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*Study on Arc Protection for CEPC High-Voltage Direct Current Long-Distance Transmission**

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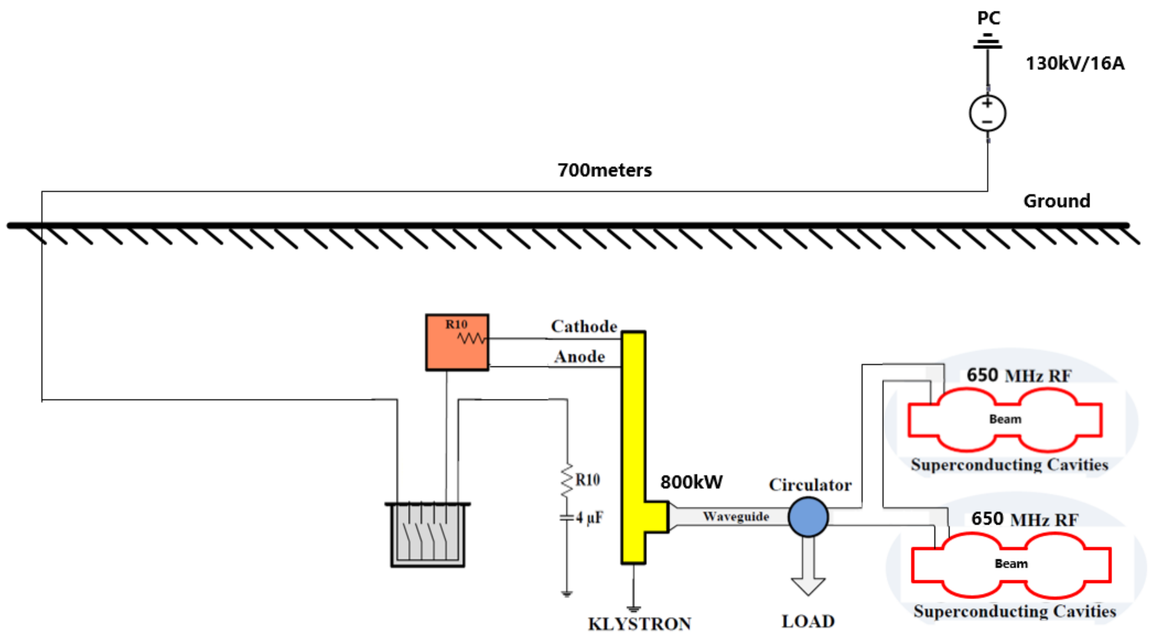
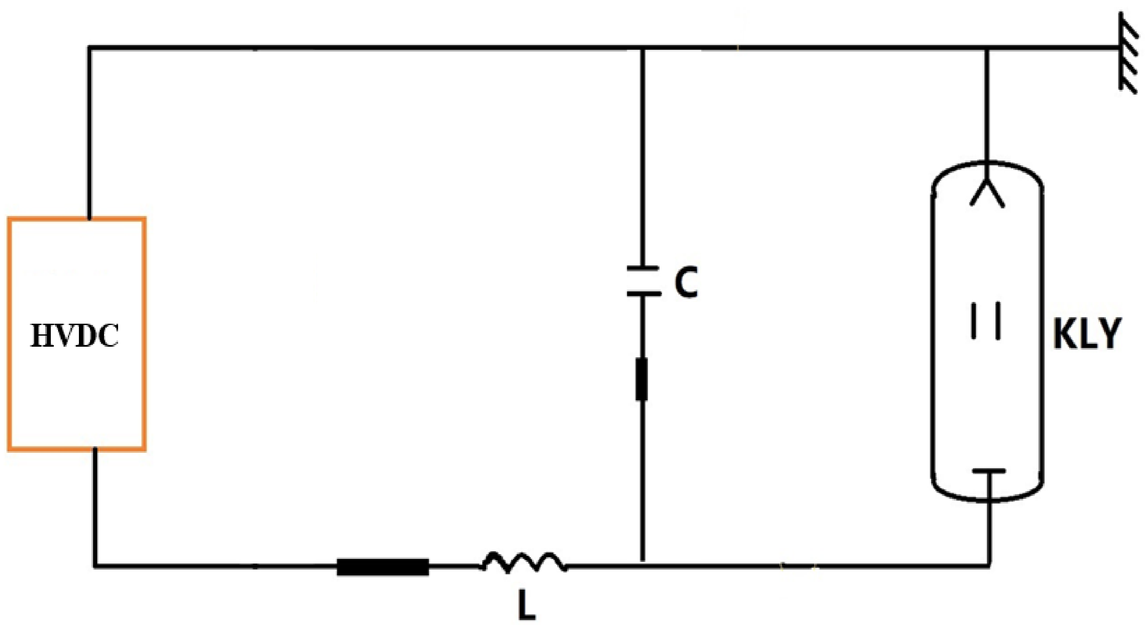
The CEPC high-voltage direct current (HVDC) power supply and the klystron are connected via a long-distance HVDC cable. When an arc short circuit occurs in the klystron, the energy generated by the discharge of the distributed capacitance in the long-distance transmission cable can directly damage the klystron. To address this, a high-voltage direct current long-distance transmission arc protection device has been developed. This device has a voltage rating higher than 120 kV and, when an arc short circuit occurs in the klystron, triggers the Crowbar device to instantly bypass and discharge the energy. The response time of the device is less than 5 microseconds, and the energy is limited to within 10 joules. This paper will analyze the discharge energy of the distributed capacitance in long-distance cable transmission based on the layout of the CEPC HVDC power supply and the klystron, establish a circuit model, conduct system simulations and energy calculations, and systematically analyze the design principles and key technologies of the arc protection device.

INTRODUCTION

Considering klystron lifetime, power redundancy and cost, the 2 cavities of CEPC collider will be powered with one CW klystron capable to deliver more than 800 kW and the klystron frequency is 650 MHz. The high-voltage DC power supply is 130 kV/16 A, operating in a one-to-one configuration with the klystron. According to the layout in the CEPC technical design report, the high-voltage DC power supply is located on the ground, while the klystron is in the auxiliary tunnel. The calculation of the high-voltage cable length includes the distance from the ground, the length of the vertical shaft, etc., with a maximum length of 700 meters.



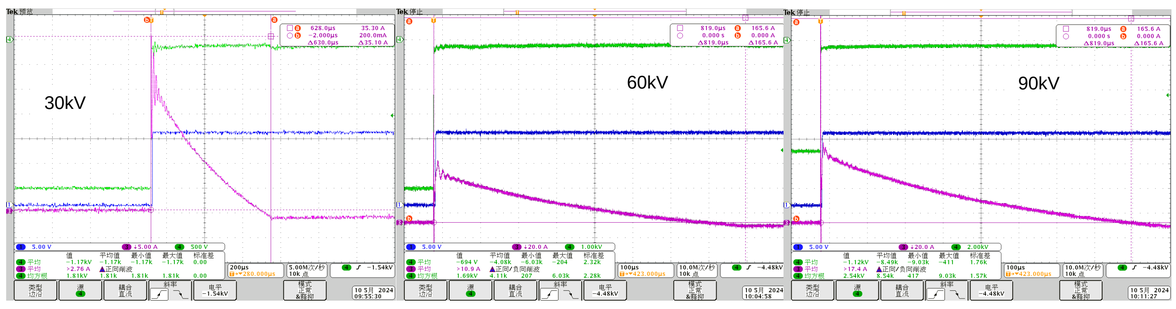
CEPC TDR high-voltage DC power supply and CW klystron structural layout diagram.



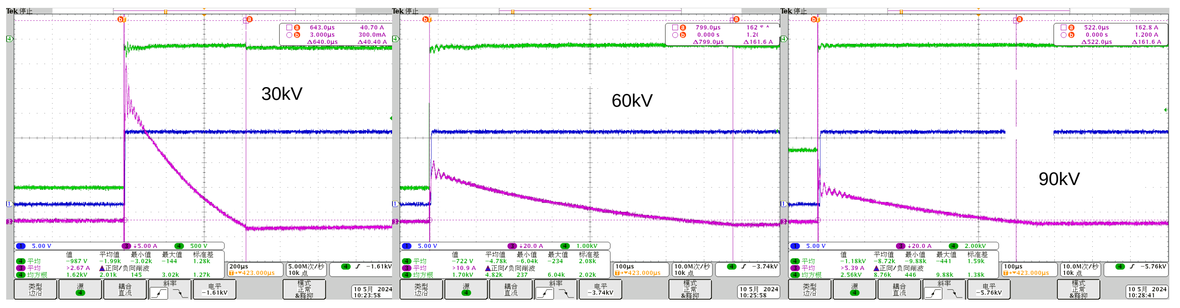
Equivalent schematic diagram for long-distance transmission of high-voltage DC.

SIMULATION ANALYSIS

The high-voltage DC power supply currently uses PSM (Pulse Switching Modulation) technology. The simulation of its output circuit shows a discharge time of approximately 110 μs. Measured discharge waveforms for the PSM high-voltage power supply at 30 kV, 60 kV, and 90 kV under no-load and load conditions were analyzed against theoretical predictions. Simulations of the natural decay of capacitance and inductance energy storage were also conducted.



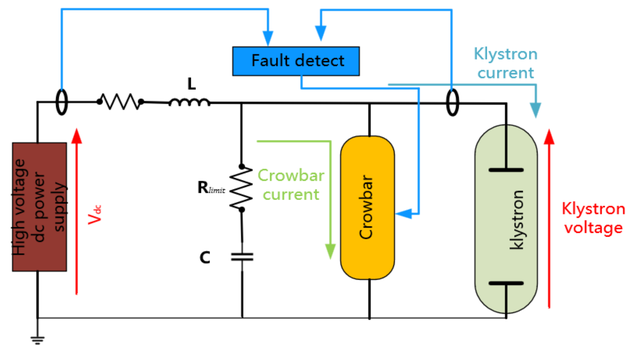
PSM power supply resistance load discharge test waveform.



PSM power supply no-load discharge test waveform.

CROWBAR

To address the above issues, a crowbar solution is implemented by connecting a crowbar in parallel at the klystron end of the long-distance high-voltage cable, as shown in Figure 6. When a short circuit in the klystron is detected, the crowbar is quickly triggered, allowing it to instantaneously bypass and release the energy, thereby protecting the klystron load. A crowbar was designed using a series of thyristors in a solid-state configuration. The design goals are to achieve a voltage withstand capability greater than 120 kV, a response time of less than 5 μs, and an energy limit of under 10 J, meeting the transmission requirements for high-voltage DC cables with a length of 1000 meters.



Crowbar scheme principle schematic diagram.

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