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Conceptual Design and Evaluation of a HTS Magnet for a SMES Used in Improving Transient Performance of a Grid-Connected PV System

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Abstract—This paper suggests a small-scale superconducting magnetic energy storage (SMES) to enhance the transient behaviors of a 100 kW grid-connected photovoltaic (PV) system, and conducts the conceptual design and performance evaluation. The stored energy of the SMES is designed as 90 kJ, and the YBCO tapes are adopted to make the SMES magnet with solenoid structure. Based on the genetic algorithm, the magnet parameters are optimized. Besides, not only the fault response of the PV system with the SMES is assessed in MATLAB, but also the electromagnetic properties and stress analysis of the SMES magnet are performed in ANSYS. The results prove that: 1) Using the SMES improves the fault-ride-through (FRT) capability and realizes an effective protection for the PV system. 2) A relatively large perpendicular magnetic field is found in both ends of the SMES magnet, and the maximum field will be induced in the middle of the SMES magnet. 3) The hoop stress and the radial stress on the SMES magnet are acceptable, and the mechanical strength is satisfied. Thus, the proposed parametric design accords with the expected objectives and the demands of the PV.

1. The SMES's structure and application

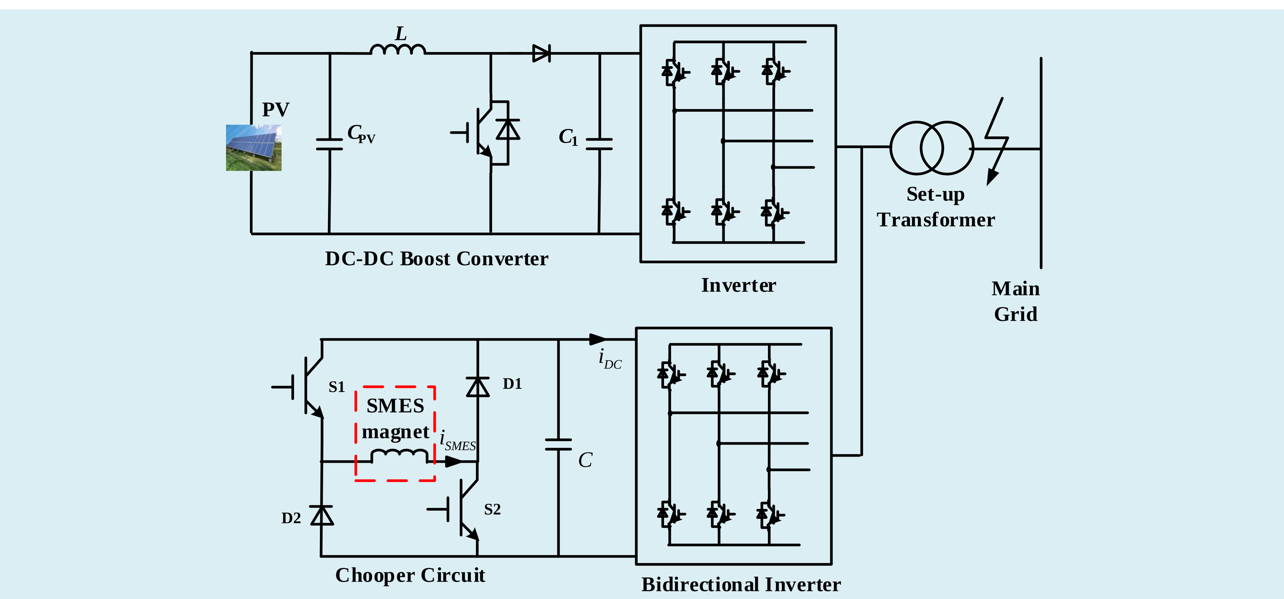

Fig. 1. Configuration of a grid-connected PV system with a SMES unit.

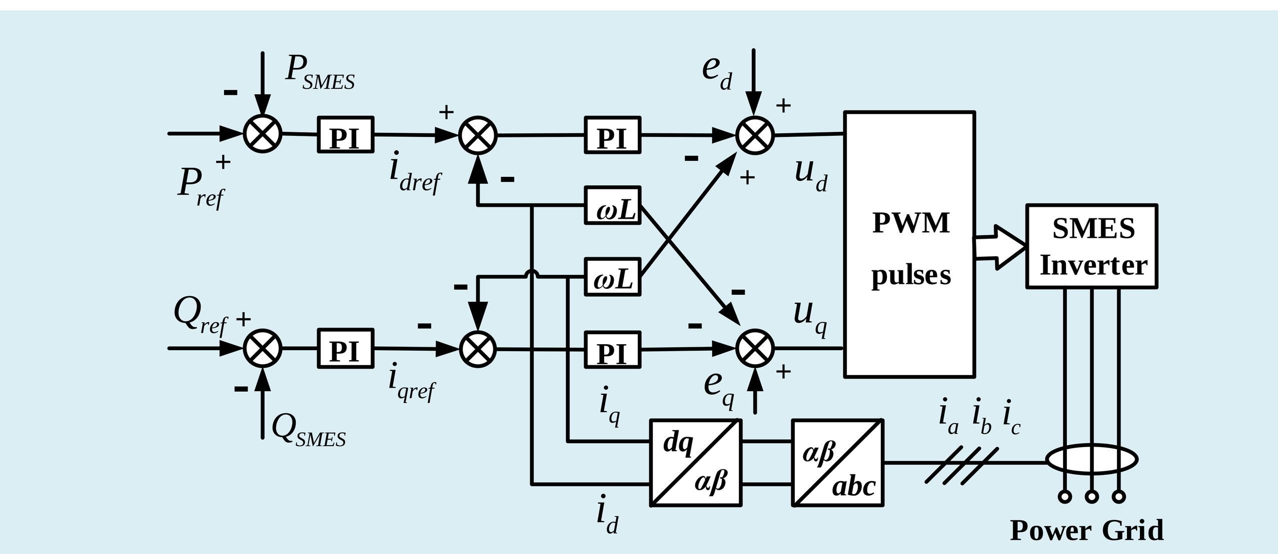

Fig. 2. Control block diagram of the SMES inverter.

2. Conceptual design of the SMES

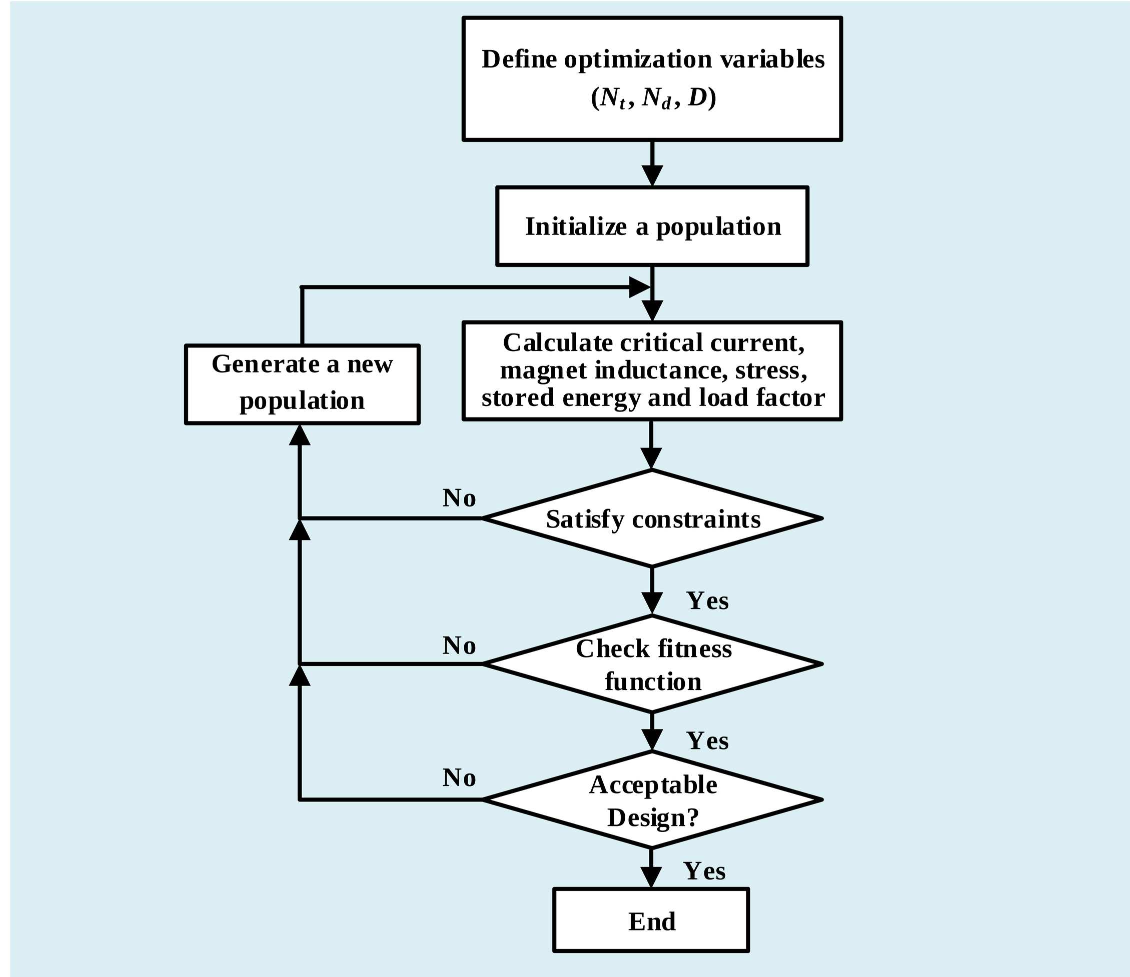

Fig. 3. Flowchart of the GA implementation in the magnet design.

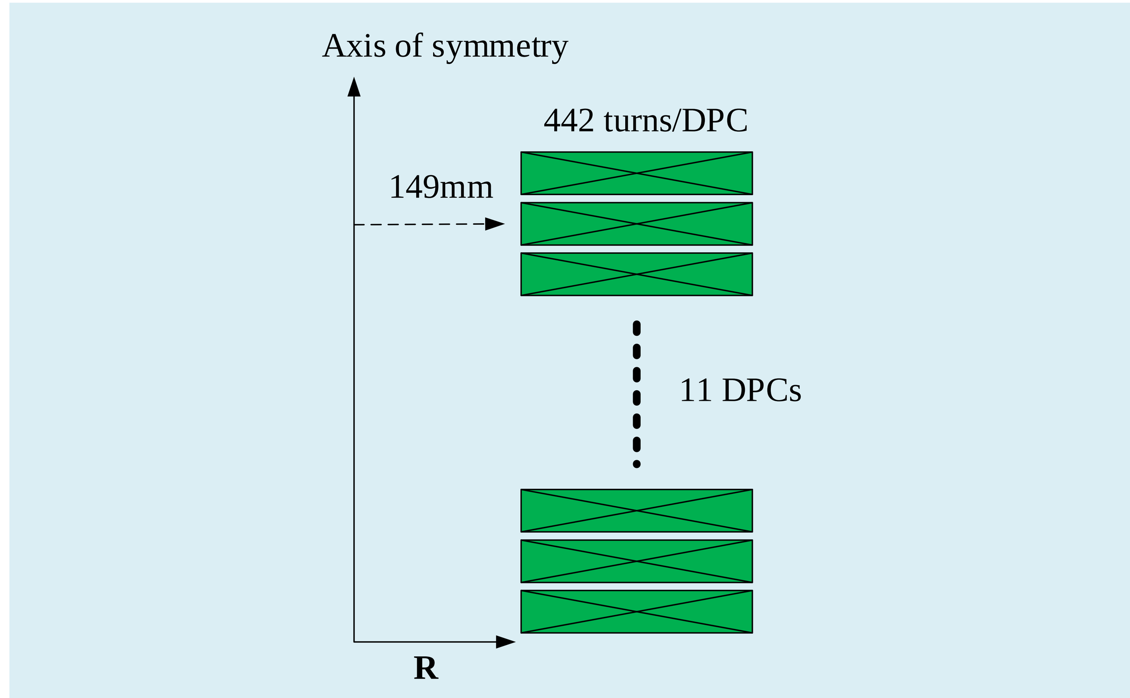

Fig. 4. Schematic structure of the designed SMES magnet.

Parameters	Value
Stored energy, E	90 kJ
Duration of delivery, Δt	2 s (normal) / 0.5 s (fault)
Voltage of the DC bus, U_{dc}	800 V
Minimum current, I_{min}	30 A
Initial working current, I_{ini}	100 A
Maximum current, I_{max}	150 A
Magnet inductance, L_s	8 H
Maximum power, $P_{SMES\text{-}max}$	80 kW

Parameters	Value
Number of turns of double pancakes, N_t	442
Number of double pancakes, N_d	11
Inner diameter of double pancakes, D	149 mm
Magnet Inductance, L_s	8.24 H
Initial working current, I_{SMES}	100 A
Critical Current, I_{max}	187 A
Stored energy, E	93 kJ
Total length of the HTS tapes, l	4.89 km
Maximum parallel magnetic field, $B_{\parallel}$	3.32 T
Maximum perpendicular magnetic field, $B_{\perp}$	4.69 T

3. Performance evaluation of the designed SMES in the PV system

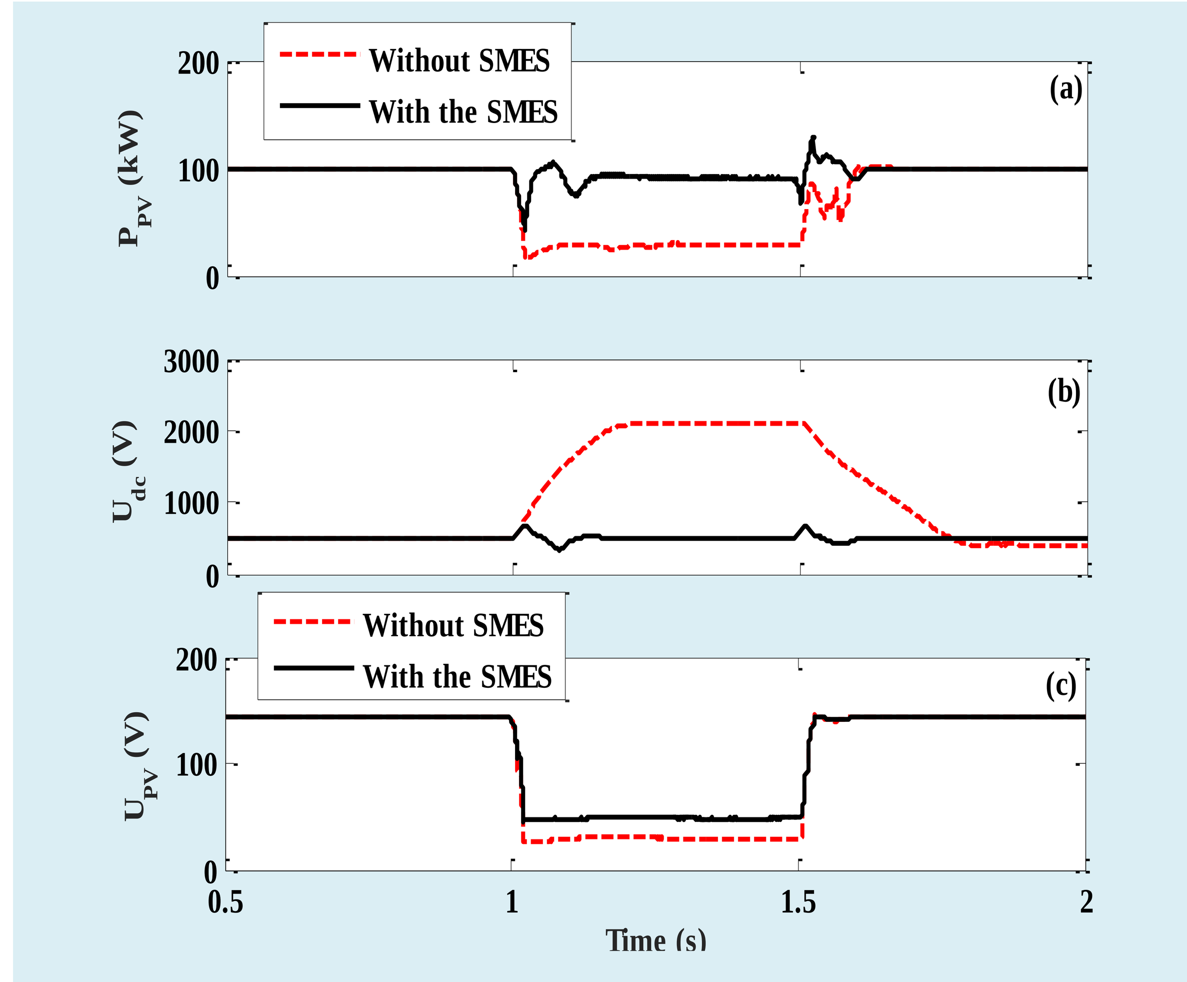

Fig. 5. Fault response of the PV system with and without the SMES. (a) PV power to the grid P_{PV}, (b) DC-link voltage U_{dc}, (c) PV terminal-voltage U_{PV}.

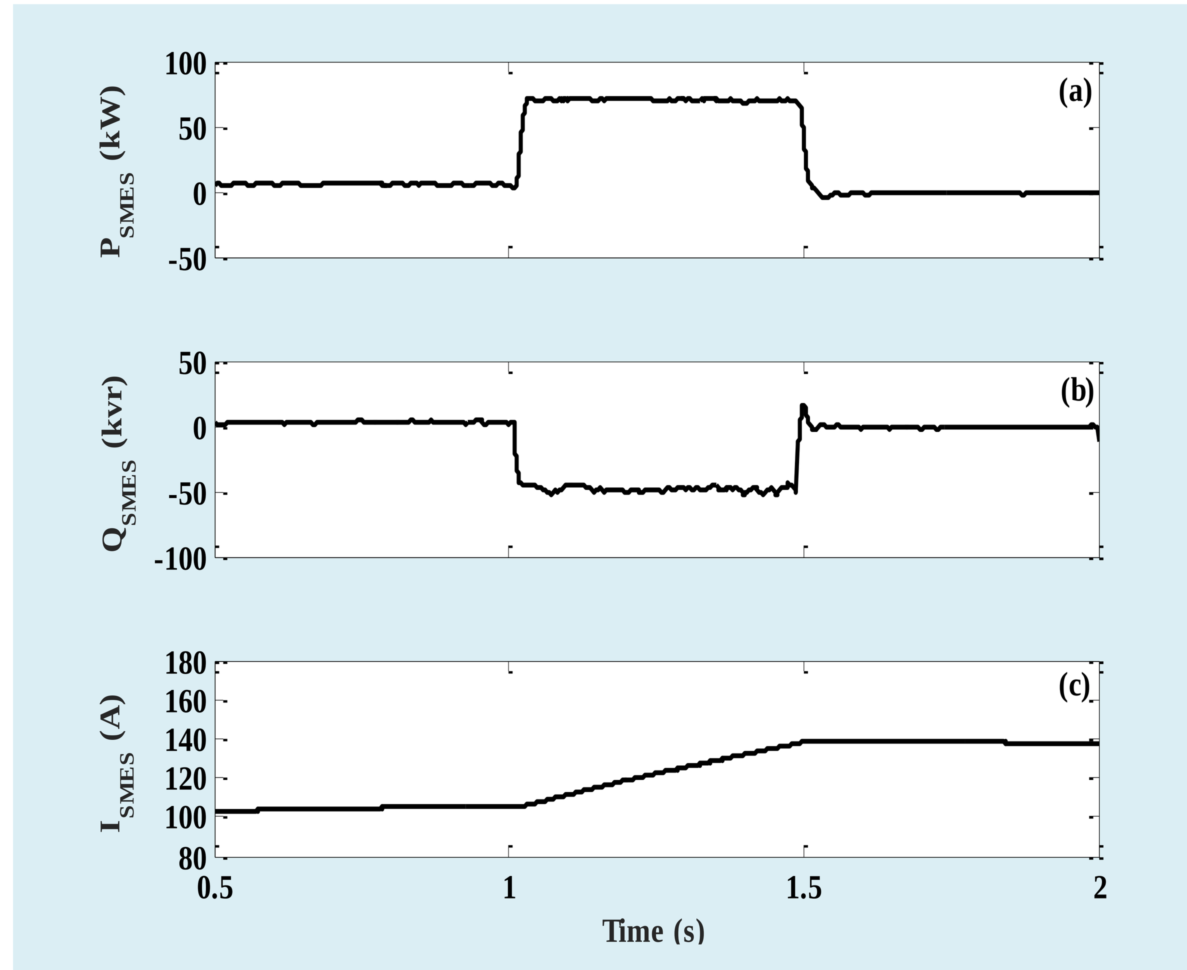

Fig. 6. Operation characteristics of the SMES under the fault. (a) Active power P_{SMES}, (b) Reactive power Q_{SMES}, (c) Magnet current I_{SMES}.

When the SMES is not applied, the PV power transmitted to the grid will reduce from 100 kW to 22 kW during the fault, and there is an induced overvoltage with its peak value of 2100 V to potentially damage the DC-link of the PV inverter. Besides, the PV terminal-voltage drops to 19.7% of the nominal level, and the PV system cannot achieve a FRT operation.

For with the SMES, the stabilities of the PV power and the DC-link voltage are enhanced, and the PV terminal-voltage is improved to 34.3% of the nominal level. Thus, using the SMES makes the PV system be persistently connected to the main grid.

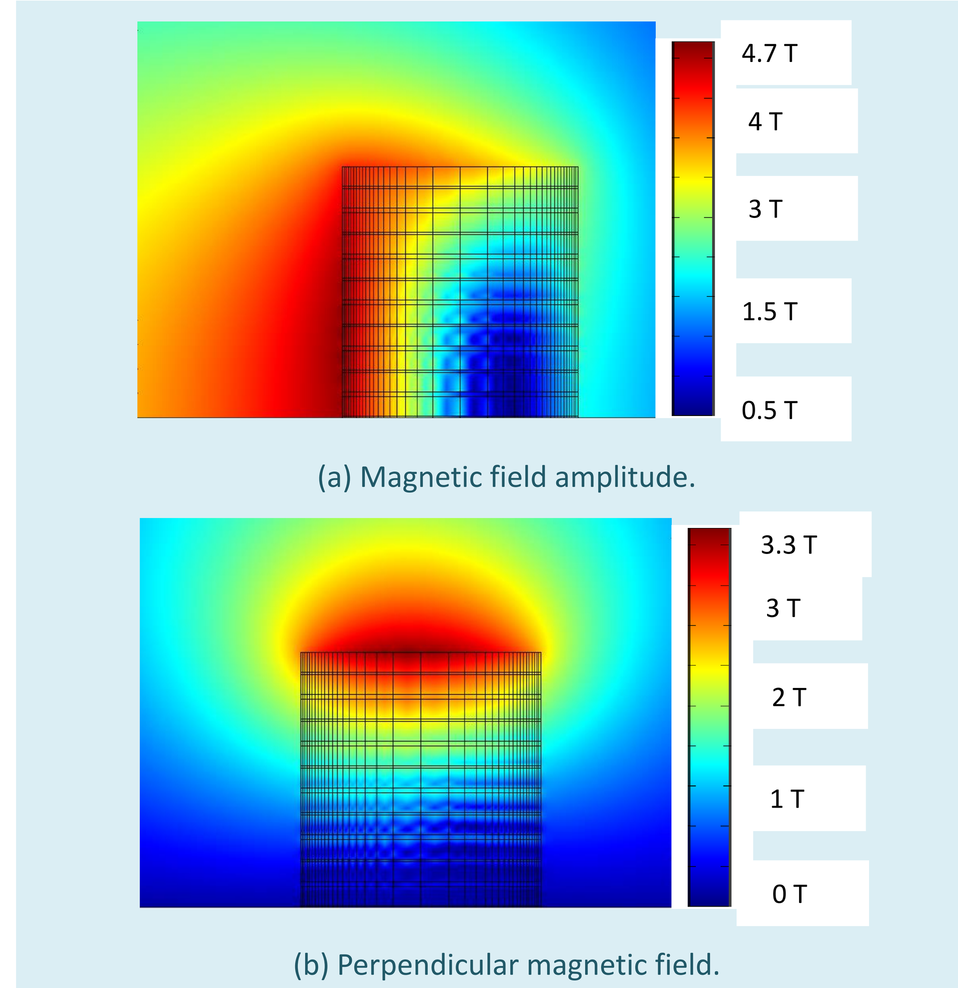

Fig. 7. Magnetic field of the SMES magnet for the peak current 140 A (upper half part of the magnet).

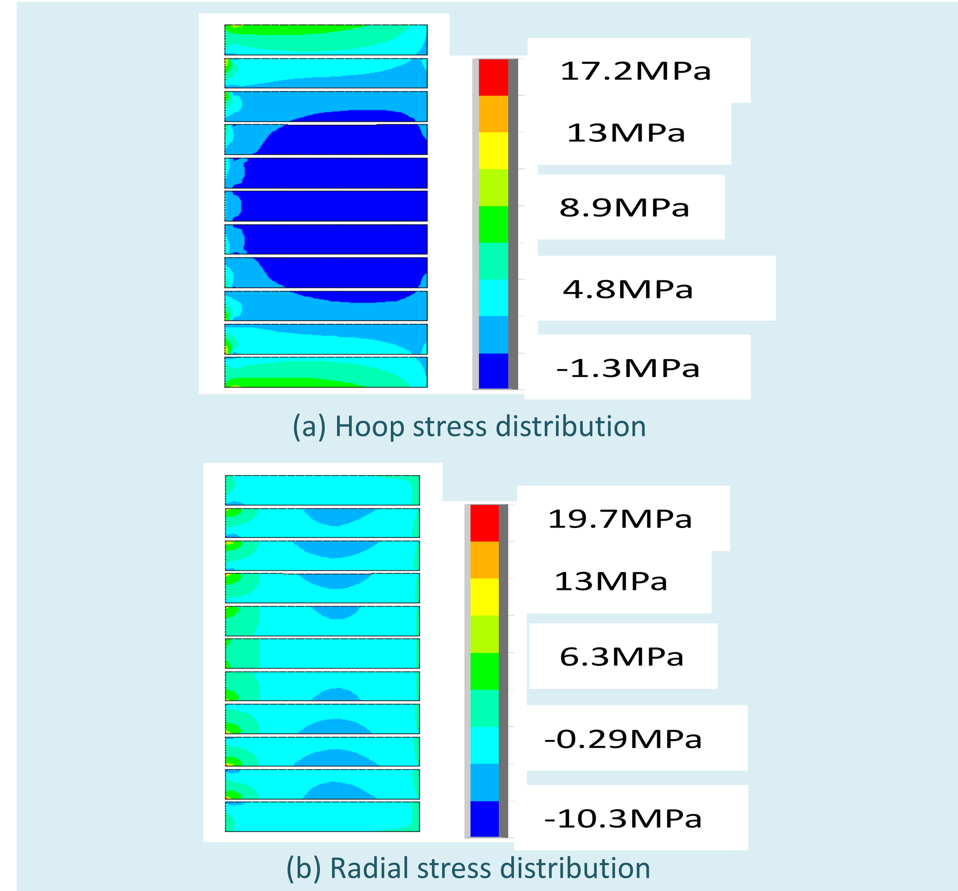

Fig. 8. Stress distribution of the SMES magnet for the peak current 140 A.

4. Conclusion

The following conclusions are drawn:

1) Using the SMES is able to improve the FRT capability and realize an effective protection for the PV system. It is obtained to smooth the PV power fluctuation, alleviate the DC-link overvoltage and compensate the PV terminal-voltage.

2) A relatively large perpendicular magnetic field will be found in both ends of the SMES magnet, and the maximum field will be induced in the middle of the SMES magnet.

3) The maximum values of the hoop stress and the radial stress on the SMES magnet are within the tolerable allowance, and the requirements for mechanical strength are satisfied.

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