HIGH-VOLTAGE SOURCE WITH OUTPUT VOLTAGE UP TO 60 KV WITH OUTPUT CURRENT UP TO 1A

Gusev I.A., Medvedko A.S., Protopopov A. Yu., Pureskin D.N., Senkov D.V.,
BINP Novosibirsk Russia

Abstract

The presented report contains the description of high-voltage source with output voltage up to 60kV and output current up to 1A. The source consist of the chopper with IGBT switches working with a principle of pulse-width modulation and the fill H-bridge converter with IGBT switches , both working on programmed from 15 to 25 kHz frequency, and the high voltage sectioned transformer with the rectifier and additional capacity filter. The transformer is made in oil tank with silicon oil. The additional capacity filter decreases the ripple and noise level in working range of output currents. The design of the high-voltage transformer provides preservation of working capacity at voltage up to 100kV. A nominal output voltage of the source is 60kV. The source can operate with series of high-voltage breakdowns in output voltage without risk of damage the components of source. In the high-voltage breakdown the released in load and matching circuit energy is less than 15J at maximum operating voltage 65kV. The efficiency of system is more than 80% at the nominally output power 60kW. 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: short time interval for voltage rise up to 60 kV after high-voltage breakdown, strong reliability to 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 15J for 60 kV operation. 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 sectioned transformer with the rectifier (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 switches Q1-Q2, 20 kHz inverter with IGBT switches Q3-Q6, impedance matching design L2 C5, and isolation transformer T1.

Table 1. Basic parameters of high-voltage source.

Parameter	**Unit**			
		Min	**Nom**	**Max**
Output voltage	kV	10	60	70
Output current	mA	0.1	1000	1100
Output power	kW		30	
Voltage ripple	%			0.5
Voltage stability	%			0.2
Transient time	ms		5	
Inverter 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-C4 are used to convert input AC 3-phase voltage 380V 50Hz to DC 550-600V voltage. Switch SW1 is used for soft start of converter and its consists two groups of contacts (not shown of sheet). 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's switches Q1, Q2 are connected in parallel and operates one by one in working circle. As a result, the working frequency of each switch is the half of operated frequency of source. The chopper switches are operated with principle of pulse-width modulation on programmed from 15kHz to 25kHz 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 25kHz frequency.

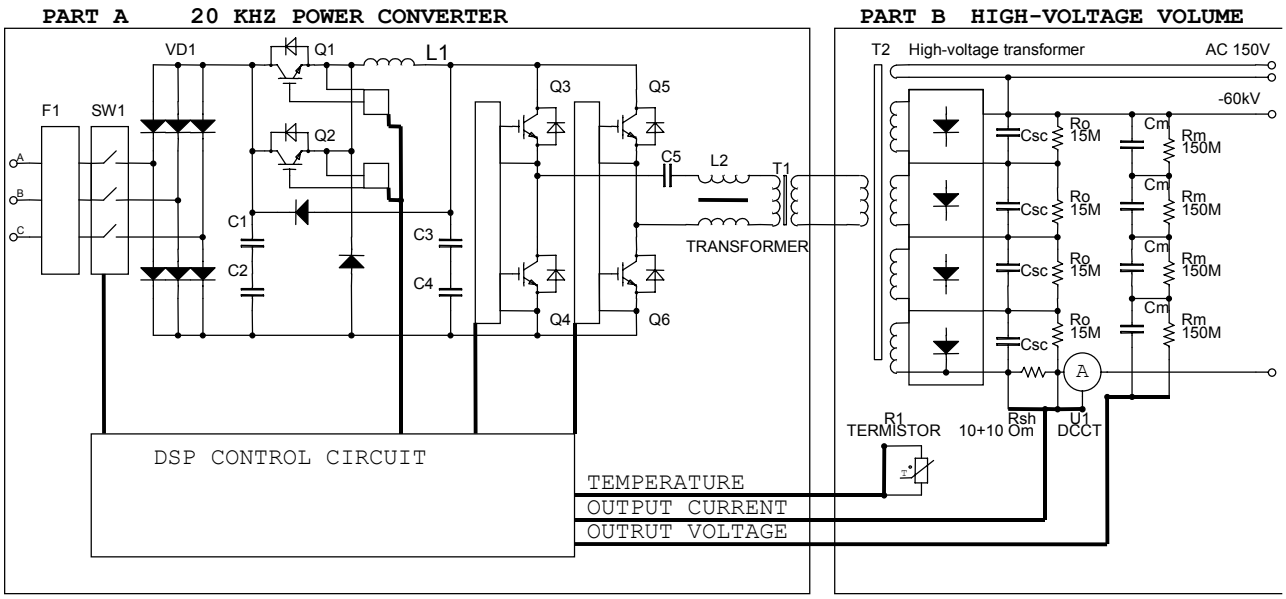

Fig. 1. The high-voltage source block-diagram.

Matching 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 10kV for 60 kV operations for load switching between 20mA and 500mA (half load). The matching circuit consists of elements C5 and L2 is used for minimizing transient process and for improving efficiently of design. Magnetising inductance of high voltage transformer, its capacitance calculated to primary side 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.

High-voltage transformer

Sectioned high-voltage transformer consists of four high voltage sections, joined in series. Each section is complete design and it includes winding, half-bridge rectifier, output filter capacitors and additional load resistor Ro. These additional loads improve transient process after switching OFF of the output current from 1A to zero load. Output voltage for section is 15 kV for 60 kV operations. Output filter capacity is chosen to decrease output voltage 40 kHz ripples less than 0,5% for full load operation. The top section of high-voltage transformer has addition winding with 150 volts AC 200 watts power output for supply of high side control circuits and the cathode heater. The transformer is designed in oil-filled tank (diameter 600mm, height 800mm). The silicon oil [1] is used.

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 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 produced in the BINP [2].

Protections and interlocks

There are two level of overcurrent protection: programmable and circuitry one. Rigid protection has a 1200mA threshold level, if the output current increases up to 1200mA or higher the converter switches OFF. The programmable threshold level is tunable. If output current is higher then programmable threshold level (from 5 to 1100mA) the converter switches OFF. Switching OFF time is less then 50 microseconds. For that reason, the breakdown energy less than 15J for 60kV operations with connected 10 meters of high-voltage cable. The converter try to switch on output voltage after 10 milliseconds with rise speed 1kV/msec. If the breakdown protection switches off the converter again rise speed is decreased to 100V/msec.

High-voltage transformer protection measures the temperature of transformer and the transformer's input current. If the input current of transformer rise up to 250A that matter the short circuit in transformer. In this case the converter is OFF.

Table2. Measured channels

Channel	Period	Range
Output voltage	50μsec	0-60.00kV
Output current (full range)	50μsec	0-1100.0mA
Output current (small current, measure with DCCT)	50μsec	0-50.00mA
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

Results

The high-voltage source was made and has being test with the electron beam gun for year. The power supply is tested with breakdown rate 1-2 breakdown in minute for output voltage 60kV within 3 hours. 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%. Continues work in full load operations is 8 hours and longer.

REFERENCES

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