Gas Tubes Protect High-Power Transmitters

by

W. N. PARKER and M. V. HOOVER

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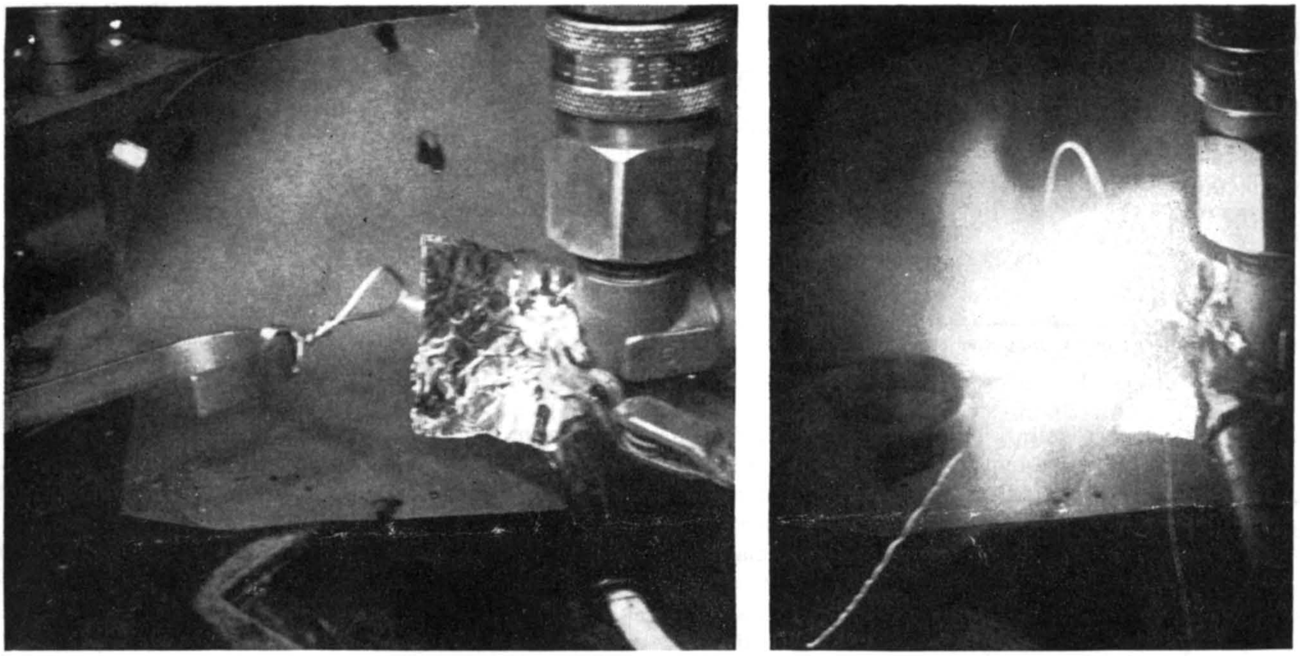
Tube Division
RADIO CORPORATION OF AMERICA
Lancaster Pennsylvania



Spark (left) when 7-kv supply of tv transmitter with electronic-crowbar fault protection is shorted. Neither solder-wire loop nor aluminum foil are damaged. Effects of same test with overcurrent relay-magnetic switch type of fault protection are shown at right

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SUMMARY —— Microsecond-response fault-detection and protection circuit minimizes flash-arc damage to power tubes. Gas tube shunted across d-c supply extinguishes flash-arc before serious damage occurs. Systems handling up to 5 megawatts can be protected

MOST POWER TUBES are subject at some time to a phenomenon known as the Rocky Point effect, which derives its name from experiences with power tubes in communications transmitters at Rocky Point, Long Island.

Nature of Effect

This phenomenon manifests itself as an internal flash-arc developing with little warning in power tubes which apparently are of good design and are operated in a conservative manner. Triggering sources range from cosmic rays to line-voltage transients, parasitic oscillations, spurious renegade primary and secondary electrons, material whiskers and photoelectrons.

The cause of this effect is not thoroughly understood and thus efforts to find a remedy are hampered. However, techniques have been evolved which protect power-tubes against Rocky Point effect. These circuits detect the development of fault conditions in a power tube and/or its circuitry and trigger a gaseous-conduction device connected in shunt with the d-c power supply, extinguishing the flash-arc in the power tube before

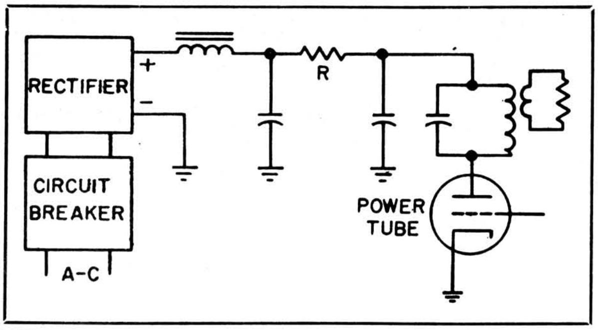

FIG. 1—Simple r-f power amplifier has limiting resistance

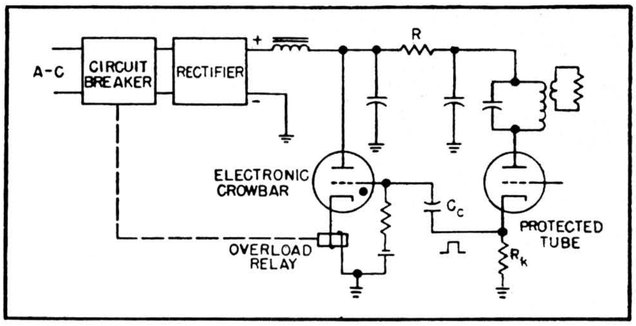

FIG. 2—Basic electronic-crowbar fault-protection circuit

serious damage results. The gaseous conduction device bypasses the rectifier output and filter-circuit energy until the rectifier is deenergized.

This protection system is known as an electronic crowbar.

Fault Protection

In the past, the chief technique available for minimizing the effects of flash-arc damage in power tubes has been the addition of resistance in series with the d-c supply to limit surge currents during faults. Figure 1 shows a circuit of this type in which *R* is the series limiting resistance. In high-power installations this type of circuit dissipates an objectionable amount of power in the series limiting resistance if even marginal protection is to be afforded.[1]

In 1951, it was suggested that an electronic crowbar be built and electronically slammed across the high-voltage-supply bus in event of a fault as a means of shunting the fault currents of a 2,000-kilowatt rectifier from the faulting tube.[2] This device placed a virtual short-circuit across the rectifier output, similar to that placed on the rectifier by the flash-arc, but transferred the short-circuit current to a device which was not damaged by the momentary short-circuit condition.

Basic Circuit

A simple electronic-crowbar circuit is shown in Fig. 2. A fault in the protected power tube results in a sudden increase in current through cathode resistor R_k, producing a positive voltage pulse which is coupled by C_c to the grid of the thyratron. This impulse ionizes the thyratron and causes it to conduct damaging current away from the faulting tube.

The current through the crowbar tube energizes the coil of the overload relay, causing the circuit breaker to open, thus deenergizing the primary source of a-c power to the rectifier.

In the sequence of these operations, plate voltage across the faulting tube is quickly reduced to a value of 15 to 20 volts, which is the voltage drop across the ionized gaseous-conduction crowbar device. This low voltage starves and extinguishes the flash-arc in the protected tube before serious damage can result. A small series resistor, *R*, provides adequate voltage across the crowbar tube to insure its conduction despite severe low-impedance flash-arcs in the protected tube.

In a typical large-power-tube installation, the value of the series dropping resistor is only about 5 ohms.

Actuation Time

Measurements have revealed that the electronic-crowbar tube is capable of beginning its protective function within 1 to 5 microseconds after the fault has been detected. When vigorously triggered, hydrogen-thyratron crowbar tubes begin to conduct within approximately 1 microsecond and mercury-vapor devices within about 5 microseconds.

A simplified diagram of a crowbar protection circuit currently in commercial use is shown in Fig. 3. This circuit is employed in the RCA TTU-12, a 12.5-kilowatt uhf television transmitter.[3]

In the arrangement shown in Fig. 3, the series resistance corresponding to *R* of Fig. 2 consists of series resistors, R_1, R_2 and R_3.

Resistor R_2 also serves as a sensing resistor. In the event of a sudden overcurrent in the load circuit as a result of a fault, a steep-wavefront positive pulse is transmitted through the transformer to the grid of the thyratron crowbar tube, which is normally biased off by the bias source.

This pulse causes almost immediate ionization of the thyratron, which then conducts and forms an effective short-circuit in parallel with the load. Energy stored in reservoir capacitor C_r and that which is subsequently furnished from the power supply is dissipated in R_1 and R_2. Because R_2 has a large value compared to the resistance of the ionized thyratron, very little current flows to the faulting load.

The series resistance of R_1 and R_2 in combination with the impedance of the power supply limits the fault current to a value not exceeding the peak-current rating of the thyratron. Conduction of the thyratron operates the overload relay, which ultimately interrupts the primary source of a-c power by the circuit breaker. Several other variations of this circuit also give effective protection.

Performance

When a wire having a diameter of 0.003 inch is placed directly across the energized 7,000-volt plate lead of the circuit shown in Fig. 3, the resulting arc is so slight that it produces only a small pit in the wire. However, a tremendous cone of fire results if the plate potential is short-circuited with the protective system disabled.

In another test of effectiveness, the positive power-supply lead is touched to a small sheet of thin metal foil at ground potential. The thin metal foil used in cigarette packages is quite satisfactory. If the protective circuit is operating properly, the foil will show no melting, pitting or burn marks. However, the foil will disappear in a cloud of vapor if the test is performed with the electronic protective circuits disabled. Results of such tests are illustrated in the photographs.

Equipment Installations

An electronic-crowbar system of protection has been employed in conjunction with the 1,700-kilowatt rectifier for part of Navy's Jim Creek million-watt transmitter.[5, 6] More recently, super-power transmitters for the Voice of America have used the electronic crowbar.[7] In these superpower installations, it is not uncommon to find rectifiers having fault-current capabilities of the order of 2,000 amperes.

The effectiveness of fault-protection circuits in these large systems may be demonstrated by a deliberate short-circuiting of the high-voltage bus or tube terminals with a movable horn gap in which one of the electrodes is a piece of conventional 0.060-inch-diameter rosin-core solder. A slight melting and pitting of the solder will result when the electronic crowbar is in operation.

When conventional breaker-protected rectifiers are used, however, the horn gaps will disappear in a frightening display of aural and visual fireworks. Although the use of grid-controlled rectifiers reduces tube damage significantly, experience has demonstrated that such rectifiers are also capable of damaging tubes and circuits.

Another advantage of rapid fault protection is that full power can be restored almost immediately when the damage due to the flash-arc is minimized. Operators of high-power transmitters are familiar with the lengthy aging process demanded by power tubes after a severe flash-arc.

These periods of operation at lower power level may require many hours or days. Furthermore, tubes which have suffered from severe flash-arc damage are often somewhat gassy and may produce a final and fatal flash-arc unless they are adequately protected during reaging.

Out of Service Time

Actual tests of electronic-crowbar circuits in super-power transmitters have demonstrated that full-power operation can safely be restored almost immediately after a flash-arc. When these protective circuits are operated in conjunction with grid-controlled rectifiers, the total down time due to a flash-arc is of the order of 50,000 microseconds, a period almost unobserved in most communications services. The down time is, of course, directly proportional to the severity of flash-arc damage.

High-speed fault protection is not limited to power tubes, but is equally applicable to circuitry associated with the tubes. Capacitors, inductors, insulation and the like can also be damaged by fault currents. Crowbar protection greatly enhances the possibility of survival of circuit components and of early restoration of normal full-power operation.

Fault Detection

The effectiveness of high-speed fault-protection circuits is contingent upon the early detection of a fault in the tube or in its associated circuitry.

In simple fault-detection systems, such as that shown in Fig. 2, the power tube is protected against faults, but the system is incapable of sensing fault conditions in the circuitry associated with the protected tube. This disavantage may be obviated by the use of a fault-detection system such as that shown in Fig. 3. In this system, any d-c fault in the tube or circuit on the load side of sensing resistor R_2 triggers the protection system into action.

Several other fault-detection systems are available.[8] A differential system of fault protection has proven very successful.[9] The operation of the differential fault detector is predicated on the fact that a fault which develops in a vacuum tube operating as an oscillator or an amplifier causes the r-f output to decrease sharply and the d-c input to increase.

In the differential fault-detector circuit shown in Fig. 4, rectifier load currents manifest themselves as a negative voltage across R_1 in the negative return of the rectifier. A sample of the r-f power output from the protected tube is coupled by a link line from the tank circuit to the parallel resonant circuit in the diode plate circuit. Rectification by the diode develops a positive voltage across resistor R_2 having a magnitude directly proportional to the r-f amplifier output. Resistor R_3 may be adjusted until the differential voltmeter reads zero voltage with respect to ground, indicating balance between the sample of rectified r-f power output and the sample of d-c input from the negative return of the high-voltage rectifier. Because the r-f power output is approximately proportional to the d-c input, the null balance from point *X* to ground

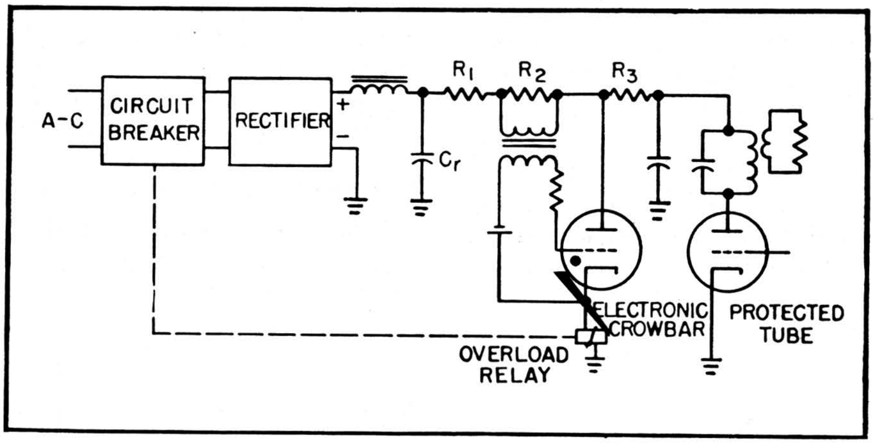

FIG. 3—High-speed protection circuit used in 12-kilowatt ultra-high-frequency television transmitter. Resistor R_2 acts as sensing element

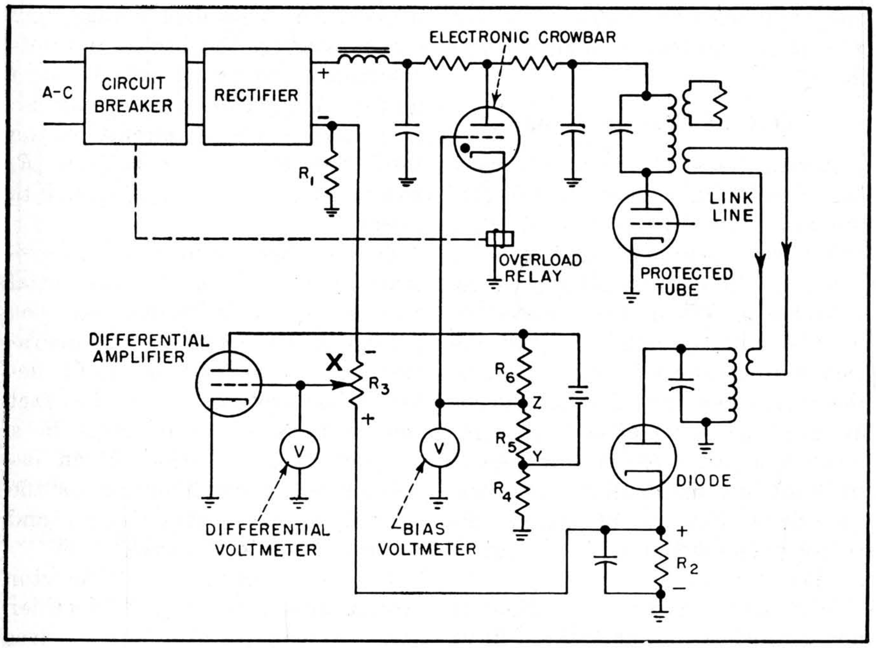

FIG. 4—Differential fault detector in high-speed protection system

should be approximately maintained at all signal levels, despite 100-percent modulation of the protected tube.

It should be noted that the voltage from point *X* to ground is zero when the high-voltage rectifier and protected tube are idle. Consequently, under all normal circumstances the differential voltage is zero, resulting in zero-bias operation of the differential amplifier.

This amplifier normally draws plate current through resistor R_4 to produce a negative voltage at point *Y* with respect to ground. When all the circuit parameters are designed properly, the negative voltage across resistor R_4 is greater than the positive voltage across resistor R_5 produced by the battery. A resultant negative voltage is produced from point *Z* to ground which biases off the thyratron, as indicated by the bias voltmeter.

Circuit Operation

In the event of a fault, the rectified r-f voltage sample across R_2 decreases rapidly toward zero, while the d-c sample voltage across R_1 in the negative return of the high-voltage rectifier suddenly becomes increasingly negative. Either or both of these sample voltages produce a resultant voltage which is increasingly negative at point *X* as fault conditions develop. A negative voltage is thus produced from point *X* with respect to ground and the differential amplifier is biased off, reducing the negative voltage across R_4 to zero.

Point *Z*, which is positive with respect to ground because of the voltage divider across the battery, then triggers the thyratron electronic crowbar. In addition to its protective function, the thyratron also interrupts a-c power to the rectifier by the overload relay and the circuit breaker.

The tubes employed in electronic crowbar service must be reliable and rugged. They must also be able to conduct heavy surge currents for a short period of time after having been idle for a long period of time.

Tubes for Electronic Crowbar

In high-power installations, the type 5563A mercury-vapor thyratron has demonstrated its effectiveness in commercial equipment[3] with circuits similar to that shown in Fig. 3.

Hydrogen thyratron tubes are also reported to have been used effectively in connection with crowbar applications in super-power transmitters.[7]

From the standpoint of long life, dependability and ruggedness, the ignitron appears to be an ideal choice for super-power crowbar service. Absence of a hot cathode in this tube is an attractive feature.

Ignitrons appear to be almost indestructible in crowbar service. One tube has been in almost daily use in the protective circuits of superpower-tube test equipment for the past seven years. In the course of this activity, the ignitron crowbar has been operated in conjunction with a 5,000-kilowatt grid-controlled rectifier in which fault currents may approach several thousand amperes at output voltages of 27 kilovolts.

Because many flash-arcs are experienced during the early operation and aging of large power tubes, this particular ignitron has been subjected to an unusually rugged life. Since the electronic crowbar has been used, not a single protected tube has been seriously damaged by flash-arcs during testing.

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