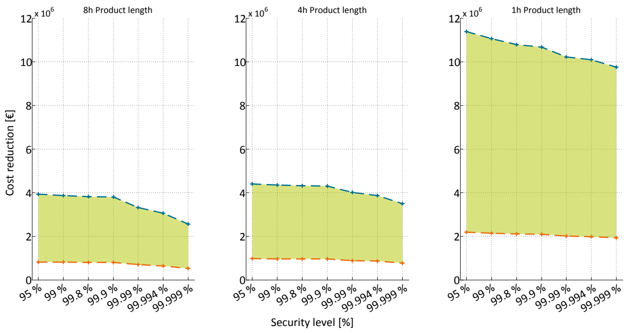

Figure 6: Economic impact (second half 2012) for different security levels and product lengths in secondary control markets for the entire German PV portfolio with the available active power proof method

Under the 99.994 % scenarios maximum cost reduction of up to 6.5 % for minute reserve markets and up to 3.9 % for the secondary reserve markets can be achieved, assuming the available active power proof method and a product length of one hour. For the secondary control reserve the cost saving potential for hourly products (at 99.994 % security level) would then be up to 10.1 mio. € using the available active power proof. For the tertiary control market cost saving potential could reach up to 2.0 mio. € under the mentioned conditions.

Influence of the proof mechanism

The amount of control reserve power that could be offered under both proof mechanisms is the same. However the prices are different, so that in the case of available active power more bids from PV systems are in the merit-order lists.

The influence of the proof mechanism on the cost saving potential is increasing from lower to higher security levels as well as it is increasing with increasing product lengths. Assuming hourly products on secondary control markets the cost saving potential at a security level of 95 % is 194 %

higher under the available active power mechanism than under the balance control mechanism. At a security level of 99.999 % this value increases to 484 %. Figure 7 shows the difference. The same behaviour can be observed on the tertiary control market. It is more severe with longer product lengths.

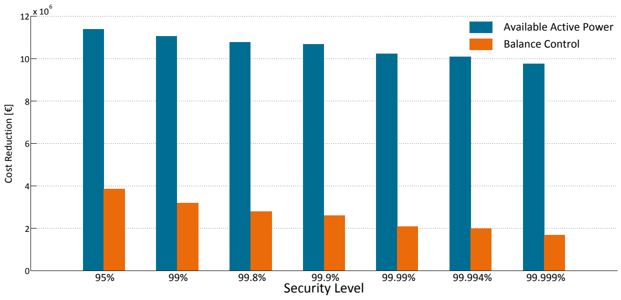

Figure 7: Difference between Balance Control and Available Active Power in the secondary control market

Despite the higher saving potential with the available active power mechanism applied, it also induces more volatility to the system, which would induce an increased demand for balancing. The quantification is subject to on-going research.

CONCLUSION & OUTLOOK

PV systems are not participating in control reserve markets yet. The market entry of PV systems is prevented due to the lack of proper regulations for the bid creation and the proof for the delivery of control reserve.

Regulations that are suitable for PV systems are suggested in this paper. This includes a way to offer control reserve with PV systems as well as the method to prove the delivery of it, called "available active power".

An economic analysis proved that there is an opportunity for PV systems to deliver control reserve economically. With the available active power proof mechanism significant cost saving potentials can be gained from a system point of view without endangering the security of supply.

If the available active power proof was applied, PV systems could generate cost reductions in the secondary control reserve market by up to 3.9 % (under the 99.994 % scenario) and therefore reduce the cost of control reserve significantly.

The proof method "available active power" will be demonstrated in a field in October 2013.

ACKNOWLEDGMENT

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