Long-Pulse Modulator for Klystron using a High-Voltage Solid-State Switch and a Droop Compensator

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Abstract

The paper presents a long-pulse modulator for klystron using a high-voltage solid-state switch and a droop compensator. The modulator guarantees the safe of klystron by limiting the amount of energy transferred to klystron in case of arc. The high performance of the modulator is also achieved by the fast transition time, high flatness and average power. The proposed prototype has produced pulses with a flat-top voltage *-90*[kV], pulse width 1ms and pulse frequency *200*[Hz]. The validity of the long-pulse modulator for klystron has been verified by the simulation and experimental works.

Keywords: droop compensator, flatness, high-voltage switch, klystron, long-pulse modulator.

1. Introduction

Recently, long-pulse modulators have been popular as radio frequency power sources for klystron [1], [2]. The advances in high-voltage switching technologies enable the use of the high-voltage switch (HVS) type for the long-pulse modulators [3], [4]. Fig. 1 shows the configuration of a long-pulse modulator using a HVS and a droop compensator. It is required to produce a pulse of *-90*[kV]/*33*[A] with the pulse width of 1ms and the repetition rate of *200*[Hz]. The operation of this klystron modulator can be described using the charging and discharging modes of the HV capacitor bank. In the charging mode, the capacitor charging power supply (CCPS) charges the capacitor bank through a droop compensator. The HVS is off and there is no pulse at the output of modulator. In the discharging mode, the HVS is on and the HV capacitor bank partially discharges through the HVS tank to form the high-voltage pulse for the klystron.

2. High-voltage solid-state switch

The high-voltage switch is made up of hundreds of low-voltage switching devices in serial connection [4]. Fig. 2 shows the schematic of a 10kV MOSFET board controlled by a HVS drive board. The gate drive circuit generates a high-frequency bipolar waveform through the transformers of HVS board. The pulse shaping circuit forms the induced voltages of transformers into the gating control voltages of MOSFETs. These bipolar gating voltages provide the capability to drive MOSFET to a negative V_{GS} voltage for more robust and reliable off-state. The voltage balancing in series operation of switches can be attained by connecting the balancing resistors and snubber circuits in parallel with each device. The serial connection of ten HVS boards forms a *100*[kV]/*80*[A] high-voltage switch which is driven by only one gate driver board. This technology can eliminate the difference in the switching times between devices. Besides, the low-voltage gate drive circuit is well isolated from high-voltage switching boards in oil tank by enhanced insulating wires. The switching devices should be able to withstand high energy pulse, low on-state resistance, and fast switching times.

2. Arc energy limiter

The klystron could be destroyed by the sharp increase of the discharging current in case of arc [2], [5]. Hence, an arc energy limiter is used to protect the klystron by a circuit of an inductor, a diode and a dissipated resistor. The fast protection circuit detects an arc current and instantly sends the error signal to gate driver. The HVS is then turned off in response to disable the klystron to the capacitor bank. The arc limiter stores the discharging energy from HV capacitor into the inductor during the HVS turn-off time delay. Consequently, there is no arc energy transferring to the klystron. When the HVS is off, the stored energy in inductor dissipates in the resistor.

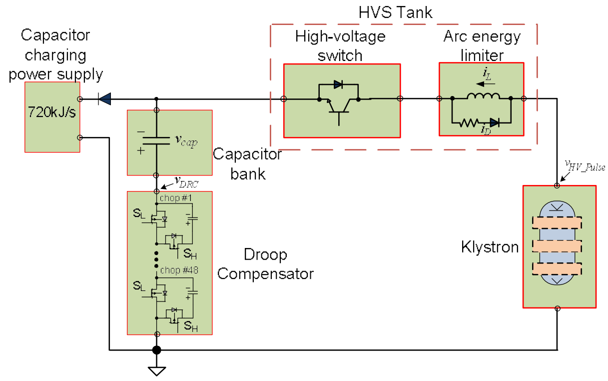

Fig. 1. The configuration of long-pulse modulator for klystron

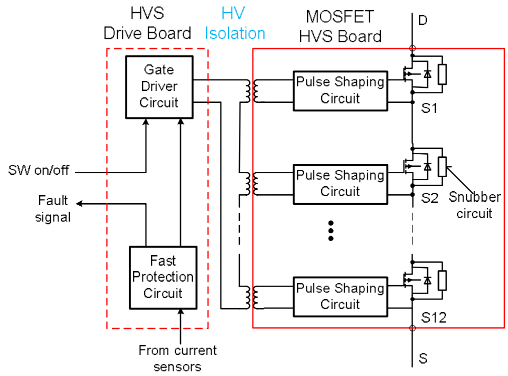

Fig. 2. The schematic of a 10kV MOSFET HVS unit

3. Droop compensator

As mentioned earlier, the HV capacitor discharges through HVS to the klystron causing a voltage droop in the capacitor. Consequently, there is a large reduction in the flat-top voltage of the output pulse. The droop compensator is proposed to compensate the voltage droop in the HV capacitor. It consists of 48 choppers connected in series. Each chopper includes a high-side switch S_H and a low-side switch S_L for controlling the charge and discharge process of chopper capacitors. The CCPS charges the droop compensator through high-side switches S_H to the full charge level at *65*[V]. Then the choppers are controlled to bypass through low-side switch S_L. When the pulse output is on, the droop compensator is controlled to add the chopper voltages to the pulse output. Hence,

TABLE 1
LONG-PULSE MODULATOR FOR KLYSTRON

Parameter	Value
Output voltage	-90 [kV]
Output current	33 [A]
Pulse duration	1 [ms]
Pulse frequency	200 [Hz]
Maximum arc energy	2 [J]
Compensated voltage	3120 [V]
Pulse flatness	0.1 [%]

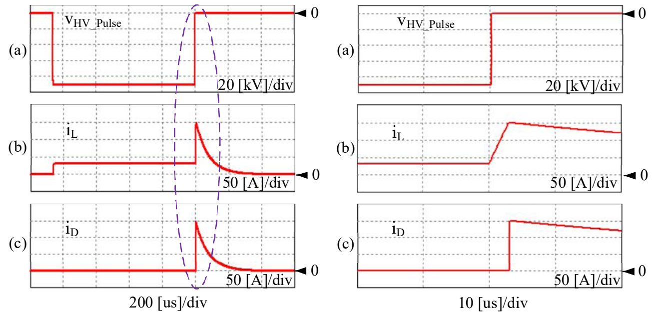

Fig. 3. Column 1: arc energy limiter; Column 2: zoom on of arc limiter (a) pulse output voltage , (b) inductor current, (c) dissipated current

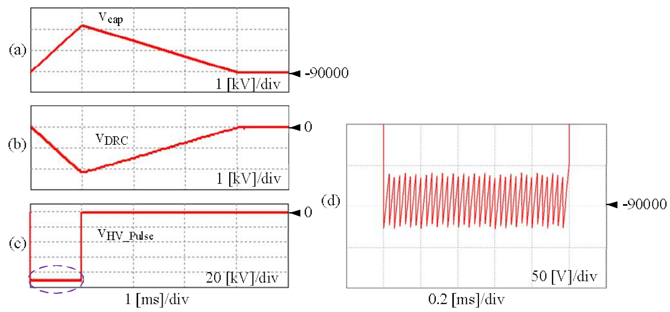

Fig. 4. Output waveforms of the klystron modulator (a) the capacitor bank voltage (b) the droop compensator voltage (c) the pulse output voltage (d) The flat-top voltage of the output pulse.

the klystron modulator accomplishes the flat-top voltage of output pulse.

4. Simulation Results

To illustrate the design process, the PSIM simulations have been executed for a long-pulse modulator for klystron. The system parameters are described in Table 1. Fig. 3 shows the principle of arc energy limiter and the response of the system in case of arc. The sharp increase of arc current is detected and the HVS is driven off in approximate *2.5*[us] later. The dissipated current flows through a diode in Fig. 3(c). Fig. 4 shows a *200*[Hz] pulse output of klystron modulator. Fig. 4(a) and Fig. 4(b) illustrate the droop voltage in the capacitor bank and the compensated voltage of the droop compensator, respectively. Fig. 4(c), (d) shows the flat-top voltage of pulse in 0.1% of ripple.

5. Experimental Results

Fig. 5 shows the experimental setup of the long-pulse modulator for klystron. The factory test of the full-scale system has almost completed. Fig. 6 shows a high-voltage pulse at the output of the long-pulse modulator for klystron without the droop compensator. The voltage of the output pulse is at *-90*[kV] in the duration of

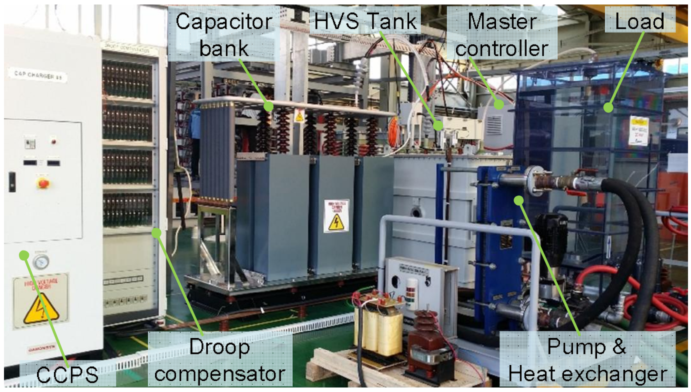

Fig. 5. Experimental setup

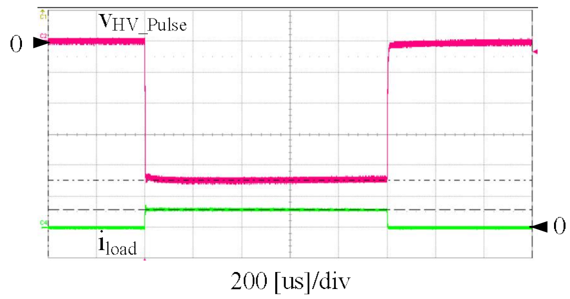

Fig. 6. The pulse output voltage and current in HVS test (a) v_{load}: the high-voltage pulse output (*20*[kV]/div) (b) i_{load}: the load current (*50*[A]/div)

1[ms] with the load current of *33*[A].

5. Conclusion

The paper has proposed a long-pulse modulator for klystron using a high-voltage solid-state switch and a droop compensator. The arc energy limiter has been applied to limit the discharging energy of HV capacitors into klystron in case of arc. The high performance of the output pulse is also achieved by the fast transition time and small flatness. The feasibility of the long-pulse modulator for klystron has been carried out by the simulation results. The experimental results of full system will be updated soon.

References

[1] M. Akemoto, H. Honma, H. Nakajima, T. Shidara, and S. Fukuda, "Long-pulse modulator for the superconducting RF test facility at KEK," in Proc. 16th IEEE Int. Pulse Power Conf., June. 2007, vol. 2, pp. 1044–1048.

[2] C. A. Martins, F. Bordry and G. Simonet, "A solid state 100kV long pulse generator for klystrons power supply," in Proc. 13th EPE Power Electron. and Application Conf., Sep. 2009, pp. 1–10.

[3] J. W. Baek, D. W. Yoo and H. G. Kim "High-voltage switch using series-connected IGBTs with simple auxiliary circuit," in IEEE Transactions on Industrial Application, vol. 37, no. 6, pp. 1832-1839, Nov./Dec. 2001.

[4] I.-H. Song, H.-S Ahn, Y.-K. Kim, H.-S Shin, C.-H.Choi and M.-H. Cho, "Development of the 120 kV/70A high voltage switching system with MOSFETs operated by simple gate control unit" in IEEE, June 2002.

[5] J. Bakken "Study and development of solid state based long pulse klystron modulators for future linear accelerator at CERN" thesis of the Norwegian University of Science and Technology, 2007.