52 KV POWER SUPPLY FOR ENERGY RECOVERY LINAC PROTOTYPE RF

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Abstract

Daresbury Laboratory is constructing a Radio-Frequency (RF) Test Facility to be capable of testing RF cavities for accelerator applications. Electrical power for the RF equipment will be provided from an existing -52 kV 6-pulse rectifier and transformer system capable of delivering 16A DC continuous current. A crowbar circuit will be provided to divert the large amount of stored energy in the smoothing capacitor bank in the event that a spark should occur between the cathode and the body or modulating anode of the klystron. Traditionally, crowbar protection has been provided by ignitrons, but modern solid state devices have sufficient performance to meet the requirements. This paper discusses the numerous design options that were considered for the circuit parameters.

INTRODUCTION

A RF test facility is under construction at Daresbury Laboratory, UK, for the Energy Recovery LINAC Prototype (ERLP), and the EU test cavity and other high power RF structures.

The ERLP project has been described in a previous publication [1]. The purpose of the ERLP is to demonstrate the technology required to develop and build the proposed 4th Generation Light Source (4GLS). In the case of the ERLP, the source of RF power is a bank of 3 Inductive Output Tubes (IOTs), connected to a 25-30 kV d.c. voltage source. The IOTs are connected in parallel on the h.v. side but feed different RF structures at 1.3 GHz.

The EU cavity project is to develop a higher order mode (HOM) damped cavity that could be used as an upgrade to any of the existing European light sources. In this case, the source of RF power is a single super-power klystron, connected to a 50 kV d.c. voltage source. In addition to the EU cavity project, the klystron could be used with other high power structures operating at up to 500 MHz.

The d.c. power supply has been provided to meet both of these requirements. It has been specified to supply 0 - 16 A at 7 - 52 kV.

POWER CONVERTER OPTIONS

There were two options available for meeting the power converter requirement.

Option 1: Purchase of a new power converter. This would be based upon switched mode technologies and would be versatile enough to deliver the required current and voltage with low ripple and low stored energy. A typical switched mode power converter able to deliver the required output would cost approximately € 750,000.

Option 2: Refurbishment of an existing power converter. In 2002, the 50 kV power converter for the klystron amplifier used in the Synchrotron Radiation Source (SRS) RF system was replaced by a modern switched mode unit. The power supply had become unreliable with spurious firing of the ignitron based crowbar circuit and difficulties with maintaining and faultfinding of the relay based control circuit. There were environmental issues regarding the polychlorinated biphenyl (PCB) filled capacitors, the asbestos resistor mats, and the mercury filled ignitron crowbar. The major components; the transformer, roller regulator, rectifier and smoothing inductor were in good condition and had very reliable operation when used on the SRS. It would be necessary to replace the capacitors, resistors and crowbar device; and the major components would require transporting a distance of 600 metres to the site of the RF test facility. After reviewing the two options, it was concluded that the second option offered the most cost effective solution.

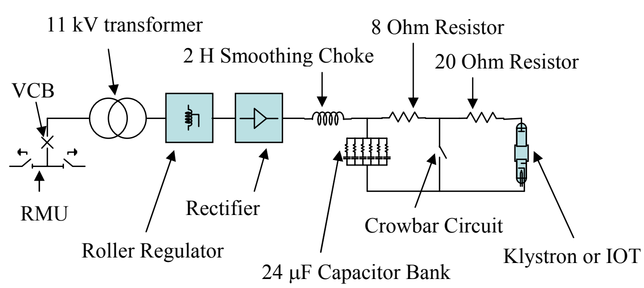

Figure 1: Block diagram of power converter

Design considerations

The transformer, roller regulator and rectifier converts the 11 kV mains to a d.c. voltage between 7 kV and 52 kV. A 2 H smoothing choke is integrated within the rectifier unit. It provides the necessary attenuation of the ripple and reduces the fault current.

The capacitor bank smoothes the output from the rectifier stage; the higher the value of capacitance, the smaller the output d.c. ripple. The chosen value of 24 µF results in a peak to peak ripple of 35 V which is approximately 0.7% of the d.c. value.

When the power supply is operational, the smoothing capacitance stores energy according to $E = \frac{1}{2} CV^2$. The total stored energy is 32 kJ. Some form of high speed protection is required to divert the stored energy into another part of the circuit in the event of a spark occurring between the cathode and the body or modulating anode. The crowbar performs this task. The fault current flowing through the klystron will trigger the crowbar and operate the vacuum circuit breaker (VCB) on the primary side of the 11 kV transformer.

CROWBAR SPECIFICATION

Crowbar Technologies

Since the design of the SRS's original ignitron crowbar in 1983, several new technologies have emerged.

Air gap - These consist of metal electrodes mounted on ceramic insulators in a metal enclosure. These have the ability to operate over the full range of voltage from zero to 52 kV, and the risk of spurious misfiring is low. However, the electrodes' exposure to the atmosphere results in oxidation and corrosion over time.

Thyratron - These devices can be triggered at low voltages like the air gap, but they have a tendency for spurious operation. They are expensive to replace and require heaters and complex control circuits.

Series connected thyristors - These devices consist of a number of thyristors connected in series. They require very precise firing pulses as even slight differences in the operation times can lead to large voltage transients. The voltage across the device is minimal, leading to very little energy loss within the actual crowbar.

Gas discharge tube - These devices are hermetically sealed ceramic tubes containing a suitable gas such as deuterium, neon or argon. They are extremely rugged and durable.

After evaluation of the different technologies, it was decided not to specify a particular technology but to invite tenders from manufacturers based upon performance criteria. Following the tender exercise, a contract was placed with a manufacturer to supply a thyristor based crowbar.

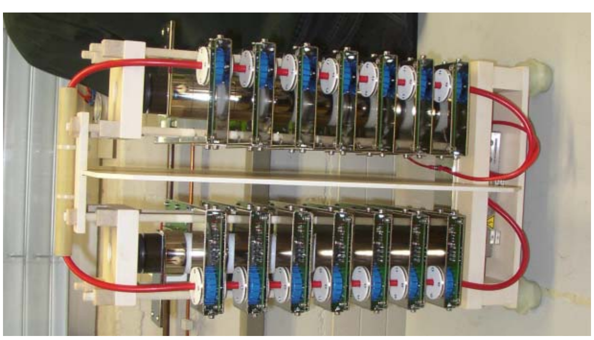

Figure 2: Thyristor based Crowbar

Crowbar operation time

The current in the klystron during a fault and the operation of the crowbar and VCB have been modelled using MICROCAP software, based upon a assumed klystron fault impedance of 1 Ohm. In order to protect the klystron or IOT, it is necessary to limit the fault energy to 10 - 20 J depending upon amplifier type.

The fault energy is determined by the d.c. voltage and the crowbar firing time. In the case of the maximum voltage, 52 kV, the energy dissipated is related to the crowbar operation time by the following graph.

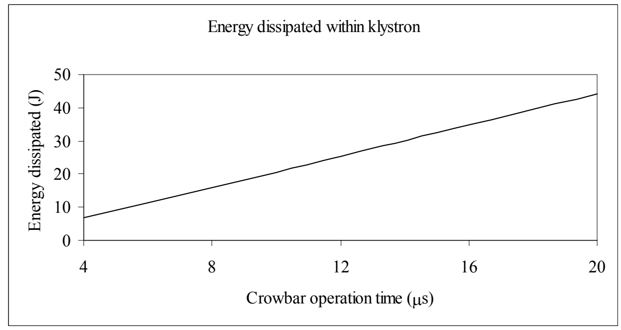

Figure 3: Energy dissipated within Klystron

From these results, the crowbar must operate within 8 μs to limit the fault energy to 20 J. To limit the fault energy to 10 J, the crowbar must operate within 5 μs, or the d.c. voltage must be reduced.

The crowbar operation time is made up of two components, fault detection, and crowbar firing. The original SRS system used voltage detection, but this was subject to transients and noise. It is now proposed to use current detection. Test results of the crowbar using one of the proposed current transformers show that the overall crowbar operation time is 5.5 μs.

Crowbar peak current and energy

The peak current flowing through the crowbar is dependent upon the charging voltage, and the resistors in the circuit. The choice of resistors is made to limit the current in the event of a fault but not to generate excessive losses during normal operation. The charge flowing through the crowbar is dependent upon the size of the capacitor bank and the VCB operation time. With valve or gas discharge type crowbars, a maximum charge flow is specified and is typically 50 Coulombs. With solid state crowbars such as the one being installed with this facility, the limiting factor is energy dissipated rather than charge flow. In both cases, the major parameters of concern are the d.c. voltage, the VCB operation time and the value of the smoothing capacitance.

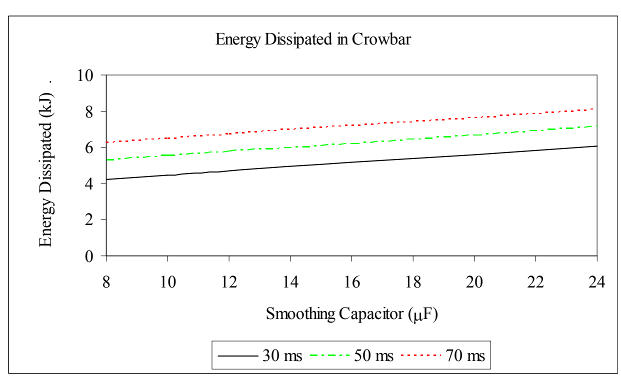

Figure 4: Energy Dissipated in Crowbar

CROWBAR OPERATION WAVEFORMS

The following graphs show the current waveforms during a klystron fault obtained from the MICROCAP simulation. The following timings are simulated:

0.0 µs: Klystron fault occurs
10.0 µs: Crowbar operates
70.0 ms: Vacuum Circuit Breaker (VCB) opens

0-100 µs after fault

The crowbar interrupts the current through the klystron during the discharge of the capacitor bank

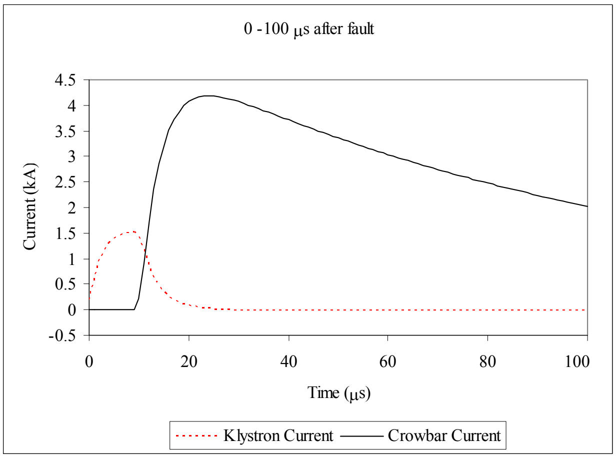

Figure 5: Current waveforms 0-100 µs after fault

0-10 ms after fault

The crowbar current reaches a minimum following capacitor discharge and rises again as it starts to pass current from the power converter through the large 2 H filter inductance.

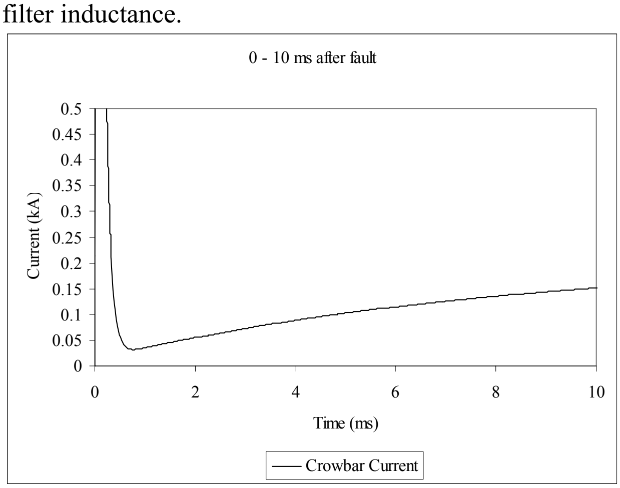

Figure 6: Current waveform 0-10 ms after fault

0-400 ms after fault

The power converter sees a short circuit due to the crowbar operation. The current rises through the smoothing inductance until the VCB opens and then decays through the smoothing choke and diodes in the rectifier bridge.

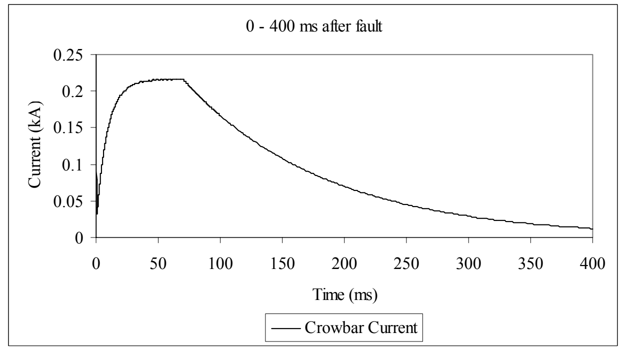

Figure 7: Current waveform 0-400 ms after fault

Parameters

Klystron / IOT peak fault current	1.54 kA
Crowbar peak current	4.6 kA
Crowbar energy dissipation	6.1 kJ
Crowbar follow through charge	39.3 C
Resistor energy dissipation	66 kJ

CONCLUSIONS

A modern crowbar based upon solid state technology and replacement capacitors and resistors will give a new lease of life to the former SRS klystron power supply and provide Daresbury Laboratory with a major new facility for RF testing and a cost effective power source for the ERLP project.

Operational tests on the crowbar will be carried out to confirm the accuracy of the simulated results in the near future.

REFERENCES

[1] M.W.Poole, S.L.Bennett, M.A.Bowler, N.Bliss, J.A.Clarke, D.M.Dykes, R.C.Farrow, C Gerth, D.J. Holder, M.A.MacDonald, B Muratori, H.L.Owen, F.M.Quinn, E.A.Seddon, S.L.Smith, V.P. Suller, N.R.Thompson, I.N.Ross, B McNeil, "4GLS: A New Type of Fourth Generation Light Source Facility," PAC 2003

[2] A.J.Moss, R.J.Smith, S.A.Griffiths, "Upgrade of the SRS Klystron Power Supply", PAC 2001