HIGH-VOLTAGE SOURCE WITH OUTPUT VOLTAGE UP TO 110 kV WITH OUTPUT CURRENT UP TO 100 mA

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Abstract

The presented report contains the description of high-voltage source with output voltage up to 110 kV and output current up to 100 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 four-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. A nominal output voltage of the source is 110 kV. 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 20 J at maximum operating voltage 120kV. The efficiency of system is more than 80% at the nominally output power 11 kW. The controller of the source is developed with DSP and PLM, which allows optimizing operations of the source. For control of the source serial CAN-interface is used. The description of the source and the test results are presented.

DESCRIPTION

The presented source was designed for some different applications at the BINP tasks. 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 30J for 110 kV operations. The basic characteristics of high-voltage source are shown in Table1.

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.

Table 1. Basic characteristics of high-voltage source.

Parameter	**Unit**			
		Min	**Nom**	**Max**
Output voltage	kV	10	110	120
Output current	mA	0.1	100	120
Output power	kW		11	
Voltage ripple	%			0.5
Voltage stability	%			0.2
Transient time	ms		50	
Converter frequency	kHz	15	20	25

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 380V 50Hz to DC 550-600V 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. First group of contacts is switched ON and the filter's capacitors C1-C2 are charged with 10A current. When the voltage on filter is up to 450 volts level the second group of contacts is switched ON and the rectifier is connected directly to 3-phase AC line.

Chopper

The chopper switch Q1 is operated with principle of pulse-width modulation on programmed from 15 kHz to 25 kHz frequency. The working frequency of inverter is the same. The operating frequency is selected depending on the characteristics of high-voltage transformer and the requirements to the spectrum of output high voltage ripple. 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. When the high voltage breakdown or over current is detected the inverter switches are switched OFF in 10 microseconds to protect power circuit from damage.

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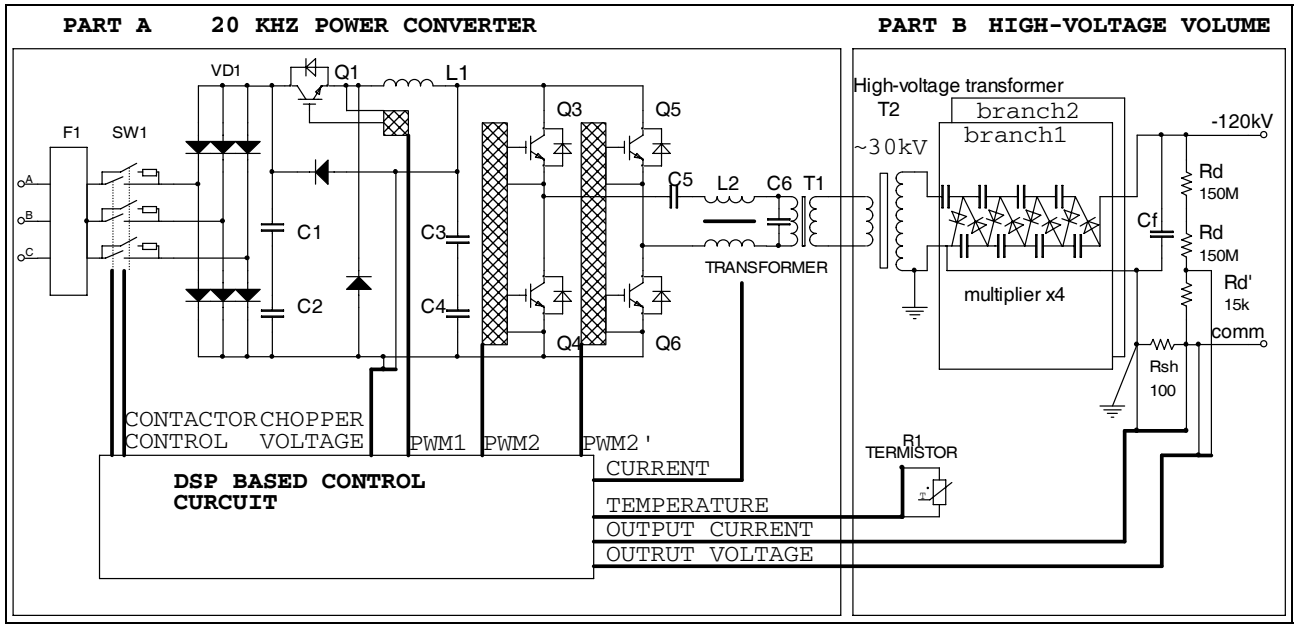

Fig.1. The high-voltage source block-diagram.

Filter Circuit

The power source must work with wide range of loads, from zero current to full load. The technical conditions for this high-voltage source are: transient process time interval must be less then 5 ms with transient overvoltage less than 20% for 110 kV operations for load switching between 1mA and 50mA (half load). 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.

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 30kV. The transformer is designed in oil-filled tank. The silicon oil [1] is used. This tank is located in the bottom part of high voltage volume. In top part of the volume is located four 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 0.5% 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 to cool IGBT switches and other elements.

The EMI-filter, input switch and input rectifier are positioned in the first 4U crate. The input filter capacitance, chopper's switches and choke are located in second crate. The chopper's capacitors, inverter and control circuit are located in the third case. And at last, there are capacitor and inductors of matching circuit located in the fourth crate.

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. These channels are shown in Table 2. The controller has CAN-bus interface which is used to link with an external control system. The used data rates are 125, 250 and 500Kbits in second. The protocol of CAN-bus interface is compatible with devises

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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 140mA threshold level, if the output current increases up to 140mA 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 110mA) 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 microseconds. The converter tries to switch on output voltage after 100 milliseconds with rise speed 100V/msec. 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 250A that matter the short circuit in transformer. In this case the converter is OFF.

RESULTS

The high-voltage source was made and now it is in tests. The tests are shown high reliability, efficiency better than 85% for full load operations. The long time stability of output voltage was better than 0,2%. Voltage ripple was better than 0,5%.

Table2. Measured channels

Channel	Period	Range
Output voltage	50μsec	0-140.00kV
Output current (full range)	50μsec	0-150.0mA
Input current high-voltage transformer	50μsec	0-300A
Feedback signal	25μsec	0-3000mV
Input 3-phase voltage (r.m.s.)	1msec	0-600V
Input current (r.m.s.)	1msec	0-150A
Temperature of IGBT switches	1sec	0-70°C
Temperature of high-voltage transformer	1sec	0-100°C

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