

DC Power Supply  
SCR-10 Series  
Model 6472C



**DC POWER SUPPLY  
SCR-10 SERIES  
MODEL 6472C**

**OPERATING AND SERVICE MANUAL  
FOR SERIALS 1125A-0101 AND ABOVE\***

For Serials Above 1125A-0101  
a change page may be included.

100 Locust Avenue, Berkeley Heights, New Jersey 07922

## TABLE OF CONTENTS

Section	Page
<b>I GENERAL INFORMATION .....</b>	<b>1-1</b>
1-1 Description .....	1-1
1-5 Specifications .....	1-1
1-7 Options .....	1-2
1-9 Accessories .....	1-2
1-11 Instrument/Manual Identification .....	1-2
1-14 Ordering Additional Manuals .....	1-2
 <b>II INSTALLATION .....</b>	 <b>2-1</b>
2-1 Initial Inspection .....	2-1
2-3 Mechanical Check .....	2-1
2-5 Electrical Check .....	2-1
2-7 Installation Data .....	2-1
2-9 Location .....	2-1
2-11 Outline Diagram .....	2-1
2-13 Rack Mounting .....	2-2
2-15 Input Power Requirements .....	2-2
2-20 208/230Vac Conversion .....	2-2
2-22 380/400Vac Conversion .....	2-2
2-30 50Hz Ac Input (Option 005) .....	2-3
2-32 Repackaging for Shipment .....	2-3
 <b>III OPERATING INSTRUCTIONS .....</b>	 <b>3-1</b>
3-1 Turn-On Checkout Procedure .....	3-1
3-3 Operating Modes .....	3-2
3-5 Normal Operating Mode .....	3-2
3-7 Constant Voltage .....	3-2
3-9 Constant Current .....	3-2
3-11 No Load Operation .....	3-3
3-13 Output Ranges — Models 6466C and 6483C Only .....	3-3
3-15 Connecting Load .....	3-3
3-18 Grounding .....	3-3
3-21 Operation Beyond Rated Output .....	3-3
3-23 Protection Circuits .....	3-3
3-25 Optional Operating Modes .....	3-3
3-26 Remote Programming, Constant Voltage .....	3-3
3-34 Remote Programming, Constant Current .....	3-4
3-40 Remote Sensing .....	3-5
3-45 Auto-Parallel Operation .....	3-6
3-48 Auto-Series Operation .....	3-6
3-53 Battery Charging .....	3-7
3-58 Battery Discharging .....	3-8
3-62 Special Operating Considerations .....	3-8
3-63 Pulse Loading .....	3-8

## TABLE OF CONTENTS (Continued)

Section	Page
<b>IV PRINCIPLES OF OPERATION</b> .....	4-1
4-1 Overall Block Diagram Discussion .....	4-1
4-3 Feedback Loop .....	4-1
4-9 Current Balance Circuit .....	4-2
4-11 Turn-On Control Circuit .....	4-2
4-13 Overvoltage Protection Feature .....	4-3
4-15 Overcurrent Protection Circuit .....	4-3
4-17 Early Overcurrent Protection Circuit .....	4-3
4-20 Phase Protection Circuit .....	4-3
4-22 Overload Circuit .....	4-3
4-26 Reference Supply .....	4-3
4-28 Overvoltage Crowbar .....	4-3
4-30 Detailed Circuit Analysis .....	4-4
4-31 SCR Regulator and Firing Circuits .....	4-4
4-45 Constant Voltage Comparator .....	4-5
4-51 Comparator Protection Circuit .....	4-6
4-53 Constant Current Comparator .....	4-6
4-57 Error Amplifier .....	4-6
4-61 Overcurrent Protection Circuit .....	4-6
4-63 Turn-On Control .....	4-6
4-65 Overvoltage Protection Circuit .....	4-6
4-67 Phase Protection Circuit .....	4-7
4-70 Early Overcurrent Protection .....	4-7
4-73 Current Balance Circuit .....	4-7
4-78 Overload Circuit .....	4-7
4-85 Reference Supply .....	4-8
 <b>V MAINTENANCE</b> .....	 5-1
5-1 Introduction .....	5-1
5-3 Test Equipment Required .....	5-1
5-5 Performance Test .....	5-2
5-7 Constant Voltage Tests .....	5-2
5-27 Constant Current Tests .....	5-5
5-35 Troubleshooting .....	5-6
5-40 Overall Troubleshooting Procedure .....	5-6
5-44 Amplifier Circuits, Open Loop Troubleshooting .....	5-9
5-49 Firing Circuits, Open Loop Troubleshooting .....	5-10
5-51 Crowbar Troubleshooting .....	5-11
5-54 Repair and Replacement .....	5-11
5-56 Air Filter .....	5-11
5-58 Hinged Front Panel .....	5-11
5-60 Printed Circuit Boards .....	5-11
5-62 Primary SCR and Diode Replacement .....	5-12
5-66 Location of Power Transformer, Choke, Output Capacitors, and Secondary Rectifiers....	5-12
5-68 Adjustment and Calibration .....	5-12
5-70 Meter Zero .....	5-12

## SAFETY SUMMARY

The following general safety precautions must be observed during all phases of operation, service, and repair of this instrument. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the instrument. Hewlett-Packard Company assumes no liability for the customer's failure to comply with these requirements.

### BEFORE APPLYING POWER.

Verify that the product is set to match the available line voltage and the correct fuse is installed.

### GROUND THE INSTRUMENT.

This product is a Safety Class 1 instrument (provided with a protective earth terminal). To minimize shock hazard, the instrument chassis and cabinet must be connected to an electrical ground. The instrument must be connected to the ac power supply mains through a three-conductor power cable, with the third wire firmly connected to an electrical ground (safety ground) at the power outlet. For instruments designed to be hard-wired to the ac power lines (supply mains), connect the protective earth terminal to a protective conductor before any other connection is made. Any interruption of the protective (grounding) conductor or disconnection of the protective earth terminal will cause a potential shock hazard that could result in personal injury. If the instrument is to be energized via an external autotransformer for voltage reduction, be certain that the autotransformer common terminal is connected to the neutral (earthed pole) of the ac power lines (supply mains).

### INPUT POWER MUST BE SWITCH CONNECTED.

For instruments without a built-in line switch, the input power lines must contain a switch or another adequate means for disconnecting the instrument from the ac power lines (supply mains).

### DO NOT OPERATE IN AN EXPLOSIVE ATMOSPHERE.

Do not operate the instrument in the presence of flammable gases or fumes.

### KEEP AWAY FROM LIVE CIRCUITS.

Operating personnel must not remove instrument covers. Component replacement and internal adjustments must be made by qualified service personnel. Do not replace components with power cable connected. Under certain conditions, dangerous voltages may exist even with the power cable removed. To avoid injuries, always disconnect power, discharge circuits and remove external voltage sources before touching components.

### DO NOT SERVICE OR ADJUST ALONE.

Do not attempt internal service or adjustment unless another person, capable of rendering first aid and resuscitation, is present.

### DO NOT EXCEED INPUT RATINGS.

This instrument may be equipped with a line filter to reduce electromagnetic interference and must be connected to a properly grounded receptacle to minimize electric shock hazard. Operation at line voltages or frequencies in excess of those stated on the data plate may cause leakage currents in excess of 5.0 mA peak.

### SAFETY SYMBOLS.



Instruction manual symbol: the product will be marked with this symbol when it is necessary for the user to refer to the instruction manual (refer to Table of Contents).



Indicates hazardous voltages.



or



Indicate earth (ground) terminal.

**WARNING**

The WARNING sign denotes a hazard. It calls attention to a procedure, practice, or the like, which, if not correctly performed or adhered to, could result in personal injury. Do not proceed beyond a WARNING sign until the indicated conditions are fully understood and met.

**CAUTION**

The CAUTION sign denotes a hazard. It calls attention to an operating procedure, or the like, which, if not correctly performed or adhered to, could result in damage to or destruction of part or all of the product. Do not proceed beyond a CAUTION sign until the indicated conditions are fully understood and met.

### DO NOT SUBSTITUTE PARTS OR MODIFY INSTRUMENT.

Because of the danger of introducing additional hazards, do not install substitute parts or perform any unauthorized modification to the instrument. Return the instrument to a Hewlett-Packard Sales and Service Office for service and repair to ensure that safety features are maintained.

*Instruments which appear damaged or defective should be made inoperative and secured against unintended operation until they can be repaired by qualified service personnel.*

ERRATA:

In parts list, under Mechanical, change the HP P/N of the cable clamp to 0100-0437.

On page 3-4, change title of Figure 3-4 to read: "Remote Voltage Programming, Constant Voltage, Unity Gain."

ERRATA:

Add the following at the end of paragraph 2-17: Fuses F1, F2, and F3 (70A each), in the phase A, B, and C lines respectively, are located inside the unit behind the rear panel. Fuses F4, F5 and F6 (300mA each), connected in the reference supply power input circuit, are located on the rear panel. fuses F7 and F8 (1.6A each), in the phase B and C input lines to the T5 primary windings, are also located on the rear panel.

In paragraphs 4-18 and 4-24, change 40% to 140%.

The standard colors for this instrument are now mint gray (for front panel) and olive (for all other external surfaces). Option X95 designates use of the former color scheme of light gray and blue gray. Option A85 designates use of a light gray front panel with gray used for all other external surfaces. New part numbers are shown below:

DESCRIPTION	STANDARD	HP PART NO.	
		OPTION A85	OPTION X95
Front Panel Assembly	06472-60004	<-----	<-----
Front Panel Lettered	06472-60013	06472-60005	<-----
Cover, Top	5000-9417	<-----	5000-6292
Cover, Side (2)	5000-9418	<-----	5000-6293
Bottom, Front Panel	5000-9447	5000-6294	<-----
Cover, Output Busbar	5000-9467	5000-6300	<-----
Cover, Barrier Strip	5000-9457	<-----	5000-9320
Bottom, Rear Panel	5000-9466	5000-6295	<-----
Panel, Rear	5000-6282	5000-6283	<-----
Mounting Plate	5000-9465	5000-6284	<-----
Pan, Bottom, Left	5000-9480	<-----	5000-6290
Bracket, Heat Sink	5000-9481	<-----	5000-9330
Post, Corner Frame (2)	5020-8446	<-----	5020-8021
Bar, Frame (2)	5020-8448	<-----	5020-8022
Tray, Capacitor	5000-9453	<-----	5000-6285
Cover, Capacitor Tray	5000-9454	<-----	5000-6286
Tray	5000-9479	<-----	5000-6289
Ear, Rack Mounting (2), Option 23	5020-7062	5020-8037	<-----
Front Panel (Crowbar Option)	5000-9382	5000-9324	<-----

In Figure 3-5, connect programming resistor between terminals A4 and A6 as shown. Programming resistor should not be connected to terminal A8.

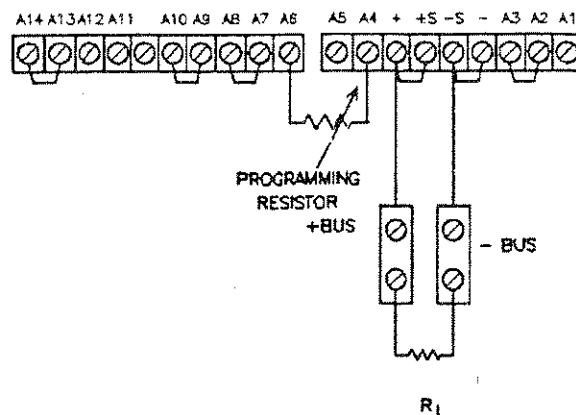


Figure 3-5. Remote Resistance Programming Constant Current

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MODEL	VOLTAGE (Maximum allowable terminal voltage before terminals are shorted)
6464C	5V
6466C	6V
6469C	8V
6472C	10V
6475C	17V
6477C	30V
6479C	30V
6483C	42V

On page 3-1, paragraph 3-2, change step c. to read as follows: to check out constant current circuit, first, turn off supply and allow the output voltage to bleed down. Then short circuit the output bus bars and rotate Voltage controls fully clockwise. Turn on supply.

On page 3-2, paragraph 3-8, add the following sentence to the beginning of step b.; Turn off supply and allow the output voltage to bleed down. Add this same sentence to paragraph 3-10, step a, paragraph 3-55, steps b and d, and paragraph 5-32, step e.

In the replaceable parts list, and on the schematic diagram change variable resistors A1R102 and A1R122 to 20K, 1/2W, HP P/N 2100-0058.

**CHANGE 8:**

One of two types of fans is used in this supply, HP P/N 3160-0240 or 3160-0285. The capacitor (C19) to be used with the fan depends on which fan is installed. With fan 3160-0240, use 8uf 370Vrms capacitor, HP P/N 0160-4122. With fan 3160-0285, use 5uf, 370Vrms capacitor, HP P/N 0160-0585.

**CHANGE 9:**

In the replaceable parts list, on page 6-10, under Main Frame - Electrical, change Fan, B1, to Fan Assembly, B1, HP P/N 3160-0498 and on page 6-12 change Bracket, Fan, B1 HP P/N 5000-9321 to HP P/N 5020-2684 TQ 1.

der Rear Panel Assembly-Electrical and on schematic diagram change the descriptive F4, F5, and F6 to; Fuse can be 0.3A 600V 0.315A, 600V.

**ERRATA:**

In the Operating and Service manual, units with Option 040, add the following note.

**NOTE**

When calibrated for Option 040, units may not meet full output voltage or current specification when used with the front panel potentiometer. This is due to the resistance tolerance of the potentiometer and programming coefficient accuracy requirements. Option 040.

## SECTION I GENERAL INFORMATION

### 1-1 DESCRIPTION

1-2 This power supply, Figure 1-1, is completely transistorized and is suitable for high power applications which require a dc source with a moderate degree of regulation. The supply is a constant voltage/constant current type that will furnish full rated output voltage at the maximum rated output current or can be continuously adjusted throughout most of the output range. The front panel CURRENT controls can be used to establish the output current limit (overload or short circuit) when the supply is used as a constant voltage source and the VOLTAGE controls can be used to establish the voltage limit (ceiling) when the supply is used as a constant current source. The supply will automatically cross over from constant voltage to constant current operation and vice versa if the output current or voltage exceeds these preset limits.

1-3 Many protection circuits are included in the supply to protect the regulator SCR's against excessive current or voltage and to protect the user's load. The supply also contains the front panel trouble lamps associated with some of the protection circuits.

1-4 Output voltage and current are continuously monitored on two front panel meters. Input power is connected to a four pin connector on the rear of the unit. The output terminals are heavy busbars also mounted at the rear of the unit. Terminal strips at the rear of the unit allow ease in expanding the operational capabilities of the instrument. A brief description of these capabilities is given below:

a. *Remote Programming.* The power supply output voltage or current may be programmed (controlled) from a remote location by means of an external voltage source or resistance.

b. *Remote Sensing.* The degradation in regulation which occurs at the load due to voltage drop in the load leads can be reduced by using the power supply in the remote sensing mode of operation.

c. *Auto-Series Operation.* Two power supplies may be used in series when a higher output voltage is required in the constant voltage mode of operation or when greater voltage compliance is required in the constant current mode of operation. Auto-Series operation permits one-knob control of the total output voltage from a "master" supply.

d. *Auto-Parallel Operation.* The power supply may be operated in parallel with another unit when greater output

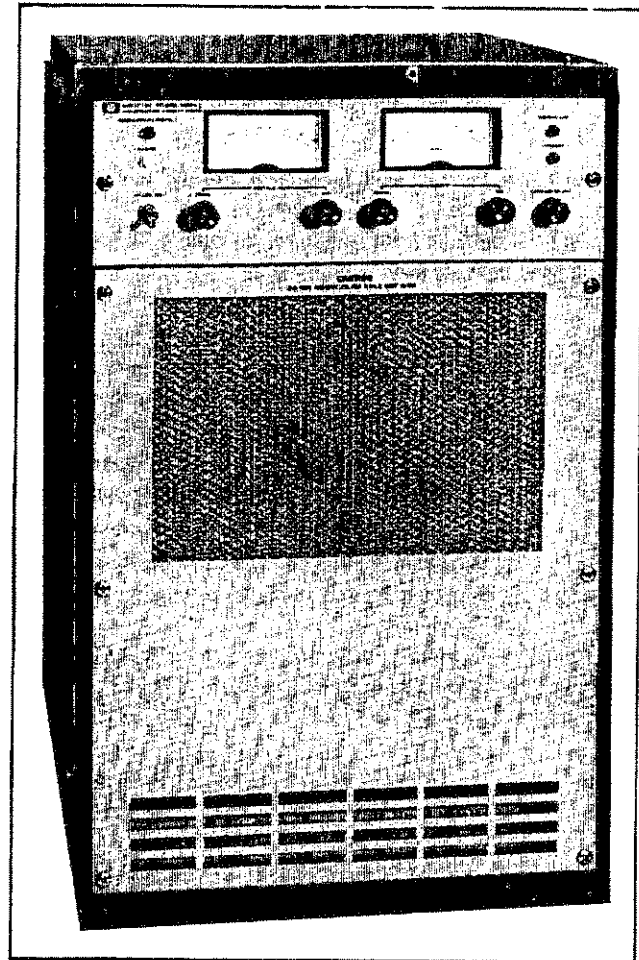


Figure 1-1. Typical 10kW Power Supply, SCR-10 Series

current capability is required. Auto-Parallel operation permits one-knob control of the total output current from a "master" supply.

e. *Battery Charging or Discharging.* The supply can be used in automatic battery charging or discharging applications. The automatic crossover between constant voltage and constant current permits the operation to be unattended.

### 1-5 SPECIFICATIONS

1-6 Detailed specifications for the power supply are given in Table 1-1 on Page 1-3.



## 1-7 OPTIONS

1-8 Options are customer-requested factory modifications of a standard instrument. The following options are available for the instrument covered by this manual. Where necessary, detailed coverage of the options is included throughout the manual. Notice that the customer must specify one of the five input power options available for this supply when ordering a unit. These options (001, 002, 003, 031, and 032), together with the other available options, are described below.

<u>Option No.</u>	<u>Description</u>
001	208Vac $\pm$ 10%, 3-phase input, 57–63Hz.
002	230Vac $\pm$ 10%, 3-phase input, 57–63Hz.
003	460Vac $\pm$ 10%, 3-phase input, 57–63Hz.
005	50Hz ac input. Standard instrument is wired for nominal 60Hz ac input. Option 005 includes re-alignment, and in some cases, internal rewiring.
006	Internal overvoltage protection crowbar ( <i>Not applicable to 6464C</i> ). Protects delicate loads against power supply failure or operator error. Monitors the output voltage and places a virtual short circuit (conducting SCR) across load within 10 $\mu$ s after preset trip voltage is exceeded. For complete specifications, refer to Appendix A.
023	Rack kit for mounting one supply in standard 19" rack.
031	380Vac $\pm$ 10%, 3-phase input, 57–63Hz.
032	400Vac $\pm$ 10%, 3-phase input, 57–63Hz.

## 1-9 Accessories

1-10 One accessory, HP Part No. 14545A, is available with this supply. It consists of four snap-on casters and can be ordered with the power supply or separately from your local Hewlett-Packard sales office.

## 1-11 INSTRUMENT/MANUAL IDENTIFICATION

1-12 This power supply is identified by a three-part serial number tag. The first part is the power supply model number. The second part is the serial number prefix, which consists of a number-letter combination that denotes the date of a significant design change. The number designates the year, and the letter A through M designates the month, January through December, respectively, with "I" omitted. The third part is the power supply serial number; a different sequential number is assigned to each power supply.

1-13 If the serial number on your instrument does not agree with those on the title page of the manual, Change Sheets supplied with the manual or Manual Backdating Changes define the differences between your instrument and the instrument described by this manual.

## 1-14 ORDERING ADDITIONAL MANUALS

1-15 One manual is shipped with each power supply. Additional manuals may be purchased from your local Hewlett-Packard field office (see list at rear of this manual for addresses). Specify the model number, serial number prefix, and part number shown on the title page.

Table 1-1. Specifications

<p><b>INPUT:</b> 208/230/380/400/460Vac <math>\pm</math> 10%, Three Phase, 57 to 63Hz, 50A per phase @ 230Vac.</p> <p><b>OUTPUT:</b> 0-64V @ 0-150A (NOTES 1 and 2).</p> <p><b>LOAD REGULATION:</b> <i>Constant Voltage</i> - Less than 0.05% plus 100mV for a load current change equal to the current rating of the supply. <i>Constant Current</i> - Less than 0.1% plus 0.15A for a load voltage change equal to the voltage rating of the supply.</p> <p><b>LINE REGULATION:</b> <i>Constant Voltage</i> - Less than 0.05% plus 100mV for any change within the input rating. <i>Constant Current</i> - Less than 0.1% plus 0.15A for any change within the input rating.</p> <p><b>RIPPLE AND NOISE:</b> <i>Constant Voltage</i> - Less than 160mVrms, 2V p-p (dc to 20MHz). (NOTE 2)</p> <p><b>TEMPERATURE RATINGS:</b> Operating: 0 to 50°C. Storage: -40 to +75°C.</p> <p><b>TEMPERATURE COEFFICIENT:</b> <i>Constant Voltage</i> - Less than 0.03% plus 4mV change in output per degree Centigrade change in ambient following 30 minutes warm-up. <i>Constant Current</i> - Less than 0.06% plus 85mA change in output per degree Centigrade change in ambient following 30 minutes warm-up.</p> <p><b>STABILITY:</b> <i>Constant Voltage</i> - Less than 0.15% plus 16mV total drift for 8 hours following 30 minutes warm-up under constant ambient conditions.</p>	<p><i>Constant Current</i> - Less than 0.3% plus 0.35A total drift for 8 hours following 30 minutes warm-up under constant ambient conditions.</p> <p><b>TRANSIENT RECOVERY TIME:</b> Less than 50ms/100ms is required for output voltage recovery (in constant voltage operation) to within 2V/0.75V of the nominal output voltage following a load change from full load to half load or vice versa (NOTE 2).</p> <p><b>METERS:</b> A front panel voltmeter (0-80V) and ammeter (0-180A) are provided. (Accuracy is 2% of full scale.)</p> <p><b>RESOLUTION:</b> <i>Constant Voltage</i> - 64mV is the minimum output voltage change that can be obtained with the front panel controls. <i>Constant Current</i> - 0.15A is the minimum output current change that can be obtained using the front panel controls.</p> <p><b>REMOTE RESISTANCE PROGRAMMING:</b> <i>Constant Voltage</i> - 300 ohms/volt (Accuracy: 2%). All programming terminals are on a rear barrier strip. <i>Constant Current</i> - 6.7 ohms/ampere (Accuracy: 2%). All programming terminals are on a rear barrier strip.</p> <p><b>COOLING:</b> Forced air cooling is employed by means of an internal fan.</p> <p><b>WEIGHT:</b> 500 lbs. net. 555 lbs. shipping.</p> <p><b>SIZE:</b> 16-3/4" W x 26-1/4" H x 26-1/8" D. The unit can be mounted in a standard 19" rack panel.</p>
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**NOTES:**

- Specifications apply only when (a) supply is delivering more than 5% of maximum rated output voltage (CV operation) or 5% of maximum rated output current (CC operation), and (b) load is drawing more than 100W. Restriction (b) is lifted when supply is delivering more than 30% of maximum rated output voltage (CV operation) or 30% of maximum rated output current (CC operation).
- For operation with a 50Hz input (possible only with Option 05), output current is linearly derated from 100% at 40°C to 80% at 50°C. Other specifications (indicated in Table) must be increased by 50% for a 50Hz input.

## SECTION II INSTALLATION

### 2-1 INITIAL INSPECTION

2-2 Before shipment, this instrument was inspected and found to be free of mechanical and electrical defects. As soon as the instrument is unpacked, inspect for any damage that may have occurred in transit. Save all packing materials until the inspection is completed. If damage is found, file a claim with the carrier immediately. Hewlett-Packard Sales and Service office should be notified.

### 2-3 Mechanical Check

2-4 This check should confirm that there are no broken knobs or connectors, that the cabinet and panel surfaces are free of dents and scratches, and that the meters are not scratched or cracked.

### 2-5 Electrical Check

2-6 The instrument should be checked against its electrical specifications. Section V includes an "in-cabinet"

performance check to verify proper instrument operation.

### 2-7 INSTALLATION DATA

2-8 The instrument is shipped ready for operation. It is necessary only to connect the instrument to a source of power and it is ready for operation.

### 2-9 Location

2-10 This instrument is fan cooled. Sufficient space should be allotted so that a free flow of cooling air can reach the sides of the instrument when it is in operation. It should be used in an area where the ambient temperature does not exceed 50°C.

### 2-11 Outline Diagram

2-12 Figure 2-1 illustrates the two basic outline shapes for power supplies of the SCR-10 Series.

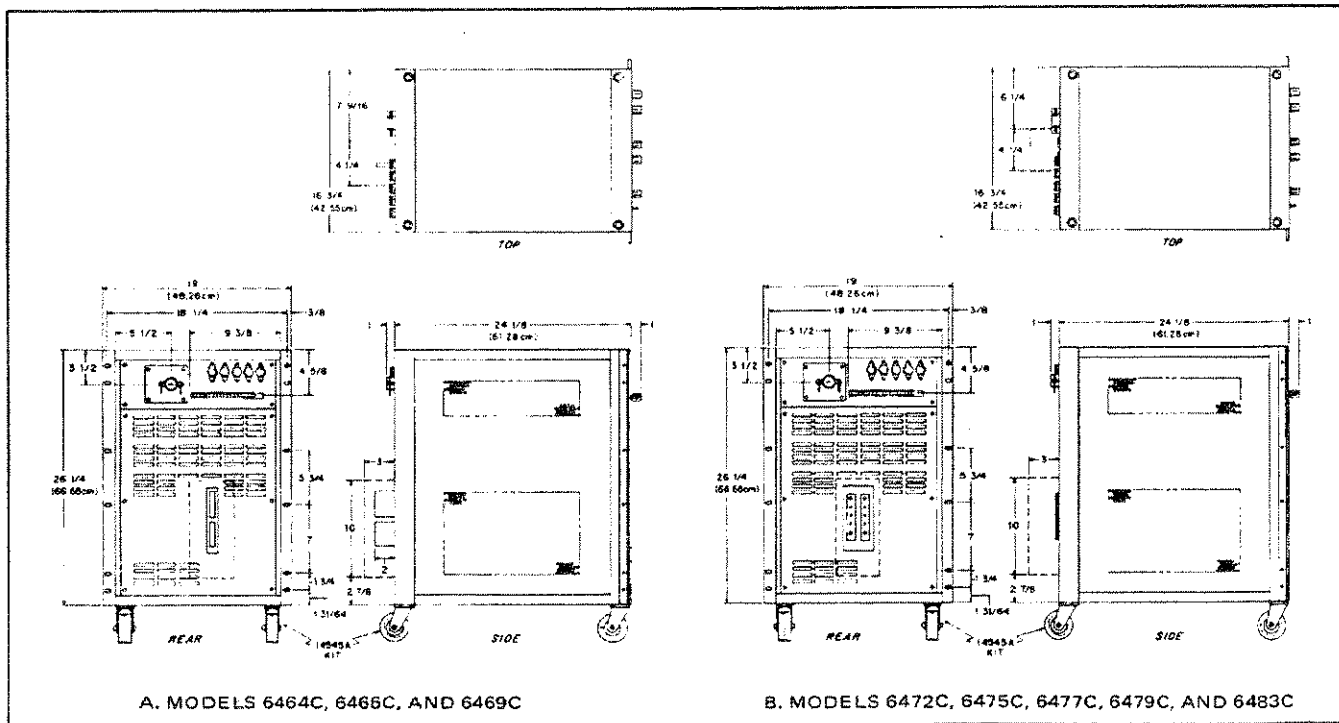


Figure 2-1. Outline Diagram

## 2-13 Rack Mounting

2-14 To rack mount the unit, Option 023 is installed at the factory. The user receives the supply with rack ears attached to the side-front of the unit. The supply can then be mounted in a standard 19-inch rack using standard mounting screws.

## 2-15 INPUT POWER REQUIREMENTS

2-16 The input power is specified by the buyer in his original purchase contract using the appropriate option number. Five input options are available; Option 001 (208Vac), 002 (230Vac), 003 (460Vac), 031 (380Vac) and 032 (400Vac). All of the optional line voltages may vary within  $\pm 10\%$ .

2-17 All ac input connections are made at the rear terminal block (a power cord and connector are not supplied with the unit). The user should ensure that the ac input wires are of the proper gauge. For example, the line current is 50 amperes (maximum) for a 230Vac input, dictating that each conductor be at least number 8 gauge wire. The safety ground wire should be the same gauge as the ac input wires to ensure that it does not open and create a safety hazard.

2-18 The ac power source to this supply may be either delta or wye with isolated neutral. The three phase input voltages must be balanced to within 8% of each other for the supply to operate. However, if the input line voltages are unbalanced by more than 3%, the unit may not meet the published ripple and noise specification; although it will meet all other specifications. Moreover, if the user's line imbalance exceeds 3%, it is advisable to check the input line currents and adjust the current balance circuit, if necessary (refer to Paragraph 5-95).

2-19 Any SCR regulated supply, because of its inherent characteristics, cannot tolerate a great degree of distortion in the input line voltage. The amount of distortion that can be tolerated is not precisely defined, but the supply should never be driven from the output of an inverter or a saturable-reactor type of regulator where the nominally sinusoidal waveshape is flattened considerably. Another cause of distortion is high line impedance. The user should contact the factory if trouble is experienced in this area.

## 2-20 208/230Vac Conversion

2-21 To convert the unit from a 208Vac (Option 001) to a 230Vac (Option 002) input, or vice versa, it is necessary only to restrap transformers T4, T5, and A3T1, T2, and T3. No other changes are necessary because the components used for Options 001 and 002 are identical. The schematic diagram, Figure 7-7, shows the transformers noted above

strapped for 230Vac operation. Hence, to convert the unit from a 208Vac input to a 230Vac input, remove the 208Vac jumpers and connect the transformers as shown on the schematic. To convert the unit from a 230Vac input to a 208Vac input, simply use the 208V terminals as follows:

a. With the unit off, remove jumper between T5-3 and T5-6. Connect new jumper between T5-2 and T5-6. Disconnect wire from fuse F8 to T5-6 and connect it between F8 and T5-5.

b. For transformer T4, remove three straps between A1-230, B1-230, and C1-230 and connect a strap between A1-208, B1-208, and C1-208.

c. On transformers A3T1, A3T2, and A3T3, disconnect three jumpers between T1-0V and T2-230, T2-0V and T3-230, and T3-0V and T1-230. Connect three jumpers as follows: T1-0V to T2-208, T2-0V to T3-208, and T3-0V to T1-208.

## 2-22 380/400Vac Conversion

2-23 To convert the unit from a 380Vac (Option 031) to 400Vac (Option 032) input, or vice versa, it is necessary only to restrap transformers T4, T5, and A3T1, T2, and T3. No other changes are necessary because the components used for Options 031 and 032 are identical.

2-24 **Transformer Connections for 380Vac Input.** For a 380Vac input, the 0V tap on the primary transformer T5 is connected to fuse F7 and the 380V tap is connected to fuse F8. The 400V tap is open. The secondary windings are connected as shown on the schematic, Figure 7-7.

2-25 Transformer T4 is connected in the delta-star configuration shown on Figure 7-7. For 380Vac operation, connect tap A1 to tap 380 on the B section, tap B1 to tap 380 of the C section, and tap C1 to tap 380 of the A section. The three 400V taps are open.

2-26 Transformers A3T1, A3T2 and A3T3 are connected in the delta-delta configuration shown on Figure 7-7. For 380Vac operation, connect T1-0V to T2-380V, T2-0V to T3-380 and T3-0V to T1-380V. The 400 taps on the three transformers are open.

2-27 **Transformer Connections for 400Vac Input.** For a 400Vac input, the 0V tap on the primary of T5 must be connected to fuse F7 and the 400V tap must be connected to fuse F8. The 380V tap is left open. Secondary taps remain connected as shown on Figure 7-7.

2-28 For transformer T4 (delta-star configuration) tap A1 is connected to tap 400 on the B section, tap B1 is connected to tap 400 on the C section, and tap C1 to tap 400 on the A section. The three 380V taps are left open.

2-29 Transformers A3T1, A3T2, and A3T3 are connected in an delta-delta configuration as follows: T1-0V to T2-400V, T2-0V to T3-400V and T3-0V to T1-400V. The 380V taps on the three transformers are left open.

### 2-30 50Hz Ac Input (Option 005)

2-31 For operation from a 50Hz source it is necessary only to readjust the output ripple as described in Paragraph 5-94. In rare instances it may be necessary to readjust the transient recovery potentiometer (A1R48) if the supply shows signs of oscillating.

### 2-32 REPACKAGING FOR SHIPMENT

2-33 To insure safe shipment of the instrument, it is recommended that the package designed for the instrument be used. The original packaging material is reusable. If it is not available, contact your local Hewlett-Packard field office to obtain the materials. This office will also furnish the address of the nearest service center to which the instrument can be shipped. Be sure to attach a tag to the instrument specifying the owner, model number, full serial number, and service required, or a brief description of the trouble.

## SECTION III OPERATING INSTRUCTIONS

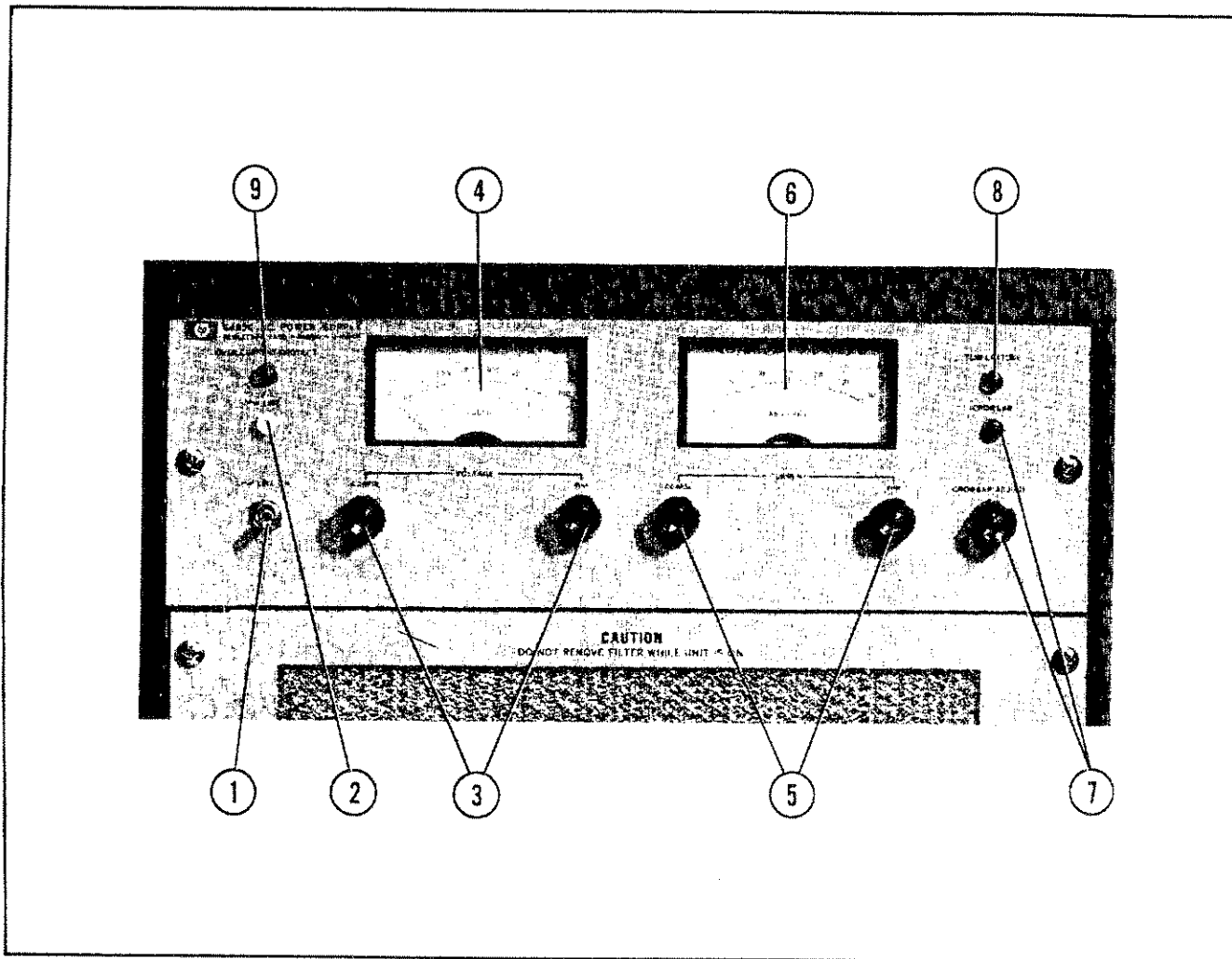


Figure 3-1. Front Panel Controls and Indicators, Typical SCR-10 Supply

### 3-1 TURN-ON CHECKOUT PROCEDURE

3-2 The following checkout procedure describes the use of the front panel controls and indicators (Figure 3-1) and ensures that the supply is operational.

- a. Set  $\sim$ LINE ON switch (1) to on and observe that pilot lamp (2) lights.
- b. After turn-on delay period (see NOTE), rotate CURRENT controls fully clockwise and adjust VOLTAGE controls (3) to obtain desired output voltage on voltmeter (4).

### NOTE

*The supply output is held off for approximately 10 to 20 seconds after turn-on by an internal control circuit.*

- c. To check out constant current circuit, first *turn off supply*. Then, short circuit output bus bars and rotate VOLTAGE controls fully clockwise. Turn-on supply.
- d. After turn-on delay, adjust CURRENT controls (5).

until desired output current is indicated on ammeter (6).

e. If supply is equipped with an overvoltage crowbar (Option 006), front panel will contain CROWBAR ADJUST pot and lamp (7). If Option 006 is not ordered this portion of panel is blank. Refer to Appendix A for crowbar operating instructions.

f. TEMPERATURE and OVERCURRENT PROTECT lamps, (8) and (9), are described in Paragraph 3-24. Before connecting actual load to supply, read the following paragraphs.

### 3-3 OPERATING MODES

3-4 The power supply is designed so that its mode of operation can be selected by making strapping connections between particular terminals on the terminal strips at the rear of the power supply. The terminal designations are plated on the P.C. board below their respective terminals. The following paragraphs describe the procedures for utilizing the various operational capabilities of the power supply. A more theoretical description concerning the operational features of this supply is contained in Application Note 90A, Power Supply Handbook (available at no charge from your local Hewlett-Packard sales office). Sales office addresses appear at the rear of the manual.

#### 3-5 NORMAL OPERATING MODE

3-6 The power supply is normally shipped with its rear terminal strapping connections arranged for constant voltage/constant current, local sensing, local programming, single unit mode of operation. This strapping pattern is shown in Figure 3-2. The operator selects either a constant voltage or a constant current output using the front panel controls (local programming; no strapping changes are necessary).

#### 3-7 Constant Voltage

3-8 To select a constant voltage output, proceed as follows:

- a. Turn on power supply and adjust VOLTAGE controls for desired output voltage with output terminals open.
- b. Short circuit output terminals and adjust CURRENT controls for maximum output current allowable (current limit), as determined by load conditions. If a load change causes the current limit to be exceeded, the power supply will automatically cross over to constant current output at the preset current limit and the output voltage will drop proportionately. In setting the current limit, allowance must be made for high peak currents which can cause unwanted crossover. (Refer to Paragraph 3-63.)

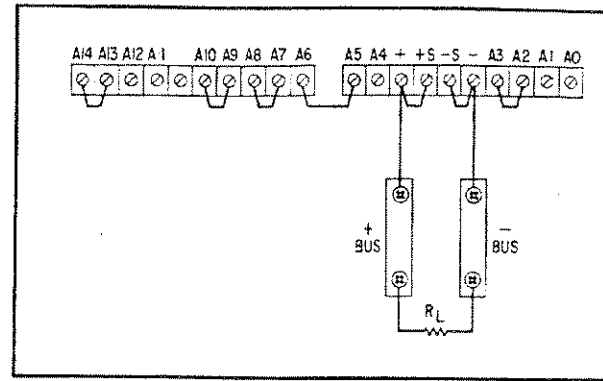


Figure 3-2. Normal Strapping Pattern

#### 3-9 Constant Current

3-10 To select a constant current output, proceed as follows:

- a. Short circuit output terminals and adjust CURRENT controls for desired output current.
- b. Open output terminals and adjust VOLTAGE controls for maximum output voltage allowable (voltage limit as determined by load conditions. If a load change causes the voltage limit to be exceeded, the power supply will automatically cross over to constant voltage output at the pre voltage limit and the output current will drop proportionately. In setting the voltage limit, allowance must be made for high peak voltages which can cause unwanted crossover. (Refer to Paragraph 3-63.)

#### NOTE

*As indicated on the Specification Table (1-1) the supply may not meet all specifications under "light load" conditions. These constraints are due to minimum operating thresholds inherent in the SCR's in the regulator. However, as shown on Table 1-1, the supply will operate satisfactorily if the supply delivers more than 30% of the rated output voltage (Constant Voltage operation) or rated output current (Constant Current operation). Only 5% of rated output voltage or current is required provided that the supply is delivering more than 100 Watts to the load.*

### 3-11 No Load Operation

3-12 When the supply is operated without a load, down-programming speed is considerably slower than in normal loaded operation. The actual time required for the output voltage to decrease to a level set by the front panel control varies from approximately 6 seconds to about 200 seconds, depending on the model number and the incremental change.

### 3-13 Output Ranges — Models 6466C and 6483C Only

3-14 Model 6466C can be operated in one of two output ranges while Model 6483C has three output ranges (refer to Specification Table, 1-1, for these units). No range switching is required but the current and voltage requirements of the load should be predetermined to ensure that the ratings for a particular range will not be exceeded. If a rating is exceeded, one of the supply's internal protection circuits will be activated. For example, if the supply is operating in the high voltage, low current range and the output current exceeds the rating for that range, the overcurrent circuit will become activated and shut off the supply.

### 3-15 Connecting Load

3-16 Each load should be connected to the power supply output terminals using separate pairs of connecting wires. This will minimize mutual coupling effects between loads and will retain full advantage of the low output impedance of the power supply. Each pair of connecting wires should be as short as possible and twisted or shielded to reduce noise pickup. (If a shielded pair is used, connect one end of the shield to ground at the power supply and leave the other end unconnected.)

3-17 If load considerations require that the output power distribution terminals be remotely located from the power supply, then the power supply output terminals should be connected to the remote distribution terminals via a pair of twisted or shielded wires and each load should be separately connected to the remote distribution terminals. For this case, remote sensing should be used. (Refer to Paragraph 3-40.)

### 3-18 Grounding

3-19 Positive or negative output voltages can be obtained from the supply by grounding either output bus. If the output is floated (neither output bus grounded) it can be operated up to 100Vdc above ground (300Vdc above ground for Models 6475C, 6477C, and 6479C).

3-20 When grounding the output, the customer's ground must be used and connected to the desired output bus on the supply. *Do not ground the output at the supply's chassis or at the ac ground terminal on the rear of the supply.* These points are at safety ground and are not the neutral of the power source (refer to Section II). By following these recommendations and running a separate lead from each output bus to the load, the user will be doubly certain that no load current will flow through the ac input wires to the supply.

### 3-21 Operation Beyond Rated Output

3-22 The shaded area on the front panel meter face indicates the approximate amount of output voltage or current that may be available in excess of the normal rated output. Although the supply can be operated in this shaded region without being damaged, it cannot be guaranteed to meet all of its performance specifications.

### 3-23 Protection Circuits

3-24 This supply contains an internal overload protection circuit which shuts off the supply in the event of a prolonged overcurrent or overtemperature condition (details given in Section IV). This circuit also illuminates the applicable indicator lamp (OVERCURRENT PROTECT or TEMPERATURE) on the front panel. If one of these lamps should light, the operator should set the LINE switch to off and turn the VOLTAGE and CURRENT controls to zero (CCW). Next, the unit should be turned back on. If the overload lamp lights again, turn the unit off and proceed to Section V, Troubleshooting. If the lamp does not light, the overload may have been caused by a line transient or an improper connection at the rear barrier strip. Ensure that all screws on the rear barrier strip are tight and that the strapping pattern agrees with the desired operation.

### 3-25 OPTIONAL OPERATING MODES

#### 3-26 Remote Programming, Constant Voltage

3-27 The constant voltage output of the power supply can be programmed (controlled) from a remote location if required. Either a resistance or voltage source can be used as the programming device. The wires connecting the programming terminals of the supply to the remote programming device should be twisted or shielded to reduce noise pickup. The VOLTAGE controls on the front panel are automatically disabled by the following procedures.

3-28 Resistance Programming (Figure 3-3). In this mode,



the output voltage will vary at a rate determined by the constant voltage programming coefficient (refer to Specifications Table, 1-1). The programming coefficient is determined by the programming current. This current is factory adjusted to within 1%. If greater programming accuracy is required, it may be achieved by adjusting A1R9 as discussed in Paragraph 5-76.

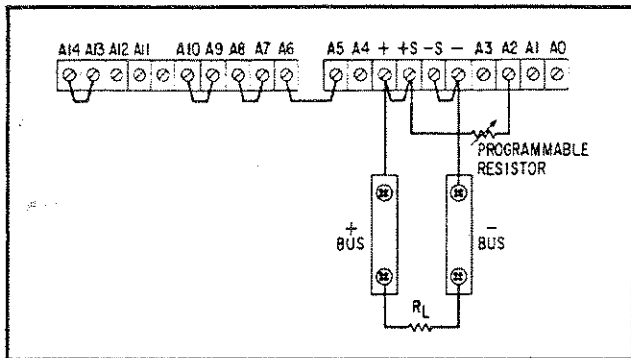


Figure 3-3. Remote Resistance Programming, Constant Voltage

3-29 The output voltage of the supply should be  $0 \pm 10\text{mV}$  when zero ohms is connected across the programming terminals. If a zero ohm voltage closer to zero than this is required, it may be achieved by inserting and adjusting A1R11 as discussed in Paragraph 5-75.

3-30 To maintain the stability and temperature coefficient of the power supply, use programming resistors that have stable, low noise, and low temperature coefficient (less than 30ppm per degree Centigrade) characteristics. A switch can be used in conjunction with various resistance values in order to obtain discrete output voltages. The switch should have make-before-break contacts to avoid momentarily opening the programming terminals during the switching interval.

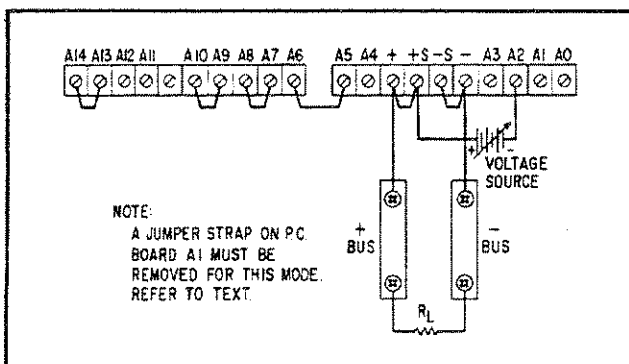


Figure 3-4. Remote Resistance Programming, Constant Voltage, Unity Gain

3-31 Voltage Programming, Unity Gain (Figure 3-4). Employ the strapping pattern shown in Figure 3-4 for voltage programming with unity gain. In this mode, the output voltage will vary in a 1 to 1 ratio with the programming voltage (reference voltage) and the load on the programming voltage source will not exceed 20 microamperes.

3-32 To prevent the internal programming current from flowing to terminal A2 and into the external voltage source a jumper strap on P.C. Board A1 must be removed (see Figure 7-1 for location of the jumper). Be sure to reconnect this jumper before converting the unit to a different operating mode.

3-33 The output voltage of this supply *cannot* be voltage programmed with gain unlike some of the other HP supplies.

### 3-34 Remote Programming, Constant Current

3-35 Either a resistance or a voltage source can be used to control the constant current output of the supply. The CURRENT controls on the front panel are automatically disabled by the following procedures.

3-36 Resistance Programming (Figure 3-5). In this mode, the output current varies at a rate determined by the constant current programming coefficient given in Specifications Table, 1-1. The programming coefficient is determined by the constant current programming current which is adjusted to within 2% at the factory. If greater programming accuracy is required, it may be achieved by adjusting A1R2 as discussed in Paragraph 5-83. The output current of the supply when zero ohms is placed across the programming terminals may be set to exactly zero by adjusting A1R28 as discussed in Paragraph 5-82.

3-37 Use stable, low noise, low temperature coefficient (less than 30ppm/°C) programming resistors to maintain the power supply temperature coefficient and stability

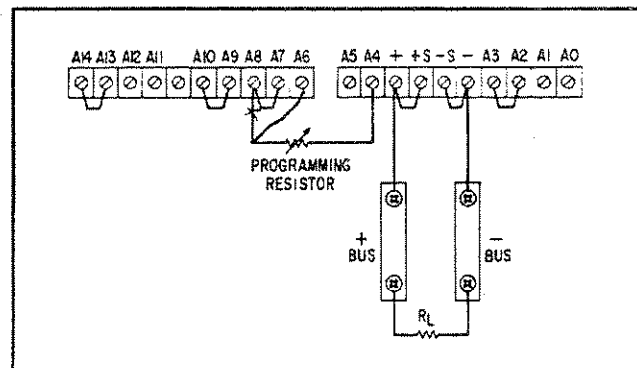


Figure 3-5. Remote Resistance Programming, Constant Current

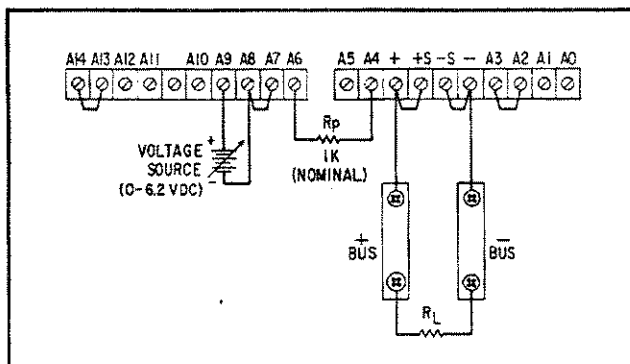
specifications. A switch may be used to set discrete values of output current. A make-before-break type of switch should be used since the output current will exceed the maximum rating of the power supply if the switch contacts open during the switching interval.

**CAUTION**

*If the programming terminals (A4 and A8) should open at any time during the remote resistance programming mode, the output current will rise to a value that may damage the load. If, in the particular programming configuration in use, there is a chance that the terminals might become open, it is suggested that a 1kΩ resistor be connected across the programming terminals. Like the programming resistor, this resistor should be a low noise, low temperature coefficient type. Note that when this resistor is used, the resistance value actually programming the supply is the parallel combination of the remote programming resistance and the resistor across the programming terminals.*

**3-38 Voltage Programming With Gain (Figure 3-6).** The power supply output current can be programmed using an external voltage source with variable gain by utilizing the strapping pattern shown in Figure 3-6. In this mode, the output current will vary linearly from 0 to maximum rating when the voltage source is programmed from 0 to 6.2 volts. The value of the voltage source appearing across terminals A9 and A10 should not exceed 7.4Vdc if possible damage to the instrument is to be avoided.

**3-39** External resistor  $R_p$  should have stable, low noise, and low temperature coefficient (less than 30ppm per degree Centigrade) characteristics in order to maintain the stability and temperature specifications of the power supply.



**Figure 3-6. Remote Voltage Programming, Non-Unity Gain, Constant Current**

Note that it is possible to use the front panel current controls already in the supply ( $R_3$  and  $R_4$ ) as the *gain* control ( $R_p$ ) by simply removing the *external*  $R_p$  and strapping terminals A5 and A6 together.

**3-40 Remote Sensing (Figure 3-7)**

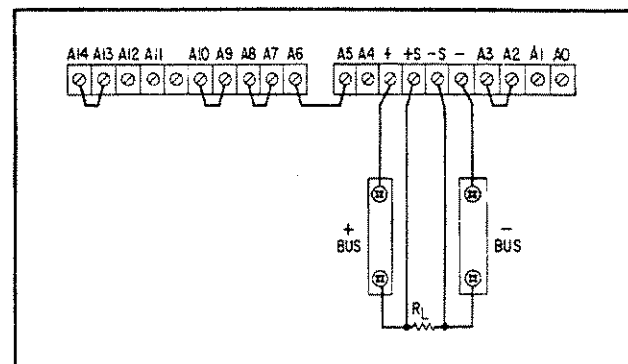
**3-41** Remote sensing is used to maintain good regulation at the load and reduce the degradation of regulation which would occur due to the voltage drop in the leads between the power supply and the load. Remote sensing is accomplished by utilizing the strapping pattern shown in Figure 3-7. The power supply should be turned off before changing strapping patterns. The leads from the sensing ( $\pm S$ ) terminals to the load will carry much less current than the load leads and it is not required that these leads be as heavy as the load leads. However, they must be twisted or shielded to minimize noise pickup.

**3-42** For reasonable load lead lengths, remote sensing greatly improves the performance of the supply. However, if the load is located a considerable distance from the supply, added precautions must be observed to obtain satisfactory operation. Notice that the voltage drop in the load leads subtracts directly from the available output voltage and also reduces the amplitude of the feedback error signals that are developed within the unit. Because of these factors it is recommended that the drop in the negative load lead not exceed 3 volts. If a larger drop must be tolerated, please consult an HP Sales Engineer.

**NOTE**

*Due to the voltage drop in the load leads, it may be necessary to readjust the current limit in the remote sensing mode.*

**3-43** Observance of the precautions in Paragraph 3-42 will result in a low dc output impedance at the load. However,



**Figure 3-7. Remote Sensing**

another factor that must be considered is the inductance of long load leads. This causes a high ac impedance and could affect the stability of the feedback loop seriously enough to cause oscillation. If this is the case, it is recommended that the following actions be taken:

- a. Adjust equalization control A1R48 to remove oscillation, or to achieve best possible transient response for given long load lead configuration. Refer to Paragraph 5-88 for discussion of transient response measurement.
- b. If performing adjustment in step (a) above does not remove oscillation, connect a capacitor having similar characteristics to those of the output capacitors (C1, C2, etc.) used in the supply, directly across load using short leads. Readjust equalization control R48 as in step (a) above after making this change.

3-44 Although the strapping patterns shown in Figures 3-3 through 3-6 employ local sensing, it is possible to operate a power supply simultaneously in the remote sensing and remote programming modes.

### 3-45 Auto-Parallel Operation (Figure 3-8)

3-46 Two (maximum) SCR-10 power supplies can be connected in an Auto-Parallel arrangement to obtain an output current greater than that available from one supply. Auto-Parallel operation permits equal current sharing under all load conditions, and allows complete control of the output current from the master power supply. The output current

of the slave will be approximately equal to the master's output current regardless of the load conditions. Because the output current controls of the slave are operative, they should be set to maximum to prevent the slave reverting to constant current operation; this would occur if the master output current setting exceeded the slave's.

3-47 Remote sensing and programming can be used, though the strapping arrangements shown in Figure 3-8 show local sensing and programming.

### 3-48 Auto-Series Operation (Figure 3-9)

3-49 Two (maximum) SCR-10 power supplies can be operated in Auto-Series to obtain a higher voltage than that available from a single supply. When this connection is used the output voltage of the slave supply varies in accordance with that of the master supply. At maximum output voltage, the voltage of the slave is determined by the setting of the front panel VOLTAGE controls on the master. The master supply must be the most positive supply of the series. The output CURRENT controls of the slave unit are operative and the current limit is equal to the lowest control setting. If any of the output CURRENT controls are set too low, automatic crossover to constant current operation will occur and the output voltage will drop. Remote sensing and programming can be used, though the strapping arrangements shown in Figure 3-9 show local sensing and programming.

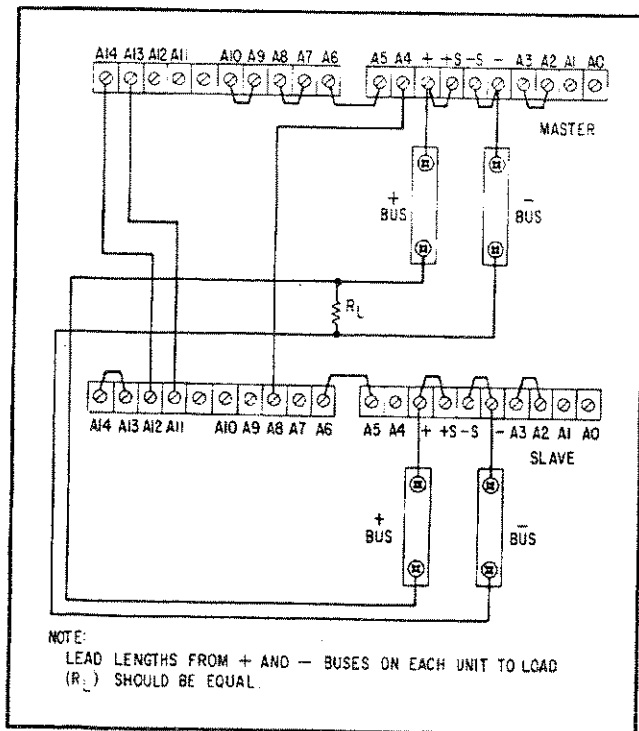


Figure 3-8. Auto-Parallel Operation

### CAUTION

*Model 6483C, of the SCR-10 Series, cannot be operated in Auto-Series because this supply can not be floated at more than 100Vdc off ground. However, "Auto-Tracking" can be utilized to obtain coordinated positive and negative voltages if the center tap of the combination is grounded (refer to Paragraph 3-52).*

3-50 In order to maintain the temperature coefficient and stability specifications of the power supply, the external resistors ( $R_X$ ) shown in Figure 3-9 should be stable, low noise, low temperature coefficient (less than 30ppm per degree Centigrade) resistors. The value of each resistor is dependent on the maximum voltage rating of the "master" supply. The value of  $R_X$  is this voltage divided by the Constant Voltage programming current of the slave supply ( $1/K_p$  where  $K_p$  is the resistance programming coefficient). The voltage contribution of the slave is determined by its voltage control setting.

3-51 Protection diodes (CR5), connected across the output

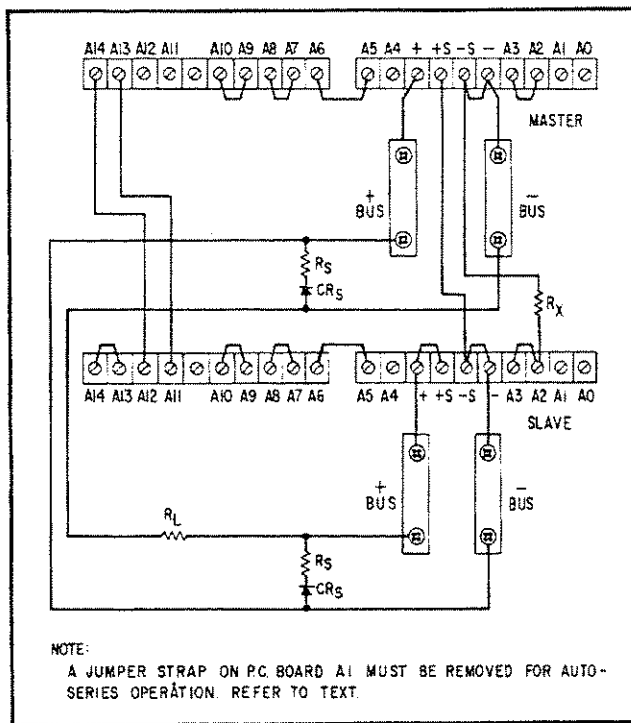


Figure 3-9. Auto-Series Operation

of each supply, prevent internal damages that could occur from reverse voltages if one supply is turned on before the other. On six models in the SCR-10 Series, current limiting resistors are required. Values and part numbers for the resistors and diodes are given in the chart below.

Model	CRp Commercial/HP Part No.	RS Value
6464C	A295F/1901-0336	Not required
6466C	A90F/1901-0335	Not required
6469C	A90A/1901-0338	0.02Ω
6472C	1N3289/1901-0307	0.03Ω
6475C	1N1187A/1901-0320	0.08Ω
6477C	S3270/1901-0326	0.20Ω
6479C	S3270/1901-0326	0.25Ω
6483C	S3270/1901-0326	0.75Ω

3-52 When the center tap of an Auto-Series combination is grounded, coordinated positive and negative voltages result. This technique is commonly referred to as "rubber-banding" and an external reference source may be employed if desired. Any change of the internal or external reference source (e.g., drift, ripple) will cause an equal percentage change in the outputs of both the master and slave supplies. This feature can be of considerable use in analog computer and other applications, where the load requires a positive and a negative power supply and is less susceptible to an output voltage change occurring simultaneously in both supplies than to a change in either supply alone.

### 3-53 Battery Charging

3-54 The automatic crossover between constant voltage and constant current displayed by the SCR-10 Series make it an ideal supply for battery charging applications. Using this feature, a battery may be charged at a constant current until the maximum charge voltage is reached at which point the supply will revert to constant voltage and continue to supply a trickle charge current sufficient to maintain full charge (see Figure 3-10). Thus, the charging operation can be unattended after properly setting the charging rate and the maximum charge voltage and connecting the battery to the output terminals of the supply.

3-55 The procedure for setting the charging rate and full charge voltage on SCR-10 Series power supplies is as follows:

- Turn both the VOLTAGE and CURRENT control fully counterclockwise (CCW).
- Place a short circuit across the output terminals and rotate the VOLTAGE control fully clockwise (CW).
- Rotate the CURRENT control to the desired charging rate as read on the front panel ammeter.
- Rotate VOLTAGE control fully CCW and remove the short circuit.
- Rotate the VOLTAGE control to the desired full charge voltage as read on either the front panel voltmeter (2% accuracy) or a more precise voltage standard. The unit may then be connected to the battery terminals, positive to positive and negative to negative.

3-56 Protection diode CRp prevents a charged battery from discharging into the supply if the supply is turned off.

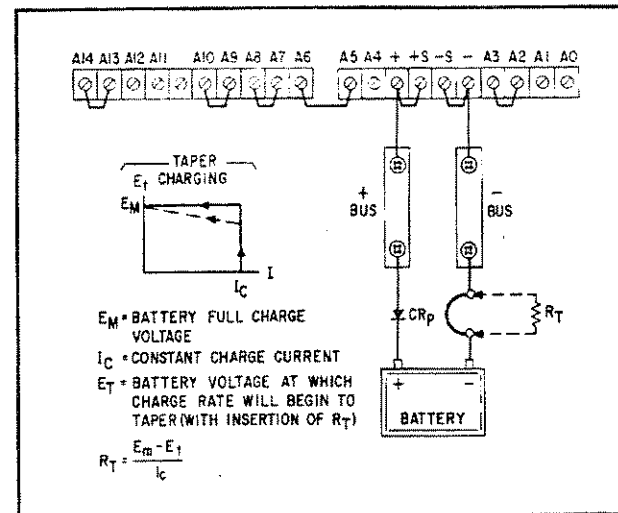


Figure 3-10. Battery Charging

## NOTE

A large battery, connected as a load, presents a large capacitance across the output terminals. This capacitance could cause the supply to oscillate; particularly if remote sensing is employed. To stabilize the supply, potentiometer A1R48 may be readjusted (increase resistance) as outlined in Paragraph 5-88. If the maximum resistance of R48 is not sufficient, jumper (R58) can be removed and an additional resistance substituted in series with the potentiometer.

**3-57 Taper Charge.** For charging lead-acid cells, the charging current should be reduced when the battery is nearing completion of its charge. This is accomplished by inserting a small resistance ( $R_T$ ) in series with one of the load leads from the supply to the battery which alters the normally rectangular charging plot in such a manner as to provide a taper charge for the last portion of the charge cycle. The value of this resistance is the difference between the full charge voltage and the voltage at which the tapering is to start, divided by the maximum charging current.

### 3-58 Battery Discharging

**3-59** Automatic constant current, unattended discharging of a battery using the SCR-10 Series requires certain changes in the strapping configuration on the rear barrier strip as illustrated in Figure 3-11. Also, a jumper strap on P.C. Board A1 must be removed (see Figure 7-1 for location). Removal of this jumper ensures that the internal programming current does not flow into terminal A2. Before operation, the user should make sure that the interconnecting leads between supply and battery are secure and cannot become opened.

**3-60** The supply initially operates in constant current mode at the value set by the current control. When the battery voltage is high the supply output voltage will be low, and as the battery discharges the supply output voltage increases. A constant voltage is maintained across  $R_X$  (constant current through  $R_X$ ). This condition will prevail until the battery voltage drops to zero. At this point, the supply will switch off and no more current will flow through  $R_X$ . Diode CRp protects the supply against reverse voltages. As shown on Figure 3-11,  $R_X$  must be selected so that its IR drop is less than the maximum rated output of the supply yet greater than the battery voltage.

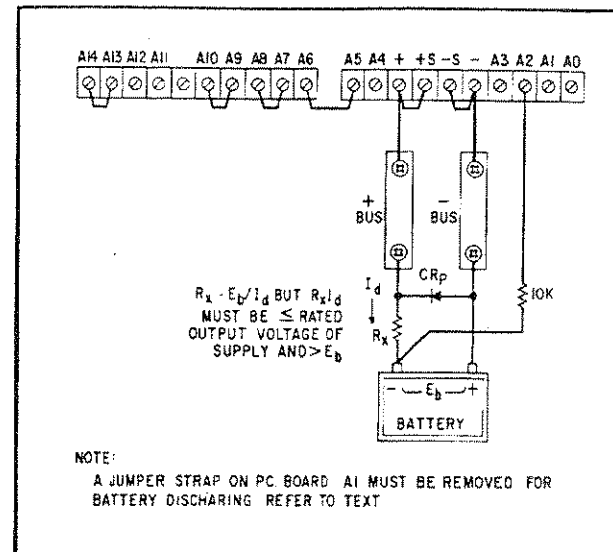


Figure 3-11. Battery Discharging

**3-61** The procedure for the connection of the component in this configuration is as follows:

- Turn off the power supply and rotate the current control full counterclockwise. (The voltage control will be disconnected by step b.)
- Remove the designated jumpers (A2 to A3 and P.C. Board) and connect A2 to the negative terminal of the battery through 10k resistor.
- Connect the negative terminal of the supply to the positive terminal of the battery.
- Insert  $R_X$  between the positive terminal of the supply and the negative terminal of the battery, energize the supply and rotate the current control to the desired discharge current as read on the front panel meter.

### 3-62 SPECIAL OPERATING CONSIDERATION

#### 3-63 Pulse Loading

**3-64** The power supply will automatically cross over from constant voltage to constant current operation, or the reverse, in response to an increase (over the preset limit) in the output current or voltage, respectively. Although the preset limit may be set higher than the average output current or voltage, high peak currents or voltages (as occur in pulse loading) may exceed the preset limit and cause crossover to occur. If this crossover limiting is not desired, set the preset limit for the peak requirement and not the average.

## SECTION IV PRINCIPLES OF OPERATION

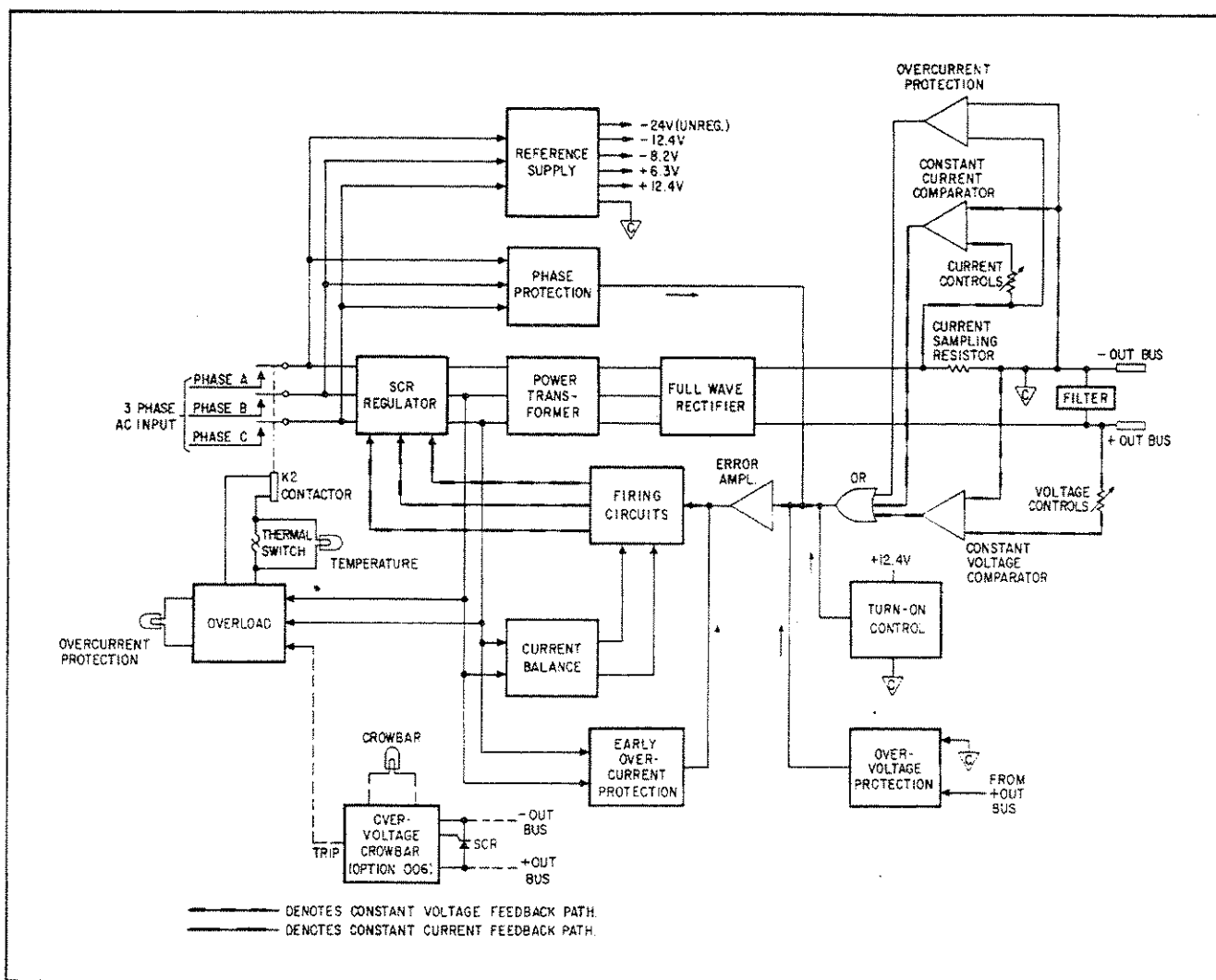


Figure 4-1. Overall Block Diagram

### 4-1 OVERALL BLOCK DIAGRAM DISCUSSION

4-2 The major circuits of the power supply are shown on the overall block diagram of Figure 4-1. The three phase ac input passes through normally closed contacts of contactor K2 to the SCR regulator circuit. Under normal operating conditions, K2 is maintained energized by the overload circuit, as will be explained later. The regulator contains three SCR's, one per phase, which operate in conjunction with the firing circuits, error amplifier, and Constant Voltage /

Constant Current comparators as a feedback loop. The feedback loop determines the firing time of the SCR's so that a regulated ac input voltage is applied to the primary of the power transformer. The adjusted ac is then stepped-down by the power transformer and receives full-wave rectification and filtering before appearing at the output bus bars as a constant dc output voltage or current.

### 4-3 Feedback Loop

4-4 During normal operation, the feedback signals

controlling the SCR firings originate within the constant voltage or constant current comparator. (The SCR's are also controlled by the current balance circuit and, in certain instances, by various protection circuits, as will be explained subsequently.) During constant voltage operation, the constant voltage comparator continuously compares the output voltage of the supply with the drop across the VOLTAGE controls. If these voltages are not equal, the comparator produces an amplified error signal which is further amplified by the error amplifier and fed back to the firing circuits. On the basis of the amplitude and polarity of the feedback signal, the firing circuits then issue a phase adjusted firing pulse to each SCR so that the original difference is counteracted. In this manner, the constant voltage comparator helps to maintain a constant output voltage and also generates the error signals necessary to set the output voltage at the level established by the VOLTAGE controls.

4-5 During constant current operation, the constant current comparator detects any difference between the voltage drop developed by the load current flowing through the current sampling resistor and the voltage across the CURRENT controls. If the two inputs to the comparator are momentarily unequal, an error signal is generated which (after amplification) alters the firing angle of the SCR's by the amount necessary to reduce the error voltage at the comparator input to zero. Hence, the IR drop across the current sampling resistor, and therefore the output current, is maintained at a constant value.

4-6 Since the constant voltage comparator tends to achieve zero output impedance and alters the output current whenever the load resistance changes, while the constant current comparator causes the output impedance to be infinite and changes the output voltage in response to any load resistance change, it is obvious that the two comparison amplifiers can not operate simultaneously. For any given value of load resistance, the power supply must act either as a constant voltage source or as a constant current source — it cannot be both.

4-7 Figure 4-2 shows the output characteristic of a constant voltage/constant current power supply. With no load attached ( $R_L = \infty$ ),  $I_{OUT} = 0$ , and  $E_{OUT} = E_S$ , the front panel voltage control setting. When a load resistance is applied to the output terminals of the power supply, the output current increases, while the output voltage remains constant; point D thus represents a typical constant voltage operating point. Further decreases in load resistance are accompanied by further increases in  $I_{OUT}$  with no change in the output voltage until the output current reaches  $I_S$ , a value equal to the front panel current control setting. At this point the supply automatically changes its mode of operation and becomes a constant current source; still further decreases in the value of load resistance are accompanied by

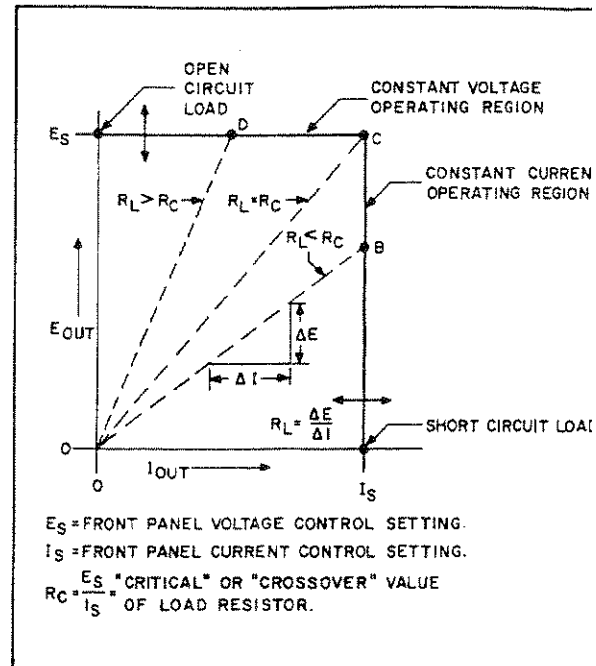


Figure 4-2. Operating Locus of a CV/CC Power Supply

a drop in the supply output voltage with no accompanying change in the output current value. With a short circuit across the output load terminals,  $I_{OUT} = I_S$  and  $E_{OUT} = 0$ .

4-8 The "crossover" value of load resistance can be defined as  $R_C = E_S / I_S$ . Adjustment of the front panel voltage and current controls permits this "crossover" resistance  $R_C$  to be set to any desired value from 0 to  $\infty$ . If  $R_L$  is greater than  $R_C$ , the supply is in constant voltage operation, while if  $R_L$  is less than  $R_C$ , the supply is in constant current operation.

#### 4-9 Current Balance Circuit

4-10 The current balance circuit maintains the rms amplitude of the input current flowing in the phase B and phase C lines equal to input current flowing in the phase A (reference) line. To accomplish this, the circuit compares the current in the phase B and C lines with that of the reference phase (A). If a difference exists, the current balance circuit issues an error signal to the firing circuits. The firing of phase B or phase C SCR is then advanced or delayed in accordance with the polarity of the original difference signal. Hence, the current balance circuit allows the unit to operate with a line-to-line input voltage unbalance of up to 5%.

#### 4-11 Turn-On Control Circuit

4-12 The turn-on control circuit is a long time constant network which achieves a slow turn-on characteristic. This feature protects load devices by minimizing turn-on overshoot. At turn-on, the control circuit provides an inhibitory

voltage to the firing circuits (via the error amplifier) keeping the SCR's off for approximately 20 seconds. After 20 seconds, the inhibit voltage is removed and the circuit no longer exercises any control over the operation of the supply.

#### 4-13 Overvoltage Protection Feature

4-14 The overvoltage protection circuit prevents the output voltage of the supply from exceeding 110% of rating. It monitors the output voltage of the supply and, if it exceeds the 110% threshold, sends a "hold" signal to the firing circuits. This circuit is seldom activated because the constant voltage comparator prevents the output voltage from exceeding the limit established by the front panel VOLTAGE controls. However, if the constant voltage comparator should fail, the overvoltage protection circuit provides the necessary backup protection.

#### 4-15 Overcurrent Protection Circuit

4-16 The overcurrent protection circuit provides backup protection for the constant current comparator being similar to the overvoltage protection circuit in this respect. The overcurrent circuit monitors the output current (IR drop across sampling resistor) and generates a "hold" signal to the SCR firing circuits if the output current attempts to exceed approximately 115% of rating.

#### 4-17 Early Overcurrent Protection Circuit

4-18 Further overcurrent protection is afforded by the early overcurrent protection circuit. This circuit minimizes output current overshoot during initial short circuit conditions. If the output of the supply is shorted, both the line current and the output current attempt to rise. The early overcurrent protection circuit monitors the line current (phases B and C) and generates a turn off signal to the SCR firing circuits if the line current exceeds about 40% of the nominal peak value. The three SCR's are then turned-off momentarily until the line current falls below the 40% threshold and the early overcurrent protection circuit is deactivated. At this time, the constant current comparator and remaining components of the feedback loop again assume control of the SCR's keeping the output current constant despite short circuit conditions.

4-19 Although the constant current comparator attempts to keep the output current from rising when the output is first shorted, it requires approximately 5 cycles of the input ac before a correction can be made. This delay is a result of the overall loop response time and is mostly caused by equalizing networks within the error amplifier. The early overcurrent circuit overcomes this delay by bypassing the error amplifier and injecting its turn-off signal directly into the firing circuits. With this arrangement, correction can begin after only one cycle of the input ac.

#### 4-20 Phase Protection Circuit

4-21 Another protection circuit used in this supply is the phase protection circuit. This circuit insures that no damage will occur internally should one or more of the input phases fail or if the ac voltage on all three input lines falls below 25% of the input rating. If such a failure does occur, the phase protection circuit clamps the feedback control signal off at the input to the error amplifier. When the input lines return to normal, the operation reverses itself.

#### 4-22 Overload Circuit

4-23 This circuit detects the presence of an extended overcurrent or an overtemperature condition and deenergizes contactor K2 if either of these conditions occur. With K2 deenergized, the 3-phase ac input path is interrupted shutting down the supply. Contactor K2 is also deenergized if the overload circuit receives a "trip" input from the overvoltage crowbar (optional circuit).

4-24 The overload circuit continuously monitors the line current on phases B and C and deenergizes K2 if the line current exceeds approximately 140% of the nominal rms line rating of the unit for a period of about one second. The overload circuit also illuminates the OVERCURRENT PROTECT lamp on the front panel under these conditions. During normal operation of the supply, the early overcurrent protection circuit and/or the constant current feedback loop will compensate for overcurrent problems before the overload circuit ever becomes activated. However, should a failure occur within these overcurrent protection circuits, the overload circuit would then become activated deenergizing K2 and shutting off the supply.

4-25 A thermal switch, mounted on the SCR heat sink, provides overtemperature protection by opening if the heat sink temperature rises to  $200^{\circ} \pm 5^{\circ}\text{F}$  (208Vac or 230Vac input) or  $170^{\circ} \pm 5^{\circ}\text{F}$  (380Vac, 400Vac, or 460Vac input). Opening the thermal switch deenergizes contactor K2 and removes the short across the TEMPERATURE lamp, allowing it to light.

#### 4-26 Reference Supply

4-27 The reference supply provides regulated bias voltages which are used by the internal circuitry throughout the main power supply. All of the voltages shown are regulated except for the -24V.

#### 4-28 Overvoltage Crowbar (Optional Circuit — not available for Model 6464C)

4-29 A built-in overvoltage "crowbar" protection circuit (Option 006) can be ordered with any power supply in the



SCR-10 Series with the exception of Model 6464C. This circuit monitors the output voltage of the supply and fires an SCR if the output voltage exceeds a preset and adjustable threshold. The conducting SCR effectively short circuits the supply reducing the output to near zero volts. Complete details concerning the Option 006 crowbar circuit are given in Appendix A.

#### 4-30 DETAILED CIRCUIT ANALYSIS (See Schematic, Figure 7-7)

#### 4-31 SCR Regulator and Firing Circuits

4-32 The SCR regulator, operating in conjunction with the firing circuits, controls the amount of ac power applied to the primary of the power transformer. Each of the three input phases (arbitrarily designated A, B, and C) has an SCR and firing circuit associated with it.

4-33 Each SCR conducts upon the simultaneous application of a negative voltage to its cathode (input ac) and a positive voltage to its gate lead. The gate signal (firing pulse) used to turn on the SCR is a positive going pulse of about 3.5 volts having a duration of approximately  $50\mu\text{sec}$ . Once the SCR is fired, it remains in conduction (even though the gate input is removed) until the input ac swings positive.

4-34 Inductors L1, L2, and L3 limit surge currents due to the conduction of their respective SCR's. A capacitive network, connected across each SCR, filters voltage transients caused by contactor K2 when it is energized or deenergized. Also connected across each SCR is a diode (CR1-CR3) which protects the SCR against reverse voltages and also serves as the return path for the current from one of the other phases.

4-35 **Firing Circuits.** The three phase firing circuits receive the output from the error amplifier and generate firing pulses that turn on the SCR's in their respective phases at the precise time necessary to fulfill the feedback loop requirements. As indicated on the schematic, everything is done in triplicate. For each phase there is a blocking oscillator which is synchronized so that each SCR conducts at identically the same phase angle in its respective phase.

4-36 The input to the firing circuits is the feedback voltage from error amplifier A1U3. This voltage varies between -1V dc to +3Vdc (with respect to common  $\nabla$  at terminal A7) as a function of the output conditions. The feedback voltage is applied to an integrating network (R7, C3-R17, C13 and R27, C23) in the emitter circuit of each blocking oscillator. The emitter capacitors produce a steadily rising ramp voltage whose origin is approximately -12.4V (see Figure 4-3). The waveform on the base of each blocking oscillator is mainly the result of internal generators A2R28, A2C4-

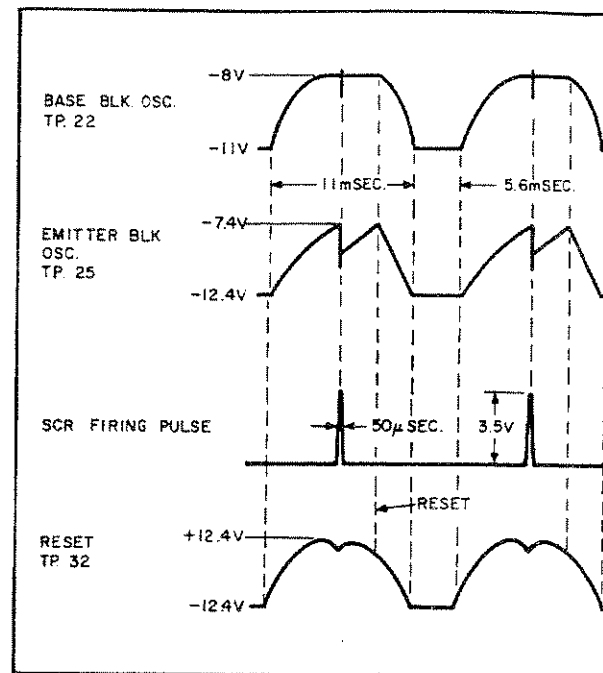


Figure 4-3. SCR Firing Circuit, Timing Diagram

A1R100, A2C14 and A1R120, A2C24 which produce an 11msec wide, rectangular shaped waveform. The 5.6msec wide negative portion is flattened by the action of clamp diodes CR6, CR16 and CR26. The positive going emitter voltage rises to meet the base voltage and when the base-emitter bias reaches about 0.6Vdc the applicable transistor (Q1, Q2, or Q3) becomes forward biased initiating blocking oscillator action. Regenerative coupling between the collector and base windings of each transformer (T7, T8, and T9) readily drives the transistor into full conduction where it remains (for about  $50\mu\text{sec}$ ) until the transformer becomes saturated. At this time, the collapsing magnetic field returns the blocking oscillator to the nonconducting state.

4-37 The firing pulses are taken from the output winding of each transformer and applied between the gate and cathode of the appropriate SCR. Diodes CR2, CR12 and CR22 connected across the output windings, are used to damp out negative overshoot. Resistors R1, R11 and R21 provide a bleed path for current flowing out of the SCR gate terminal while diodes CR1, CR11 and CR21 block the voltage established by the gate current from reaching the output winding.

4-38 Capacitors C1, C11, and C21 between base and emitter of each blocking oscillator transistor prevent spurious triggering. The base current which flows when the transistors conduct is limited by resistors R3, R13, or R23 connected to each base winding.

4-39 **Reset Operation.** At the end of each input line cycle the applicable emitter ramp capacitor (C3, C13, or C23) a

base capacitor (C4, C14, or C24) are reset to their starting voltages (-12.4V and -11V, respectively). The resetting operation is performed by the positive going rectified waveform received by the firing circuits at TP32 (Figure 4-3). Input diodes CR5, CR15, and CR25 clamp the base of the waveform at the -12.4V reference level. The reset signals are coupled to the ramp and base capacitors through diodes CR3, CR4 (phase A) CR13, CR14 (phase B) and CR23, CR24 (phase C). Reset starts during the negative transition of the reset waveform and the base and emitter capacitors require about 2msec to reach their starting voltages. The capacitors remain at this point for about 5.6msec whereupon a new ac input cycle begins and the entire operation is repeated.

**4-40 Firing Angle Determination.** The firing angle of the SCR's determines the amount of ac power applied to the input transformer and, thus, the amplitude of the dc output. An SCR that is fired at an early point in the input cycle provides a higher output than one that is fired later in the input cycle.

**4-41** Two types of inputs to the firing circuits control the time at which the firing pulses are generated. The input having the greatest degree of control is the main feedback loop input from the error amplifier. As previously mentioned, this input varies between -1V and +3V according to the output conditions. A more positive feedback voltage increases the steepness of the positive going ramp on the emitters of each blocking oscillator and the SCR's are fired early in the input cycle. The reverse is true for a more negative feedback voltage. In this manner, the feedback voltage corrects for output changes due to variations in the load resistance or line voltage.

**4-42** The second input to the firing circuits consists of the phase B and phase C control signals from the current balance circuit. These signals correct for small line-to-line variations in the three phase input currents. To accomplish this, the control signals are fed directly to base capacitors C14 and C24 in the phase B and C blocking oscillators. If the line currents are all equal to each other the two control signals are at 0V potential and do not affect the firing circuit. If the line currents become unequal, the phase B or phase C control signal swings momentarily positive or negative, depending on the polarity of the original difference. A control signal that momentarily swings negative at the base of the blocking oscillator, allows the emitter ramp voltage to catch the base voltage earlier in the cycle thus increasing the SCR firing angle. A positive going current balance control signal has the opposite effect.

**4-43 SCR Firing Circuit and Regulator Behavior at Low Outputs.** Each firing circuit and its associated SCR has a minimum operating threshold below which turn-on of either,

or both, will not occur. This threshold point varies and is determined by the inherent characteristics of both the firing circuit and the SCR of interest.

**4-44** When the supply is delivering medium and high output power, each SCR conducts once during every ac input cycle of its associated phase. However, at low power outputs, only two or even one SCR will conduct during the associated input cycle. Moreover, at very low outputs, the active SCR may skip one, or more, cycles between conduction periods. Because of these factors, the regulation, stability, overshoot, and linear programming characteristics of the supply are somewhat degraded at low outputs. The minimum outputs in both Constant Voltage and Constant Current operation at which the supply will perform within specifications are given in the output ratings of Table 1-1 in this manual.

#### **4-45 Constant Voltage Comparator**

**4-46** This circuit consists of the front panel programming resistors (R1 and R2), a differential amplifier stage, (A1U1 and associated components), and a constant current source, A1Q1. An integrated circuit is used for the differential amplifier to minimize differential voltages due to mismatched transistors and thermal differentials.

**4-47** The constant voltage comparator continuously compares the voltage drop across the VOLTAGE controls with the output voltage and, if a difference exists, produces an error voltage whose amplitude is proportional to this difference. The error signal ultimately alters the conduction angle of the SCR regulators which, in turn, alter the output current so that the output voltage becomes equal to the voltage drop across the VOLTAGE controls. Hence, through feedback action, the difference between the two inputs to U1 is held at zero volts.

**4-48** One input of the differential amplifier (pin 1) is connected to the output voltage sensing terminal of the supply (-S) through impedance equalizing resistor A1R1. The other input of the differential amplifier (pin 10) is connected to a summing point (terminal A2) at the junction of the programming resistors and resistor R6. Instantaneous changes in the output voltage or changes in the voltage at the summing point due to manipulation of the VOLTAGE controls produce a difference voltage between the two inputs of the differential amplifier. This difference voltage is amplified and appears at the output of the differential amplifier (pin 11) as an error voltage.

**4-49** Resistor R2, in series with the summing-point input to the differential amplifier, limits the current through the programming resistors during rapid voltage turn-down. Diodes CR1 and CR2 prevent excessive voltage excursions from over-driving the differential amplifier.

4-50 During constant voltage operation, the programming current flowing through the programming resistors (VOLTAGE controls) is held constant by the action of constant current source, Q1. A constant current flowing through the programming resistors assures linear constant voltage programming.


#### 4-51 Comparator Protection Circuit (used only on Models 6472C, 6475C, 6477C, 6479C, and 6483C)

4-52 As indicated in the above paragraph heading, this circuit is only used in the higher voltage Models of the SCR-10 Series of power supplies. The circuit consists of a small three phase power supply which is used to forward bias diode A1CR3. The power supply consists of wye connected transformers A3T1, A3T2, and A3T3, and a half-wave rectifier (A1CR5, CR6, CR7) and filter (A1C4). During normal operation, this supply forward biases protection diode CR3, which is connected in series with the summing input to A1U1 (pin 10). Under these conditions, the diode acts as a near short circuit and has no effect on the operation of the constant voltage comparator. However, under no-load conditions (or with a highly capacitive load), if the supply is rapidly down programmed, diode CR3 becomes reverse biased due to a positive going transient at its cathode. With diode CR3 reverse biased, the input path to comparator A1U1 is opened preventing damage to the device.

#### 4-53 Constant Current Comparator

4-54 This circuit is similar in appearance and operation to the constant voltage comparator circuit. It consists of the coarse and fine current controls (R3 and R4) and a differential amplifier stage (U2 and associated components). As in the constant voltage comparator, an integrated circuit is used for the differential amplifier to minimize differential voltages due to mismatched transistors and thermal differentials.

4-55 The constant current comparator circuit continuously compares the voltage drop across the CURRENT controls with the voltage drop across the current sampling resistors A4R123A-A4R123B. If a difference exists, the differential amplifier produces an error signal which is proportional to this difference. The remaining components in the feedback loop (amplifiers, firing circuit and SCR's) function to maintain the drop across the current sampling resistors, and hence the output current, at a constant value.

4-56 One input of the differential amplifier (pin 1) is connected to the supply's common point  which is tied to the outbound side of the sampling resistors. The other input of the differential amplifier (pin 10) is connected to a summing point (terminal A6) at the junction of the programming resistors and the current pullout resistors R25 and R26.

Changes in the output current due to load changes or changes in the voltage at the summing point due to manipulation of the CURRENT controls produce a difference voltage between the two inputs of the differential amplifier. This difference voltage is amplified and appears at the output of the differential amplifier (pin 12) as an error voltage which ultimately varies the conduction of the SCR's.

#### 4-57 Error Amplifier

4-58 Operational amplifier stage U3 provides most of the feedback loop gain. During normal operation, U3 receives the feedback voltage at its non-inverting input from either the constant voltage or constant current comparator via OR gate diode CR23 or CR24. Diode CR23 is forward biased and CR24 reverse biased during constant voltage operation. The reverse is true during constant current operation.

4-59 Under overcurrent conditions, U3 can also be driven by the overcurrent protection circuit via OR-gate diode CR25. As previously mentioned, protection circuit inputs are applied directly to pin 3 of U3.

4-60 Feedback networks C15, R50 and C20, R46 shape the high frequency rolloff in the loop gain response to stabilize the feedback loop.

#### 4-61 Overcurrent Protection Circuit

4-62 Stage U2 monitors the output current (IR drop across the sampling resistors) and conducts if the output current exceeds about 115% of the output current rating. Resistor A1R38 is factory selected to set the 115% threshold point.

#### 4-63 Turn-On Control

4-64 This circuit minimizes turn-on overshoot by keeping the SCR's off for approximately 20 seconds after the unit is turned on. At turn-on, Q4 conducts, providing a less positive voltage to the error amplifier. This voltage keeps the SCR's off until C23 charges up turning off Q4. Diode CR27 provides a quick discharge path for C23 when the supply is turned off.

#### 4-65 Overvoltage Protection Circuit

4-66 This circuit prevents the output voltage from exceeding approximately 110% of the maximum voltage rating. Under non-overvoltage conditions, transistor Q10 is cutoff due to the -12.4V bias connected to its base. If the voltage at the + output bus becomes positive enough (exceeds the 110% threshold) Q10 conducts clamping the error amplifier input. Resistor R82, mounted on standoffs, is factory selected to obtain the desired trip point.

#### 4-67 Phase Protection Circuit

4-68 This circuit protects the SCR's and power transformer in case one of the input phases should fail. The three phase input ac is rectified by CR38, CR39 and CR40, filtered by C30, and the resultant voltage on the base of Q9 is normally negative enough to hold the transistor off. However, if one of the input phases fails, (or if all three phases drop below 25% of the nominal voltage) the voltage across C30 becomes positive enough to break down zener diode VR10 and drive Q9 into conduction. The conduction of Q9 clamps the input to the error amplifier to a less positive voltage, thus turning off the SCR's.

4-69 Resistor R77, in the base circuit of Q9, is factory selected to obtain the desired trip point.

#### 4-70 Early Overcurrent Protection

4-71 This circuit provides rapid protection for the load during initial short circuit conditions. When activated, this circuit injects a negative cutoff voltage directly into the firing circuits by passing the loop delay caused by the error amplifier.

4-72 A voltage that is proportional to the line current is applied to stage A1Q3 from a rectifier and filter (shared by the overload circuit). Without an overload, transistor Q3 is conducting but not sufficiently to breakdown VR4 in its collector circuit. Thus, A1Q2 is cutoff and the circuit is deactivated. The circuit becomes activated if the input line current rises to about 40% of its normal peak value. In this case, the increased conduction of Q3 breaks down zener diode VR4, forward biasing CR19 and CR22 and permitting Q2 to conduct. The negative output voltage is applied to the firing circuits halting SCR conduction until the output current falls to an acceptable level.

#### 4-73 Current Balance Circuit

4-74 This circuit controls the firing of the phase B and phase C SCR's so that the input currents on these lines are equal in amplitude to the input current on the phase A (reference) line.

4-75 The current balancing circuit for each of the corrected phases (B and C) receives its input directly from the associated input wire, which is run physically through the air-core of input transformer A3T10 and A3T11, respectively. Each input wire serves as the primary of its input transformer, inducing the ac current flowing along that wire into the secondary winding. The ac current waveform on each input wire is of a rectangular shape and consists of positive and negative excursions. The negative current flows through the SCR associated with the input line while the positive current

flows through a companion diode (CR1, CR2, or CR3) and is, in fact, the return current from another phase. The return current for the reference phase (A) flows through diode CR2 or CR3 and, therefore, appears on the phase B or C line as a positive going pulse. The return current for phase B appears on the input lines of phase A or C, and the return current for phase C appears on the input line of phase A or phase B.

4-76 It is the function of each current balancing circuit to maintain the amplitudes of these positive and negative input currents equal. The positive pulses are rectified by CR46/CR48, filtered by C34/C44, and the resultant positive dc current is applied to the pin 2 of U4/U5 via summing resistor R95/R115. The negative excursions are rectified by CR45/CR47, filtered by C35/C45, and the negative dc current is summed with the positive current by summing network R94, R95/R114, R115. If the amplitude of the positive and negative currents are unequal, an error signal is developed at the output of U4/U5 and fed to the firing circuits. This error signal affects the bias on the base of Q2/Q3 and ultimately advances or delays the firing of the SCR's according to the polarity of the original error signal. Once the amplitudes of each of the positive and negative input currents become equal, no error signal (zero volts) is generated by U4/U5.

4-77 Potentiometers R101 and R121 provide a means of offsetting minor differences in the phase B and phase C current balance loop.

#### 4-78 Overload Circuit

4-79 The overload circuit detects the presence of an over-temperature or extended overcurrent condition and deenergizes power contactor K2 if either of these conditions occur. The circuit also provides a visual indication of both conditions.

4-80 **Overcurrent Circuit.** Diodes CR50 through CR53 and capacitor C52 rectify and filter the phase B and C line voltage to provide a dc voltage which is equivalent to the line current. During normal conditions, (no overload) the rectified voltage is not sufficiently positive to turn-on unijunction transistor Q11. With Q11 off, relay K1 is energized once power is applied to bridge rectifier CR54-CR57 through the LINE switch. Closed contacts (8 and 12) of K then allow K2 to energize, permitting application of the main three phase power to the unit.

4-81 If the rms amplitude of the line current rises above 40% of the input line rating, Q11 turns on providing a positive pulse to transformer T6. This pulse fires an SCR (CR58) connected across relay K1. With K1 deenergized, the ac path to contactor K2 is broken deenergizing this relay

and removing the ac power. Notice that 2 phase power is still applied to the overload circuit keeping CR58 in conduction and illuminating the OVERCURRENT PROTECT lamp through closed contacts of K1. It requires approximately one second for the relays to deenergize and shut off power.

4-82 Overload relay K1 is also deenergized if the crowbar circuit (optional circuit) is activated. The pulse is applied to an additional winding of T6 to SCR CR58. The OVERCURRENT PROTECT lamp will also be illuminated in this case together with the CROWBAR lamp.

4-83 After an overload occurs and the condition has been corrected, the operator must set the LINE switch to OFF, wait at least 3 seconds, and then set the LINE switch to ON.

4-84 **Overtemperature Circuit.** The overtemperature components are TC1 and parallel connected TEMPERATURE lamp DS3. Thermal switch TC1 is closed without an overtemperature condition. The near short circuit, created by TC1 across TEMPERATURE lamp DS3 keeps the lamp off during this condition. If the heat sink temperature rises above the limits specified in Paragraph 4-25, TC1 opens

deenergizing contactor K2 and allowing the TEMPERATURE lamp to light. When the unit cools sufficiently, T again closes.

#### 4-85 Reference Supply

4-86 The reference supply is a self-contained feedback supply employing a series regulator. The supply provides several reference voltages which are used throughout the unit.

4-87 The reference voltages are all derived from a full wave rectifier (CR28 through CR33) and filter (C25) which provide an unregulated -24Vdc. The regulating circuit consists of series regulator Q5, driver Q6, and differential amplifier stage Q7 and Q8. The differential amplifier compares the voltage at the junction of a voltage divider (equal resistors R64 and R69) connected across the output (24.8V) with the voltage at the supply's common point,  $\nabla C$ . Any difference in voltage is detected and fed to series regulator Q5 the correct phase and amplitude to maintain the output constant. The +6.3 and -8.2 voltages are developed across zener diodes VR1 and VR5. Output capacitors C27 and C28 stabilize the regulator feedback loop.