Results for a MV-Hybrid-Microgrid Test Campaign in the MW-Range

Moritz Bader, Roland Singer, Christoph Siedle
Department Power Electronics and Grid Technologies
Fraunhofer Institute for Solar Energy Systems ISE
Freiburg, Germany
moritz.bader@ise.fraunhofer.de

***Abstract*— To Control voltage and frequency in Microgrids with generation coming largely from power electronic devices, new control schemes need to be implemented for inverters. A droop control has been developed and implemented as part of research project "Zukunftskraftwerk PV" which is supported by the German Federal Ministry of Economic Affairs and Energy (BMBF, Funding Number: 0325768E). A laboratory setup was built, consisting of an inverter with 1 MVA, a second inverter with 725 kVA, a diesel genset with 270 kVA and a load bank with 1.5 MVA apparent power. The control mode of the inverters could be changed between a standard current controlling mode, used in PV plants and the droop control. The objective of the tests was to examine the behavior of the control in different scenarios, such as falling to island mode with imbalance of power production and consumption within the Microgrid, and applying load steps to check the power sharing between the sources and changes in frequency and amplitude of the voltage in island mode. This paper presents details about the concept of the droop control and a discussion about results, gained from the tests.**

Keywords-micro grids; droop control; grid sustaining; diesel hybrid systems

I. INTRODUCTION

Control of Inverters can be categorized according to figure 1. There are two main categories, the current controlling type (current source) and the voltage controlling (voltage source) type with two subcategories each. For current controlling those are grid feeding and grid supporting. Both are used to inject a certain power into the grid (Maximum Power from the MPPT in case of PV plants). Grid supporting type offers additional system services, like reactive power injection in case of line faults, required by national grid codes. Again, in both cases, the inverter behaves like a current source that synchronizes with the grid frequency. Therefore a standalone operation of inverters with current controlling type of control in island grid is not possible. For standalone operation of Inverters in island grids the control needs to be voltage controlling. Subcategories here are grid forming and grid sustaining. Grid forming inverters behave like ideal voltage sources, creating a voltage of fixed amplitude and frequency. Parallel operation of grid forming inverters without communication between the devices is not possible. Grid sustaining inverters can be used in parallel or single operation in island grids or connected to the mains grid. They are synchronizing without additional communication and adapt their voltage amplitude with Droops for active and reactive power sharing. Grid sustaining control can be used in rural areas with a weak grid connection or even no connection to the mains grid at all. In these areas often diesel gensets are installed which could be downsized or completely replaced by inverters. This paper presents measurement results on how Droop control inverters work in parallel with each other, a diesel genset or inverters with current controlling type of control.

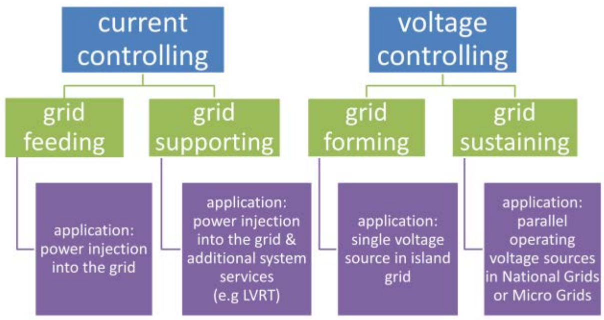

Figure 1. Categorization of different inverter control techniques

II. IMPLEMENTATION OF DROOP CONTROL

Figure 2 shows the implementation of the droop control, used for the inverters. There are droops for both, active and reactive power. The measured output Power of the inverter is compared with the power set points P_{ref} and Q_{ref}. Multiplication with the droop coefficients k_p and k_q leads to a value for the phase angle and amplitude of the voltage. A voltage drop over virtual impedance is added, to ensure a stable operation when the mains impedance or the impedance between inverter and other power sources is rather small. The voltage is controlled by a highly dynamic voltage controller. In case of grid disturbances like overload or short circuits, the current of the inverter needs to be limited. Therefore, the controller is equipped with an alternating current limiting functionality.

Funded by the Federal Ministry of Economic Affairs and Energy of Germany (funding code 0325768E)

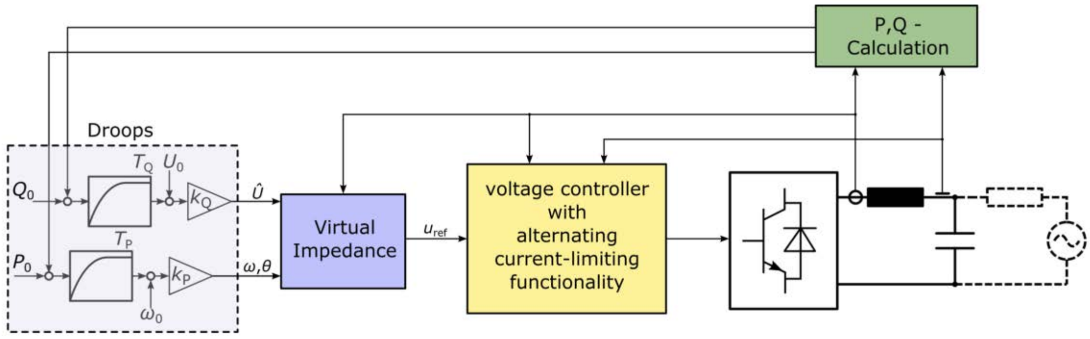

Figure 2. Implementation of Droop-Control on DUT 1 and DUT 2

III. Measurement Setup

In Figure 3 the measurement setup can be seen. Two inverters one 1 MVA and the other with 727 kVA, a 1.5 MVA load bank and a 270 kVA Diesel Genset are forming a Microgrid. The devices are connected via two MV/LV-transformers, one LV/LV-transformer and optional low and medium voltage chokes to simulate weaker grid conditions. The connection of the Microgrid to the mains grid can be cut during operation to simulate a loss of mains. The DC-Side of the first inverter DUT 1 is supplied by a unidirectional dc-source with 1000 kW maximum output power. This device is used as a PV-inverter or Droop-controlled inverter and is connected to the medium voltage grid threw the transformer. The dc-source of the second inverter is bidirectional and has a maximum power of 600 kW. Here, only the droop control described above is implemented. The device is connected to a low voltage transformer. On the other side of the transformer the load bank and the genset are connected. The Genset has the ability to run in idle mode for about 24 h and can be configured in two control modes, either P-cos(φ)-control or droop control. Genset, load and DUT 2 are connected to the medium voltage level threw the second LV/MV-transformer.

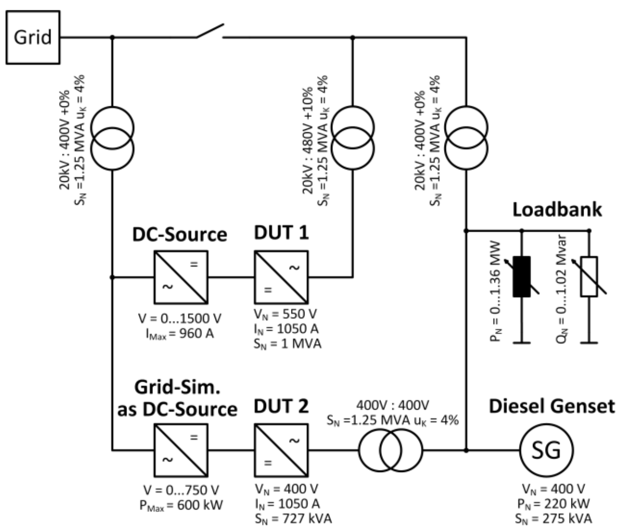

Figure 3. Laboratory Setup

TABLE I. Nominal Values and Control Methods of Generation Units

	DUT 1	***DUT 2***	***Diesel Genset***
Nom. Voltage V_N	550 V	400 V	400 V
Nom. Frequency f_N	50 Hz	50 Hz	50 Hz
Nom. Apparent Power S_N	1 MVA	725 kVA	275 kVA
Nom. Active Power P_N	900 kW	600 kW	220 kW
Power Factor cos(φ)	0.9	0.83	0.8
Nominal Current I_N	1050 A	1050 A	397 A
Control Method	PV-Mode or Droop Ctrl	Droop Ctrl	Droop Ctrl or P-cos(φ)-ctrl
Droop Coefficient k_P	1% f_N/P_N	1% f_N/P_N	1% f_N/P_N

IV. Measurement Results

The setup shown in the previous chapter was used for several tests to see the stability of the Droop-Controlled inverter DUT 2 in different scenarios. In this chapter, a few representative results are presented.

A. *Falling to Island with two Droop-Controlled Inverters and Diesel-Genset in P-cos(φ)-Control*

At the beginning of the test, the switch at the connection to the mains grid is closed. Both devices DUT 1 and DUT 2 are in Droop-Controlled-Mode and the Genset is in P-cos(φ)-Controlled-Mode. A load of 500 kW is set at the Load bank. DUT 1 is feeding in 120 kW, the Genset injects its nominal power of 220 kW. DUT 2 consumes 25 kW. With these settings, an additional active power of about 100 kW is contributed via the mains grid connection. Then the connection is opened and the load inside the island grid has to be fed by the inverters and the Genset. Figure 4 shows phase currents and voltages of Genset, Load Bank, DUT 1 and DUT 2. DUT 1 and DUT 2 are sharing the residual load from the moment of disconnection. The genset is just feeding the power which is set by the power set point all the time.

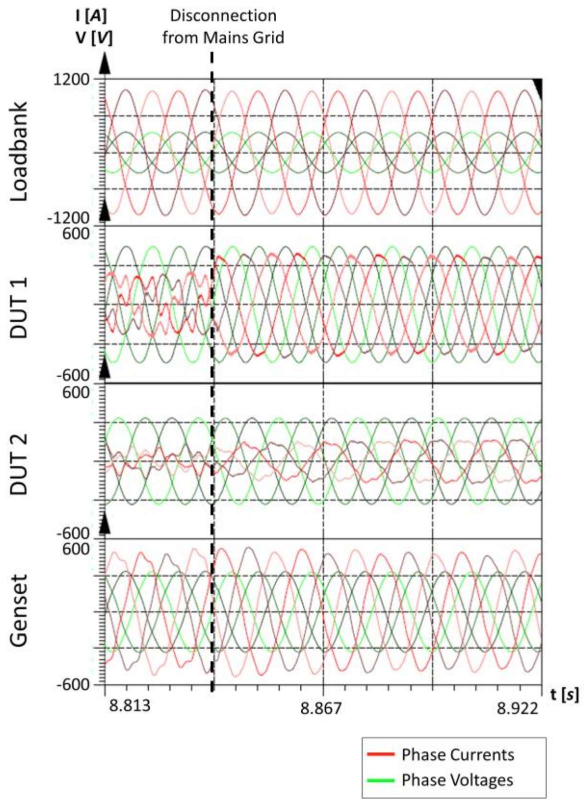

Figure 4. Falling to Island

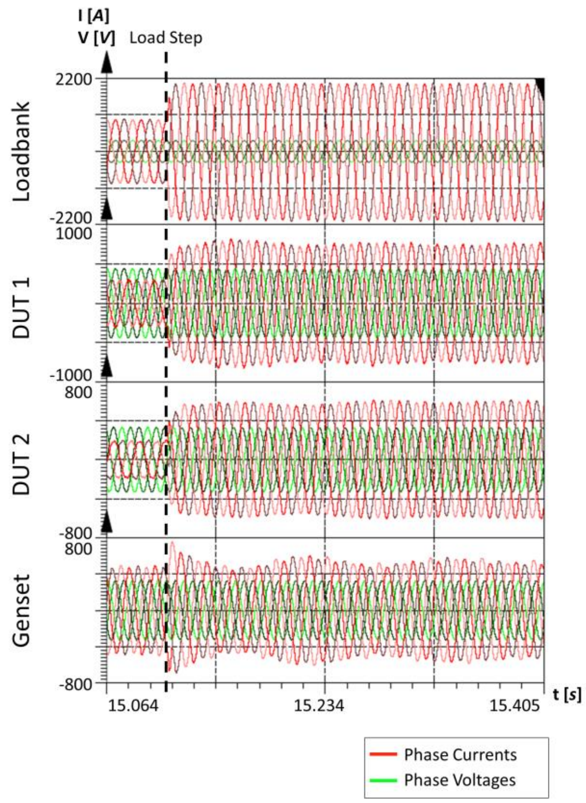

Figure 5. Load Step in Island with two Droop-Controlled Inverters and a Genset in P-cos(φ)-Control

B. Loadstep in Island with two Droop-Controlled Inverters and a Genset in P-cos(φ)-Control

Initial Situation for this test case is the same as the final situation from the previous Falling to Island Test in A. A Load of 500 kW is supplied by DUT 1 and DUT 2 with Droop Control and the Diesel Genset with P-cos(φ)-Control. DUT 1 feeds in 190 kW and DUT 2 feeds in 60 kW. The Genset runs at nominal Power with 220 kW and a cos(φ) of 0.8. Then a load step to 1000 kW is applied. Figure 5 shows the phase currents and voltages of the sources and the load bank. Looking at the currents, the settling process of the power sharing between inverters and genset can be seen. Because of the inertia, the genset raises its power right after the step occurs and the P-cos(φ)-Control reduces it back to the set point at nominal values. Also DUT 1 and DUT 2 are raising their feed-in power immediately. After the genset is back to its set point at nominal values, the additional 500 kW is shared between the two inverters. Now DUT 1 injects 500 kW and DUT 2 290 kW. The power sharing is achieved via the Droop Coefficients that lead to a new stabile situation at a new frequency value. Before the event the frequency was at 50 Hz and afterwards at 49.8 Hz. This way the load step is handled without any interruptions or instabilities and the load is supplied without oscillations. To get back to nominal frequency a secondary control needs to be implemented, which was not part of the simulation setup and should be tested in future scenarios.

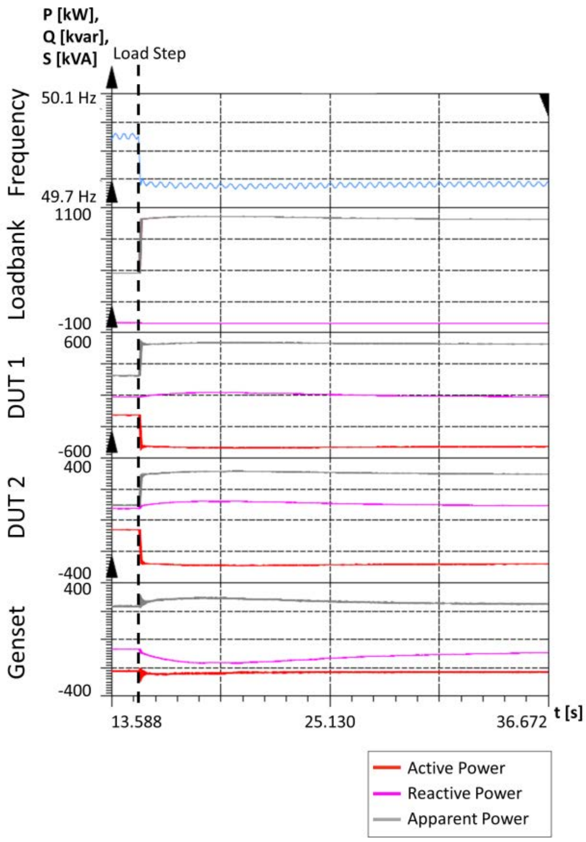

Figure 6. Frequency, Acitve, Reactive and Apparent Power for situtation in figure 5

C. Loadstep in Island with a PV-Inveter, a Droop-Controlled Inverter and Genset with P-cos(φ)-Control

DUT 1 is in PV-mode, DUT 2 uses Droop control and the Genset feeds in constant active and reactive power in P-cos(φ)-Control. In this setup DUT 2 is the only grid forming generator. Initially the load of the Island is 500 kW then the value is raised to 900 kW. DUT 1 is set to feed in a constant 590 kW and the Genset feeds in 115 kW with a cos(φ) set to 0.9. Figure 7 shows active, reactive and apparent power of the load and the sources. The step results in a raise of active and reactive power of the Genset. The values are controlled back to the set point in about 30 s. In the final state, DUT 2 provides the additional demand of 400 kW by changing from consuming 200 kW to feeding in 200 kW.

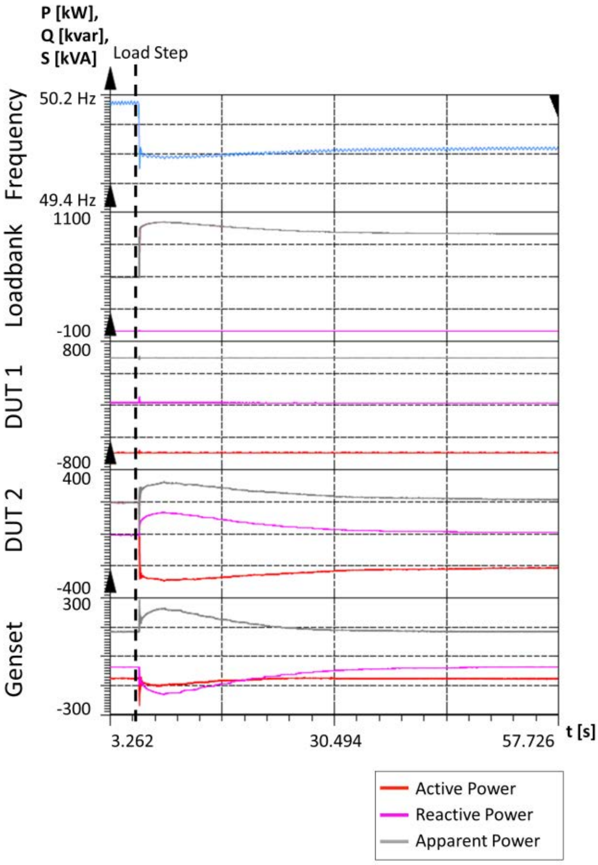

Figure 7. Load Step in Island with PV-Inverter, Droop-Controlled Inverter an Genset with P-cos(φ)-Control

D. Load Step Ohmic-Inductive with two Droop-Controlled Inverters

For the scenario in figure 8 the Genset is shut down, DUT 1 and DUT 2 are in Droop-Mode. The load given by the load bank is 750 kVA with cos(φ) = 1. DUT 1 feeds in 485 kW and 70 kvar inductive power, DUT 2 injects 276 KW and 54 kvar capacitive power. Then the load is changed to 810 kVA with cos(φ) = 0.81. The changes of active and reactive power are shared between the two Droop-Controlled inverters. The resulting power values are 445 kW active and 360 kvar inductive reactive power from DUT 1 and 245 kW and 150 kvar inductive reactive power from DUT 2. Active and reactive power of the load are not changed immediately, but in short steps, due to the switching procedure of the load bank. However with only two Droop-Controlled inverters, without Genset, a static situation is reached almost immediately after all changes.

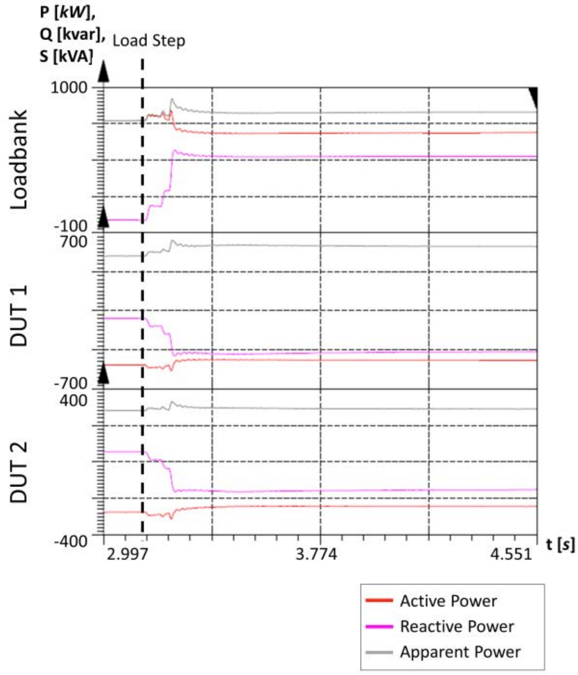

Figure 8. Ohmic-Inductive Load Step with two Droop-Controlled Inverters

E. Current Limiting in Overload Situation

In this scenario the connection to the Mains Grid is open as well and the Inverters, the Genset and Loadbank are forming an Island Grid. DUT 1 is in PV-Mode and DUT 2 and the Genset are in Droop Control Mode. Figure 9 shows active, reactive and apparent power of sources and Load Bank. At the beginning DUT 1 feeds in 785 kW, DUT 2 is around 0 kW and the Genset injects 35 kW. This way almost all the load is supplied by DUT 1, which is a current controlled PV-inverter. Then DUT 1 is shut down resulting in a sudden demand of 785 kW that needs to be provided by the remaining sources. Because droop control of the genset is too slow and the load step is higher than the maximum power of DUT 2 the shut-down of DUT 1 results in a transient overload situation for DUT 2. Initially the inertia effect of the Genset raises the active power output so the total output of the sources is sufficient. But this effect is only for about one grid period. Then the power of the genset is oscillating for about 0.7 s until the power is finally raised depending on the droop coefficient. During the oscillations, DUT 2 periodically is in an overload situation. Here the voltage control is alternated by the current limiting controller. The current limiting effect can be seen at the phase voltages and currents in figure 10. They lose their sinusoidal form but despite that, the system is kept in a stabile state and after the Gensets power is raised, DUT 2 comes back to normal operation. This way a blackout of the Island Grid is prevented.

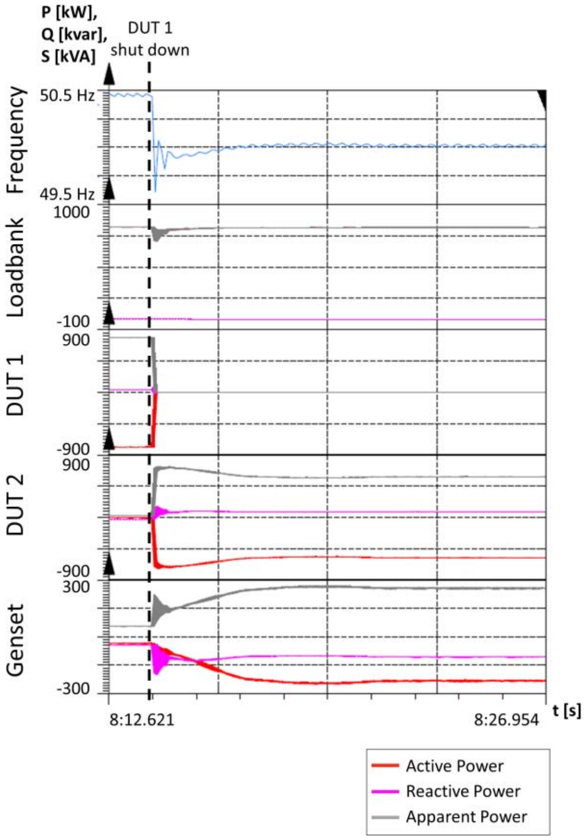

Figure 9. Overload Current Limiting from DUT 2 due to PV (DUT 1) shut down

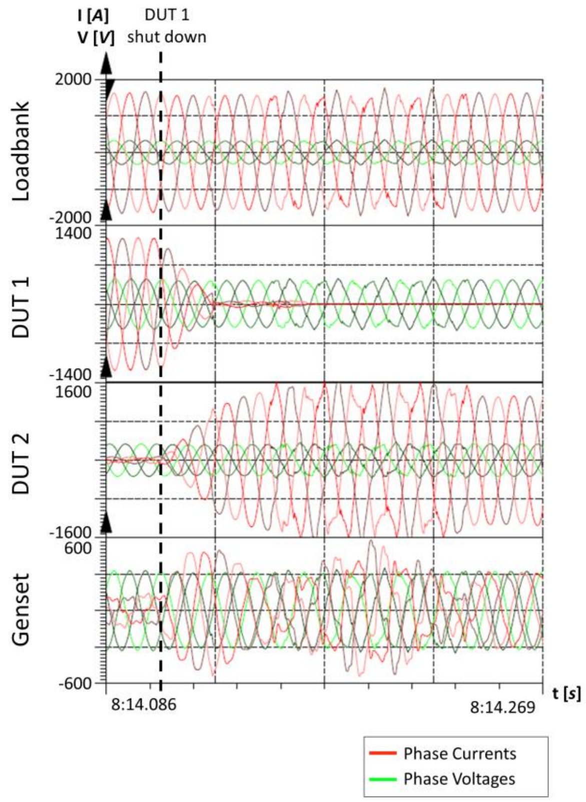

Figure 10. Overload Current Limiting from DUT 2 due to PV (DUT 1) shut down, Currents and Voltages

F. *Blackstart*

For blackstart tests the voltage amplitude of a single inverter is ramped up from 0 to nominal voltage in 2 s. Once the voltage has reached the nominal value, the other sources are activated. Figure 11 shows the blackstart with DUT 2 and a load of 400 kW.

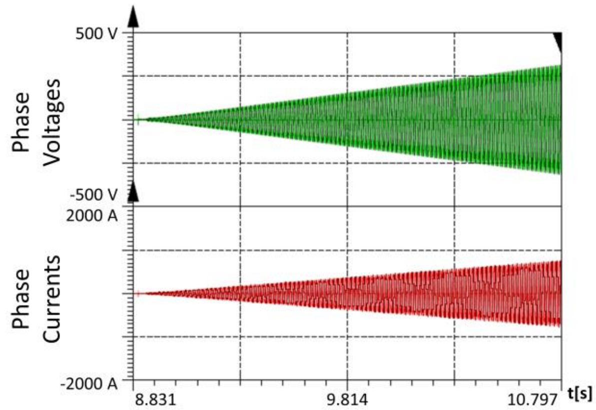

Figure 11. Blackstart of DUT 2 with 400 kW Load

SUMMARY AND OUTLOOK

A Droop-Control for a Microgrid has been successfully implemented on two inverters, one with 725 kVA and one with 1 MVA nominal apparent power. The control has been tested in a 20 kV Medium Voltage laboratory test environment, including a 275 kVA Diesel Genset and a 1.5 MVA load bank. With the test setup, the Droop control was tested in different scenarios. The inverter reacts fast to load changes as well as changes in generation by other sources. This reduces the stress on Gensets by reducing the active power gradient. The control has the ability to handle overload situations. It was shown, that a parallel operation with a Diesel Genset is possible as long as the droop coefficients are parametrized properly. During the tests, the parametrization was done manually. In further experiments, a grid management with secondary and tertiary control should be added to adapt the droop coefficients automatically. With this grid management resynchronization of a Microgrid to the mains grid should be tested too.

REFERENCES

[1] K. de Brabandere, “Voltage and frequency droop control in low Voltage grids by distributed generators with inverter front-end”, Dissertation, Katholieke Universiteit Leuven, 2006

[2] A. Engler, “Droop control in LV-grids”, International Conference on Future Power Systems, Amsterdam, 2005

[3] S. Reichert and R. Singer, “Stability analysis of droop-control in diesel-hybrid systems”, IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), 2016