





SMES-Battery Energy Storage System for Stabilization of a Photovoltaic-Based Microgrid

Lei Chen a,*, Hongkun Chen a, Jun Yang a, Xin Liu a, Ying Xu b, Li Ren b, Yuejin Tang b

^a School of Electrical Engineering, Wuhan University, Wuhan 430072, China ^b Huazhong University of Science and Technology, Wuhan 430074, China

Abstract—As superconducting magnetic energy storage (SMES) and battery are complementary in power capacity and energy density, introducing a SMES-battery energy storage system (ESS) has potentials to be more cost-effective and techno-efficient. This paper investigates the effects of a SMES-battery on stabilizing a photovoltaic-based microgrid under fault conditions. Related theoretical analysis of the SMES-battery is conducted, and the suitable control and coordination methods of the SMES-battery are proposed. Further, the simulation modeling and performance evaluation are performed in MATLAB, and here the comparison of with the SMES-battery and only with the battery is carried out. The results demonstrate that: i) the SMES-battery is better than the battery to timely handle the transient faults of the microgrid. ii) the SMES-battery can more effectively ensure a seamless mode-transition for the microgrid under the external fault, and reduce the fault current in the point of common coupling (PCC) to avoid an unnecessary off-grid under the internal fault. Thus, the feasibility of the SMES-battery for the transient performance enhancement of the microgrid is well confirmed.

1. System Description

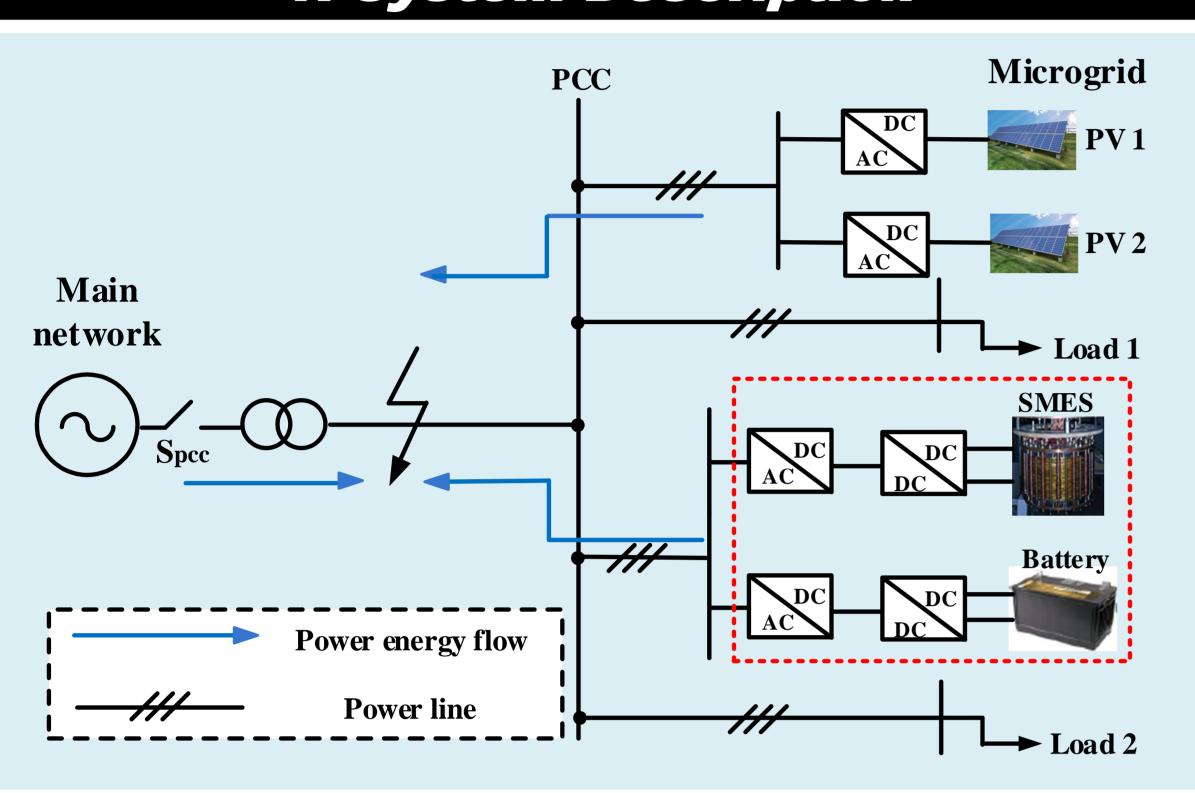


Fig. 1. Configuration of a photovoltaic-based microgrid with a SMES-battery.

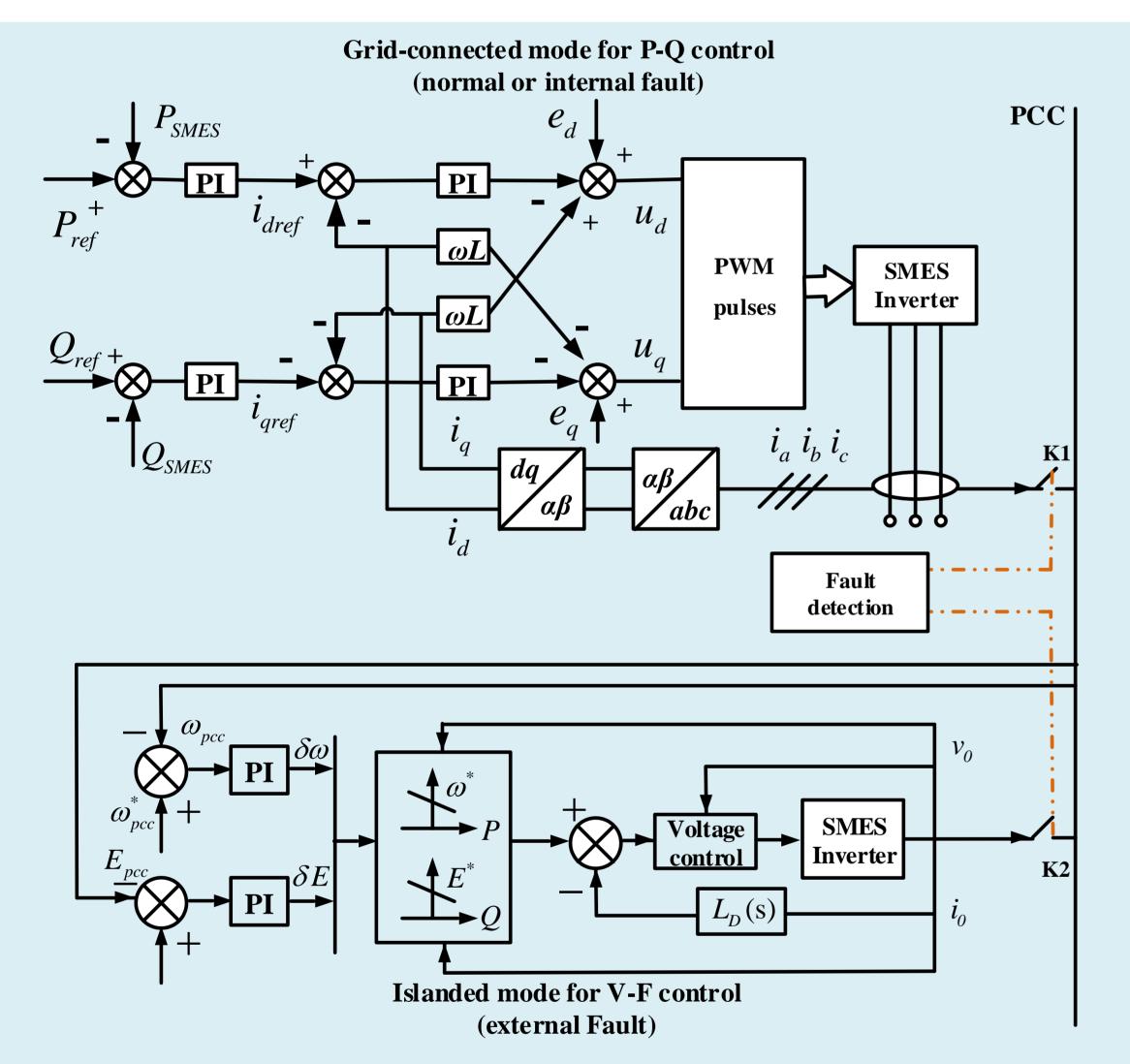


Fig. 2. Control block diagram of the SMES for the microgrid.

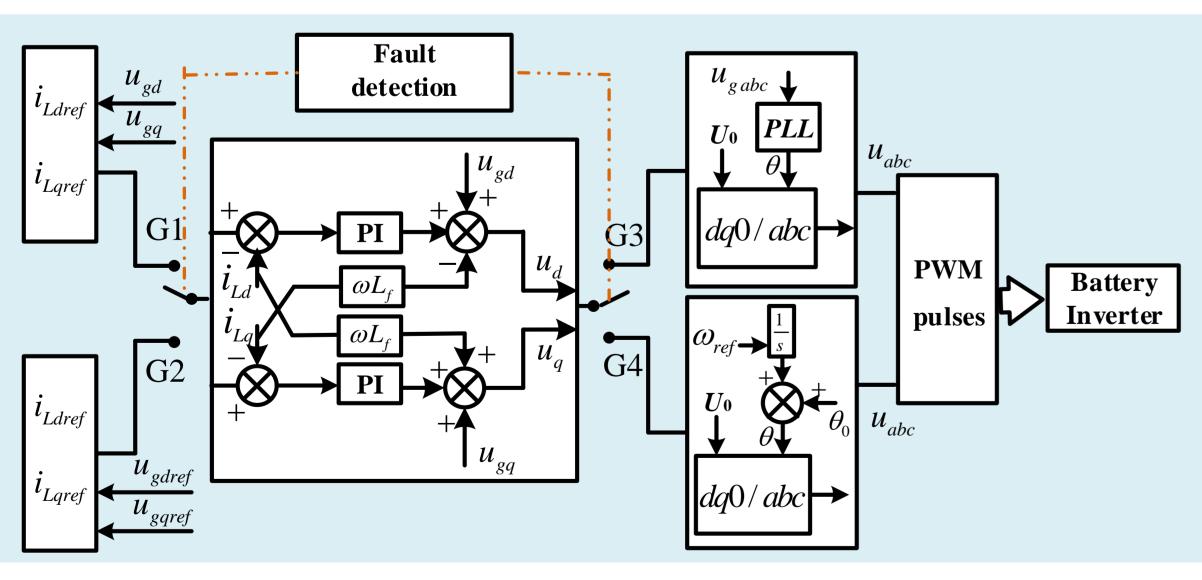


Fig. 3. Control block diagram of the battery storage for the microgrid.

The SMES and the battery are independently controlled to share and meet the power demand of the microgrid, and a fully active topology including two DC/DC and DC-AC converters is adopted.

The functions of the SMES for the microgrid are defined as that: 1) In normal state, the SMES is used to mitigate the PV fluctuation in a short-term period. 2) In the case of an external fault, the microgrid will transfer to its islanded mode, and the SMES can control the voltage and frequency for realizing a smooth transfer. 3) When an internal fault occurs, the microgrid is suggested to keep the grid-connected status, and the SMES will adjust the power flow to alleviate the fault current in the PCC. For the battery storage, it acts as a backup support for the SMES.

2. Coordination of the SMES-battery for the Microgrid

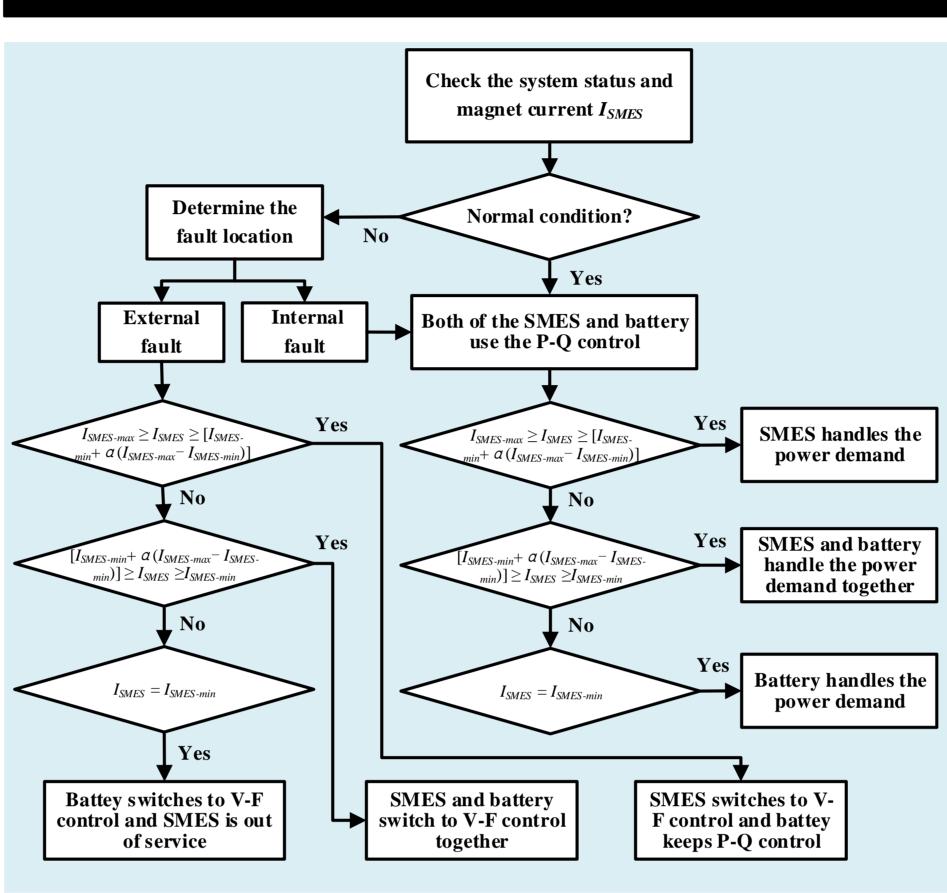


Table I Coordination of the SMES-battery to handle the internal fault.

Criterions	Constant P-Q control	
	SMES	Battery
I _{SMES-max} ≥ I _{SMES} ≥ [I _{SMES-}	P _{ref} , Q _{ref}	0
$_{\min} + \alpha(I_{SMES-max} - I_{SMES-min})]$ $[I_{SMES-min} + \alpha(I_{SMES-max} - I_{SMES-min})] \ge$	P _{ref} -P, Q _{ref} -Q	P, Q
I _{SMES} ≥ I _{SMES-min} I _{SMES} = I _{SMES-min}	0	P _{ref} , Q _{ref}

Table 2 Coordination of the SMES-battery to handle the external fault.

Criterions	Control mode selection	
	SMES	Battery
Normal condition (S _{pcc} is closed)	P-Q	P-Q
$I_{SMES-max} \ge I_{SMES} \ge [I_{SMES-min} + \alpha(I_{SMES-min})]$ $\underset{max}{\overset{\cdot}{=}} I_{SMES-min})]$ & (S _{pcc} is opened)	V-F	P-Q
$[I_{SMES-min} + \alpha (I_{SMES-max} - I_{SMES-min})] \ge I_{SMES} \ge I_{SMES-min}$	V-F	V-F
$I_{\text{SMES}} = I_{\text{SMES-min}}$	P-Q	V-F

Fig. 4. Design of the coordination method for the SMES-battery.

3. Simulation analyses

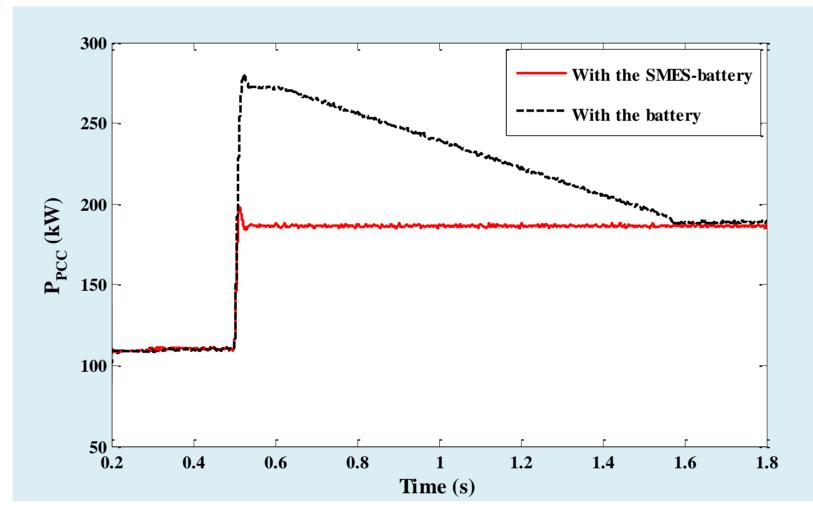


Fig. 5. Power exchange at the PCC under the internal fault.

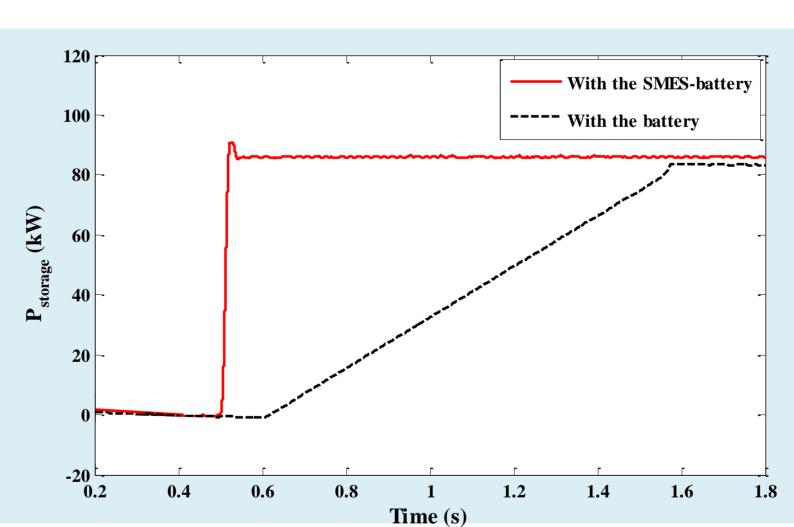


Fig. 6. Output of the energy storage under the internal fault.

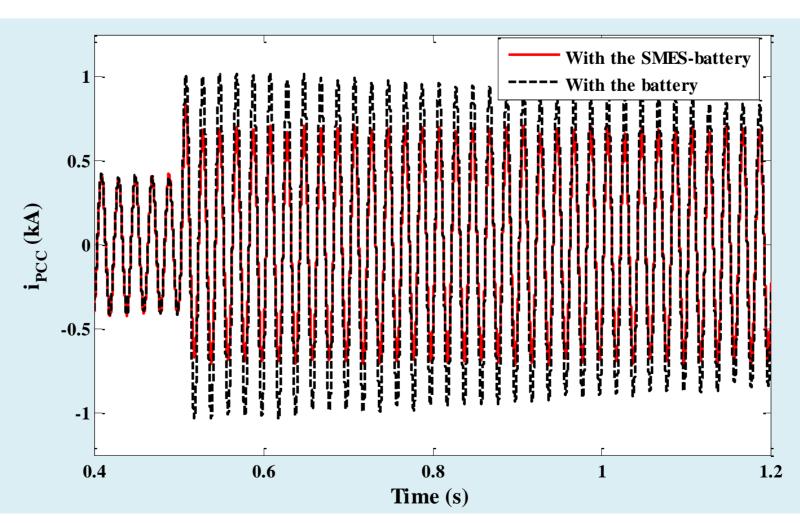


Fig. 7. Fault current in the PCC under the internal fault.

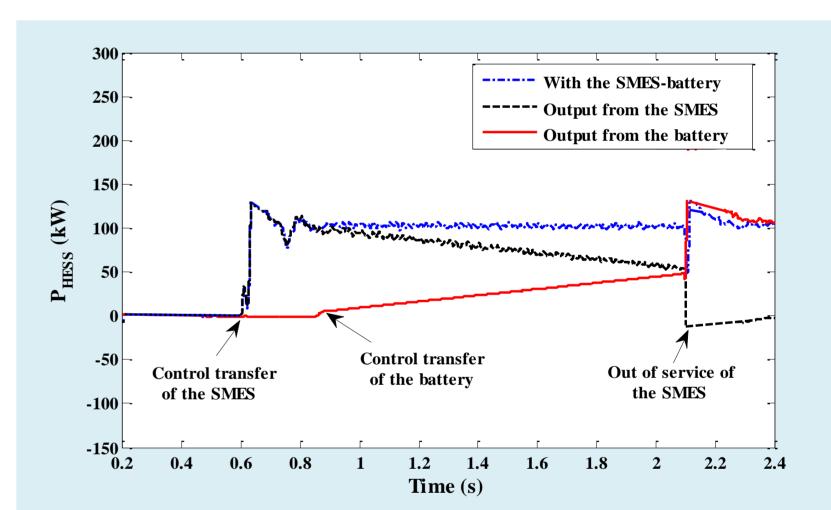


Fig. 8. Response of the SMES-battery under the external fault.

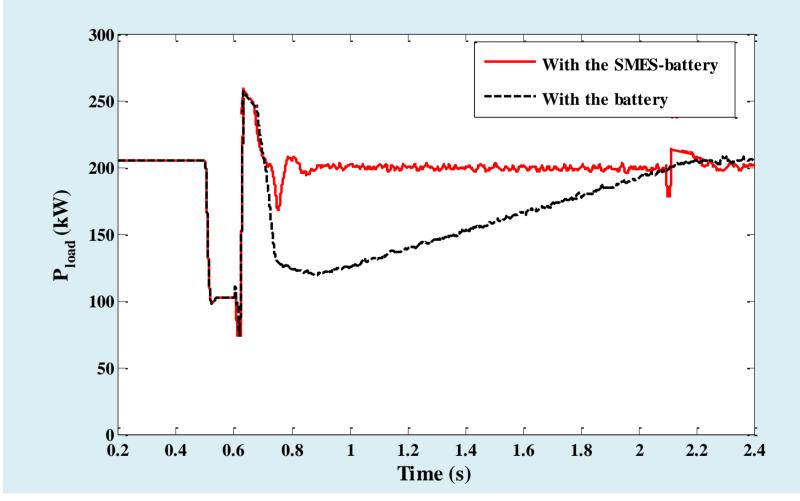


Fig. 9. Load power of the microgrid under the external fault.

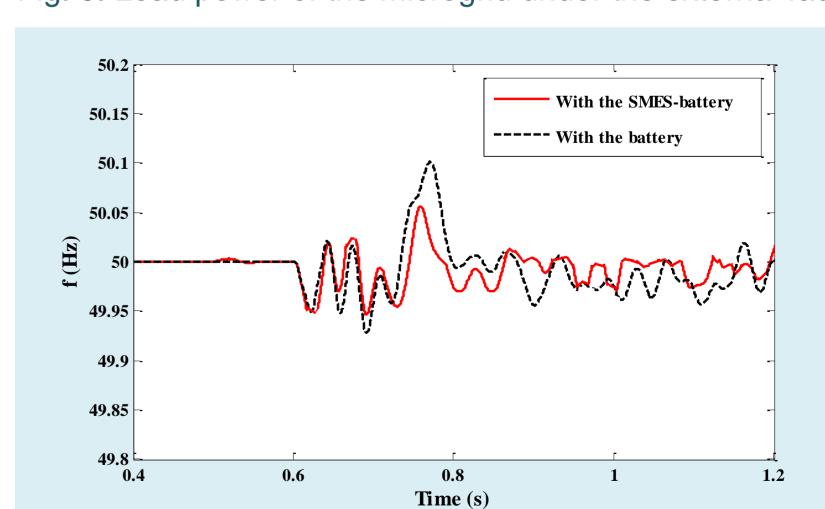


Fig. 10. Frequency of the microgrid under the external fault.

4. Conclusion

The demonstrated results draw the following conclusions:

- 1) The SMES-battery is better than the battery to timely handle the transient fault issues of the microgrid. At the initial stage of the fault feeding, the SMES-battery plays its role.
- 2) The SMES-battery can more effectively ensure a seamless mode transition for the microgrid under the external fault, and reduce the fault current in the PCC to avoid an unnecessary off-grid under the internal fault. Thus, the transient stability and operation flexibility of the micro-grid are well enhanced.
- As our follow-up works, the parameter optimization and prototype design of the SMES-battery for the microgrid will be conducted, and the results will be reported in later articles.