PARALLEL OPERATION OF SYNCHRONOUS GENERATORS
- INTEGRATION OF DG

A simple network consisting of two synchronous generators (including prime-movers, governors and automatic voltage regulators), distribution lines and a load is provided in the DRTS. The students change the active power of the load at the DRTS software and measure the active power of each synchronous generator and the operating frequency (steady-state and minimum or maximum value).

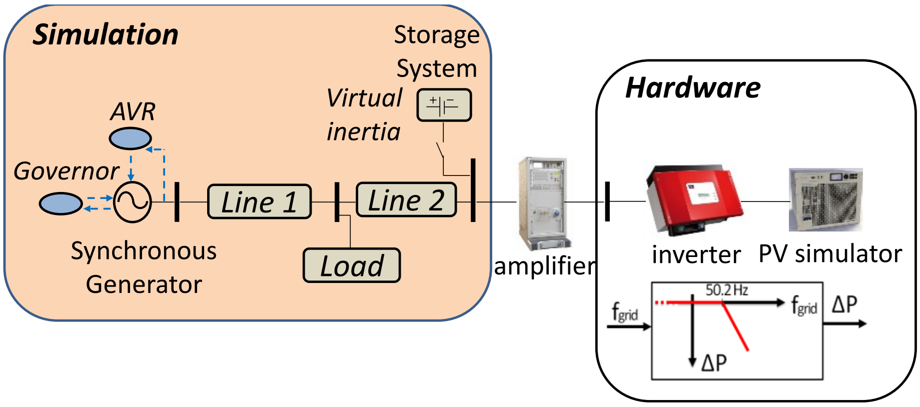

Figure 1. Parallel operation of a synchronous generator, hardware PV inverter and storage with virtual inertia (PHIL simulation).

An actual PV inverter replaces the one synchronous generator and is connected to the simulated network in the DRTS (PHIL configuration shown in Fig. 1). The irradiation from the PV simulator is increased and the students note the increase in the system frequency (concrete experience). A problem-based learning approach is applied based on the “50.2 Hz problem”, which was noted in 2011. According to the standards at that time, the DGs had to disconnect at frequency values exceeding 50.2 Hz, meaning that in this case, several GWs of PV generation would be simultaneously disconnected from the network affecting system stability [1]. The students are asked to solve this problem and comment on how DG can participate to primary frequency control (reflective observation). The students are led to the solution of applying a P(f) droop characteristic at the PV inverter similar to conventional generation (abstract conceptualisation).

Next the P(f) droop characteristic of the PV inverter is activated (required by recent standards [2], shown on the right side of Fig. 1). The active power of the simulated load is decreased (step) and again the active load is shared between the synchronous generator and the DG (active experimentation). The active power of the PV inverter with and without droop control is shown together with the system frequency in Fig. 2 and 3, respectively. From the results it is clear that the decrease of the active power of the physical inverter based on its droop characteristic leads to an improved frequency response compared to the operation without droop control (Fig. 3). It is understood that in cases of low load and high DG production the active power of the DG is controlled without the need of a communication network.

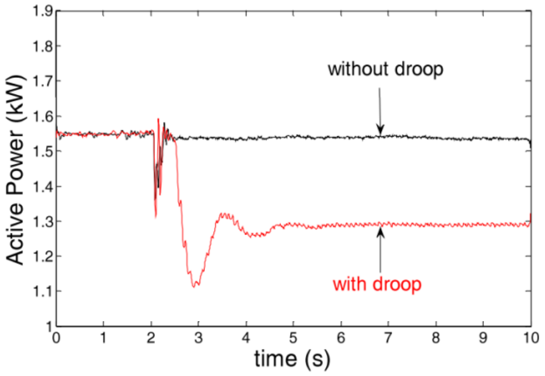

Figure 2. Active power of the hardware PV inverter with and without P(f) droop control.

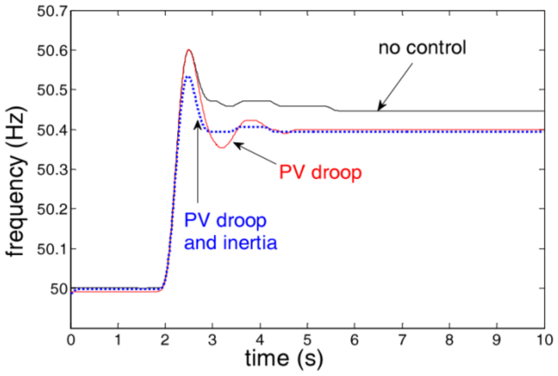

Figure 3. Frequency without P(f) control, with P(f) control of the hardware PV inverter and combination with virtual inertia provided by the storage system.

Moreover, the capability of inverter-based DG and storage to compensate the reduced rotational inertia of the power system due to the increased DG integration is demonstrated making use of the "virtual synchronous generator" concept [3]. Accordingly, a storage system emulates the rotational inertia of synchronous generators following equation (1). The storage system is simulated in the DRTS and its active power during the PHIL test is shown in Fig. 4. The improved frequency response at dynamic conditions is shown in Fig. 3.

$$P_{storage} = k_i \frac{d\omega}{dt} \tag{1}$$

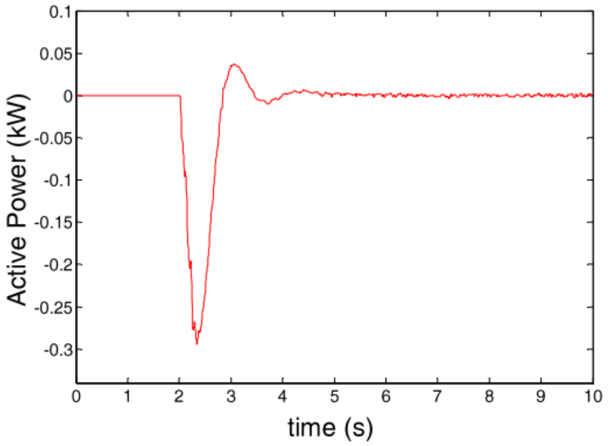

Figure 4. Active power of the storage system providing virtual inertia

The experiments are designed, so that the students are actively involved, e.g. they set the P(f) droop parameters of the PV inverter via its software interface, experiment with different gains of the inertia emulation (ki) and change the load in the DRTS and the irradiation in the hardware PV simulator. Moreover, the students measure the active power of the hardware PV inverter and the system frequency with a power analyser and the active power of the synchronous generator and frequency in the DRTS. At the end of the exercise, they are asked to provide a report based on the measurements, i.e.: to calculate for the given test-case (synchronous generator and PV operating with droop control) the power sharing and frequency and compare with the experimental results. Additional questions aim to explain why DG droop control is mainly used for over-frequency and not so often for under-frequency events.

References:

[1] J. Boemer et al., “Overview of German grid issues and retrofit of photovoltaic power plants in germany for the prevention of frequency stability problems in abnormal system conditions of the ENTSO-E region continental Europe,” in Proc. 1st Int. Workshop Integr. Sol. Power Power Syst., Aarhus, Denmark, vol. 24, 2011.

[2] P. Kotsampopoulos, N. Hatziargyriou, B. Bletterie, and G. Lauss, “Review, analysis and recommendations on recent guidelines for the provision of ancillary services by distributed generation,” in Proc. IEEE Int. Workshop Intell. Energy Syst., Vienna, Austria, Nov. 2013, pp. 185–190.

[3] V. Karapanos, P. Kotsampopoulos, and N. Hatziargyriou, “Performance of the linear and binary algorithm of virtual synchronous generators for the emulation of rotational inertia,” Elect. Power Syst. Res., vol. 123, pp. 119–127, Jun. 2015.

source:

P. Kotsampopoulos, V. Kleftakis, N. Hatziargyriou, “Laboratory Education of Modern Power Systems using PHIL Simulation”, IEEE Transactions on Power Systems, Vol. 32, Issue: 5, September 2017