Enhanced Startup and Synchronization Transients for Virtual-Oscillator Grid-Tie Inverters Using Predictive Feedback-Based Method

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IEEE ENERGY CONVERSION CONGRESS & EXPO PHOENIX, ARIZONA, USA ☀ OCT. 20-24

Summary

- Blackstart using parallel-connected inverter-based-resources (IBRs) and virtual-oscillator-control (VOC) may face issues like prolonged synchronization settling time, high inrush currents, large voltage drop, potentially causing the failed blackstart attempt.
- Proposed predictive current feedback, eliminating peak transients by pre-synchronization, which enables the virtual oscillator (VO) to:
  - Smooth synchronization for inverters.
  - Identically function as conventional VOC-based inverters during normal operation, no mode-transition is needed.
- Validation and conclusion:
  - Synchronization time for typical configuration is 0.25s, around 16 line cycles.
  - Proposed method achieves 0.05s, 3 line cycles, 80% increase in synchronization speed.

Proposed VOC

Feedback to the VO is based on the predicted value:

$$\widehat{i_f}(s) = v_{i\alpha}(s) \cdot H_{LP}(s) - v_{G\alpha}(s) \cdot H_{LP}(s)$$

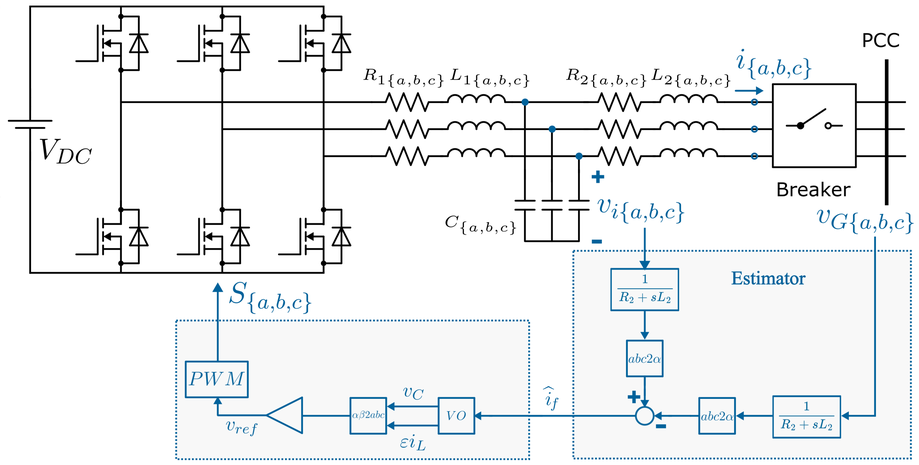
- $v_{i\alpha}(s)$ is the α-component of the three-phase voltage measured at the inverter side.
- $v_{G\alpha}(s)$ is the α-component of the three-phase voltage measured at the PCC side.
- $H_{LP}(s) = 1/(R_2 + sL_2)$ is the first-order low-pass filter for voltage measurement.

During breaker open (open-circuit operation):

- The estimator gives non-zero predicted feedback to VO for pre-synchronization.

During breaker closed (normal operation):

- The predicted feedback is ideally equivalent to the actual output current.
- The control algorithm aligns with the conventional VOC, the functions of the VOC are ensured.



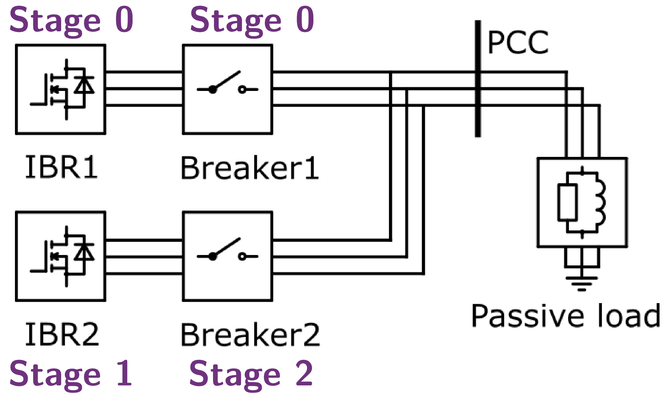
Validation:

Two-IBR Three-Stage Blackstart Procedure

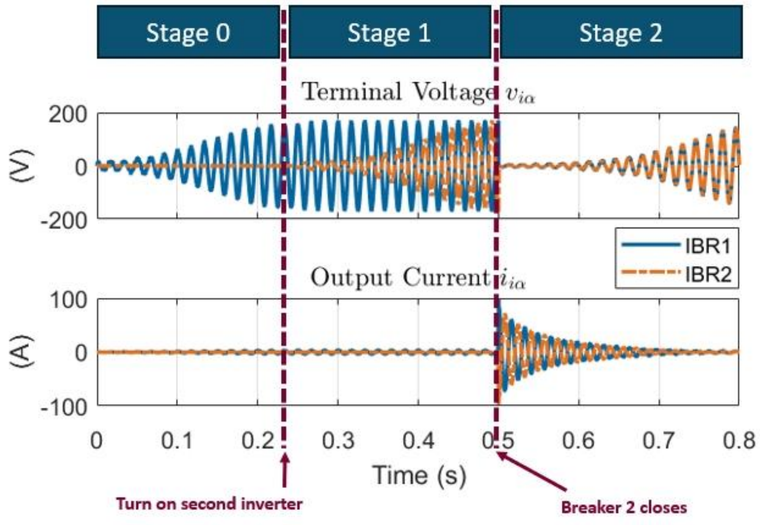
Stage 0: Turn on the IBR1, and close the Breaker 1 for IBR1. Only IBR1 is supplying the load demand.

Stage 1: Turn on the IBR2, and the Breaker 2 remains open. IBR2 starts to operate with open circuit output.

Stage 2: Close the Breaker 2 for IBR2. The output of IBR2 initiates, and the load power is distributed equally by both IBRs after reaching the steady state.



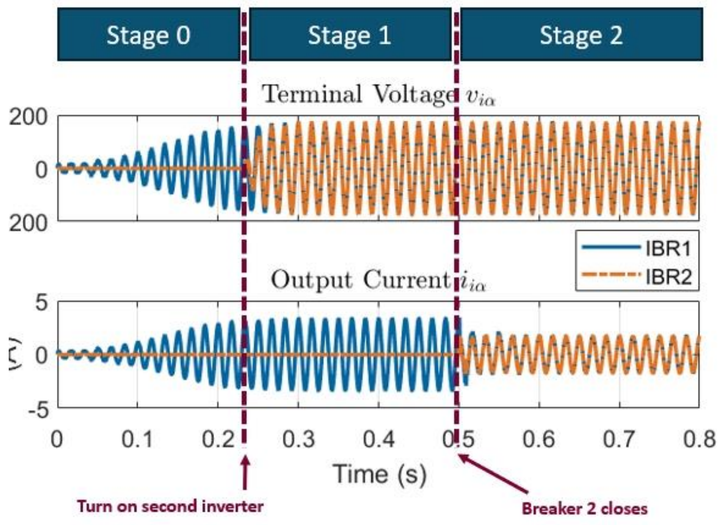
Typical phenomenon using conventional VOC



Observation:

- No pre-synchronization before closing the breaker.
- High inrush current and large PCC voltage drop.
- Extended synchronization (~16 line cycles, ~0.25s).

Enhanced transients using proposed VOC



Conclusion:

- Pre-synchronization during Stage 1.
- No inrush current and no PCC voltage drop.
- Faster synchronization (~3 cycles, ~0.05s, 80% increase compared with the typical configuration).

This research was supported by Department of Energy, SETO: DE-EE0009340, and also by the Massachusetts Clean Energy Technology.