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Application Study of a Flux-Coupling-Type SFCL for Low-Voltage Ride-Through Operation of a Virtual Synchronous Generator

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Abstract—To solve the low-voltage ride-through (LVRT) issue of a virtual synchronous generator (VSG) under severe grid fault, this paper proposes the solution of a modified flux-coupling-type superconducting fault current limiter (SFCL). According to the equivalent analysis circuit of the VSG under the fault, the functions of the SFCL are discussed from the aspects of current limitation, voltage compensation, and energy dissipation. Using MATLAB, symmetrical and asymmetrical faults are both simulated to assess the transient behaviors of the VSG, and the SFCL parameters are changed to clarify the quantitative effects. From the simulation results, the SFCL parameters are properly determined to provide favorable performance. The SFCL can visibly decrease the fault current of each phase lower than the safety margin, and make the VSG own a preferable voltage profile. Additionally, the SFCL is able to positively stabilize the VSG by enhancing the active power, mitigating the frequency fluctuation and consuming the excess energy. A satisfactory LVRT operation is gained, and the efficacy of the SFCL on reinforcing the VSG robustness is validated.

1. The VSG's structure and control algorithm

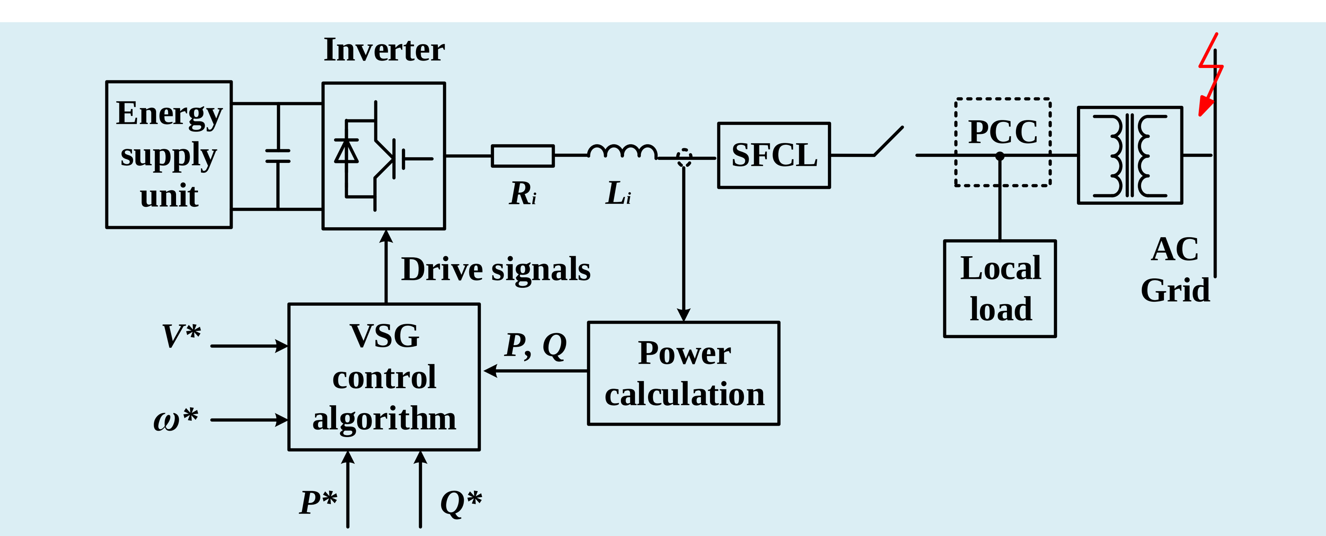


Fig. 1. Schematic diagram of a VSG integrating the SFCL in the PCC.

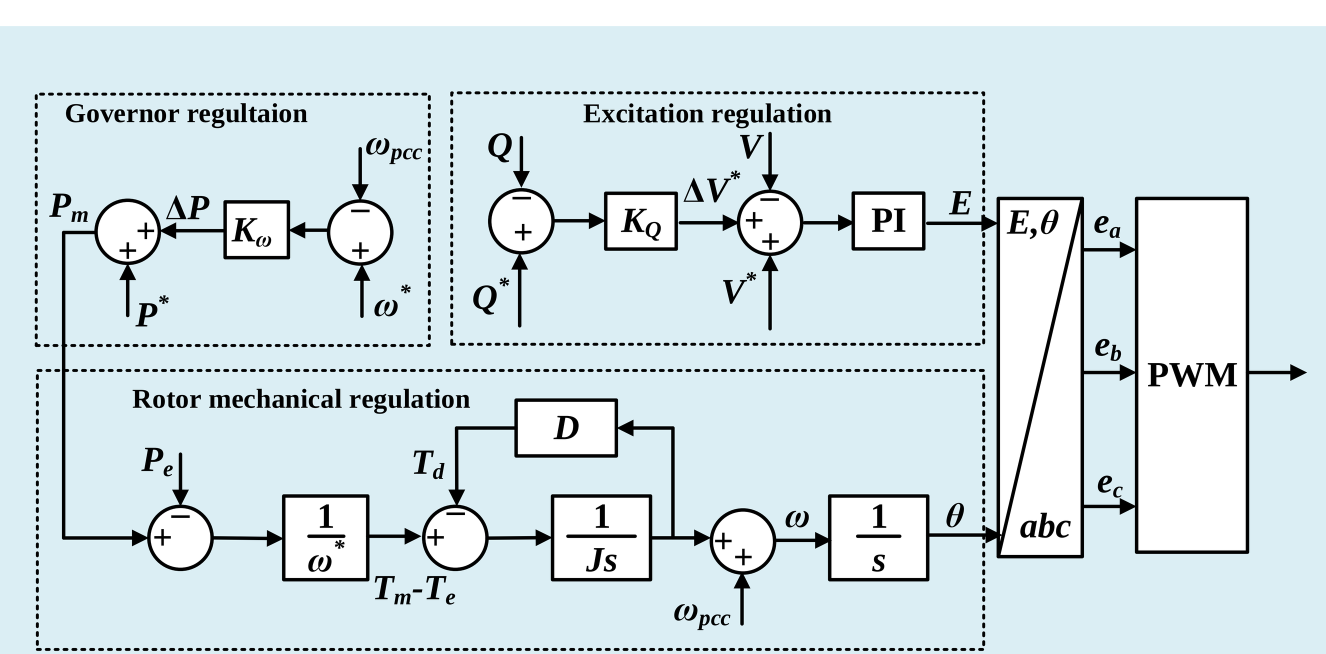


Fig. 2. Block diagram of the VSG control algorithm.

2. Description of the SFCL and Its effects

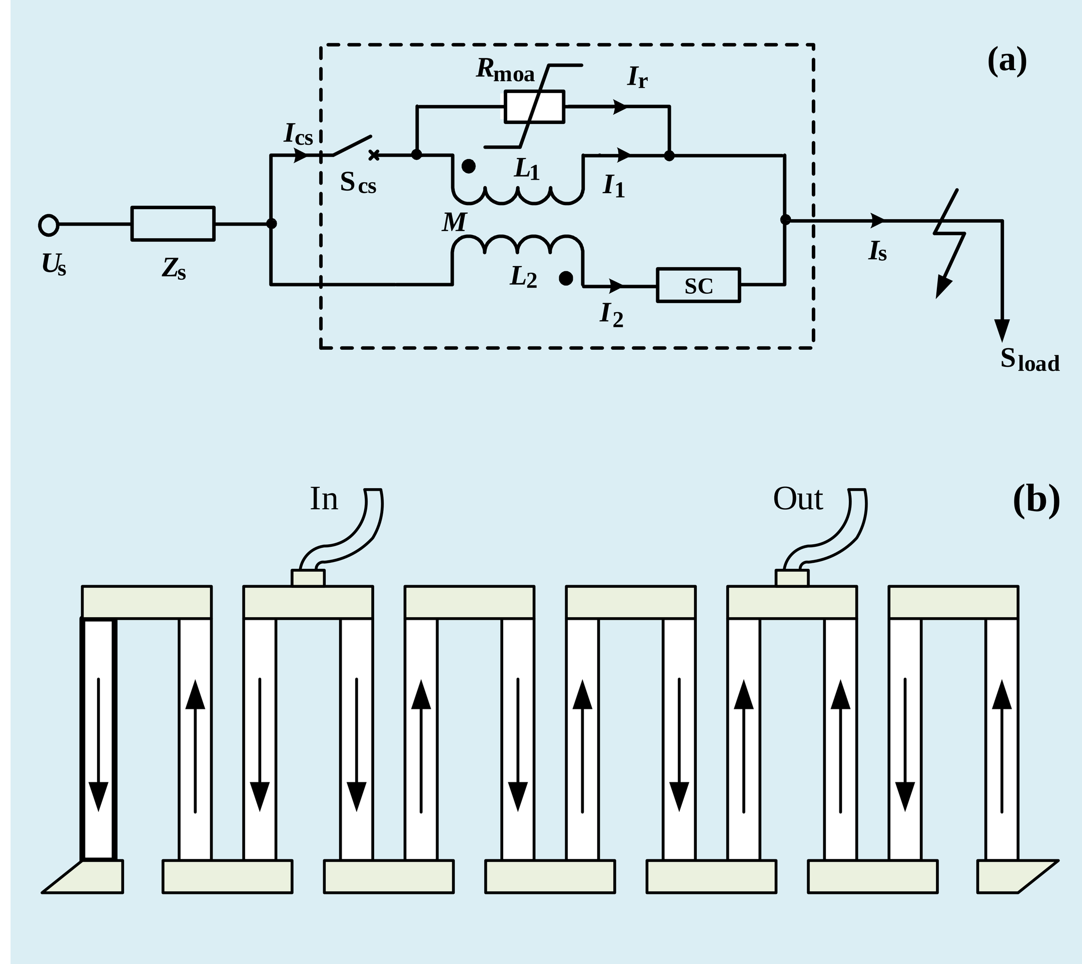


Fig. 3. (a) Modified flux-coupling-type SFCL.
(b) Schematic inner connection diagram of the SC.

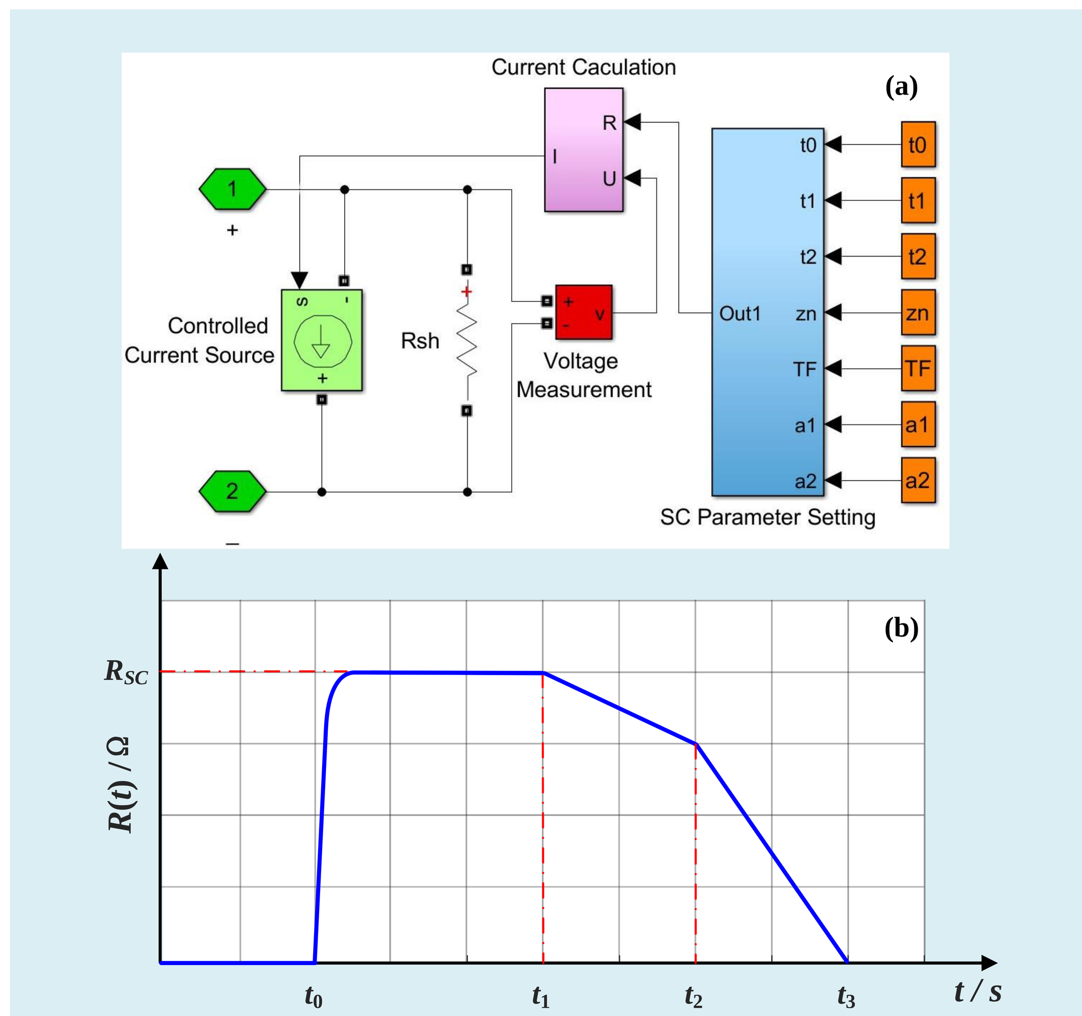
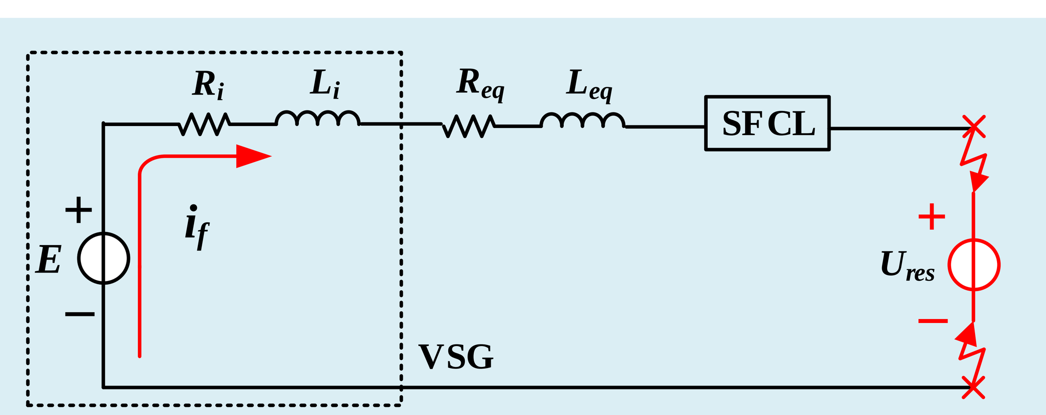


Fig. 4. SC modeling method. (a) Electrical model for MATLAB simulation. (b) Quench and recovery behaviors.



$$i_{f-\lim}=\frac{E\sin(\omega t+\theta_1-\beta_{\lim})-U_{res}\sin(\omega t+\theta_2-\beta_{\lim})}{\sqrt{(R_f+R_{SC})^2+\omega^2(L_f+L_2)^2}}+\left[I_{f0}-\frac{E\sin(\theta_1-\beta_{\lim})-U_{res}\sin(\theta_2-\beta_{\lim})}{\sqrt{(R_f+R_{SC})^2+\omega^2(L_f+L_2)^2}}\right]e^{-\frac{L_f+L_2}{R_f+R_{SC}}t}$$

Fig. 5. Fault analysis circuit of the VSG with the SFCL.

3. Performance evaluation of the SFCL for LVRT enhancement of the VSG

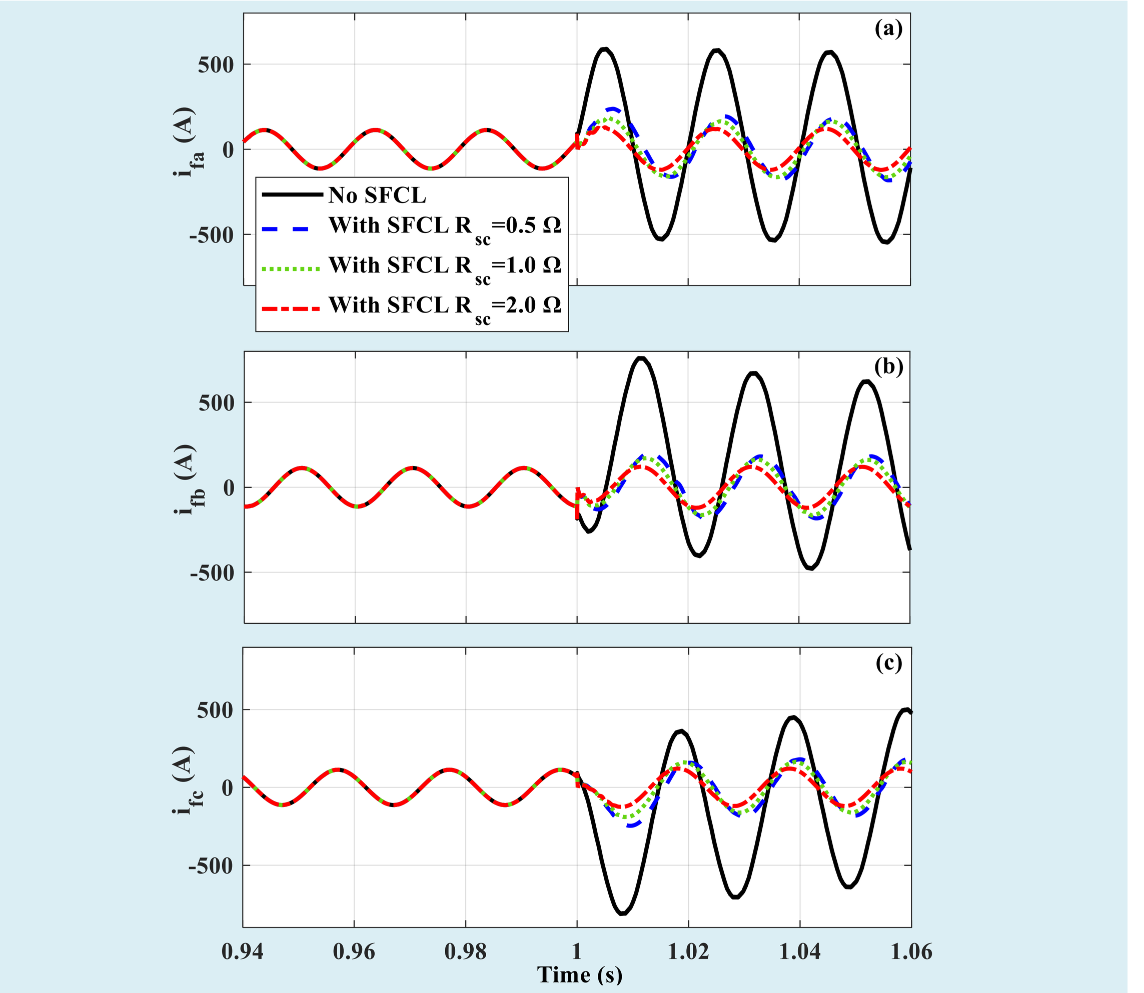


Fig. 6. Short-circuit current of the VSG under the symmetrical fault. (a) Phase-A, (b) Phase-B and (c) Phase-C.

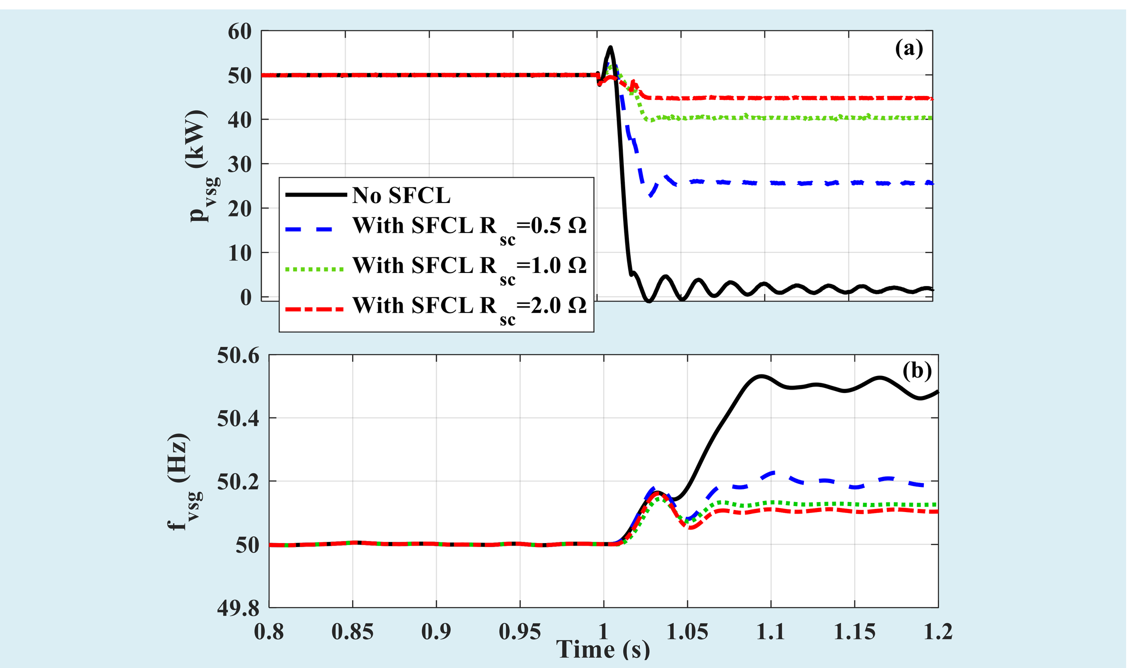


Fig. 7. Transient behaviors of the VSG under the symmetrical fault. (a) Active power and (b) generator frequency.

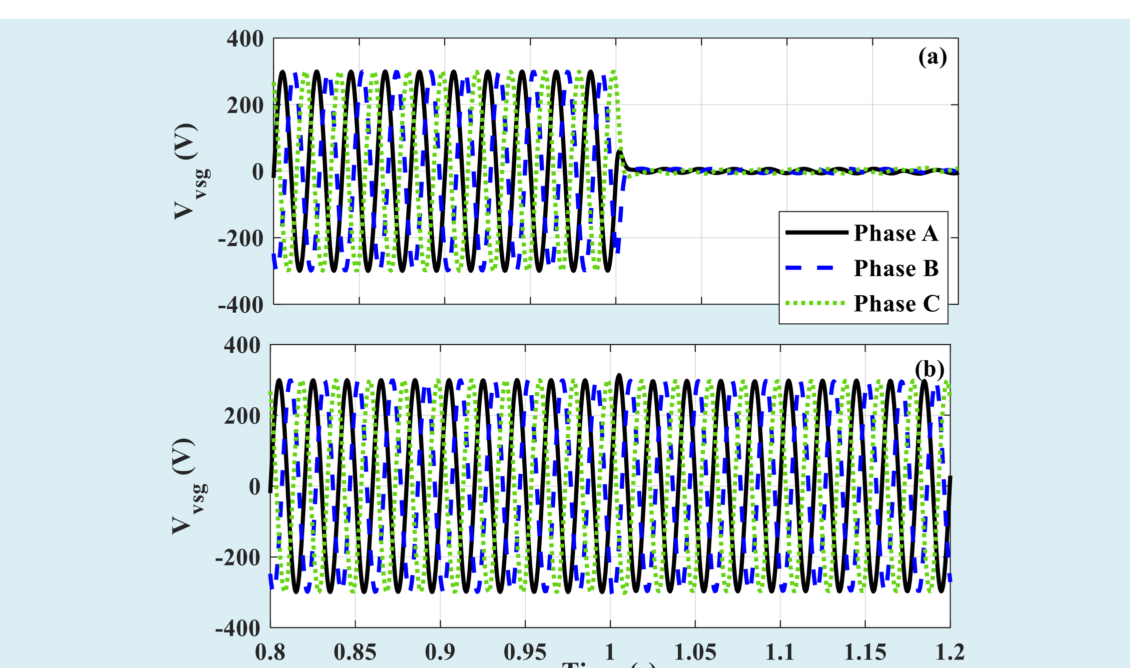


Fig. 8. Three-phase voltage of the VSG under the symmetrical fault. (a) No SFCL and (b) with the SFCL of Rsc = 2 Ω.

Concerning that the SC resistance is increased to R_{sc} = 2 Ω, the SFCL may suppress the fault current of each phase within 1.3 times of the rated level, and an adequate safety margin is produced. Furthermore, the VSG frequency dynamic is visibly inhibited by the SFCL, and the maximum frequency deviation is reduced from 0.5 Hz to 0.1 Hz.

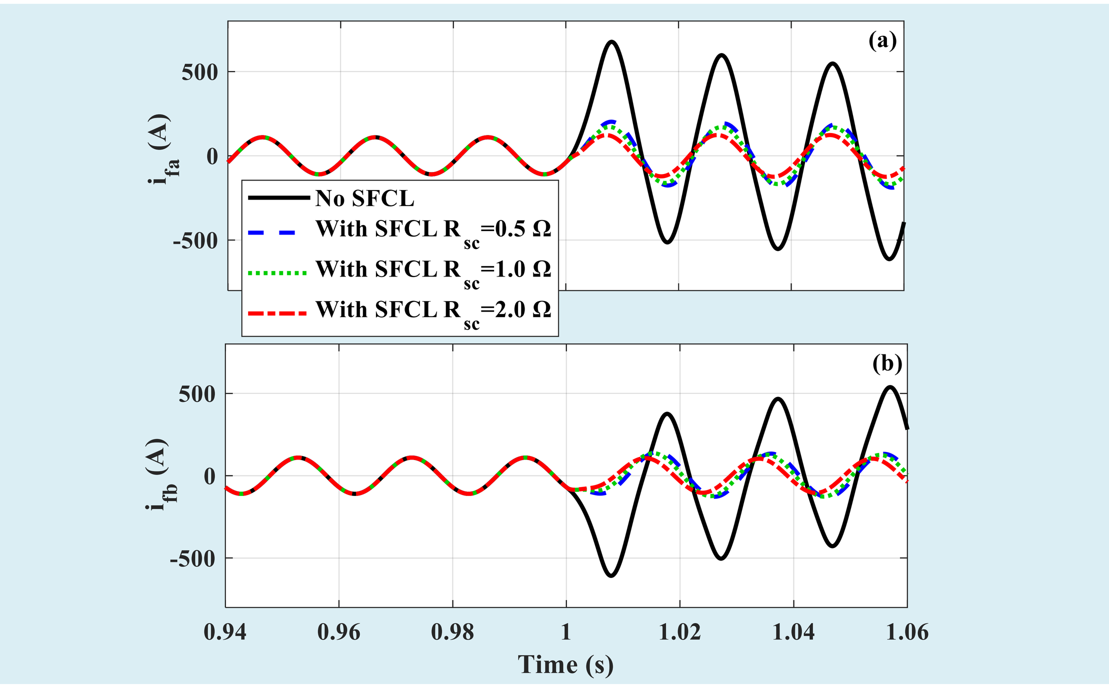


Fig. 9. Short-circuit current of the VSG under the asymmetrical fault. (a) Phase-A and (b) Phase-B.

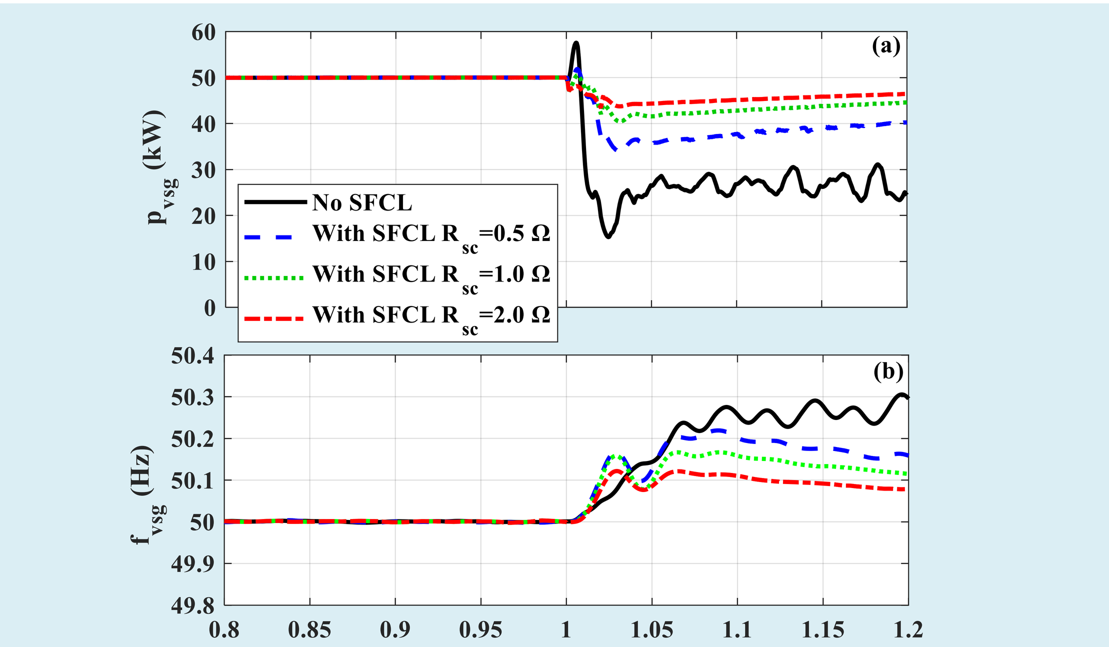


Fig. 10. Transient characteristics of the VSG under the asymmetrical fault. (a) Active power and (b) generator frequency.

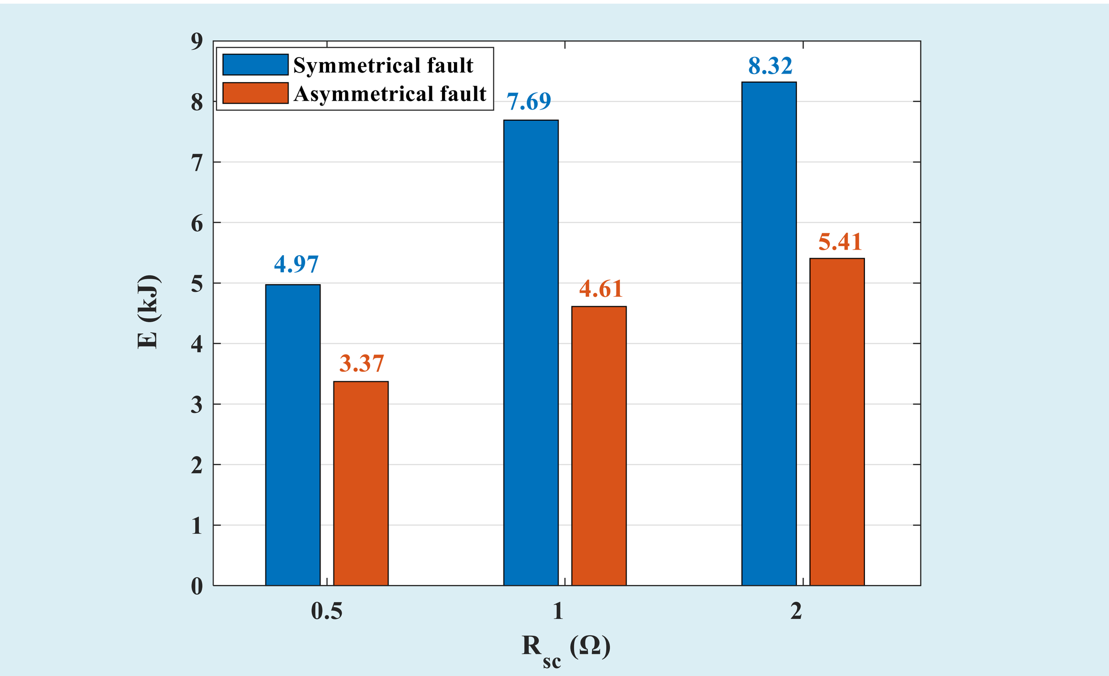


Fig. 11. Energy dissipating feature of the SFCL under fault conditions.

4. Conclusion

This paper explores the feasibility of applying a modified flux-coupling-type SFCL in fulfilling the LVRT enhancement of a VSG under symmetrical and asymmetrical faults. From the theoretical analysis and simulation validation, a proper design of the SFCL parameters is obtained to offer great contributions.
i) The SFCL is able to powerfully reduce the fault current of each phase within the safety margin, and to make the VSG have a preferable voltage profile.
ii) The SFCL can visibly improve the active power and decrease the frequency fluctuation for the VSG. Thereupon, a satisfactory LVRT operation is realized.

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