

In addition to the grid voltage, Figure 6 (b) also shows the current at the grid connection point, which is the current supplied to the test grid by the grid simulator, and the currents of the two VISMA systems (Figure 6 (c) and (d)). The currents of the two VISMA systems are not zero before the grid disconnection. However, these are not active currents, but reactive currents of the capacitive base load (filter capacity at the inverter output) of the VISMA systems, which are located between the main contactor of the inverter and the measuring point. Active power is not fed in before the grid is disconnected, as the grid frequency is close enough to the nominal frequency of 50 Hz (see Figure 8 and 9). The fact that the VISMA does not feed in any active power at this point is also due to the primary control (frequency-dependent active power setpoint), which specifies zero as the setpoint (see Figure 10), since the grid frequency corresponds to the nominal value. The transient of the fed-in current of the two VISMA systems is approximately 5 ms, i.e. exactly the duration of the voltage dip. After this short time, the transient process is already completed and the two VISMA systems have completely taken over the supply of the load. This behaviour can also be seen in Figure 8. At 5 s, the power feeding into the test grid via the grid connection point (gcp) turns zero due to the disconnection (opening of the grid contactor K1, cf. Figure 5) and the two VISMA systems feed into the test grid according to their primary control characteristic and thus completely supply the load. The reduced power consumption of the ohmic load resistor in the island grid can be attributed to the fact that the grid voltage is lower than before the disconnection.

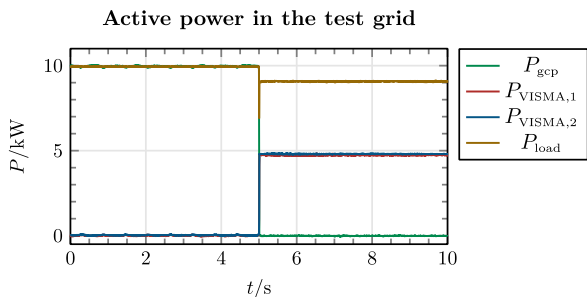


Fig. 8. Active power feed-in into the test grid via the grid connection point (feed-in power of the grid simulator) P_{gcp} and of the VISMA systems $P_{VISMA,i}$ as well as the consumer power of the ohmic load resistor P_{load} . Before the grid disconnection at 5 s, the load is completely supplied by the grid simulator. The VISMA systems do not feed in any power at this time. After disconnection, the two VISMA systems take over the supply of the load. The load is distributed equally to both systems due to the same parameterisation.

The drop in the virtual rotor frequency can be seen in Figure 9. The upper diagram shows the variation of the rotor frequency in a range from 5 s before to 5 s after the transfer of the test grid from grid-parallel operation to island grid operation. The frequency fluctuations of less than 10 mHz before grid disconnection are due to the grid voltage of the grid simulator. However, because the primary control has a dead band of ± 10 mHz, the VISMA systems not react at this point.

The transition to the new steady state of the island grid takes about 40 ms, cf. Figure 9. After this time, the rotor frequency of the VISMA stabilises and remains constant at 49,91 Hz starting at 5,04 s. The rotor frequency is used as an input variable for the primary control and the required control power is calculated and transferred to the VISMA as a setpoint (compare Figure 10).

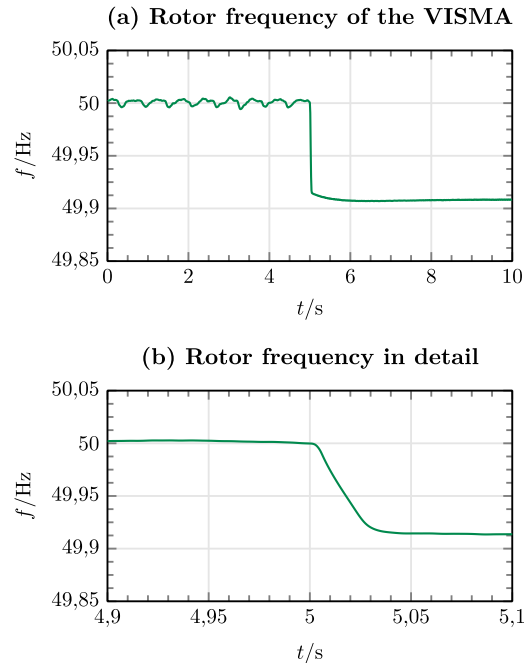


Fig. 9. Frequency of the virtual flywheel of the VISMA, which at the same time corresponds to the grid frequency of the experimental grid. Before grid disconnection, the grid frequency is specified by the grid simulator. With the transition to island operation, the frequency drops. The drop ensures that the primary controller is activated and outputs a target active power. The grid frequency stabilises when an equilibrium is reached between generated and consumed active power in the test grid. This occurs after 40 ms.

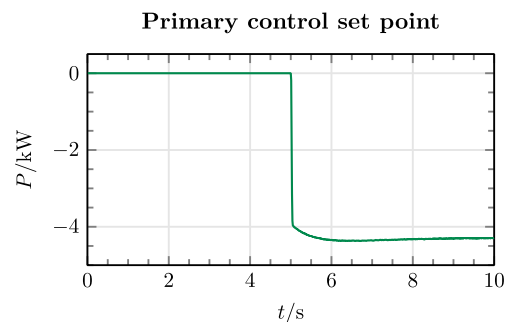


Fig. 10. Calculated active power of the primary power controller as a function of the grid frequency in Figure 9.

5. Conclusion

The results presented in this paper show that the virtual synchronous machine is able to provide grid parallel operation and island operation with uninterrupted transition between the operation modes with one and the same controller. The primary controller is able to participate in the ancillary services in grid-parallel operation and makes

stable grid operation possible in the island grid. This has the advantage that communication between several VISMA systems can be dispensed with and the grid structure is very modular.

The experiment shown here only has a controller for frequency maintenance, the voltage regulation was not discussed here. However, further experiments have already shown that a comparable controller for voltage control already works in pure island grid operation. Experiments are still pending for both grid operation.

Acknowledgments

We gratefully acknowledge support from the Federal Ministry of Education and Research (BMBF grant no. 03EK3055G).

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