DESIGN AND DEVELOPMENT OF PULSED MODULATORS FOR RF ELECTRON LINACS

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Abstract

Pulsed Modulators required for RF sources, based on klystrons and magnetrons, for RF electron linacs have been designed and developed at Electron Beam Centre, BARC, Mumbai, India. Electron guns in these linacs have also been powered by pulsed modulators. Line-type modulators, as well as IGBT-based solid-state modulators have been developed for these applications. A 150 kV/100 A line-type modulator has been tested on klystron to generate 7 MW peak RF Power. Magnetron modulator has undergone testing up to ~40 kV, 165 A on resistive load. Solid-state modulator, using fractional-turn pulse transformer has been designed, developed and tested successfully on magnetron load up to output power of 1.3 MW peak. A transformerless solid-state modulator for electron gun of 6 MeV cargo-scanning linac, uses the Marx adder configuration and has been successfully tested up to 40 kV. In addition, line-type modulators for electron guns up to 85 kV have been successfully commissioned and are in operation in the linac systems. This paper describes the salient design features of these modulators, development of pulse transformers, details of test set-up and discusses the test results of these modulators.

INTRODUCTION

Industrial electron RF linacs [1], including the 10 MeV RF Linac and 3 MeV DC Accelerator, have been indigenously designed and developed at Accelerator & Pulse Power Division, BARC, India. Several industrial applications such as plastic modification, semiconductor irradiation [2] have been demonstrated with these accelerators. 6 MeV and 9 MeV linacs as x-ray sources for cargo-scanning and radiography have been built and characterized. These linacs operate in the pulsed mode, which requires the use of pulse modulators for the RF source as well as the electron guns. The design, development, testing and operation of various pulse modulators is presented in this paper.

MODULATORS FOR E-GUNS

Electron guns [3], acting as injectors to RF linacs, are powered by modulators. The ratings of these modulators are rated from 40-85kV, with peak current ranging from 1-4A. Pulse width varies between 3-10µs, while pulse repetition rates lie between 250-400 Hz, depending upon the application for which the linac is used. Both line-type and solid-state modulators have been designed and developed indigenously. A brief description is given in this section.

Line Type Modulators

An indigenously developed 85 kV line-type modulator, shown in Figure 1, has been used in the 6 MeV linac [4] as x-ray source for cargo-scanning applications. This is rated for 4 A with 6 µs pulse width and 250 Hz repetition rate. A 10-stage PFN capacitor (72 nF total), shown in Figure 1, is charged resonantly through a charging choke of 20 H. Impedance of the PFN is kept as 50Ω in order to facilitate the use of coaxial cables between the primary circuit and the pulse transformer kept at a distance of ~20m, close to the gun. Hydrogen thyratron, rated for 18kV, acts as the switch, which causes the stored energy in PFN capacitors to discharge through the 1:20 pulse transformer to obtain 85 kV at its secondary.

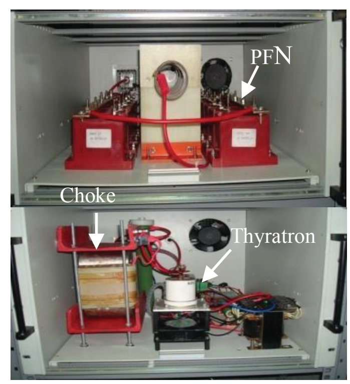

Figure 1: Primary circuit of 85 kV modulator

Solid-state Modulators

A transformerless solid-state modulator using the Marx adder configuration [5], has been designed, developed and tested. Figure 2 shows the 84-stage IGBT-based adder and the output of 40 kV, 10 µs pulse at 250 Hz rep.rate. Rise time achieved is <250 ns.

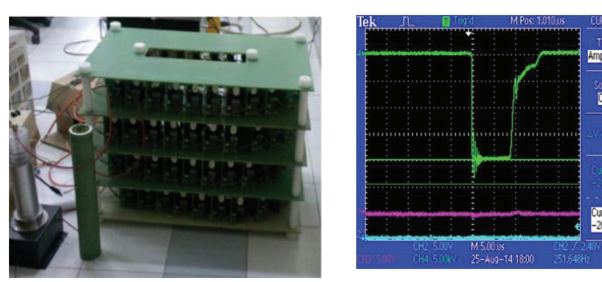

Figure 2: Marx adder (84-stage) and output of 40 kV on resistive load

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Another topology for solid-state modulator uses a single-stage IGBT-based system with a 1:90 pulse transformer, shown in Figure 3. A primary pulse of 1 kV is applied for obtaining an output pulse of 90 kV.

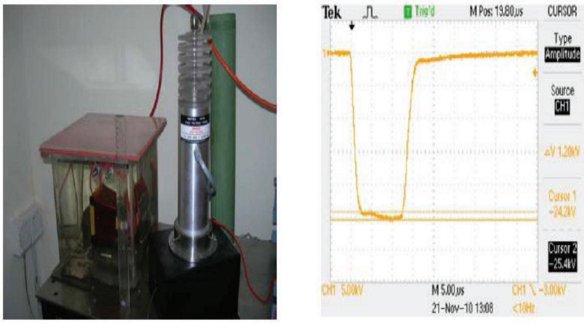

Figure 3: IGBT-based modulator with 90 kV output pulse

MAGNETRON MODULATORS

Magnetrons are used in the 6 MeV cargo-scanning linac as the RF Power Source. The magnetron requires 38kV/168 A for an output RF power of 3 MW (peak) at 250 Hz. A line-type modulator has been designed and developed. Output voltage of 38 kV with 4.5 µs pulse width has been achieved, as shown in Figure 4a, on a resistive load at 250 Hz. In this modulator, it has been configured that alternate pulses with different peak voltage can be produced with the help of 2 set-points for the charging voltage. This feature, required for dual operation of the linac at 6/3 MeV has been successfully implemented, as depicted in Figure 4b.

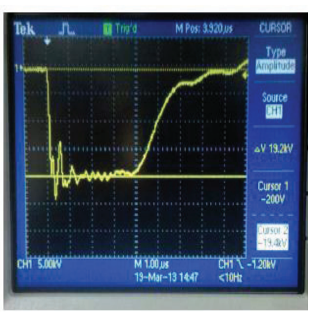

Figure 4a: Peak output voltage of 38 kV (rise time <350 ns)

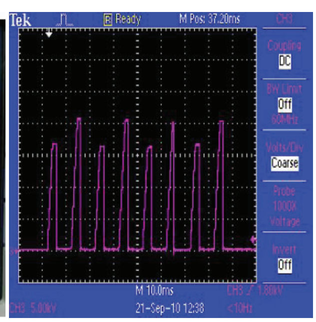

Figure 4b: Waveform showing alternate pulses with different peak voltages

A solid-state modulator, based on amorphous cut-C cores, has been designed, developed and tested for the same ratings as above. This modulator, based on 1 kV IGBTs with fractional-turn windings on the pulse transformer [6] is under testing presently. Figure 5 shows the output voltage of 30 kV and magnetron current of ~80A peak. Operation at 30 Hz has been achieved on a resistive load.

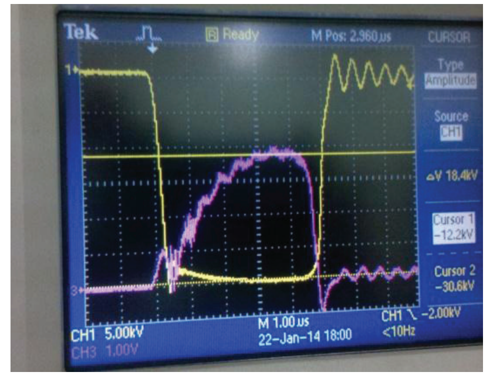

Figure 5: Output pulse of 30 kV (yellow) and magnetron current of ~80A (pink)

KLYSTRON MODULATORS

Pulsed modulators have been designed and built for both single-beam and multi-beam klystrons. A 150kV/110A/7µs/250 Hz line-type modulator [7], shown in Figure 6, has been successfully tested on the klystron load. The indigenously developed pulse transformer for this modulator is shown in Figure 7. Peak RF power of 7.5 MW has been achieved at the output of klystron, as shown in the waveforms of Figure 8.

Figure 6: Modulator with single-beam klystron on test

Figure 7: Pulse transformer (1:10.7) for 150kV/110A klystron modulator

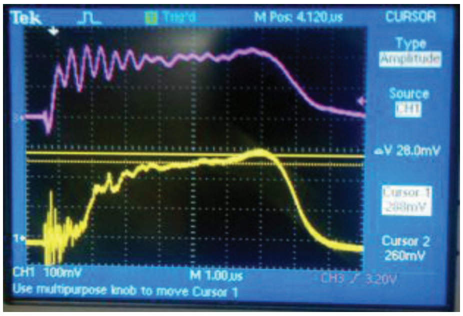

Figure 8: RF Output pulse of 7 MW & klystron peak current of 102A

In the 10 MeV Industrial linac system, an indigenously built 55 kV, 270 A, 10 µs, 400Hz line-type modulator with a multi-beam klystron as load, is in satisfactory operation for many years in the 10 MeV Industrial Linac system.

CONCLUSION

Indigenous design and development of line-type and solid-state modulators has been successfully demonstrated. Design standardization for production of line-type modulators for various linac systems is under way. Prototype solid-state modulators have been successfully developed and will be tested with their respective loads shortly.

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