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WANL-TME-1849
August 28, 1968

Westinghouse Astronuclear Laboratory

A DEVICE FOR HIGH VOLTAGE SURGE PROTECTION

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UNCLASSIFIED NERVA RESEARCH
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INFORMATION CATEGORY

UNCLASSIFIED

Authorized Classifier W. J. Jones Date 9/3/65

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ABSTRACT

The memorandum presents a description of an electric furnace used to heat test specimens, and it describes furnace damage caused by electrical arcs when a breaking specimen suddenly opens the inductive circuit.

The device, which is applicable to any d-c circuit, provides a gap containing a dielectric material in parallel with the device to be protected. The gap is set to break down at a voltage well below the safe operating voltage of the device to be protected. A high voltage suddenly impressed on the parallel combination causes arcing across the gap and places a short circuit across the protected device. The current flow through the arcing circuit prevents further build-up of voltage to a level that might damage the protected device.

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DESCRIPTION OF THE FURNACE SYSTEM

The device described here was needed to protect the high temperature furnace from electrical arcing in the event of a specimen failure. The test furnace and equipment is described below.

The furnace is designed to test a graphite rod at high temperatures using resistance heating. A diagram of the furnace is shown in Figure 1.

The furnace is a pressure vessel. The furnace body (item 4) and the end cap (item 9) are at ground potential. The other furnace end cap (item 1) is at full positive potential of the rectifier, and it is insulated from the furnace body by a furnace insulator (item 5). The positive end of the furnace is connected to one end of the test specimen (item 8) through electrically conductive pieces and it is electrically insulated from the furnace body. The test specimen is connected to the return side of the power supply only at its other end. Therefore the current is forced down the length of the specimen.

Normal testing requires that the specimen be heated for a prescribed time and that power be removed gradually. The power used is approximately 1 Mw. The specimen is cooled by flowing gas through it.

The power supply is a double way rectifier using four Westinghouse Semitron Rectifiers coupled through a bus switching system to permit combinations of series-parallel operation of the rectifiers. It may be operated with all four rectifiers in series, or with all four rectifiers in parallel, or with four rectifiers in series-parallel. The rectifier supplies power to the furnace electrode through 38 feet of water-cooled bus bar and 11 feet of water-cooled cable. The power supply is fused for diode protection, and has a network for

voltage surge protection caused by operating transients. The system was not designed for opening the d-c circuit under load. The rectifier surge suppressor is for protection of the diodes from switching transients on the a-c side of the system. All four rectifiers are operated in series for the tests described here.

THE PROBLEM

Specimens failed during tests in the past by breaking into two pieces, thereby opening the circuit on the d-c side. The accumulative inductance of the bus bar and the interphase transformer winding put an inductive voltage on the d-c side of the circuit.

When a specimen breaks, a d-c arc is formed between the two broken pieces maintaining the current. Cooling gas passing through the center of the specimen extinguishes the arc, and rapidly opens the circuit. A high voltage is impressed across the circuit because of energy stored in the magnetic field associated with the circuit inductance. This voltage can be expressed as a function of rate of current change and inductance. $e = L \, di/dt$ where

e = the voltage impressed across the open circuit

L = the inductance of the circuit

di/dt = the rate of current change

The voltage is sufficient to cause the breakdown of the furnace insulator (item 5 of Figure 1).

Figure 2 is a simplified equivalent circuit representing the rectifier, rectifier transformer, the test specimen, the affected insulator, and the protective shunt (in dotted lines).

The input a-c power is represented by a generator,

- L_1 = lumped inductance for bus and cable
- R_1 = lumped resistance for the bus and cable
- C_1 = lumped capacitance for the bus and cable
- R_s = lumped resistance of the specimen
- L_s = the lumped inductance of the specimen
- C_s = the lumped capacitance of the specimen
- S_1 = opens the circuit representing specimen breaking
- C_2 = the capacitance of the insulator separating positive
and negative sides of the furnace
- C_3 = the capacitance of the surge shunt
- R_3 = the resistance of the surge shunt
- L_4 = lumped inductance in transformer return
- R_4 = lumped resistance of the transformer return

Assume a normal current flowing in the circuit from the generator through L_1 , R_1 , R_s , L_s , C_s , S_1 , L_4 , and R_4 . Then when S_1 is opened suddenly a voltage is impressed across C_1 and C_2 that is many times the applied voltage. The dielectric strength of C_2 (the insulator) is less than that of C_1 and the insulation breaks down, C_1 is the spacing between the positive and negative bus bars. The arc is sustained until the normal circuit overload relay trips the circuit. By this time sufficient energy has been expended in the arc to cause damage to the furnace by melting the material at the furnace body and end cap.

In order to prevent re-occurrence of the furnace damage, it was felt that some type of device that would prevent arcing or discharge the energy stored in the magnetic fields would be required.

THE DESIGN REQUIREMENTS

The design goals of the device were to prevent arcing at the furnace and breakdown of the insulator. The arc gap was proposed.

An air gap between two graphite electrodes was chosen. This gap would be placed in parallel with the furnace. It was necessary to trip the a-c input to the power supply because the rectifier would continue to supply power to the arc until an excessive current was drawn from the power supply.

In order to accomplish this, a d-c relay was placed in parallel with one of the resistors in series with the air gap. The d-c relay operated an a-c relay which tripped the power supply.

The theory of operation of the surge shunt follows.

During a normal test operation with a voltage of approximately 240 Volts d-c and a current of about 4000 amperes, the resistive element is degraded by high temperatures and breaks in two pieces. The inductance of the bus bar and inter-phase winding of the rectifier transformer try to maintain the current and arcing begins at the break. Now coolant gas flowing in the resistive specimen blows the arc away from the pieces and extinguishes it. This is done quite rapidly and opens the circuit and stops the direct current. A voltage is immediately developed across the break (SW₁ of Figure 2) and across the insulator (C-2 of Figure 2) and across the arc gap (C-3 of Figure 2).

The least resistance to this voltage is offered by the adjustable gap. The arc is established across the air gap. The energy stored in the inductive field is released across the gap and through the resistive network. (Refer to Dwg. No. 388D369). A voltage is developed across the resistor in parallel with relay coil K-1 and the relay is energized. When the relay is energized it immediately released normally energized relay K-2 which trips the input power at the switch gear. At the same time a relay K-2 lights indicator circuitry showing that the device is energized. Note that the K₁ contact across the rectifier trip circuit was not in the circuit at this time. The circuitry prevents operation of furnace until the device has been reset. The relay chassis is shown in Fig. 7.

TESTING AND USING THE SURGE SHUNT

The surge shunt was manufactured according to Dwg. No. 100E071. See photographs of the surge shunt Figure 3 and Figure 4. The small leads seen across the back resistor are connected to the coil of relay K-1 of Dwg. No. 388D369. The large cable at the right end of the surge shunt is one of two 500 MCM copper cables that connect the device to the power supply. The terminal lug for the second cable may be seen in Figure 4. It is connected at the rear of the last copper clamp at the left of the photograph. The entire device is housed in a fireproof cabinet in an area free of flammable mixtures.

Tests were run to determine the gap setting required to activate the surge shunt at a voltage that would be comfortably above the normal operating voltage but low enough to begin the discharge of the field at an early part of the voltage wave.

A high potential checker was used to test gaps. Using the flat face cylindrical electrodes (refer to Dwg. No. 100E071), gaps could be set to get voltage breakdown of the gap near 1000 Volts. The main shortcoming of the electrode was that arcing would occur over a wide range of voltages for the same gap settings.

For a .015-inch gap, voltages that established an arc ranged from 850 Volts to 1200 Volts. Two spherical electrodes were tested with no improvement on voltage control. See Dwg. No. 388D368.

The flat face electrode was adopted and a .013-inch air gap gave a voltage range of 700 to 900 Volts for establishing an arc.

The surge shunt was mounted on a wall about 20 feet from the rectifier and was connected across the bus bar using 500 MCM cable.

A specimen failure occurred shortly after the installation and the surge shunt tripped and its circuitry worked satisfactorily, but the insulator was arced over once more and the arcing damaged the furnace. The damage to the furnace, however, was significantly reduced.

PERFECTING THE DESIGN

Two modifications were made to the surge shunt. The first was a modification to the relay circuit to speed up the tripping of the switch gear. A contact of relay K-1 was connected directly to the trip device to permit it to operate at the time of the first voltage rise. This change reduced the time of initial operation of the trip circuit by .030 seconds. This is the present configuration as shown in Dwg. No. 388D369.

The second significant change was inserting a solid dielectric in the arc gap and at the same time reducing the gap dimension from .013 inches to .0025 inches.

The arc over occurs at the same voltage as it did with the air gap, but now the arc destroys the paper dielectric leaving a .0025-inch air gap to maintain the discharge circuit. This short gap maintains the arc until the voltage has reached a safe level. The dielectric used was Kraft unvarnished electrical paper Grade PDS-4864-1 x .0025. The nominal dielectric strength of this paper is between 700 and 1000 Volts. It was tested at 600 to 900 Volts.

The arc destroys the face of both positive and negative electrodes, see Figure 9 and Figure 10. The electrodes are easily restored by machining about .005 inches from the damaged face.

The electrodes are replaced after machining, a new piece of craft paper is inserted between the electrodes, and the relay circuit is reset to put the surge shunt back into operation.

The dimensions and material of the furnace insulator were also changed to further safeguard the furnace. The smallest dimension of the insulator was changed from 0.125 inches to 0.375 inches. The material was changed from epoxy-glass with a minimum dielectric strength of 334 vpm to silicon glass with a minimum dielectric strength of 350 vpm.

SUMMARY

Specimen failures during tests at high temperatures cause a large voltage to be impressed across the furnace insulator breaking it down. To protect the insulator, a device employing a small gap is placed in parallel with the furnace. The gap breaks down at a much lower voltage than that required to damage the insulator and provides a discharge path for the energy trapped in the circuit. Other circuits triggered by the breakdown of the gap remove incoming power. This device has operated repeatedly at two existing installations and has protected the furnace and insulator in all cases.

Figure 1
FURNACE DIAGRAM

Figure 2

EQUIVALENT CIRCUIT FURNACE SYSTEM

Figure 3
FRONT VIEW OF SURGE SHUNT

Figure 4

OBLIQUE VIEW OF SURGE SHUNT

Figure 5
SURGE SHUNT

Figure 6

SCHEMATIC DIAGRAM CONTROL CIRCUIT SURGE SHUNT

Figure 7

RELAY CHASSIS FOR SURGE SHUNT

Figure 8

SURGE SHUNT ELECTRODES

Figure 9

Surge Shunt Positive Electrode
and Paper Dielectric After Arcing

Figure 10

Surge Shunt Negative Electrode After Arcing