High-Current Arc Discharge (HCAD) Test System for Aeronautic Power

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***Abstract*— High-potential DC power distribution systems such as those found in aeronautics are at risk to failures different from AC and low-voltage DC systems. Detection and mitigation of such failures are important in aerospace and other technology fields. In collaboration with the Air Force Research Laboratory, APELC has developed a high-current arc-discharge (HCAD) system for test and research applications.**

The HCAD system is an instantly reconfigurable arc-discharge source capable of driving 60-Amps continuously or >1-kA in pulsed-discharge mode. The system can be configured for unipolar or bipolar power up to 600 VDC in both pulsed and continuous modes. The system employs 28 F of capacitance for pulsed discharge and uses high-current IGBTs to energize and de-energize the load. HCADS features internal current limiting resistors, a hand-held fiber optic remote, calibration fixture, and voltage and current diagnostics. This paper presents the design of the HCAD system.

Keywords—DC power distribution, failure analysis, arc discharge, avionics power, high-current discharge

I. INTRODUCTION

High-potential DC power distribution systems such as those found in aeronautics are at risk to failures different from AC and low-voltage DC systems. Detection and mitigation of such failures, in conjunction with prevention, are of importance for not only the aerospace field but also to electric vehicles, solar power systems, and data centers [1-3] . In collaboration with the Air Force Research Laboratory, APELC has developed a high-current arc-discharge (HCAD) system for test and research applications. The development was driven by the need to understand system failures and related effects for DC-power distribution.

The HCADS is an instantly reconfigurable, 1-MJ, arc-discharge source capable of driving 60-Amps continuously or >1-kA in pulsed-discharge mode. The system can be configured for unipolar or bipolar power up to 600 VDC in both pulsed and continuous modes. The system employs 24 F of capacitance for pulsed discharge and uses high-current IGBTs to energize and de-energize the load. HCADS features internal current limiting resistors, a hand-held fiber optic remote, calibration fixture, and voltage and current diagnostics. This paper presents the design of the HCAD system.

II. CIRCUIT TOPOLOGY

The HCAD system consists of two 300-V, 33-A TDK-Lambda Genesys high-current power supplies. The two basis capacitor banks consist of seven, 97-Farad Maxwell Ultracapacitor modules, rated at 48 V each.

The two circuit configurations are series and parallel arrangement of the two basis capacitor banks and their respective power supplies. The series circuit configuration is shown in Fig. 1. In series mode the load can be a three-terminal bi-polar load or a two-terminal load subjected to the stacked differential potential of the two banks.

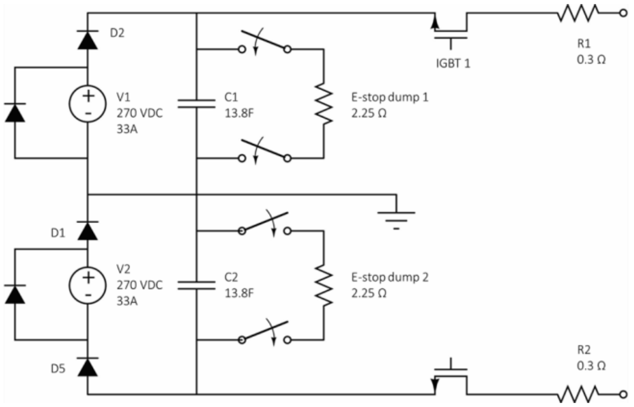

Fig. 1. Series configuration of the basis capacitor banks.

In addition, the series configuration can be used in a direct mode. In direct mode, the capacitor banks are manually switched out of the circuit and the power supplies supply current directly to the load, as controlled by the IGBTs. This configuration is used when a longer duration and lower peak current is desired. The parallel configuration is shown in Fig. 2.

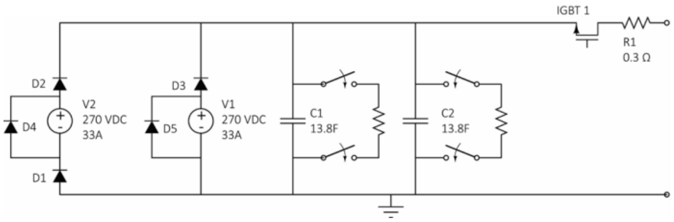

Fig. 2. Parallel configuration of the basis capacitor banks.

This circuit mode is realized by ensuring the circuit is de-energized and throwing a switch on the front panel of the HCAD system. The series/parallel switch controls a set of high-current relays. The relays change the circuit so that the user avoids manually making and breaking high-current connections.

III. SYSTEM INTEGRATION

The HCAD circuit components, controls, indicators and energy stores are all contained in a single 7-ft electronics rack. The integration of the system into a single rack yields some measure of portability given the 1200-lb weight of the system. The size, weight, and input-power requirements are listed in Table 1 below.

TABLE I. SIZE, WEIGHT, AND INPUT POWER FOR THE HCAD SYSTEM.

Symbol	Parameter	Value	Units
D	Depth	42 (106.7)	in (cm)
W	Width	30 (76.2)	in (cm)
H	Height	83.5 (212.1)	in (cm)
Wt	Total Weight	1200 (544.3)	lbs (kg)
Input supply	# of Phases	3	Phase
Input Supply voltage requirement		208	V
Input supply current requirement		90 (45/supply)	I

At the front panel of the HCAD rack shown in Fig. 3, the user controls power and system configuration (series or parallel) prior to a given test. Front panel indicators display the voltage on each capacitor bank, without dependence on the system power supplies or system mode. The emergency stop button shown in Fig. 3C immediately disables the power supplies and dumps the capacitor banks into high-energy resistive load to safely de-energize the system. This is important since the capacitor banks can store over 1MJ of energy.

Fig. 3. HCADS Power and Control Panel (Front): (A) Power key-switch (controls), (B) Parallel/Series toggle switch, (C) Emergency-Off Button, (D) Fire Button (Momentary push), (E) Fiber optic remote input, (F) Bank 1 and 2 charge voltage LED indicators.

The system output can be controlled using a manual switch at the front panel, or by using a fiber-optic remote control. The fiber-optic remote permits the operator total isolation from the system and allows integration with a global experiment timing schedule.

Fig. 4 shows the general location of the circuit components for the HCADs rack. The master control and indication panel is at user eye-level, the TDK Lambda Genesys power supplies are at the top of the front panel. High-current relays, IGBTs, and manual disconnects are below the control panel. The Ultracapacitors, which are the heaviest system component, are located at the base of the rack and are arranged as shown in Fig. 5.

Fig. 4. HCADS front panel and circuit component locations.

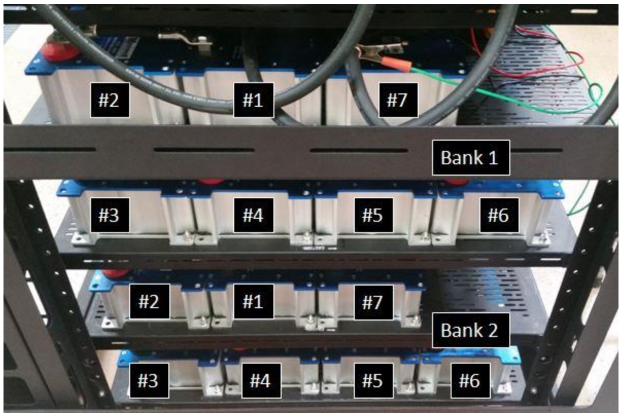

Fig. 5. Configuration of the Ultracapacitors which are serially connected to form each bank.

Fig. 6 shows the rear panel of the HCAD rack. At the top, internal high-energy resistors can be connected to the HCAD output for use as a calibration load. High-current output connections and the manual capacitor disconnect switch are available at the midpoint. At the rear base of the rack are two sets of high-energy resistors.

The first set is the current limiting series output resistance. These 0.3-Ohm resistors provide a short-circuit current limitation on the system. Below the current limiting resistors is the resistive dump circuit. The resistive dump can be used in conjunction with the safety stick to slowly de-energize any circuit in proximity to the HCAD rack to ensure no charge is stranded at a high potential.

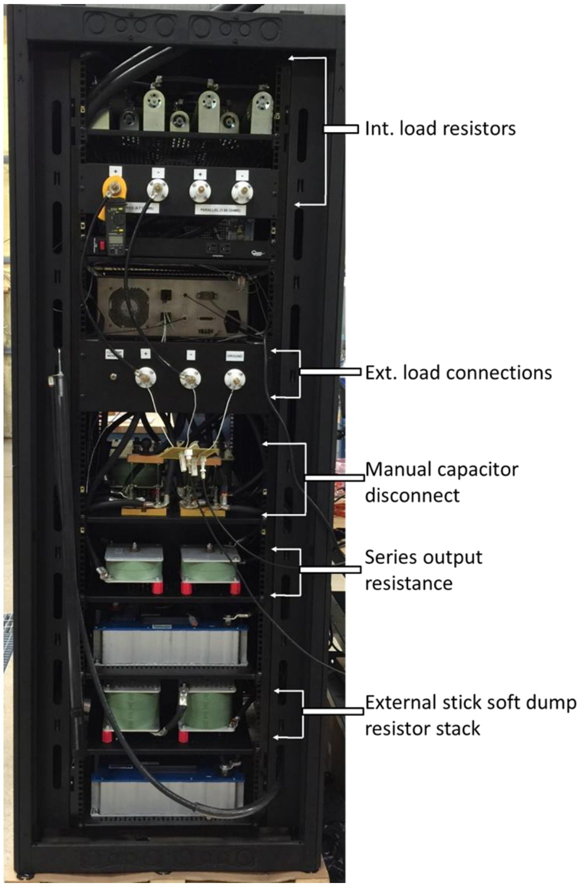

Fig. 6. Rear panel of the HCAD rack.

IV. EXPERIMENTAL DATA

The data important to collect for system characterization included the pulsed-discharge into a resistive load and the direct discharge into a resistive load for each configuration of the basis capacitors.

Fig. 7 shows the voltage and current characteristics as the serial configuration is discharged into the 9-Ohm calibration load using a bi-polar charge voltage of +/- 290 VDC. This test exhibited a peak current of 67Amperes with a 16% droop and a peak voltage of 524 V with an 8% droop.

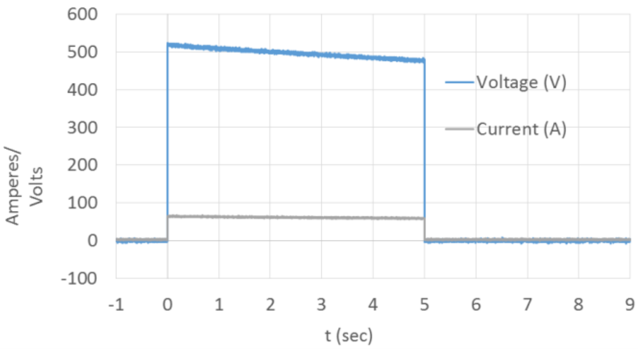

Fig. 7. Series capacitive discharge into 9 Ohms at 290 VDC charge.

Fig. 8 shows the voltage and current characteristics as the serial configuration is connected directly to the 9-Ohm calibration load using a bi-polar charge voltage of +/- 290 VDC. In this mode, the capacitor stack is disconnected from the active circuit. This test exhibited a steady current of 33 Amperes and a constant voltage of 290 VDC.

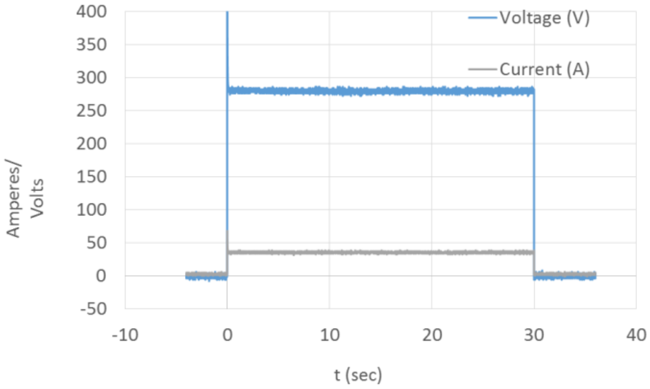

Fig. 8. Series direct current into 9 Ohms at 290 VDC.

Fig. 9 shows the voltage and current characteristics as the parallel configuration is discharged into the 2.2-Ohm calibration load using a charge voltage of 290 VDC. This test exhibited a peak current of 128 Amperes with a 10% current droop and a peak voltage of 280 V with an 8% voltage droop.

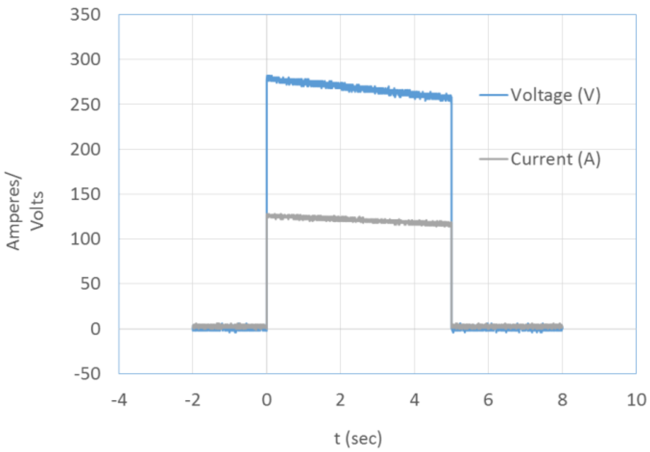

Fig. 9. Parallel capacitive discharge into 2.2 Ohms at 290 VDC charge.

Fig. 10 shows the voltage and current characteristics as the parallel configuration is connected directly to the 2.2-Ohm calibration load using a voltage of 150 VDC. In this mode, the capacitor stack is disconnected from the active circuit and the negative-polarity IGBT (IGBT 2) and the low-side current-limiting resistor are bypassed in the active circuit. This test exhibited a steady current of 66 Amperes and a constant voltage of 150 VDC.

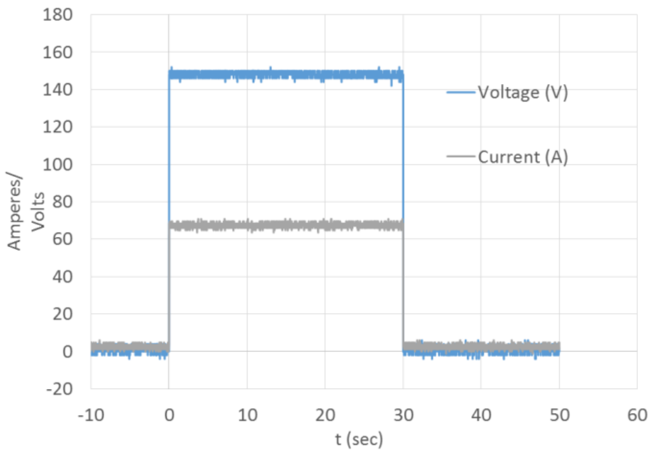

Fig. 10. Parallel constant current into 2.2 Ohms at 150 VDC.

Fig. 11 shows the voltage and current characteristics as the parallel configuration is discharged into the 0.3-Ohm current-limiting load using a charge voltage of 290 VDC. This test exhibited a peak current of 984 Amperes with a 21% current droop and a peak voltage of 286 V with an 8% voltage droop.

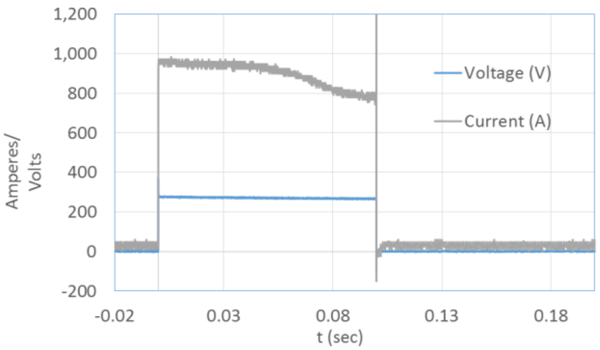

Fig. 11. Parallel capacitive discharge into 0.3 Ohms at 290 VDC charge.

V. SUMMARY

The HCAD system prototype displayed functionality in each configuration and its derivative modes. The prototype demonstrated versatility and ease of use through its intuitive user interface and met the current and voltage design requirements established by aerospace-power researchers' experimental needs. HCAD system specifications are summarized in Table II.

TABLE II. SYSTEM PARAMETER SUMMARY FOR THE HCAD SYSTEM.

Parameter	Value	Units
Peak Voltage	+/- 300	V
Peak short-circuit current – capacitive discharge mode	1000	A
Peak current – constant current mode	66	A
% Voltage Droop (27.68 F, 0-5 sec w/ 2.25 Ohm load)	9	%
% Voltage Droop (6.92 F, 0-5 sec w/ 9.3 Ohm load)	8	%
Capacitance (Parallel)	27.68	F
Capacitance (Series)	6.92	F

ACKNOWLEDGMENT

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