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Publication Date
1977-08-01

To be submitted for publication

LBL-6810
Preprint

Energy and Environment Division

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August 8, 1977

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Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

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HIGH VOLTAGE CROWBAR WITH CASCADE-TRIGGERED SERIES IGNITRONS*

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It is customary to use a crowbar to protect sensitive high-voltage high-power equipment, such as the LBL neutral beam sources and associated electronics equipment, from damage due to fault currents.[1,2] The crowbar grounds out the power supply involved and diverts the fault current until the primary ac power can be interrupted. The fault damage is not significant if the crowbar action occurs in 10^{-5} sec or less. Usually the crowbar is an ignitron or a spark gap, and the circuitry is simple and reliable. Above approximately 30 kV, however, ignitrons should be used in series for reliable operation, and the complexity of triggering the tubes at intermediate potentials has made many designers turn to spark gaps instead. Unfortunately, a spark gap has a strong tendency to quench itself, particularly as the gap length increases at higher voltages. To prevent this, a keep-alive circuit can be added (such as a suitable parallel capacitor with a series R).[3] The crowbar must also be able to function when the operating voltage is near zero, as in the case of a load fault where a sparkdown has already shorted out the voltage before the crowbar can be actuated.

A recent experience with the self-quenching problem on a 120-kV spark gap type crowbar, used on one of the neutral beam power supplies at this laboratory, prompted another look at ignitrons, where this is not a problem, and a search for a better trigger system for the five series tubes required to stand off the voltage. The result was a simple direct-coupled cascade-triggered series tube system that is referenced to ground but without transformers. It can actuate the crowbar in about 2 μsec using a 3-kV trigger pulse even if the voltage of the power supply it is shunting is near zero. An explanation of the circuit action is as follows:

With respect to the accompanying circuit diagram (Fig. 1), the cathode of the tube at the ground end, IG_1, is isolated by a series diode so that it can be driven negative with a 3-kV, 50-μsec trigger pulse from a trigger pulser. (The pulser is a separate assembly and is located outside of the high-voltage area for easy access.) About 50 A of ignitor current is established by a series 60-Ω resistor between the ignitor and ground. This ignitron then becomes conducting and drives the cathode of the next tube negative 3 kV to trigger it through a second series resistor and diode between its ignitor and ground. The process continues in cascade for the remaining tubes with a delay of about 0.5 μsec added for each. The diodes that return the subsequent ignitor currents to ground are also in series. These diodes are in inverse to the normal hV, dc potential across the crowbar. Varistors across the individual diodes prevent overvoltage of these and also of the individual ignitrons because of the voltage buildup across the untriggered ones arising from the progressive switching. The varistor current also flows to the ignitors and speeds the triggering action when high voltage is present.

It should be noted that this circuit can also be connected for "normal" grounded cathode operation simply by moving the ground point to the cathode of IG_1. Triggering in this case is by a positive 3-kV pulse applied to the former ground point with respect to the cathode. This mode requires a significantly longer trigger time, however, when a load fault has occurred and the voltage across the crowbar is low. By triggering the cathode, tube conduction is faster because the trigger pulse also appears as anode-cathode potential.

One of the common reasons that ignitrons in intermittent or low duty service, as in this crowbar case, occasionally lose voltage-holding ability after an extended period is that mercury vapor can accumulate on the anode insulator and progressively bridge this insulator with a layer of small conducting mercury droplets. To avoid this, a thermal gradient should be established so that the anode region is maintained a few degrees warmer than the cathode. Simple, effective heat pipes have been developed at LBL for this. The crowbar described here has a central heating system with one freon-11 boiler with five individual, flexible, insulating tubes feeding warm vapor to simple heat exchangers that are made as integral parts of the anode connectors. The condensed vapor returns to the boiler by gravity through the same tubes. Approximately 5 watts per ignitron at the boiler is adequate.

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*This work was done under the auspices of the U.S. Energy Research and Development Administration.

[1] W.N. Parker, et al., "Electron Tube Protective System," March 9, 1950, U.S. Pat. No. 2,575,232, assigned to RCA.

[2] W.N. Parker and M.V. Hoover, "Gas Tubes Protect High Power Transmitters," Electronics <u>29</u>, 1 (1956), pp. 144-147.

[3] J. Nishidai, et al., "Crowbar System of IT5-2," Nissin, KOUGI 77-51, June 1977, Nissin Electric Co., Ltd., Kyoto, Japan.

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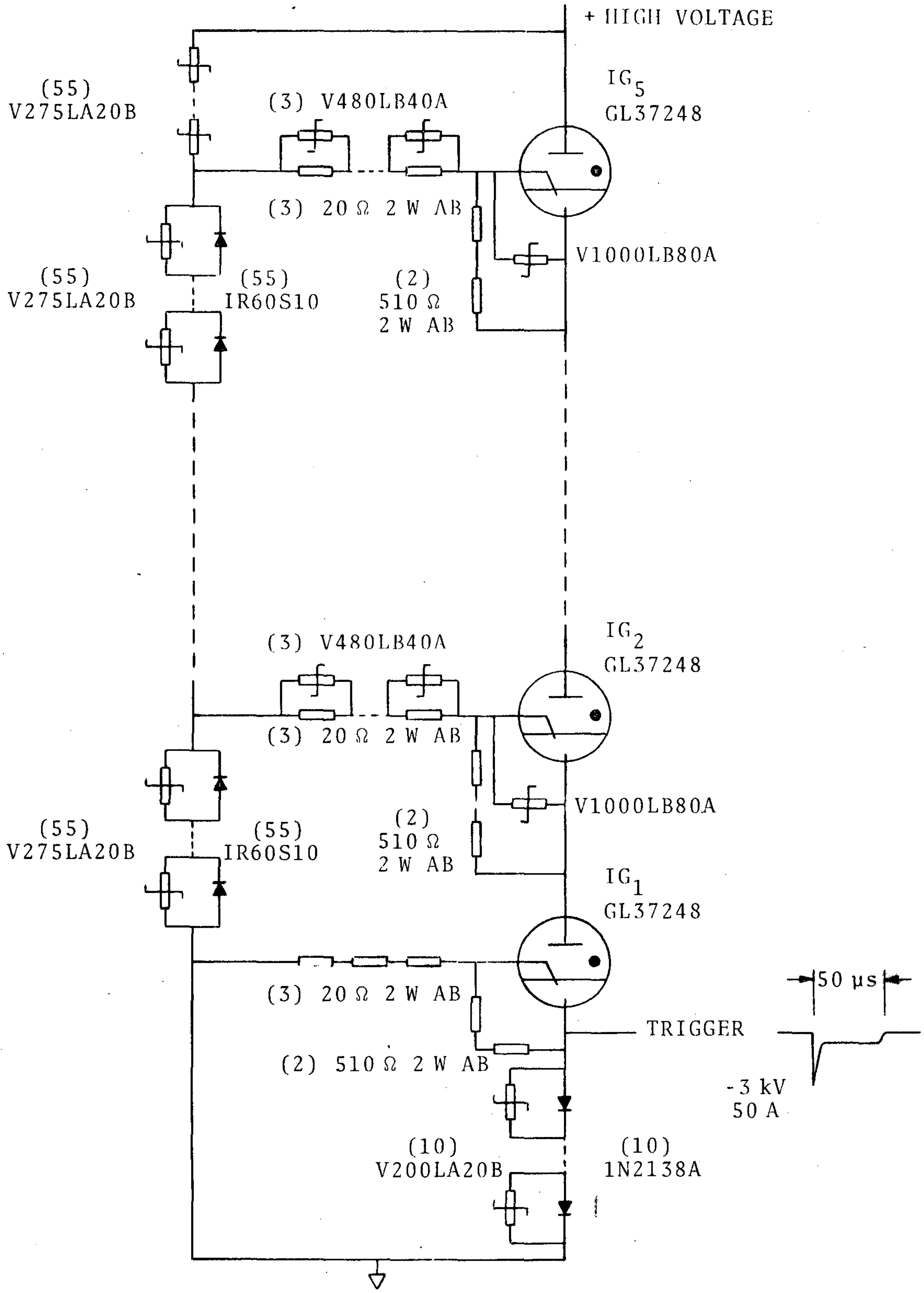
SERIES IGNITRONS



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