INTERCONNECTION MANAGEMENT IN MICROGRIDS

Michel Vandenbergh, Alfred Engler, Randolf Geipel, Markus Landau, Philipp Strauss

ISET e.V. Division of Engineering and Power Electronics Königstor 59, D-34119 Kassel
tel +49-561-7294103 fax +49-561-7294200 mvandenbergh@iset.uni-kassel.de

Introduction

Microgrids comprise low voltage distribution systems with distributed energy sources, storage devices and controllable loads, operated connected to the main power network or islanded, in a controlled and coordinated way. The operation of microgrids offers distinct advantages to customers and utilities, i.e. improved energy efficiency, minimisation of overall energy consumption, reduced environmental impact, improvement of reliability and resilience, network operational benefits and more cost efficient electricity infrastructure replacement.
In order to validate the different functions of a microgrid, a specific test configuration has been set up in the Design Centre for Modular Systems Technology (“DeMoTec”) of the Institut für Solare Energieversorgungstechnik (ISET). In this highly innovative microgrid configuration, the grid control is distributed among three distant inverters which are not linked by any fast communication link. For primary control purposes, the sharing of power between these different grid-forming inverters is made possible using the selfsync™ algorithm.
Several critical situations have been studied, which included the transition from interconnected to island operation after a fault on the main grid or the transition from island to interconnected operation (Re-connection to mains after fault, microgrid black start). In all these situations, the microgrid has demonstrated that it is today possible to combine a reliable uninterruptible power supply with the integration of a high penetration level of renewable energy sources (wind and PV).
Concerning the secondary control of the inverters, the implementation of a microGrid supervisory controller was a crucial task for the demonstration of the microgrid in ISET’s DeMoTec. An adapted communication environment based on internet and XML-RPC has been set up in order to allow the microgrid supervisory controller to send control set points to the local generator controllers (Remote Terminal Units) of the different power units.

Microgrid test configuration

The three-phase microgrid under test includes the following components:

- 3 grid forming units (2 battery units and 1 diesel generator set)
- 2 renewable energy generators: PV and wind
- several loads with different priority levels
- several automatic switches for sectionalizing the microgrid into up to 3 “low voltage” island grids, in order to increase the reliability.

- supervisory control for a fully automatic operation of the microgrid (disconnection, re-connection, black-start, optimal dispatch)
- Connection to main medium voltage grid via a 100 kVA transformer
- A purely resistive line simulator with a resistance of 230 mOhms, representing about 400 meters of a typical rural low voltage line (NAYY 4*50 SE) has been inserted between the microgrid bus and the Battery Inverter 1.

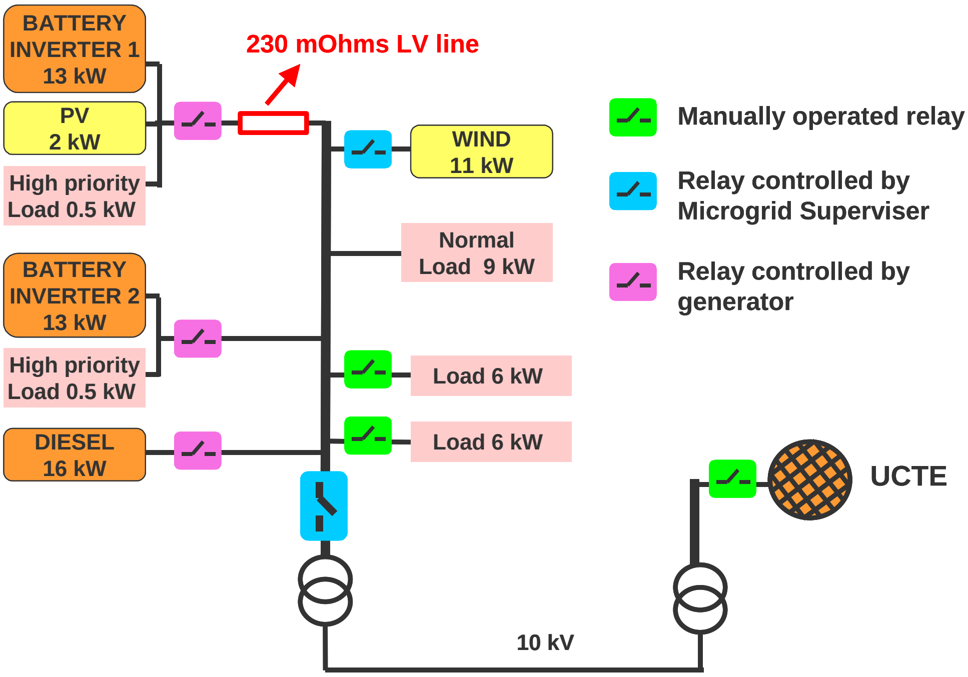

Figure 1: Layout of the microgrid installation in the DeMoTec

Testing the island mode

The island mode of operation has been validated on the DeMoTec microgrid. The test has demonstrated that two battery inverters with active power/frequency droops can share their active power in island mode even if the distance from the main load to each battery unit is very different. As is shown on Figure 1, a simulated low voltage line has been inserted between the battery unit 1 and the microgrid bus. The battery unit 2 is directly connected to the microgrid bus. This simulated line with a resistance of 230 mOhms, represents about 400 meters of a typical rural low voltage line (e.g. NAYY 4*50 SE).

Figure 2 and Figure 3 present the results of the islanding test. The actions of the supervisory controller are also visible. The high impedance fault on the main grid with the consequent islanding of the microgrid happens at time t1=2083.27. At time t2=2400, after the diesel start, the supervisory controller, sends a new setpoint to the diesel in order to reduce the power of the battery units to zero. The remaining power fluctuations are due to the variations of both the load profile and the wind power production. A new event was an increase of the microgrid load by 6 kW (2 kW per phase). We can see the immediate response of the battery inverters which take each half of the new load. After a while, the new set point of the diesel is sent by the supervisory controller and battery powers are close to zero. The last event at time t3=2500 is the reduction of the microgrid load by 6 kW (2 kW per phase). Again, instant response of the battery inverters which take each half of the extra energy till the supervisory controller sends a new power setpoint to the diesel unit.

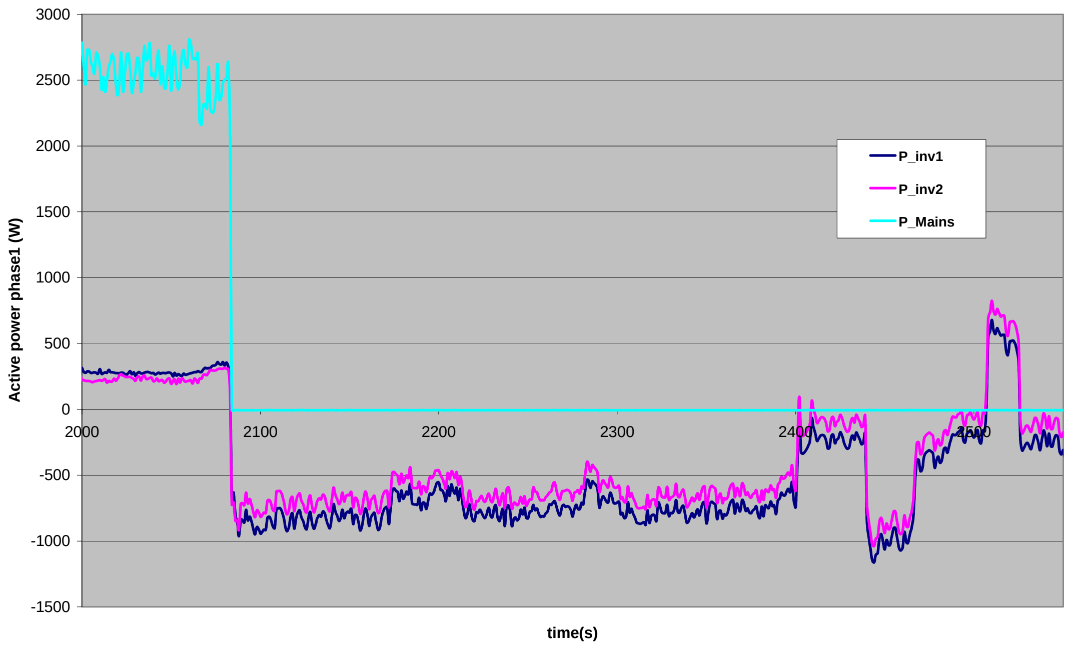

Figure 2: Inverters sharing power on phase1 before and after microgrid islanding

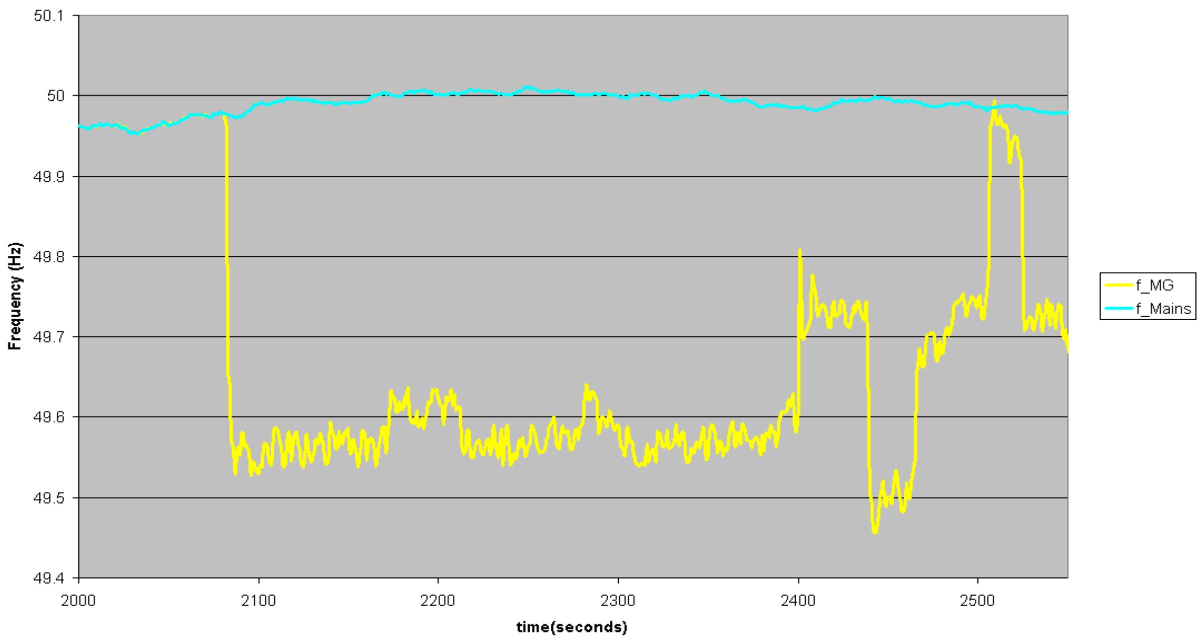

Figure 3: frequencies of mains and microgrid before and after microgrid islanding

Validation of emergency functions

The supervisory controller emergency functions have been validated on the microgrid described on Figure 1. The black-start procedure is well illustrated by the frequency plot in Figure 4. At the start, the microgrid is splitted in three island systems. Each battery inverter is powering its internal protected grid and the main microgrid bus is out of voltage. We assume also a power failure on the main grid. The first action from the microgrid supervisory controller is to start the back-up diesel unit, which restores the voltage on the microgrid bus (light blue line). The two battery inverters then automatically synchronize to the microgrid bus. In order to do this reconnection smoothly, they reduce their frequency. The batteries are then charged by the diesel unit. After restoration of the Mains, the microgrid central controller activates the synchronizer of the microgrid switch and after a few seconds, the whole microgrid is back in grid connected operation.

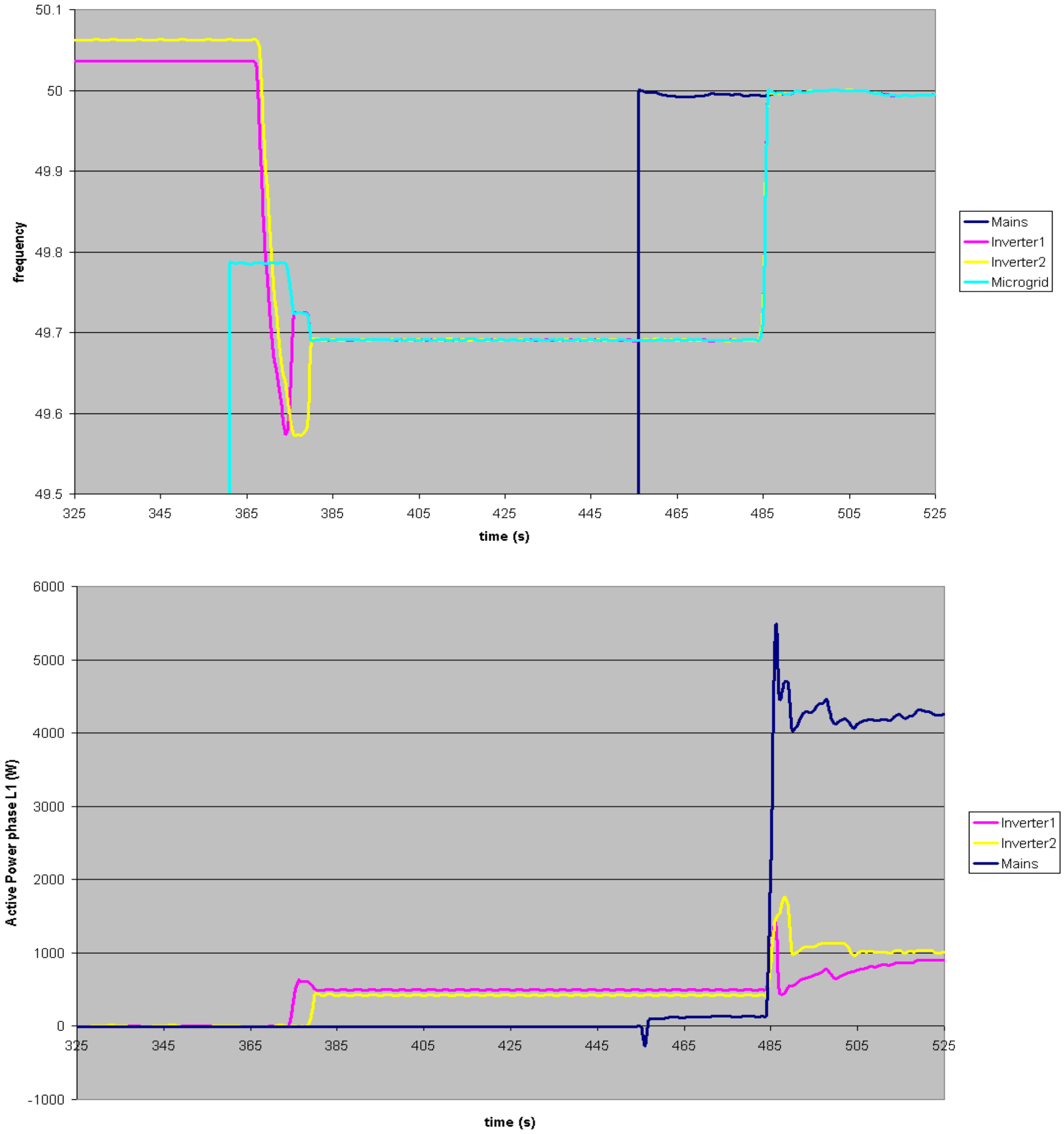

Figure 4: Black-start test: frequency and active power on phase 1

Figure 4 presents also active power on phase L1 during black-start. Power is provided to both inverters first by the diesel unit (370s < time < 485s), and secondly by the main grid. After restoration of mains and before synchronization (455s < time < 485s), the little power provided by the mains is due to the losses in the 0.4/10 kV transformer. After synchronization, the power provided by the mains includes 2 kW for a microgrid load.

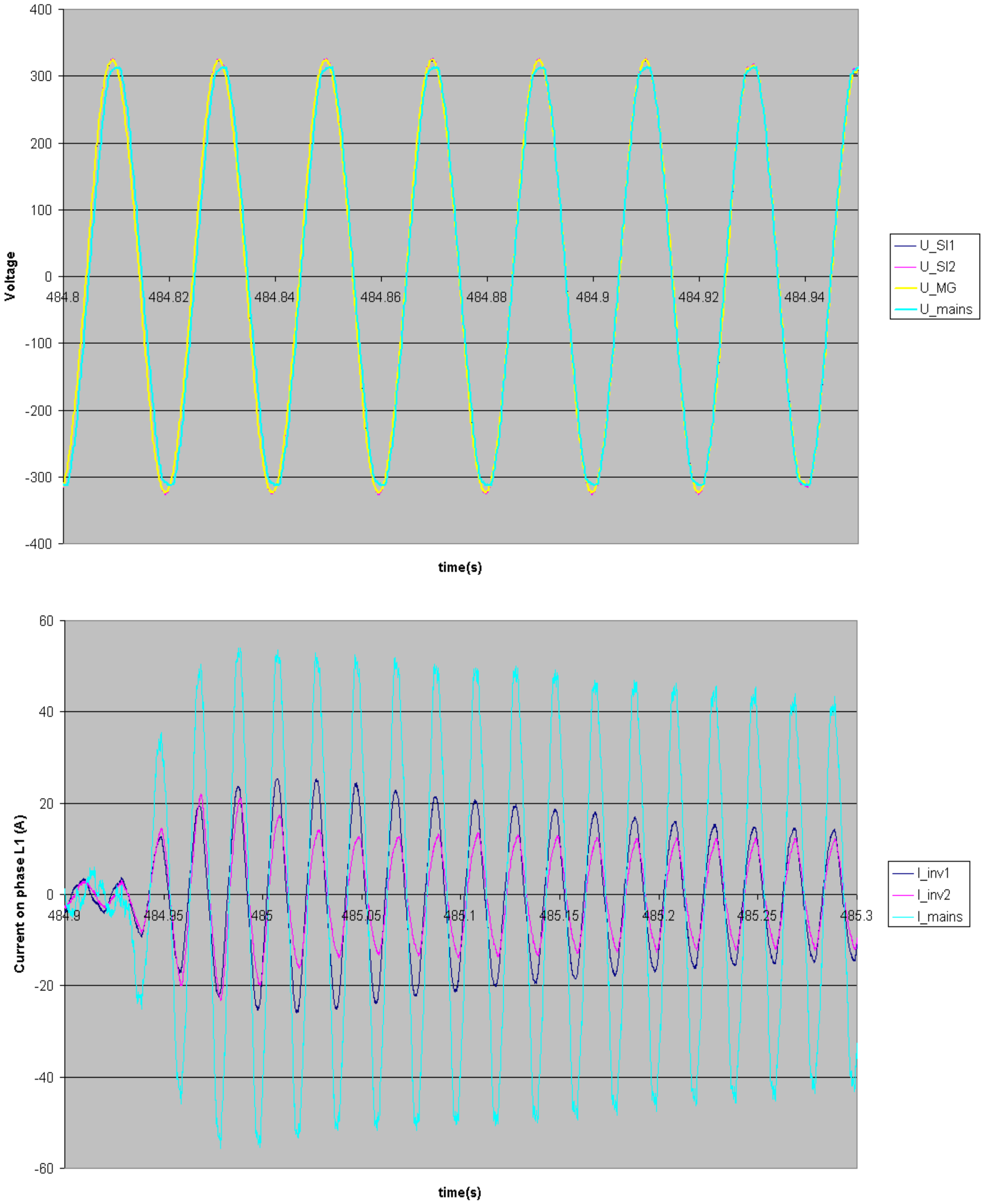

Figure 5: Black-start test: voltage and current during reconnection to mains

During emergency (and normal operation) states, power quality issues have been investigated. No significant voltage dips have been recorded during these procedures. The two plots on Figure 5 present the current and voltage wave forms on phase L1 during the synchronization procedure to the Main grid. The microgrid main switch is closed at time t_{close}=484.93 s, without any dip in the voltage. The current wave form shows also how the two battery inverters, which are connected with very different LV line length to the microgrid bus, are sharing the active power.

Conclusions

A three phase microgrid has been installed with three grid forming units (1 diesel 16 kW and two battery units 12 kW), a wind generator 15 kVA and several photovoltaic generators. Several switches have been installed in order to increase the reliability of the microgrid, which can be sectionalized into up to three island systems. The communication infrastructure allowed to implement a microgrid supervisory controller. Normal and emergency microgrid functionalities (black-start, island mode, islanding, reconnection, frequency control, power sharing,...) have been successfully tested. Power quality during the tests was kept within standards.

Aknowledgement

The authors wish to express their gratitude to the European Commission for the financial support provided to this work within the microgrids project (ENK5-CT-2002-00610), and to the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety for the financial support in the project “Vernetzung modularer Systeme” (FKZ 0329900B).

References

1. Microgrid Laboratory Facilities - M. Barnes, A. Dimeas, A. Engler, C. Fitzer, N. Hatziargyriou, C. Jones, S. Papathanassiou, M. Vandenbergh - International Conference on Future Power Systems, Amsterdam, 16.-18.11.2005

2. Applicability of droops in low voltage grids – A.Engler - International Journal of Distributed Energy Resources, Volume1 Number 1, January-March 2005

3. http://microgrids.power.ece.ntua.gr/: Microgrids project homepage

4. www.iset.uni-kassel.de/abt/FB-A/demotec/ground/plan.html: Virtual Visit in DeMoTec (Microgrid Laboratory facility of ISET)