Specification for the Charge Supplies
Capacitor Charge/Discharge Power Supply (CCDPS) for FLARE

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1 Overview

A FLARE CCDPS module consists of a number of storage capacitors connected in parallel to a discharge switch. Each module is charged by a matched pair of switching power supplies, connected together to produce a bipolar output. In normal operation, a DPST normally-open relay closes for the charging period and disconnects the charging supplies prior to discharge. A network of resistors and diodes provide protection for the power supply under several failure scenarios discussed in Section 4.

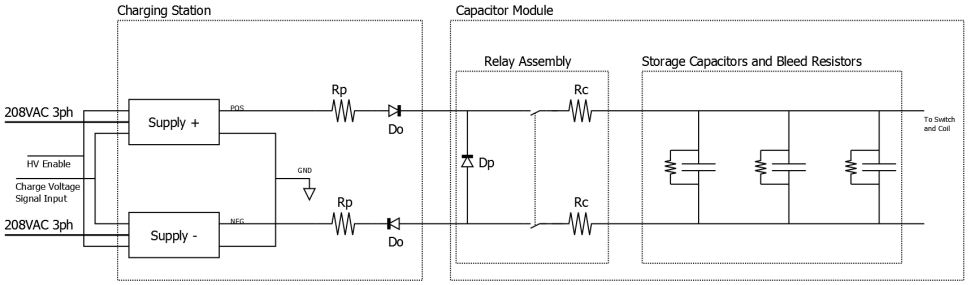


Figure 1: Charging scheme in use for the FLARE CCDPS banks. The resistor values are given in Table 1.

2 Charging Supplies

Each bank for the experiment has at least two supplies - having equal positive output and negative output to produce a bipolar output. TDK-Lambda supplies are used heavily, as their supply curves are closer to constant-power and are therefore more cost-effective in meeting the charge time specification (whereas the Spellman supply is constant-current, resulting in a power output that is quadratic in time). The constant-power charging curves were accounted for late in the design process; earlier iterations assumed constant current and required multiple supplies in parallel on some banks to meet the charge time specification – no bank requires parallel supplies in this final design. PFA and PFB are charged by the separate bipolar supplies to support charging to different voltages, as are TFA and TFB similarly. Under initial operation the reduced-energy banks will be connected in parallel, trading operational flexibility for reduced expenditures in the early phase. All charging supplies operate on 3-phase 208VAC or 24VDC. For the 24VDC modules a power supply is included so all the power supplies ultimately derive power from 208VAC.

					OH	EF	GF	PFA/B	TFA/B	DCI	DCO
Supply models (see table below)					(a)	(b)	(a)x3	(a)	(c)	(d)	(e)
Protection Resistor value (Rp) [Ω]					180	2.2	54	100	640	180k	70k
Protection Resistor rating [W]					50	20	200	100	20	1	1
Charge Resistor value (Rc) [Ω]					1600	10	720	2000	5600	1.6M	640k
Charge Resistor rating [W]					2000	2000	2000	2000	2000	10	10
Charge module bleed resistor value (Rb) [MΩ]					-	-	-	-	-	2000	800
	Manufacturer	V_{max} [kV]	Qty. Ea. full power	Qty. Ea. initial	Supply (+) model				Supply (-) model		
(a)	TDK-Lambda	10	6	3	402L-10kV-POS-208VAC				402L-10kV-NEG-208VAC		
(b)	TDK-Lambda	1	1	1	402L-1kV-POS-208VAC				402L-1kV-NEG-208VAC		
(c)	Spellman	10	2	1	SLM10P1200				SLM10N1200		
(d)	UltraVolt	30	1	-	30C24-P60-I10				30C24-N60-I10		
(e)	UltraVolt	30	1	-	30C24-P125-I10				30C24-N125-I10		

Table 1: Charge supply and resistor specifications.

	Supply Model	Qty. Ea. full power	Current draw (ea) [A]	Subtotal [A]
(a,b)	TDK-Lambda 402L	14	25	350
(c)	Spellman SLM10	2	7	14
(d,e)	Mean Well LRS-350-24	1	2	2
			Total Amps:	366

Table 2: Facility power requirements for charging supplies. All supplies operate on 208VAC 3-phase.

Manufacturer	HV ON pins	$V_{control}$ range	$V_{control}$ pin	Voltage ref (GND) pin
TDK-Lambda 802L	8,14	0-10V	22	24
TDK-Lambda 402L	8,14	0-10V	22	24
Spellman SLM10	11,12 (J2)	0-10V	3	9
Advanced Energy/UltraVolt	4,7	0-10V	6	5

Table 3: Supply control interface.

Facility power requirements for the charging supplies are listed in Table 3. All charge supplies shall have their power interrupted by normally-open relay upon receipt of the Emergency Stop signal.

The high voltage output stage of each supply is enabled by relay-closure at the bank module NEMA box, as commanded by a fiber-isolated Digital Output from an NI 6229 module at the CCDPS DAQ chassis (one channel per coil system). All charging supplies are controlled by 0-10VDC analog signal representing a charge voltage from 0 to the maximum supply output voltage listed in Table 1. This control signal is produced by Analog Output from an NI 6229 module at the CCDPS DAQ chassis (one channel per coil system). Please see the Specification for CCDPS DAQ for connection schematic.

3 Charge Connect Modules

One charge connect module is installed at each capacitor bank module. The charge connect module consists of two charge resistors, one DPST relay for connecting the charge supply to the bank, and one protection diode, as seen in Figure 2. The charge resistors reduce the risk of charging supply damage in the case of a busswork arc, ground fault, or capacitor failure; they are rated to 2kW and are of wire-wound type (as the added inductance improves fault isolation) except for DCI and DCO which only require 10W power rating. The role of the protection diode is described in Section 4.

The DCI and DCO modules utilize the 60kV variant of the charge connect module, which is designed for immersion of the components in insulating oil. The 60kV variant may be operated below 30kV without oil. Included in this variant is a bleed resistor that slowly discharges the capacitor as a final redundant energy dump. The bleed resistor is included with the charge connect module in this case in order to reduce the component count near the discharge and crowbar switches, enabling the lowest inductance design. The larger, lower-voltage banks utilize a bleed resistor installed on each individual capacitor; those are discussed in the Dump section of the specification of each of those banks. The 60kV charge connect module also includes the supply protection resistors so that they are immersed in oil without requiring another oil reservoir.

4 Charge supply protection

If a bank pre-fires, the charge relays will still connect the charging supplies to the bank and any programmed crowbar will not operate. This potentially presents a large reversed voltage to the charging supply. The charging supply might also be exposed to reversed voltages if the charge disconnect relay fails in the closed state. A protection diode is installed across the charging supply connection to mitigate these risks (labeled Dp in Figure 1, value given in Table 4). Under normal charging the diode is reverse-biased and does not

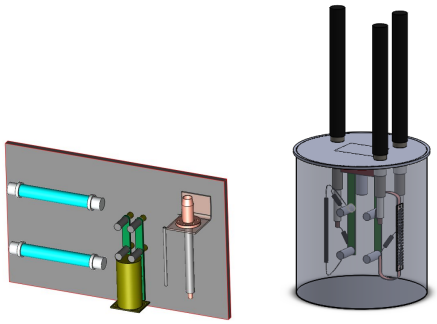
Diode	OH	EF	GF	PFA/B	TFA/B	DCI	DCO
Do	B412-50-25	B412-50-25	B412-50-25	B412-50-25	B412-50-25	B412-50-25	B412-50-25
Dp	B412-50-25	B412-50-25	B412-50-25	B412-50-25	B412-50-25	B980-125	B980-125

Table 4: Diode specifications. All model numbers are from manufacturer EDAL.

conduct appreciable current. In the event of a pre-fire and bank reversal the diode becomes forward-biased. The current in the diode is then limited by the charge resistor, and the voltage reversal presented to the charging supply is limited to the forward voltage drop of the diode.

Protection resistors are installed on the output of each power supply that operate in complement to the protection diodes described above. If a connected capacitor bank pre-fires, reversed voltages on the charging supply cable are limited to the protection diode's forward voltage drop; the additional protection resistor limits the current that arises in the supplies' internal protection diodes due to the resulting forward bias. Additionally if a short-circuit failure occurs along the charge line the protection resistors will limit the prompt current until the supplies can register the overload condition. These resistors are designed not to limit the supply current under normal operation. The combination of charge resistor, protection diode, and protection resistor follows the recommendations of Ref. [2], adapted to a bipolar supply.

In the event of a ground fault the bipolar capacitor bank will shift far away from balanced voltages – potentially doubling the voltage with respect to ground. If such a fault occurs while the charge disconnect relay is still connected to the charge supply then the lifted voltage might destroy the supply. Output diodes are installed that would become reverse-biased in this case, providing a voltage drop to match the supply output and preventing damage. These are labeled Do in Figure 1, and values are given in Table 4.



(a) (b)

Figure 2: Charge connect module CAD models: (a) 20kV variant, (b) 60kV variant. The resistor values are given in Table 1.

5 Mounting in rack

Every 802L is 5U, every 402L is 4U, spellmans need a shelf (26lb load) and are about 3U tall. Total is 68U, which is at least 2 standard racks (40-42U each). The UltraVolts can go on one shelf with their 24V supply.

6 References

References

[1] Statement of Work for Design of Capacitor Charge/Discharge Power Supply (CCDPS) for FLARE FLARE-CCDPS-150828, Revision 0, Sept. 9th 2015

[2] Interfacing Pulsed Power Systems to Switching Power Supplies, Presented at International Power Modulator Conference, Hollywood, California, July 1-3, 2002

7 Appendices

7.1 Vendor specifications and datasheets