Short Circuit Studies - Integration of DG

These experiments show fundamental concepts of traditional short circuit analysis, but mainly focus on the behaviour of inverter-based DG (e.g. PVs, wind turbines with permanent magnet synchronous generators) during faults.

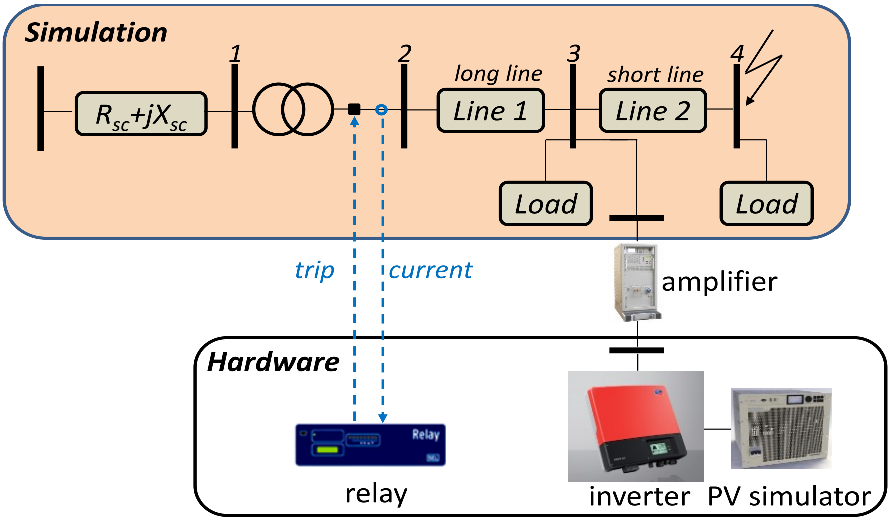

Figure 1. Short circuit testing of inverter-based DG (PHIL and CHIL simulation).

First, the students apply short circuits at different locations of a simulated low voltage distribution network in the DRTS and measure the resulting current. A hardware relay monitors and controls a simulated circuit breaker at the secondary of the transformer (Fig. 1). The students observe that as the location of the fault moves away from the transformer, the short circuit current flowing from the upstream network is decreased (due to the greater equivalent impedance) and the trip time of the hardware relay is increased. Also the voltage at the different buses is monitored during the short circuits. As an example, Fig. 2a shows the current flowing through the secondary of the transformer during a short circuit on bus 2, where the circuit breaker trips. Fig. 2b shows the node voltages during a short circuit on bus 4.

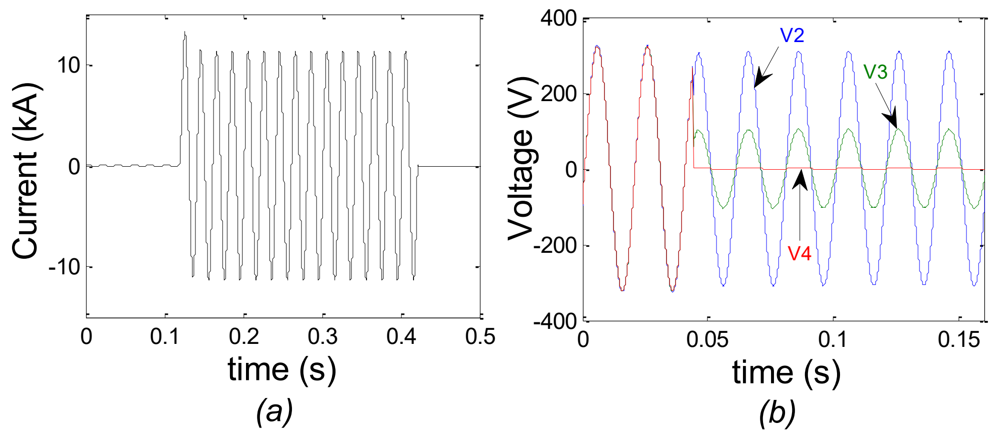

Figure 2. Current waveform during a short circuit on bus 2 and tripping of the circuit breaker (a). Voltages of buses 2,3 and 4 during a short circuit on bus 4 (b)

Prior to connecting the physical PV inverter to the network in a PHIL configuration, the location of the three-phase short circuit and of the PV inverter need to be determined, (i.e. chosen between buses 2,3,4 of Fig. 1), so that during the fault the voltage of the inverter bus drops to approximately 1/3 of its pre-fault value. The PV inverter is neglected in this approximate calculation, as its nominal power is small and its fault contribution is much smaller than the current drawn from the upstream network. The loads are neglected for the same reason. Having achieved this, the physical inverter is connected to the simulated network and a three-phase short circuit is applied, as illustrated in Fig. 1.

The physical PV inverter operates at low power before the fault and its behaviour during the fault is recorded by an oscilloscope, as shown in Fig. 3(b). The short circuit current is increased to approximately 3 times the pre-fault current in response to the voltage drop at 1/3 (concrete experience). This happens because the control algorithm of PV inverters is normally designed to maintain operation at fixed active power (and power factor) for a constant input from the DC side (reflective observation). The experiment is repeated with nominal power. Fig. 3(c) demonstrates that there is a limit at approximately 1.3 times of the nominal current which does not allow a higher increase (concrete experience). It is concluded that the current limitation (typically below two times of the nominal current, depending on the manufacturer) is incorporated in the control algorithm of the inverter in order to respect the thermal limits of its switching devices (abstract conceptualisation). A second PV inverter of a different manufacturer is used and the experiment is repeated (active experimentation). It is noted that the inverters exhibit a partly different behaviour during the fault i.e. gradual increase of the current until the maximum value (see Fig. 3(c)) or fast increase of the current until the maximum value and then gradual reduction. In this way, the students learn that the contribution of inverter-based DG depends on the pre-fault operating condition of the inverter, the voltage drop at its terminal and its specific control algorithm. The usual assumption in practical calculations of 1.5-2 times of the nominal current is tested [1]. An interesting analysis of the actual operation of inverter-based DG during faults can be found in [2].

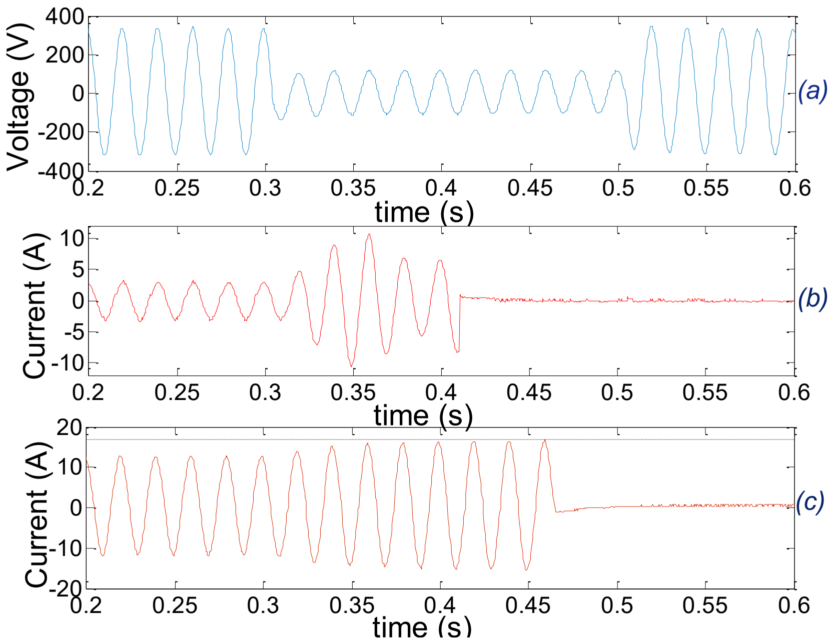

Figure 3. Short circuit behavior of the PV inverter at low power (b) and nominal power (c). The current limitation is visible.

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References:

[1] T. N. Boutsika and S. A. Papathanassiou, “Short-circuit calculations in networks with distributed generation,” Elect. Power Syst. Res., vol. 78, no. 7, pp. 1181–1191, Jul. 2008.

[2] C. A. Plet and T. C. Green, “Fault response of inverter interfaced distributed generators in grid-connected applications,” Elect. Power Syst. Res., vol. 106, pp. 21–28, Jan. 2014

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