Experimental validation of fast frequency control from ReGen plants

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Content

Preface

This report is the outcome of WP5 as the deliverable in the project "Ancillary services from renewable power plants" (RePlan). RePlan is funded by the Danish TSO as POS project 2015 no. 12347, and is carried out in collaboration between DTU Wind Energy, DTU Elektro, Aalborg University Energy Technology, Aalborg University Wireless Communication Networks and Vestas Wind System A/S. DTU Wind Energy is manager of the project.

1 Scope of document

This deliverable report summarizes the results of work package 5 (Experimental validation of fast frequency control from ReGen plants), which includes the experimental setup and the results of the conducted tests regarding the use of photovoltaic units to provide fast frequency control.

The overall objective of this work package is to validate whether ReGen plants can provide fast frequency control, assess the control capabilities of the plants and the accuracy in reserve provision.

2 Introduction

In Deliverable 3.5, a statistical method for offering fast frequency reserves from aggregated ReGen plants while minimizing energy curtailment was proposed. The methodology is generic and can be applied for various intermittent resources, such as photovoltaic (PV) and wind power plants as well as for any fast frequency control service. Fast frequency control refers to services which require the service providers to change their output continuously, following reference signals which change every few seconds or less.

In the proposed method several assumptions were made, which will be addressed in future work. More specifically, advanced methods for representing the uncertain available ReGen plants output in the near future, as well as the uncertain requested power change due to service delivery, need to be developed. Due to these methodology assumptions, the statistical nature of the method that requires extensive testing for validation and the limited available time for experiments, the experimental validation focused on assessing the capability of ReGen plants in providing fast frequency reserves within the proposed framework. Finally, the tests were carried out using PV units, since controllable wind turbines were not available for testing.

3 Methodology

In this Section the statistical method proposed in Deliverable 3.5 is briefly summarized.

3.1 Introduction

Providing fast frequency reserves requires units which are able to change their power output very quickly. Fast frequency reserves refer to primary or secondary frequency control, which require a very fast response in the order of seconds. Apart from fast conventional power plants (e.g. hydro power plants), such services can be provided by other means, namely demand response, batteries or ReGen units. In Figure 1 a 4 hour sample of a fast regulation signal from the PJM synchronous area of the US is shown. This service is classified as secondary frequency control and the regulation signal is dispatched every 2 seconds to the units which provide this service.

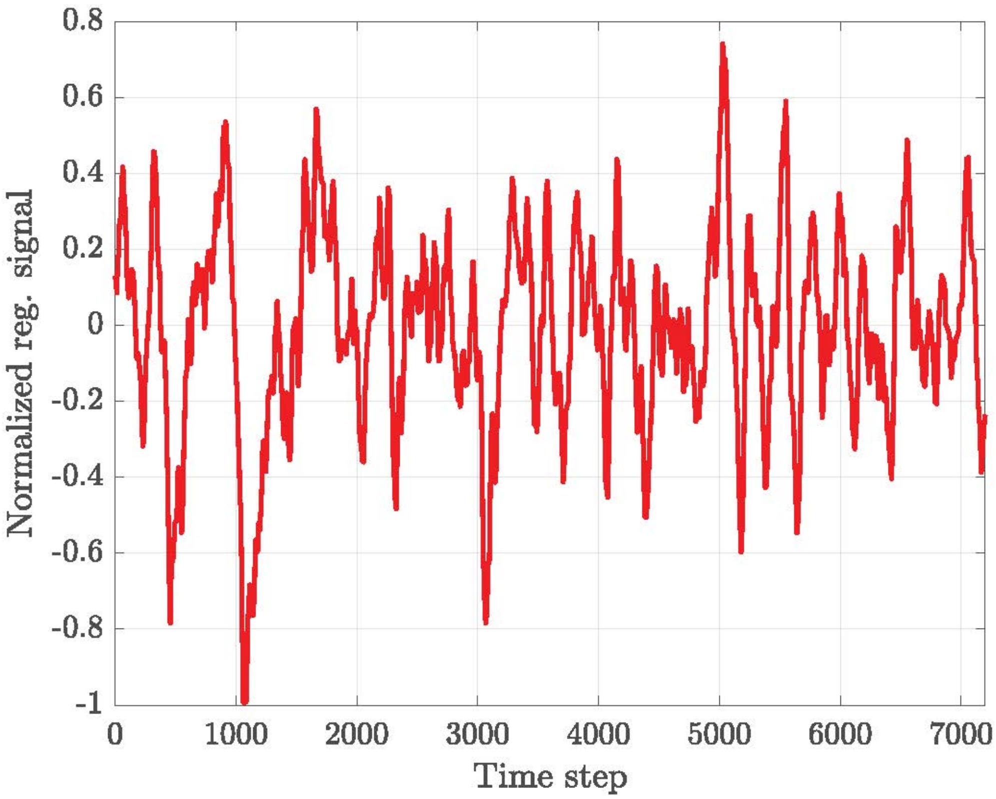


Figure 1: Example of a regulation signal from PJM with a 2 sec time step.

Conventional power plants (CPPs) offering such services are scheduled in a robust manner, i.e. they reserve enough power capacity to be always available to track the signal. The same applies for demand response or batteries; however, these resources are energy constrained, unlike CPPs. Since their energy capacity is limited, these resources have to account for the possible evolution of the signal and its energy content, so that they are not depleted during reserve provision.

If a ReGen unit is to offer such a service, it needs to provide a power reference to the system operator, which will act as a reference of the provided service. To do so, a ReGen unit with variable production needs to curtail energy and be able to follow requests for increasing production. In Figure 2 a robust PV schedule is shown, where the PV is significantly curtailed to be able to follow any regulation signal without tracking errors, considering that the PV output is known.

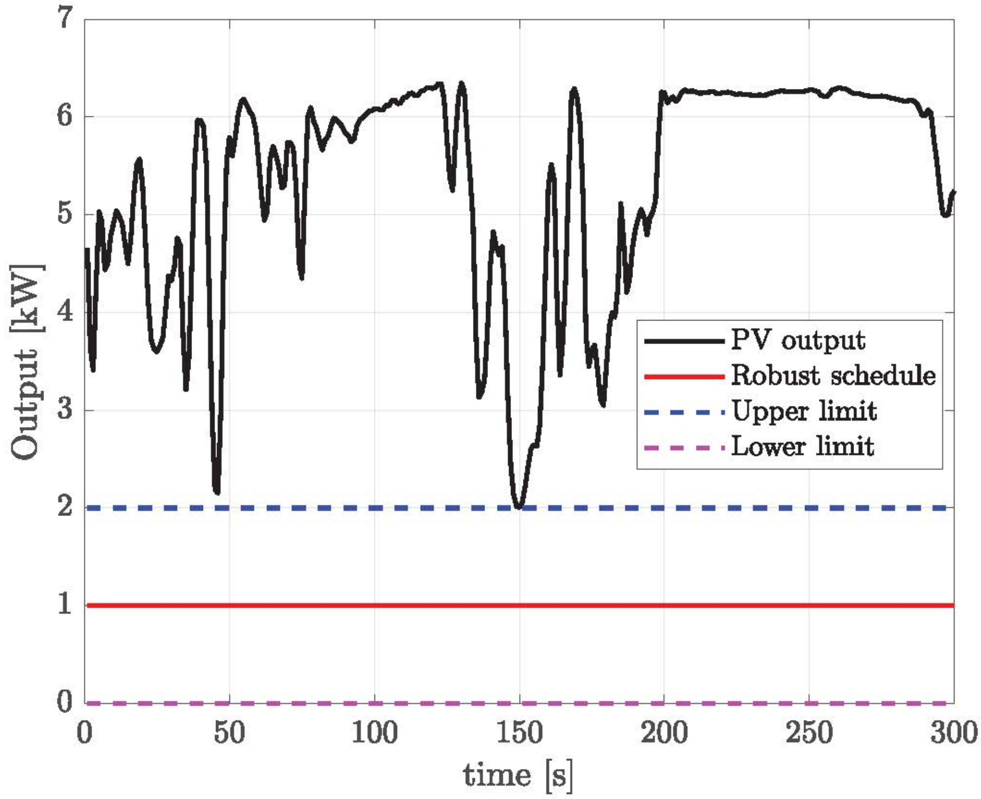


Figure 2: Example of a robust PV scheduling against regulation signal uncertainty.

3.2 A statistical approach for frequency reserve provision

In Deliverable 3.5 a statistical approach for providing fast frequency reserves by employing ReGen units was proposed. In this context, the ReGen units' schedule is updated at a regular time step, e.g. 5, 10 or 15 minutes, because maintaining constant power schedules for long periods (hourly for instance) is difficult for ReGen units.

First, the aggregator of these resources needs to forecast the expected ReGen production. This can be done my using historical data, weather measurements and weather forecasts to produce scenarios for the ReGen output. The same is done for the regulation signal, where the aggregator can also use statistical models and based on past observations of the signal produce scenarios for the upcoming period. These scenarios are then used to express statistical properties of the tracking error for different scheduled values. The higher the power schedule the less energy is curtailed, but if a low ReGen production scenario is realized, or if up-regulation is requested when production is low, then this will result in a considerable tracking error. However, since reserve provision is divided into periods, the average error can be corrected by choosing more conservative power schedules in the following periods.

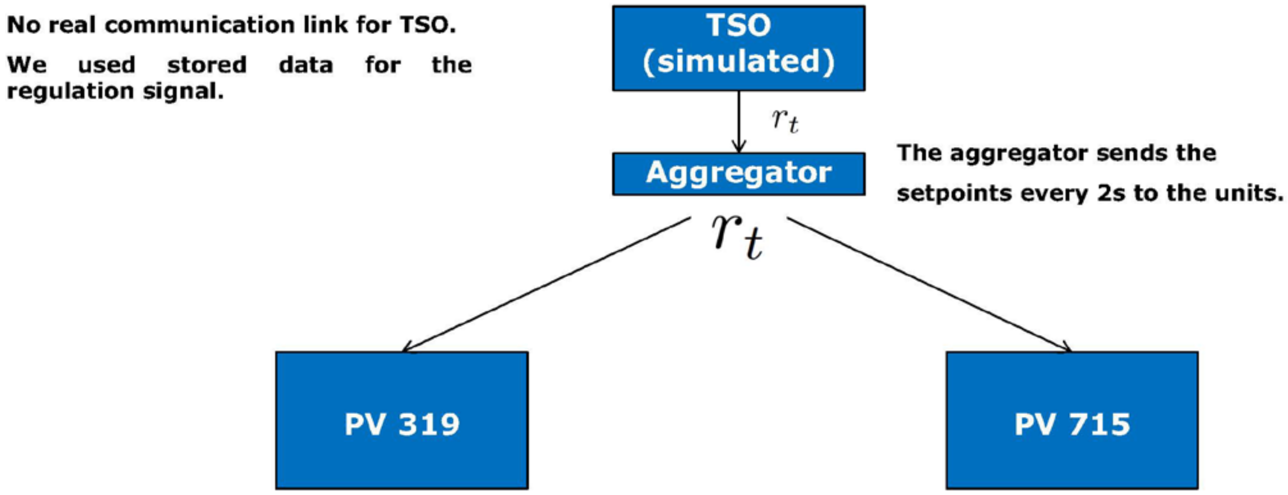
4 Experimental setup

We used two controllable PV units installed in SYSLAB for the experimental validation. The PV units are fully controllable and their output can be controlled between zero and the maximum available production. The units are named by the building close to which they are installed. As a result, the first PV plant is named PV319 and the second PV715. Additionally, PV power, solar and temperature real-time measurements are available with a one-second granularity. In Figure 3 a PV plant installed near building 715 is shown.

Figure 3: One PV plant located near building 715.

The scheduling period was set equal to 5 minutes and the aggregator 1 minute before the beginning of each period calculated the power schedule for each PV. The service which was experimentally tested was secondary frequency control and the regulation signal scenarios were sampled from historical regulation PJM signals. The PV production was forecasted using a linear regression model based on the available solar radiation and temperature measurements. The targeted average tracking error was set to 2% and 1.5 kW of bidirectional reserve was offered.

When secondary frequency control is provided, the regulation signal is sent by the system operator to the service providers typically every 2-4 seconds. In our tests, we used a historical regulation signal sample to simulate the role of the system operator. The regulation signal was retrieved every 2 seconds. Reserve P_{res} was constant throughout the experiment and only the scheduled values P_{sch} were updated every 5 minutes. The aggregator dispatched the reference signals to the PV units every 2 seconds. The communication setup is shown in Figure 4.



$$P^i_{\mathrm{ref},t} = P^i_{\mathrm{sch}} + r_t \, P^i_{\mathrm{res}}$$

Figure 4: Communication setup of the test.

To evaluate the effect of frequency reserve provision on the energy curtailment, we used a linear regression model to estimate each PV's production if it wasn't controlled during the test. The converter's maximum available power, and as a result the uncontrolled and maximum energy production, are unknown due to the imposed curtailment during the tests. Therefore, an estimation method is necessary and a linear regression model based on solar irradiation was used to predict the theoretical energy production of each PV unit if it wasn't controlled and curtailed.

5 Results

In this Section the performance of the frequency control for the two PV plants is presented. In the upper plot of Figure 5 the actual PV output, the baseline and the reference signal are shown. By baseline we refer to the constant power schedule of each PV unit every 5 minutes and is the power value to be tracked if the reference signal is equal to zero. The terms power schedule and baseline are thus used interchangeably.

Overall, the reference signal can be followed very accurately when there is enough PV production, which means that all the involved system delays and dynamics are faster than the reference signal dynamics. On the lower subplot the evolution of the average reserve error is shown. Poor tracking at the beginning of the period has a significant impact on the error, which reaches a value close to 13%. In the following period the very good tracking performance significantly and continuously reduces the average error, until t = 2000 s, where the error is again increasing. However, since almost an hour has passed from the beginning of the test, this error has a much smaller effect on the average error, compared to the period 200 - 500 s. The average error at the end of the test was 2.78 %, which is close to the targeted value of 2 %.

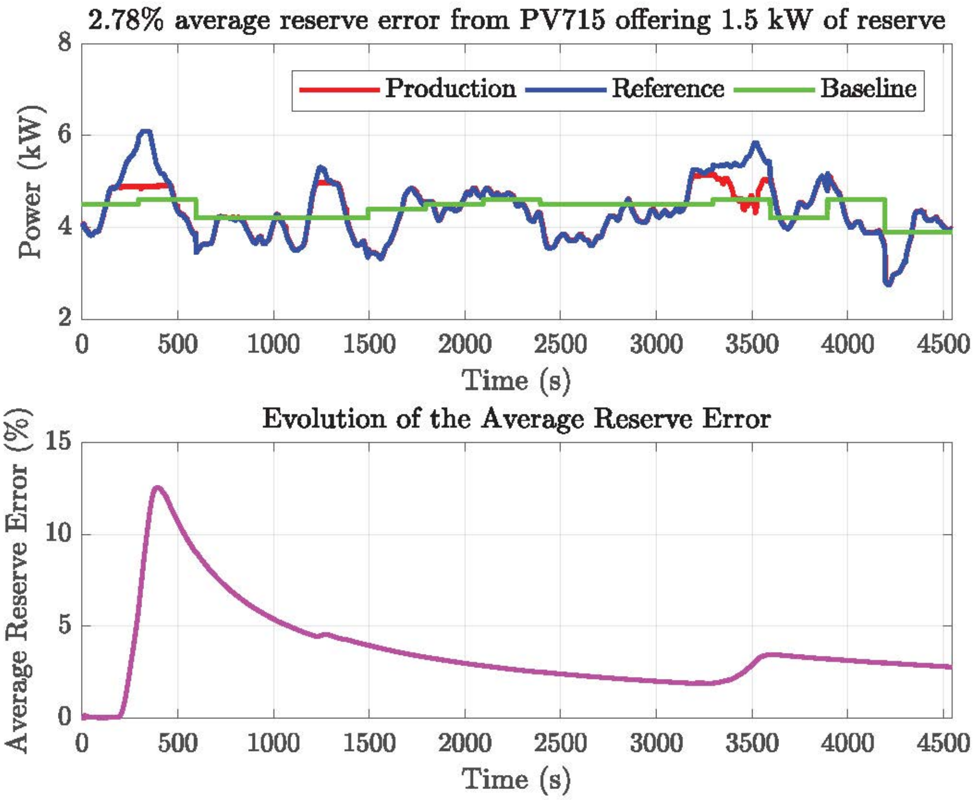


Figure 5: Regulation signal tracking (upper plot) and evolution of the average reserve error (lower plot) for PV unit 715.

The same plot for the second PV unit is shown in Figure 6. Similar to PV715, the second PV cannot track the reference signal during the period 200 - 500 seconds, which can be attributed to the same passing cloud. For the following 15 minutes tracking is almost perfect but a large PV production reduction is observed for PV319 at t = 2000 s. Since both units are located relatively close to each other and such a reduction was not observed for PV715, it can be attributed to a stationary obstacle casting a shadow over some PV arrays at this time of the day and year. This large PV output reduction has a significant impact on performance, as seen in the lower subplot. The average tracking error initially increases and then gradually decreases, as in the case of PV715. However, the average error at the end of the test was very high, close to 16 %, due to the aforementioned obstacle.

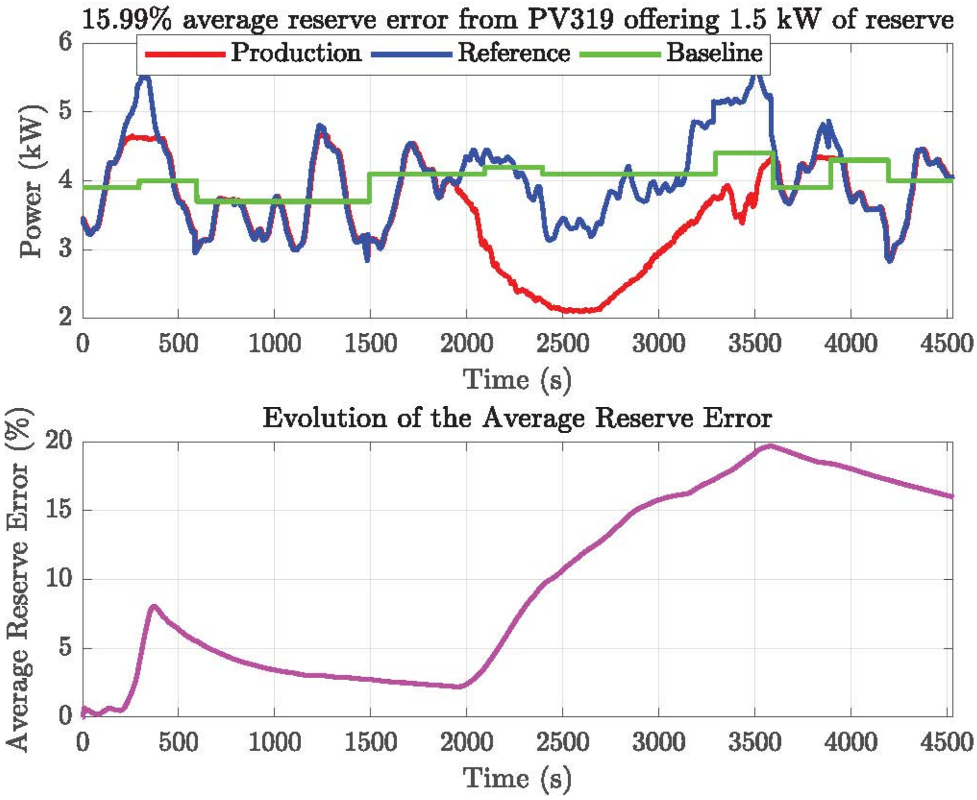


Figure 6: Regulation signal tracking (upper plot) and evolution of the average reserve error (lower plot) for PV unit 319.

In Figure 7 the baseline (or else the power schedule) sent to the PV unit 715 is shown, along with the predicted power production. The accumulated energy curtailed over the course of approximately 1.5 hours of testing is estimated close to 0.25 kWh, which for an offered reserve of 1.5 kW is very small compared to the losses of a battery system.

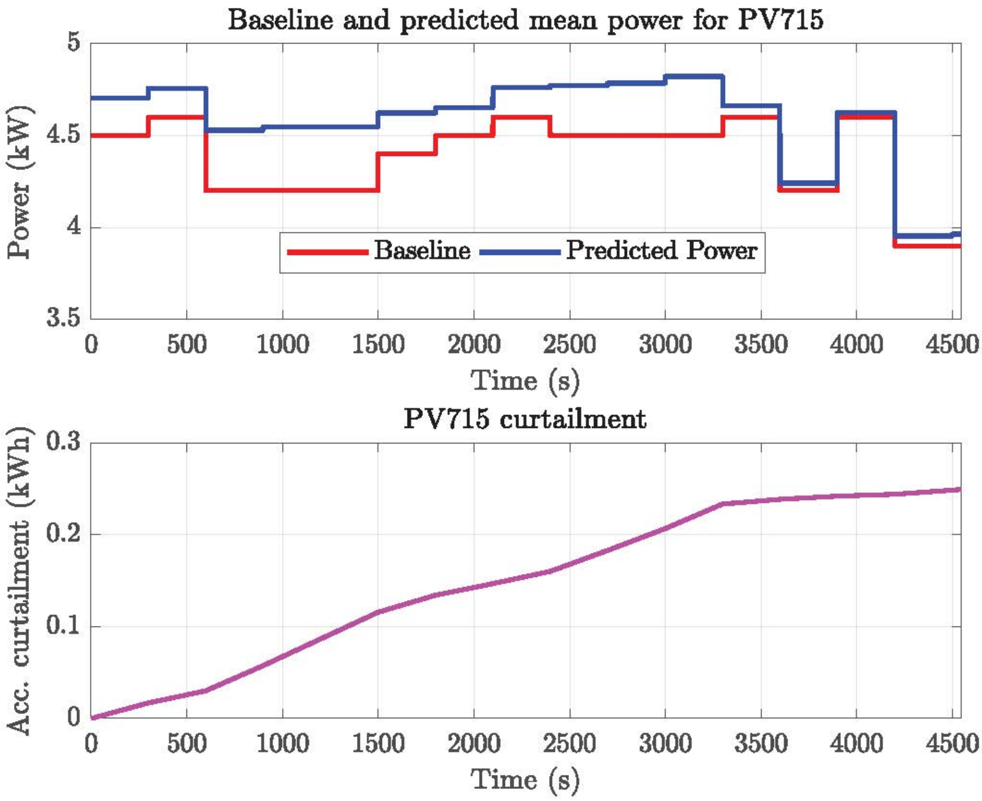


Figure 7: Comparison of the scheduled and estimated power (upper plot) and evolution of the accumulated energy curtailment (lower plot) for PV unit 715.

In Figure 8 a similar plot is shown for PV unit 319. In this case the total curtailment is equal to 0.2 kWh. It must be noted however that this calculation is based on the energy production estimation from the solar irradiation. Due to the shadowing of this PV unit for a long time period, the calculated baseline was too high and the predicted power was also overestimated, because the shadowing event was unforeseen and not taken into account.

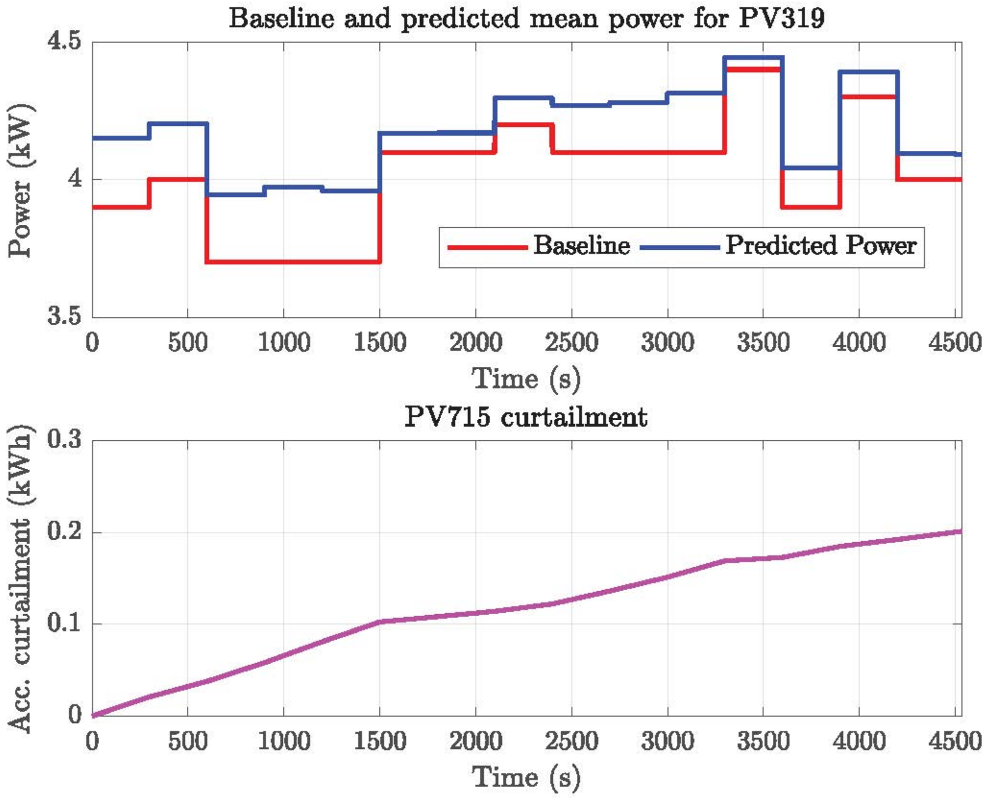


Figure 8: Comparison of the scheduled and estimated power (upper plot) and evolution of the accumulated energy curtailment (lower plot) for PV unit 319.

6 Conclusions

Experiments conducted under realistic conditions showed that it is possible to offer fast frequency reserves using small PV units. It was found that the communication delays and the units dynamics allow PV units equipped with controllable inverters to provide frequency reserves with extremely good accuracy when there is enough available production. While more tests are required to assess the effectiveness of the proposed approach, it was found that the presented statistical method works well in allowing PV units to provide frequency reserves accurately with small energy curtailment.

The tests further demonstrated the striking dependency of the service provision quality to the quality of the price and weather forecasts.

Future works must therefore focus on more advanced methods for representing the unknown ReGen plants output in the near future, as well the regulation signal, must be developed. This will allow aggregations of ReGen plants to offer frequency reserves with user-defined average tracking errors and minimal energy curtailment. Additionally, the proposed method can be tested for providing primary frequency control, which has faster response requirements.

It is necessary to develop more accurate environmental models and utilize more sophisticated forecasting tools for estimating the uncontrolled PV output from solar irradiation measurements, to reliably calculate the curtailed energy when the PV output is curtailed. Initial tests showed that energy curtailment is smaller than efficiency losses incurred by battery systems providing similar services but this has to be validated via extensive testing.

Finally, the coordinated control of PV units will be tested in the future, where it is expected that coordination will further improve performance because units with unused available production can compensate for PV units which cannot track their reference signal.