DEVELOPMENT OF POWER SUPPLIES FOR 3-Φ, 240 KW RF SYSTEM WITH CROWBAR PROTECTION FOR SUPERCONDUCTING CYCLOTRON AT VECC

S. K. Thakur*, T. P. Tiwari, J. S. Prasad, A. De, Y. Kumar, S. Som, S. Saha, R.K. Bhandari
Variable Energy Cyclotron Centre, Kolkata, India.

Abstract

RF system of K-500 Super-conducting Cyclotron at VECC is a complex three phase system operating in the frequency range of 9 MHz to 27 MHz with maximum acceleration potential of around 100KV feeding to each of three Dee cavities placed in median plane of cyclotron 120º apart through coupling capacitors. Each phase consists of chain of amplifiers and resonator operating in synchronization and at final stage of each phase, high power water cooled Tetrode Tube (Eimac4CW150,000 E) is used as high power amplifier each capable of delivering 80 KW of RF power. Individual power supplies for biasing Anode, Filament, Grid and Screen for all three high power Tetrode Tubes are designed and developed in house. Anode supply is common to all three tubes, rated at 20KV, 22 Amp, 450 kW along with fast acting crowbar protection using Ignitron. All these power supplies are commissioned and have been in operation for more than one year successfully. This paper describes about the technical aspects of the power supplies for RF Amplifier Tubes and special features of protection systems.

INTRODUCTION

For three RF amplifiers, which uses Tetrode Tube (Eimac 4CW 150,000E), three set of power supplies each for Filament (15.5V, 215A), Grid (-500V, 0.1 A), Screen Grid (1600V, 0.5 A) and a common power supply (20KV, 22 Amp) for Anode are designed and developed in house. Each of the power supplies are equipped with control and monitor systems with Local/Remote control facility, power switchgear with interlocking, protective systems etc as shown in Fig-6. A PLC system is interfaced with individual power supplies by which each power supplies can be controlled as well as interlocking and monitoring of parameters can be done in Remote mode of operation.

FILAMENT POWER SUPPLY

A variac controlled, voltage regulated power supply with a regulation of ± 1%. This consists of a step down 3-ph transformer with full bridge rectifier followed by a filter. A control circuit added with variac auto zero and soft start feature in the power supply adjusts the variac, corresponding to its set value. The input 415V, 50 Hz, 3-ph ac supply ramps up in steps through variac from zero to around 80% voltage corresponding to output 15.5 V dc in approximately 3 minutes. Soft start is an added feature to limit the filament current during cold condition. Heater current is approximately 210 A corresponding to 15.5 V.

*thakur@vecc.gov.in

GRID POWER SUPPLY

It is a series regulator type power supply that uses IGBT as series element for voltage regulation as shown in Fig-1. A low ripple and highly regulated power supply with adjustable voltage which ranges from -200 V to -500V for setting the Grid biasing of amplifier.

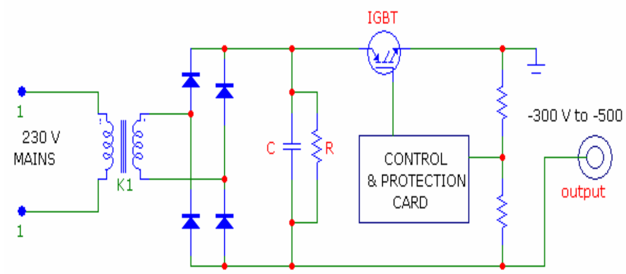

Fig-1: Schematic of Grid Power Supply

SCREEN POWER SUPPLY

Screen Grid power supply (1600V, 0.5 Amp, 60 ppm) is a series regulator type which uses water cooled tetrode tube (Eimac 4CW2000) as regulating element connected in common cathode mode. Three individual regulator tubes with their respective circuitry are used except their common anode voltage which is kept at around 2500Vdc. Part of output voltage is sampled and fed back to an error amplifier which ultimately drives the transistor for adjusting Grid biasing of series regulator tube as shown in Fig-2. A very stable power supply with very low ripple voltage is designed and developed along with fast crowbar protection feature which is initiated by either main anode crowbar as well as screen over current.

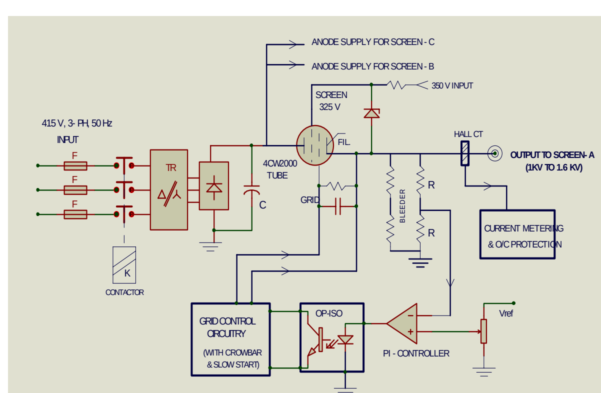

Figure 2: Schematic of Screen power supply.

Tube may exhibit reverse screen current depending upon the operating condition which may lead to high plate current. In order to suppress this problem, adequate amount of bleeder resistance is used. Suitable interlocking facility such as water, main Anode ON, phase fail etc are employed along with crowbar and over current (reverse / forward) in each power supply. Output voltage and current is monitored by individual hall CTs and being displayed at Local control panels as well as in control room.

ANODE POWER SUPPLY

All three High Power Amplifiers (HPA) are powered by a single Anode power supply rated at 20 kV, 22 Amp (Fig.-3). EHT uses two high power transformers, each 250KVA, 415V / 3700V & 3700 V rating, forced air cooled whose primary connected in delta and secondary connected in star & delta for 12 Pulse mode output. The 3-ph power system is connected to each of two transformers via air core choke in each line and fast interrupting circuit breaker. “Siemens” make circuit breakers are used which disconnects from mains ac lines within 4-5 cycles. Chokes are employed to restrict input line current in the event of crowbar or short circuit.

A primary SCR based soft start feature is added in one transformer in order to reduce inrush current. In second transformer, a primary online voltage regulating oil cooled motorised Variac is used to adjust output voltage from 10KV to 20 KV. Forced air cooled 3-Ph full wave bridge rectifier assembly is used in each of four secondaries of both Transformers. Each rectifier assembly gives output 5 KV dc connected in series making a 20 KV dc voltage with ripple frequency 600 Hz. A capacitor filter is used to smoothen output ripple.

Various protection like over-voltage, over current, phase failure, thermal overload, over temperature, spark/arc protection have been incorporated in this power supply. Various fault conditions were simulated in this power supply and all above-mentioned protection features were checked reliably before putting with actual load.

RF and microwave tubes are prone to internal arc that can lead to a permanent damage if excessive energy is dissipated. So, a shunt diverter topology was chosen in which stored energy in electrical system is diverted to the ground by quick shorting the output terminals of power supply through Ignitron (NL7703) as a Crowbar switch followed by tripping of mains Circuit Breakers. Internal arcing in the tube is a common phenomena which depends upon operating conditions. Thus crowbar protection is the most critical part in the power system used for the protection of high power very expensive RF and microwave devices. Three final power amplifier Tubes which feed RF power to 3 nos of main cavities placed in the cyclotron through individual coupling Capacitors and quarter wave coaxial transmission line in each halves. Thus HPA is main constituent of RF system which needs to be protected reliably through a Mercury filled Ignitron (NL7703). The Crowbar switch system should meet following requirements:-

Operating voltage:- 20 KVdc
Full load current :- 22 Amp
Peak current :- 900 A (during discharge)
Stored Energy in filter capacitor :- 6000 Joule
Energy transfer per shot < 50 Joule
Operating time :- < 5 μsec
CB tripping time :- 0.15 sec
Charge transfer :- < 1 Coulumb.

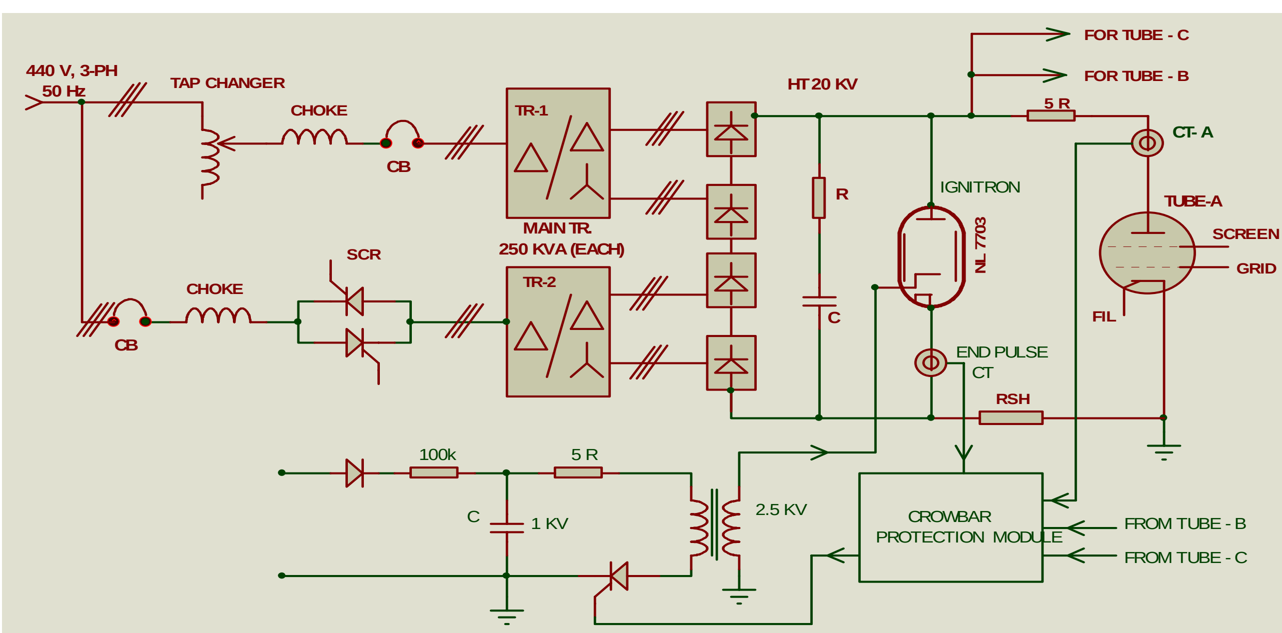

Figure 3: Schematic of Anode Power Supply (20 KV, 22 Amp) with Ignitron Crowbar Protection scheme.

Summary of Measurements

Crowbar system performance was thoroughly tested at various voltage level and ultimate protective capability is performed by wire survivability test. The wire provides an approximately calibrated measure of energy deposition for fusing. As per the manufacturer, the energy deposition in tube should be limited to less than 50 Joule during a fault. Empirical test result with a 6 inch long piece of 30 AWG copper wire indicates almost same energy deposition for fusing.

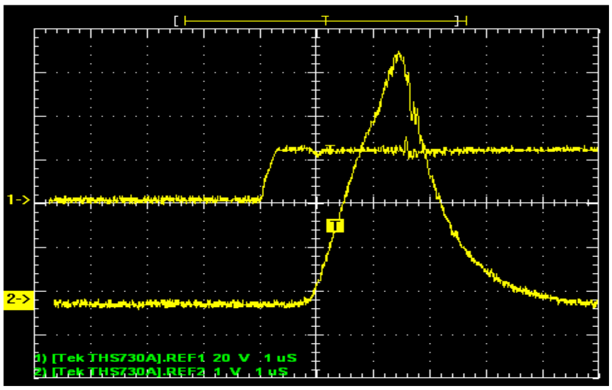

Figure 4: Crowbar measurement, Ch-1-Fault current & Ch-2 Trigger signal to Ignitron and time delay around 3 µs.

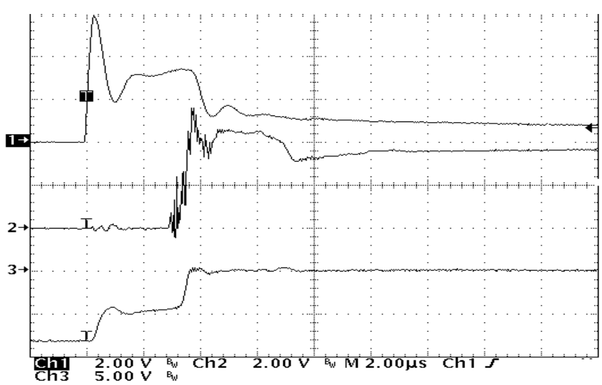

Figure 5: Fault current (ch-1), Crowbar current(ch-2) sensed by pearson CTs (1V=100 Amp) and Load Voltage (ch-3) 5V=10KV.

To conduct the test, a high voltage relay is connected in series with the wire and connected across the output terminals of the power supply. The fault is initiated by closing the relay and wire survival test was performed. The current flowing through the wire is sensed by the fast acting Pearson CTs. The signal is sent to the fault processing circuitry which issues the triggers signal to the Ignitron and finally main CBs opens. Fig-4 shows that a trigger signal is generated within 3 µs. Fig-5 shows the output voltage comes to zero within 4 µs when Ignitron fires. For reliability, this test was performed several time for few days and not a single time wire was blown.


Figure 6: Anode Transformers & Local Control Panel showing monitoring, fault indications & controls.

Challenges and Experience

During the design & development of such a high power system at high voltage, a reliable and robust protective Crowbar system became the most significant challenge. Initially wire survivability test could not pass even at lesser voltage. Noise & grounding problems creates spurious triggering & delayed response time as well. Then with modified protection system hardware architecture, final crowbar circuitry was designed and proper layout of switch assembly, system response time was improved after 2-3 attempts and subsequently wire survivability test could pass.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Amiya Mitra, TRIUMF, Vancouver, Canada for his valuable guidance. The authors would also like to thank each and every Technical staffs of HVPS Section, VECC for their sincere effort for the development & installation of power supplies for RF system successfully.

REFERENCES

[1] A. K. Mitra, "Measurements of Crowbar Performance of the 20 kV, 130 A dc Power Supply of the TRIUMF rf System" IEEE, 1991.

[2] S. G. E. Pronko and T. E. Harris, "A New Crowbar System for the Protection of High Power Gridded Tubes and Microwave Devices". IEEE Int. Vac. Elec. Conf., 2001.

[3] Eimac 4CW150,000E data sheet, published in May, 1983.

[4] Richardson Electronics application notes for Ignitron mounting and maintenance.

[5] Various VECC reports and News Letters published in VECC.

[6] S. Som, Dr. R. K. Bhandari, "Development of RF system for K-500 Cyclotron" presented in 18th International conf. on Cyclotron and their applications.