Practical Implementation of the SNOOPI-Box for a Smart Voltage Control in the Distribution Grid

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***Abstract*—The increasing amount of photovoltaic systems leads to voltage rise in the distribution grid. By providing reactive power, photovoltaic and battery inverters can reduce the voltage. Without any communication, the SNOOPI-Box smartly controls the reactive power output of inverters so that all inverters along a feeder provide reactive power in a coordinated way. In contrast to the voltage dependent reactive power curve, which is often implemented in inverters, this coordination ensures that inverters closer to the distribution transformer also help to reduce the voltage although the voltage rise at the beginning of a feeder is much smaller. Moreover, the SNOOPI-Box notices if the grid topology has changed and adapts the reactive power control to this change. This paper presents the practical implementation of the SNOOPI-Box in a distribution grid in Germany and shows field test results.**

I. Introduction

At the end of 2017, 1.6 million PV systems with a total nominal power of 43 GW were installed in Germany. In 2014 and 2017, the German Renewable Energies Act (EEG) sets the goal of a yearly increase of installed PV power of 2.5 GW [1]. This means that in 2030 75.5 GW PV power has to be installed in Germany which corresponds to an increase of more than 75 %.

98 % of all PV systems in Germany are connected to the low voltage distribution grid [1]. Already today, the increasing amount of PV systems in distribution grids leads to an inverse load flow and a considerable voltage rise along the feeder at times with high PV generation. This situation is shown in Fig. 1, where P_G is the active power fed-in by the distributed generation (DG).

According to the German DIN EN 50160 norm, the voltage in the low voltage distribution grid has to be within the boundaries of ± 10 % of the nominal voltage [2,3]. Thus, it is necessary to reduce the voltage in order to enable further integration of PV systems into the distribution grid. By providing reactive power Q_G, PV and battery inverter can reduce the voltage rise along the feeder and can contribute to an increased amount of PV systems without the necessity of grid reinforcements.

Within the framework of the project SNOOPI (Smart Network Control with Coordinated PV Infeed), new regulation tools are developed to comply with set voltage boundaries. The voltage regulation tool based on reactive power control is designed to be scalable and transferable and can be applied to all distribution systems with high PV infeed paving the way for an even higher penetration of PV. The project is carried out by a consortium of the German engineering firm Energynautics, the German DSO EWR and the Swedish university KTH and funded by the German Federal Ministry for Economic Affairs and Energy.

The main goal of the project SNOOPI is to develop an autonomous and transferable SNOOPI-Box controlling PV and battery inverters so that all inverters along a feeder provide reactive power in a coordinated way. This means that inverters at the beginning of a feeder provide a similar amount of reactive power as inverters at the end of the feeder although they measure smaller voltages. This is achieved without any communication. In addition, the SNOOPI-Box can also identify a topology change and adapts the reactive power control to it. Without this ability, the inverter would provide too less or even none reactive power any more, if the location has changed from the end of a feeder to the beginning of a feeder where the voltages are lower.

For developing and testing the SNOOPI-Box in a real distribution grid, a field test area in the network area of the German DSO EWR has been selected. The first step of the project was to build a simulation model of the grid of the field test area in DIgSILENT PowerFactory including loads, battery systems and PV infeed. The simulation model has been verified using measurements of phasor measurement units (PMU's). Besides testing the control algorithm in the simulation model, different switching states and different locations of the seven battery systems were investigated.

After the successful test of the control algorithm in the simulation model, the tool was tested in a laboratory setup consisting of a battery and an inverter. The reactive power control by the inverter and the communication between the voltage regulation tool and the inverter have been tested thoroughly. A user-interface was developed based on a web-browser application allowing the change of variables and visualization of measurement data such as voltage, active

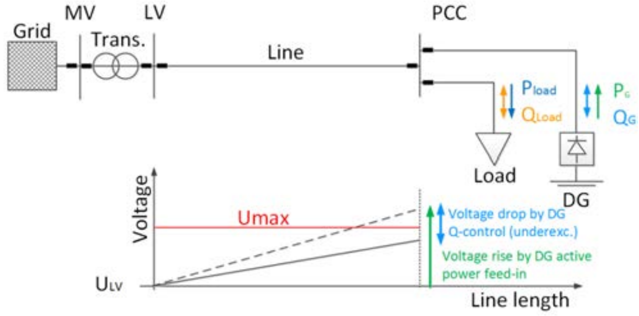

Fig. 1. Impact of active and reactive power on the voltage. [4]

and reactive power while the control algorithm is running.

In the final step of the project, the field test is carried out. In order to analyse the impact of the SNOOPI-Boxes in a distribution grid with high voltages, a switching state resulting in a long feeder and maximum voltages around 1.05 p.u. has been chosen. The seven battery systems are located along or close to this feeder. Thus, the behaviour of SNOOPI-Boxes at different positions can be analyzed.

This paper focuses on the practical implementation of the SNOOPI-Box in the field and is structured as follows: First, the SNOOPI-Box and the algorithms implemented in the SNOOPI-Box are presented. This includes the voltage regulation tool, which ensures a coordinated control, and the learning mechanism, which is necessary for the voltage regulation tool and for identifying a topology change. The third section gives an general overview of the field test and describes the different steps for preparing and implementing the field test. In the fourth section results of the field test are shown. The paper is concluded by an outlook.

II. The SNOOPI-Box

Fig. 2 shows one of the seven installed SNOOPI-Boxes controlling a battery inverter. The SNOOPI-BOX is completely autonomous because the box works independently without communicating with other boxes or devices. Thus, no communication infrastructure has to be implemented and even in remote locations with unstable communication situations, the SNOOPI-Box works reliably. Only violations of voltage limits are reported to the DSO. Without any communication or configuration the SNOOPI-Box learns its position in the grid. Depending on its position, the reactive power control is adjusted. Thus, inverters located at the beginning of a feeder contribute in providing reactive power as much as inverters at the end of a feeder although they register smaller voltages as can be seen in Fig. 1. Even if the topology of the grid changes, the algorithm adapts autonomously to this change.

The SNOOPI-Box is transferable because it is applicable to almost any arbitrary PV or battery inverter. This is achieved by using a SunSpec protocol enabling an interaction with all compliant devices of members and partners of the SunSpec Alliance. Among them are the world's leading manufacturers of inverters: SMA, Huawei, SolarEdge, Sungrow, ABB, Fronius and many others.

Fig. 2. One of the seven SNOOPI-Boxes controlling a battery inverter installed during the field test.

A. Voltage Regulation Tool

The control algorithm implemented in the SNOOPI-Box is based on a voltage-dependent reactive power control. The reactive power setpoints are determined using an autonomously parameterized $Q(U)$ characteristic curve, where Q is the reactive power and U the voltage. The parameterization ensures a coordinated behavior of all inverters. In Fig. 3 the $Q(U)$ curve is displayed. Q_{min} and Q_{max} are the minimum and maximum reactive power which can be provided by the inverter. These limits are specified by the the inverters capability curve or limits imposed by the manufacturer. The Fronius inverter, which is used in the field test of this project, can provide $\pm 53\%$ of the nominal reactive power. The grey area in Fig. 4 represents the working area of the Fronius inverter.

The values U_3 and U_4 of the $Q(U)$ curve depend on the maximum voltage U_{max} measured at the connection point:

$$U_3 = U_N + 0.5 \cdot (U_{max} - U_N), \quad U_4 = U_{max}, \quad (1)$$

where U_N is the nominal voltage. Thus, the inverter starts to provide reactive power if the voltage reaches 50% of the maximum voltage excess. At a voltage which equals the maximum measured voltage U_{max}, the reactive power is at its maximum. The value U_1 is given by the minimum measured voltage U_{min}. The value U_2 is determined analogously to U_3:

$$U_1 = U_{min}; \quad U_2 = U_{min} + 0.5 \cdot (U_N - U_{min}). \quad (2)$$

Due to the increase of the maximum voltage along a feeder, the maximum voltages at inverters at the beginning of a feeder are smaller. The dependency of the starting point U_3

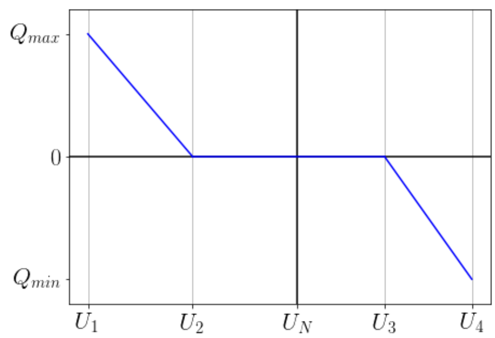

Fig. 3. $Q(U)$ characteristic curve.

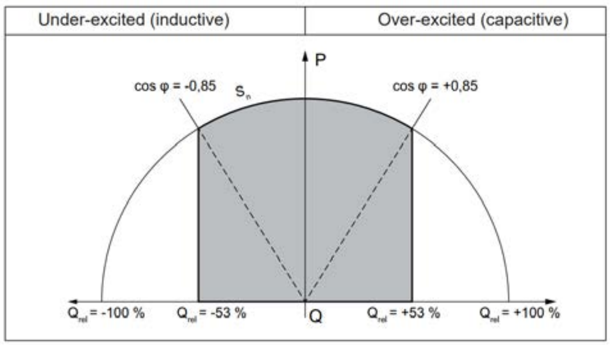

Fig. 4. Possible working area of the inverter. All valid operating points defined by active and reactive power, P and Q, are within the grey area. [5]

on U_{max} ensures that all inverters along a feeder will start to provide reactive power at the same time.

The voltage change caused by the reactive power depends on the reactance of the cable. Simplified this can be expressed as follows [6]:

$$dU \approx \frac{RP + XQ}{U_N^2}. \tag{3}$$

Here, dU is the voltage change, R the resistance, X the reactance, P and Q the active and reactive power, and U_N the nominal voltage. In a distribution grid, the relation R/X is generally larger than 1. Thus, the active power has a larger influence on the voltage than the reactive power. Both, the resistance and the reactance increase proportionally with the length of the cable. As a result, inverters at the beginning of a feeder have a smaller influence on the voltage than inverters at the end of a feeder when providing the same amount of reactive power.

The above parameterization also specifies the slope of the $Q(U)$ curve in dependence of the position in the grid: The smaller the maximum voltage, the smaller is the influence of the inverter and the steeper is the slope. The maximum allowable slope with regard to the stability of the $Q(U)$ control was discussed, amongst others, in [7] and [8].

In [7] a slope of 11 $\%_{Q_{max}}/U$ is recommended which corresponds to an reactive power increase from 0 to Q_{max} within 2.3 % of the nominal voltage. This value was received for inverters at a low voltage feeder under extreme conditions. A reactive power increase within 1 % of the nominal voltage (25 $\%_{Q_{max}}/U$) violates only one stability criterion in most cases. In [8] all tested parameterizations resulted in a stable behavior of the inverter. The steepest parameterization investigated was a reactive power increase from 0 to Q_{max} within 1 % of the nominal voltage with a minimum power factor $\cos(\varphi) = 0.85$. The parameterization in (1) and (2) was chosen such that, in most cases, a voltage change of 1 % would not result in a reactive power change greater than Qmax. If the $Q(U)$ characteristic curve is steeper, the value U_1 is decreased and U_4 is increased in order to maintain stability.

B. Learning Mechanism

The SNOOPI-Box adjusts the reactive power control autonomously. As described in the previous section, this is achieved by the dependence of the $Q(U)$ characteristic curve on the maximum voltage. The maximum voltage is determined easily by the measurement of the voltage. Depending on the weather and the season when the SNOOPI-Box is installed, it can take several month until the maximum voltage reaches its highest value. However, this does not impair the voltage reduction but only the utilization of reactive power.

The more difficult task is to realize a change of the grid topology. If a switching in the distribution grid changes the position of the SNOOPI-Box from the beginning of the feeder to the end of the feeder, the voltage at the inverter will increase. In this case, the SNOOPI-Box will adapt the maximum voltage without the need for further functions. In the reverse case however, i.e. the position of the SNOOPI-Box is changed from the end of the feeder to the beginning of the feeder, the voltage at the inverter decreases. Without further functions, the maximum voltage will remain at its high level. This problem is solved by analyzing the voltage changes at the connection point.

As explained in the previous section, the resistance R and the reactance X increase proportionally with the line length. Thus, it follows from equation (3), that voltage changes due to active or reactive power infeed are larger at the end of the line than at the beginning. The SNOOPI-Box uses this effect in order to notice a change in the grid topology.

Every day, the SNOOPI-Box analyzes the voltage changes of the past day and determines a reference value ΔU which is based on the voltage changes and indicates a topology change. During a defined learning phase of several days, the SNOOPI-Box learns the statistical behaviour of the value ΔU. The learning phase is only accepted as valid, if the learned data is consistent and doesn't indicate a topology change during the learning. After completing a valid learning process, the SNOOPI-Box daily compares the newly determined ΔU with the learning phase and decides whether the topology has changed and the $Q(U)$ characteristic is reset.

III. Implementation of the Field Test

A. Selection Procedure

During the first phase of the project, three potential field test areas in the distribution grid of EWR were identified and replicated as simulation models in DIgSILENT Power Factory. The areas were selected according to the amount of connected PV systems, the voltage level of the substation on the low voltage side as well as on the medium voltage side, and the topology of the low voltage grid. For developing realistic simulation models, grid data was provided by EWR Netz GmbH, such as low voltage grid plans (in form of single-line diagrams and an export of the geographical-information-system), grid data from HV/MV-substation and measuring data.

Besides selecting a suitable grid area, the challenge was to provide grid data of a suitable quality for the partner Energynautics, so that the data could be transferred into a computable grid model. To validate the model, measuring instruments have been installed at several points in the selected grid area. The data from the measuring instruments was regularly provided to improve the quality of the simulation model.

B. Field Test Area

One of the three preselected areas turned out to be the most suitable in order to conduct the field test and was chosen for this project. The field test area is a rural area with high PV penetration. A large wind power plant is connected in the overlaying medium voltage feeder, leading to potentially high voltages at the distribution transformer. Therefore, the remaining allowed voltage rise becomes significantly smaller during times of high wind infeed. The grid topology could be easily changed by a switching resulting in a long feeder with a large voltage rise. This was important as currently none of the grid areas has voltage problems.

Seven battery systems equipped with a SNOOPI-Box have been installed in the distribution grid of the field test area. Although the algorithm is also applicable to PV inverters, the tests focus initially on battery inverters. Fig. 5 shows a map of the field test area. The green letters indicate the positions of the battery systems in the real distribution grid and in the simulation model. Most battery systems are located at a long feeder (illustrated in blue) with voltages between 0.93 p.u. and 1.06 p.u.. The following subsection describes how these positions were selected.

C. Contracting

EWR has identified potential locations by investigating plans and on-site inspections. Concerning the selected grid area, where the batteries should be installed, there are six locations near cable distribution cabinets, one location near the considered local substation and several PV systems on roofs in the low voltage grid. For a realistic setup, an installation of the battery systems at customers with PV systems is preferred. However, it is possible to connect the storage system to the grid without a PV system.

EWR has checked if and how the battery storage units can be connected to a substation or to cable distribution cabinets. As EWR, apart from the site of the local substation, does not have its own land in the grid area under consideration, private land must be used to set up the battery storage facilities. The installation requires the consent of the property owner, as well as prior technical, commercial and legal clarifications. For example, in addition to insurance aspects, a possible adjustment of the EEG (German Renewable Energy Law) feed-in tariffs has to be considered by introducing battery storage systems in existing customer systems. The same applies to the replacement of inverters, as these components have an influence on the feed-in tariff of customers, depending on the given delivery model and valid EEG of the generating plant. Over the years the EEG has been revised several times. The date of the installation of the system indicates which EEG feed-in tariff is valid. Due to the legal assessment and resulting conflicts of the feed-in tariffs of the production facilities, it was decided not to replace any inverter. This is because the owners of generation, consumption and storage are different persons/instances.

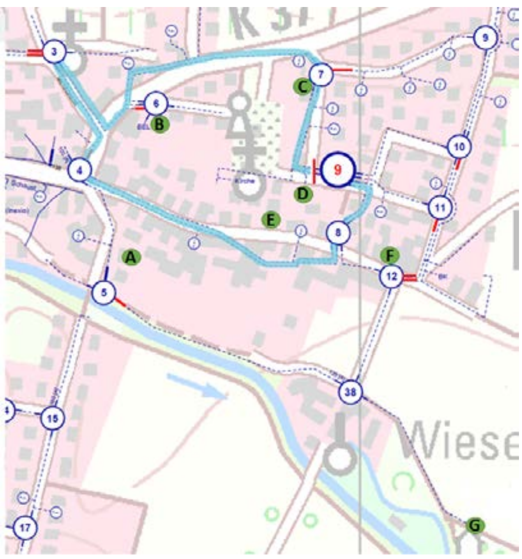

Fig. 5. Map of the field test area. The green circles indicate the positions of the battery systems.

A contract has been set up for the customers, which specifies all general conditions for the installation of a battery storage and the use of land for all people involved. After the theoretical clarification of the preferred connections, in the first step the mayor was informed representatively for the community with information folders about the project, whereupon a presentation followed in the local council. The other non-public locations were determined by personal presentation of the project on site, so that after completion of the site clarification all seven battery-storages have received an installation site. The installation sites were secured by the conclusion of licensing agreements between the municipality, the private customers and the EWR Netz GmbH. These ensure the installation site and regulate the future dismantling of the facilities.

D. Battery Installation

Due to the local situation, three of the seven battery storages have been installed at outdoor locations. For this purpose, suitable outer housings have been procured and rebuilt. The equipment was set up by installing cable ducts, connecting cables and ventilation/air conditioning in these housings. The installation of the indoor batteries was set up on an installation frame in purpose of an easy and space-saving construction. The battery storage was constructed in a workshop of the EWR Netz GmbH, so that the entire system could be delivered with the required updates and first functional tests in advance. The battery systems consist of a lithium-ion battery, a battery inverter and a smart meter provided by Fronius. The SNOOPI-Boxes have been connected to the battery storage units in cooperation with the project partner Energynautics on site. The controllers have been connected to the control unit via the network interfaces of the system and have been provided with an internet connection. Although the SNOOPI-Boxes don't need a communication setup for the voltage regulation tool, an internet connection was established to allow for monitoring and remote access during the field test.

E. Field Test Plan

At the beginning of the field test a field test plan was developed defining the time period and the type of tests which will be analysed. In the first phase of the field test, the correct behaviour of the SNOOPI-Boxes and the inverters is tested. In this phase, the control algorithm and other settings can be adjusted as often as desired and needed. The following phase of the field test will be an unaffected test run over two to three month. During this test run, the battery systems and the SNOOPI-Boxes shall operate without any interferences or only if it is indispensable. This test run will be during the summer so that the PV infeed and the voltages are rather high and the influence and the learning behaviour of the SNOOPI-Boxes can be analysed. After that, desired adjustments can be implemented. The next phase will be an investigation of different network switch states in order to test the adaptability of the SNOOPI-Box. The last phase will again be an unaffected test run during the winter so that the reactive power control of the summer and of the winter can be compared with each other.

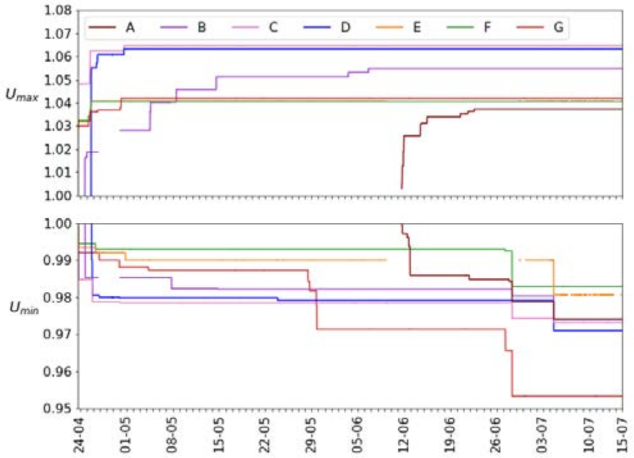

Fig. 6. Learning of the maximum and minimum measured voltage of all battery systems.

The field test was started successfully at the beginning of April 2018. In July/ August a new and improved method of identifying a topology change was implemented. The method is based on an independent and high-resolution single-phase voltage measurement of the SNOOPI-Box. The switching of the grid was performed on 20 September. The field test will be concluded at the beginning of 2019.

IV. Results

A. Learning Behaviour

Fig. 6 shows the learning of the maximum and minimum voltage of the SNOOPI-Boxes. The systems C and D measure the highest voltages which is expected as they are located at the end of a feeder with high PV penetration. Apart from system G, they also measure the lowest voltages. System G is connected at the end of a different long feeder with few PV systems. Thus, the voltage drop due to loads is more significant. For the battery systems which are located in the same feeder, the figure shows that the maximum voltage reflects the distance to the distribution transformer quite well. Thus, the maximum voltage is a good measure to calibrate the $Q(U)$ curves.

The maximum voltage reaches its final value only in July on a sunny day with high PV infeed. Before the maximum value is reached, the inverter will provide more reactive power than needed. But once the final value is adopted, the inverter will provide only reactive power when it is needed, i.e. mainly during the summer months as the PV infeeds and thus the voltages are higher.

Fig. 7 shows the value ΔU for all systems. As can be seen, the level of ΔU does not necessarily reflect the distance to the distribution transformer. One reason for this is that the single-phase voltage measurement of the SNOOPI-Boxes is not always connected to the same phase. This influences the result as different loads and generators are connected to the different phases. However, the value ΔU is only determined to be able to identify a topology change. For this, it is important, that the value is quite stable, which is the case. If the topology has changed, ΔU will change significantly and the SNOOPI-Box will be able to notice this change.

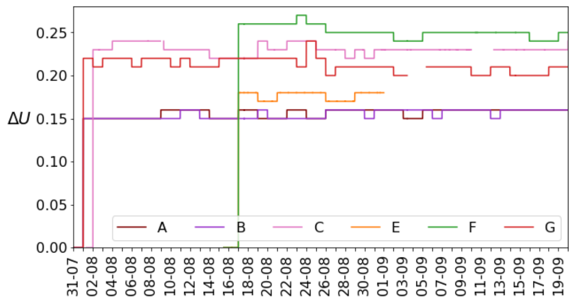

Fig. 7. ΔU for all battery systems.

B. Q(U) Control

In dependence of the maximum and minimum voltage, the $Q(U)$ characteristic curve of the inverters is parameterised. Fig. 8 shows the $Q(U)$ curves of the systems B, C and E. As can be seen, battery systems located closer to the distribution transformer have a smaller dead band and a steeper slope.

Fig. 9 shows two example days of the reactive power control of the systems B, C and E. The reactive power infeed at the bottom depends on the measured voltage at the top and the parameterised $Q(U)$ curve of Fig. 8. Looking at the first day, the inverter E provides almost the same amount of reactive power as the inverter B or C, although the voltage at battery E is much smaller. Due to the parameterization all three inverters provide reactive power coordinately. On the second day however, the reactive power infeed of system E is quite low during midday compared to the reactive power infeed of B and C. This is probably due to high loads at the beginning of the feeder which reduce the voltage.

In contrast to the PV infeed, which depends highly on the weather and is therefore relatively coordinated within a distribution grid area, loads along a feeder can vary quite much. As loads reduce the voltage, they also influence the coordination of the SNOOPI-Boxes which are based on a voltage dependent $Q(U)$ curve. However, the main goal of the SNOOPI-Box is to reduce the voltage in a distribution grid in critical situations. As high loads reduce the voltage possibly more than reactive power, a coordinated reactive power infeed is in these situations not as crucial as in situations with high PV infeed and without high loads. In these situations, the parameterisation ensures a coordinated behaviour, which can be seen in the results.

Fig. 10 shows the Pearson correlation coefficient of the reactive power infeed of all seven battery systems from the 1st of August (after the maximum voltage at all battery systems has reached its highest value). The Pearson correlation coefficient is a measure of the linear correlation between two variables. A coefficient between 0.1 and 0.3 indicates a small correlation, between 0.3 and 0.5 a moderate correlation and a coefficient larger than 0.5 indicates a strong correlation [9].

The reactive power infeed of all battery systems apart from F and G correlates moderately or strongly. The correlation between B, C and D is even very strong, since all three have a correlation coefficient around 0.9. This was also expected due to the positions of the battery systems at the end of the same feeder. Systems F and G correlate only little with the other ones as it is not connected to the same feeder.

In Fig. 11 the implementation of the characteristic curve

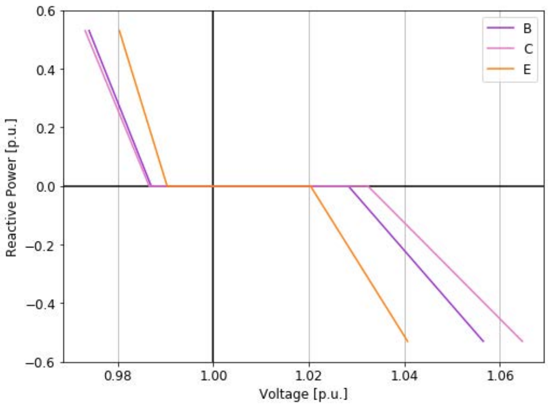

Fig. 8. Parameterised $Q(U)$ characteristic curve of three battery inverters at different positions.

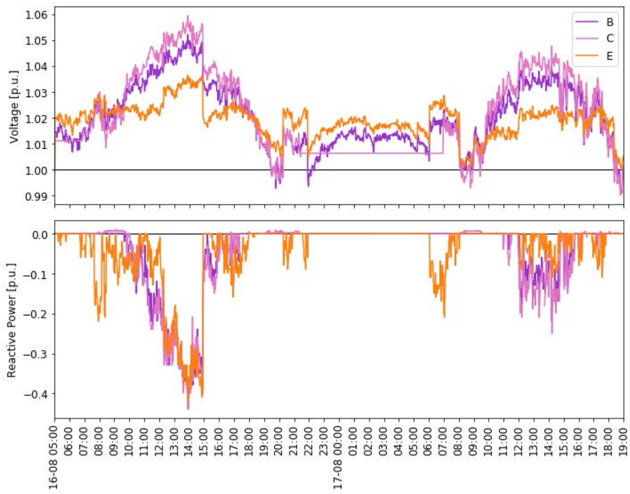

Fig. 9. Example of the voltage dependent reactive power control of three battery inverters at different positions. Top: Measured voltage. Bottom: Reactive power infeed.

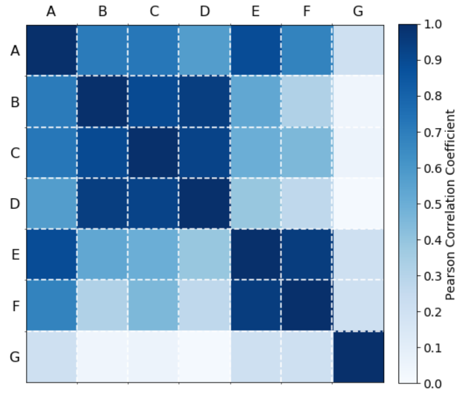

Fig. 10. Correlation of the reactive power infeed of the different battery systems from 1 August to 20 September.

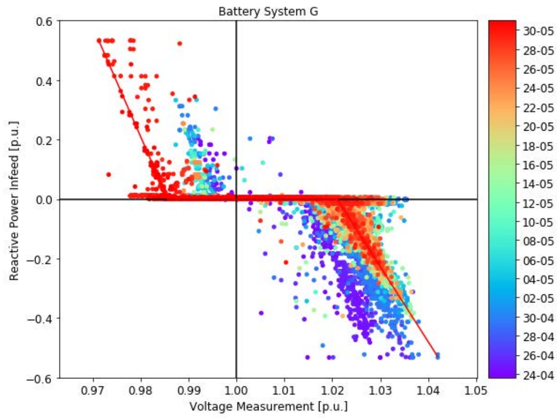

Fig. 11. Reactive power infeed versus the voltage measurement for the battery system G. The colour indicates the time course and the learning progress of the system.

can be analysed. The reactive power infeed versus the voltage measurement is shown for battery system G. The color indicates the time of the data point and thus the learning progress of the system. The red line indicates the $Q(U)$ curve of the latest time of the dataset. The reactive power setpoints have been implemented quite well. The reasons for deviations can be an inaccurate or wrong implementation of the inverter, a measurement deviation or error, or the time frame between passing the setpoint to the inverter and measuring the output. Over the time the dead band of the $Q(U)$ curve is getting larger and the slope is getting smaller as higher voltages have been measured and the $Q(U)$ curve has been adjusted.

C. Switching

The reference value ΔU is determined in order to notice a change in the grid topology. On 20 September, the grid was switched, so that the feeder is fed from the back. After the switching, the battery system C is not placed at the end of the feeder but at the beginning. Fig. 12 shows ΔU from the beginning of September until a few days after the switching. The SNOOPI-Boxes were able to identify the switching by investigating the course of ΔU. Dependent on how much ΔU changes and if it changes suddenly as for system G or over several days as for system C, the time period until the switching is detected varies.

In Fig. 13 and 14, the implementation of the $Q(U)$ curve is shown for system B and system C for a time period around the switching. The purple and blue color represents the reactive power infeed before the switching. For system B, the orange color indicates the time when the topology change was detected. Before the switching, ΔU of system B was very stable and has not varied much. Thus, the increase of ΔU after the switching was a significant indicator for a topology change. The $Q(U)$ curve was reset and had a much smaller dead band than before. For voltages smaller 1.0 p.u. the new learning progress can be observed as the $Q(U)$ curve has started to get broader again.

System C needed a longer time frame to identify the topology change as the change of ΔU was not as significant. The importance of detecting a topology change can also be observed in Fig. 14. During the time period between the switching and the detection of it, almost no reactive power was provided by system C which can be seen by the lack of green and orange data points for a reactive power smaller than zero. After the switching, the voltage level was much smaller than before. As the previous $Q(U)$ curve had a large dead band, no reactive power was provided for these small voltages.

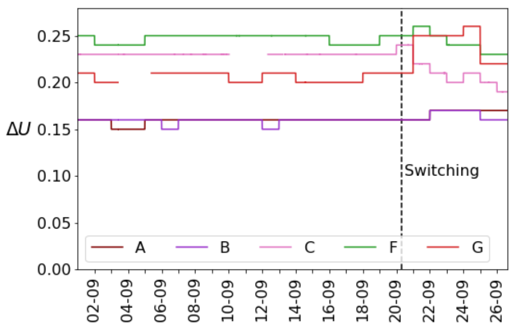

Fig. 12. ΔU for all battery systems. On 20 September the grid was switched.

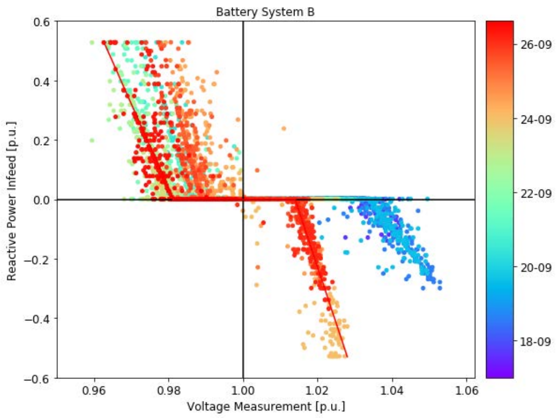

Fig. 13. Reactive power infeed versus the voltage measurement for the battery system B. The colour indicates the time course.

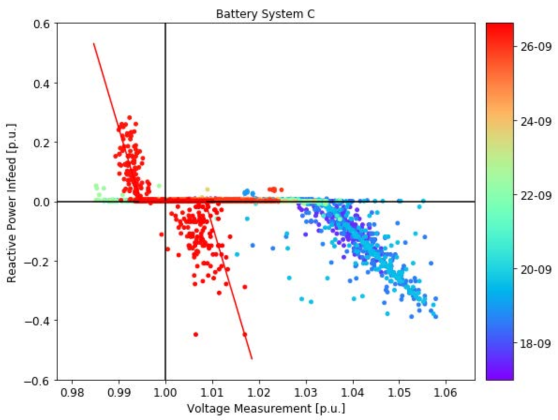

Fig. 14. Reactive power infeed versus the voltage measurement for the battery system C. The colour indicates the time course.

V. Conclusion and Outlook

By parameterising the $Q(U)$ characteristic curve in dependence on the maximum measured voltage, all inverters in a distribution grid provide reactive power coordinately without communicating with each other. The advantage of a coordinated behaviour is that inverters placed at the beginning of a feeder also help to reduce the voltage although they don't measure high voltages. This is important as the influence of the reactive power on the voltage in distribution grids is often quite small.

At the moment the field test is carried out and the reactive power control and the learning behaviour of the SNOOPI-Box is be tested in a real system. In addition to the reactive power control, an active power control will be implemented in the SNOOPI-Box. The main goal of the active power control is to cut the midday peak of the PV generation by charging the battery without having a major impact on the self consumption rate [10].

The German law of the digitisation of the energy transition from 2016 states that large consumers and large producers have to implement a smart meter and a smart meter gateway [11]. The smart meter gateway allows the grid operator to read out smart meters remotely and to have access to controllable consuming or producing devices. For the latter, a control box is needed. By building up a communication to the smart meter gateway, the SNOOPI-Box can be such a control box if desired. In this way, the SNOOPI-Box can report voltage deviations to the grid operator and the grid operator can access and control the battery or PV system remotely. As the German federal office for information security has established regulations regarding the communication protocols of the smart meter gateway [12], the SNOOPI-Box can be applicable to every smart meter gateway.

The final outcome of the project will be a device which reduces the voltage considerably by controlling reactive and active power without impairing the system operator. As the SNOOPI-Box is applicable to almost any inverter and hardly any presettings are necessary, it is easy to install at many inverters in a distribution grid with voltage problems. Even if the status of the grid changes, for example if new PV systems are installed or by a switching, the SNOOPI-Box doesn't have to be reconfigured but adjusts its control autonomously. In addition, it reports a critical grid status to the grid operator and allows for controlling the inverter remotely. Thus, it will pave the way for a high PV penetration.

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