Study Committee C4
Power System Technical Performance
Paper ID: 10822

Grid-Forming Control for STATCOMs – a Robust Solution for Networks with a High Share of Converter-Based Resources

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Abstract

The high penetration of non-synchronous renewable energy resources has resulted in power system stability challenges. Robust and stable operation of interconnected power grids can be ensured, if a certain number of generation units provide so-called grid-forming capabilities. These can be achieved either by synchronous generators, or by non-synchronous generation using power electronic converters. For large, interconnected power systems, e.g., the Continental Europe system, it is especially important considering extreme contingencies like system separations following large disturbances (system splits). In future converter-dominated grids, these grid-forming functionalities can be provided by power converters to secure the stable operation of the power system. In this paper, grid-forming (GFM) control capability is proposed for static synchronous compensators (STATCOMs), which are installed and operated by Transmission System Operators (TSOs). This approach is realized by emulating the behavior of a voltage source behind an impedance. Software-in-the-loop simulation results show that the proposed GFM control simultaneously counteracts changes in the grid voltage and positively contributes to the restoration process of the grid. By employing the proposed GFM control, the STATCOM maintains stable operation in weak grids even with extremely low short circuit current levels.

Technical Requirements

From the TSOs point of view, it is not desirable to predefine specific control concepts. Rather, the goal is to define functional requirements at the connection point. It should be noted that these requirements and consequently the design of GFM might also depend on the converter technology, the voltage level at the connection point, etc.

Within the scope of a pilot project of a STATCOM without energy storage, three main technical requirements were defined in the context of GFM (without priority):

- Acting as a voltage source by providing an inherent (current) response to voltage and phase angle changes in the power system. An inherent response means that in the first few cycles, the current response is not caused by the measurement of grid quantities and setpoint adjustments.
- Robust operation during system split or islanding operation, i.e., the STATCOM must be capable of operating at both high and very low short circuit ratios (SCR = 0.25) without changing the control mode.
- Fault ride-through capability with dynamic voltage control under balanced and unbalanced short-circuit faults.

The Need for Grid Forming in STATCOM

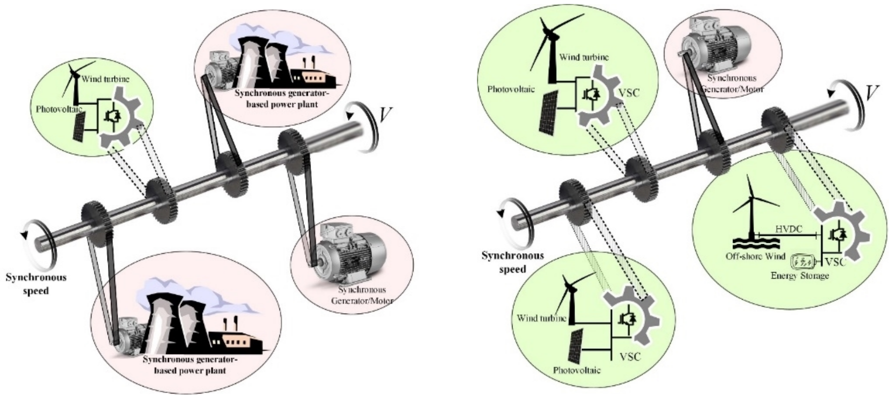

Figure 1 (a) Traditional power grid, (b) Modern power grid.

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Grid Forming Control Behavior

OBJECTIVES

- The STATCOM emulates the behavior of a voltage source behind an impedance
- The STATCOM's behavior is simple, predictable, and contributes to stabilizing the grid
- Enabling the STATCOM to operate at very low short circuit levels (1 per unit , or even less)
- The STATCOM counteracts changes in the grid voltage, e.g., provides positive- and negative-sequence currents during faults
- The STATCOM behaves as an R-L circuit for the harmonics, similarly to a generator but with higher damping

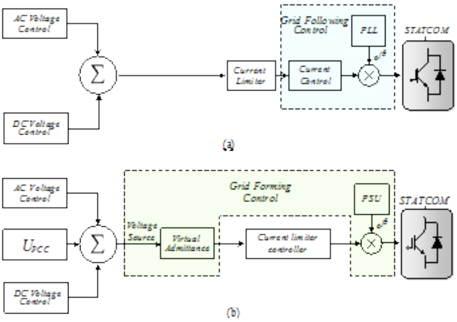

Figure 2 (a) Control structure for Grid following (GFL) control, (b) Control structure for Grid forming GFM control.

Software-in-the-Loop (SIL) Results

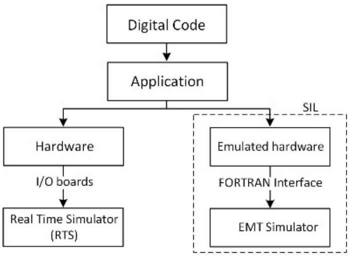

Figure 3. The concept for the SIL platform that is used in the EMT simulation

A. Grid Voltage Magnitude Step

Initial part of the transient

- GFM exhibits a similar behavior of an ideal voltage source
- With additional energy storage, the GFM behaves the same as an ideal voltage source
- GFL does not

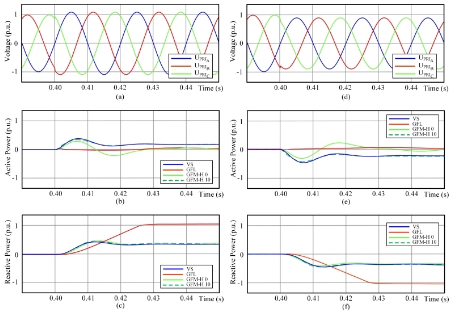

Figure 4. Simulation results: Grid voltage magnitude step. 0.1 p.u. (left) and -0.1 p.u. (right).

B. Grid Voltage Angle (Δϕ) Step

Initial part of the transient

- GFM exhibits a similar behavior of an ideal voltage source
- With additional energy storage, the GFM behaves the same as an ideal voltage source
- GFL does not

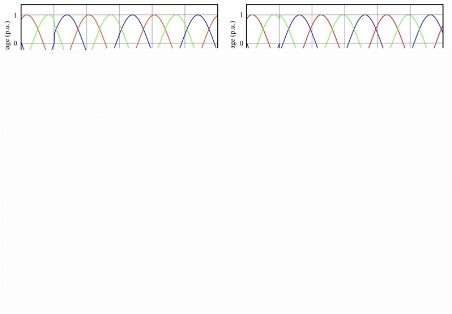

Figure 5. Simulation results: Grid voltage angle step. $\Delta\phi=20^{\circ}$ (left) and $\Delta\phi=-20^{\circ}$ (right).

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Study Committee C4

Power System Technical Performance

Paper ID: 10822

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C. Single phase-to-ground fault

- GFM supports the grid with both positive- and negative-sequence currents
- GFL supports the grid only with positive-sequence current

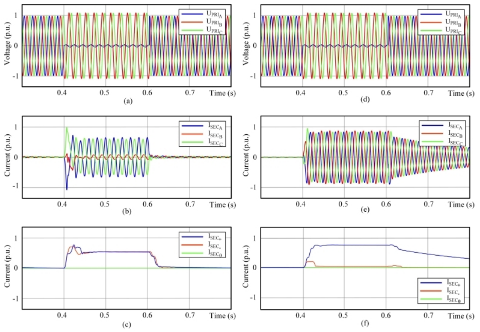

Figure 6. Simulation results: Single phase-to-ground fault. GFM-H0 (left) and GFL (right).

D. Three phase-to-ground fault

- Both GFM and GFL show similar behavior during symmetrical faults, and both support the grid.
- After the fault is cleared, the GFM returns back to the normal operation faster.

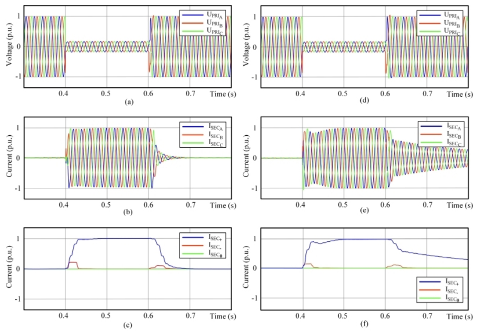

Figure 7. Simulation results: Three-phase-to-ground fault. GFM-H0 (left) and GFL (right).

E. Short circuit level (SCL) drop

- GFM adapts to extreme changes in SCL
- GFL cannot operate in extreme SCL conditions

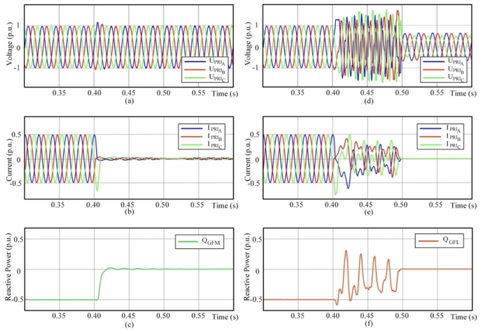

Figure 8. Simulation results: Short circuit level (SCL) drop (from 100 p.u. to 0.25 p.u.) GFM-H0 (left) and GFL (right).

Conclusion

- Grid forming (GFM) control is a necessary solution toward a reliable operation of STATCOMs.
- The main objective of GFM for STATCOM is to emulate the behavior of a voltage source behind an impedance, based on the VDE guideline.
- The software-in-the-loop (SIL) results lead to the conclusion that the GFM control is superior compared to the Grid following (GFL) control, especially in weak-grid conditions.
- The first GFM control of a STATCOM will be realized in a pilot project in the 380 kV network of the German TSO Amprion. The commissioning is planned for 2023, enabling the first field experience with the new control approach as an important milestone.