Experimental analysis of -100kV VM for use in automated non-destructive HV DC tests

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The thesis focuses on modifying a high DC voltage power supply by replacing the ZVS resonant converter with a controllable single-phase inverter. The existing system (-100 kV, -1mA) lacks controllability, limiting its application in DC voltage supply and high voltage testing. By introducing a controllable inverter, the thesis aims to assemble a controlled high DC voltage power supply by modifying the existing system in order to perform automated high DC voltage tests.

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Background

Rapid improvement of power electronics and increase of voltage levels, creates a need for implementing high voltage testing techniques to verify the reliability of newly designed equipment. High DC voltage tests are usually performed in high voltage laboratories using standard high voltage equipment which is usually vast in size. The Cockcroft - Walton voltage multiplier (VM) is in fact an AC/DC converter with high output DC voltage and low output current. One was developed in the BFH power electronics laboratory with rated DC output voltage of -100kV and -1 mA current. Its small size and compactness make him a candidate to be used as a high DC voltage source for automated high DC voltage tests.

Starting point

To perform automated high voltage tests on various equipment using CW voltage multiplier, it was initially necessary to make few modifications at existing voltage multiplier circuit. Present manually operated ZVS resonant converter was not suitable for desired operation of voltage multiplier and proper surge protection in the case of short circuit needed to be designed.

Objective

Through the modifications, the thesis aims to create a controlled high DC voltage power supply that offers flexibility, controllability, and safety for various high voltage experiments and automated high DC voltage testing procedures.

Implementation

The implementation phase of the thesis involves two key modifications. Firstly, the ZVS resonant converter is replaced with a controllable single-phase GaN inverter, providing enhanced control over output voltage and frequency. This enables dynamic and flexible high DC voltage experiments with the existing multiplier circuit. The controllable inverter, originally designed for educational purposes, offers improved monitoring of input and output electrical parameters, ensuring comprehensive surveillance and control over the multiplier circuit's output voltage. Additionally, mechanisms for detecting and cutting off discharges during high voltage tests are considered, allowing the GaN inverter to be turned off to prevent unwanted circuit behavior.
The second modification focuses on the development and implementation of a measuring and protection circuit for the voltage multiplier circuit's outputs. A critical objective is to limit the discharging current to 100 µA to ensure safe operation during high voltage experiments. The thesis aims to gain proficiency in operating and controlling the power converter (GaN inverter), validate the detection of discharge events in the device under test, and enhance the protection circuit to ensure reliable and secure operation.

Results and outlook

The results of the thesis include a prototype of a coded state machine for dynamic short circuit detection in a voltage multiplier circuit. Implemented with a microcontroller and FPGA module, it generates control and modulation signals for the GaN inverter's power switches. The state machine's states are explained using a diagram, and a coded ramp test profile is described. Recorded waveforms demonstrate discharge moments and a typical response time of 150-250 µs. The state machine automates tests, detects and halts energy transfer during short circuit events, demonstrating the feasibility of using phase current as a measuring parameter for short circuit detection and mitigation.