HV PULSE MODULATOR WITH SWITCH ON HV IGBT TRANSISTOR

A. Dolgov, O. Kildisheva
TV and Radio Apparatus Corporation (TIRA Corporation Ltd.),
14, Shkipersky protok, Saint-Petersburg, 199106, Russia;
tira@mail.rcom.ru

The new generation modulator with a solid-state switch to provide the plate pulse supply of RF generators of hydrogen-ion linear accelerators is described. The use of a solid-state switch, instead of a vacuum tube, allowed to increase the efficiency and reduce the modulator overall dimensions due to eliminating the auxiliary power supplies for the vacuum tube and to use a comparatively low charging voltage level.

PACS: 29.17+w

1. INTRODUCTION

Two modulator versions are provided: for “Koleso” endotron and for “Congress” RF amplifier line. The main parameters of the modulator are given in Table .

Parameter	Value	
Version	“Congress” RF amplifier line	“Koleso” endotron
Peak pulse power, MW	1.33	1.33
Peak pulse voltage, kV	24	14
Peak pulse current, A	58	95
Peak pulse voltage control limits, kV	14...24	8...14
Flat top duration, µs	10...150	10...150
Pulse top ripple, at most	±1%	±1%
Voltage instability from pulse to pulse, at most	±0.5%	±0.5%
Maximum pulse-repetition rate, Hz	100	100

The modulator allows a possibility to work in the training mode at a pulse-repetition rate to 1 Hz, while maintaining the stability of specified output pulse parameters. The modulator has local or remote control.

2. PULSE FORMING DEVICE

The modulator represents the pulse generator with ф partial discharge of capacitive storage and step-up pulse transformer. This version permitted to ensure the required output parameters of the modulator at specified pulse-duration control range and wide load impedance variation. The simplified diagram of the modulator is given in Fig.1.

The capacitive store is made by using the К75-63-type capacitors with a total capacitance of 660 µF. The specified ripple on the pulse top is obtained by the introduced second-order compensating circuit: Lcor, Ccor, Rcor [1]. One can successfully reduce the storage capacitance in comparison with the one-order compensating circuit and, therefore, the cost and overall dimensions of the modulator, though this leads to a small decrease of the modulator efficiency (by 3-4% appr.).

The main feature of this modulator is a solid-state switch (SSS) T1 based on the IGBT transistor. At present, the commercial transistors of such class are available from different producers (EUPEC, HITACHI, MITSUBISHI) for a voltage up to 6500 V and currents up to 1700 A. The optimization of the storage overall dimensions and cost, taking into account the existing range of capacitors and transistors, led to the choice charging - voltage level – 2.2 kV. As a switch there was used the EUPEC FZ800R33KF2-type transistor that has the better dynamic and static parameters, as compared with the similar transistors of other producers.

The main problem of the design of pulse-forming device was to ensure the reliable operation SSS both under normal condition and at load breakdowns. The greatest danger for the transistor is the overvoltage arising at transistor switching off due to an energy accumulated in parasitic inductances of the discharge circuit. Even at switching of 700 A rated current, the SSS voltage too much the charging voltage (see Fig.2).

The solution of this problem was obtained by means of three main ways:

1. Use of several damping circuits operated in different modes.
2. Design of specialized smart driver for transistor control.
3. Choice of protection-system operation algorithm.

Let us consider each way in more details. Five damping circuits are provided in the modulator to reduce the overvoltages that appear in the transistor at its switching off:

1. The circuit Cd2, Rd_on, Rd_off, Dd and circuit Dd_Lm, Rd_Lm are designed to provide the transistor protection against the overvoltages arising at switch normal operation due to of the energy stored in discharging circuit parasitic inductances (stray pulse transformer inductance, storage parasitic inductance and bus inductance) and due to magnetization inductance. The transistor voltage under design conditions is determined with two processes: “quick” – by Ldc energy distribution and “slow” – by Lm energy distribution between resistors Rd_on, Rd_off and Rd_Lm. There is the optimum ratio between these resistors to reduce the peak transistor voltage.

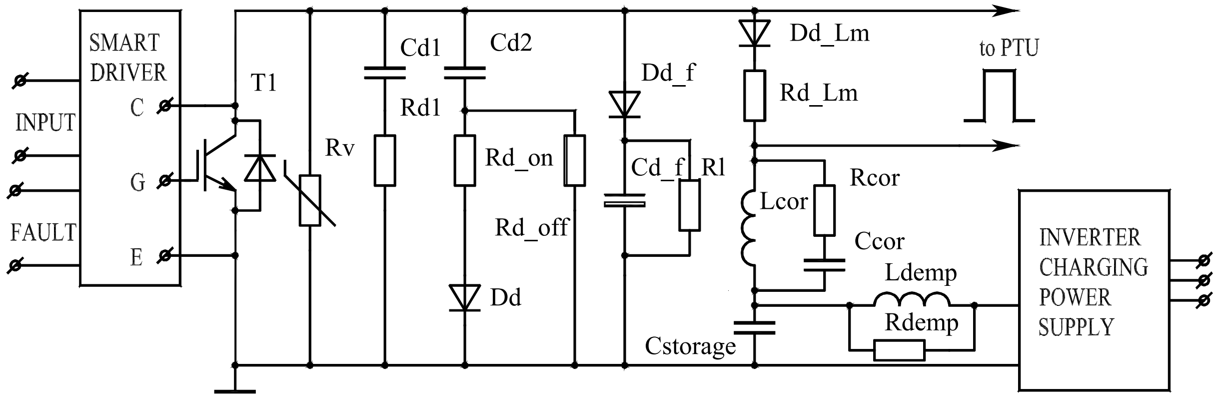


Fig.1. Simplified diagram of pulse-forming device

However, during specific implementation of this design, the largeness of the elements was taken into consideration, the parasitic inductances of these damping circuits become too much. Because of this factor, these circuits do not practically limit the SSS voltage with the duration up to 2µs. In consequence of this circumstance two more additional damping circuits with minimum parasitic inductances were designed.

2. The circuit Cd1, Rd1 serves for damping the oscillations arising because of the transistor module self-inductance. It consists of RF ceramic capacitors and noninductive resistors;
3. The varistor assemblage Rv intended for transistor protection against the overvoltages of very shot duration (we have initiated) and low average energy. The executed tests have shown that the EPCOS varistors have the best speed of response and best characteristic linearity. The SIOV20S420K-type varistors that operate at overvoltage above 2800V have been chosen. The board with the varistors and damping circuit Cd1, Rd1 is located directly on the transistor.
4. The qualitative change arises at load breakdown. Though all the above-mentioned circuits will continue to work, nevertheless they have not necessary energy-intensive capability that would permit to limit the overvoltages at short-circuit current switching. The circuit Cd_f, Dd_f, Rl is designed for single operation at load breakdown and under any other fault conditions. The capacitance of capacitor Cd_f is 40 µF, which permits, at 1600 A current (allowed for this transistor) single switching off, to limit the transistor overvoltage up to 550 V value, relative charging voltage 2200 V, i.e. the transistor peak voltage will not exceed 2750 V. The SSS current and voltage oscillograms are given in Fig. 3 at load breakdown.

The SSS control is fulfilled by means of an especially designed smart driver that provides:

- Galvanic isolation of control circuits and gate circuits SSS, which improve the reliability of the control system and modulator on the whole at switching the high currents in discharge circuit;
- Triggering pulse amplification;
- The SSS switching on and off modes with minimum dynamic and static losses;
- Isolated power supplies for switching on (+15V) and reliable switching off at the expense of SSS negative bias (-8V);
  - Transistor gate voltage limitation;
  - Transistor collector overvoltage active limitation at the expense of controllable switch-off speed control (up to 10 µs).

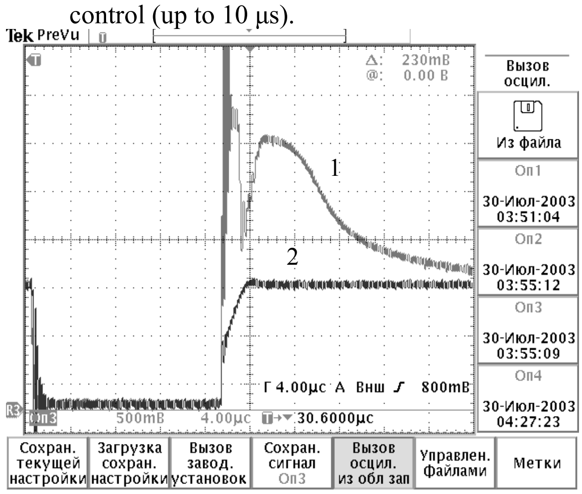
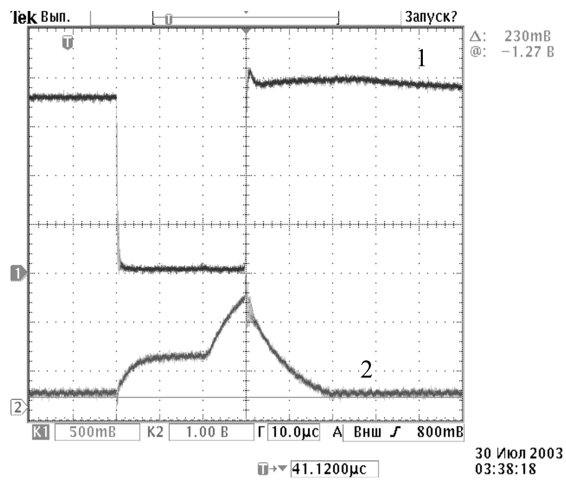


Fig.2. Switch voltage in design condition (200V/div, 30 µs/div): 1 – without damping circuits;
2 – with designed circuits



PROBLEMS OF ATOMIC SIENCE AND TECHNOLOGY. 2004. № 1.
Series: Nuclear Physics Investigations (42), p.66-68.

Fig.3. Switch voltage (1) and current (2) at load breakdown condition (600V/div, 750A/div 30μs/div)

The driver represents the board being the size of 89x118 mm that is placed close to SSS.

To provide the SSS reliable protection against the load breakdowns, the modulator protection system monitors three signals:

1.SSS driver signal about transistor saturation voltage;

2.Load current from shunt;

3.Voltage on damping capacitor Cd_f.

If the SSS current resulted from load breakdown increases so that the transistor pulls out of saturation during the pulse, the SSS emergency "slow" switching off process begins in switch voltage active limitation mode. The driver transfers the fault signal to the protection system that turns off the modulator as soon as the SSS cut-off has been finished.

If, at any other faults (partial load breakdown), the transistor will not pulls out of saturation during the pulse but the protection system detects the current increase, then the protection system turns off the modulator only after normal pulse duration finish.

If the load breakdowns occur at pulse end, the load currents during the pulse may become less than the threshold of the protection-system operation by the signal from shunt. In this case, the damping capacitor Cd_of voltage will begin to increase. If it reaches the 2.5 kV value during several pulses, the protection system will turn off the modulator.

All the actions above have permitted to provide the safe modulator operation, and this was verified by experiment at the modulator dummy load short-circuit by means of TGI1-1000/25 thyratron. All the oscillograms shown are taken on this experimental installation. The peak switch current runs up 1750 A (at normal current 700A) at load breakdown. At storage charge the rated voltage of 2.2 kV, the switch peak voltage did not exceed 2.7 kV at any emergency operation (see Fig.3).

3. CHARGING POWER SUPPLY

The storage charging power supply represents the power supply without input line transformer and with intermediate frequency conversion. It is based on the bridge resonance voltage converter with IGBT transistors and operated at 15...30 kHz frequency. The power supply control system allows one to stabilize the storage charging voltage at ac-line voltage variation of +10%, -15%. The stabilized voltage value can be controlled online within the 1.4...2.3 kV range with keeping high efficiency. The maximum storage charging speed provided by the charging power supply is 20 J/s.

4. CONSTRUCTION

The pulse modulator is located in two "Rittal" cabinets united into one installation. The installation dimensions are 600x1400x1800 mm. A volume (20% appr.) is reserved inside the installation to place the customer equipment. The charging power supply represents two packaged products: converter and HV transformer with the HV rectifier. The HV rectifier and Pulse-transformer units are made as two leak-proof oil tanks that allowed one to reduce their overall dimensions and improve the cooling conditions of the components comprised.

5. CONCLUSIONS

The use of a solid-state switch permits:

- to increase the modulator efficiency at the expense of the reduction of static loss switch and elimination of additional sources (filament);

- to reduce the charging voltage levels, which allows to reduce the modulator overall dimensions;

- to increase the pulse power by means of combining of on output pulse transformers, which is an actual problem for klystron modulators for power linear accelerators [2].

REFERENCES

1. P.N.Matkhanov. Circuit synthesis for correction of pulse shape of tube pulse modulators // *Proceedings of LETI, Radio engineering and electronic.* 1959, v. 2, p. 109-116
2. R.L.Cassel, J.E.Delamare, M.N.Nguyen, G.C.Pappas // *Solid State Induction Modulator Replacement for the Conventional SLAC 5045 Klystron Modulator. SLAC-PUB-8907, September 2002.*

ВЫСОКОВОЛЬТНЫЙ МОДУЛЯТОР С ПЕРЕКЛЮЧАТЕЛЕМ НА ВЫСОКОВОЛЬТНОМ IGBT ТРАНЗИСТОРЕ

А. Долгов, О. Килдишева

Описан модулятор нового поколения с твердотельным переключателем для обеспечения анодного импульсного источника ВЧ-генераторов линейных ускорителей ионов водорода. Использование твердотельного переключателя вместо вакуумной лампы позволило увеличивать эффективность и уменьшить габаритные размеры модулятора из-за устранения вспомогательного электропитания вакуумной лампы и использования сравнительно низкого заряжающего уровня напряжения.

ВИСОКОВОЛЬТНИЙ МОДУЛЯТОР З ПЕРЕМИКАЧЕМ НА ВИСОКОВОЛЬТНОМУ IGBT ТРАНЗИСТОРІ

А. Долгов, О. Килдишева

Описано модулятор нового покоління з твердотельным перемикачем для забезпечення анодного імпульсного джерела ВЧ-генераторів лінійних прискорювачів іонів водню. Використання твердотільного перемикача замість вакуумної лампи дозволило збільшувати ефективність і зменшити габаритні розміри модулятора через усунення допоміжного електроживлення вакуумної лампи і використання порівняно низького заряджаючого рівня напруги.

PROBLEMS OF ATOMIC SIENCE AND TECHNOLOGY. 2004. № 1.
Series: Nuclear Physics Investigations (42), p.66-68.