A HIGH VOLTAGE POWER SUPPLY FOR A DIAGNOSTIC INJECTOR OF NEUTRAL ATOMS

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Abstract

For the purpose of active corpuscular diagnostics of plasma parameters in thermonuclear facilities the Budker Institute of Nuclear Physics SB RAS created the Diagnostic Injector of Neutral Atoms (DI) with the following parameters: neutral atom energy range from 20kV up to 55 kV, atomic current up to 2A (ion current up to 5A) and operation time up to 50 ms. The High Voltage Power Supply (HVPS) makes it possible to obtain modulated or unmodulated stabilized voltage in all the range, at output current as high as 8A. A capacitor storage bank is used as a primary source of energy. Voltage from capacitors is transformed to high voltage with the help of a multi-channel IGBT converter with PWM regulation. The report describes the realization of HVPS, design, commissioning and results.

1 INTRODUCTION

Basic Parameters of High Voltage Power Supply (HVPS) for the Diagnostic Injector of Neutral Atoms (DI) are given in Table 1.

Table 1: HVPS parameters

Parameter	Range	Value
Output voltage	20 – 55	kV
Output current	up to 8	A
Voltage tuning step	<1	kV
Levels of ripples and instabilities of output voltage	$\leq \pm 1$	%
Rise/fall time	<100	μs
Output capacitance of HV PS and cable	<2	nF
Minimum pulse duration	2	ms
Maximum pulse duration	50	ms
Feasibility of 100% amplitude modulation; minimum pulse duration	2	ms
minimum interval between pulses	2	ms
Minimum pause between cycles	300	s

2 DESIGN PRINCIPLES OF THE HVPS FOR THE DIAGNOSTIC INJECTOR

The principle of separation into the high voltage part (High Voltage Rectifier) enclosed in the tight vessel filled with SF6 gas and the low-voltage part consisting of a multiphase converter operated at high conversion frequency was used during the design of the HVPS for the DI [1]. High Voltage Rectifier (HVR) consists of eight rectifying cells connected in series. Each cell consists of the step-up transformer with the turn ratio Ktr = 1:20, diode rectifier and capacitors filter with the varistors protection against over-voltages (Fig.1 and Fig.2).

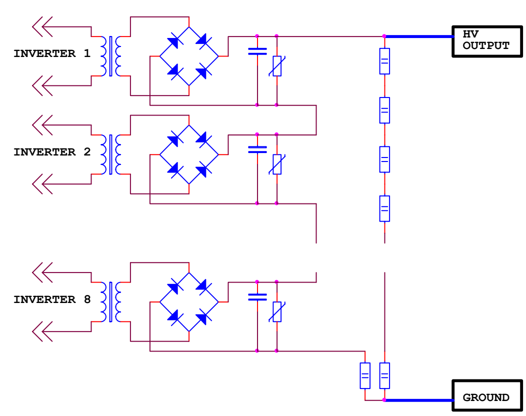

Figure1: Circuit diagram of the HV part of the HVPS for DI.

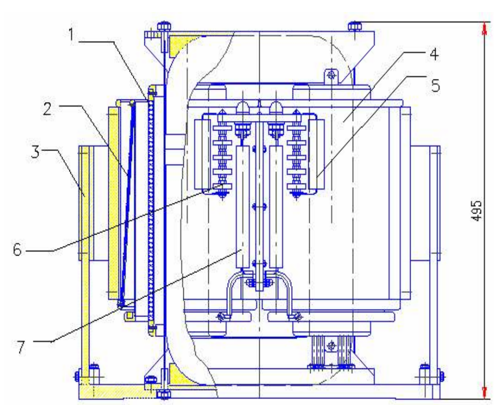

Figure 2: Design of "Rectifying cell" of HVPS for DI. Where are: 1 -primary winding; 2- secondary winding; 3 –organic glass HV insulator; 4 – shield of secondary winding; 5- output filter capacitors; 6- varistors protection; 7- HV rectifying diodes.

Rectifying cells are located in the tight vessel filled in with SF6 at excessive pressure of 0.7 atm.

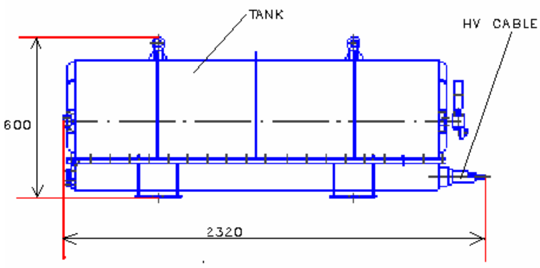

Figure 3: Housing vessel for the High Voltage rectifier.

It is evident direct energy feeding from the power mains is impossible because of impermissibly strong pulse perturbations of the mains. At the same time, the average power consumption of the installation is rather low (about 2 kW). In this situation, the best version of the solution of the task seems to be the use of the capacitor storage bank. Maximum of the energy required for a single operation cycle of the HVPS (50 ms) taking into account the efficiency factor is up to:

Q=Pt / 500 kW*50 ms = 25 kJ.

The capacitor storage bank we assumed the following:

- not to make harder safety requirements of the device and not to use semiconductor components of higher voltage class and voltage of the capacitor storage should not exceed 1 kV;
- for the optimum use the energy of the storage, its voltage required for one operation cycle of the DI is reduced by 30%. In this case nearly half of the earlier stored energy is used.

An electrolytic capacitor "B43458" with the nominal capacitance of 12000 μF (450V) of "Siemens Matsushita Components" (EPCOS) production is used as a basic element of the capacitor storage bank. Two of such capacitors connected in series make a capacitor cell of 6000 μF and operation voltage of 900 V. Each such a «cell» is equipped with the fuse whose operability is controlled by electronics. Twenty five of such «cells» connected in parallel make just the capacitor storage of energy required for the operation of the HVPS. Its capacity is: C= 25*6000 μF = 0.15 F. The capacitor storage bank is charged to its maximum voltage of U1= 900V, it has the stored energy over of 60 kJ. Energy consumed by one operation cycle of the Diagnostic Injector in its nominal regime of 25 kJ reduces the capacitor storage voltage down to U2 =650V.

Converter of the capacitor bank energy into high voltage of stable amplitude comprises eight identical converter modules. Each module consists of two power devices connected in series: a single cycle PWM-IGBT converter (“Chopper”) which forms the adjustable stable primary DC voltage 200-650 V, and the voltage resonant “Inverter” of high frequency 10 kHz. All these modules (Fig.5) are operated with a 1/16 period phase shift.

Figure 4: Housing 19-inch rack for the electrolytic capacitor ("B43458" type) storage bank.

Thus the “Choppers” function is the producing of DC voltage to be transformed by “Inverters” into AC voltage with frequency of 10 kHz. The level of the voltage determines the amplitude of the High Voltage Power Supply (HVPS) and provides its deep control ranging from 10% up to its nominal value. The PWM-control of the IGBT- Inverters enable the control of the output voltage executing the precise stabilization of the output voltage of HVPS. The “Chopper” operating frequency is two times higher than the inverter operating frequency (20 kHz). Switching ON/OFF “Choppers” and “Inverters” is synchronized thereby forming output voltage of the HVPS.

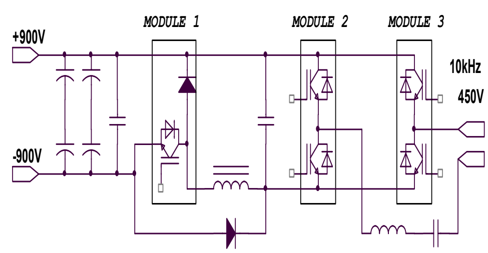

Figure 5: Functional diagram of the IGBT-converter module.

The ripple frequency of the output voltage of the high voltage rectifier is 10*2*8=160 kHz. Such a high frequency of ripples enables to use a simple capacitor filter with small output stored energy (less than 2 Joules) thus making the operation in the regime of regular breakdowns safe for the ion-grid system of the atomic injector (DI). In course of experiments on diagnostics of plasma parameters in plasma devices the beam of neutral atoms with a 100% amplitude modulation of energy and an arbitrary modulation frequency determined by characteristics of the diagnostic apparatuses. Such a regime is achieved by variation of the output voltage of HV source from zero up to 100%.

3 EXPERIMENTAL RESULTS

A High Voltage Power Supply has been designed and tested one year ago, it has been operating with Diagnostic Injector with output
current up to 8 A. The operation range of stabilized output voltage is from 10% to 100% of the 55kV maximum voltage. HVPS satisfies the parameters, presented in Table 1.

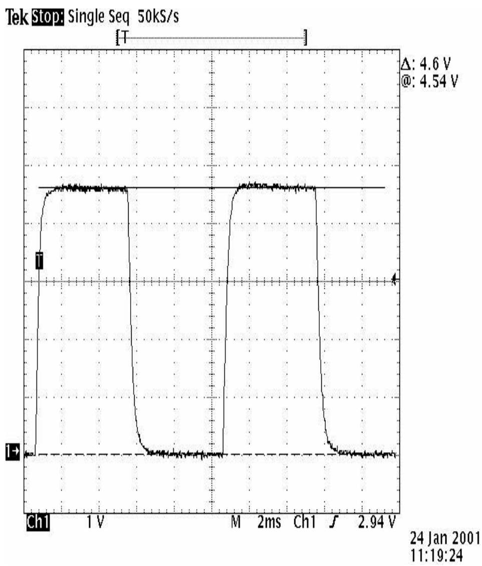

Figure 6: Typical oscillograms of the HVPS operation with Diagnostic Injector in the modulated regime, U (out)=46kV.

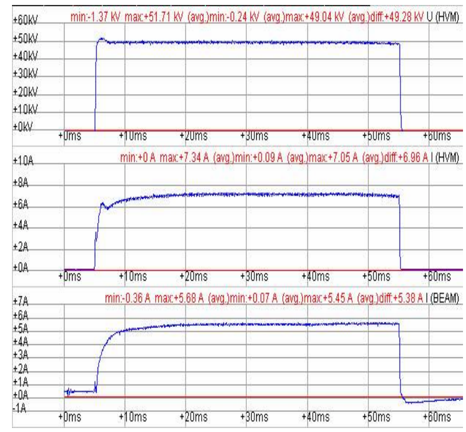

Figure 7: Typical oscillograms of HVPS output unmodulated voltage (upper), total output current of HV PS, including current through grid divider (middle), the ion beam current I (beam) measured in the DI grounding circuit.

4 ACKNOWLEDGEMENTS

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