EMERGENCY ISLAND OPERATION OF A MEDIUM-VOLTAGE UTILITY GRID WITH A LARGE BATTERY

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Abstract

The future electricity supply has to be secured by renewable energy sources. To achieve that, we suggest renewable powered subsystems, which are able to balance demand and supply within their local grid and, as an emergency backup option, can run in an island operation.
The utility of Versorgungsbetriebe Bordesholm (VBB) initiated a real-world laboratory of the energy transition. They put a Battery Energy Storage System (BESS) into operation to control the voltage and frequency of their micro grid system. The BESS of 15 MWh and 12.5 MW was realized by RES Deutschland GmbH (RES). In normal grid-tied operation, the BESS is pre-qualified for the frequency containment reserve (FCR) market. Only for the case of emergency, the battery should also be able to take over grid forming functions to operate VBB as an island grid.
During island operation, the consumers of VBB are supplied by distributed generators such as photovoltaic (PV) systems (approx. 1.4 MWp) and biomass power plants (2.4 MW), which also recharge the BESS in case of a supply surplus.
By means of a synchronous coupling switch at the grid connection point of VBB, the local grid can be disconnected from and synchronously reconnected to the public grid. This enables an island operation without interruption.
The aim of this paper is to proof whether the BESS as a grid-forming power plant together with PV and biogas plant is able to maintain uninterruptedly the power supply while switching into island operation or not. Real-world experiments on the VBB medium-voltage grid with the BESS alone showed a very stable grid-forming operation of the *SMA Sunny Central Storage* inverters. Even with an artificial load step during switching corresponding to occurring maximum load in the VBB medium-voltage grid of 4 MW, no interruptions or transients occurred. However, higher harmonics in the voltage profile occurred during one grid period after switching. The black start capability of the BESS could also be shown.
Finally, the experiment was repeated in a conservative way without any load steps including the whole medium-voltage grid of the VBB including distributed generators and consumers. The uninterrupted transition between grid-tied and island operation was very smooth and no disturbances were detected. This demonstrated the ability of the utility of VBB to supply their grid and customers in case of an upstream grid outage in an island operation in a manual way. To do this only with renewable energy sources is a milestone in the energy transition. Furthermore, the automated switching into island operation in case of any fault shall get enabled in a follow-up project.

1 Introduction

1.1 Motivation

In terms of the transition to 100% renewable energy supply, it is essential to adopt the grid-forming functions of today's conventional power plants. To achieve that, we suggest renewable powered subsystems, which are able to balance demand and supply within their local grid and, as an emergency backup option, can run in an island operation. It is imaginable, the future power grid mainly consists of microgrids which operate interlinked by means of a cellular power grid [1].

The municipal utility of Bordesholm, Versorgungsbetriebe Bordesholm (VBB), initiated such a real-world laboratory of the energy transition. RES Deutschland GmbH implemented a Battery Energy Storage System (BESS) of 15 MWh and 12.5 MW in the micro grid of VBB. In normal grid-tied operation, the BESS is pre-qualified for the frequency containment reserve (FCR) market. Only for the case of emergency, the battery should also be able to take over grid forming functions to operate VBB as an island grid. The consumers of VBB are supplied by distributed generators such as photovoltaic (PV) systems (approx. 1.4 MWp) and biomass power plants (2.4 MW), which also recharge the BESS in case of a supply surplus.
By means of a synchronous coupling switch at the grid connection point of VBB, the local grid can be disconnected from and synchronously reconnected to the public grid. This enables an emergency operation without interruption.

The BESS-project of VBB is comparable to a project of the regional utility of WEMAG, which also implemented a 15 MWh BESS in their grid to operate on the FCR market. However, the island capability of WEMAG was not implemented as in Bordesholm. [2]

Other projects which implemented an island capability in the german power grid is LINDA in Niederschönenfeld [3] and IRENE / IREN2 in Wilpoldsried [4]. The former mainly provides its island capability by means of a large hydroelectric power station. The latter is supplied by a lot of photovoltaic, biogas and wind energy power plants which generates a 500% supply surplus of the utilities demand. But a microgrid with a grid-forming BESS to this extend hasn't been realized yet.

1.2 Aim

The aim of this paper is to proof whether in Bordesholm the BESS as grid former together with PV and biogas plant is able to maintain uninterruptedly the power supply while switching into island operation or not. For this purpose, real-world experiments are examined.

2 Methodology

2.1 Operation paths of micro grids

In general, micro grids have different possibilities to achieve an island operation. The possible operation paths of micro grids between grid-tied and island grid operation are shown in Figure 1.

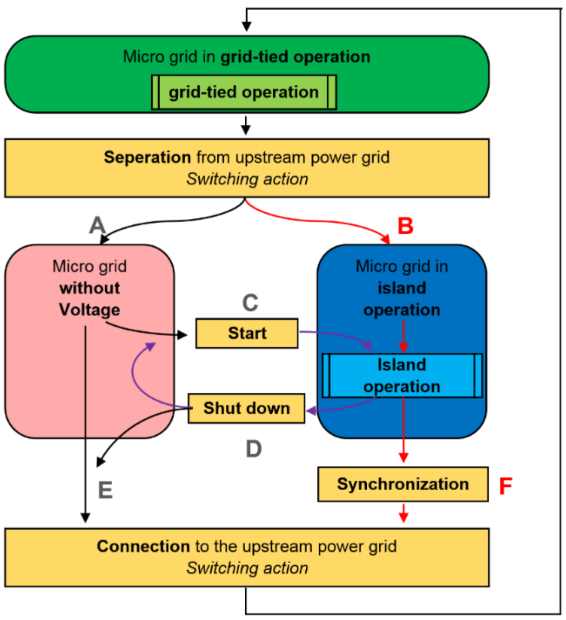


Figure 1: Possible operation paths of a micro grid between grid tied and island grid operation.

As shown in Figure 1, a micro grid can initiate an island operation by separation from the upstream power grid. To achieve an island operation, it can fall into a blackout (A) and then start (C) the island power grid or it can just try to maintain uninterruptedly the supply after separation (B). Although, to maintain uninterruptedly the supply after separation (B) takes much more effort and requirements for grid control. Similarly, the island operation can be terminated in to ways, too. Either way the island power grid can be shut down (D) and reconnected to the upstream grid in a state without voltage (E), or the frequency and phase of the island power grid has to get resynchronized to frequency and phase of the upstream power grid and then reconnected by means of a synchronous coupling switch (F).

The project in Bordesholm intends to implement the capability to go the operation path of B→F.

2.2 Power grid infrastructure and Measurement

The medium-voltage (MV) power grid infrastructure of the VBB utility and distribution of measurement devices of the VBB are shown in Figure 2. It consists of three branches connected to two ring main circuits with switches in Normally Open condition. Additionally, the biogas plant and BESS feed directly to the MV mains switchgear.

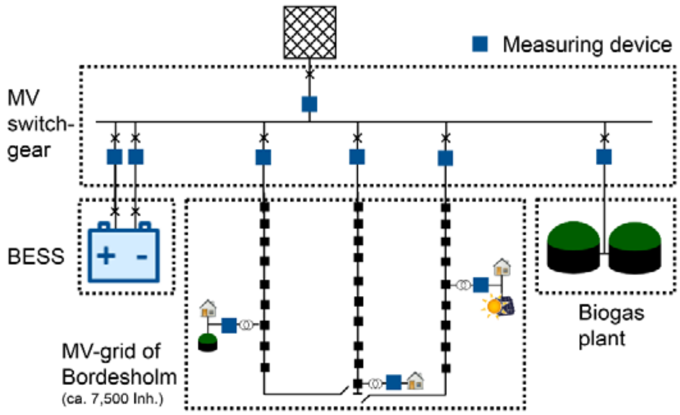


Figure 2: Power grid infrastructure and distribution of measuring devices of VBB.

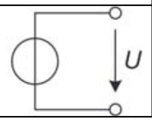
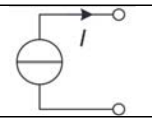
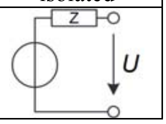
Seven measuring devices (UMD 98 by PQ plus) are centrally placed in MV switchgear at each terminal. Additionally, 3 measuring devices are installed at the low-voltage (LV) side of 3 substations. A seamless transition between island and grid-tied operation shall be achieved by means of a synchronous coupling switch at the grid connection point.

2.3 Inverter parameterization

There are several inverter behaviors which are presented in [5]: grid-forming, grid-feeding, grid-supporting. The differences between these behaviors are shown in Table 1.

The inverters of the BESS installed in Bordesholm are normally operated as grid-feeding inverters. Nevertheless, for island operation the parameterization can be changed to a grid-forming behavior, which works as in island operation like anideal voltage source.

Table 1: Electrical behavior of inverters [5]

	Grid-forming	*Grid-feeding*	*Grid-supporting*
Source type	Ideal voltage source	Ideal current source	Non-ideal voltage source
Control type	Const. frequency/ voltage	PQ control	Droop control
Output impedance	Z=0	Z=∞	Finite, nonzero
Output frequency	Fixed frequency	Grid synchronized	Frequency droop
Application	Island grid/ isolated	Grid-connected	Grid-connected or isolated
Equivalent circuit			

SMA Input zu der Parametrierung?

2.4 Experiments

A series of experiments were executed, but this paper only presents the most relevant ones. In general, following capabilities were tested according to the chosen operation path B→F (cf. Figure 1):

- Uninterrupted supply during manual switching into island operation
- Stability of supply during island operation
- Frequency and voltage resynchronization to upstream public grid
- Uninterrupted supply during switching into grid-tied operation
- Black start by means of the BESS

In order to test a scenario as realistic as possible, the BESS was used both as a "virtual load Bordesholm" and as a grid former. shows the corresponding experimental setup with a virtual load corresponding to the maximum load of the VBB demand (4 MW).

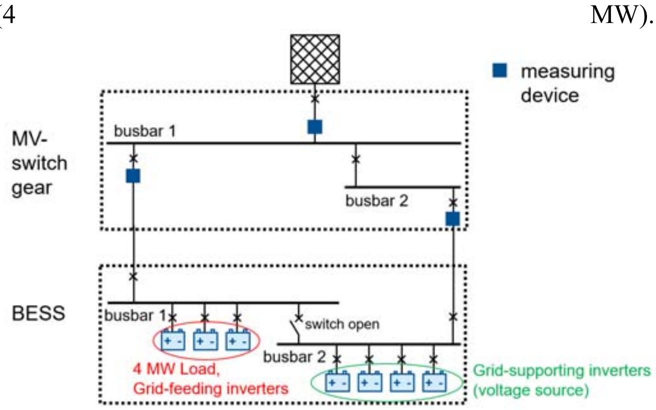


Figure 3: Experimental setup to test grid forming capability (green inverters) of the BESS with a "virtual load Bordesholm" (red interverters)

Once the experiments were successful, the experiment was finally repeated including the entire MV power grid of VBB (cf. Figure 2) in a conservative way without any intended load steps.

3 Results

3.1 Uninterrupted supply during switching into island operation

The worst case to test the capability of uninterrupted supply during switching into island operation corresponds to the experimental setup of . Figure 4 shows the measured 3-phase voltage (above) and current (below) in two time scales during the switching action.

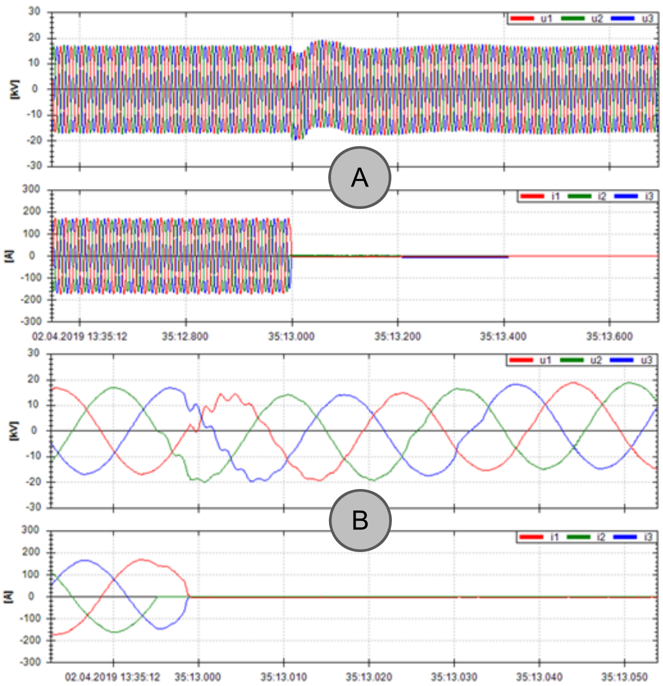


Figure 4: Time course of voltage (above) and current (below) in A: large Scale (1 sec) and B: small scale (60 ms) during switching into island operation

3.2 Stability of supply during island operation

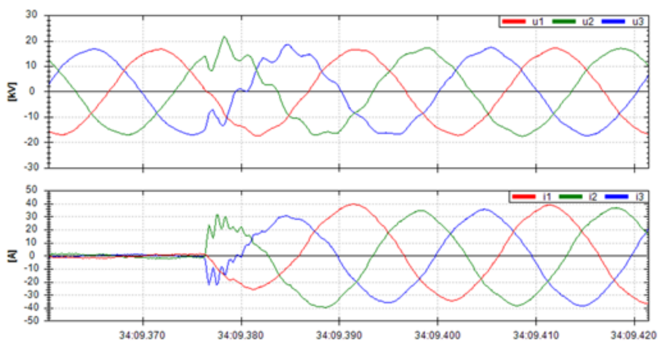


Figure 5: Time course of voltage (above) and current (below) in small scale (60 ms) during an instant load step of 1 MW in island operation

3.3 Frequency resynchronization to public grid frequency

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3.4 Uninterrupted supply during switching into grid-tied operation

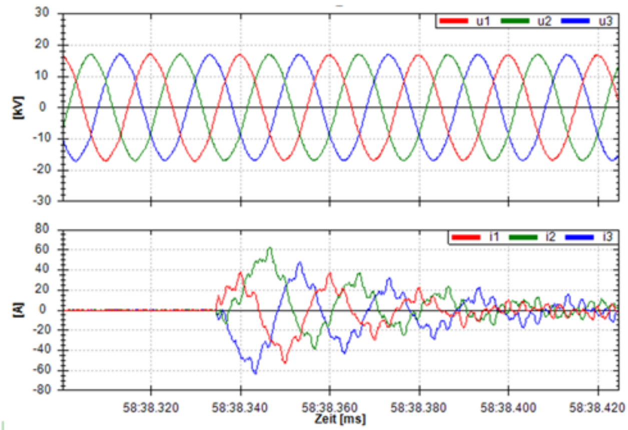

Figure 6: Time course of voltage (above) and current (below) in small scale (60 ms) during switching into grid-tied operation

3.5 Black start by means of the BESS

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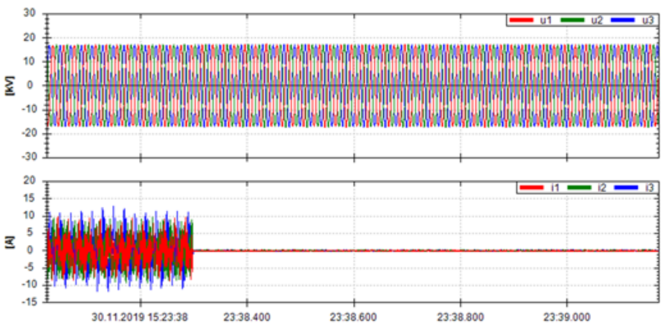
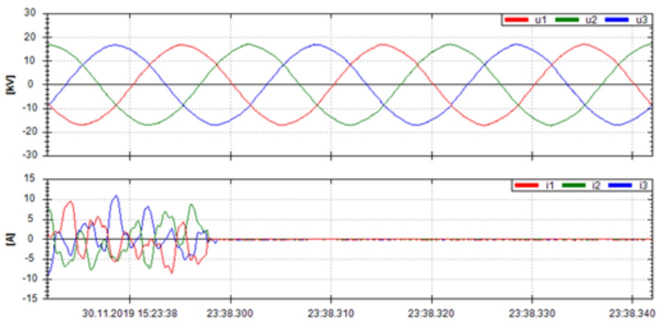
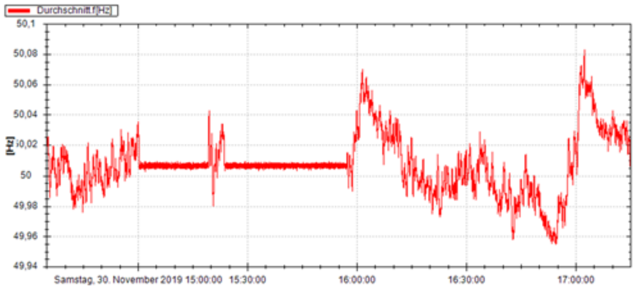
3.6 Final experiment with the whole MV utility grid







4 Conclusion

- *Wirtschaftlichkeit auch gegeben*
- *Technik ist so schon verfügbar*
- *Inselnetzfähigkeit von MV power grids ist machbar!*

5 Acknowledgements

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