Integrated Synchronization Control of Grid-Forming Inverters for Smooth Microgrid Transition

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Abstract

This paper develops an integrated synchronization control technique for a grid-forming inverter operating within a microgrid that can improve the microgrid's transients during microgrid transition operation. This integrated synchronization control includes the disconnection synchronization control and the reconnection synchronization control. The simulation results show that the developed synchronization control works effectively to smooth the angle change of the grid-forming inverter during microgrid transition operation. Thus, the microgrid's transients are significantly improved compared to the case without synchronization control.

Highlights

1) Provides comprehensive analysis of the synchronization mechanism for a grid-forming inverter

2) Designs an integrated synchronization control technique in the grid-forming inverter to achieve smooth transients for various microgrid transition operations

3) Presents the detailed design and implementation as a good example or reference for replication by those researching microgrid smooth transition operations.

Design of the Integrated Synchronization Control for Grid-Forming Inverter

Strategy of Synchronization Control

- **Fixed control structure**: both voltage control in grid-forming and grid-feeding inverters to avoid switching between voltage and current control
- **Fixed phase angle−synchronization control**: guarantees that the same phase angle Θ is used before and after transition operation ($\Theta_1 = \Theta_0$)
- Smooth change of voltage references (V_{od}*, V_{oq}*) by using a filter.

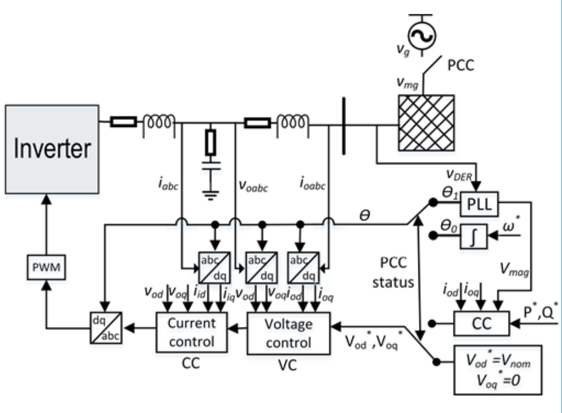


Fig. 1. Schematic diagram of the control algorithm for grid-forming and grid-feeding inverters

Development of the Synchronization Control

Mechanism of Synchronization Control

- **Coordination**: triggers the right synchronization block at the right time and sends the correct augmented angle Θ_0
- **Disconnection synchronization control**: adds the angle difference ($\varphi = \Theta_1 - \Theta_0$) to the angle Θ_0 directly and checks the angle difference φ, disconnects the microgrid when it is within the predefined threshold
- **Reconnection synchronization control**: The grid-side voltage is used as an angle reference for the inverter to approach, and the goal is to let the angle of the inverter's output voltage increase/decrease toward the angle of the grid voltage.

Scenario	Steady State	Transition	Enable
Grid-connected	1	0	N/A
Disconnection	1	2	Enable1
Islanded	0	0	N/A
Reconnection	0	1	Enable2

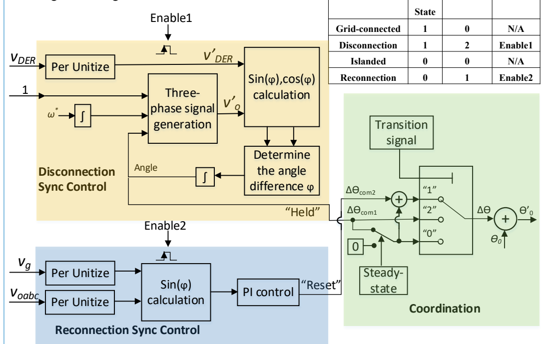


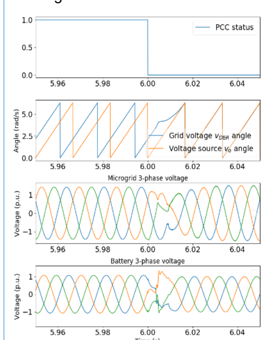
Fig. 2. Schematic of the integrated synchronization control of grid-forming inverter

Simulation Results I

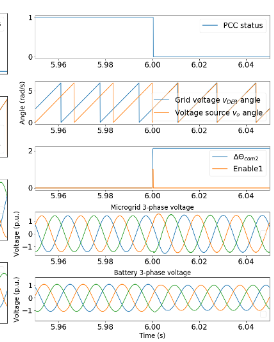
Simulation model: A 100% renewable microgrid with two battery energy storage systems (BESS), two PV units, commercial building and residential loads. BESS 1 works as the grid-forming source.

Test Case 1: Disconnect from the main grid

Description: The microgrid performs intentional islanding at 6 s. The steady-state value remains "1," and the transition signal changes from "0" to "2" during the disconnection.



Without disconnection synchronization control: point of common coupling (PCC) status, angle of the grid voltage v_{DER} and voltage source v_0, microgrid voltage, and BESS 1 output voltage

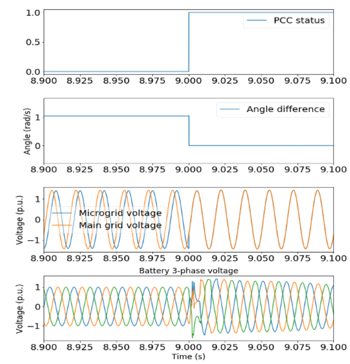


With disconnection synchronization control: PCC status, angle of the grid voltage and voltage source, angle compensation, microgrid voltage, and BESS 1 output voltage

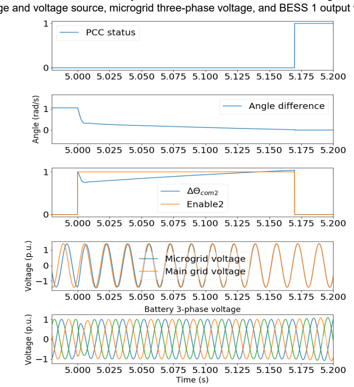
Simulation Results II

Test Case 2: Reconnect to the main grid

Description: The microgrid is requested to reconnect to the main grid between 5 and 9 s. If the reconnection criteria are not met, the microgrid reconnects to the main grid at 9 s.



Results without reconnection synchronization control: PCC status, angle of the grid voltage and voltage source, microgrid three-phase voltage, and BESS 1 output voltage



Results with reconnection synchronization control: PCC status, angle of the grid voltage and voltage source, microgrid three-phase voltage, and BESS 1 output voltage

Conclusions

This paper presents an integrated synchronization control that smooths the angle change of a grid-forming inverter during microgrid transition operation. This is shown to improve the microgrid's transients and dynamics during microgrid transition operation. This integrated synchronization control includes the disconnection synchronization control and reconnection synchronization control. The simulation results show that the proposed synchronization control technique works effectively to smooth the angle change of the grid-forming inverter during microgrid transition operation.

Additional Reading

Jing Wang, Changhong Zhao, Annabelle Pratt, and Murali Baggu. 2018. "Design of an Advanced Energy Management System for Microgrid Control Using a State Machine." *Applied Energy* 228: 2407–2421.

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