POWER SOURCE FOR HIGH-VOLTAGE COLUMN OF INJECTOR TO PROTON SYNCHROTRON WITH OUTPUT POWER UP TO 5KW

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Abstract

The presented report contains the description of power source with output voltage of sinusoidal shape with amplitude up to 150V, frequency 400Hz and output power up to 5kW, operating on the primary coil of high voltage transformer - rectifier of precision 1.5MV electrostatic accelerator – injector for proton synchrotron. The source consists of the input converter with IGBT switches, transformer and the synchronous rectifier with IGBT switches also. Converter works with a principle of pulse-width modulation (PWM) on programmed from 15 to 25 kHz frequency. In addition, PWM signal is modulated by sinusoidal 400Hz signal. 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 efficiency of system is more than 80% at the nominal output power 5kW. The description of the source and the test results are presented.

DESCRIPTION

The presented source was designed as part of high-voltage power source for proton synchrotron injector, developed in BINP. The high voltage source consists of 1.5MV high voltage column with input matching circuit, operated on 400Hz frequency, and the power source with 400Hz 150V harmonic output. The block-diagram of high voltage source is shown on Fig.1. The matching circuit is necessary due to the high voltage column design feature, such as series inductance of high voltage transformer is compatible with magnetizing inductance, the capacitance of high voltage transformer calculated to primary side organize with the inductance the oscillatory circuit with 1.5kHz resonant frequency [1]. But the maximal working frequency of high voltage column consisting of sectioned transformer with rectifier is 600Hz. So the capacitor bank C1 decrease the resonance frequency of contour to operating frequency. The inductance L1 organize the partial including of the Harmonic 400Hz PS into resonance circuit, protecting the PS from large reactive currents from resonance circuit. Also L1 and C1 together are low-pass filter, which preventing the high voltage column from high frequency harmonics, from power source, where they are generated by converter and synchronous rectifier under the PWM. The basic characteristics of high-voltage source are shown in Table1.

Overview

Design of the power part of the source is shown on Fig.2. The power source consists of the 20kHz power converter with insulated gate bipolar transistors (IGBT) as switches (part A) and the isolation transformer with synchronous rectifier (part B). The design of power converter consists of 3-phase diode rectifier VD1, electromagnetic (EMI) filter F1, switch SW1, rectifier's filter L1 C1-C8, 20 kHz inverter with IGBT switches Q1-Q4, isolation transformer T1, synchronous rectifier O5-Q8, output low-pass filter L2 C9 and three current sensors: U1, U2 and U3.

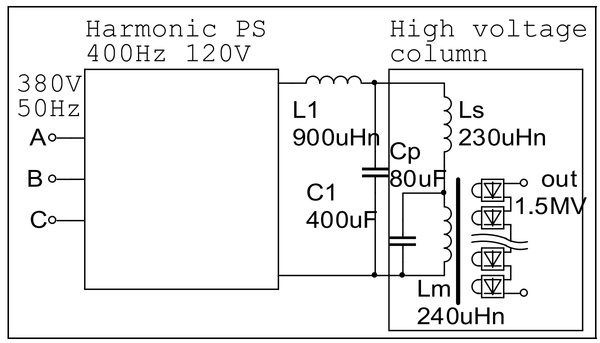

Fig. 1 High voltage source block-diagram

Table 1. Basic parameters of power source.

Parameter	Unit	Value		
		Min	Nom	Max
Output voltage	V r.m.s.	10	120	150
Output current	A r.m.s.		65	80
Output power	kW		5	7
Output voltage long time stability	%			0.1
Power source output frequency	Hz	200	400	600
Inverter frequency	kHz		20	

Input rectifier

EMI filter is used to prevent high-frequency noise from the power line from the PWM source. 3-phase diode rectifier and filter C1-C4 are used to rectifier input AC 3-phase voltage 380V 50Hz and to get DC 550-600V voltage. Switch SW1 is used for converter soft start.

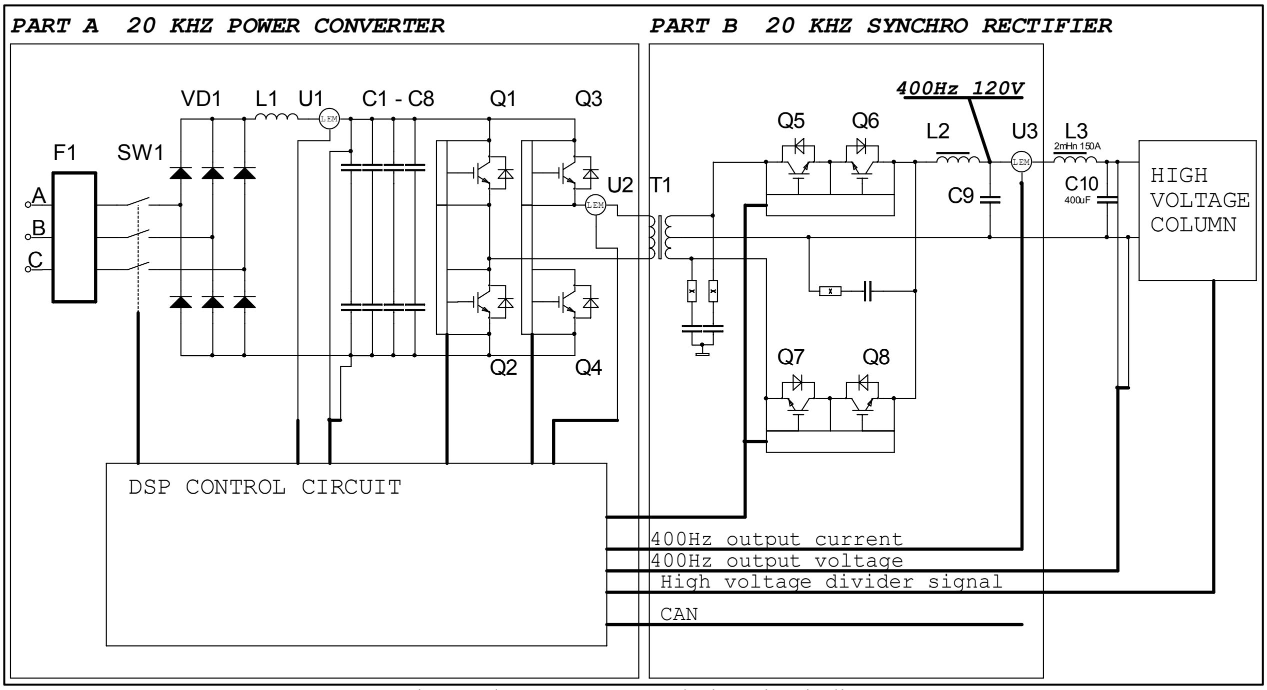

Fig. 2. The power source design circuit diagram.

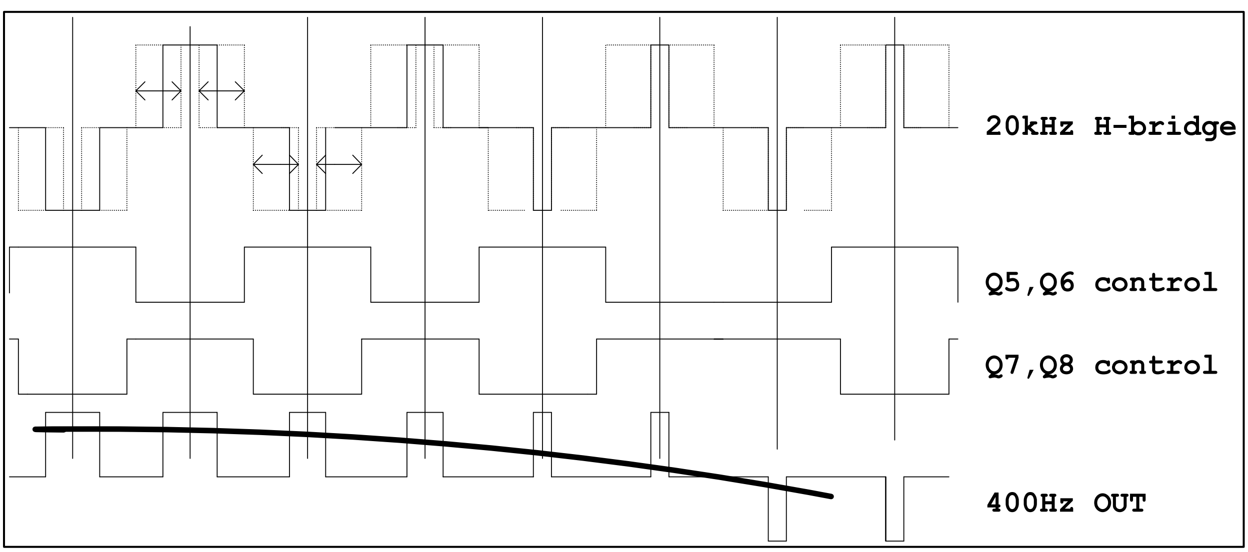

Fig. 3. The power source principle of operation.

Inverter

Full-bridge inverter Q1-Q4 converts DC 550V voltage to AC voltage with 20 kHz frequency. Inverter works with principle of pulse-width modulation (PWM) with 2 circles (Fig.4): (A) freewheeling when switches Q2, Q4 are switched ON and (B) energy addition when Q1, Q4 or Q2, Q3 are ON. With this conditions the IGBT switches is in soft switching mode. As a result, the switching energy loss are minimised, the switching transient process improves. The modulation signal is 400Hz sinus, so the output signal from inverter presents 20kHz PWM AC voltage with module sin modulation $\tau_B = Ampl \cdot T \cdot |\sin(\Omega t)|$ (Fig.4) were T is half of period 20kHz, Ω is $2 \cdot \pi \cdot 400$, $0 \leq Ampl \leq 1$ is amplitude of output 400Hz sin signal.

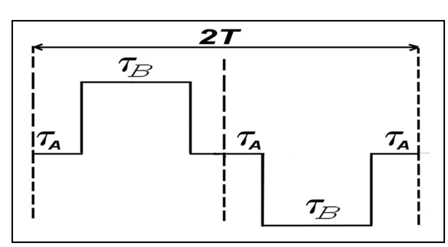

Fig. 4. PWM signal.

Synchronous rectifier

After the isolating transformer the modulated voltage feeds to synchronous rectifier switches Q5 Q6 and Q7 Q8. Each switch consists of two IGBTs in series connection, so each switch can operate with positive and negative polarity of input voltage. Switches controls by control circuit and works synchronously with inverter. The principle of obtaining 400Hz-sinusoidal voltage is shown on Fig.3. After synchronous rectifier the voltage feed to L2C9 filter. This LC circuit filtrates the 20kHz component of signal. So in the output the power source has the 400Hz-sinusoidal voltage with regulated amplitude, which feed to matching circuit L3C10 and after that on high voltage column.

The output voltage of column regulated from 10kV to 1500kV with changing amplitude of 400Hz-sinusoidal voltage with 100ppm accuracy.

Design

The power source is made in one 4U and two 6U crates in the rack of 19" Euromechanics standard. There are distilled water is used to cool IGBT switches and other elements.

There are EMI-filter, input switch and rectifier constructed in the first 4U crate. There is filter capacitors, inverter and control circuit located in the second crate. And at last, there is synchronous rectifier and low-pass filter located on third crate.

Control circuit

The control circuit is realised in digital signal processor (DSP), programming logic matrix array (PLM), and analog input matching circuits. The control and analog groundings are isolated from external signals and groundings and, that way, the control circuit has obtained low noise level. It allows to operate with better then 0.05% measurement accuracy. All the IGBT switches are protected from short circuit and overcurrent. The controller measured 7 analog channels with 12bits resolution. These channels list is shown in Table 2. The controller has CAN-bus interface which is used to link with a control system. The used data exchange 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

Breakdown protection controls output voltage from divider. If the rate of voltage variation exceeds the reference level, the high voltage breakdown is detected, and the converter switches OFF the IGBTs. Switching off time is less then 50 microseconds. The converter trays to switch on after 10 milliseconds with rise speed 1kV/msec. If the series breakdown is detected, protection decreases the rise up to 100V/msec.

High-voltage transformer protection measures the transformer's input current. If the input current of transformer increases up to 100A that matter the short circuit in transformer. In this case the converter became OFF.

Table2. Measured channels

Channel	Period	Values range
Output high voltage	50µsec	0-1500.0kV
Power source Output voltage	50µsec	0-200V
Power source Output current	50µsec	0-100A
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

RESULTS

The power source was developed and has being test with the high voltage column during last year. 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%.

REFERENCES

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