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Report 1908

AUTOMATED CHARGE-DISCHARGE FACILITY FOR STUDY OF DIRECT-CURRENT ELECTRICAL POWER SOURCES

by

Edward J. Dowgiallo, Jr.

August 1967

U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
FORT BELVOIR, VIRGINIA

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Report 19[illegible]

AUTOMATED CHARGE-DISCHARGE FACILITY FOR STUDY OF DIRECT-CURRENT ELECTRICAL POWER SOURCES

Task 1M624101D190-06

August 1967

Distributed by

The Commanding Officer
U. S. Army Engineer Research and Development Laboratories

Prepared by

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Energy Conversion Research Laboratory
Electrotechnology Department

SUMMARY

This report describes a facility consisting mainly of a controller for charging and discharging electrical power sources. The facility also includes a data storage system and data reduction equipment. The controller has five modes of operation: Constant current and constant voltage charge, constant power and constant current discharge, and an open-circuit voltage period. Each mode has certain preset end points. A comparator monitors cell voltage continuously and can override the end points, caus a printout of ampere-hours, watt-hours, or time; all modes of operation and end points can be set up by diode pins in program boards, and the constant power, voltage, or current level is programmed by a clip-card reader. Twenty-five different modes and sixteen different levels can be preprogrammed in any sequence.

FOREWORD

The facility described in this report was designed to analyze high-energy density batteries, fuel cells, and hybrid systems which might be used as the primary power sources for vehicle propulsion. The type of data obtainable using this facility has not been and is not likely to be available from the electrochemical industry.

Authority for the project covered in this report is contained in Task 1M641010190-06, "Regenerative Electrochemical Cells."

The design and construction of the facility were carried out from October 1965 to November 1966 by Edward J. Dowgiallo, Jr., Electrical Engineering Technician, under the supervision of Dr. Galen R. Frysinger, Chief, Energy Conversion Research Laboratory, Electrotechnology Department, and under the direction of Donald J. Looft, Acting Chief, Electrotechnology Department.

CONTENTS

AUTOMATED CHARGE-DISCHARGE FACILITY FOR STUDY OF DIRECT-CURRENT ELECTRICAL POWER SOURCE

I. INTRODUCTION

1. Subject. A facility consisting of a programmable controller, a data storage system, and data reduction equipment was designed and assembled to obtain data for analyzing the performance of prototype electrical power sources. The controller operation and its main circuitry are described in detail in this report. The main functions of the controller are: (a) To set and maintain the following modes of operation: Constant power, constant current, or constant voltage levels of charge or discharge. (b) To set end points of ampere-hours, watt-hours, or time. (c) To change modes of operation when certain values of the following limits are reached: High voltage, low voltage, or low leakage current. When these limits are reached, the circuitry will override the programmed end points.

2. Background. Since current interest is increasing in the use of high-energy batteries for vehicle propulsion and research on these power sources is a responsibility of Energy Conversion Research Laboratory at U. S. Army Engineer Research and Development Laboratories, a means of automatically instrumentating a wide variety of controlled conditions to determine the electrical characteristics of various electrochemical power sources was found necessary. The charge-discharge controller was designed to satisfy this Army requirement. The first stage of the internal program required setting up certain charge and discharge constant levels and the end points for various modes of operation.

II. DESCRIPTION

3. Controller System. The controller system is described by sections presented in the order that an operator would normally preset them before an automatic run. The controller simply sets charge or discharge current, voltage, or power levels to be imposed on the power source being analyzed and maintains these by varying the output of operational power supplies in the same circuit. Any change of the power source under test from a particular preset constant electrical level will be quickly compensated for by the power supplies. The controller will switch from any of the aforementioned modes of operation when preset end points are reached, such as ampere-hours, watt-hours, or time. At any time, these end points

can be overridden if a high-voltage limit or low-voltage limit (representing the discharge voltage or leakage current of the electrical power source) is reached.

4. Program Section. The program section consists of units 1, 2, and 3 shown in Fig. 1. All the modes of operation and the end points in the controller are preset by program boards. These program boards[1] consist of three rack-mounted sections of six matrix modules. Each matrix module has an electrical and mechanical arrangement that is one group of 10 by 10 holes with 10 continuously vertically bussed upper rows and individual lower silver-plated beryllium copper contacts. The individual lower contacts are each connected to separate mercury-wetted relays. The relay coils are common on the opposite end from the program board. A 28-volt direct-current power supply is connected between the common sides of the coils and the continuously vertically bussed upper contacts so that a diode pin inserted between the two decks will activate the desired relay. All the modes of operation are preset with these pins. Thirty programming holes are available to determine each mode of operation. Such a set of holes is referred to as a channel. A 25-channel scanner (described later) successively applies the 28-volt direct current to the pinned relay coils of each chosen channel. Each channel can activate the same 30 relays. When a channel is activated, all the relays of that channel that have a diode pin in their corresponding program board insertion hole change their state. There are two states for each function: P is the condition of a function with the diode pin inserted, and N is the normal condition of a function with the diode pin removed. The functions for each state are identified in Table I. The program boards are also used in a similar manner to give contact closures to each counter for preset of the end points.

5. Preset End Point Section. The preset end point section consists of units 4, 5, and 6 shown in Fig. 1. Power, time, and amperes are represented by a proportional voltage that is coupled to a voltage to frequency converter (ref. 1) with a range of 0 to 10 volts and a full-scale frequency of 10,000 hertz. The output frequency of the converter is coupled to two preset counters (ref. 2). The first counter divides the input signal by "N," a number up to 5 digits determined by the system program boards. An output pulse is produced each time the number of input pulses from the converter equals "N." This pulse is coupled to a second counter that counts the pulses to a preset end point also determined by the system program boards. This initiates a print command signal to a digital recorder (ref. 3) which records

1. Sealectoboard Program Boards Model SBX-102965-2, Sealectro Corporation, Mamaroneck, New York.

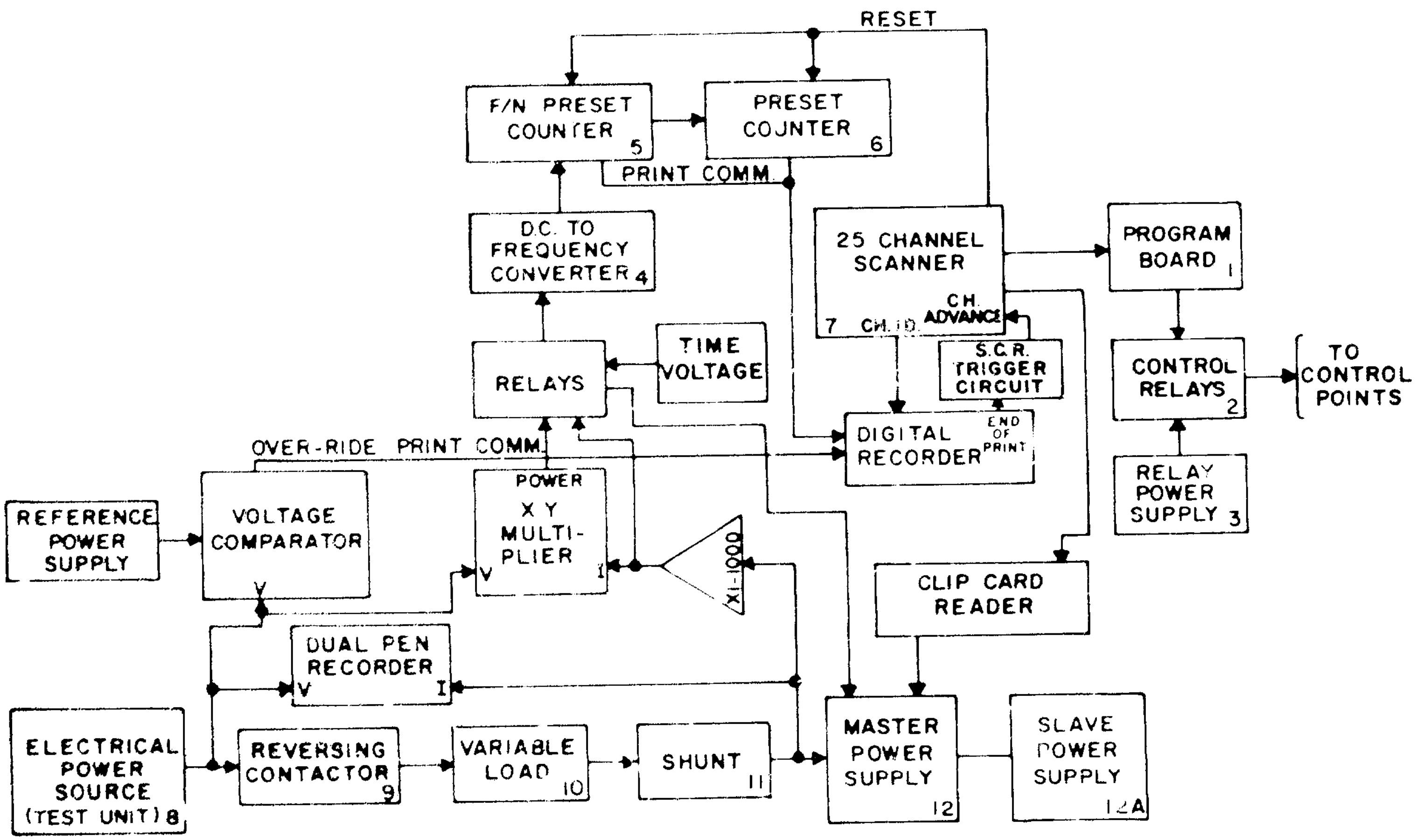

Fig. 1. Block diagram of controller system.

Table I. Channel Program Identification
(Same for Each of the 25 Channels)

Program Board Insertion Holes	Function P	Function N
1	Reversing Contactor - Reverse (Charge)	Contactor - Open
2	Reversing Contactor - Forward (Discharge)	Contactor - Open
3	Comparator Input - Leakage Current	Comparator Input - Electrical Power Source Voltage
4	Power Supplies Program Relays	Power Supplies Program Relays
5	" " " "	" " " "
6	None	None
7	Power Supplies Program Relays	Power Supplies Program Relays
8	" " " "	" " " "
9	" " " "	" " " "
10	" " " "	" " " "
11	Voltage or Current	Power
12	2,000-Ampere Contactor (Load Shunted)	Contactor - Open
13	Multiplier Output to Converter	Multiplier Output for Constant Power Mode
14	Shunt (Amplified Voltage) to Converter	Open
15	Time Voltage to Converter	Open
16	None	None
17	Power or Voltage	Current
18	None	None
19	Current	Voltage or Power
20	None	None
21	A (Load Relay) Closed	Open
22	B and C Closed	"
23	D "	"
24	E "	"
25	F "	"
26	G "	"
27	H and I "	"
28	J "	"
29	K "	"
30	L "	"

Note: The functions of program board insertion holes 4 through 10 are explained in paragraph 8. Program board insertion holes 6, 16, 18, and 20 were not used.

these end points. The end points which represent ampere-hours, watt-hours, or time are printed out for two reasons: (a) To check the controller accuracy and (b) to record the value of these parameters if preset limits cause an override of the original end points.

6. Clip-Card Reader. The clip-card reader unit[2] provides the resistance that sets the electrical levels of the electrical power source by serving as a programming reference to the operational power supplies. This resistance causes the supplies' electrical outputs to change in such a way that the programmed electrical levels of the electrical power source are maintained constant. The clip-card approach to analog control system programming is a unique design concept of direct card setting of precision potentiometers. The controller incorporates 16 potentiometers. The spring-loaded wipers of these 1,000-ohm potentiometers are pushed back a distance determined by the amount of the clip-card remaining when the card is inserted. The card is a rigid vinyl sheeting cut to an accuracy of one part in 1,000. These potentiometers program the master power supply, and any constant current, power, or voltage level of operation can be maintained when the scanner is in the corresponding channel. For example, several different constant power discharge profiles could be cut in cards to be filed and used when required. The clip-card reader reduces programming time and eliminates operator error.

7. Comparator Section. The comparator section consists of the voltage comparator program circuit (Fig. 2). This circuit continuously monitors the electrical power source voltage or the leakage current depending on the program board activation of insertion hole 3 (Table I). The comparator compares a high-voltage reference signal with the voltage of the electrical power source being analyzed. If the source voltage exceeds the reference voltage, the high-limit switch of the comparator closes, shorting comparator pins 8 and 9 (Fig. 2), activating relay 32 which couples a print command signal to the digital recorder. This records the end point, since the normal counter end point has been overriden, and advances the 25-channel scanner (unit 7 in Fig. 1) to the next channel by triggering a silicon controlled rectifier relay circuit. The 25-channel scanner (ref. 4) is an electronically controlled stepping switch. This scanner furnishes two separate contact closure outputs for each of the 25 channels. One contact closure programs the power supplies by connecting the proper preset potentiometer of the clip-card reader to the power supply program terminals. The other contact closure activates the relays by means of the program

2. Clip-Card Reader Model PC-3100, Jordan Controls, Inc., Milwaukee, Wisconsin.

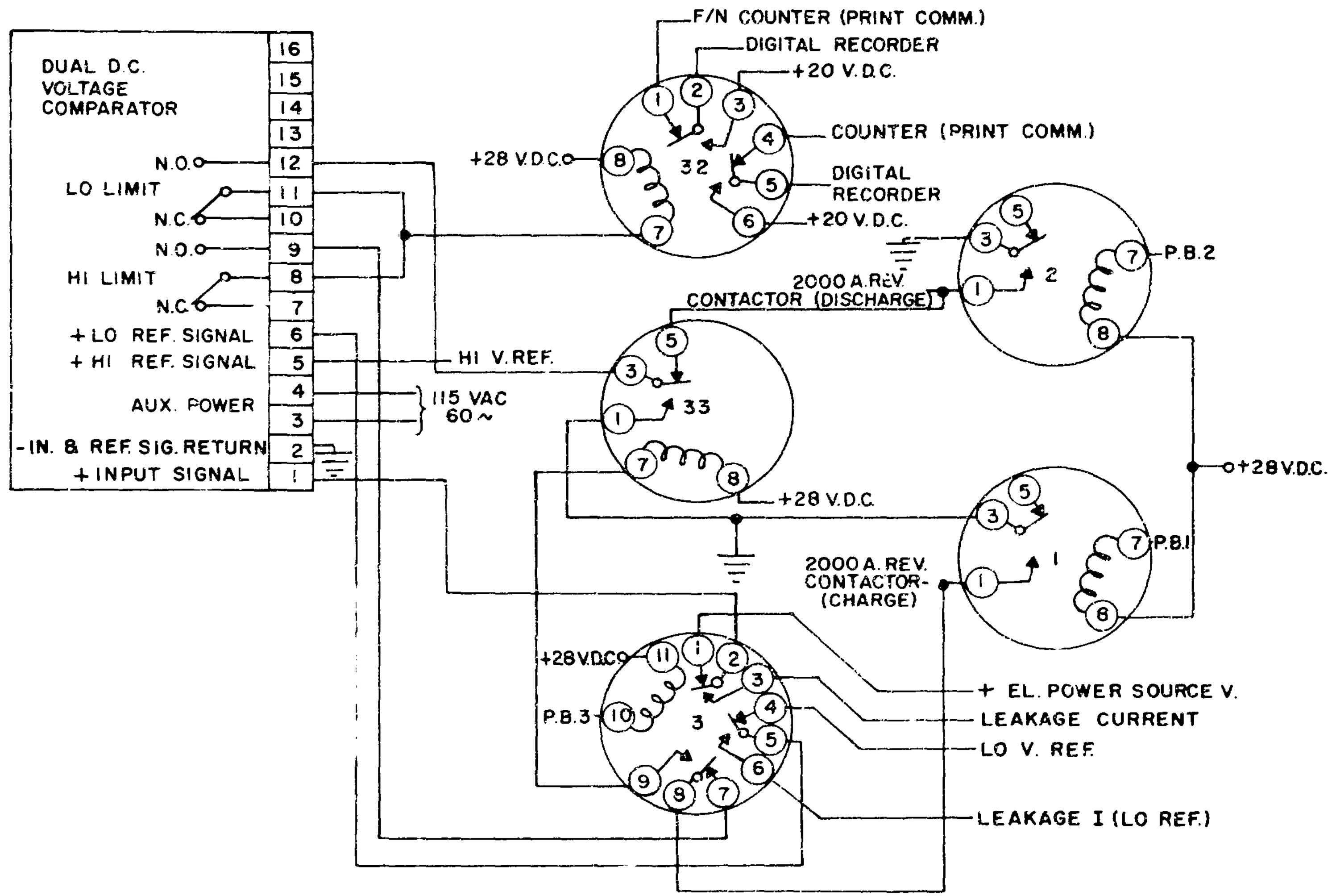

Fig. 2. Voltage comparator program circuit.

board diode pins. This programs the end points and the modes of operation. A two-digit Nixie display on the front panel of the scanner indicates the number of each active channel as it is registered by the scanner; also, a 4-2'-2-1 binary coded decimal output of channel identification is continuously coupled to the digital recorder. Twenty-five numbered pushbutton switches on the front panel allow the operator to select channels to be programmed or skipped. Unselected channels are automatically skipped in all modes of operation. The scanner has five modes of operation, selected by front panel pushbuttons: Continuous scan, single scan, manual, remote, and reset.

8. Power Supply Programming. The basic programming circuit (refs. 5 and 6) for the 0- to 8-volt direct-current and 0- to 1,000-ampere power supplies is shown in Fig. 3. (The switches are shown in the N condition.) Each numbered switch of the schematic is a relay controlled by the correspondingly numbered program points given in Table I. The program board holes that must be diode pinned are given for some typical modes of operation in Table II. The zener diodes shown in Fig. 3 prevent the power supply voltage from exceeding 10 volts. The master-slave operational power supplies are the units with electrically varying outputs that maintain the electrical power source constant at the preset electrical levels. A description of the circuit containing these supplies and a typical mode of operation follows.

a. High-Current Circuit. The high-current circuit is shown in Fig. 4. Maximum system current can flow through units 8, 9, 10, 11, 12, and 12A in Fig. 1. The reversing contactor[3] is rated at 2,000 amperes maximum current and is activated by a 28-volt direct-current power supply. The programmable load consists of the resistor configuration shown in Fig. 5. The load can be varied in steps from 0.01 ohm (1,000 amperes) to 2 ohms (33 amperes) by activating the proper relays in series or parallel. Several shunts can be chosen depending on the maximum current during any one operational sequence. The largest shunt is 3,000 amperes, 60 millivolts, four terminal, and air cooled. The final units in the high-current circuit are the remote programmable power supplies. The master power supply has a voltage range of 0 to 8 volts (ref. 7) and a current range of 0 to 1,000 amperes. Present capabilities are 0 to 8 volts at 2,000 amperes, 0 to 16 volts at 1,000 amperes, or 0 to 58 volts at 300 amperes. These values are obtained by connecting slave power supplies. This high-current circuit is the main control loop of the controller. The various operations of the controller center around setting the master-slave power supply levels

3. Reversing Contactor Assembly A-890F, The Hartman Electrical Company, Mansfield, Ohio.

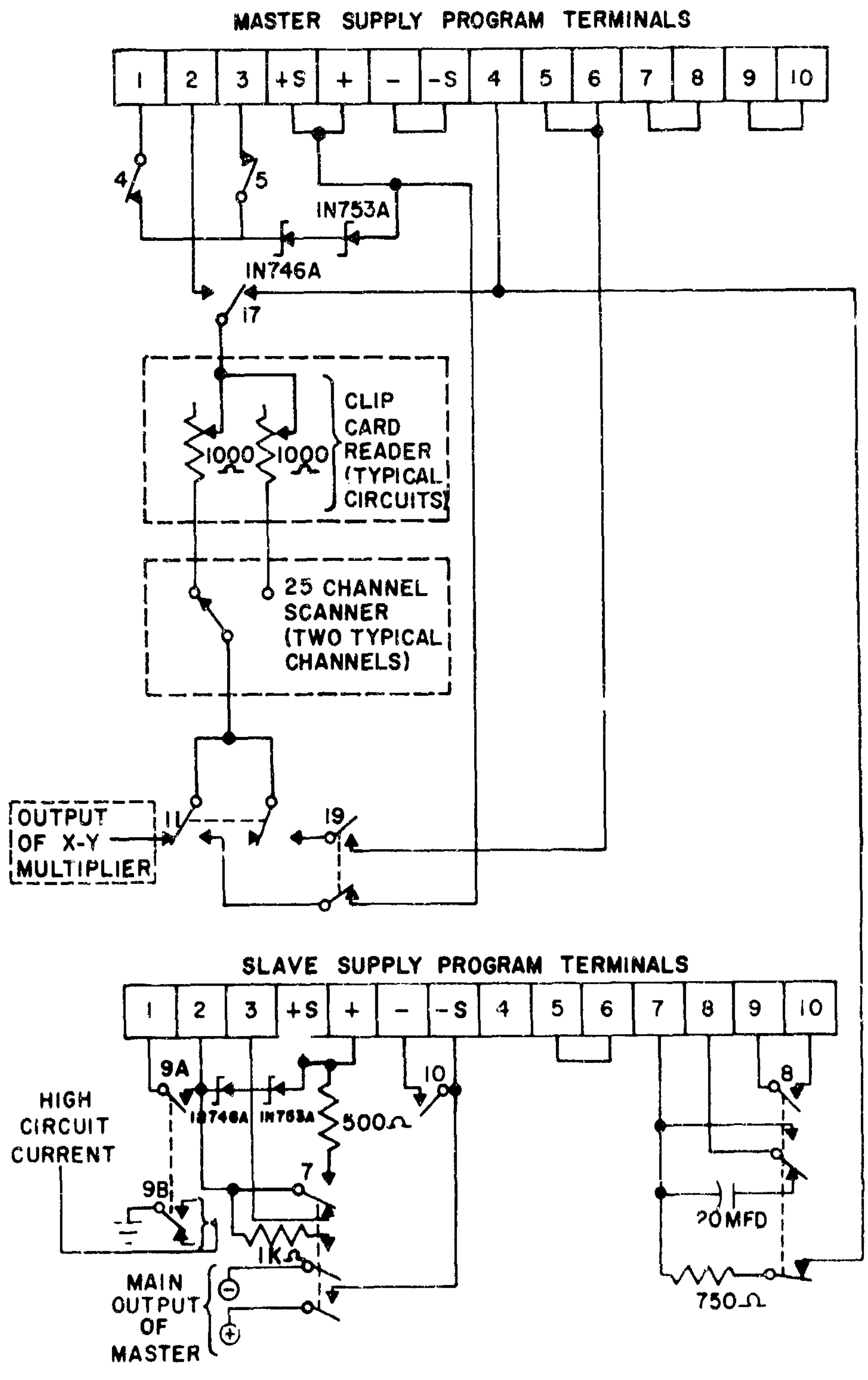

Fig. 3. Programming circuit for power supplies.

Table II. Program Board Pinned Holes for Some Typical Modes of Operation

Mode	End Point	Pinned Holes
Constant Current Charge	Time	1, 7, 8, 11, 12, 15, 19
Constant Current Discharge	Time	2, 7, 8, 11, 12, 15, 19, 21-30 (Required Load Resistance)
Constant Voltage Charge	Leakage Current	1, 3, 5, 7, 8, 11, 12, 17
Constant Power Discharge	Ampere-Hours	2, 5, 7, 8, 14, 17, 21-30 (Required Load Resistance)

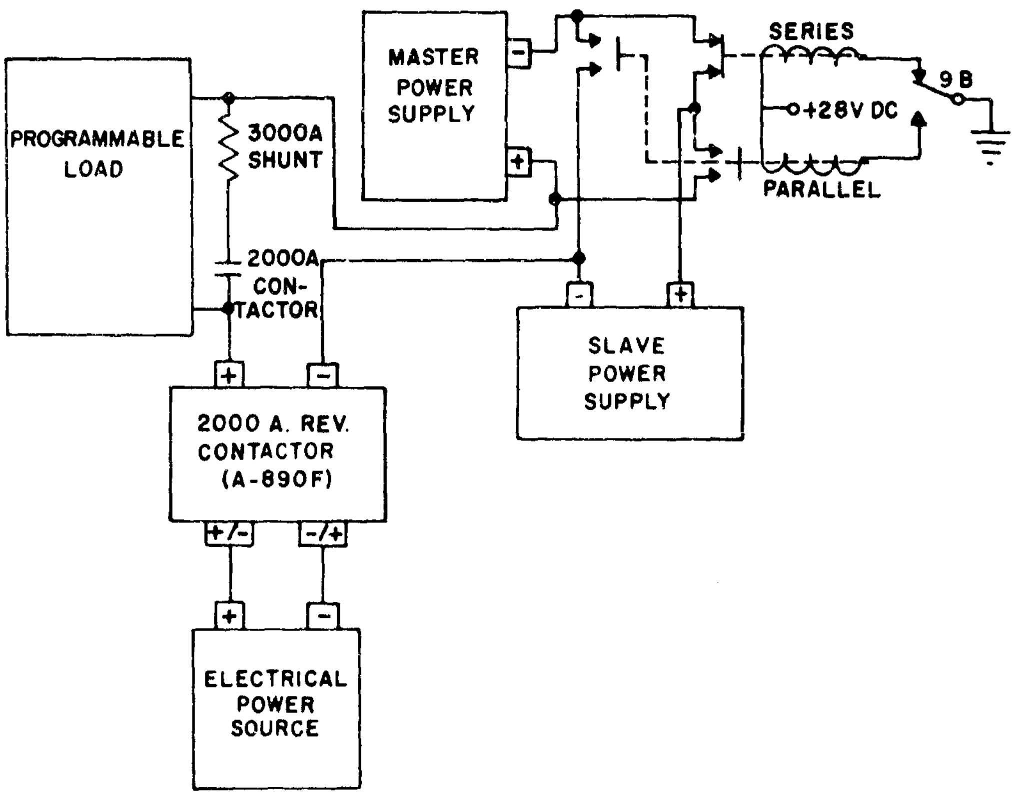

Fig. 4. High-current circuit.

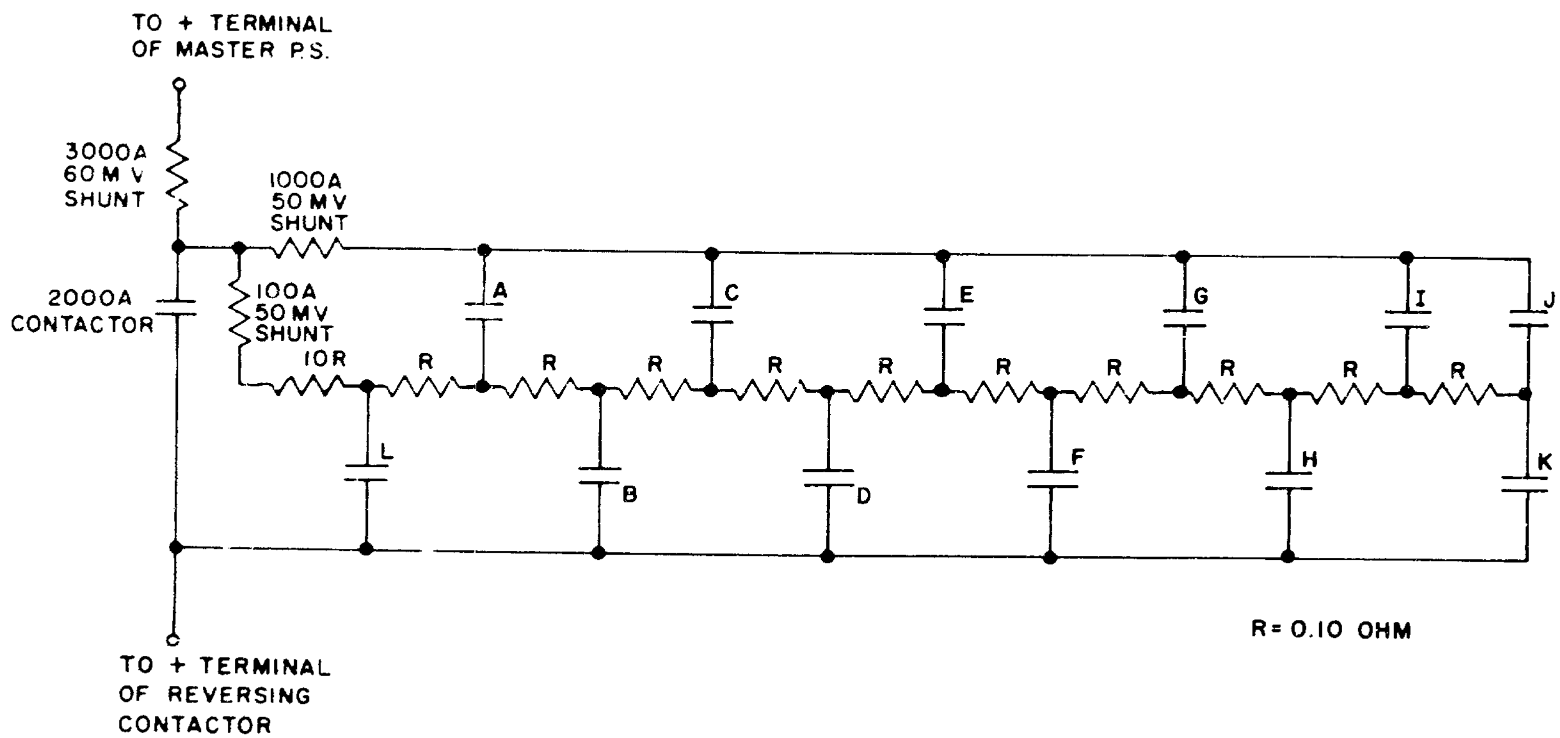

Fig. 5. Programmable load and shunts.

by the clip-card resistors, closing the proper program switches for different modes, and ending operation in any mode to switch to another mode.

b. Constant Power. The constant power mode of power supply programmed operation is shown separately (Fig. 6A) because this is a new and unique approach. The multiplier[4] is a quarter square multiplier. The amplified shunt voltage (e_1) (proportional to the main loop current) is coupled to input 1, and the electrical power source voltage (e_2) is coupled to input 2. The output voltage $e = -e_1(-e_2)/E = +e_1e_2/E$ where E is an arbitrary scaling voltage in 1-volt steps from 0 to 11 volts. The variable 1,000-ohm resistor (R_P, Fig. 6) is the constant power programming resistance of the clip-card reader unit selected by the scanner. The output voltage of the multiplier is applied, by way of the 1,000-ohm rheostat (R_P), between program terminals 1,2 and -S,-(ground) of the master power supply. A series loop is now formed consisting of: Ground, the multiplier output voltage (V_M), R_P, a resistor in the power supply (R_R), a reference voltage of -6.2 volts also in the power supply, and back to ground (Fig. 6B). A constant voltage input differential amplifier is connected between the R_P-R_R junction and ground. This amplifier maintains zero volts at the R_P-R_R junction by generating a correction signal causing the master (and slave) supply to change its main output voltage until no error exists at its input. Once R_P is set, the constant current through it is maintained by this feedback control of the multiplier output voltage to hold the difference at zero volts. This maintains a constant output power from the electrical power source.

III. DISCUSSION

9. Charge-Discharge Facility. The controller is made up basically of commercially available equipment requiring a few interconnecting circuits and wiring for the program boards and the control relays. The components cost less than $30,000. The three power supplies make up about one-third of this cost. The controller is the basic component of a facility consisting of a data acquisition system (ref. 8), a data plotting system (ref. 9), and a calculator with a page printer and remote tape punch reader.[5] These systems are necessary for data storage and reduction since the controller can operate around the clock and will accumulate large

4. Multiplier-Divider Model Q3-M1P, Philbrick Researches, Inc., Dedham, Massachusetts.

5. Calculator Model 8-48, Mathatronics, Inc., Waltham, Massachusetts.

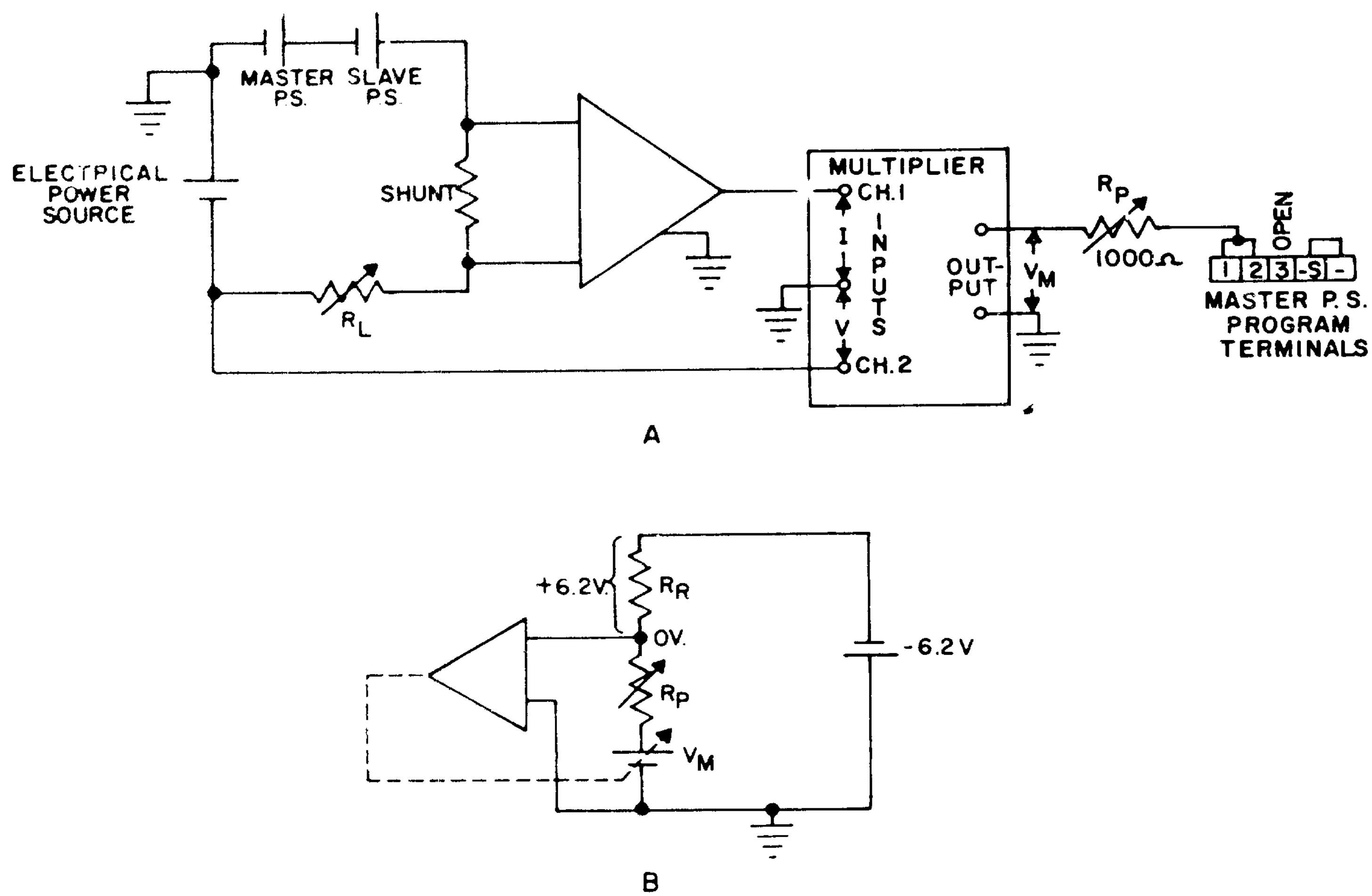

Fig. 6. Simplified constant power circuit.

quantities of raw data. The controller can produce data for analyzing high-energy batteries obtained by the following five typical modes of operation:

Mode	End Point
Constant Current Charge	Time Voltage Watt-Hours
Constant Voltage Charge	Time Leakage Current
Constant Current Discharge	Time Voltage Watt-Hours
Constant Kilowatts Discharge	Voltage Time Ampere-Hours
Oper Circuit	Time

These modes and any charge or discharge constant electrical level of operation can be programmed to simulate the power profile of any operating device using electrical power. Since the power profile does affect the efficiency of a high-energy electrical storage device, it must be specified for these purposes. Batteries have been discharged at constant current levels to 800 amperes and at constant power levels to 550 amperes.

10. Future Use. The present approach will progress in the following manner: (a) Characterize the power source and (b) simulate the power source by an analog. Finally, a more automatic approach will be incorporated; this will give direction to (a) and (b) such as to select information and guide future data taken through an adaptive-type feedback approach. This approach lends itself to analyzing preprototype electrical power sources and feeding back this information to the developer with user oriented direction in a fast reliable manner. This function is properly the user's in order to meet the developer on an equal technical basis and should speed up the evolution from research to the first prototype models.

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3. Digital Recorder Model 562A, Operating Manual, Hewlett-Packard Co., Palo Alto, California, 1962.

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9. Digital Data Plotting System Model DY-2031C, Operating and Service Manual, DYMEC Division, Hewlett-Packard Co., Palo Alto, California, May 1966.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia 22060

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
AUTOMATED CHARGE-DISCHARGE FACILITY FOR STUDY OF DIRECT-CURRENT ELECTRICAL POWER SOURCES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
October 1965 to November 1966

5. AUTHOR(S) (Last name, first name, initial)
Dowgiallo, Edward J., Jr.

6. REPORT DATE
August 1967

7a. TOTAL NO. OF PAGES
28

7b. NO. OF REFS
9

8a. CONTRACT OR GRANT NO.

9a. ORIGINATOR'S REPORT NUMBER(S)
1908

b. PROJECT NO.

c. Task No. 1M624101D190-06

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

d.

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13. ABSTRACT

This report describes a facility consisting mainly of a controller for charging and discharging electrical power sources. The facility also includes a data storage system and data reduction equipment. The controller has five modes of operation: Constant current and constant voltage charge, constant power and constant current discharge, and an open-circuit voltage period. Each mode has certain preset end points. A comparator monitors cell voltage continuously and can override the end points, causing a printout of ampere-hours, watt-hours, or time. All modes of operation and end points can be set up by diode pins in program boards, and the constant power, voltage, or current level is programmed by a clip-card reader. Twenty-five different modes and sixteen different levels can be preprogrammed in any sequence.

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