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Reliability Design for High Power RF Source Systems in Large Particle Accelerators

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INTRODUCTION

The RF power source system is a critical component of the CEPC, providing the high energy required to accelerate positrons and electrons in order to compensate for energy losses due to synchrotron radiation and interactions between the beam and cavity impedance. Its reliability and stability directly affect the operational efficiency of the entire facility. Based on operational experience from existing facilities, the RF power sources, due to their high power, high voltage, and active equipment characteristics, consistently exhibit high failure rates during long-term operation across all systems. Therefore, for future advanced particle accelerators, which will incorporate large clusters of RF power sources characterized by numerous devices distributed over wide areas, enhancing long-term operational reliability will pose a significant challenge and is a common issue faced by all accelerator facilities today. This paper summarizes the challenges faced, design approaches, and the processes involved in the development and testing of prototypes, providing a technical reference for achieving high reliability in large particle accelerators.

Over recent years, IHEP has developed various types of RF power sources based on particle accelerator projects, including:

A） Microsecond-level RF power sources

characterized by pulse widths of several microseconds. The pulse modulator delivers peak power at the hundred-megawatt level, with average power ranging from 10 kW to 100 kW. Solid-state modulators offer the distinct advantage of high repetition rate stability (up to 17.2 ppm).

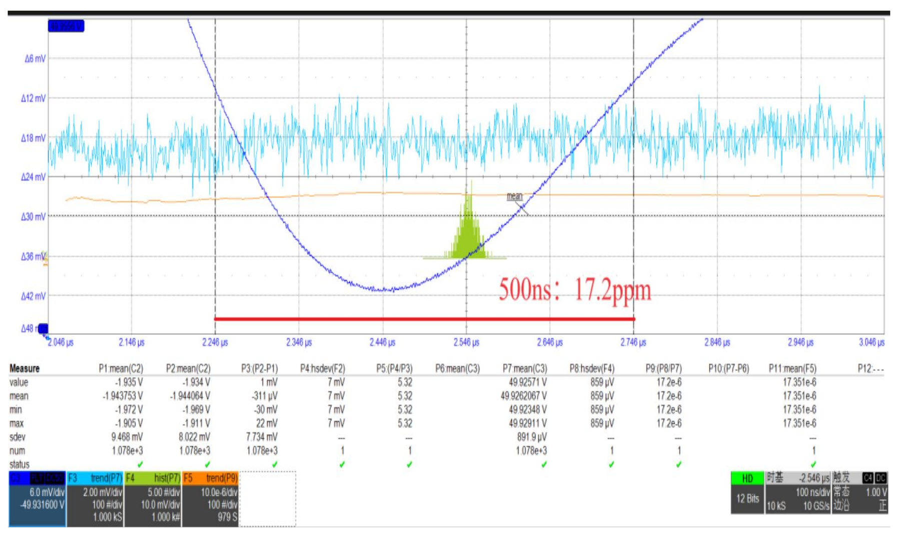
B）Hundred-microsecond-level RF power sources

featuring long pulse widths (100 μs to 10 ms). The pulse power supply provides peak power from hundreds of kilowatts to 10 MW. Key characteristics include flexible pulse width modulation (with programmable pulse leading/trailing edges and pulse width) and high repetition rate stability (up to 107 ppm).

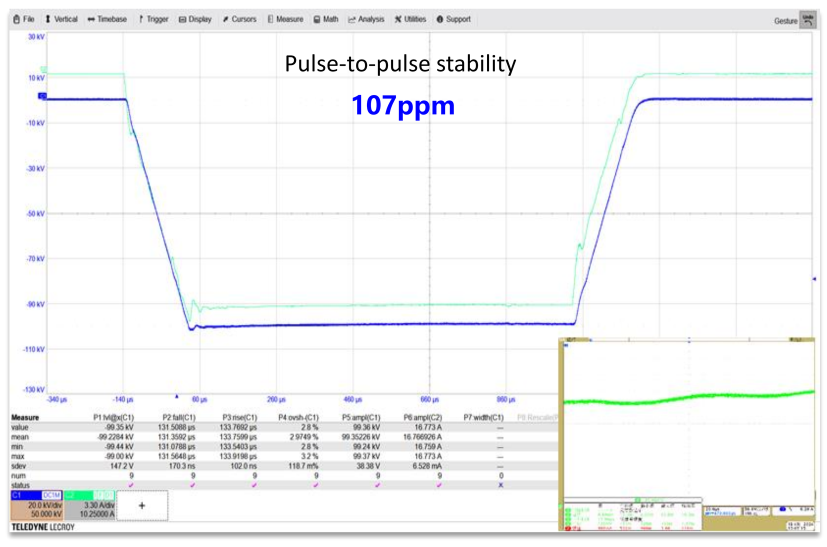
C） Long-pulse/Continuous-wave (CW) RF power sources

distinguished by megawatt-level average power output. These systems are characterized by high power, low ripple, and long-term stability (0.1% at megawatt-level power output).

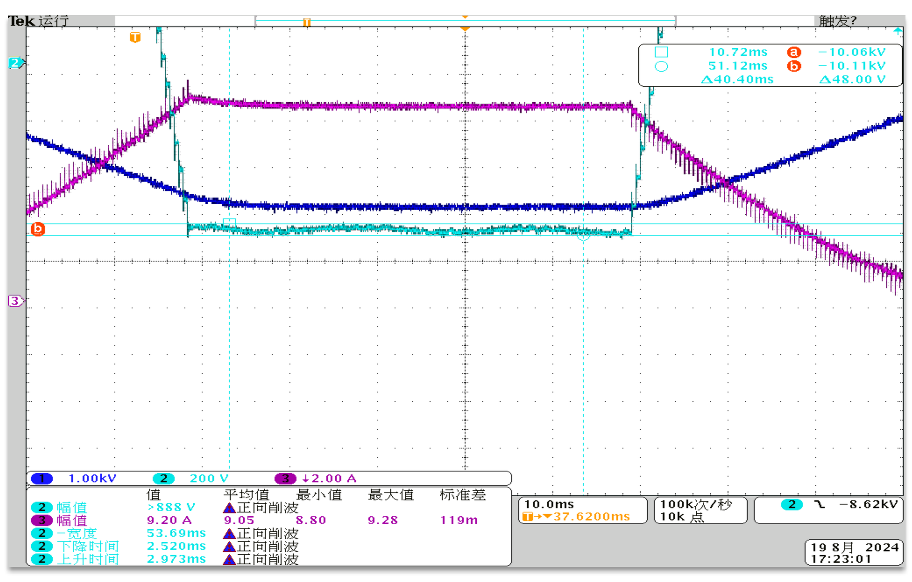
For future large-scale particle accelerator projects, their high-brightness targets necessitate the integration of hundreds of diverse RF power source systems. These systems feature high power levels (up to the hundred-megawatt range) and widespread distribution (covering a broad power range). For such a large-scale installation, high-reliability design is crucial for ensuring the high availability of the accelerator.



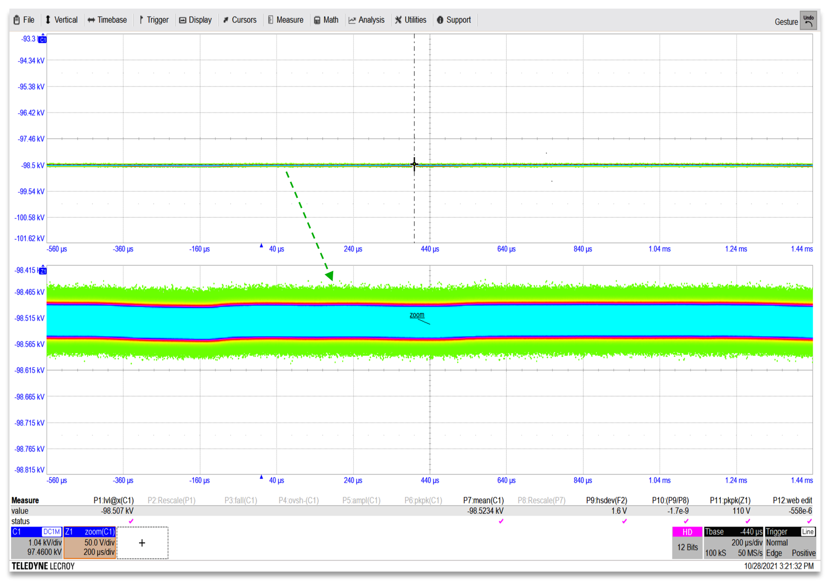
A) Microsecond-level（<10μs） pulse modulator



B) Long pulse (100μs-10ms) RF pulse power source

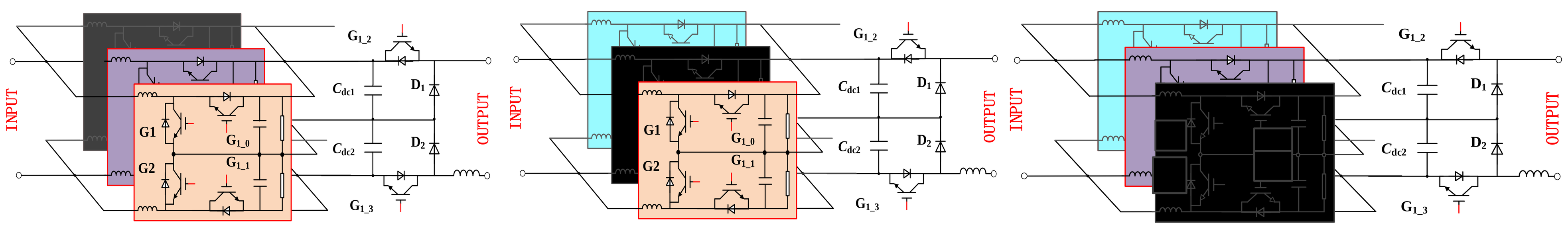


C) Long pulse (50ms) RF pulse power source

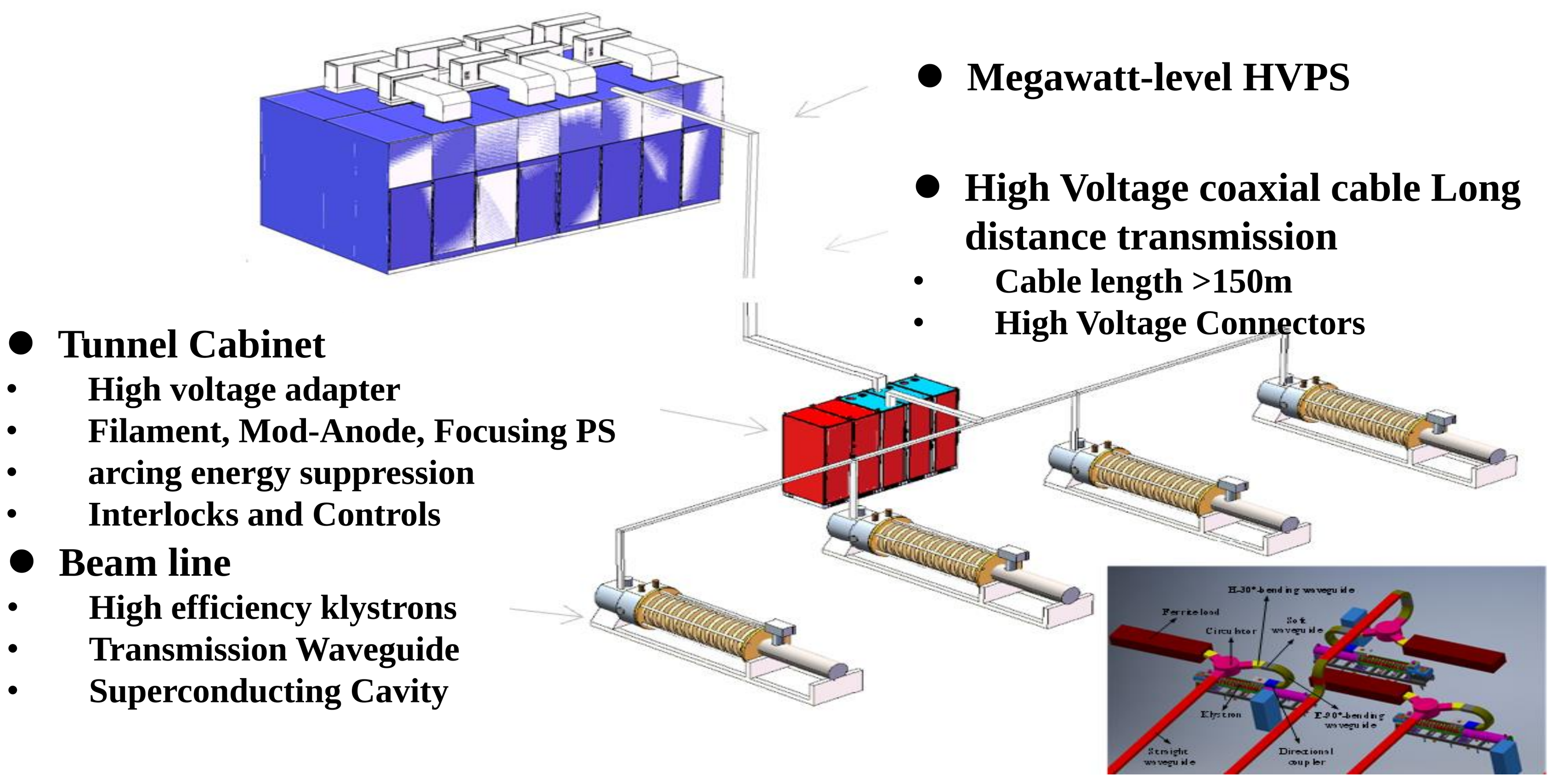


D) CW RF pulse power source

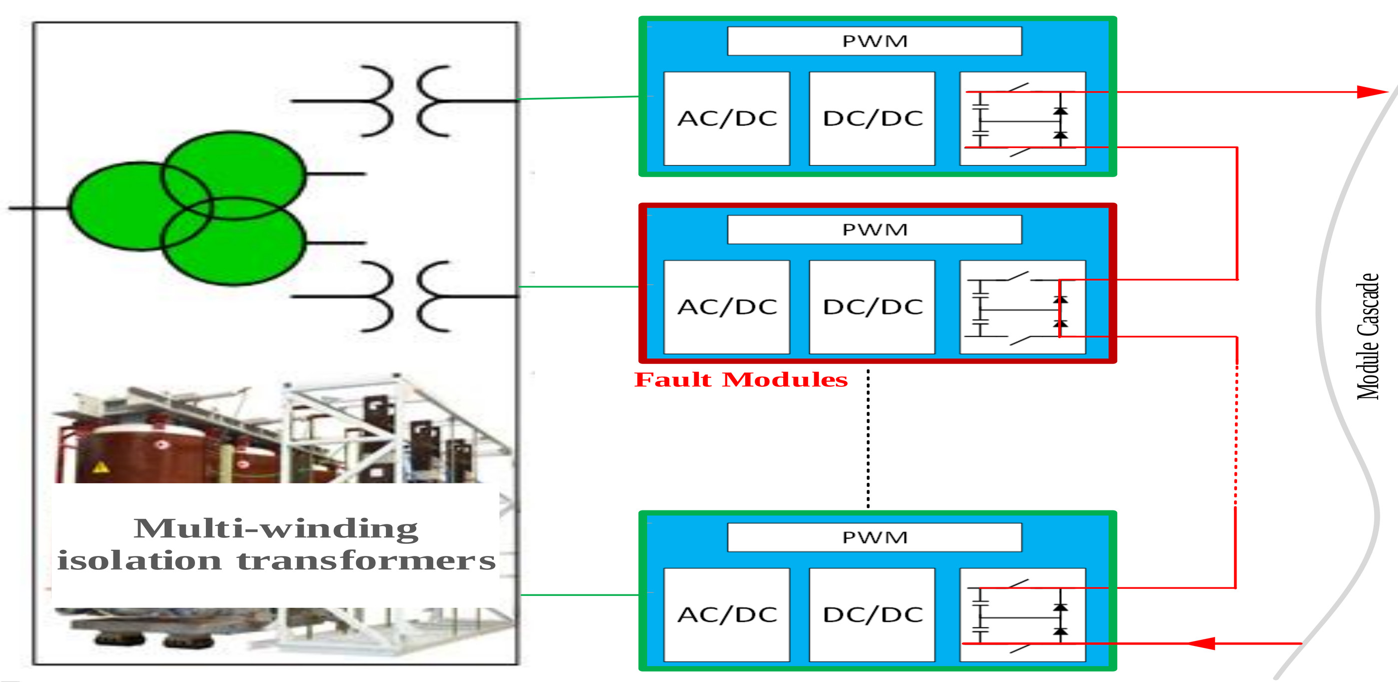
RF power sources with different pulse modes developed by IHEP team

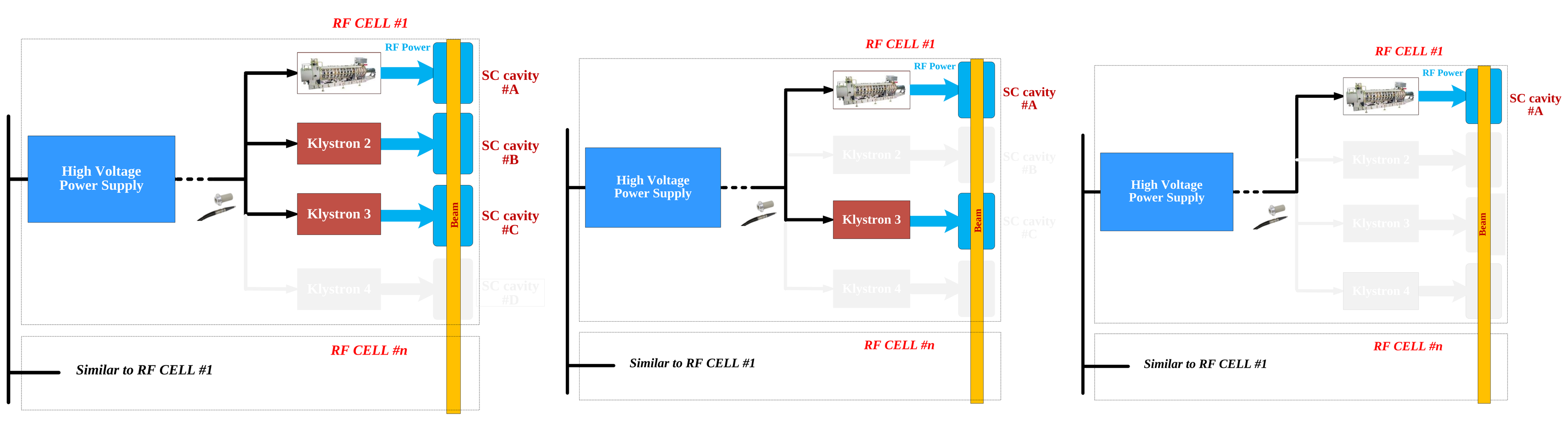


- **Fault-tolerant control (unit modules):** Multiple redundancies, mutual redundancy between power branches; a single path failure does not affect the system's high-voltage output. Redundant control between unit modules ensures the reliability of cascaded high-voltage DC output.



RF Power System Megawatt-level HVPS to Klystron with 1 to 2 or 1 to 4 Layout Schematic

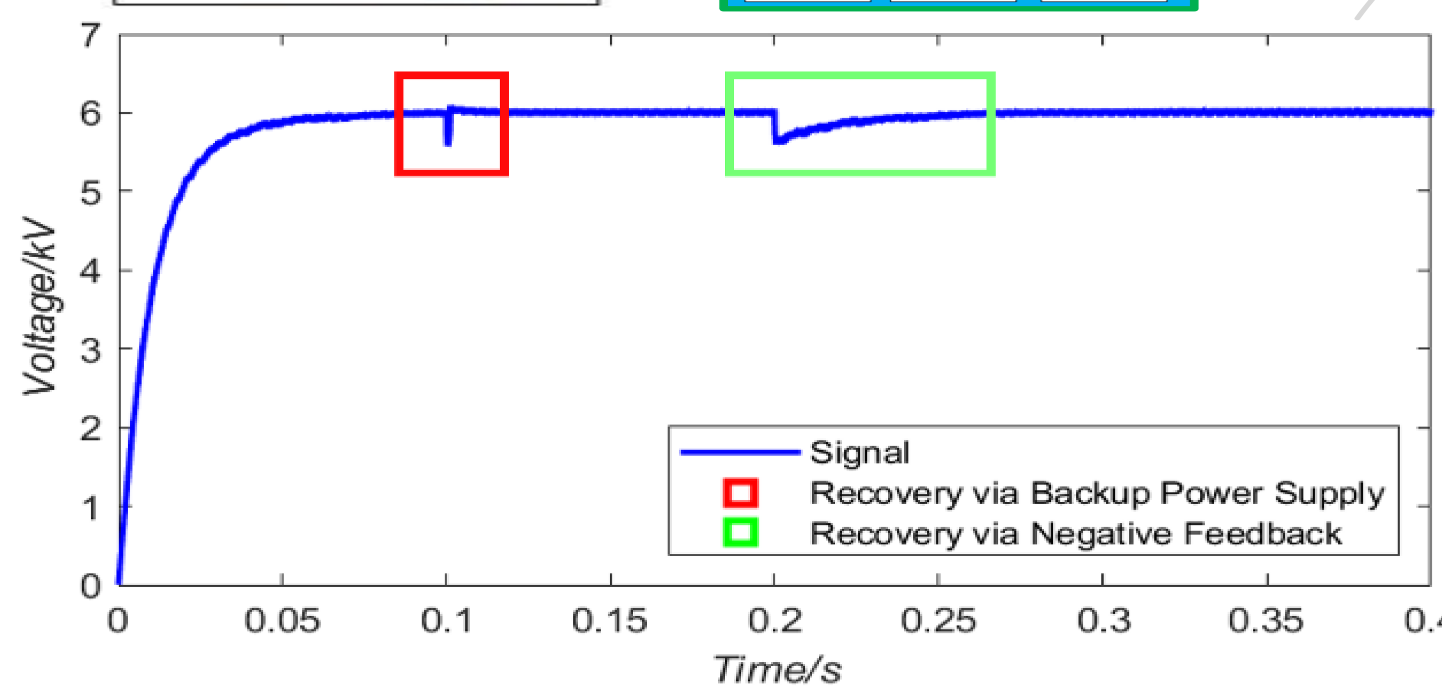




1 klystron fault
(1 drives 3)

1 klystron fault
(1 drives 2)

1 klystron fault
(1 drives 1)



- **Fault-tolerant control (Klystron load):** **1-to-4, 4 klystron can be selectively redundant (standby, operation maintenance, etc.). The engagement and disengagement of the load of a single or several fast regulation pipes, and the stability/protective logic control of the high-voltage power supply system.**

- **Fault-tolerant control (system level):** A failure of a unit module does not affect the high-voltage/microwave power output at the system level, ensuring the stable operation of the system.
- A combination of closed-loop feedforward and feedback comprehensively enhances the system's anti-interference capability and dynamic performance.
- **Overall Output Voltage Ripple Comparison (Ripple expected in the order of 0.01% level, 1% for conventional HVPS)**

REFERENCE

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