

# 10HZ PULSED POWER SUPPLIES AND THE DC SEPTUM POWER SUPPLY FOR THE ISIS SECOND TARGET STATION (TS-2)

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## Abstract

The Extracted Proton beamline for the ISIS second target station has two 10Hz pulsed magnet systems and a DC Septum magnet system which extract the protons from the existing 50Hz beamline. The pulsed Kicker 1 magnet system deflects the beam 12.1mrad, pulsed Kicker 2 deflects the beam 95mrad and the DC Septum magnet system deflects the beam 307mrad. This paper describes the topology, installation, testing and successful operation of each of the power supplies.

## INTRODUCTION

ISIS, Figure 1, sited at the Rutherford Appleton Laboratory (RAL) is one of the world's most intense pulsed neutron sources. Intense bursts of neutrons are produced at 20mS (50Hz) intervals when a heavy metal target is bombarded by a high-energy (800MeV) proton beam from a synchrotron accelerator releasing neutrons by the process of spallation. A second target station (TS-2) has been constructed. TS-2 provides a 10Hz beam for 7 day 1 instruments with provision for a further 11 instruments. The 10Hz proton beam is achieved by operating two slow pulsed magnets and a DC septum magnet to extract the proton beam from EPB 1 to TS-2 Extract Proton Beam line (EPB). The TS-2 EPB, 149 metres long, has 56 magnets and their associated power supplies to produce magnetic fields for the beam optics. The power supply ratings range from 1.5kW to 160kW with one 680kW DC septum power supply and the two 10Hz pulsed power supplies.

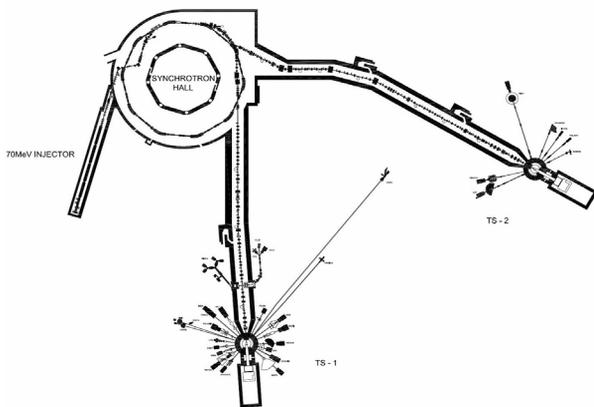


Figure 1: ISIS Layout.

## 10HZ PULSED POWER SUPPLIES

The pulsed power converters and the kicker magnets (the same magnet design was used for each kicker system) were designed and manufactured by Danfysik AS in Denmark. They provide a half sine wave current profile with a 600μS flat top which will give 100ppm field stability within each of the kicker magnets. Each power converter is based on a high voltage capacitor bank to drive up the current to the required level (319A Kicker 1 and 2556A Kicker 2) and a low voltage capacitor bank to achieve the flat top requirement for a minimum of 600μS. The stored energy in the magnet is recovered back into the high voltage capacitor bank to reduce the power requirements.

Table 1: Pulsed Power Converter Ratings

PSU Type	Power (kW)	Voltage (V)	Current (A)	Qty.	Topology
K1 12.1mrad	2	235	450	1	IGBT
K2 90mrad	30	1355	2800	1	IGBT

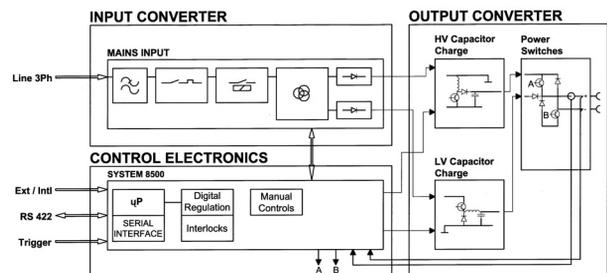


Figure 2: Block diagram of Danfysik 10Hz pulsed power converter.

### Input Converter

The AC main input supply is EMI filtered and over current protected with a manually operated circuit breaker. There is two stage switching to minimise the inrush current. A three phase transformer (Delta input, star/delta outputs) converts the mains voltage to a lower level and provides galvanic isolation.

The transformer output voltage is rectified and filtered with a L-C low pass filter to produce a dc link voltage for the output converter.

### Output Converter

The output converter consists of three principle blocks. A high voltage capacitor pre-charger, a low voltage capacitor pre-charger and the power output switches IGBT A and IGBT B (see Figure 2).

### High Voltage Capacitor Charger

The high voltage capacitor charger is a buck/boost converter boosting the dc link voltage to a value between 50 and 100% of nominal value set by the regulation module. The buck/boost converter is based on standard Danfysik 859 series building blocks. The 859 converter is a current mode switch regulator suitable for charging larger capacitor loads. The voltage regulation is manufactured to an accuracy of 0.25% thus ensuring a rise time jitter of better than  $\pm 60\mu\text{s}$ . The control module has a fibre optic interface for input and output. The input fibre optic interface is a PWM modulated signal with a fixed frequency noting the charge voltage level. A missing pulse disables the charging converter.

The output fibre optic interface has three indication states:

- Continuous off. (module fault, IGBT fault or over load)
- Pulses. (charging in progress)
- Continuous on. (capacitor voltage within specification and ready to be fired)

### Low Voltage Capacitor Charger

The low voltage capacitor charger is a buck converter controlling the dc link voltage to a value equal to the required voltage at flat top. This is a voltage level given by the regulation module. This voltage is constantly adjusted by the digital loop to an accuracy of 1%. This equals a flat top deviation of better than 100ppm.

The control module for the LV capacitor charger works on the same principle as the HV capacitor charger.

### Switch Control Principle

When the capacitors are charged to their specified value, a ready signal is generated and sent to the regulation loop. A trigger signal from ISIS will then start the 10Hz pulse sequence. IGBT A and IGBT B are turned on. The flat top period begins after the digitally controlled output current reaches the desired set value, which is 319A for kicker 1 and 2556A for kicker 2. IGBT A is then turned off and IGBT B will continue to carry the output current. Figure 3 shows the measured half sine wave current pulses for the kickers.

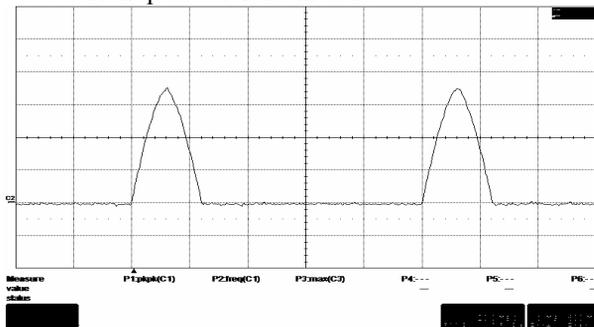


Figure 3: Measured 10Hz pulse.

The flat top for kicker 1 and slope-top for kicker 2 is digitally loop controlled with a duration of a minimum of  $600\mu\text{s}$  (see figure 4 and figure 5). IGBT B will then open starting the recovery period. In the recovery period the current will flow back to the HV capacitor through its top diode. As soon as IGBT B is opened the capacitor pre-chargers will also start to re-charge ready for the next pulse.

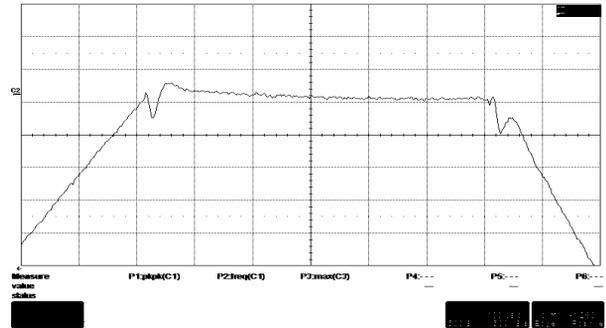


Figure 4: Kicker 1 measured 10Hz flat top.

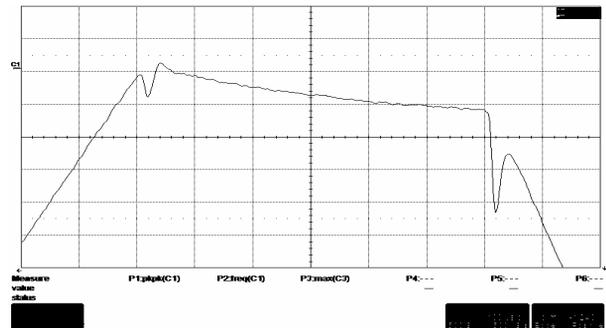


Figure 5: Kicker 2 measured 10Hz slope-top.

On Kicker 1 a measure of the flat top accuracy is achieved from the following principle:

$$\text{dc flat top voltage} = \text{resistive load} \times \text{current.}$$

Then the voltage across the load inductor will be zero. No voltage across the inductor is an indication of no change of current.

On kicker 2 to maintain the 100ppm field in the magnet it was realized that instead of a flattop we had to introduce a small slope into the wave shape. This is due to Eddy currents in the magnet and the magnet steel time constant. The slope-top wave shape is maintained by sampling the current value at the beginning and at the end of the flattop. Based on the difference between the two measurements, the LV capacitor bank voltage (which affects the slope) is adjusting accordingly. The Regulation Module has the option to maintain a specified slope-top instead of a flattop. The slope is now a function of the current

$$\text{slope} = a \times I_{\text{set}} + b$$

instead of a constant as on kicker 1.

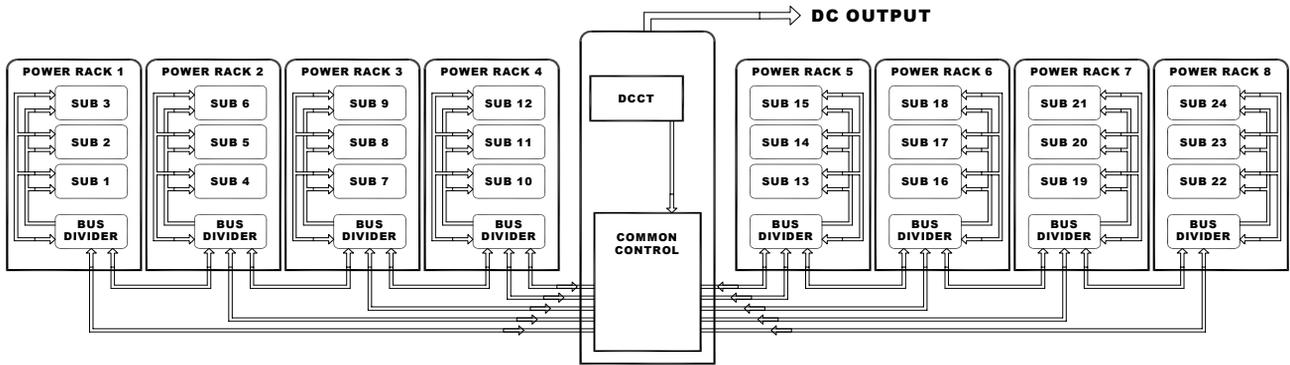


Figure 6: Septum power converter.

**SEPTUM POWER CONVERTER**

The septum power converter is a modular type, designed and manufactured by Kempower OY. The converter consists of twenty-four identical sub-converters each rated at 68V @ 420A connected in parallel. The topology of each sub-converter is IGBT technology (see figure 7). There are 8 power cabinets each containing 3 sub-converters, 1 cabinet for the DCCT, 1 cabinet for the common control, 1 cabinet for the mains switch and 4 cabinets for the EMC filter. Where practical, mechanical and electrical symmetry has been maintained throughout the design (see figure 6). The main EMC filter will enable the power converter to run at a maximum of 15% total harmonic distortion. Cooling of the sub-converter is a combination of water cooling and forced air cooling.

Table 2: Septum Power Converter Rating

Magnet Type	DC Power (kW)	DC Voltage (V)	DC Current (A)	Qty.	Topology
Septum	680	68	10000	1	IGBT

The septum power converter is designed with n+2 redundancy. In the event of a sub-converter failure, the remaining converters will take up and share the extra current within 40mS thus enabling the extracted proton beam continuous operation.

*Sub-Converter*

Each sub-converter has a 400V three-phase input which is EMI filtered. There are two contactors (one either side

of the primary rectifier) the second of which has two stage switch to limit the inrush. The rectified output then passes through the primary LC filter. The output then passes through the IGBT module which is switching at 16.7kHz and through two high frequency transformers. The output is rectified and filtered again to give an output of 68V@420ADC. (See Figure 7 for a block diagram.)

Table 3: Septum Magnet Load

Magnet Type	Turns	Max. DC Voltage	Max. DC Current	Inductance	Resistance
Septum	14	53	9000	340µH	5.5mΩ

*Magnet*

The load for the Septum Converter is the TS2 EPB Septum magnet (see Table 2 for specification). The magnet is water cooled (340Litres/minute) The water system is PLC controlled with flow and temperature interlocks going back to the main power converter interlock system. There is also a fast trip interlock which uses trip amplifiers to monitor the change in voltage due to the change in resistance.

*Output Busbars*

The output busbars which connect the power converter to the magnet are 2 off Ø63mm with a Ø12mm hole in the centre. The water flow through the busbar is 19Litres/Minute. The maximum volt drop in the busbars is 1.2Volts.

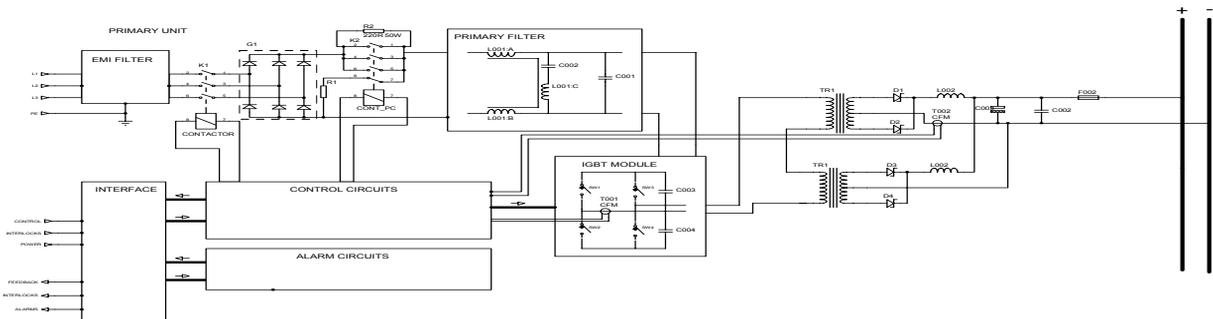


Figure 7: Septum sub-converter.