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CROSSBAR SYSTEMS
NO. 3 AND 5A
CONTROLLED FERRORESONANT
RECTIFIER CIRCUIT
NEGATIVE 48V DC, 50 AMP
AUTOMATIC REGULATION

CHANGES

D. Description of Changes

D.01 Change title from:

CROSSBAR SYSTEMS
NO. 3
CONTROLLED FERRORESONANT
RECTIFIER CIRCUIT
NEGATIVE 48V DC, 50 AMP
AUTOMATIC REGULATION

To:

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BELL TELEPHONE LABORATORIES, INCORPORATED

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CROSSBAR SYSTEMS
NO. 3
CONTROLLED FERRORESONANT RECTIFIER CIRCUIT
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AUTOMATIC REGULATION

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SECTION I - GENERAL DESCRIPTION

1. PURPOSE OF CIRCUIT

1.01 To provide isolated, filtered and regulated dc power from a single-phase 60-Hz ac source for automatically charging and floating a 23- or 24-cell lead-antimony or lead-calcium battery.

2. PRINCIPLE OF OPERATION

2.01 This rectifier is of the controlled ferroresonant type, which furnishes power through the output of a ferroresonant transformer, the state of which is electronically controlled.

BASIC FERRORESONANT TRANSFORMER

2.02 The basic ferroresonant transformer consists of an iron core upon which are wound separate primary and secondary coils, separated from each other by magnetic shunts in the windows of the core. These shunts cause some of the flux induced by the primary to be diverted from the secondary winding, resulting in a certain amount of isolation between the two windings. This construction produces a transformer having a high leakage reactance between its primary and secondary windings. It also allows the magnetic flux levels in the two sections of core to differ with respect to both amplitude and phase. The situation is analogous to a circuit in which the primary and secondary are wound on one conventional core, and the primary is connected in series with an inductor whose reactance is equal to the effective leakage reactance produced by the magnetic shunts in the shunted construction.

2.03 The transformers secondary is connected across an ac capacitor whose value is chosen such that it will resonate with the leakage inductance, causing the secondary section of the core to go into ac saturation.

2.04 Because its core saturates, the transformer can provide a relatively constant output voltage at its secondary. By rectifying and filtering the output from a properly tapped secondary, a relatively constant dc voltage is made available to power a load. Changes in the primary voltage (input variations) will only slightly alter the saturation level of the core, producing only a small change in output voltage. Loading the output will lower the Q of the resonating circuit, reducing core saturation, and also resulting in only a small change in output voltage. As loading increases still further, the Q of the resonant circuit gradually decreases. Eventually the resonant circuit will become unable to maintain saturation of the transformer core. Loading beyond this point results in a rapid drop in output voltage. Under such extreme loading the leakage inductance limits output current.

2.05 There are several disadvantages to using the ferroresonant transformer circuit in its basic form. First, since the magnetic characteristics of the core determine the degree of voltage regulation, it is difficult to obtain precise regulation. Second, it is difficult to adjust output voltage, since it is dependent upon the number of turns tapped from the secondary. Third, the output voltage is sensitive to variations in input frequency. Fourth, the load at which current limiting commences changes with input voltage variation; a high input voltage induces more energy into the resonating circuit, and requires more loading to bring the core out of saturation.

CONTROLLED FERRORESONANT CIRCUIT

2.06 Electronically controlling the ferroresonant transformer through negative feedback eliminates the problems found in the basic ferroresonant circuit.

2.07 It is possible to control the amount of flux absorbed in the transformer secondary, and thus the output voltage, by simulating core saturation with an inductor and a triac. By turning on the triac at varying phase angles with respect to line voltage, the output voltage is raised or lowered. Thus the output voltage becomes essentially independent of input voltage, frequency, load current, temperature, and magnetic characteristics and is easily adjusted without alteration of secondary taps. Should all electronic control fail, the high leakage reactance between the transformers primary and secondary will effectively limit output current.

3. GENERAL DESCRIPTION OF OPERATION

3.01 The ac input is fed through a contactor to the input coil of a ferroresonant transformer, which is isolated from the output coil by magnetic shunts.

3.02 A center-tapped winding on the output coil of the ferroresonant transformer is connected to a rectifier stack, followed by an output filter. The ferroresonant capacitor is also connected to the output coil.

3.03 A triac, series-connected with an inductor across the resonating capacitor, controls regulation. A regulating circuit supplies gate pulses to turn the triac on earlier or later in the ac cycle to compensate for changes in input voltage or output loading. A current limiting circuit overrides the voltage regulator if output current increases beyond a predetermined limit. Under overload conditions the current limiting circuit assumes control of gate pulses to the triac, lowering output voltage sufficiently to maintain output current within the preset limit. If the control circuit fails, then the ferroresonant transformer leakage inductance limits output current.

3.04 This rectifier is equipped with auxiliary circuits which perform certain operations in accordance with signals received from the plant and circuits which transmit signals to the plant concerning rectifier status.

SECTION II - DETAILED DESCRIPTION

1. POWER CIRCUIT

INPUT

1.01 Nominal 208/240-volt single-phase ac input power is connected to terminals L1 and L2 of contactor K3, which either connects or interrupts input power to the primary winding of ferroresonant transformer T1.

FERRORESONANT TRANSFORMER

1.02 Transformer T1 performs part of the regulation function, with triac CR3 and regulation, current limiting and pulse circuit CP-RCPC performing the remainder. The primary winding is magnetically decoupled from the secondary winding by magnetic shunts located between the two windings. The amount of decoupling determines the maximum output current the secondary can deliver in the event all electronic regulation fails.

AUXILIARY

1.03 Transformer T3 supplies power to the sensing and alarm relays CP-SAR and to the regulation, current limiting and pulse circuit CP-RCPC. The dc power supply fuses F1 and F2 protect T3 from faults in either the ac control relays or in the power supply circuitry on CP-RCPC. Taps are provided on T3 primary to permit operation with ac input of either 208 or 240 volts. Failure of F1 or F2 will cause the rectifier to shut down but not lock out, lighting the RECT FAIL lamp and grounding the RFA lead to the plant.

CONTROLLED SECONDARY CIRCUIT

1.04 The high voltage from T1 secondary terminals 7 and 9 is added in series with the lower voltage from T1 terminals 5 and 6, and the sum is connected across capacitor C4. The C4 and leakage inductance of T1 form a resonant circuit. The series combination of triac CR3 and inductor L2 is connected across C4. Control pulses from CP-RCPC turn the triac on at varying phase angles with respect to line voltage. While the triac is turned on, inductor L2 is essentially connected in parallel with C4, thus changing the impedance of the resonant tank circuit. This impedance change causes current flowing in the tank circuit to change in phase relative to current flowing in the primary winding of T1. Thereby maintaining a constant voltage across the tank circuit. Since the power output portion of T1 secondary (terminals 4, 5, and 6) is closely coupled magnetically to the tank circuit winding of T1 (terminals 5 through 9), the power output voltage will also remain constant despite variation of input line voltage or output loading. A resistance-capacitance network consisting of R4 and C5 supresses switching transients generated in the tank circuit.

RECTIFICATION AND FILTERING

1.05 The power secondary winding is connected to the power rectifier stack, consisting of silicon diodes CR1 and CR2, in a full-wave center-tapped configuration. Capacitors C1-C3 form a filter which smooths the rectifiers negative 48-volt dc output. Bleeder resistor R1 discharges the filter capacitors when the rectifier is disconnected from the battery and ac input is removed.

PROTECTION

1.06 An external charge fuse protects the rectifiers output circuitry. If the charge fuse operates, a signal from the plant CFA lead causes the rectifier to shut down and lock out, light the RECT FAIL lamp and send an RFA signal to the plant.

OUTPUT METERING

1.07 Meter shunt R3 is connected in series with the positive (grounded) output of the rectifier. As output current increases, a small voltage drop appears across R3. This voltage drop causes ammeter M1 to deflect and sends a signal, proportional to output current, to the current limiting circuit on CP-RCPC. The meter is calibrated such that a voltage drop of 50-millivolts across R3 will cause the meter to indicate a current of 75 amperes. Note - This rectifier can deliver a maximum of 50 amperes output current.

2. PULSE CIRCUIT

2.01 The pulse circuit, which generates gate pulses for triggering triac CR3, is located on CP-RCPC. The pulse circuit power supply, isolation transformer T2 and bridge rectifier CR6-CR9 furnishes a pulsating dc voltage to synchronize the pulse circuit with the ac input line. A voltage-controlled relaxation oscillator consisting of unijunction transistor Q2, capacitor C7, and resistors R18 and R27 furnishes a series of triggering pulses to the gate terminal of silicon controlled rectifier CR4. The CR4 modifies the waveshape of the pulsating dc to provide a triggering waveform through diode CR10 to the gate of triac CR3. The voltage regulation and current limiting circuits, also on CP-RCPC, provide a voltage for controlling the oscillator. Thus the triggering waveform applied to the triac is advanced or delayed with respect to line voltage phase, so that the voltage at the rectifiers output remains constant.

3. VOLTAGE REGULATING AND CURRENT LIMITING CIRCUIT

VOLTAGE REGULATOR

3.01 Error amplifier A3 on CP-RCPC samples the rectifiers output voltage and compares it to a constant reference voltage to produce an error signal. The error signal is coupled to the pulse circuit oscillator through diode CR5 to control the timing of the oscillator. As long as the output of amplifier A3 is more positive than that of amplifier A2, the voltage regulator will control the pulse oscillator such that the rectifiers output voltage remains constant.

CURRENT LIMITING CIRCUIT

3.02 Operational amplifiers A1 and A2 and associated stabilizing circuitry on CP-RCPC form the current limiting circuit. Amplifier A1 monitors the rectifiers output current by measuring the voltage drop across the meter shunt R3. The A1 amplifies this voltage and couples it to amplifier A2 through a voltage divider circuit consisting of potentiometer R9, resistors R4 and R14 and zener diode CR3. Amplifier A2 functions as a comparator whose output remains negative until rectifier output current increases beyond a preset level. When rectifier output current reaches that predetermined limit, the output of A1 is a positive voltage, which is then coupled through diode CR1 to the pulse circuit oscillator, thereby lowering the rectifier output voltage to maintain output current within the specified limit. Potentiometer R9 permits adjustment of the output current limit between 50-percent and 105-percent of the rated value.

3.03 A current walk-in circuit which prevents a large current surge at the time of rectifier turn-on is also provided on CP-RCPC. Field effect transistor Q1 and capacitor C3 perform this function. When the rectifier is OFF the gate terminal of Q1 is shorted to the drain terminal through contacts of relay K1; therefore Q1 does not conduct. When the rectifier is turned ON; relay K1 operates, breaking the path between Q1 gate and drain terminals and biasing Q1 ON. The Q1, conducting shorts out the current limit adjust potentiometer R9, and applies a positive voltage to the input of A2. Thus, A2 applies a positive signal to the pulse oscillator, thereby limiting rectifier output current. Simultaneously, capacitor C3 begins charging through resistor R12, gradually biasing Q1 OFF and delivering a negative going ramp waveform to the input of A2. Thus, the output of A2 gradually decreases, allowing the rectifier to deliver more output current. The C3 and R12 are chosen such that they provide a long time constant. Consequently, the rectifier output current increase from zero to load current is gradual and nearly linear.

4. ALARM CIRCUITS

NORMAL OPERATION

4.01 Under normal operating conditions the rectifier will remain energized and connected to the load unless it is manually turned off, or unless certain trouble conditions cause automatic shutdown.

HIGH VOLTAGE AND CHARGE FUSE ALARM SHUTDOWNS

4.02 If battery voltage exceeds a predetermined limit, external high voltage shutdown circuitry in the plant will supply ground to pin 6 on plug P5. If the rectifiers output current is equal to or greater than 2-1/2 amperes, relay K2 on CP-SAR will operate through the closed contacts of relay K4 (also on CP-SAR). Closed contacts of relay K2 (on CP-SAR) will apply battery to relay K3 (on CP-SAR), which will then release relay K1, shutting down the rectifier. Relay K1, releasing, lights the RECT FAIL lamp and extends ground through pin 8 of plug P5 to operate an external rectifier fail alarm.

4.03 If a fault causes operation of a charge fuse and its associated alarm fuse, circuitry in the plant will provide battery potential to the rectifier at pin 14 of plug P5, causing relay K3 (on CP-SAR) to operate. Relay K3, operated, releases relay K1, shutting down the rectifier, lighting the RECT FAIL lamp and supplying ground at pin 8 of plug P5 to operate an external rectifier fail alarm.

VOLTAGE DETECTOR FOR SENSING LEADS

4.04 Circuit pack CP-SAR also provides a voltage sensing circuit, consisting of transistor Q1, diode CR1, and associated biasing circuitry. Under normal operating conditions current flowing in a voltage divider network (R3-R6 and zener diode CR1) biases Q1 into conduction, thereby operating relay K1 (on CP-SAR). If one or both voltage sensing leads RB or RG opens, current through the voltage divider network will cease, biasing Q1 into cutoff and releasing relay K1 (on CP-SAR). Relay K1, released, will automatically transfer the voltage sensing lead reference point from the battery to the rectifiers output terminals.

5. RECTIFIER TESTING

GENERAL

5.01 Before testing or adjusting the rectifier turn it off by depressing the POWER ON/POWER OFF switch; the POWER OFF indicator lamp will light. Disconnect plug P5 from the rectifier and remove all external output protective fuses. This will isolate the rectifier from the load and will automatically transfer the voltage sensing reference point from the battery to the rectifier output.

OUTPUT VOLTAGE ADJUSTMENT

5.02 After completing the procedure described in 5.01 depress the POWER ON/POWER OFF switch to start the rectifier; the POWER ON indicator lamp will light. Observing correct polarity, insert dc voltmeter probes into OUTPUT VOLTS test jacks J3(-) and J4(+). Adjust output voltage with potentiometer R11, OUTPUT VOLTS ADJUST, located on the rectifiers control panel.

OUTPUT CURRENT LIMITING ADJUSTMENT

5.03 Output current is adjustable from 50-percent to 105-percent of the rated value, and is factory adjusted to 100-percent of the rated output. To adjust the output current limit proceed as follows:

(a) If the rectifier is operating, and output current is not greater than the desired limit, shut down the rectifier (refer to 5.01 for procedure) and attach an artificial load to insure that output current exceeds the desired limit.

(b) Adjust the output current limit with potentiometer R9, CURRENT LIMIT ADJUST, located on the rectifiers control panel. Do not allow rectifier output current to exceed 105-percent of the rated value. This rectifier is rated at 50-amperes output.

SECTION III - REFERENCE DATA

1. WORKING LIMITS

1.01 Input Requirements:

(a) Phase: Single-phase, 2-wire

(b) Frequency: 57 to 63 Hz

(c) Line-to-Line Voltage:

184 to 220Vac, Y Option
212 to 254Vac, Z Option

1.02 Output Capabilities: dc voltage at output terminals at full-load.

48.0 to 57.2 volts, 50 amperes

1.03 Output Polarity:

Negative output, positive ground

1.04 Electrical Characteristics: Output voltage regulation for combined line and load variation.

±1/2 Percent Steady State	For output within range of 48-54.5 volts and load current between no load and full load.
±1/2 Percent Steady State	For output within range of 54.6-57.2 volts and load current between no load and 10 percent of full load.
Transients	For step load changes between 5 and 45 amperes and ac line voltage transients within the input range stated above, when connected to a 200-Ah battery: recovery to within ±1/2 percent regulation within 0.075 second.

Noise - 38 dBrn, measured with a noise meter having 600 ohms input impedance and using C- message weighting, at the terminals of a 200-Ah battery.

1.05 Environmental Ratings

(a) Operating Ambient Temperature: 0°C to +50°C

(b) Storage Temperature: -40°C to +60°C

(c) Heat Dissipation: 1878 BTU/HR

2. FUNCTIONAL DESIGNATIONS

2.01 Switches

Designation	Meaning
S1 - Power On/Power Off	Alternate action push-switch, initiates start sequence. When locked in "ON" position, it lights the POWER ON lamp.

2.02 Fuses

Designation	Meaning
F1, F2 - dc power supply	Protects T3 dc power supply transformer and supply circuit on CP-RCPC.
F3 - Output Volts	Protects against faults to ground at the J2 and J3 OUTPUT VOLTS test jacks. The alarm contact is not used.

2.03 Lamps

Designation	Meaning
POWER ON	Lighted when POWER ON/POWER OFF switch is in the "ON" position.
POWER OFF	Lighted when POWER ON/POWER OFF switch is in "OFF" position and when in "ON" position if rectifier is shut down by plant HV or CFA signals or loss of line voltage.
RECT FAIL	Lighted whenever relay K3 on CP-SAR operates to shut down and lock out the rectifier (due to signal on CFA lead). Also lighted when rectifier is shut down by signal on HV lead, or when dc power supply fuses F1 or F2 operate, causing rectifier shutdown.

2.04 Circuit Packs

Designation	Meaning
SAR	Sensing and alarm relays
RCPC	Regulating, current limiting and pulse circuit

3. FUNCTIONS

3.01 This rectifier is designed to perform the following functions:

(a) Float and charge a 23- or 24-cell battery.

(b) Isolate its output from the ac source.

(c) Limit its output to a safe value.

(d) Provide a switch for manual starting and shutdown of rectifier.

(e) Allows current limiting function to override voltage regulation to prevent damage due to extreme overload.

(f) Limits inrush current during turn-on.

(g) Provides for adjusting and regulating voltage at battery terminals.

(h) Provides an ammeter to indicate the rectifiers output current with plus-or-minus 2-percent accuracy.

4. CONNECTING CIRCUITS

4.01 This circuit will function with the following circuits:

(a) Negative 48-Volt Power Plant - Control, Alarm, Charge and Discharge Circuit - SD-26452-01.

5. MANUFACTURING TESTING REQUIREMENTS

5.01 This circuit shall be capable of performing all the functions specified in this Circuit Description.

6. ADJUSTMENTS

6.01 The following control settings are recommended:

Designation	Setting
Output Voltage Adjust	52.08 volts dc
Current Limit Adjust	50 amperes (Caution - do not allow output current to exceed 52.5 amperes.)

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