300 kV HIGH-VOLTAGE SOURCE WITH UP TO 15 kW OUTPUT POWER

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Abstract

The presented report contains the description of high-voltage source with output voltage up to 300 kV and output current up to 50 mA. The source consist of the chopper with IGBT switches working with a principle of pulse-width modulation and the full H-bridge converter with IGBT switches, both working on programmed from 15 to 25 kHz frequency, and the high voltage transformer powering the eight-stage multiplier with the additional capacity filter at output. The transformer and multiplier both are made in common volume separated on oil tank part with silicon oil for transformer and SF6 part for multiplier. The additional capacity filter provides low ripple and noise level in working range of output currents. The source can operate in normal mode with series of high-voltage breakdown in output voltage. In the high-voltage breakdown the released in load and matching circuit energy is less than 40 J at maximum operating voltage 300 kV. The efficiency of system is more than 80% at the nominally output power 15 kW. The description of the source and the test results are presented.

DESCRIPTION

The presented source was designed for accelerator electron gun of Siberian Synchrotron and Terahertz Radiation Centre. That was reason for some specific terms like: strong reliability to high-voltage breakdown, low energy dissipated in high voltage breakdown, low voltage ripple for maximal power operation. The energy is dissipated in components of source and in the load during the high voltage breakdown less than 30 J for 260 kV operations. The basic characteristics of high-voltage source are shown in Table 1.

OVERVIEW

The circuit diagram of power part of high-voltage source is shown in Fig.1. The high-voltage source consists of the 20 kHz power converter with insulated gate bipolar transistors (IGBT) as switches (part A) and high-voltage transformer with the four-stage multiplier (part B). The power converter consists of 3-phase rectifier VD1, electromagnetic (EMI) filter F1, switch SW1, rectifier's filter capacitors C1-C2, 20 kHz chopper with IGBT switch Q1, 20 kHz inverter with IGBT switches Q3-Q6, output filter circuit L2 C5 C6, and isolation transformer T1.

Input Rectifier

EMI filter is used to eliminate high-frequency noise to the power line from the source. 3-phase rectifier and filter C1-C2 is used to convert input AC 3-phase voltage 380 V 50 Hz to DC-link 550-600 V voltage. Contactor SW1 consists of 2 groups of contact: the first is used for soft start of converter and another is used for normal operations.

Table 1. Basic Characteristics of High-Voltage Source

Parameter	Unit			
		Min	Nom	Max
Output voltage	kV	10	260	300
Output current	mA		15	50
Output power	kW			15
Voltage ripple (full load)	%			0.2
Long term stability	%			0.1
Transient time	ms		50	
Converter frequency	kHz	15	20	25

Chopper

The chopper switch Q1 is operated with principle of pulse-width modulation on programmed from 15 kHz to 25 kHz frequency synchronously with inverter. The output voltage of chopper is changed from 10 to 450 volts DC by control circuit to obtain the required output high voltage of source.

Inverter

Full-bridge inverter Q3-Q6 converts DC voltage from chopper's capacitors C3-C4 to AC voltage with programmed from 15 to 25 kHz frequency.

Filter Circuit

The matching circuit consists of elements C5 and L2 and low pass filter L2 C6 are used for minimizing transient process and for improving efficiently of design. The matching circuit is used for protection reasons. When there is a high voltage breakdown or over current the matching circuit limits the rate of current rise in the inverter. Magnetising inductance of high voltage transformer, its capacitance calculated to primary side in parallel with C6 and the matching circuit organize low-pass filter for all high harmonics of inverters rectangular waveform voltage. That way, sinusoidal voltage is feed in the high-voltage transformer, because all high harmonics are filtered. In other case, the presence of high harmonics causes power dissipation in the coils because of skin-effect. Also this harmonics can induce the singing in the winding of high-voltage transformer and this effect increases the output zero load voltage and complicates the reduction transient over voltage.

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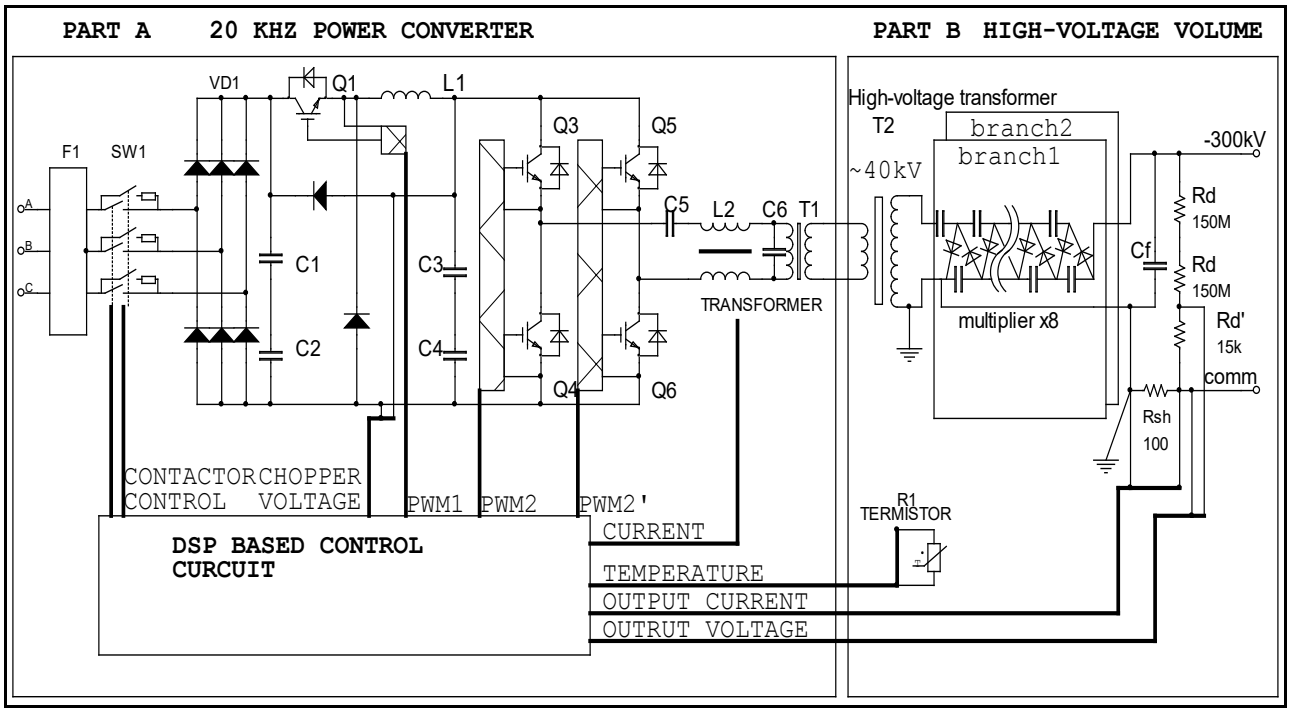

Figure 1: The high-voltage source block-diagram.

High-Voltage Transformer and Multiplier

Sectioned high-voltage transformer consists of two high voltage sections, joined in series. The nominal output voltage of transformer is 40 kV. The transformer is designed in oil-filled tank. The silicon oil [1] is used. This tank is located in the top part of high voltage volume. In the bottom part of the volume is located eight stage multiplier. The multiplier has two parallel connected brunches. Each brunch is the same.

The multiplier brunch is complete design and it includes multiplier, output filter capacitors, output current sensor and voltage divider resistors Rd, Rd`. Output filter capacity is chosen to decrease output voltage 40 kHz ripples less than ±0.1% for full load operation. The sulfur hexafluoride (SF6) is used as insulator is this part of the high voltage volume.

Design

The converter is made in one 4U and three 6U crates in the rack of 19" Euromechanics standard. There are distilled water is used for power converter elements cooling. The Fig. 2 presents converter rack view.

Control Circuit

The control circuit is realised in digital signal processor (DSP), programming logic matrix array (PLM), and analogue input buffers. The control and analogue grounds are isolated from external signals and grounds and, that way, in control circuit has obtained low noise level. It allows operation with better then 0.1% accuracy. All the IGBT switches are protected from short circuit and overcurrent. The controller measured seven analogue channels with 12-bits resolution. The controller has CAN-bus interface which is used to link with an external control system. The used data rates are 125, 250 and 500 Kbits in second. The protocol of CAN-bus interface is compatible with devises produced in the BINP [2]. This controller circuit is an improved development of previous version used high voltage source [3].

Protections and Interlocks

There are two level of overcurrent protection: programmable and circuitry one. Rigid protection has a 55 mA threshold level, if the output current increases up to 55 mA or higher the all converter switches OFF. The programmable threshold level is tunable. If output current is higher then programmable threshold level (from 5 to 55 mA) the converter first tries to limit current on this level than in case of failure all converter switches OFF. Switching OFF time is less then 50 ms. The converter tries to switch on output voltage after 100 milliseconds with rise speed 100 V/ms. High-voltage transformer protection measures the temperature of transformer and the transformer's input current. In case the input current of transformer rises up to 250 A that matter the short circuit in transformer. In this case the converter is OFF.

RESULTS

The high-voltage source was designed tested and now it operates with 300 keV electron gun at Siberian Synchrotron and Terahertz Radiation Centre. The tests are shown high reliability, efficiency better than 85% for full load operations. The long time stability of output voltage was better than 0,1% at 260 kV output voltage.

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Figure 2: Power converter rack.

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