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A GROUND DETECTOR FOR A FLOATING, HIGH CURRENT DC SYSTEM

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PREPARED FOR THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION UNDER CONTRACT AT(07-2) 1

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ABSTRACT

An instrument is described for detection of electrical grounding of the 3.6 megawatt DC test loop in the Heat Transfer Laboratory of the Savannah River Laboratory. The DC loop is ungrounded except for leakage through cooling water in the buses and loads. A high-frequency, low-voltage signal is applied to the positive DC bus. A tuned amplifier receives the signal from the negative bus. Loss of the received signal indicates a ground at either bus or at the load. Alarm and shutdown circuits are actuated whenever a ground occurs.

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A GROUND DETECTOR FOR A FLOATING, HIGH-CURRENT DC SYSTEM

INTRODUCTION

At the Heat Transfer Laboratory of the Savannah River Laboratory (SRL), resistance heating of various devices for heat transfer studies is accomplished by passing high currents (up to 30,000 amperes) through the devices from a bus-connected bank of controlled rectifiers.[1] The buses and loads are cooled by water flowing through electrically insulated connections from an earth-grounded water supply. The buses and loads are not grounded except through the cooling water, which is purified and deionized to provide as high a resistance as practicable.

If a single fault to ground should occur anywhere in the floating DC system, the current through the ground system (building structural members, water pipes, etc.) would be small, and no immediate danger would exist. However, if two or more ground faults should occur simultaneously, the shunted current could cause rupture of the pressurized water system, damage to the building structure, or damage to parts of the DC system itself. Depending on the voltages and currents involved, personnel hazards ranging from a shower of molten fragments to a flash steam explosion might result. Any ground fault, therefore, that might occur should be detected and the system shut down immediately by means of appropriate electrical interlocks and alarms.

An instrument was designed to detect ground faults in a high-current, nongrounded DC system, and to actuate suitable shutdown circuits. The detection and protection device also prevents startup of the system when a ground fault exists.

DC POWER SUPPLY SYSTEM

Six large rectifier units are connected to two water-cooled buses to supply DC power to various loads for thermohydraulic studies at SRL (Figure 1). Each rectifier unit is operated from 480-volt, three-phase, 60-hz transformers. Each rectifier is capable of supplying 5000 amperes at up to 120 volts DC to the buses. Total power capability is 3.6 megawatts DC output when all six units are in service.

Because the rectifiers are controlled by silicon-controlled-rectifiers (SCR) in full-wave configuration, a large, 360-hz ripple is contained in the DC output. This ripple was found to

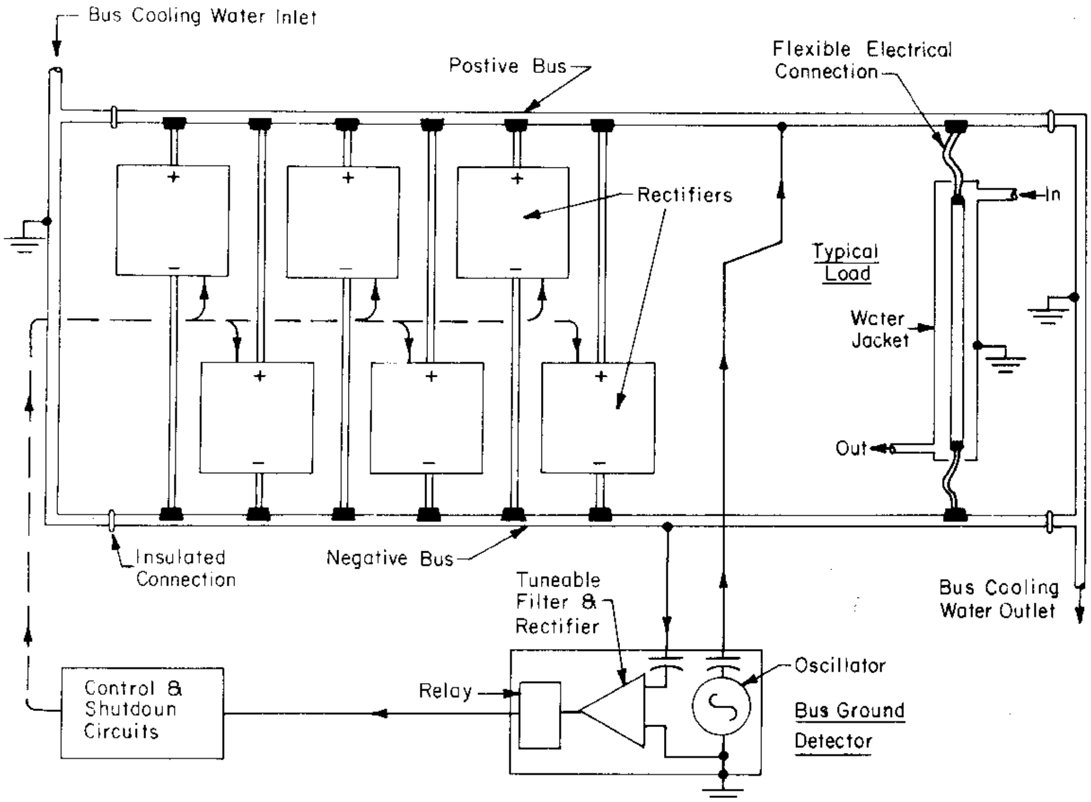

FIGURE 1. Block Diagram of the Heat Transfer Laboratory, SRL

affect adversely any low-frequency resistance measuring device between the system and ground. Also, galvanic action (when the system is filled with water) contributes a varying DC potential between the DC system and ground, making ohmmeter measurements unreliable. In fact, a high current at low voltage yielded the only believable resistance readings, and this was only practical when the rectifiers were turned off and the water resistance was comparatively low.

GROUND FAULT SIGNAL DETECTION

Operating experience has shown that most ground faults occur at one end or the other of the load near the bus connection. Also, the measured voltage from either bus (positive or negative) to ground was normally between 20% and 80% of the bus-to-bus voltage, and this measurement increased to nearly 100% or decreased to nearly zero whenever a ground fault occurred. A voltmeter, connected to one bus, then became the ground detector. Procedures required constant monitoring of the voltmeter reading during operation. Operation of the facility was continued using the voltage monitoring method of ground fault detection.

After further study, a high-frequency, AC-coupled device was tried. A grounded laboratory function generator was coupled through a capacitor to the positive DC bus, and a grounded oscilloscope was connected to the negative bus. With a 10 khz signal of approximately 5 volts amplitude applied from the generator, a detectable 10 khz return was seen on the oscilloscope, superimposed on the DC and ripple signals. Then a 10 khz pass filter was added to the oscilloscope input with capacitive coupling, and the DC and ripple signals were reduced to insignificance, leaving a relatively pure 10 khz sine wave. Tests showed that the 10 khz waveform disappeared if the system were grounded at either bus or at any point on the load. An instrument was then designed, using that principle.

DESIGN OF THE GROUND FAULT DETECTOR

The instrument consists of a medium power oscillator, a tuned filter, a driver amplifier, a relay, and modular power supplies built into a single chassis with a front panel for rack mounting (Figure 2).

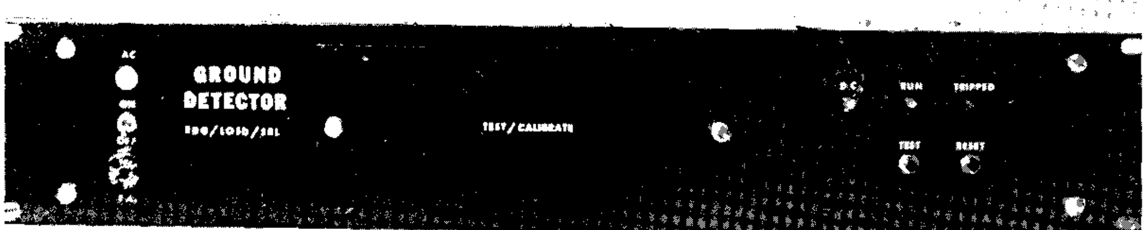

FIGURE 2. Front View of Instrument

The oscillator (Figure 3) uses an *Intersil* 8031 integrated circuit (IC1) with controls for frequency adjustments and waveform symmetry (Intersil, Inc., Cupertino, California).[2] The IC1 is capacitively coupled to an amplifier (Q1) and an emitter follower (Q2). Output from Q2 is across a level control that is AC-coupled to a power Darlington follower (Q3). The output of Q3 is then connected to a rear terminal through a 1.0 mfd capacitor rated at 1000 volts DC. The rear terminal is connected externally to the positive bus of the DC system.

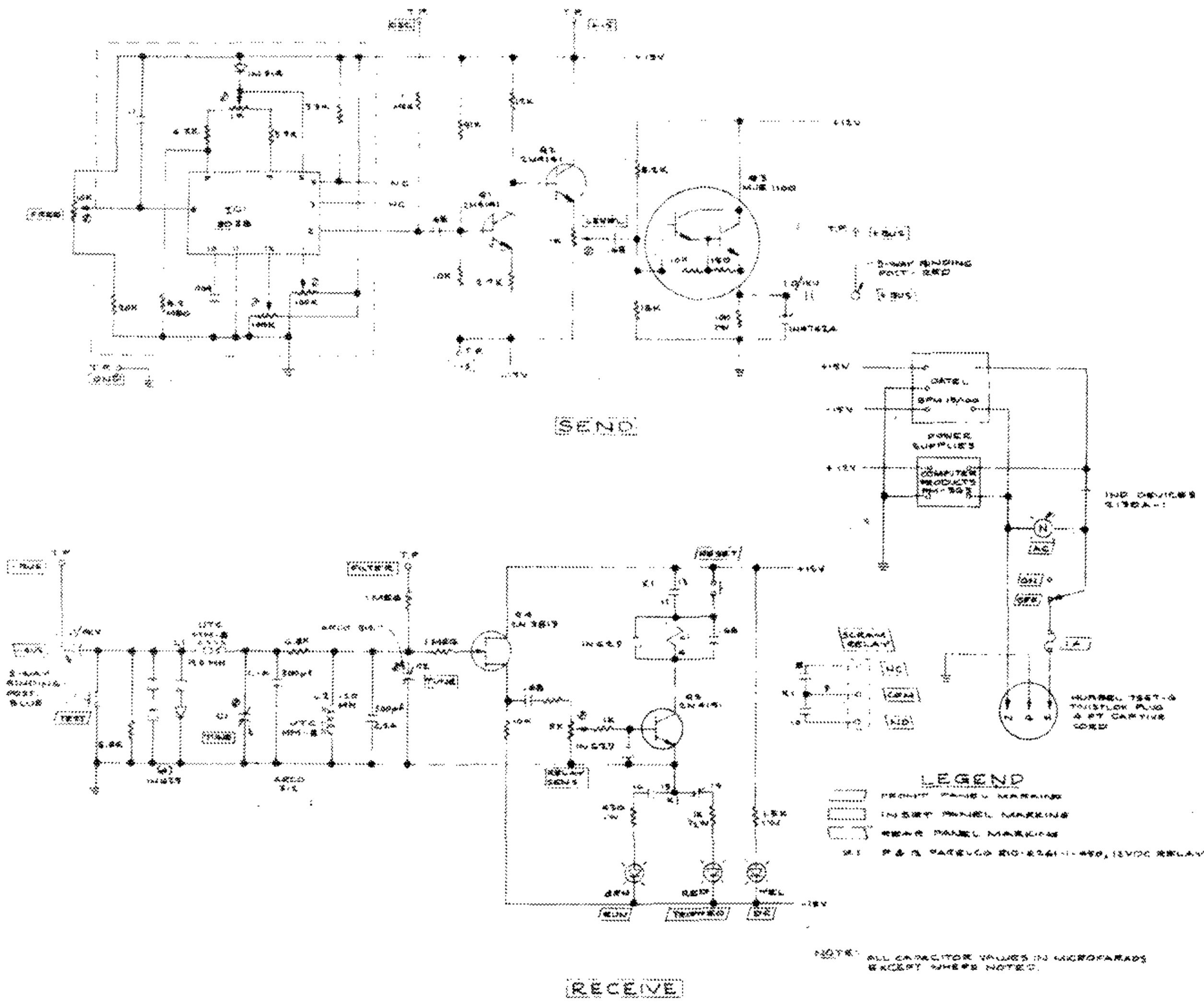

FIGURE 3. Schematic Diagram of the Ground Fault Detector

A second rear terminal is connected externally to the DC negative bus and internally through a 0.1 mfd capacitor to a two-stage filter. L1, C1, and C1A form the first filter stage; L2, C2, and C2A form the second stage. Loading is minimized by a 6.8 kilohm resistor between stages and a 1 megohm resistor to the gate of a field-effect transistor (Q4) connected as a source follower. Output from Q4 is capacitively coupled to a sensitivity control that feeds driver Q5; Q5 drives relay K1 in its collector circuit. One set of Form C contacts on K1 is connected to rear terminals for use in external shutdown circuits, while other contacts provide reset-hold and indicator lamp functions. Test points and adjustment controls are accessible behind a removable cover on the front panel (Figure 4). External connections are all on the chassis rear apron (Figure 5).

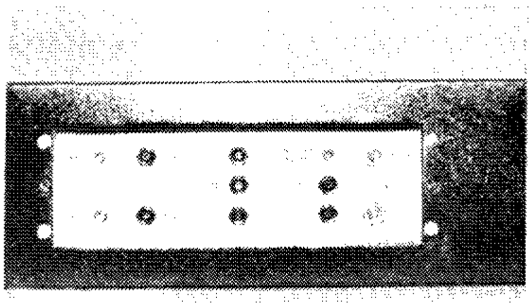

FIGURE 4. Test Panel With Cover Removed

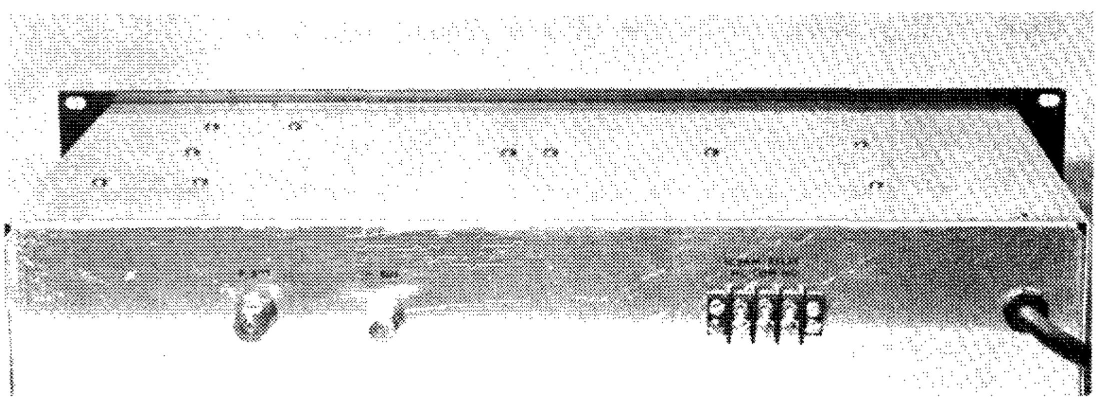

FIGURE 5. Rear Panel Connections

DETECTOR OPERATION

In operation, the oscillator frequency is set at 10 khz sinusoidal, and the low impedance output is applied to the positive DC bus at approximately 1 volt amplitude. The signal is returned through the load to the negative bus, from which it is picked off and applied to the filter. The filter stages are LC circuits tuned to 10 khz, so that even a small signal at that frequency will cause oscillatory action in the filter tanks, producing a higher amplitude waveform at the output than is being received. This voltage increase is accomplished at the expense of signal power. Therefore, current amplification must be employed with minimal loading, after which the signal is used to operate a relay. Grounding either bus or any point on the load then shorts out the signal, causing the relay to de-energize, which in turn shuts the DC system down.

The instrument's input and output are protected from spikes appearing on the buses (from SCR firing or other sources) by shunt diodes. A test button on the front panel grounds the filter input to test relay operation, and manual reset of the relay is accomplished with another front panel button. Indicator light-emitting diodes on the panel display internal power supply and relay conditions continuously.

The instrument is designed to operate in a fail-safe mode; power supply failure, oscillator or other circuit component failure, relay removal or failure, or shutoff of AC power will activate the alarm and shut down circuits. Only shorting of the relay driver transistor or welding of the relay contacts (neither of which is likely) can cause an unsafe failure, and the manual test is available to guard against these.

Operating safety of the Heat Transfer Laboratory has been considerably enhanced by use of the ground detector.

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