State of Charge Management for Grid-Connected PV with Supercapacitor System Considering LVRT Operation

2023 CURENT Industry Conference

Apr. 2023

Paychuda Kritprajun[1], Leon Tolbert[1], Jingjing Sun[1], Jinxing Wang[1], Nattapat Praisuwanna[1], Yunting Liu[2], Maximiliano Ferrari[3]

[1]The University of Tennessee, Knoxville
[2]The Pennsylvania State University
[3]Oak Ridge National Laboratory

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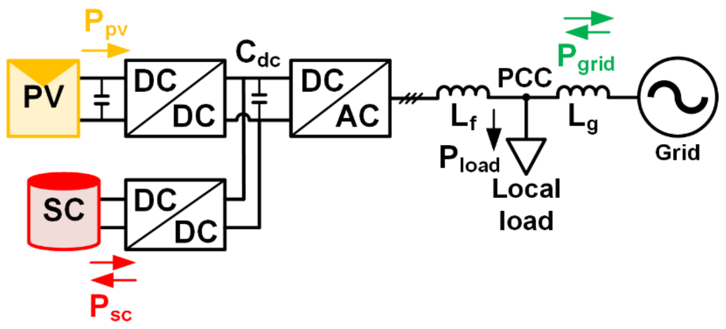
Background

- DC-link stability of the PV system can be maintained by supercapacitor (SC) under both normal and fault operation modes.
- SC has limited energy capacity; its unviability can impact the PV system stability under severe fault conditions.



Schematic of grid-connected photovoltaic with supercapacitor system (PVSS).

Objectives

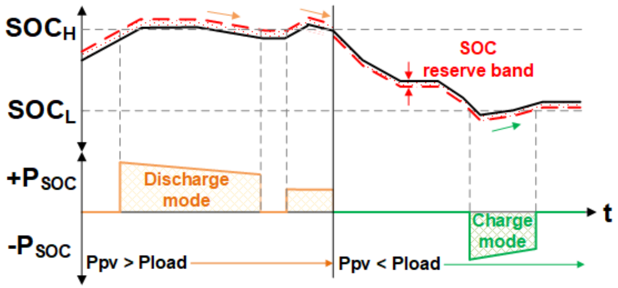
- To guarantee the availability of supercapacitor to provide support to the PV system during low voltage ride-through (LVRT) operations complying with IEEE 1547-2018 revision's grid code requirements.
- To achieve SOC management within a short time while ensuring the safe operation of both grid and PVSS.

Technical approach

- A concept of state-of-charge (SOC) reserve band for LVRT operation of PVSS.
  - The dynamic reserve SOC band is calculated based on the operating conditions of the PVSS, rather than using a fixed reserve SOC band proposed in the literature, to effectively utilize the use of the SC.
- Power-voltage droop curve based on voltage sensitivity factor to adjust the power during SOC management based on grid conditions.
- SC current adjustment based on SC thermal model to maximize the SC capacity and ensure SC safe operation during the SOC management.

State of Charge Management Considering LVRT Operation

SOC reserve band for LVRT operation



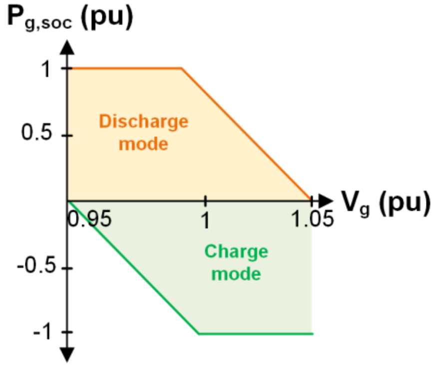
$$P_{sc,lvrt} \times t_{lvrt} = 0.5C_{sc} \times \left(\boldsymbol{V_{sc,lvrt}^{2}} - V_{sc}^{2}\right)$$

$$SOC_{lvrt} = SOC_{sc} + \frac{\left(V_{sc,lvrt} - V_{sc}\right)}{V_{sc,max}}$$

Estimate the SOC after LVRT operation by:

- Unbalanced power ($\boldsymbol{P_{sc,lvrt}}$) during LVRT operation.
- Required time to support during LVRT event ($\boldsymbol{t_{lvrt}}$) is 5s* [1].

Active power – voltage droop curve for SOC management

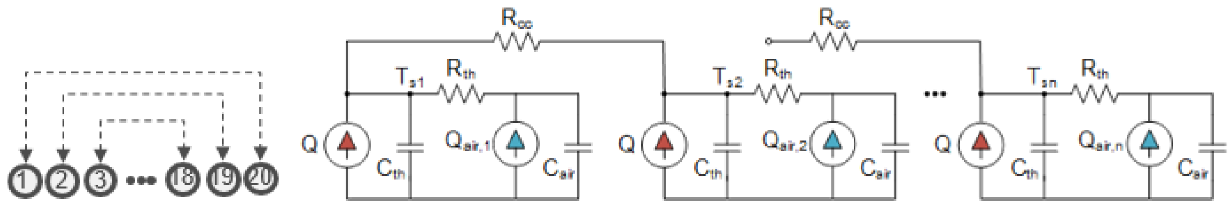


$$P_{g,soc} = \frac{1}{S_{vp}}\left(V_{grid,lim} - V_{grid}\right) + P_{g,0}$$

Adjust the power during SOC management based on grid conditions.

- Reduce the power during charging operation when grid voltage is close to the lower limit.
- Reduce the power during discharging operation when the grid voltage is close to the upper limit.

Thermal network model



SC string thermal network

- Adjust the SC current based on SC cell temperature to maximize its capacity and ensure its safe operation.

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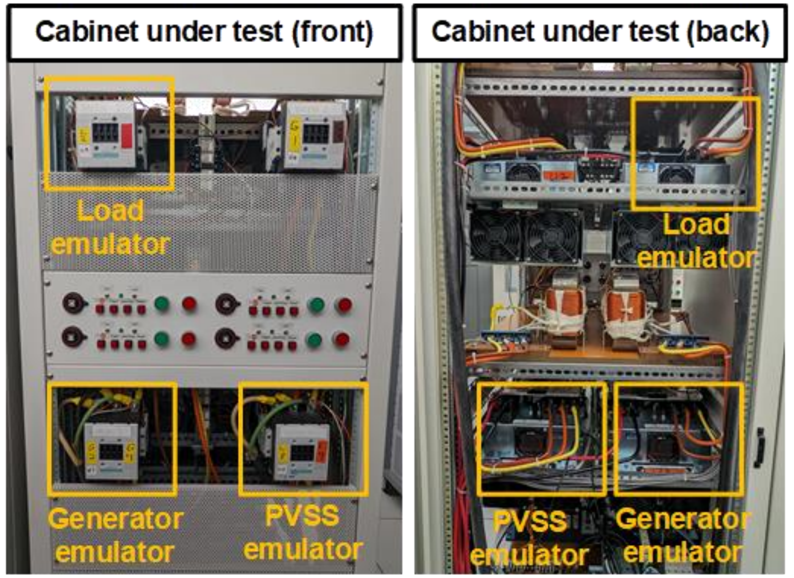
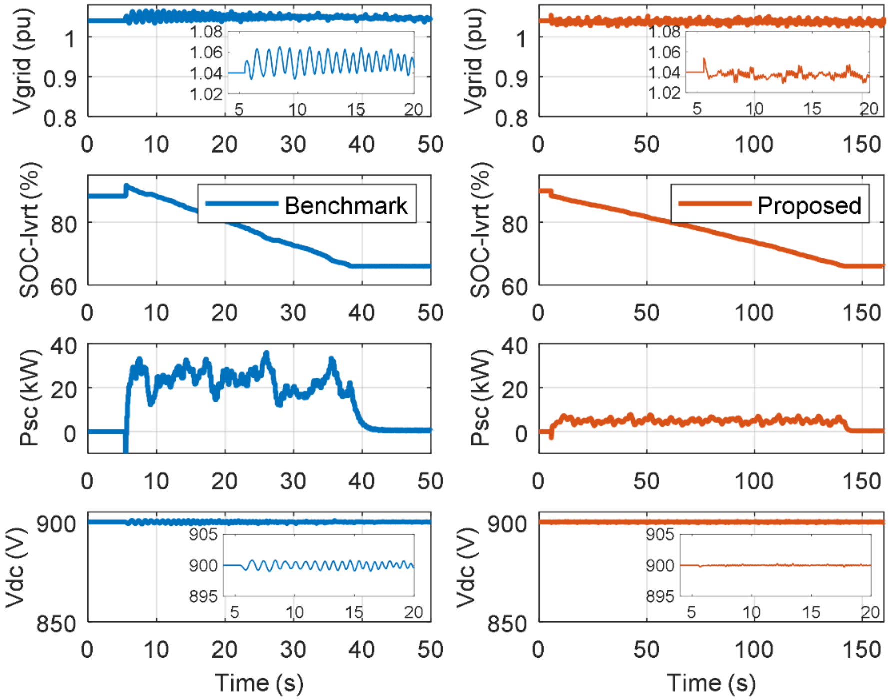
* Category II based on [1] "IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces," IEEE Std 1547-2018 (Revision of IEEE Std 1547-2003), pp.1-138, 2018.

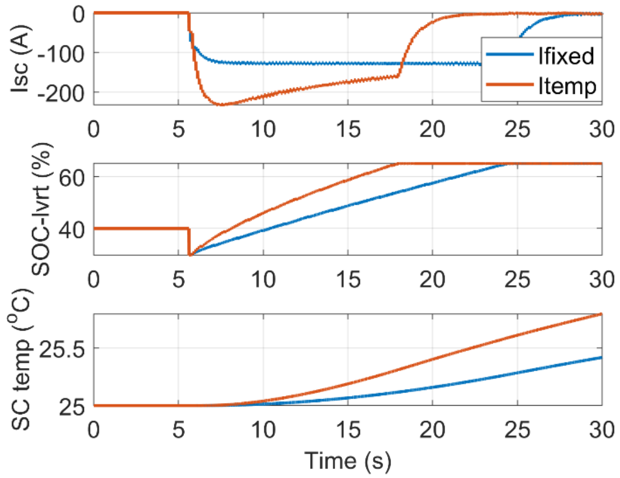
Experimental Test Results



Experimental test setup on Hardware testbed



Experimental results of SOC management based on the constant setpoint power (blue) and the proposed method with adjusted power based on grid condition (red).



Experimental results of SOC management based on the fixed current (blue) and the current depending on the SC temperature (red).

Conclusion

- Availability of the SC can be ensured during LVRT operation to avoid the slow response of PV curtailment that reduces the stability of PVSS during grid faults.
- A traditional constant power causes a power fluctuation due to the disabling and enabling of the SOC management from the oscillation of the grid at the limit.
    - This power fluctuation can lead to the disconnection of other nearby devices in the grid.
- Less oscillation of the grid voltage at the limit when implementing the power-voltage droop curve with voltage sensitivity factor.
- By incorporating the SC temperature, the SOC management can be done faster.
    - The SC capacity can be maximized while safe operation can be ensured.

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Acknowledgements

This work made use of shared facilities sponsored by ERC program of the National Science Foundation (NSF) and DOE under NSF award number EEC-1041877 and the CURENT Industry Partnership Program.

Other US government and industrial sponsors of CURENT research are also gratefully acknowledged.