# HIGH-VOLTAGE MODULATOR WITH SMALL ENERGY ACCUMULATION IN THE OUTPUT FILTER

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*Abstract*

A compact power source for the Injector of neutral atoms designed for diagnostics of plasma in thermonuclear installations is described. It forms output voltage up to 55 kV with an output current up to 3A during the two seconds pulse. The power source is constructed by the module method. It consists of six identical cells. Each cell includes an IGBT inverter operating at a frequency of 5 kHz, a high-voltage transformer with a 1:20 transformation ratio, bridge diode rectifier and capacitance filter. Outputs of the cells are set up in series. The inverters are phased-in such a way that the main frequency of output voltage ripple equals to 5kHz*2*6=60kHz. A capacitance filter with accumulated energy less than 2 J is enough for decreasing of ripple amplitude to level less than 1% under the nominal load. Combination of such an output filter with comparatively low leakage inductance of the high-voltage transformers and high speed of response of protection circuits of IGBT inverters allowed reliable protection for the grid system of the Injector against a break-down without expensive crowbar switch. The report presents the features of technical realization of the power source and its experimental and operational characteristics.

## 1 INTRODUCTION

Spectroscopy of neutral beam induced radiation is widely used in plasma fusion devices for diagnostic purposes [1]. The typical diagnostics requirement is to have up to 55 kV energy of neutral particles (Hydrogen) with equivalent current up to 3A (equivalent current means here the value of ions current before neutralizing). Some time the spectroscopy methods wants to have continuous current during all «short» of Injector, some time the measurements need to have a modulation of the diagnostic beam enables one to improve signal to noise ratio due using of synchronous detecting of signals. Usually design of plasma source of Injector is very delicate and sensitive to energy dissipated inside its electrodes (grids), especially due breakdowns in plasma. To increase the reliability and lifetime of grids the power supply (Modulator) with as small as possible stored energy is desirable. The grids system of DNBI has limits as: number of grids breakdowns during one «short» should be less than 16 and limited by Modulator; Modulator should switch OFF the output power within 100-200 μsec; energy dissipated into grid during one breakdown should be in the level of few joules.

The BINP team had developed the Diagnostic Neutral Beam Injector (DNBI) which capable to meet the requirements of variety of these diagnostics and developed the Modulator with relatively small energy accumulated inside its reactive elements — output capacitors and leakage inductance. It can produce the output voltage inside range 20 to 55 kV with load current up to 3 A. In addition, Modulator can perform a «rectangular» modulation of output voltage with rise/fall time less than 200 μsec and with 100% amplitude modulation. Minimal time interval of the «OFF» state shall be longer than 2 ms, maximal time interval of the «ON» state can be up to 2 sec. The Modulator is based on the modular power converter system with switch mode PWM technology. Crowbar protection is unnecessary [2].

## 2 DESIGN PRINCIPLES OF HIGH VOLTAGE MODULATOR

In general, the High Voltage Modulator (HVM) can be presented as a combination of High Voltage Part and Low Voltage Part. HV Part is placed close to Injector, directly in site of plasma fusion device. LV Part can be placed at the electrical equipment zone in distance up to 50 m to Injector. Both HV and LV Parts of HVM consists of six identical cells. Each cell includes an IGBT inverter operating at a frequency of 5 kHz, a high-voltage transformer with a 1:20 transformation ratio, bridge diode rectifier and capacitor filter. Outputs of the cells are set up in series. Combination of such an output filter with comparatively low leakage inductance of the high-voltage transformers and high speed of response of protection circuits of IGBT inverters allowed reliable protection for the grid system of the Injector**.**

### *2.1 High Voltage Part of HVM.*

In order to provide high reliability of Modulator, only passive elements are used in the High Voltage Part as: transformers, capacitors, diodes and varistors (Fig.1). HVM consists of 6 identical modules connected in series. The operation frequency was chosen to be 5 kHz. In order to satisfy the requirements on ripple level (±1%) and to minimize the energy stored by the HVM output filter, each of 6 modules are forced to operate in their individual phase, shifted relative to the neighboring one by 1/12 of period (200 μsec/12 = 16,6 μsec). The resulting main ripple frequency of HVM output voltage is 5 kHz x 2 x 6 = 60 kHz.

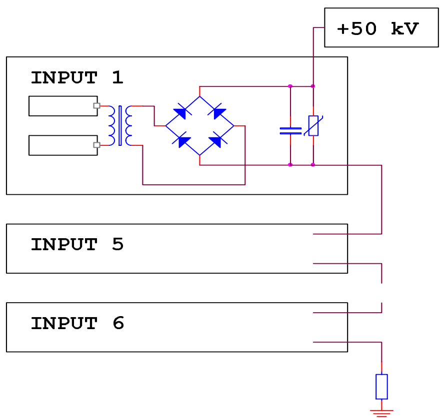


Figure 1: High Voltage Part of HVM.

In order to reduce the HVM dimensions and provide the insulation of HVM high voltage part at double operation voltage (100 kV), the SF6-gas with an excessive pressure of 0.7 ATM was chosen.

## *2.2 Low Voltage Part of HVM*

HVM is powered with a three-phase mains of 400/230 V, 50 Hz via matching transformer with the power consumption of up to 180 kW in an active stage (during the pulse) and approximately 1 kW in average for operation period of 300 sec. Low voltage part of HVM consists of: input thyristor rectifier with LC-filter; 6 modules of 5 •Hz inverters (30kW each); dummy load made as IGBT-Switch with set of resistors; low level electronics for timing, protection, control, and stabilization. (Fig.2).

An output voltage of thyristor rectifier with LC-filter is controlled within the range from 0 to 500 V. The conversion of the LC-filter output voltage into an alternating voltage with a frequency of 5 kHz is provided by 6 identical H-type full bridge IGBT- Inverters with PWM control (Fig.3.).

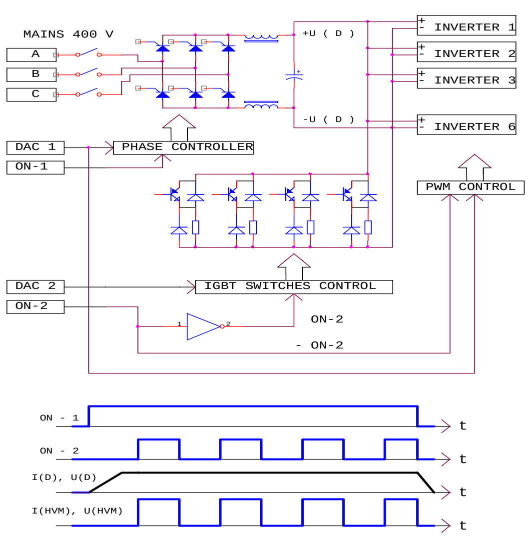


Figure 2: Low Voltage Part of HVM.

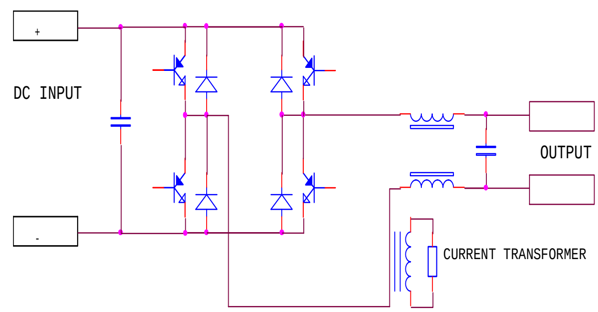


Figure 3: Full Bridge Inverter.

One can see that according to the neutral beam modulation law the pulsed power consumption with zero-to-180 kW jumps is possible. Such mode of operation affects extremely negatively both on the power transformer (mechanical stresses) and on the quality of the power mains. In order to avoid the mode of mains current interrupting two special solutions were developed: first one is a smooth charging of the filter capacitors by slow shifting of phase of thyristor bridge opening; another one is dummy load application. Dummy load in the Modulator is the assembly of resistors joined in parallel with filter output via IGBT switches (see Fig.1.). Dummy load is switched OFF when Inverters are switches ON, or, by the other hands, when Modulator applies high voltage to Injector. During modulation process Inverters and Dummy load are switched ON/OFF in anti- phase mode and, as a result, system consuming practically constant current during the DNBI operation cycle and with 100% load current variation was achieved.

# 3 EXPERIMENTAL RESULTS

A High Voltage Modulator has been designed and tested two years ago, it has been operating with Diagnostic Neutral Beam Injector with extracted current up to 2.5 A. The DNBI system operates now at CRPP, Lausanne, Switzerland. High Voltage Modulator (HVM) satisfies the following output parameters, presented in Table 1. Figures 4 and 5 presents some typical diagrams of Modulator during operation with Injector.

Table 1: DNBI parameters

| Parameter | Range | Value |
|---|---|---|
| Output voltage range | kV | 20 – 55 |
| Output current | A | up to 2.5 |
| Output voltage tuning step | kV | 0.1 |
| Output voltage ripple and an instability level | % | <1 |
| Output voltage rise/fall time (10-90%) | us | <100 |
| Output voltage mini-mum pulse duration | ms | 1 |
| Maximal pulse duration | s | 2 |

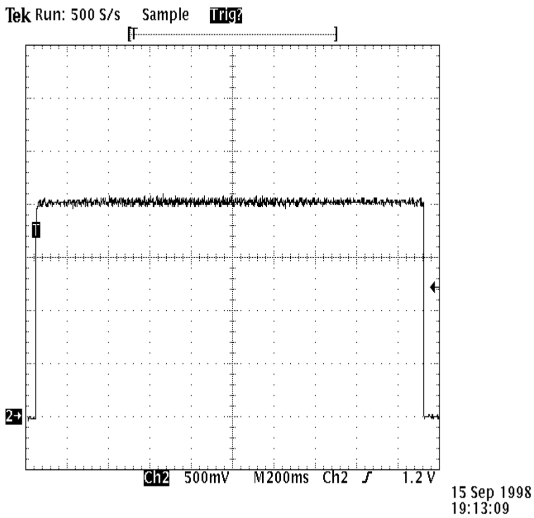


Figure 4: Waveform of 1.9-sec 40 kV, 2A pulse

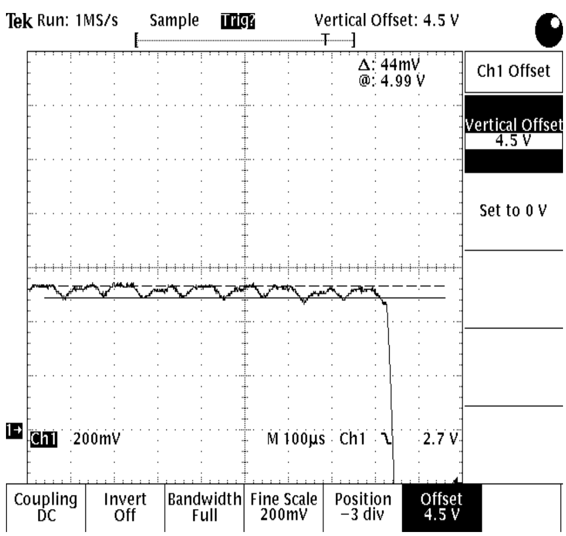


Figure 5: Ripples of 2-sec 50 kV pulse with 2A output current (vertical offset 4.5V, 1V:=10kV).

## REFERENCES


[1] E.Hintz and B.Schweer, Plasma Phys. Control. Fusion 37 (1995) A87-A101

[2] D.E. Poole, L.M. Ford, S.A. Griffiths, M.T. Heron, C.W. Horrabin, «A Crowbarless High Voltage Power Converter For RF Klystrons», EPAC97, p.2326