MULTI GIGAWATT HIGH CURRENT PULSED ELECTRON ACCELERATOR TECHNOLOGY DEVELOPMENT PROGRAM AT BARC

Archana Sharma, Romesh Chandra, S. Mitra, Sandeep Singh, Vishnu Sharma, K. Senthil, Ankur Patel, S. R. Ghodke, A. Roy, P. C. Saroj, Ritu Agarwal, T. S. Kolge, Hitesh Choudhary, Ranjeet Kumar, M. Danish Beg, K. C. Mittal and L. M. Gantayet[1]
Accelerator and Pulse Power Division, Bhabha Atomic Research Centre, Mumbai India-400085
[1]Beam Technology Development Group, Bhabha Atomic Research Centre, Mumbai India-400085

Abstract

High current intense electron beams were investigated earlier for Flash X-rays and nuclear electromagnetic pulse generation. Starting with moderate parameters of 200 kV, 6 kA, 60 ns pulsed electron beam source from a system named Kilo Ampere Linear Injector (KALI-75) our latest development is KALI-30 GW system rated for 1 MV, 30 kA, 80 ns.

First repetitive pulse LINAC without spark gap switching was developed as Linear Induction Accelerator (LIA-200) for technology demonstrations at 100 Hz. Also a repetitive Marx generator coupled reflex triode system to operate at 10 Hz. Next to this series of development LIA-400 has been developed to a capacity of 400 kV, 4 kA, 100 ns, 300 Hz. To make these pulse power systems applicable for big LINAC projects like nToF studies or ADS program, a high current electron gun has also been developed to give 100 A, 2 ns,10 Hz pulses.

INTRODUCTION

High current intense electron beams were investigated earlier for fusion related studies followed by high power microwaves (HPM), Flash X-rays (FXR) and nuclear electromagnetic pulse (NEMP) generation. In these systems, relativistic electron beams (REB) are produced by high voltage pulse power systems terminated to a suitable electron gun diode. In changing global scenario, numerous applications of repetitive pulsed power systems have been experimentally demonstrated to meet industrial and inter-disciplinary R&D activities.

KALI SYSTEMS

The design and development of high voltage pulsed electron accelerator program in Bhabha Atomic Research Centre has been initiated in early 1970s. Starting with moderate parameters of 200 kV, 6 kA, 60 ns pulsed electron beam source from a system named Kilo Ampere Linear Injector (KALI)-75. Latest development is KALI-30 GW system rated for 1 MV, 30 kA, 80 ns. During this development many involved technologies were developed viz. Compact pulse transformers (air core and amorphous core based), Unipolar and bipolar Marx generators, to create impulse from DC charging. For shaping the output pulse across the load, various kinds of pulse forming lines (PFL) such as castor oil/transformer oil or demineralized (DM) water filled coaxial PFL, Blumlein and strip forming lines have been adopted. For efficient energy transfer and low rise time (<10 ns), fast switching of 100s

Figure 1: KALI 30 GW System.

of kV and 10s of kA current, solid state switches cannot be utilized. Hence coaxial high pressure spark gaps and trigatron electrodes are implemented. During system development, in-situ pulsed diagnostics for the measurement of fast rising current using self integrating Rogowski coil were developed and for voltage measurements aqueous voltage dividers from 100s of kV to a few MV regimes were developed. In APPD, BARC single shot systems are developed in successive up gradation of output peak power of these KALI systems with a suffix of pulse energy in joule such as KALI-75 J, KALI-200 J, KALI-1000 J and KALI-5000 J. All these systems were based on spark gap switches and interval between two pulses is 5-10 minutes [1, 2]. It is very critical to control pre-pulse by choosing appropriate design [5] to generate REBs of desired parameters [6]. The KALI 30 GW system image is shown in Fig.1. Figure 2 shows the output voltage and current pulse of KALI 30 GW system.

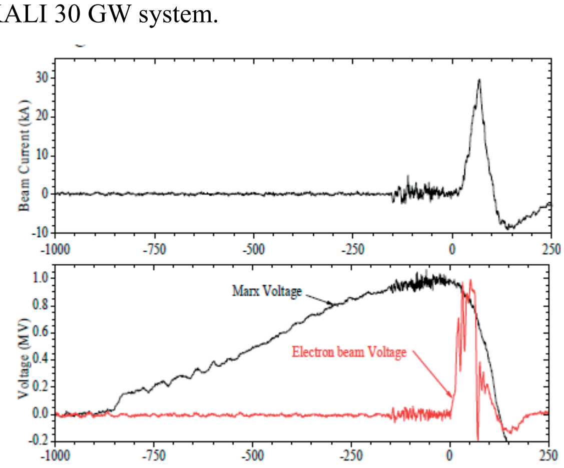

Figure 2: Electron beam current (above) and Marx voltage and Diode Voltage for KALI 30 GW system.

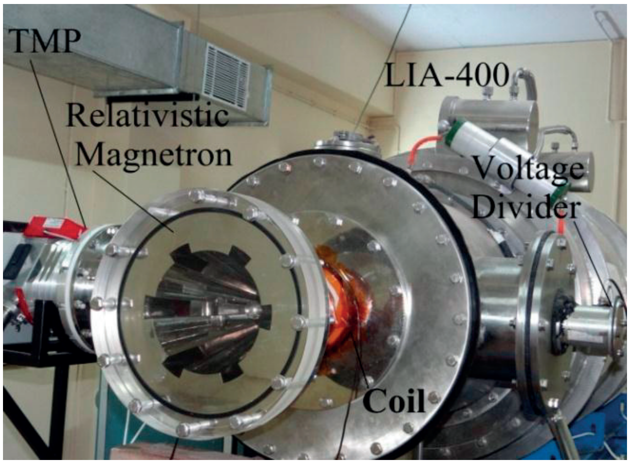

Figure 3: LIA 400 System with Relativistic magnetron

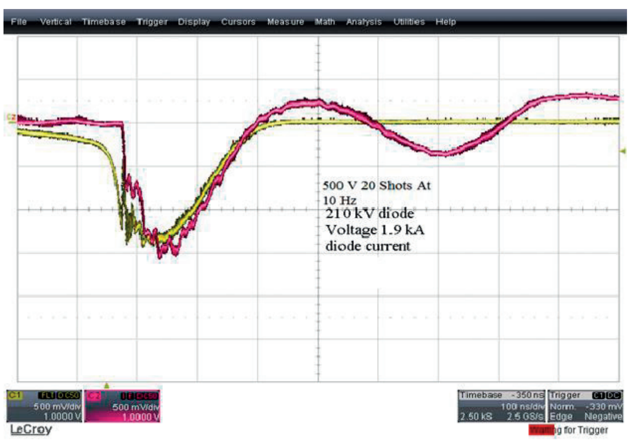

Figure 4: LIA 400 operation at 10 Hz repetition rate.

HIGH REPRATE SYSTEMS

With the invention of new dielectric materials for high energy density capacitors, special amorphous cores forpulse transformers and magnetic pulse compression based topologies systems have been made on a mobile platform with higher repetitive pulsed operation. The first repetitive pulse LINAC without spark gap switching was developed in early 2000 as Linear Induction Accelerator (LIA)-200 for technology demonstrations with a rating of 200 keV, 5 kA, 100 ns, 100 Hz [3]. It has been used for learning behaviour of new solid state capacitor charging power supplies, magnetic core application for pulse transformers, pulse compression, switching and inductive voltage adder configuration for voltage multiplications. This system is used for various R&D in cathode materials to get higher emission current. In this system two water capacitors and a water pulse forming line with isolated induction cavities in inductive voltage adder (IVA) configuration) is used, it worked well at a cost of size and additional auxiliaries. Next to this series of development is LIA-400, which has more compact packaging with solid insulated strip forming line and parallel combinations of energy storage capacitors to achieve low inductance and thinner amorphous ribbons in core to reduce losses. This system has been developed and tested to its full capacity of 400 kV, 4 kA, 100 ns, 300 Hz. An image of LIA-400 system with Relativistic Magnetron as a load is shown in Fig. 3. A voltage current waveform at 210 kV, 1.9 kA at 10 Hz rep rate is shown in Fig.4. With the development of all these pulsed LINACs, wide areas of research were nurtured in the department for variety of nuclear and industrial applications.

APPLICATIONS

The Pulse power systems are basically used for High Power Microwave (HPM) generation and radiography experiments. The applications can be thus broadly divided into two parts,

HPM Applications

For HPM generation, Vircator are considered as the simplest device. The HPM propagation at the distant objects and its effects on various electronics circuitry were studied. In order to increase the electron beam

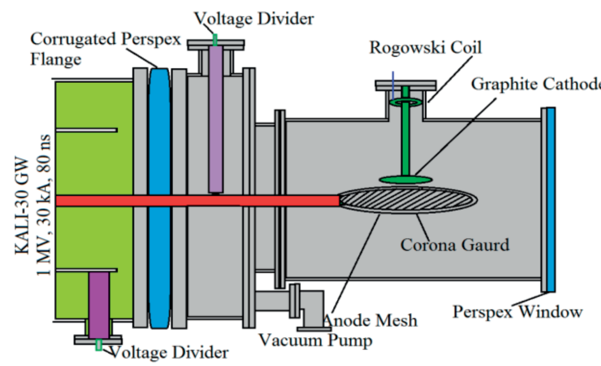

Figure 5: The schematic of a reflex triode Vircator.

to microwave conversion efficiency, in-depth investigations were done on axial Vircator, coaxial Vircator, reflex triode and recently axial magnetron with LIA-400. Among these devices the Magnetron has shown the best results. To measure the transmitted electromagnetic pulses field and power measurement in

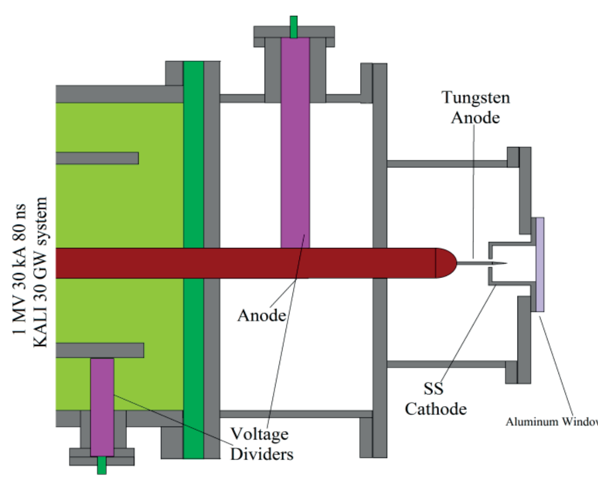

Figure 6: The schematic diagram of a FXR diode.

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different modes and their inter-conversions are also part of ongoing research. Higher electrical to beam conversion efficiency, then from beam to HPM conversion efficiency is the real challenge at higher power levels (>100MW). Fig.5 shows a schematic of reflex triode Vircator.

FXR Generation

In conventional X-ray sources, many high voltage 100 keV-10MeV low beam current X-rays sources are available but they have limitation of low prompt dose and they cannot capture a dynamic even like defect in a moving turbine blade or magneto dynamic studies to know the status of the object or detect any defect [4]. To produce higher X-ray dose with high voltage and kilo amperes of electron beam current from cathode to a high Z-target in industrial pinch or Rod pinch have been studied using these pulsed LINACs[7, 8]. Figure 6 shows a schematic of FXR diode on KALI 30 GW system. In Fig.7 a comparison of the radiographs taken by Neutron radiography and Flash radiography done at KALI 30 GW system is shown.

CONCLUSION

A range of systems (50 kV to 1 MV and 100 A to 30 kA) have been developed in BARC. It has been noticed that low impedance systems are more suitable for the HPM generation through Vircator devices and FXR application needs high impedance system. But for the new complicated types of devices like Relativistic magnetrons, Backward wave oscillators high impedance (>100 ohm) systems are preferred, thus in future our focus will be on the development of high impedance systems only.

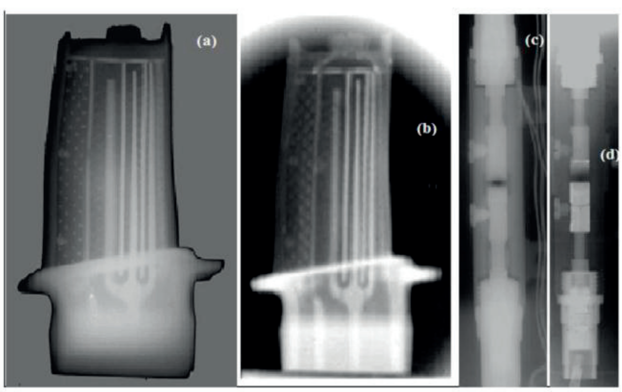

Figure 7: Radiography images of (a) turbine blade recorded by FXR and (b) by neutron radiography, (c) INSAT cable cutter with FXR and (d) with neutron radiography.

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REFERENCES

[1] Amitava Roy et al., “Intense Relativistic Beam Generation and Pre-pulse Effect in High Power Cylindrical Diodes”, Journal of Applied Physics 103, 014905, 2008.

[2] Maenchen, G. Cooperstein, J. O’Malley, and I. Smith, “Advances in pulsed power-driven radiography systems,” Proc. IEEE, vol. 92, no. 7, pp. 1021–1042, Jul. 2004.

[3] D. D. P. Kumar et al. “Characterization and analysis of a pulse power system based on Marx generator and Blumlein,” Rev. Sci. Instrum., vol. 78, no. 11, pp. 115 107-1–115 107-4, Nov. 2007.

[4] Archana Sharma et al. “Development and Characterization of Repetitive 1 kJ Marx Generator Driven Reflex Triode System for High Power Microwave Generation”, IEEE Transactions on Plasma Science. Vol. 39, No. 5, pp. 1262-1267 May 2011.

[4] C. Ekdahl, “Modern Electron Accelerators for radiography”, IEEE-PS, Vol.30, No.1, Feb.2002; pp.254-261.

[5] Amitava Roy et al. “Intense Relativistic Beam Generation and Prepulse Effect in High Power Cylindrical Diodes” Journal of Applied Physics 103, 014905, 2008.

[6] Y. Zhang et al. “Simple Solutions for Relativistic Generations of the Child-Langmuir Law and the Langmuir-Blodgett Law”, Physics of Plasmas 16, 044511, 2009.

[7] Rakhee Menon et al. “Generation and Dose Distribution Measurement of Flash X-ray in KALI-5000 System Review of Scientific Instruments, 79, 103301 (2008).

[8] Akhtar M. Shaikh, 18th World Conference on Non-destructive Testing, *www.ndt.net /article/ wcndt 2012 papers/646_wcndtfinal 00647.pdf*