

Direct Pressure-tolerant DC Transformer Scheme and Control Method Applied to Subsea Power Supply

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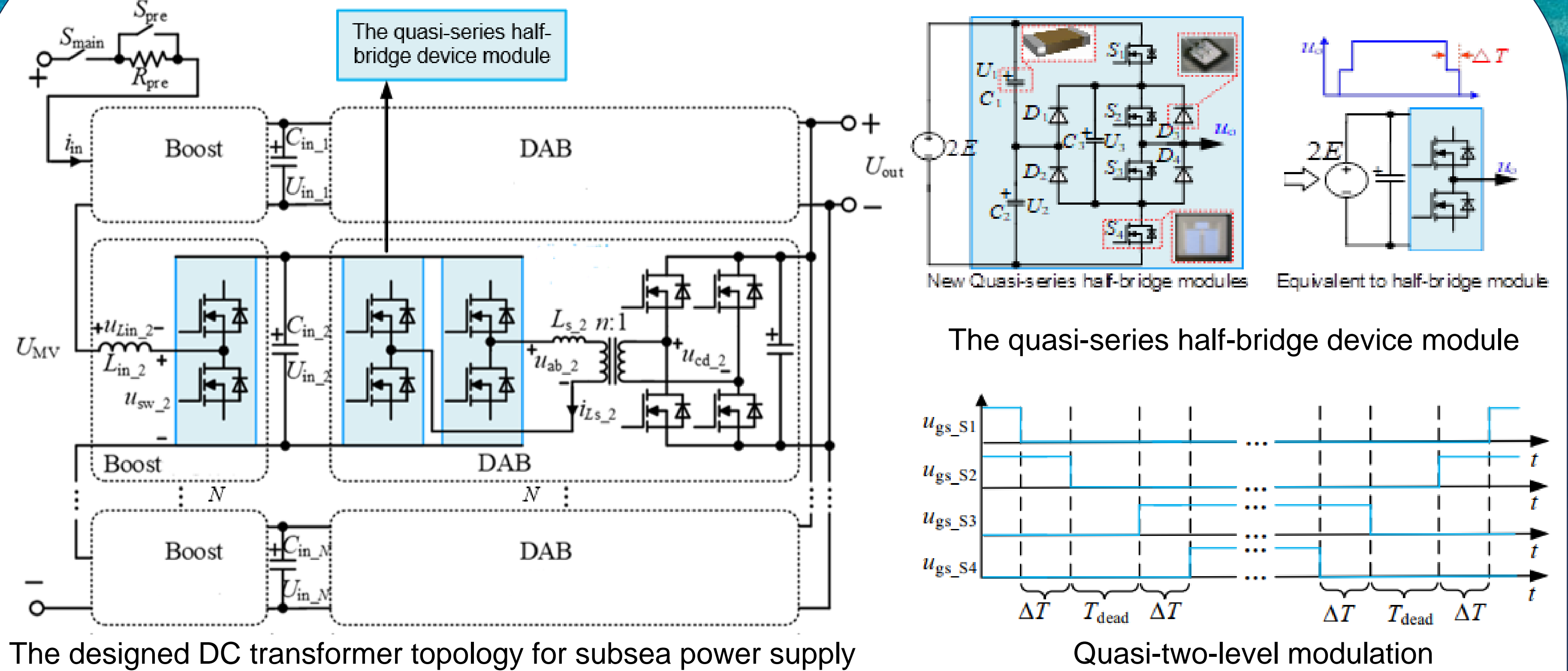
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Abstract

In order to realize the high-power density design of deep-sea DC transformer, the new quasi-series half-bridge module is adopted to reduce the number of cascaded units. A component solution for direct pressure-tolerant DC transformer was built by screening and testing a large number of power electronics devices and optimizing key components. Then the insulating liquid is filled into the flexible pressure-averaging enclosure to ensure the insulation and heat dissipation, the scheme can remove the thick metal pressure-bearing enclosure and additional heat dissipation equipment, effectively improve the power density. The corresponding closed-loop control method and soft-start control strategy are proposed, and finally through the experiments under the standard atmospheric pressure and simulated deep-sea environment, the feasibility of direct pressure-tolerant DC transformer scheme is verified.

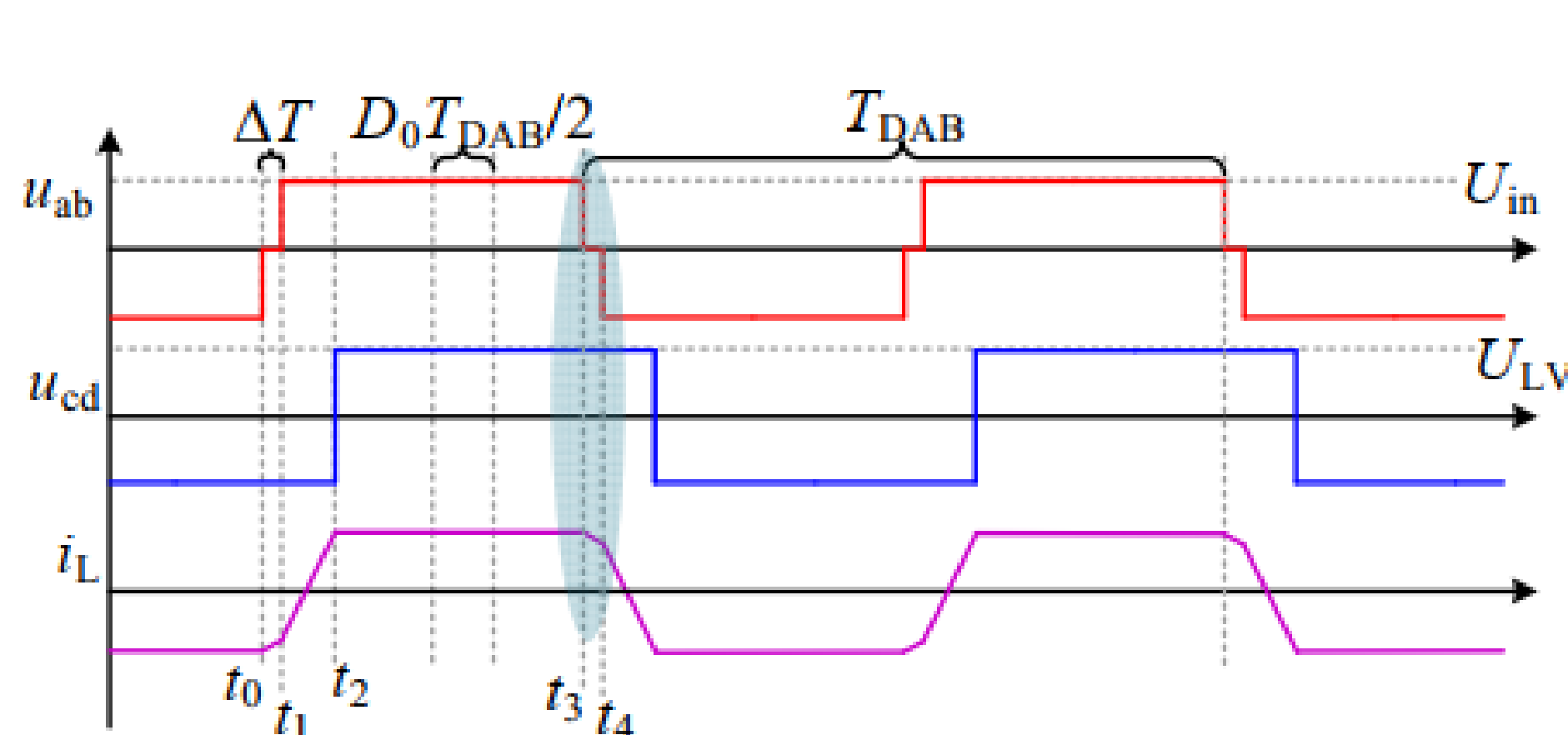
Topology



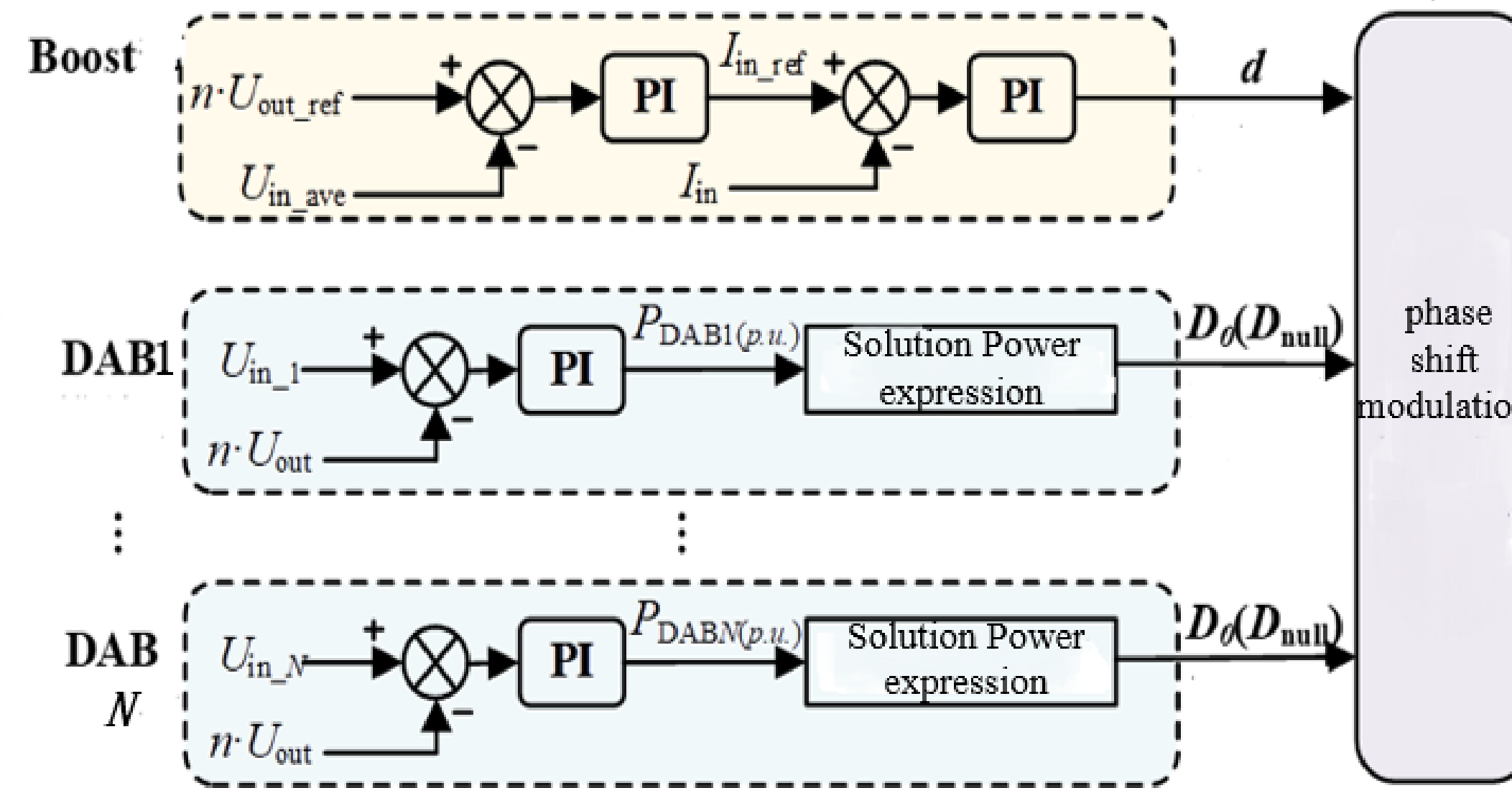
The designed DC transformer topology for subsea power supply

A quasi-series half-bridge device has higher voltage withstand level, high integration, the effect of the delay time on the intermediate level can be ignored, then the quasi-series module is considered to be equivalent to the conventional two-level half-bridge module. Each DC unit contains Boost and DAB, where Boost can regulate the voltage and provide stable voltage to ensure that DAB always works in voltage matching mode, which can reduce the high frequency current stress and the device level loss.

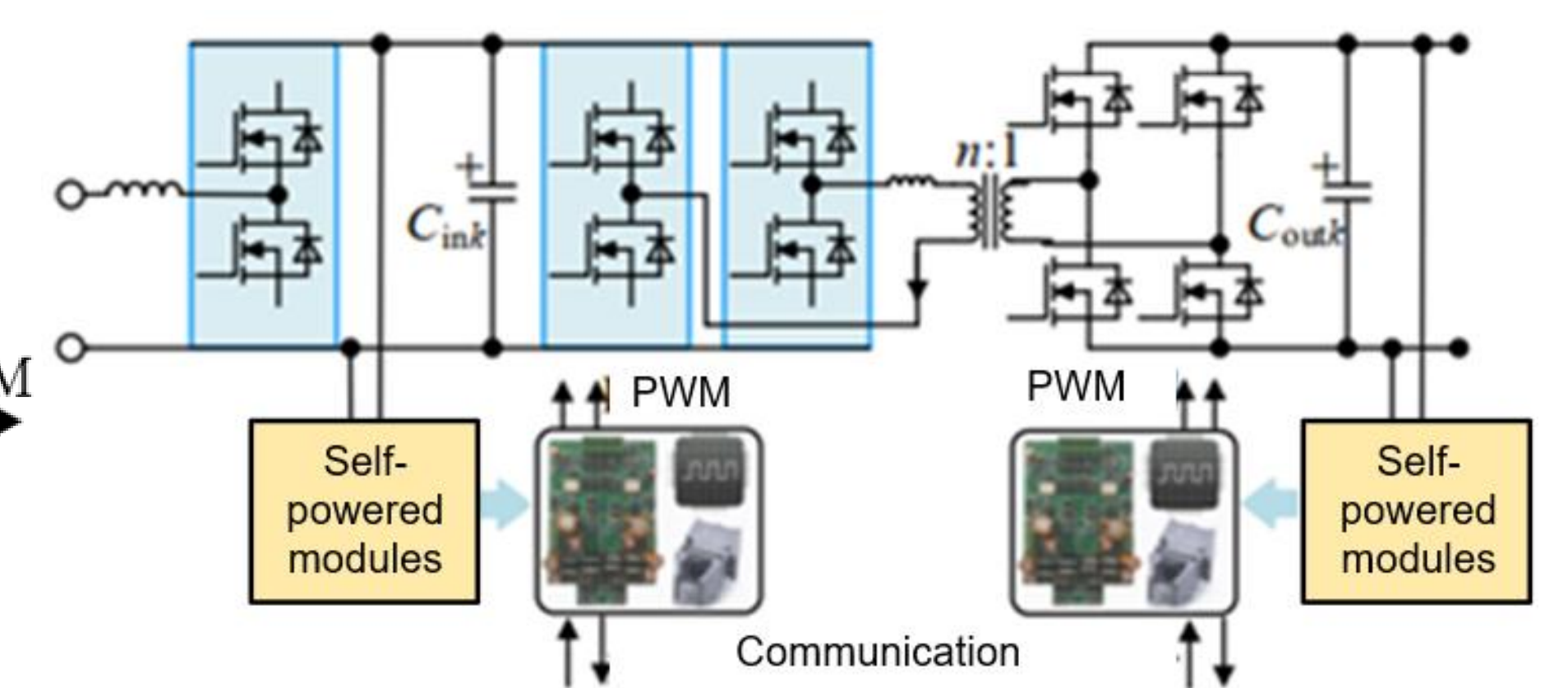
Control Method



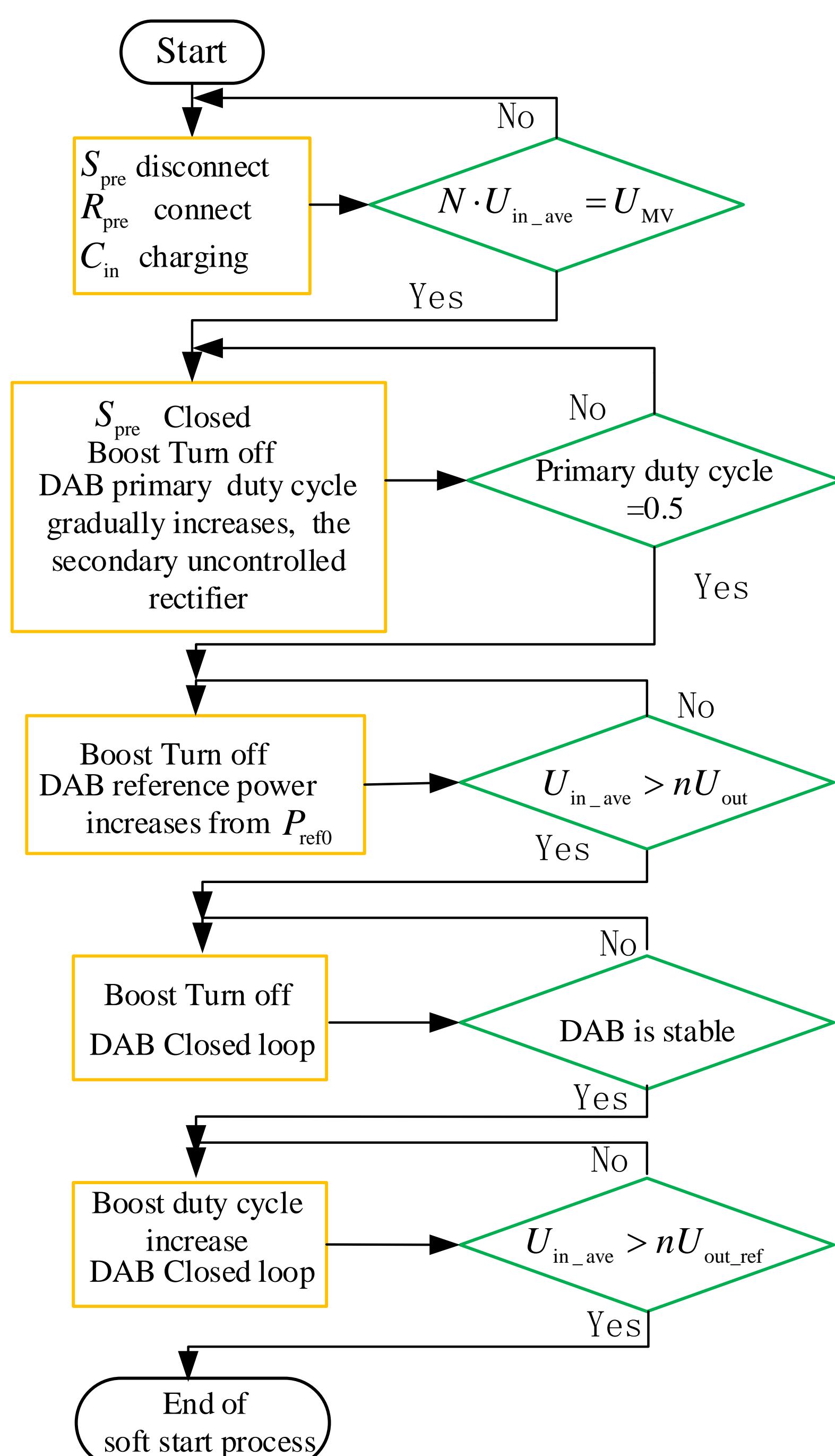
Single-phase shift modulation methods of DAB



The schematic of closed loop control method



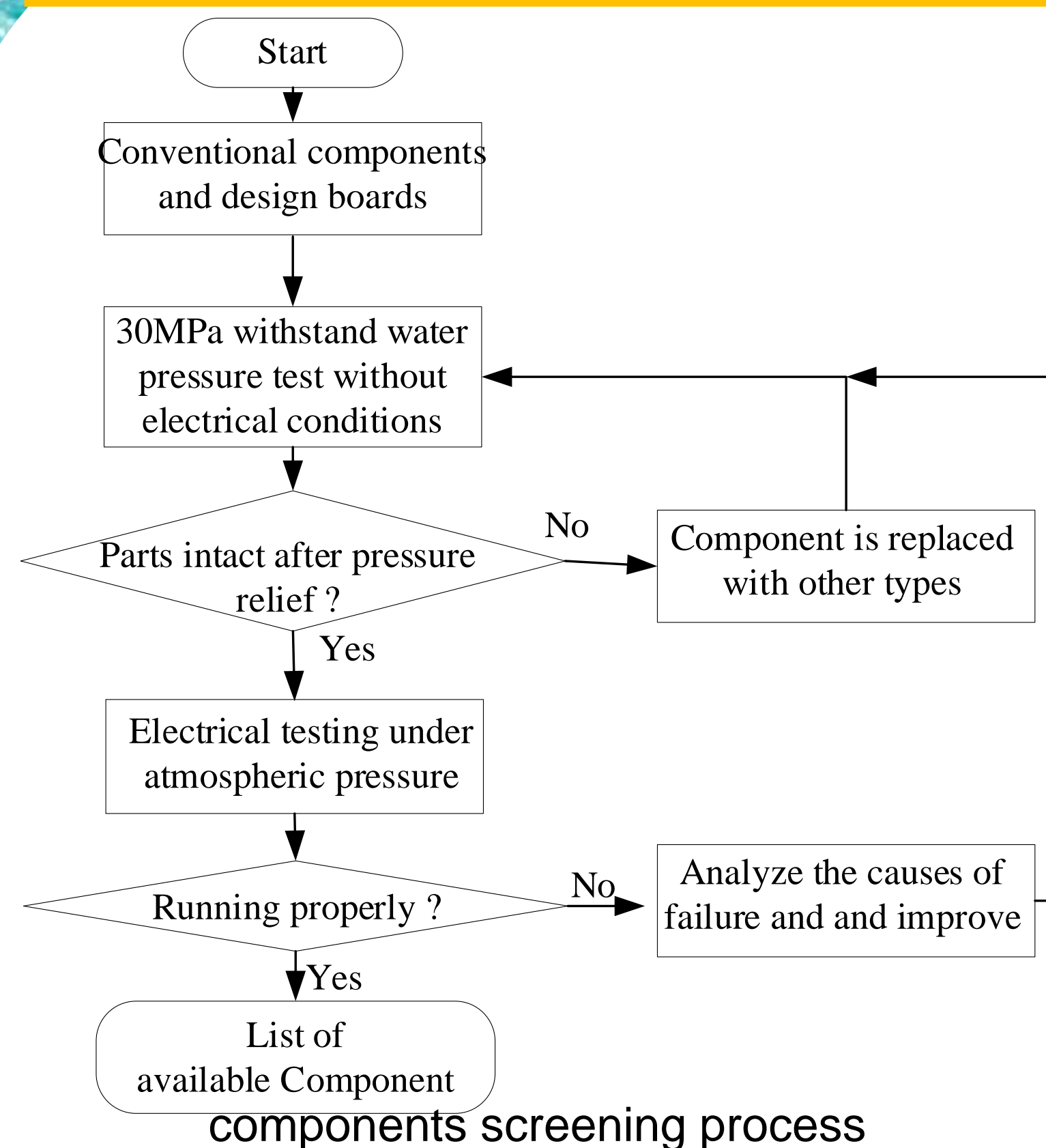
The diagram of DC transformer self-powering method



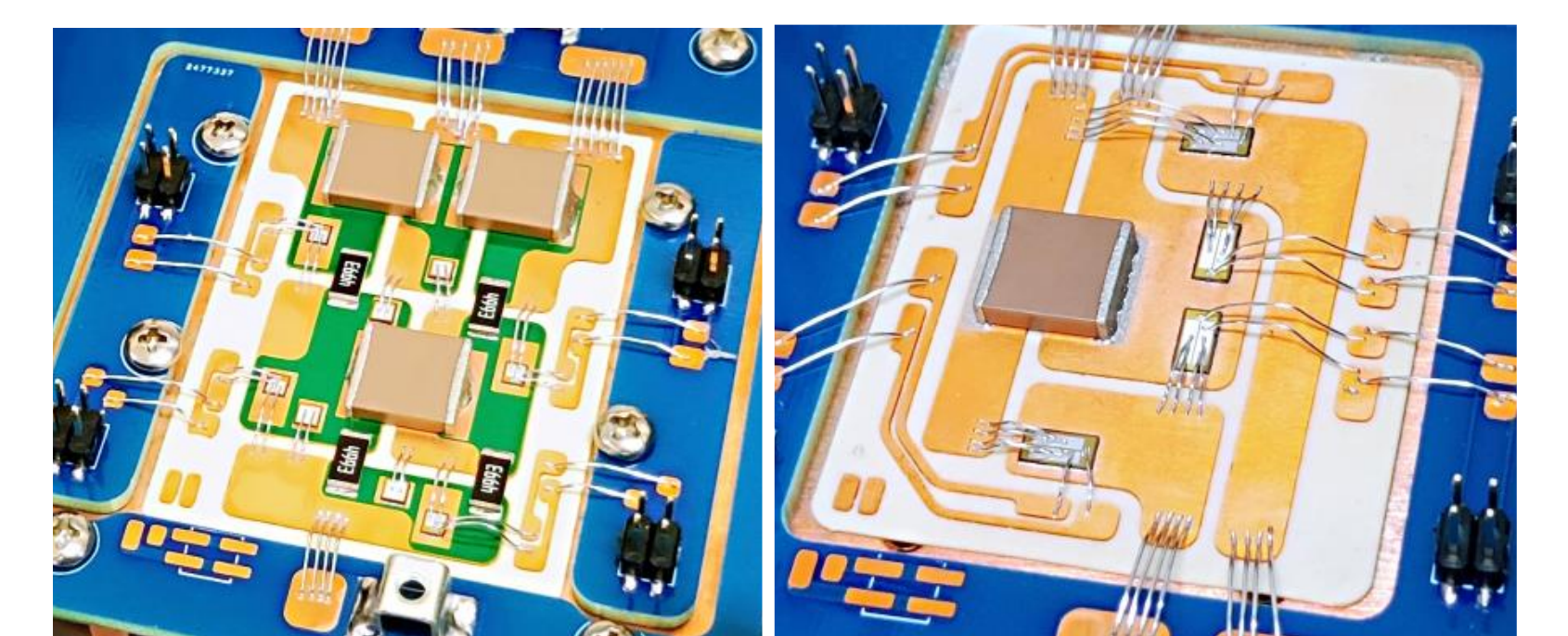
The DC transformer soft-start control strategy

The specific soft-start control strategy consists of five steps.

Direct Pressure-tolerant Design—Components



Pressure bucket with automatic increase and decrease of water pressure Water pressure test(30MPa, 60MPa)



The quasi-series half-bridge module half-bridge low-voltage module Direct pressure-tolerant power modules(die package)



Improved self-powering is directly potted with epoxy resin

Die package removes the plastic housing and gel and relies on insulating fluid for heat dissipation and insulation, and the liquid is completely filled to avoid the air gaps, which effectively increases the power module's direct Pressure-tolerant capacity.

The electrolytic capacitor is sensitive to pressure and cannot tolerate pressure directly, the module is directly potted with epoxy resin, and the volume is not changed

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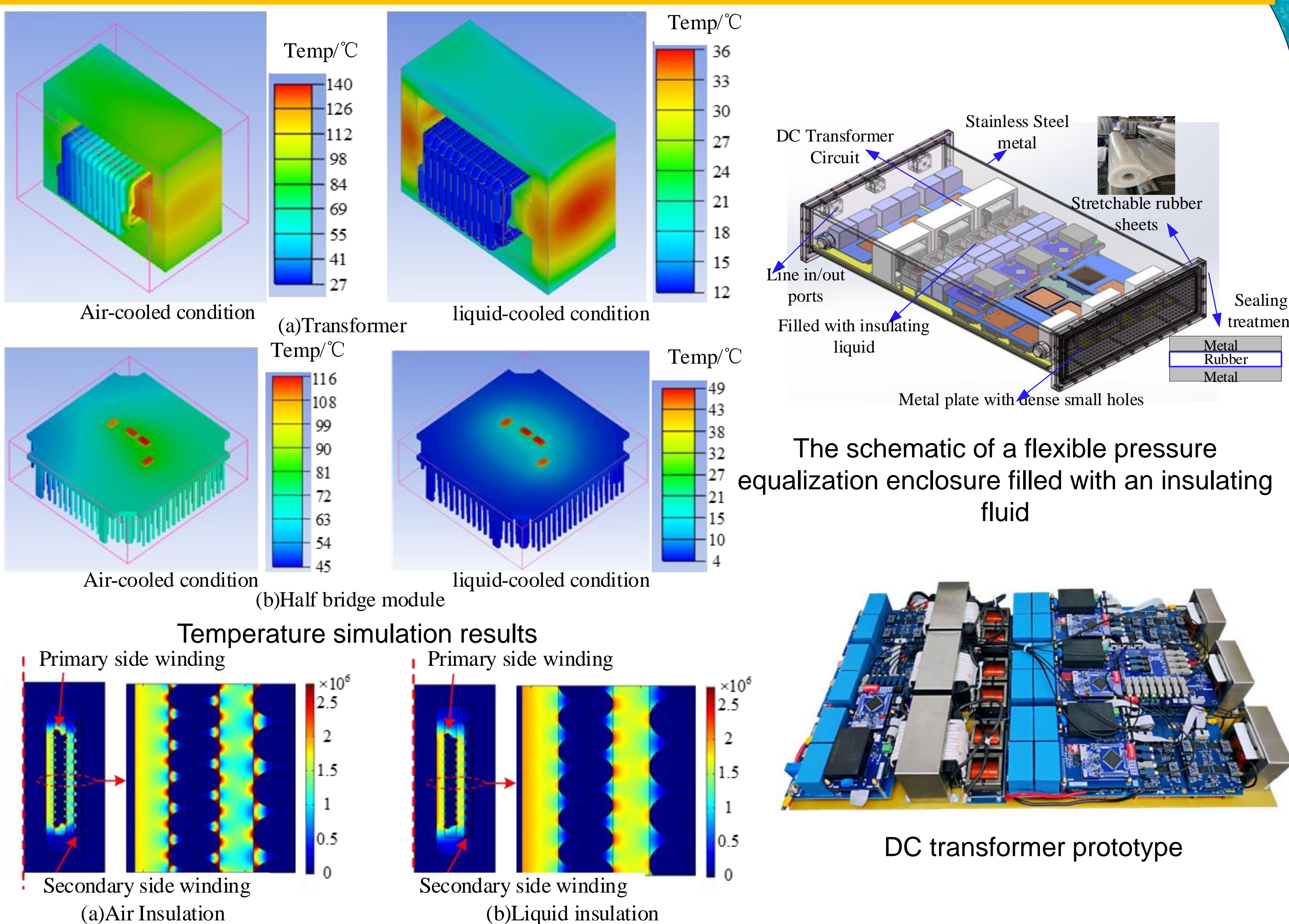
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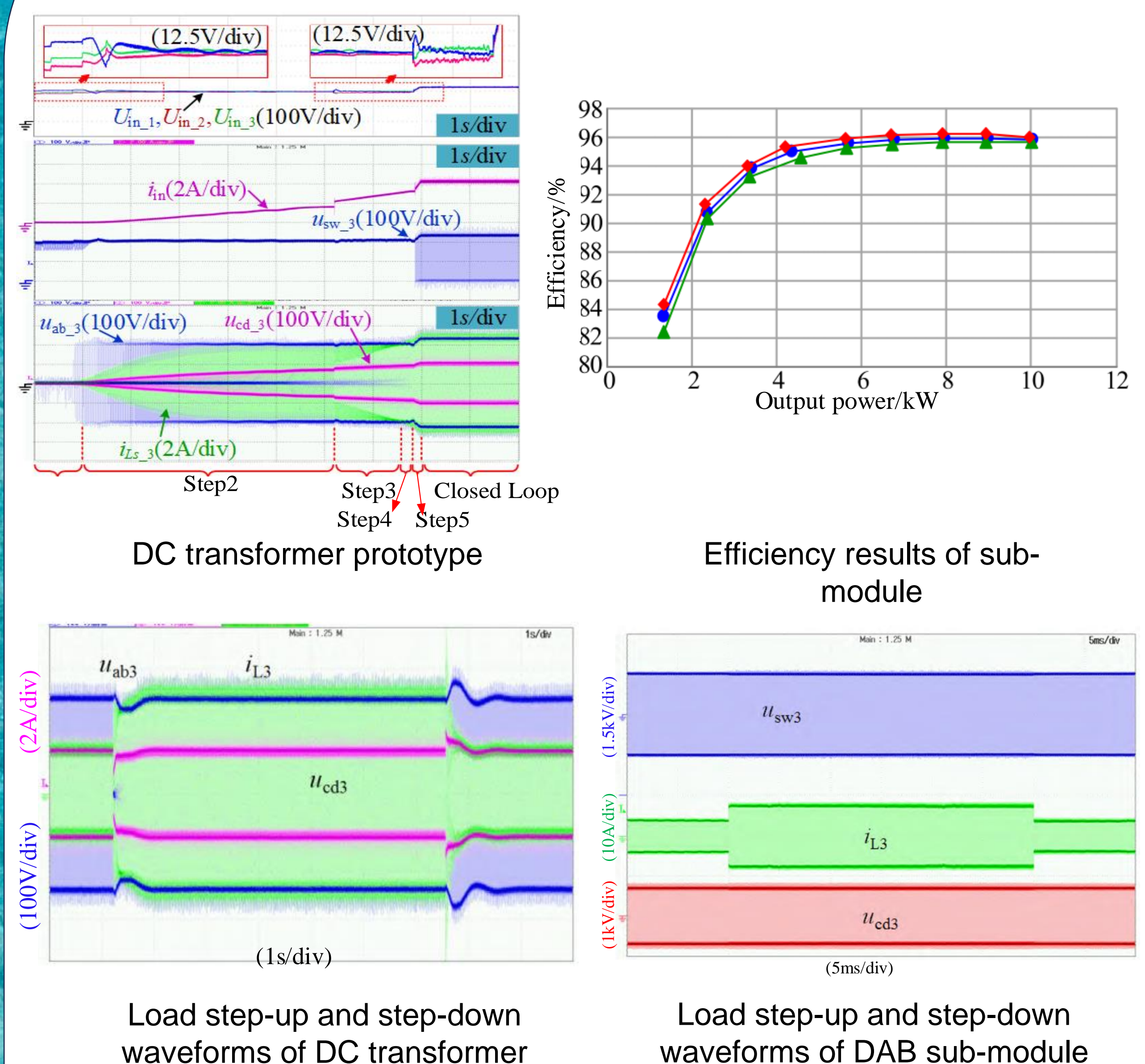
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Direct Pressure-tolerant Design —Insulation, heat dissipation, pressure-tolerant



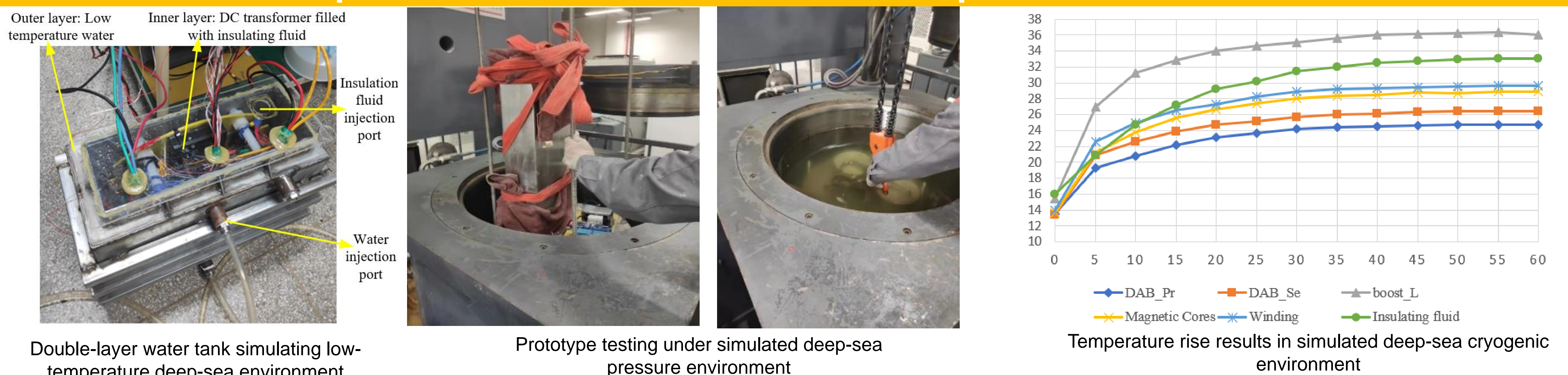
The insulated fluid-filled flexible pressure-balanced enclosure avoids the use of heavy and bulky metal enclosures and meets the insulation and heat dissipation design, which effectively increases the power density of the DC transformer.

Experimentation —standard atmosphere



At the same transmitted power, the maximum efficiency is 96.3%, and the efficiency decreases when the input voltage is reduced. The maximum efficiency is 96.0% at an input voltage of 1.4kV and 95.7% at an input voltage of 1.26kV.

Experimentation—Simulation of deep-sea environment



The highest temperature of each component of the unit module is only 38°C, which verifies that filling with insulating liquid can achieve good insulation and heat dissipation. The feasibility of direct pressure-tolerant design of DC transformer is verified.

Conclusions

A direct pressure-tolerant DC transformer scheme design and experiments are completed for the high-power density demand of deep-sea DC transformers, and the following conclusions are obtained:

- 1) By using high-voltage quasi-series half-bridge modules and increasing the sub-module voltage level to 1.5 kV, the number of cascaded unit modules is reduced and the size can be greatly reduced.
- 2) Through the screening process of the design, the components in the market that can meet the demand of direct pressure-tolerant are obtained, in addition to the improvement of power half-bridge and self-powering modules to enhance the pressure-tolerant capacity, these key components provide the basic conditions for the development of direct pressure-tolerant transformers.
- 3) The use of a flexible enclosure filled with insulating liquid ensures the insulation and heat dissipation of the internal DC transformer, and avoids the use of a pressure-bearing enclosure, which effectively increases power density.
- 4) Through the experiments, designed closed-loop and soft-start control strategy can ensure stable and safe operation of DC transformer.