Grid-Forming Inverters: The Up-to-date Solution from Ingeteam

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Background & Aim

The ever-increasing penetration of inverter-based renewable generations and storage devices, such as photovoltaic generation and batteries, poses significant challenges and opportunities for both power utilities and equipment manufacturers. Traditionally, the inverters are operated in the so-called grid-following mode to accommodate the requested active and reactive power and synchronize with the grid by utilizing phase-locked loops (PLLs). This synchronization process brings challenges for grid-following inverters to operate in a stand-alone system or contribute to the system restoration after a blackout[1]. Considering the low inertia characteristic of power networks due to extensive integration of renewable generation with a low short-circuit ratio (SCR), grid stability can be decreased as the grid-following inverters may introduce more significant frequency deviations after a disturbance[2-3]. Therefore, grid-forming inverters, either synchronizing with the grid or operating independently by generating an internal voltage reference[4], have been considered to be of great importance for future grids with 100% renewable generation. Particularly, the current Australian grid is experiencing a substantial transition, where traditional generators are facing termination of operation and will need to be replaced by inverter-based renewable generation.

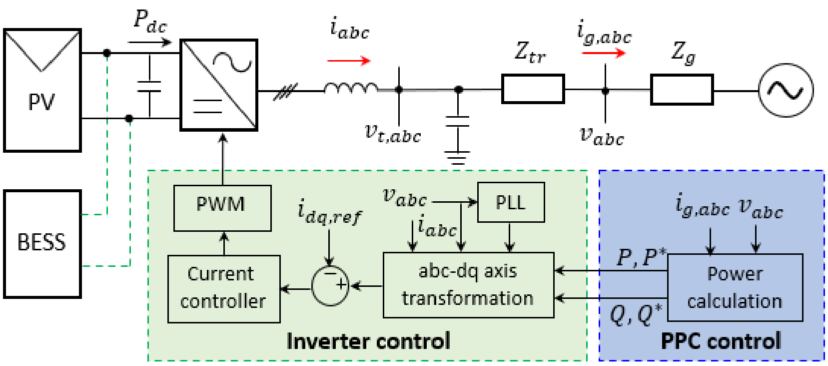
This paper aims to present the latest technology of Ingeteam grid-forming inverters for large-scale photovoltaic generation and storage systems by:

- Highlighting the newly developed functionalities of grid-forming inverters; and
- Illustrating the stable and robust response of grid-forming inverters in contingencies by comparing with grid-following control mode.

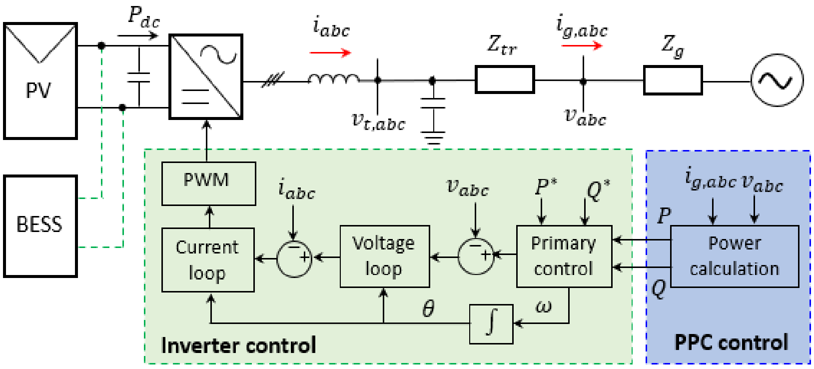
Grid-Forming Control Mode

1. Grid-forming vs grid following inverters

Inverters in grid-following control mode are expected to operate as current sources that inject desired active power and reactive power according to the commands from the power plant controller (PPC). Thus, a PLL algorithm is needed to follow up on the phase angle of grid voltage. In contrast, inverters in grid-forming mode are expected to operate as voltage sources that can either follow frequency and voltage setpoints or active and reactive setpoints. Figure 1 depicts the generic grid-following inverters and grid-forming inverters in terms of control blocks and equivalent circuits.



(a)



(b)

Figure 1. Comparison of grid-following and grid-forming inverters: (a) generic grid-following inverter and (b) generic grid-forming inverter.

2. Highlights of Ingeteam Grid-forming inverters

Ingeteam's grid-forming inverters can contribute to system inertia, operate in island mode with black start capability, and balance the loads instantaneously. Mainly, configurable virtual inertia constant and virtual impedance are introduced against frequency and voltage variations. Moreover, the virtual inertia response and virtual impedance algorithm have been coordinated with the primary frequency control and voltage droop control defined at PPC. Figure 2 shows the active and reactive power responses integrated with the virtual inertia and impedance.

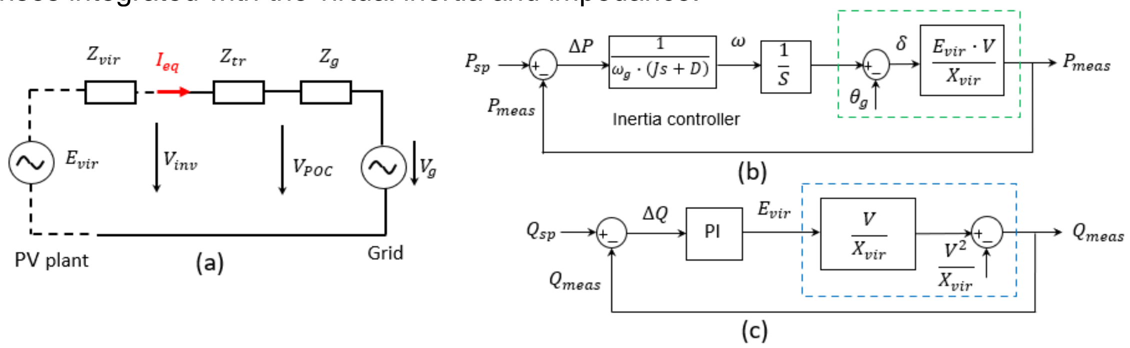


Figure 2. (a) Equivalent circuit of the grid-forming inverter; (b) Instantaneous P with configurable virtual inertia constant; (c) Q response with virtual impedance control.

In grid-connected applications, Ingeteam's grid-forming inverters follow P and Q setpoints defined at the point of connection by the PPC. When facing a disturbance in either the measured frequency or voltage, inverters will provide an instantaneous response dictated by the control depicted in Figure 2, which will be followed up by the PPC executing both the frequency and voltage droop controls. The dynamic of the PPC controls needs to be properly tuned in order to accommodate the natural response from the inverters and achieve steady-state operation based on the configured parameters. For stand-alone applications, Ingeteam's inverters can follow frequency and voltage set-points generated internally, perform black start and offer a smooth transition from the island to the grid-connected mode of operation.

Test System Configuration

To illustrate the improvements of Ingeteam's latest technology, inverters with grid-following and grid-forming control modes are simulated and analyzed using the test network shown in Figure 3. The test network uses 61 storage inverters (IS Power B 1500V) to represent a 100 MVA plant with a terminal voltage of 630. The SCR at the point of connection and inverter level are 1.2 and 1.02.

Five groups of tests have been conducted namely generator rejection, load rejection, grid faults, grid voltage disturbances, and transition to island operation. To be more specific, for instance, generator rejection is simulated by applying a 3-phase fault at the load bus and tripping the 30 MW synchronous generator, and transition to island operation trips the entire synchronous plants.

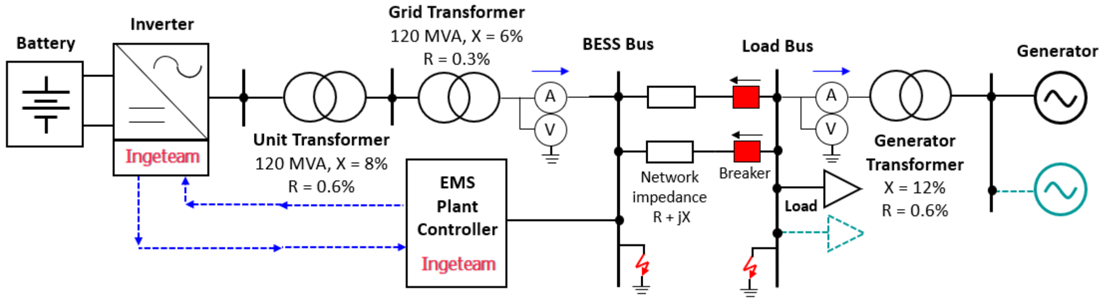


Figure 3. Test network configuration.

Results and Discussion

The simulation results of generation rejection and islanding transition illustrate the instantaneous response and capability of emulating the traditional synchronous generator of grid-forming inverters in presence of partial or entire loss of external voltage source, as shown in Figures 4 and 5.

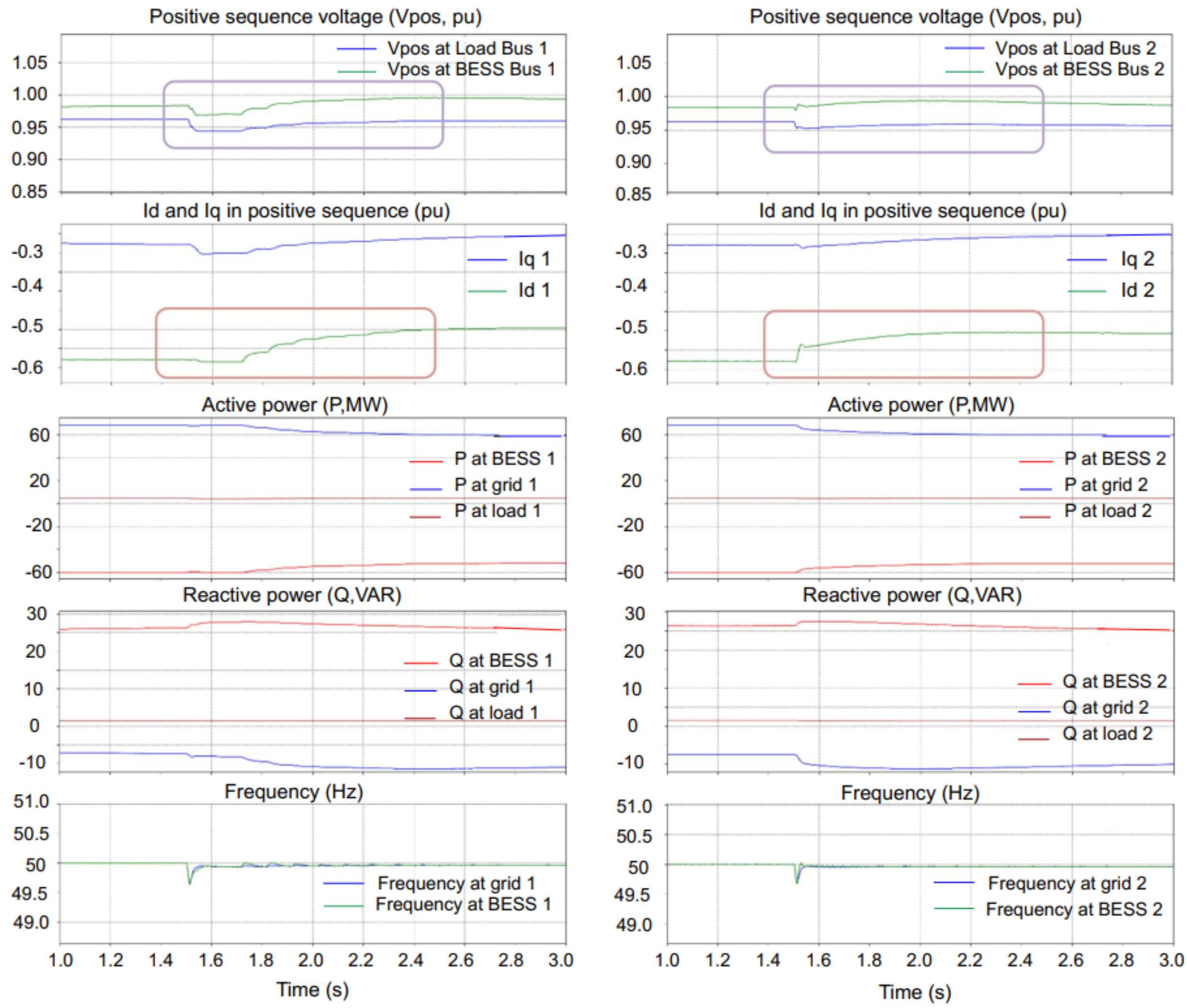


Figure 4. Generation rejection response of grid-follow inverters and grid-forming inverters.

It can be observed that the grid-forming inverters react instantaneously against frequency variation when the disturbance starts, and the voltage at the load bus remains almost unaltered due to virtual impedance emulation.

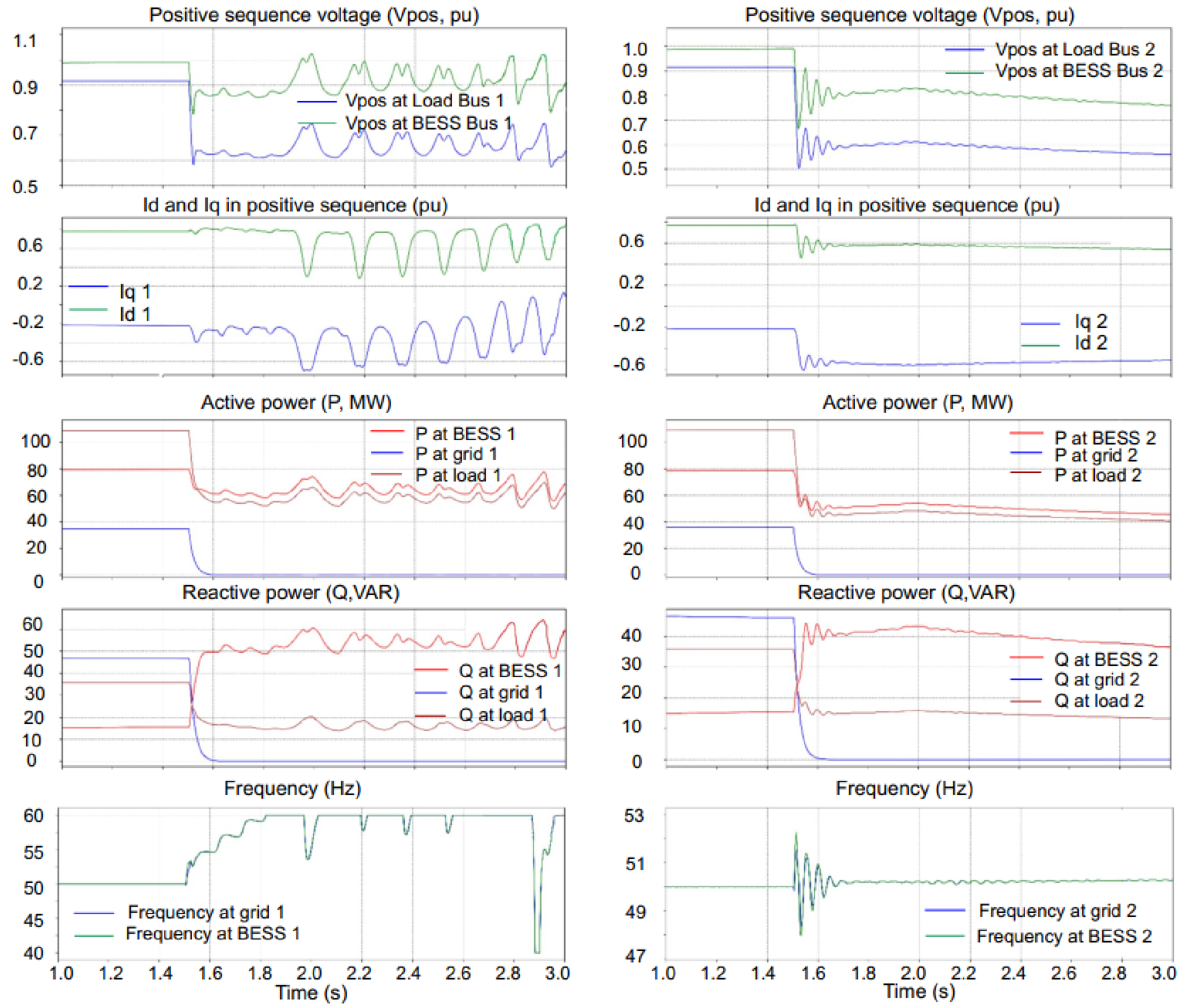


Figure 5. Islanding transition response of grid-follow inverters and grid-forming inverters.

Ingeteam's grid-forming inverters can rapidly adapt P and Q generation to the disturbances in voltage and frequency, while grid-following inverters show a delayed response. The results also demonstrate stable and robust responses for the tests of load rejection, unbalanced fault, and line trip. Furthermore, it must be noted that due to continuous improvement made in our controls, the above tests with grid-forming and grid-following controls have been performed with an SCR at inverter terminals of 1.

References

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