Advanced Energy Management System for Microgrid Control Using a State Machine

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Abstract

A state machine is proposed as the solution for an automated microgrid energy management system (EMS) to improve transient performance during transition operations. It characterizes microgrid operation by seven states that cover all the operating modes: two for steady-state operation (grid-connected and islanded), four for transition operation (preparing for disconnection, transitioning to islanding, preparing for reconnection, and transitioning to grid-connected), and one for emergency operation (black-start operation). A unique dispatch algorithm is developed for each state to achieve the control objective, and the transition function is implemented in the state machine as control logics to transition the system from one state to the next. The feasibility and effectiveness of the developed state machine is validated by simulation in MATLAB with an example microgrid, and the test results show excellent performance of the state machine to achieve the target control objective in each state and to improve the system's transient performance during transition operation.

Highlight

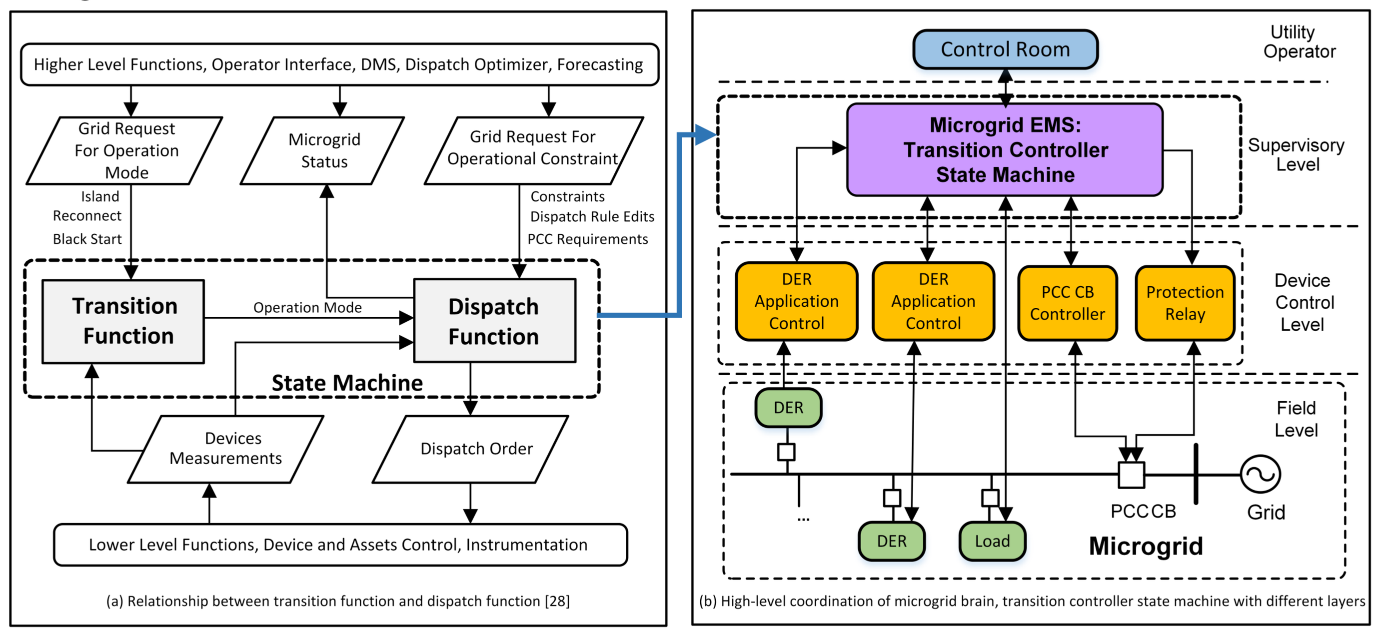
1) A state machine-based EMS classifies microgrid operation into seven states and achieves fully automatic operation.

2) The transition function is implemented as the control logics to transition the system.

3) The dispatch function adopts a hybrid approach: optimization algorithms for steady states and rule-based algorithms for transitions.

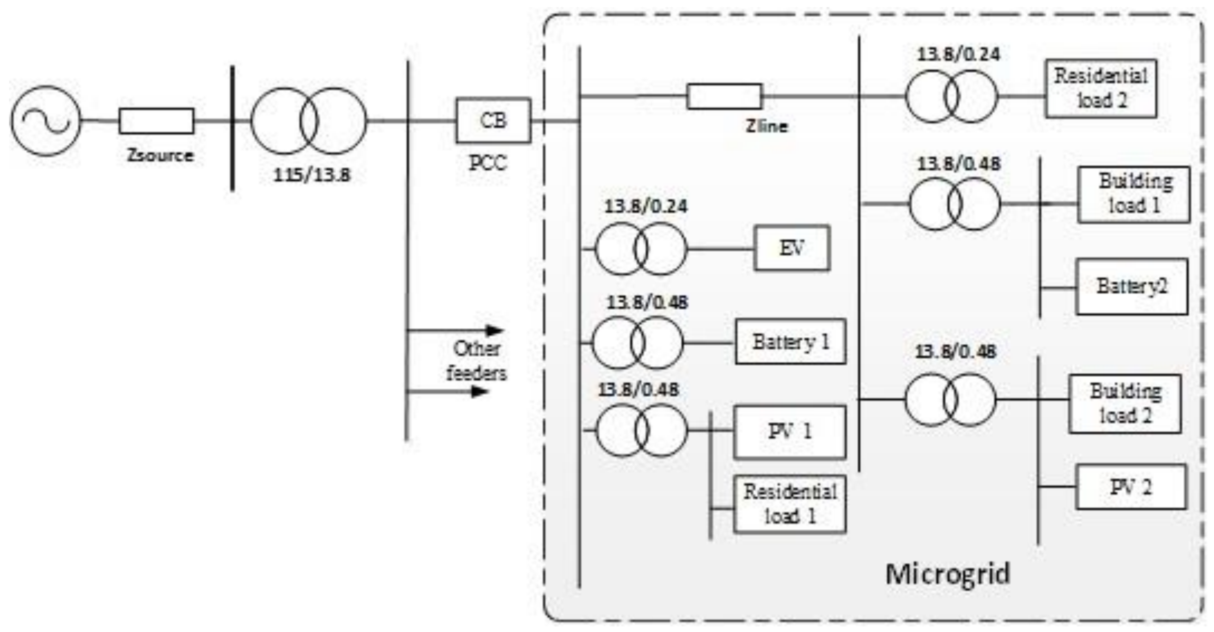
Two Core Functions in a Microgrid EMS Based on IEEE Std. 2030.7

- **Dispatch function**: dispatches assets with certain operation modes and set points
- **Transition function**: manages the transitions between grid-connected and islanded mode, ensuring dispatch is adjusted for a given state.



Schematic diagram and parameters of the sample microgrid

- All assets are controllable



Design of States of Microgrid Transition Operation State Machine

- Seven states: two steady-state states, four transition states, and one emergency state
- Transition logic to transfer from one state to the next.

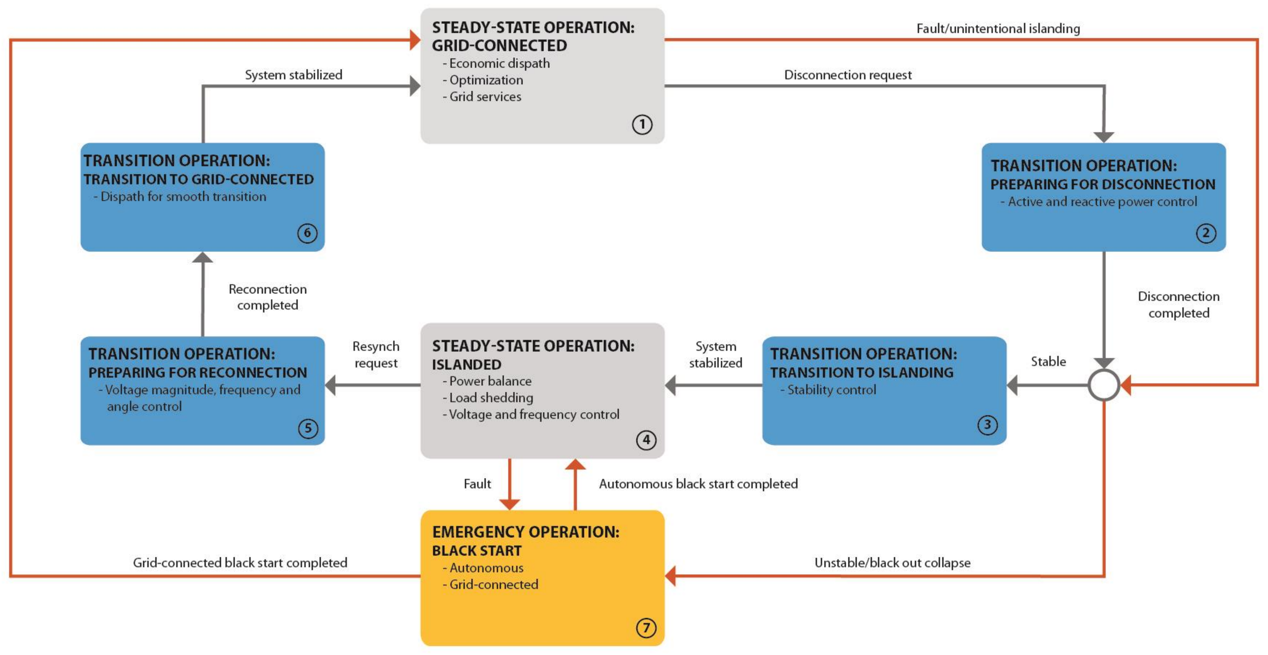
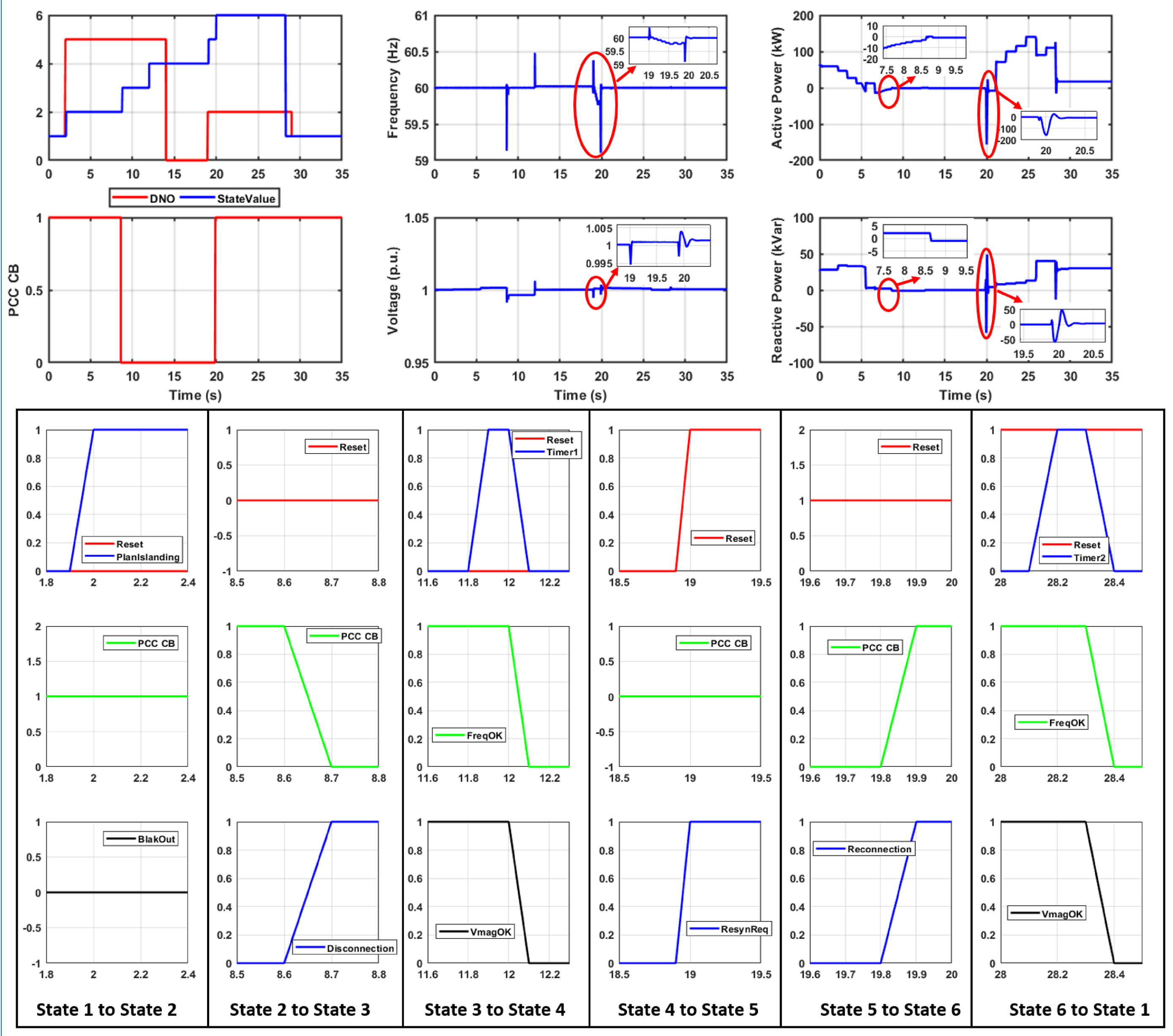


Table 1 Control Strategy in Each State

State	Operation mode	Control Strategy
1	Grid-connected	**Optimization control**: meet the PCC power exchange requirement (an error band is usually added) and optimized operation of microgrid assets.
2	Preparing for islanding (pre-transition)	**Active islanding control**: control the power flow at the PCC to "zero"(or a small error band can be added) to minimize the detrimental effects caused by a power imbalance during the islanding transition period.
3	Transitioning to islanding (post-transition)	**Surviving control**: the grid-forming source keeps the control references constant, and the grid-feeding sources keep the same control references to stabilize the system. **Smooth transition strategy**: the voltage at the PCC (magnitude, frequency, and angle) in State 2 is sent as a voltage reference for the grid-forming source in islanding mode.
4	Islanded	**Stability and optimization control**: the grid-forming source adopts voltage and frequency control for stability control, and the grid-feeding sources adopt optimization control.
5	Preparing for reconnection (pre-transition)	**Active synchronization control**: eliminate excessive differences in voltage magnitude, voltage phase angle, and voltage frequency between the main grid and the microgrid at the PCC.
6	Transitioning to grid-connected (post-transition)	**Smoothing control**: dispatch assets to minimize the PCC power exchange and guarantee that critical loads are powered. **Smooth transition strategy**: the grid-feeding DERs' power references at the end of State 5 are control references, and the averaged output power of grid-forming sources are power references.
7	Blackout and black-start	**Black-start control**: this is a set of predefined sequences of orders for either an autonomous or grid-connected black-start.

Simulation Results I

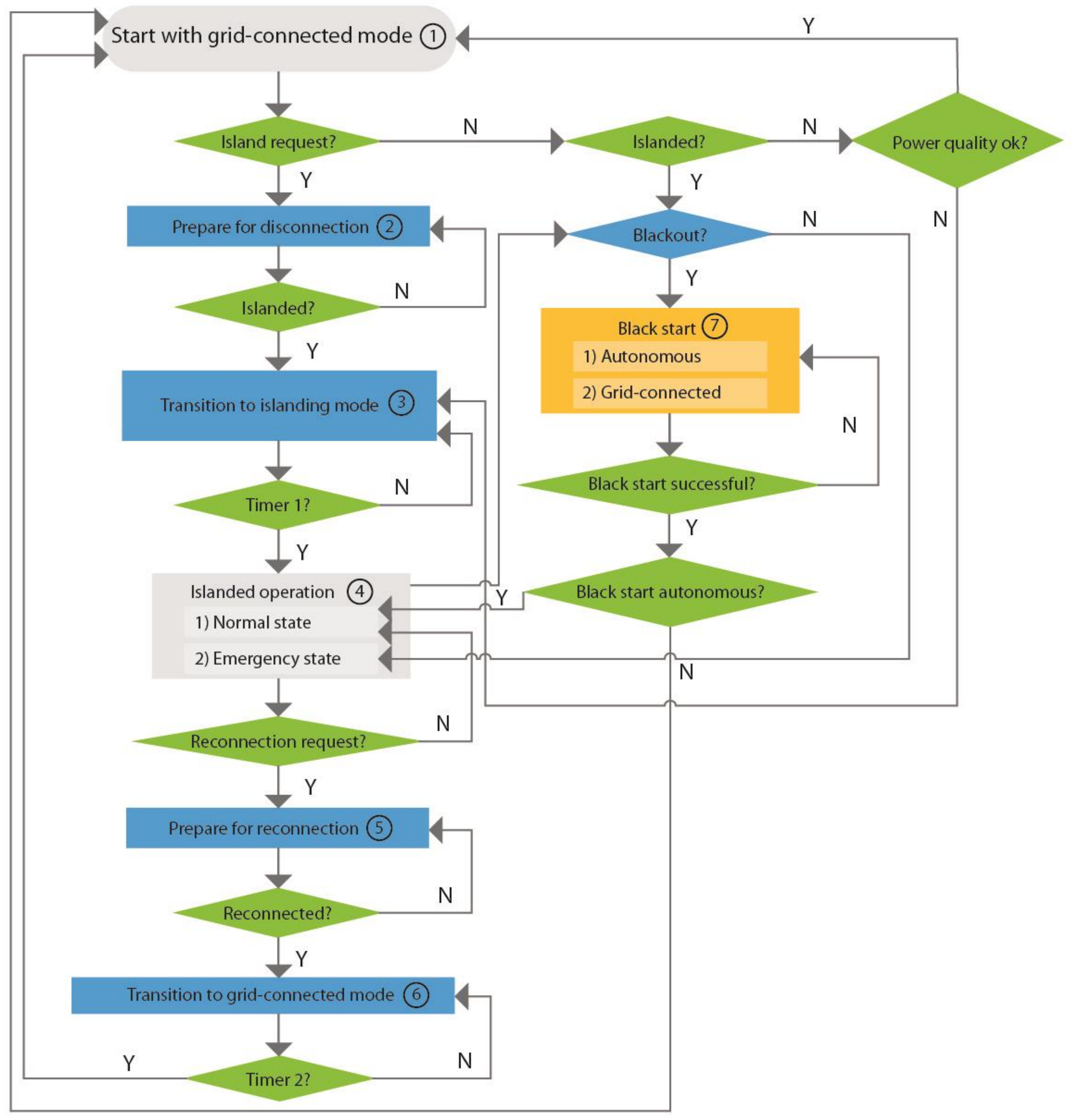
Transition Operation Test: grid-connected→ preparing for disconnection→ transition to islanded→ islanded→ preparing for reconnection→ transition to grid-connected→ grid-connected



Test results of normal transition operation: PCC measurements (top) and transition logics (bottom)

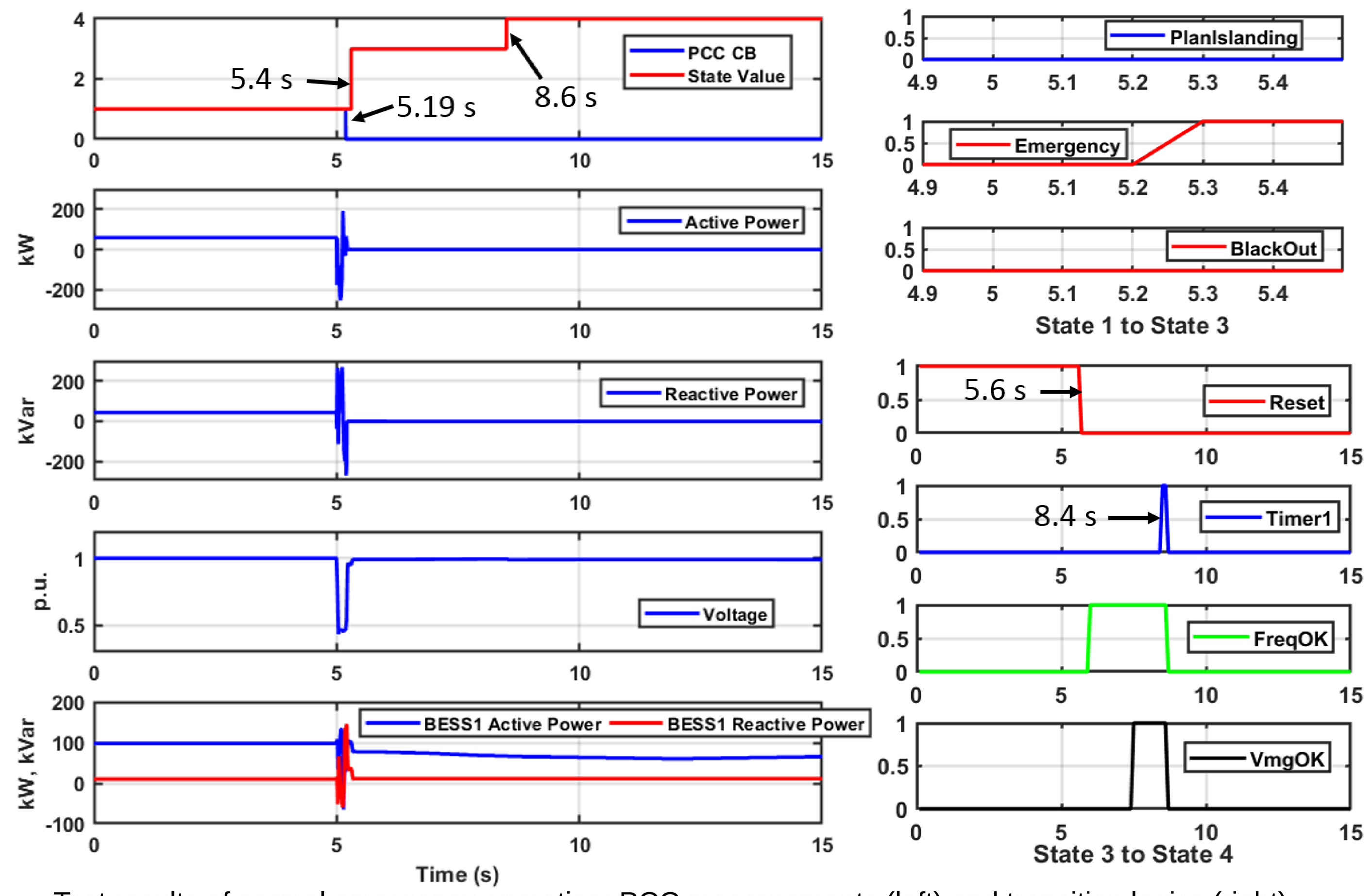
Design of Transition Logic

- Defined based on recommendation from IEEE Std 2030.7
- 13 paths for transition operation.



Simulation Results II

Emergency Operation Test: external fault initiated in grid-connected mode



Test results of normal emergency operation: PCC measurements (left) and transition logics (right)

Conclusions

A state machine-based EMS is developed to manage operation of microgrid for full automation. This state machine integrates dispatch function and transition function into one control frame. The results show that the developed state machine can transition from one state to the next correctly and timely, and the dispatch function can respond to the DNO's command/grid disturbances correctly, achieving smooth microgrid transition operation and performing black start if needed.

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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