Islanding operation of a community power grid with renewable energy sources and a large battery

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1. Introduction

With a growing share of decentralized renewable power generators, grid control will have to be managed without large power plants in the future. Decentralisation basically allows for an additional local power supply, which could be used in the event of a global blackout, for example. In all these cases, large batteries can form the central elements.

The innovative municipality of Bordesholm in northern Germany supports such a concept. The local energy supplier, the Versorgungsbetriebe Bordesholm (VBB), recently put a large battery into operation. Figure 1 shows the battery storage building on the left. The large battery was realized by RES Deutschland GmbH (RES) with other partners (see Figure 1 right) and has a total capacity of 15 MWh and a maximum output of 12.5 MW, of which 10 MW are registered for regular operation. It consists of seven identical independent strings, each with a battery block, inverter and mains transformer. Figure 1 shows seven gates in the building to the respective battery strings.

Figure 1: Left: Building of the battery system in Bordesholm.
Right: Project partners of the battery storage.

In normal operation the battery is prequalified for the primary control power market. However, the inverters and grid infrastructure are also designed to supply the Bordesholm municipality with the battery as an island grid. In 2019, a first preliminary study on island grid operation was presented at the conference „Zukünftige Stromnetze“ in Berlin. Here, concrete measurement results of island power grid tests with the battery that has been put into operation are now presented.

The large battery is able to serve as a network former in island operation and to keep the voltage and especially the grid frequency stable. This means that decentralised generators such as photovoltaic (PV) systems (approx. 1.4 MWpk) and the biomass system (up to 2.4 MW) present there can remain in operation and feed in power.

The central inverters from SMA are operated in normal grid operation in current-control mode according to prequalification. In order to work as grid formers in island operation, they can be switched to a voltage-control mode. In voltage-control mode, the control system contains a slight voltage and frequency droop. This enables voltage-controlled operation in both grid-connected and isolated operation.

The new grid infrastructure also includes a synchronous coupling switch with which the electricity grid of the municipality of Bordesholm can be connected synchronously from island operation to the interconnected grid. In addition to monitoring grid synchronicity, the unit also supplies measurement signals for voltage, frequency and phase of the grid sections to be connected to the hybrid controller from SMA. This controller is then able to adapt the voltage, grid frequency and phase of the island grid to that of the interconnected grid.

Measuring devices are installed at several points in the power grid to document the island grid test, especially in the switching station with the connection to the interconnected grid and the synchronous coupling switch. These can measure the mains voltage and currents of selected feeders with high resolution with 128 measured values per mains period.

2. Preliminary experiment

An experiment with an artificial load was carried out as a preliminary study for a trial with the Bordesholm municipality (see Figure 2). Only the battery system was connected to the grid via the synchronous coupling switch. Then, three of the seven battery inverters were switched in current-controlled operation as loads of a total of 4 MW. This corresponds approximately to the highest demand of the municipality of Bordesholm. The remaining four battery inverters then supplied the "virtual community of Bordesholm" in voltage-controlled operation as a large battery. In the following, various experiments were carried out on the transition to island operation, re-synchronisation and various load changes.

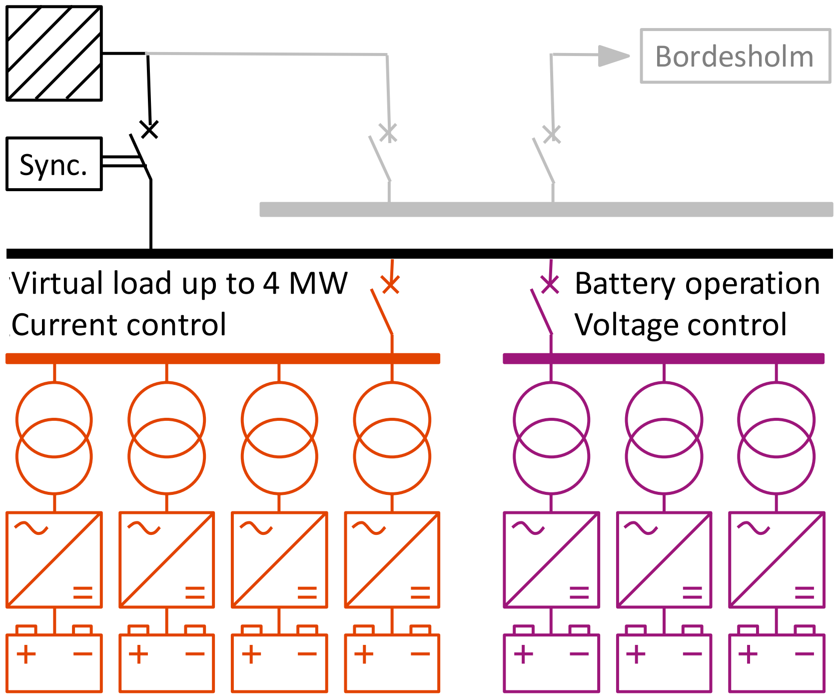

Figure 2: Preliminary test with battery inverters as load: voltage and current at the grid connection point at the transition to the island grid without residual load.

In all cases, the four battery inverters for battery operation on the interconnected grid were switched to voltage-controlled operation. In the first test, the residual load on the synchronous coupling switch was then reduced to almost zero. The switch was then opened and the arrangement automatically, i.e. without interruption, switched over to island grid operation. The measurements of the voltage at the battery and the current through the tie breaker are shown in Figure 3 as a time curve. The switching time can be recognized by the fact that the current changes from a low, noisy current to completely zero. At this point in time, no particularity at all can be detected in the voltage curve. This shows that the four inverters in grid-forming mode can switch over to island grid operation without any control fluctuations.

In another similar experiment, the residual load on the synchronous coupling switch was not previously set to zero. Instead, the loads were fed with the full capacity of 4 MW from the interconnected grid. In this situation the synchronous coupling switch was opened again. The four inverters of the battery had to immediately take over the full power of 4 MW and at the same time switch over to island grid operation. The corresponding curves for current and voltage are shown in Figure 4. Here, too, the switching time can be recognized by the decrease in current. The voltage shows some transient compensation processes after the switching time. However, it does not collapse under any circumstances and the curve only contains some additional oscillations. However, these have subsided after one grid period at the latest, so that here too an uninterrupted transition to islanding operation could be shown.

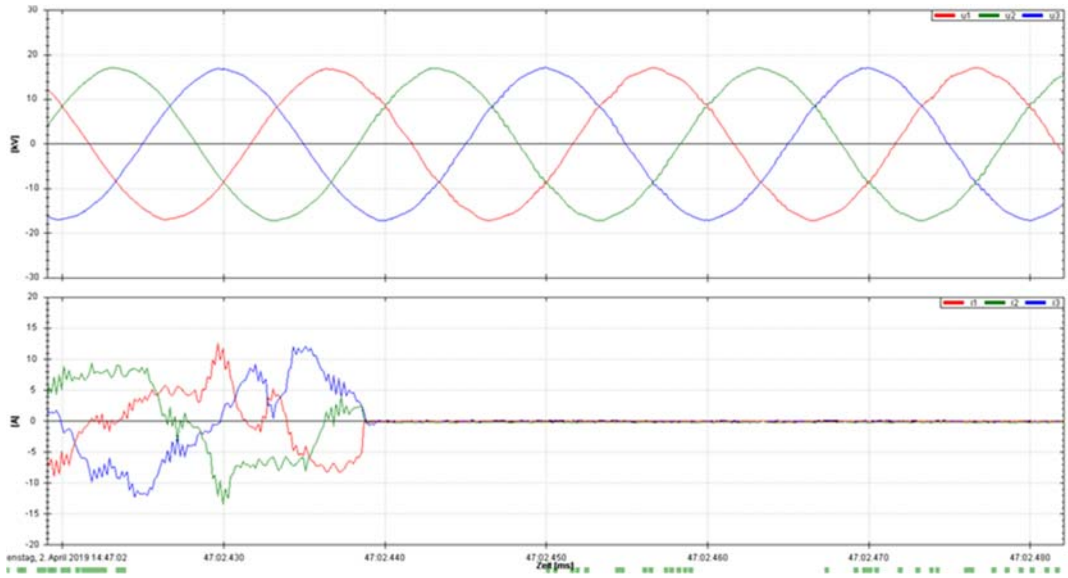

Figure 3: Measurement results of the preliminary test with battery inverters as load: Voltage and current at the grid connection point at the transition to the island grid without residual load.

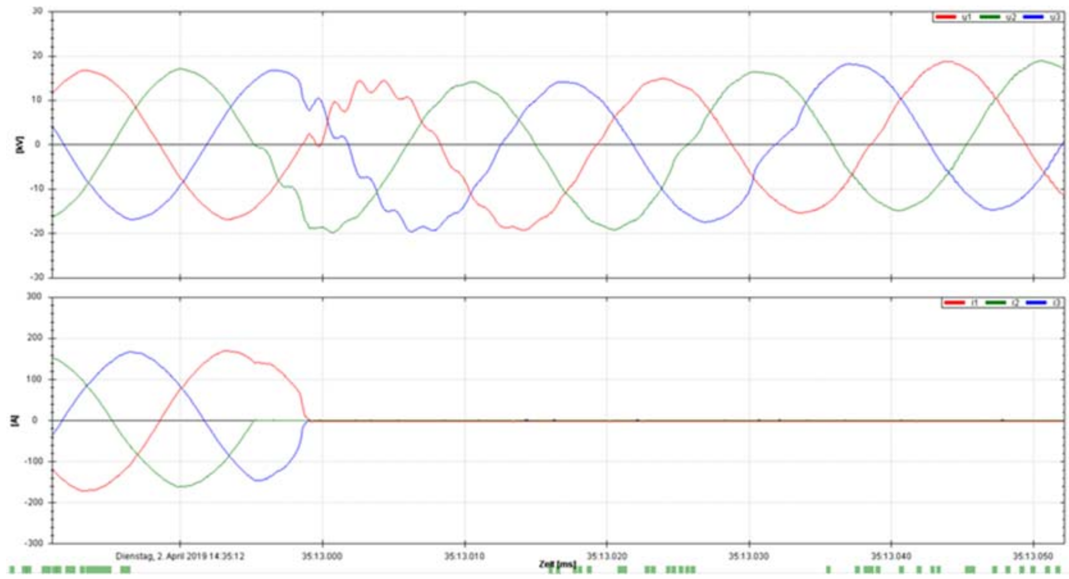

Figure 4: Measurement results of the preliminary test with battery inverters as load: Voltage and current at the grid connection point at the transition to the island grid with residual load.

Figure 5 and Figure 6 show a positive and a negative load step of 1 MW each. Such load steps could occur in Bordesholm when switching part of the biomass plant on or off and are therefore not entirely unlikely. Here, too, slight transients can be seen in the grid voltage curve during a grid period. However, neither significant overvoltages nor a voltage drop, however short, will occur.

Furthermore, a black start in islanding operation was successfully performed during these preliminary tests. In total, the start-up of the battery in island network operation takes a few dozen seconds. However, the blackstart requires manual entries in the inverter control system. In case of a real unplanned blackout, the time-limiting element would be the arrival of a suitable specialist. This would take about 15 to 30 minutes.

All in all, these measurements make us confident that with a planned switching, an island grid test could be carried out with the municipality of Bordesholm as the consumer without affecting the power supply.

Such a demonstration of island network operation has meanwhile been carried out on 30 Nov. 2019. The following chapters show the results.

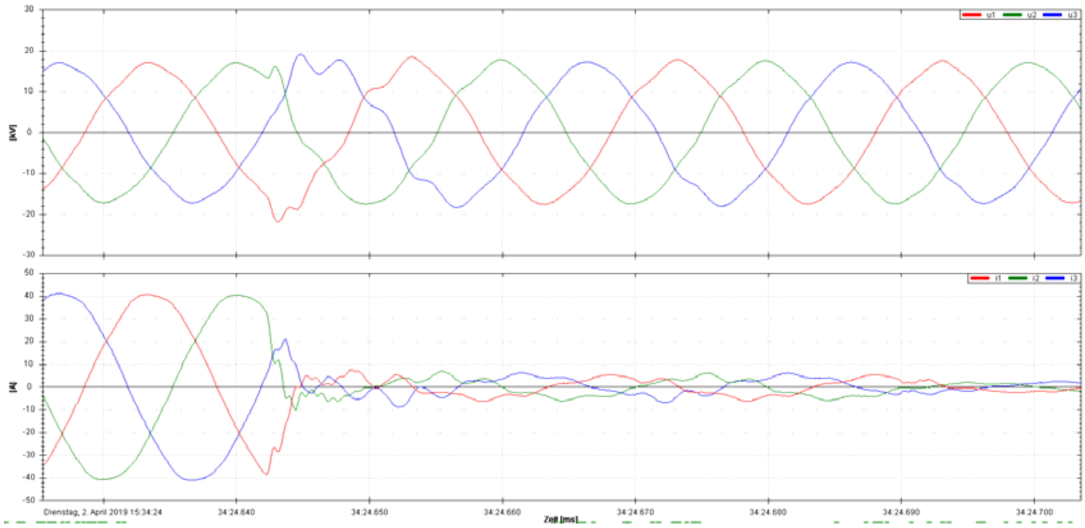

Figure 5: Measurement results of the preliminary test with battery inverters as load: voltage and current at the grid connection point with a negative load step of 1 MW.

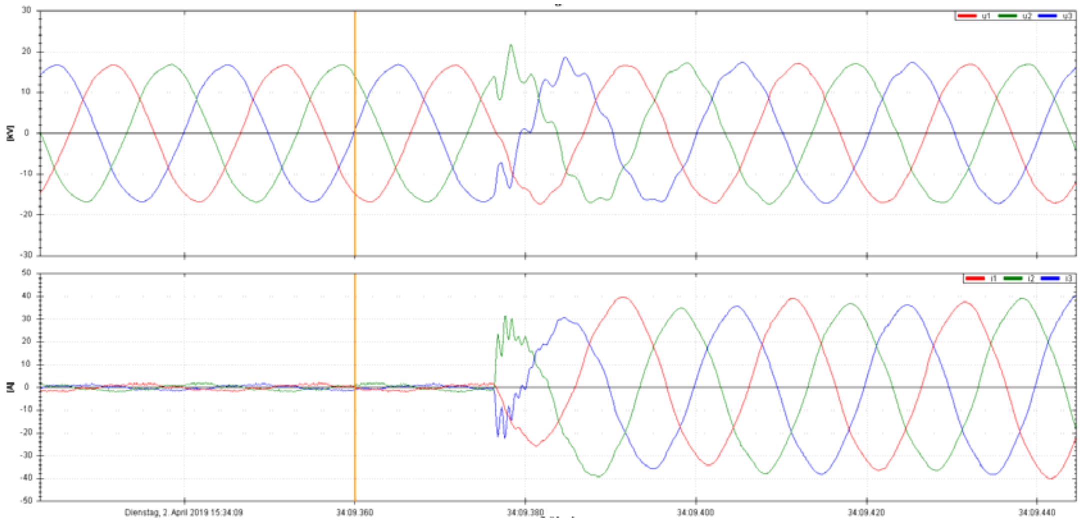

Figure 6: Measurement results of the preliminary test with battery inverters as load: voltage and current at the grid connection point at a positive load step of +1 MW.

3. Preparation of the island grid trial

For the successful implementation of the island grid trial in the Bordesholm utility network, a number of preparations have to be made.

Figure 7 shows an overview of all measuring devices installed so far in the medium-voltage network of the Bordesholm utility company. 8 measuring devices are located at the outgoing feeders in the medium-voltage switchgear. 3 further devices are installed on the low-voltage side at local substations. At a local grid station the behaviour of a small combined heat and power plant can be observed. The largest PV system in the grid to date is connected to another one, and at a third local network station the voltage at the end of a medium-voltage beam can be observed.

All measuring instruments are of the type UMD 98 from PQ-plus. This type of measuring device is capable of permanently measuring up to 128 measured values per grid period with a resolution of 100 ms and event-related high resolution. Violations of limit values for current and voltage or a manual signal will trigger a high-resolution measurement of the device. Manual triggers are implemented with the help of remote-controlled TCP/IP switches, which are installed in the switching station as well as in the local network stations and connected to a separate fiber optic network.

All measuring devices are connected to a data server of the utility Bordesholm and are now read out automatically. Among other things, data on current, voltage, power factor, active, reactive and apparent power are stored with a resolution of one second.

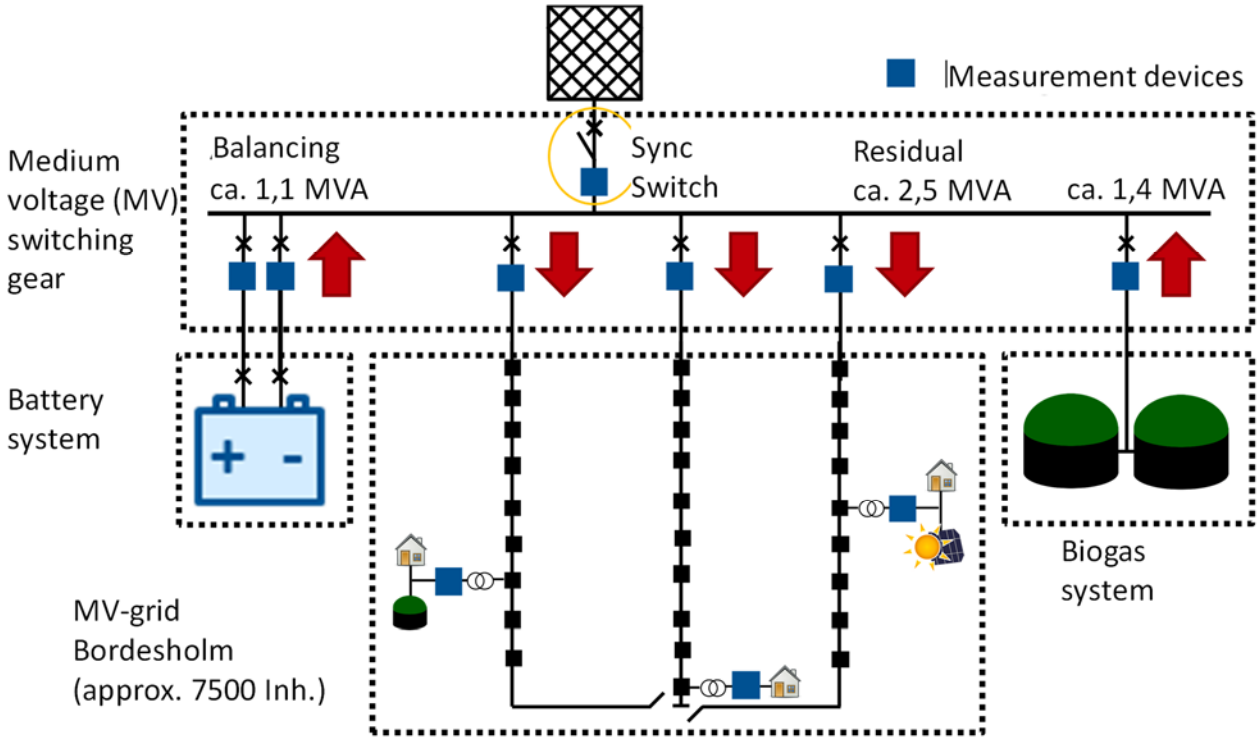

Figure 7: Overview of the installed measuring instruments in the medium-voltage grid of the utility Bordesholm.

4. Implementation and evaluation of the results of the island grid trial

The island network test was carried out on 30.11.2019 in the period of 15-16 h.

In everyday operation, the battery inverters are operated in current-regulated mode. However, this mode does not allow island grid operation, but is mandatory for the provision of primary control power. For the island grid test, the inverters were previously switched to the voltage-controlled mode described above. This is currently done manually and requires the change of some settings, which still takes several minutes. With these settings, the inverters can switch seamlessly from grid-connected operation to island grid operation.

Before and after the island grid connection, the battery storage has regulated the residual load at the grid connection point against 0 A. Meanwhile, the measuring devices continuously recorded RMS values of current, voltage and power factor values at one-second intervals.

At the time of the island grid switching, the load of Bordesholm municipality was about 2.5 MVA. This already includes the feed-in of the photovoltaic systems of the municipality of Bordesholm and a total of 8 combined heat and power (CHP) systems. Their capacity at the corresponding time is unknown. This residual demand of 2.5 MVA was largely covered by the biomass plant with about 1.4 MW, while the battery compensated the remaining 1.1 MVA. The capacities changed during the island grid test in an order of magnitude below 10%.

4.1. Switching to island grid operation

The high-resolution measurement for the island network switching was triggered manually by means of a video transmission from the switching station. However, as the image was delayed by a few seconds, the measurement for the 1st island network connection was triggered just too late. Therefore, it was decided to repeat the switching. The 2nd switching was then successfully recorded with high resolution. Fig. 8 shows the voltage and current at the time of the island switching in a resolution of 128 samples per power supply period.

Figure 8 shows that the current at the grid connection point was regulated with a noise level close to 0 A. The switching can be recognized by the fact that suddenly no more current flows over the network connection point (at 15:23 h and 38,298 s). In the meantime, no changes in the voltage curve can be detected. Thus, the transition from interconnection to island grid operation was very stable and uninterrupted.

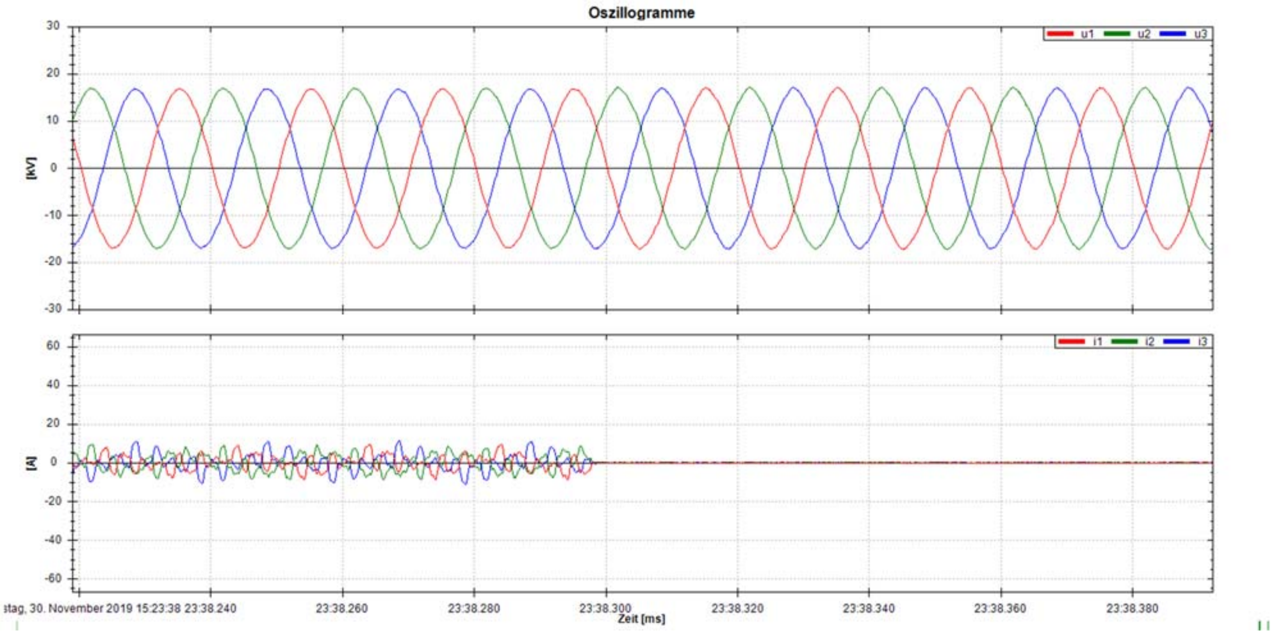

Figure 8: Measurement results in the island grid test: voltage and current at the grid connection point at the transition to the island grid without residual load.

4.2. Resynchronisation

To end the island grid operation, resynchronization by the battery system was initiated at approx. 15:57 hrs. The battery regulates the voltage and frequency of the island grid to the voltage and frequency of the interconnected network. Only when the voltage and frequency level and phase position match can the island network be seamlessly connected to the interconnected network again.

Fig. 9 and Fig. 10 show the temporal course of frequency and voltage level before, during and after the resynchronization process (highlighted in blue). The connection to the interconnected grid took place at the end of the area highlighted in blue (at 15:58 and 38 seconds).

Figure 9 clearly shows how the grid-forming battery system keeps the frequency of the island grid very stable between 50.005 and 50.01 Hz and actively adapts the island grid frequency to the fluctuating grid frequency in the interconnected grid when resynchronization starts.

Figure 10 shows that the three-phase voltage is reduced by approx. 30 V per phase in the resynchronization process and, after reconnection to the interconnected grid, jumps to voltage levels of 11.67 kV, 11.98 kV and 11.78 V for the individual phases. With this voltage jump, a transient process can be seen over approx. 10 s.

A high-resolution measurement of the reconnection to the interconnected system is shown in Figure 11. In this picture it can be seen that at the moment of reconnection, a higher compensating current flows over a period of approx. 60 ms (3 grid periods). Up to 60 A flows briefly at the peak and quickly normalizes to up to 10 A at the peak. At the same time, no change can be detected in the high-resolution voltage curve. Thus, the connection to the interconnected grid was stable and without disturbances.

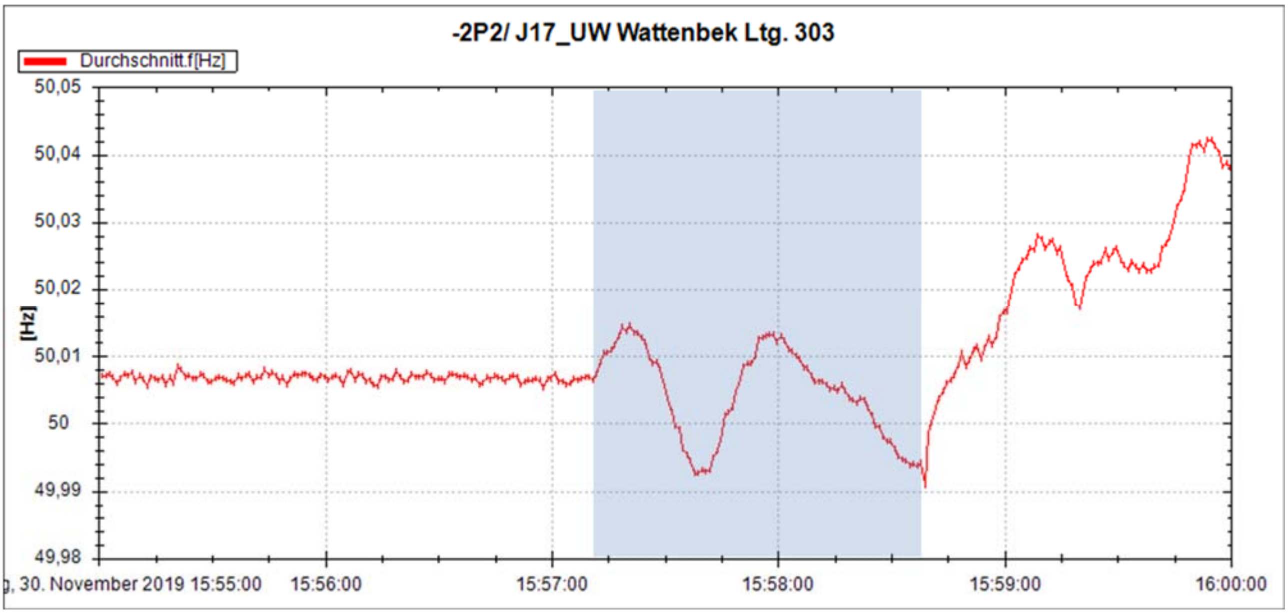

Figure 9: Measurement results in the island grid test: Grid frequency at the grid connection point when resynchronizing from island grid to interconnected grid operation.

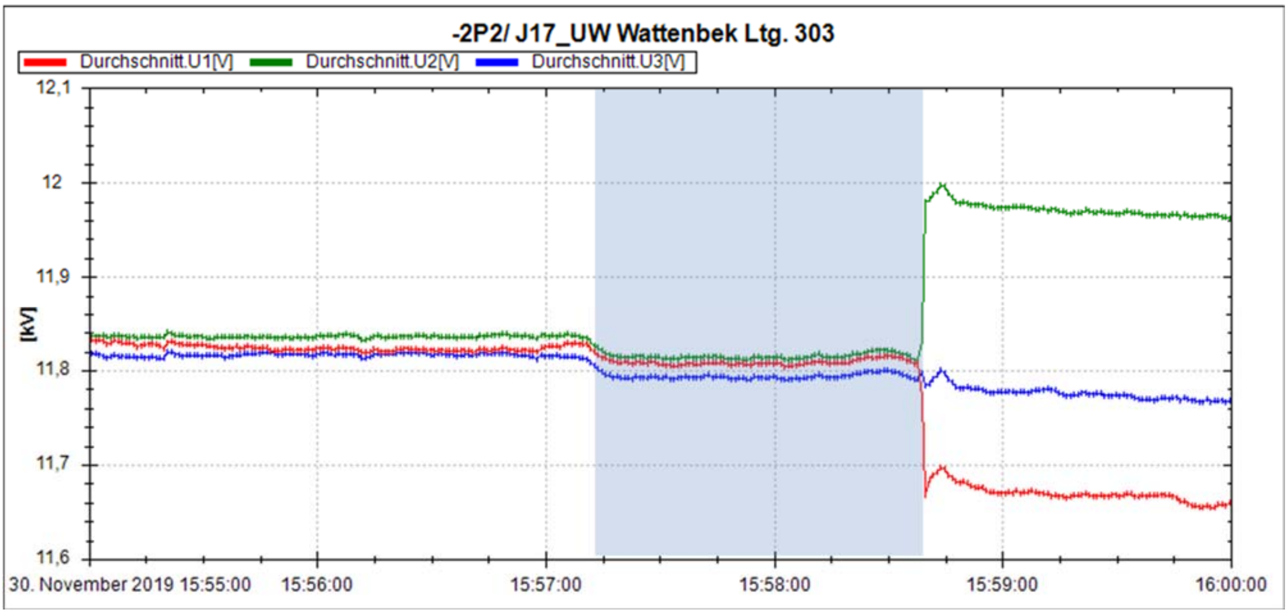

Figure 10: Measurement results in the islanding grid test: RMS values of the grid voltages at the grid connection point when resynchronizing from the islanding grid to interconnected grid operation.

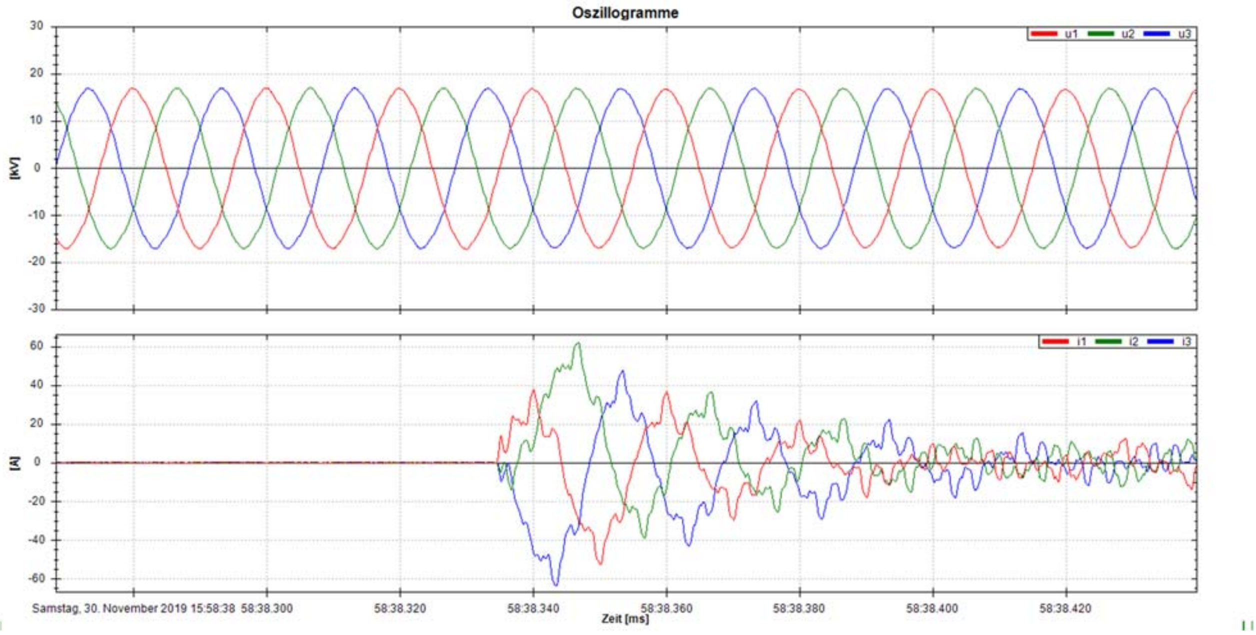

Figure 11: Measurement results in the island grid test: Voltage and current in high time resolution at the grid connection point when resynchronizing from the island grid to interconnected grid operation

4.3. Island grid operation

In the following, Fig. 12, Fig. 13 and Fig. 15 show the course of frequency, voltage level and voltage distortion over the entire period of the island grid test.

During the first transition to island operation (as mentioned above) not all planned measurements could be carried out completely. Therefore, between about 15:22 h and 15:24 h the grid of the municipality of Bordesholm was synchronized and connected to the interconnected grid again in order to carry out the transition to island operation a second time. With this second disconnection from the interconnected grid, all planned measurements could be carried out as planned. This temporary interruption is clearly visible in the voltage and frequency curve.

Figure 12 shows that the frequency is kept very constant and stable between 50.005 Hz and 50.01 Hz during the two periods of islanding operation, whereas the frequency in interconnected operation shows significant fluctuations. In particular, the phenomenon can be observed that in the interconnected grid high frequency jumps always occur on the hour, and then new auctions are always held on the spot market on the basis of load forecasts. The deviation between forecasts and real load flows then causes these frequency jumps.

Figure 13 shows that in interconnected operation the voltage of each phase is different. The voltage peaks before 3 p.m. are probably due to the switch-off of the switching fields as parallel coupling points to the upstream power grid of Schleswig-Holstein Netz AG. With the island grid circuit, the battery system forming the network takes over the sole voltage regulation. The battery inverter Central Storage of the company SMA is able to control each phase voltage separately and can thus eliminate the asymmetry in the voltage level. It can be seen that the voltage at the grid connection point is regulated very stable to approx. 11.82 kV per phase in islanding operation (corresponds to a chained voltage of approx. 20.47 kV).

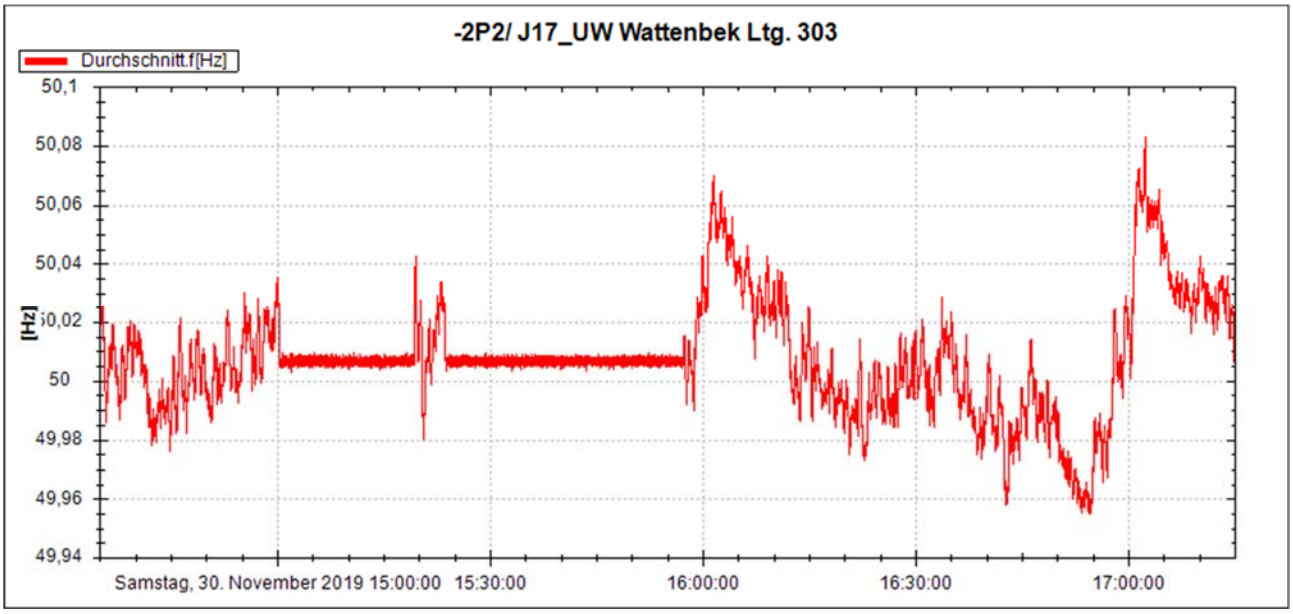

Figure 12: Measurement results in the islanding grid test: Grid frequency of the grid voltages at the grid connection point during the entire islanding network test.

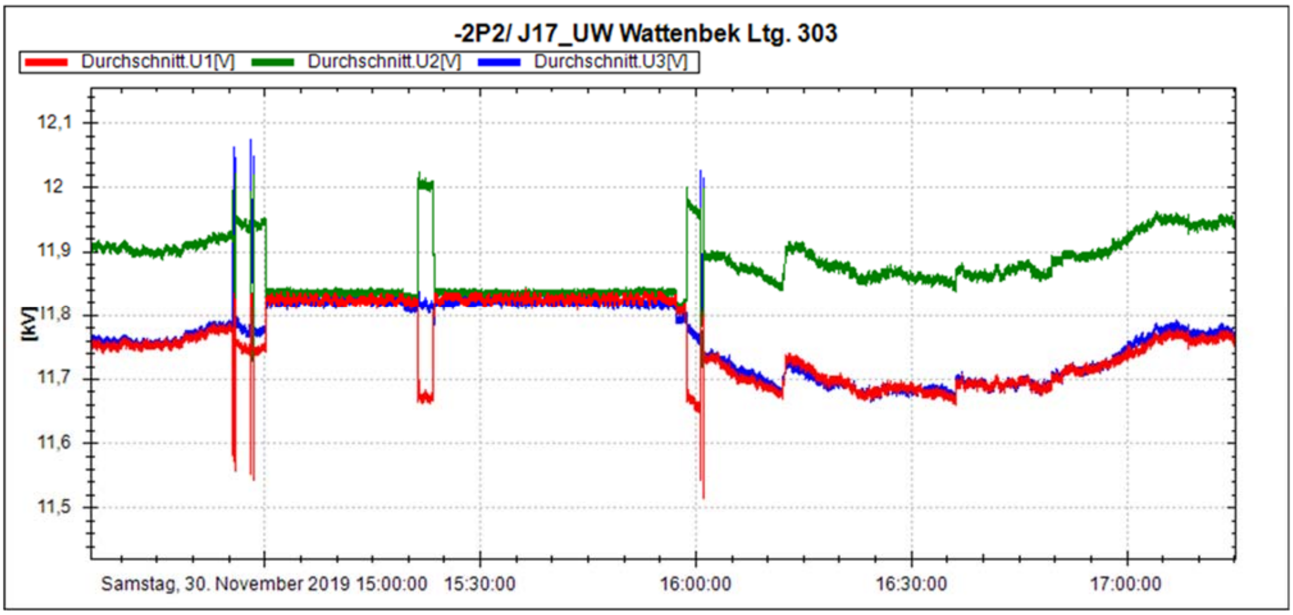

Figure 13: Measurement results in the islanding grid test: RMS values of the phase voltages at the grid connection point during the entire islanding grid test.

Figure 14 shows the respective sum of the phase currents on battery supply line 1 (top) and battery supply line 2 (bottom) during the entire island grid test. Battery strings 1 to 3 are connected via battery supply line 1 and battery strings 4 to 7 are connected via battery supply line 2. The sum of the two curves gives the total current supplied by the battery. The currents flowed from the battery into the mains over the entire duration of the test. On the one hand, it can be seen that the current is distributed very evenly over the entire duration to the respective battery strings. Furthermore, one can see that several small and one larger load jump occurred. The larger load jumps were mainly caused by the biomass power plant. This was further controlled by a marketer as if it was located on the interconnected grid. The testers had no influence on its performance. Annoyingly, a particularly large load jump occurred in the short period of time when island operation was interrupted. Therefore, this load jump could not be used to test the reaction of the battery system. Nevertheless, several load jumps and changes occurred during island operation. A comparison with Fig. 12 and Fig. 13 shows that these load changes hardly cause any measurable differences in mains frequency and mains voltage. This shows the excellent characteristics of the inverter control.

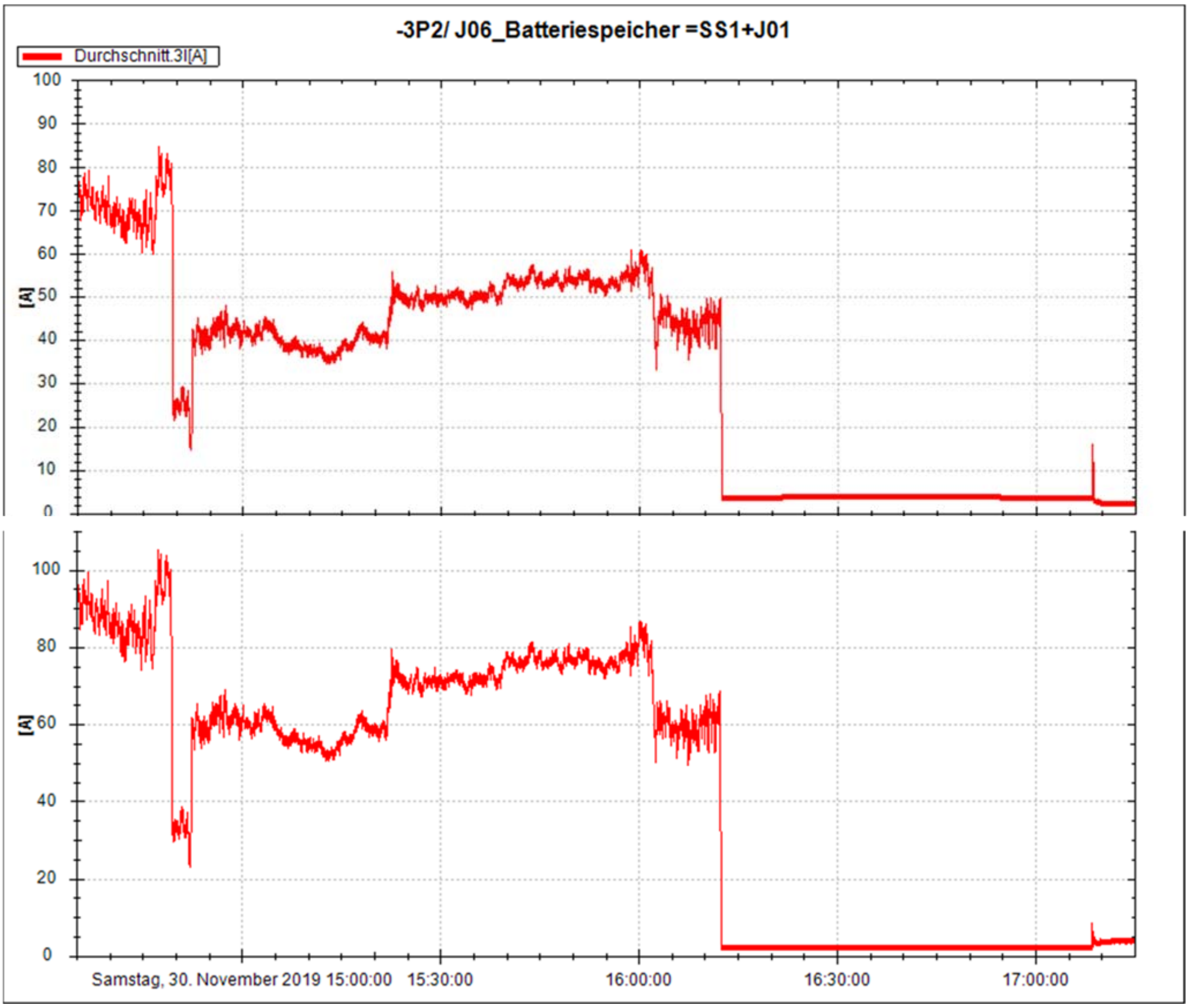

Figure 14: Measurement results in the isolated network test: Sum of the phase currents on battery supply line 1 (top) and battery supply line 2 (bottom) during the entire isolated grid test.

Additionally it is interesting to look at the course of the Total Harmonic Distortion of the phase voltage (THDU). This describes the total harmonic distortion of the voltage sine wave. Figure 15 shows the course of the total harmonic distortion of the phase voltage over the entire islanding grid test at the grid connection point. It can be seen from Fig. 15 that the THDU increases from approx. 0.7-1.2 % in interconnected operation during island grid operation to 1.3-1.8 %. This can probably be largely attributed to the control step of the battery inverter. In the high-resolution measurements, a clear ripple could be detected in the voltage sine wave, which could be explained by these control stages. However, the total harmonic distortion of the phase voltage of 1.8 % does not exceed critical limit values.

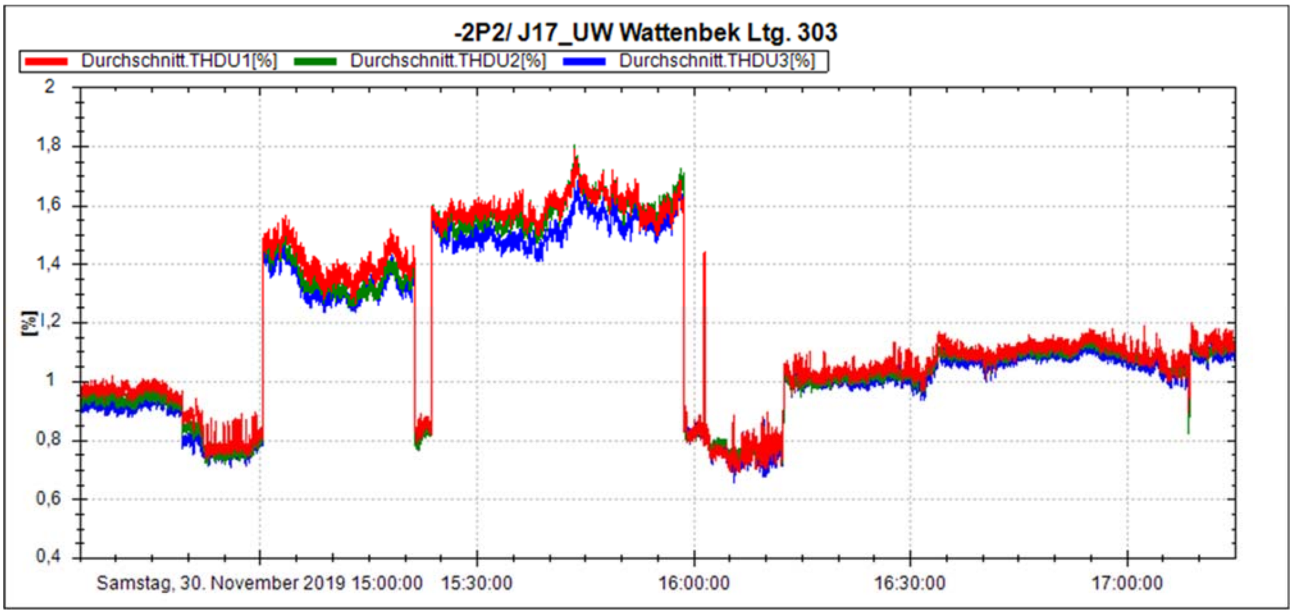

Figure 15: Course of the three-phase Total Harmonic Distortion of the voltage (THDU) during the entire island grid test at the grid interconnection point.

4.4. Decentralized feeders

During the entire test procedure, an inverter of a photovoltaic (PV) system was observed with a video recording. The PV system is located on the roof of the hall from which the experiment was coordinated. This inverter remained continuously in grid-connected mode and the island grid detection did not trigger in any case, which was intended. It can be assumed that the other inverters in the Bordesholm grid continued to work in the island mode and supplied the community with renewable electricity. The biogas plant also continued to supply electricity without any problems. This means that the battery inverters are able to maintain the island grid in such a way that decentralised feeders remain on the grid and can thus contribute to a longer-term power supply even in island operation.

During and after the test there was no negative feedback from customers. Although they were informed, they were unable to perceive the island grid connection.

5. Summary and conclusion

In this trial, an entire community was supplied with electricity for almost one hour using decentralized renewable feeders and a battery. The battery was responsible for balancing the feed-in and consumption in the power grid as well as for the regulation and grid stability of the power grid. Despite load changes, the grid frequency and grid voltage remained more stable than in interconnected grid operation.

The transition from interconnected grid operation and the back-synchronisation took place seamlessly and without electricity customers being able to notice the transitions. The course of the grid voltage showed no overvoltage or voltage drops and remained sinusoidal. Even in a high-resolution measurement, no disturbances in the course of the grid voltage could be detected.

The battery inverters from SMA were operated in a voltage-regulated mode, which allows both interconnected and isolated operation with a seamless transition. In everyday operation, however, the inverters are in current-regulated mode. Therefore, a seamless transition to island operation is currently only possible in planned mode. A spontaneous island grid operation, e.g. in case of an unplanned blackout, cannot be guaranteed seamlessly at present. However, after a black start of the battery, the Bordesholm municipality could be supplied with electricity again at short notice.

Overall, this trial shows that stable grid control based on decentralised renewable feeders is possible without large power plants.