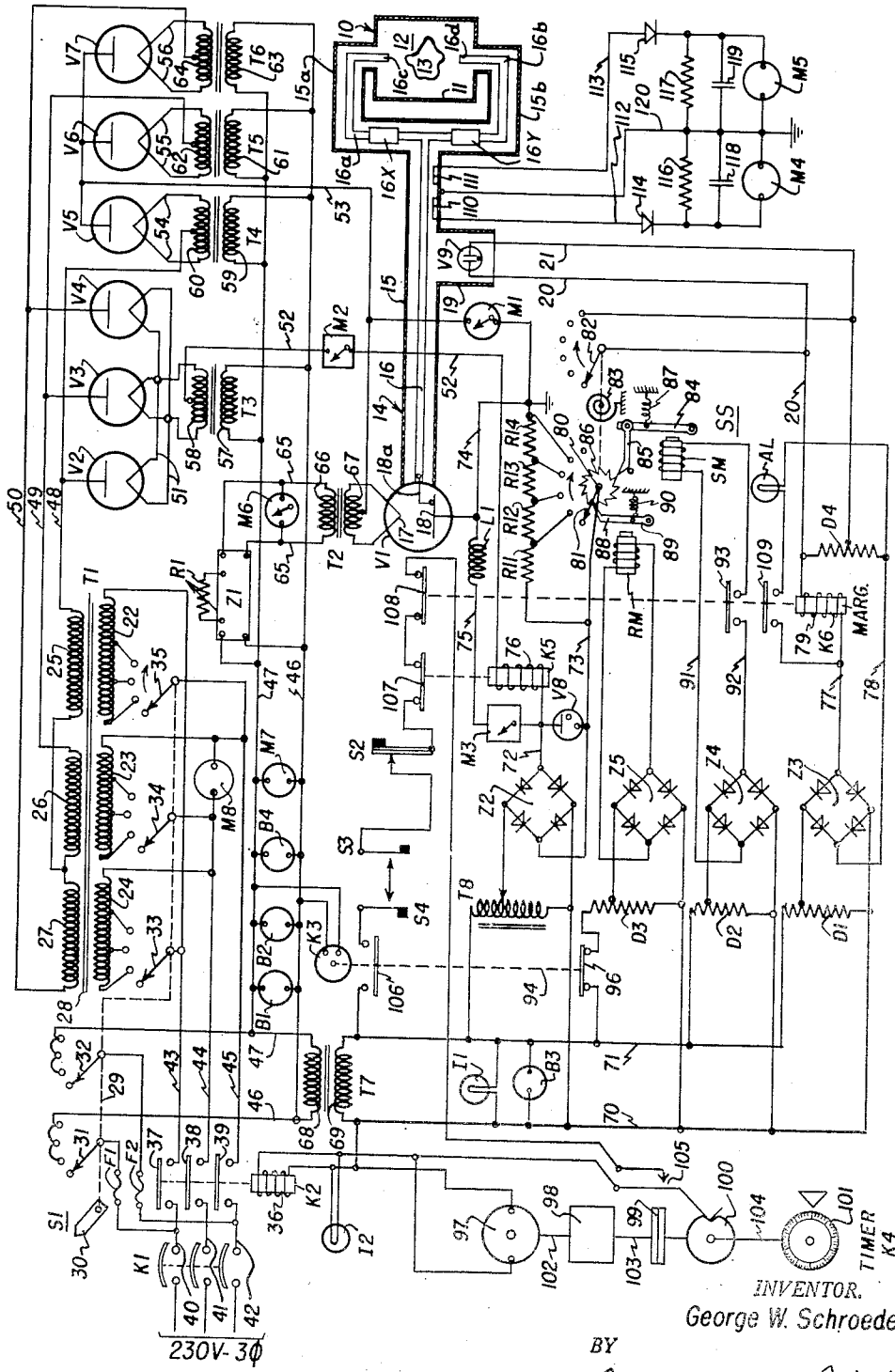
Oct. 26, 1954

G. W. SCHROEDER

2,692,946

PROTECTIVE SYSTEM FOR HIGH-FREQUENCY GENERATORS

Filed April 18, 1951



Patented Oct. 26, 1954

2,692,946

UNITED STATES PATENT OFFICE

2,692,946

PROTECTIVE SYSTEM FOR HIGH-FREQUENCY GENERATORS

George W. Schroeder, Sandy Hook, Conn., assignor to General Electric Company, a corporation of New York

Application April 18, 1951, Serial No. 221,630

12 Claims. (Cl. 250—36)

1

The present invention relates to protective systems for high-frequency generators and more particularly to such systems for protecting magnetron generators incorporated in ultra-high frequency heating apparatus.

Ultra-high frequency heating apparatus usually comprises a cavity adapted to receive semi-conducting material that is to be heated, an ultra-high frequency generator including a magnetron tube, and an interposed transmission line that may be either of the coaxial conductor type or of the wave guide type. In such apparatus, it is highly desirable that the impedance of the load match the impedance of the generator, but this is not always possible since the impedance of the load depends upon the weight and character of the material that is to be heated in the cavity, whereby some impedance mismatch is always present and causes a reflection of ultra-high frequency power from the cavity back through the transmission line to the generator, the amount of reflected ultra-high frequency power being proportional to the amount of impedance mismatch and to the amount of incident power supplied from the generator to the cavity through the transmission line. In fact, should the apparatus be operated without any load in the cavity, the reflected ultra-high frequency power is substantially equal to the incident ultra-high frequency power. This reflected ultra-high frequency power produces a heating effect upon the magnetron tube incorporated in the ultra-high frequency generator, which heating effect is proportional to the amount of reflected ultra-high frequency power. Thus in the event of a severe impedance mismatch, the reflected ultra-high frequency power is sufficiently great to effect undue and damaging heating of the magnetron tube causing direct failure thereof by cracking of the glass seal that is disposed about the connection extending through the wall thereof to the plate arranged therein, notwithstanding the provision of the air blower and the water cooling coil that are normally operatively associated with the magnetron tube. Specifically it has been discovered that in the event the impedance mismatch is of such severity that the microwave voltage-standing wave ratio exceeds a value of about 3.0, the magnetron tube will invariably fail.

Accordingly it is the general object of the present invention to provide an improved protective system for a high frequency generator so as to prevent damage thereto resulting from an impedance mismatch between the generator and the connected load.

2

Another object of the invention is to provide in a high frequency power supply system including a high frequency generator, an arrangement for selectively setting the amount of incident high frequency power output from the generator in accordance with the amount of reflected high frequency power back to the generator.

Another object of the invention is to provide in a high frequency supply system, an improved circuit network for protecting the high frequency generator incorporated therein against damage as a result of reflected high frequency power back thereto and for selectively setting the incident high frequency power output from the generator in accordance with the amount of reflected high frequency power back thereto.

A further object of the invention is to provide in ultra-high frequency heating apparatus, an improved protective system of the character noted.

Further features of the invention pertain to the particular arrangement of the elements of the ultra-high frequency heating apparatus and the associated protective circuit network, whereby the above-outlined and additional operating features thereof are attained.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawing, in which the single figure is a diagrammatic illustration of ultra-high frequency heating apparatus and a power supply and protective circuit network therefor embodying the present invention.

Referring now to the drawing, the ultra-high frequency heating apparatus and the power supply and protective circuit network there illustrated, and embodying the features of the present invention, comprises a cooking oven 10 provided with a metal liner 11 defining a cavity 12 arranged to receive semi-conducting material 13 that is to be heated, an ultra-high frequency generator arrangement including a magnetron tube V1 that may be of General Electric Company type Z-1492, and an interposed transmission line 14. The transmission line 14 is of the coaxial conductor type including an outer grounded tubular conductor 15 and a centrally disposed insulated rod-like conductor 16. The outer end of the transmission line 14 is bifurcated terminating in two arms embracing the oven 10. The extremities of the two outer conductors 15a and 15b of the two arms of the transmission line 14 are connected to the liner 11; while the extremities of

the two inner conductors 16a and 16b of the two arms of the transmission line 14 respectively project through two associated openings formed in the liner 11 and respectively terminate in two inwardly projecting antennas 16c and 16d disposed in the cavity 12. Also the two inner conductors 16a and 16b of the two arms of the transmission line 14 respectively carry two sleeve transformers 16x and 16y in order to insure that the impedance of the transmission line 14 matches the impedance of the magnetron tube V1. The magnetron tube V1 comprises a filamentary cathode 17 and a plate 18, the plate 18 being electrically connected to the inner end of the inner conductor 16 of the transmission line 14 by the usual coupling loop 18a and to ground potential. The magnetron tube V1 is capable of oscillating at an ultra-high frequency of the order of 1,000 megacycles, whereby centimeter electromagnetic standing waves are produced in the cavity 12 when the magnetron tube V1 is operating.

An attenuator 19 is connected to the transmission line 14 and may take the form of a length of hollow conducting tubing constituting a section of wave guide with cross-sectional dimensions sufficiently small so as not to propagate waves of the frequency in the transmission line 14. The attenuator 19 is secured to the outer conductor 15 of the transmission line 14 in surrounding relation with respect to an opening formed in the outer conductor 15 so that a portion of the field in the transmission line 14 may extend into the attenuator 19. An element V9 in the form of a gaseous discharge tube is arranged within the attenuator 19 and positioned away from the transmission line 14 toward the outer end of the attenuator 19 a distance corresponding to the maximum field intensity to which it is desired to subject the element V9, it being understood that the intensity of the field within the attenuator 19 decreases with distance away from the transmission line 14 toward the outer end thereof. Specifically the gaseous discharge tube V9 may take the form of a ¼ watt neon glow lamp and is provided with a pair of electrodes that are respectively connected to the exterior via two conductors 20 and 21. Also the position of the attenuator 19 along the transmission line 14 and with respect to the position of the magnetron tube V1 is such that the distance between the attenuator 19 and the magnetron tube V1 is equal to ½ the wave length of the ultra-high frequency energy in the transmission line 14 or to any integral multiple of the ½ wave length noted. This arrangement insures that the gaseous discharge tube V9 is subject to ionization by a microwave voltage at the same level of intensity as that at the magnetron tube V1.

More particularly the resulting microwave voltage to which the gaseous discharge tube V9 is subjected is proportional to the square root of the generated microwave power plus the in-phase component of that microwave voltage caused by the standing microwaves in the transmission line 14, while the microwave voltage caused by the standing waves in the transmission line 14 is directly proportional to the impedance mismatch. Thus it will be understood that in the event of a resulting microwave voltage in excess of a predetermined safe value, produced by a severe impedance mismatch, the gaseous discharge tube V9 is ionized and ignited. As explained more fully hereinafter, ignition of the gaseous discharge tube V9 is effective to bring about a reduction in the microwave power that is generated by the magnetron tube V1, whereby the resulting microwave voltage to which both the gaseous discharge tube V9 and the magnetron tube V1 are subjected is correspondingly reduced so that the resulting microwave voltage does not exceed the predetermined safe value in order to prevent damage to the magnetron tube V1.

The power supply system for the magnetron tube V1 comprises a source of 230 volts, 3-phase, A. C. power, an associated oil circuit breaker K1 that is selectively operative between open and closed positions, a plate power transformer T1 having a delta connected primary winding and a star connected secondary winding, a manually operable power selector switch S1, and a plate power relay K2. In the plate power transformer T1, the primary winding includes the three phase sections 22, 23 and 24, and the secondary winding includes the three phase sections 25, 26 and 27 respectively coupled by an associated core 28. The power selector switch S1 includes a rotatably mounted operating shaft 29 provided with an operating handle 30 and carrying five switch blades 31, 32, 33, 34 and 35 that are provided with individually associated contact banks. The plate power relay K2 includes a winding 36 and three contact bridging members 37, 38 and 39.

When the oil circuit breaker K1 occupies its closed position, the three conductors of the source of power are respectively connected to three power supply buses 40, 41 and 42 that are respectively terminated by contacts controlled by the bridging members 37, 38 and 39; also the other contacts respectively controlled by the bridging members 37, 38 and 39 respectively terminate feed conductors 43, 44 and 45. Thus it will be understood that when the plate power relay K2 occupies its operated position, the power supply buses 40, 41 and 42 are respectively connected by the bridging members 37, 38 and 39 to the feed conductors 43, 44 and 45.

The feed conductors 43, 44 and 45 are respectively connected to the switch blades 33, 34 and 35; which switch blades 33, 34 and 35 have access to contacts in the associated contact bank respectively terminating taps provided on the primary winding sections 24, 23 and 22. Thus it will be understood that by appropriately setting the power selector switch S1 that the taps may be appropriately set upon the winding sections 22, 23 and 24 of the primary winding of the plate power transformer T1 so as to effect the induction of corresponding secondary voltages in the secondary winding sections 25, 26 and 27 thereof. Finally the power supply buses 40 and 42 are respectively connected directly via associated fuses F1 and F2 to the switch blades 31 and 32; and the contact banks associated with the switch blades 31 and 32 are multipled together and connected respectively to two filament supply conductors 46 and 47. Thus it will be understood that when the power selector switch S1 is operated out of its home position, the phase voltage between the power supply buses 40 and 42 is connected between the filament supply conductors 46 and 47 via the switch blades 31 and 32 and the engaged contacts in the associated contact banks. The outer ends of the primary winding sections 25, 26 and 27 are respectively connected to feed conndductors 48, 49 and 50; and the inner ends of the winding sections 25, 26 and 27 are commonly connected together to form the star previously noted.

Also the power supply circuit comprises a first

bank of rectifier tubes V2, V3 and V4 provided with plates respectively connected to the feed conductors 48, 49 and 50 and provided with filamentary cathodes connected in multiple to a conductor pair 51; as well as a second bank of rectifier tubes V5, V6 and V7 provided with plates commonly connected to an output conductor 53 and provided with filamentary cathodes respectively connected to conductor pairs 54, 55 and 56. A rectifier filament transformer T3 is provided for the first bank of rectifier tubes and includes a primary winding 57 connected across the filament supply conductors 46 and 47, and a secondary winding 58 connected across the conductor pair 51, the mid-tap of the secondary winding 58 being connected to an output conductor 52. Three rectifier filament transformers T4, T5 and T6 are provided for the respective rectifier tubes V5, V6 and V7 in the second bank. The rectifier filament transformer T4 includes a primary winding 59 connected across the filament supply conductors 46 and 47, and a secondary winding 60 connected across the conductor pair 54, the mid-tap of the secondary winding 60 being connected to the feed conductor 48. The rectifier filament transformer T5 includes a primary winding 61 connected across the filament supply conductors 46 and 47, and a secondary winding 62 connected across the conductor pair 55, the mid-tap of the secondary winding 62 being connected to the feed conductor 49. The rectifier filament transformer T6 includes a primary winding 63 connected across the filament supply conductors 46 and 47, and a secondary winding 64 connected across the conductor pair 56, the mid-tap of the secondary winding 64 being connected to the feed conductor 50.

Also the magnetron tube V1 is provided with a filament power controller Z1 having input terminals connected across the filament supply conductors 46 and 47, and output terminals connected across a conductor pair 65. Also the magnetron filament power controller Z1 is provided with an adjustable filament controller rheostat R1 so that the voltage across the conductor pair 65 may be selectively set. Also the magnetron tube V1 is provided with a filament transformer T2 including a primary winding 66 connected across the conductor pair 65, and a secondary winding 67 connected across the filament 17 of the magnetron tube V1, the mid-tap of the secondary winding 67 being connected to the output conductor 53. Further the power supply circuit comprises an isolation transformer T7 including a primary winding 68 connected across the filament supply conductors 46 and 47, and a secondary winding 69 connected across two feed conductors 70 and 71. Finally the magnetron tube V1 includes a magnet coil L1 that is provided with a local exciting circuit; the local exciting circuit including a magnet control transformer T8 of the auto-transformer type. Specifically the extremities of the winding of the transformer T8 are connected across the feed conductors 70 and 71; while one extremity of the winding of the transformer T8 and an adjustable tap thereon are connected across the input terminals of a full wave dry rectifier bridge Z2; the output terminals of the bridge Z2 being connected across a pair of conductors 72 and 73 that are included in the excitation circuit of the magnet coil L1. Specifically one terminal of the magnet coil L1 is connected directly by a conductor 74 to the plate 18 of the magnetron tube V1 and to ground potential; and the other terminal of the magnet coil L1 is connected to a conductor 75, which, in turn, is connected to the conductor 72. The conductor 73 is connected via four resistors R11, R12, R13, and R14 arranged in series relation to the conductor 74 and to ground potential. Further a voltage regulator tube V8 of the gaseous discharge type is connected directly across the conductors 72 and 73. Finally there is provided a direct current overcurrent relay K5 that includes a winding 76 that is connected between the conductor 72 and the output conductor 52.

In view of the foregoing, it will be understood that the magnet coil L1 is normally energized with direct current via the local exciting circuit including the bridge Z2, the conductors 72, 73, 74 and 75 and the resistors R11, R12, R13 and R14, and that the high D. C. voltage produced by the two banks of rectifier tubes is present between the output conductors 52 and 53 and thus appears between the cathode 17 and the plate 18 of the magnetron tube V1 via the circuit including the winding 76 of the overcurrent relay K5, the conductor 75, the magnet coil L1 and the conductor 74; whereby the magnetron tube V1 oscillates in the usual manner impressing the generated microwave voltage via the coupling loop 18a upon the inner conductor 16 of the transmission line 14 so as to effect the production of the centimeter electromagnetic standing waves in the cavity 12 so as to heat the material 13 supported therein.

The input terminals of a voltage divider D1 are bridged across the feed conductors 70 and 71, and the output terminals of the voltage divider D1 are bridged across the input terminals of a full wave dry rectifier bridge Z3. The output terminals of the bridge Z3 are respectively connected to two conductors 77 and 78. Also an ultra-high frequency overvoltage relay K6 is provided that includes a winding 79, one terminal of which is connected to the conductor 20. Further the input terminals of a voltage divider D4 are connected between the conductors 20 and 78; and the output terminals of the voltage divider D4 are connected between the conductors 20 and 21 that extend to the electrodes of the glow lamp V9. In view of the foregoing, it will be understood that when the glow lamp V9 is un-ionized that the winding 79 of the ultra-high frequency overvoltage relay K6 is energized in series relation with the voltage divider D4, whereby the latter relay is not operated since it is of the marginal type. On the other hand, when the glow lamp V9 is ionized, the upper portion of the voltage divider D4 is effectively short-circuited, whereby the winding 79 of the ultra-high frequency overvoltage relay K6 is energized sufficiently to effect operation thereof. Subsequently when the glow lamp V9 is again de-ionized, the upper portion of the voltage divider D4 is again effectively inserted in the series circuit for energizing the winding 79 of the ultra-high frequency overvoltage relay K6 in order to cause the latter relay to restore.

Further the circuit network comprises a control switch SS of the step-by-step type including an operating shaft 80 mounted for rotation step-by-step and carrying a wiper 81 having a home position illustrated, a plurality of control positions, and a final position disposed in the clockwise direction with respect to its home position. The wiper 81 is connected to the conductor 73 and is provided with a contact bank terminating

conductors extending to the junctions between the resistors R11, R12, R13 and R14 and the conductor 74. Thus it will be understood that the resistors R11, R12, R13 and R14 are normally included in the local exciting circuit for the magnet coil L1 and that the resistors R11, R12, R13 and R14 are successively short-circuited by the wiper 81 as the control switch SS is stepped from its home position into its successive control positions, thereby successively removing the resistors R11, R12, R13 and R14 from the exciting circuit for the magnet coil L1. The magnetron tube V1 of the type Z–1492 possesses the characteristic that the ultra-high frequency power output thereof is inversely proportional to the excitation of the magnet coil L1 thereof. Thus the ultra-high frequency power output of the magnetron tube V1 is at a normal maximum when the four resistors R11, R12, R13 and R14 are included in the local exciting circuit for the magnet coil L1. Also the operating shaft 80 carries a wiper 82 that is adapted to short together the conductors 20 and 21 when the control switch SS occupies its final position, thereby short-circuiting the glow lamp V9 and the upper portion of the voltage divider D4 so as to provide a locking circuit positively to retain the ultra-high frequency overvoltage relay K6 in its operated position.

The control switch SS further comprises a coil spring 83 normally biasing the operating shaft 80 in the counterclockwise direction; which coil spring 83 is wound up, storing energy therein, when the operating shaft 80 is stepped away from its home position. The control switch SS is stepped away from its home position by an arrangement including a stepping magnet SM provided with an armature 84 that carries an operating pawl 85 that cooperates with a ratchet wheel 86 carried by the operating shaft 80, the armature 84 being biased in the clockwise direction away from the stepping magnet SM by a coil spring 87. The operating shaft 80 is restrained in its operated position against the bias of the coil spring 83 by a latching pawl 88 that is carried by an armature 89 in cooperating relation with respect to the ratchet wheel 86. The armature 89 is operatively associated with a release magnet RM and is normally biased in the clockwise direction away from the release magnet RM by a coil spring 90.

In view of the foregoing, it will be understood that the control switch SS normally occupies its home position; however when a series of impulses are received by the stepping magnet SM, the armature 84 is alternately attracted and released so that the stepping pawl 85 cooperating with the ratchet wheel 86 rotates the operating shaft 80 step-by-step in the clockwise direction so that the wiper 81 is rotated out of its home position through its control positions and ultimately into its final position. The operating shaft 80 is restrained in any operated position by the latching pawl 88; however the operating shaft 80 may be released and returned in the counterclockwise direction by the coil spring 83 so that the wiper 81 is moved back into its home position merely by the momentary energization of the release magnet RM, the release magnet RM attracting the armature 89 and withdrawing the release pawl 88 from the ratchet wheel 86.

For the purpose of energizing the stepping magnet SM a circuit is provided that includes a voltage divider D2 having input terminals connected across the feed conductors 70 and 71, and output terminals connected across the input terminals of a full wave dry rectifier bridge Z4. The output terminals of the bridge Z4 are connected to two conductors 91 and 92. The conductor 91 is connected to one terminal of the stepping magnet SM, and the other terminal of the stepping magnet SM is connected to a contact controlled by a bridging member 93 provided on the ultra-high frequency overvoltage relay K6, the other contact controlled by the bridging member 93 being connected to the conductor 92. Thus it will be understood that when the ultra-high frequency overvoltage relay K6 is operated the bridging member 93 closes the circuit for energizing the stepping magnet SM of the control switch. Also the power supply circuit comprises a plate power delay relay K3 that may take the form of a Telechron timer motor having an operating winding connected across the filament supply conductors 46 and 47 and provided with an operating shaft 94. Thus the plate power delay relay K3 is of the slow-to-operate type, the shaft 94 thereof being operated 30 seconds after the winding thereof is energized. For the purpose of energizing the release magnet RM, a circuit is provided that includes a voltage divider D3 having input terminals connected across the feed conductors 70 and 71 via a pair of contacts controlled by a bridging member 96 provided on the plate power delay relay K3, and output terminals connected across the input terminals of a full wave dry rectifier bridge Z5. The output terminals of the bridge Z5 are connected directly to the terminals of the release magnet RM. Thus it will be understood that when the plate power delay relay K3 occupies its restored position that the circuit for operating the release magnet RM is closed.

Further in the power supply circuit arrangement a water coil, not shown, is operatively associated with the magnetron tube V1 and is supplied with cooling water during operation of the magnetron tube V1. In this water cooling arrangement, a water flow interlock switch S3 is provided that occupies its closed position only when the water is flowing through the water cooling coil noted; and a water temperature interlock switch S2 is provided that occupies its closed position only when the temperature of the water after it has passed through the water cooling coil is at a safe operating temperature. Further the oven 10 is provided with a door, not shown, with which an oven door interlock switch S4 is operatively associated, the oven door interlock switch S4 being closed only when the oven door noted occupies its closed position. Finally a timer K4 is provided that includes an electric drive motor 97 of the synchronous type, and preferably of the Telechron type, a gear box 98, a slip clutch 99, a control cam 100, and a manually operable control dial 101. Specifically the drive motor 97 is provided with a drive shaft 102 that terminates in the gear box 98; and the gear box 98 is provided with a driven shaft 103 that terminates in one of the clutch plates of the slip clutch 99; and the control cam 100 and the control dial 101 are rigidly secured to an operating shaft 104 terminating in the other clutch plate of the slip clutch 99. Thus the operating shaft 104 may be rotated by the control dial 101 independently of the gear box 98 by virtue of the arrangemnt of the slip clutch 99, whereby the control cam 100 is rotated therewith effecting closure of an associated pair of switch springs 105. Operation of the drive motor 97 returns the operating shaft 104 back toward its home position at a timed rate, whereby

the control cam 100 is returned back into its normal position at the expiration of the set time in order again to open the set of switch springs 105. Accordingly it will be understood that when the control dial 101 is rotated out of its normal position to set a variable time that the drive motor 97 returns the operating shaft 104 back into its normal position after the expiration of the preset time, whereby the control cam 100 effects closure of the set of switch springs 105 during the preset time noted.

The winding 36 of the plate power relay K2 is provided with an operating circuit that includes the feed conductors 70 and 71, the set of switch springs 105, the water temperature interlock switch S2, the water flow interlock switch S3, the oven door interlock switch S4, a pair of contacts controlled by a bridging member 106 provided on the plate power delay relay K3, a pair of contacts controlled by a bridging member 107 provided on the direct current overcurrent relay K5, and a pair of contacts controlled by a bridging member 108 provided on the ultra-high frequency overvoltage relay K6. Further a water pump, not shown, is provided for the purpose of circulating water through the cooling coil, not shown, of the magnetron tube V1, the water pump being operated by a water pump motor B1 connected between the filament supply conductors 46 and 47. The water mentioned is circulated through a cooler, not shown, that is provided with a cooling fan, not shown, that is operated by a water cooling fan motor B2 that is connected across the filament supply conductors 46 and 47. The magnetron tube V1 is also provided with a cooling blower, not shown, that is operated by a magnetron cooling blower motor B4 that is connected across the filament supply conductors 46 and 47. The rectifier tubes V2, etc. are provided with a rectifier cooling blower, not shown, that is operated by a rectifier cooling blower motor B3 that is connected across the feed conductors 70 and 71.

Considering now the general operation of the power supply circuit, the power selector switch S1 is first manually set into one of its positions corresponding to the desired ultra-high frequency power level output of the magnetron tube V1; the material 13 to be heated is placed in the cavity 12; the door of the oven 10 is closed in order to effect closure of the oven door interlock switch S4; the manual dial 101 is rotated out of its normal position to set a time during which it is desired to heat the material 13 in the cavity 12 so as to effect closure of the set of switch springs 105; and finally the oil circuit breaker K1 is operated into its closed position. Closure of the oil circuit breaker K1 effects the supply of power to the filament supply conductors 46 and 47, whereby the primary winding 68 of the isolation transformer T7 is energized to effect the supply of power to the feed conductors 70 and 71. The power supplied to the filament supply conductors 46 and 47 effects operation of the water pump motor B1, the water cooling fan motor B2, and the magnetron cooling blower motor B4; while the supply of power to the feed conductors 70 and 71 effects operation of the rectifier cooling blower motor B3. Also the supply of power to the filament supply conductors 46 and 47 energizes the primary windings 57, 59, 61 and 63 of the rectifier filament transformers T3, T4, T5 and T6, whereby voltages are induced in the respective secondary windings 58, 60, 62 and 64, thereof, so as to cause heating of the filamentary cathodes of the rectifier tubes V2, V3, V4, V5, V6 and V7. Also the supply of power to the filamentary supply conductors 46 and 47 effects the energization of the primary winding 66 of the magnetron filament transformer T2 through the associated magnetron filament power controller Z4, the associated filament control rheostat R1 having been previously set to establish the desired filament supply current for the filamentary cathode 17 of the magnetron tube V1, whereby the voltage induced in the secondary winding 67 of the magnetron filament transformer T2 effects heating of the cathode 17 of the magnetron tube V1.

Further the supply of power to the feed conductors 70 and 71 closes the previously-traced local exciting circuit including the rectifier bridge Z2 and the resistors R11, R12, R13 and R14 for the magnet coil L1 of the magnetron tube V1, whereby the ultra-high frequency power of the magnetron tube V1 is preset at the maximum value. Also the supply of power to the feed conductors 70 and 71 completes the previously-traced circuit including the rectifier bridge Z5 for operating the release magnet RM of the control switch SS so as to insure that the control switch SS occupies its normal or home position at this time; the last-mentioned circuit being completed by virtue of the restored position of the plate power delay relay K3 at this time. Further the supply of power to the feed conductors 70 and 71 completes the previously-traced circuit including the rectifier bridge Z3 and the divider D4 for energizing the winding 79 of the ultra-high frequency overvoltage relay K6, whereby the latter relay being of the marginal type remains in its restored position at this time. Finally the supply of power to the filament supply conductors 46 and 47 effects the energization of the winding of the plate power delay relay K3, whereby the latter relay being of the slow-to-operate type is operated only after a predetermined time interval, about 30 seconds, so as to permit heating of the filamentary cathodes of the various rectifier tubes V2, etc., and heating of the filamentary cathode 17 of the magnetron tube V1.

Upon operating the plate power delay relay K3 interrupts, at the bridging member 96, the previously-traced circuit for operating the release magnet RM of the control switch SS so as to effect the release of the armature 89, whereby the control switch SS is conditioned to be operated away from its home position. Also upon operating the plate power delay relay K3 completes, at the bridging member 106, the previously mentioned series circuit for energizing the winding 36 of the plate power relay K2, this circuit including the feed conductors 70 and 71, the bridging members 106, 107 and 108, the water temperature interlock switch S2, the water flow interlock switch S3, the oven door interlock switch S4, and the set of switch springs 105 of the timer K4. When this circuit is completed, the plate power relay K2 operates connecting the power supply buses 40, 41 and 42 to the feed conductors 43, 44 and 45, whereby the primary winding sections 22, 23 and 24 of the plate power transformer T1 is energized so that power is supplied via the feed conductors 48, 49 and 50 to the rectifier tubes V2, V3, V4, V5, V6 and V7. Also the drive motor 97 of the timer K4 is energized in multiple with the winding 36 of the plate power supply relay K2 so that the operating shaft 104 is rotated back toward its home position through the gear box 98 and the associated slip clutch 99 so that timing of operation of the supply circuit is initiated by the timer K4. Also it is noted that a pilot lamp 12 is illuminated in multiple with the winding 36 of the plate power

relay K2 in order to indicate that operation of the timer K4 has been initiated and that the plate power relay K2 occupies its operated position. Further a pilot lamp I1 is illuminated directly across the feed conductors 70 and 71 in order to indicate the supply of power thereto from the isolation transformer T1.

The rectifier tubes V2, etc., effect the supply of high voltage direct current to the output conductors 52 and 53 in a well-known manner so that oscillation of the magnetron tube V1 is initiated, whereby the ultra-high frequency power is supplied from the magnetron tube V1 via the transmission line 14 to the cavity 12 effecting heating of the material 13 therein. Under standard and normal conditions, operation of the power circuit proceeds until the expiration of the preset time interval, whereupon the control cam 100 is returned back into its normal position effecting opening of the set of switch springs 105 and the consequent de-energization of the winding 36 of the plate power relay K2, extinguishing of the pilot lamp I2, and arresting of operation of the drive motor 97. The plate power relay K2 then restores disconnecting at the bridging members 36, 37 and 38 the power supply buses 40, 41 and 42 from the feed conductors 43, 44 and 45 so as to effect de-energization of the plate power transformer T1 in order to arrest operation of the rectifier tubes V2, etc. and the magnetron tube V1. When the pilot lamp I2 is thus extinguished it indicates that it is safe to open the door, not shown, of the oven 10 so that the material 13 may be removed from the cavity 12. When the door, not shown, of the oven 10 is thus opened, the oven door interlock switch S4 is returned into its open position.

During operation of the power supply circuit, should the flow of water through the water cooling coil, not shown, associated with the magnetron tube V1 be arrested, the water flow interlock switch S3 would be returned into its open position effecting the restoration of the plate power relay K2. In a similar manner, should the temperature of the water flowing through the water cooling coil, not shown, associated with the magnetron tube V1 exceed a safe temperature, the water temperature interlock switch S2 would be operated into its open position effecting the restoration of the plate power supply relay K2. Further should the door, not shown, of the oven 10, be inadvertently opened, the oven door interlock switch S4 is returned into its open position effecting the restoration of the plate power relay K2. Also should the control dial 101 of the timer K4 be prematurely returned manually back into its normal position the set of switch springs 105 is opened effecting the restoration of the plate power relay K2. Moreover during the operation of the power circuit should the magnetron tube V1 draw an abnormally high overload current, the direct current overcurrent relay K5 is operated in order to interupt, at the bridging member 107, the circuit for energizing the winding 36 of the plate power relay K2 so as to effect the restoration thereof.

Reconsidering the operation of the power circuit, the impedance of the load comprising the material 13 disposed in the cavity 12 normally reasonably matches the impedance of the magnetron tube V1, whereby there is no excessive reflected ultra-high frequency power from the cavity 12 back to the magnetron tube V1. However in the event of a substantial mismatch between the impedance of the load in the cavity 12 and the impedance of the magnetron tube V1, there is a substantial reflected ultra-high frequency power from the cavity 12 back to the magnetron tube V1, whereby an excess and unsafe microwave voltage is present across the magnetron tube V1 that would effect undue and damaging heating thereof. However this excess microwave voltage greater than a safe value, due to the reflected ultra-high frequency power, is present in the transmission line 14, and consequently a portion thereof is present in the attenuator 19 so that the glow lamp V9 is ionized and ignited. When the glow lamp V9 is thus ignited, the upper portion of the divider D4 is effectively short-circuited effecting sufficient energization of the winding 79 of the ultra-high frequency overvoltage relay K6 to cause operation thereof.

Upon operating the ultra-high frequency overvoltage relay K6 interrupts, at the bridging member 108, the circuit for energizing the winding 36 of the plate power relay K2 so as to effect restoration of the latter relay and the consequent removal of power from the plate power transformers T1 and the consequent protection of the magnetron tube V1. Also the ultra-high frequency overvoltage relay K6 completes, at the bridging member 93, the previously-traced circuit for energizing the stepping magnet SM of the control switch SS, whereby the armature 84 is attracted causing the pawl 85 cooperating with the ratchet wheel 86 to drive the operating shaft 80 one step in the clockwise direction out of its home position into its first control position so that the wiper 81 short-circuits the resistor R11 normally included in the local exciting circuit for the magnet coil L1. The operating shaft 80 of the control switch SS is restrained in its first control position by the cooperation between the release pawl 88 and the ratchet wheel 86, and energy is stored in the coil spring 93.

When operation of the magnetron tube V1 is arrested, no incident ultra-high frequency power is supplied via the transmission line 14 to the cavity 12, whereby the glow lamp V9 is extinguished again inserting the upper portion of the divider D4 into series relation with the winding 79 of the ultra-high frequency overvoltage relay K6 so as to cause the latter relay to restore since it is of the marginal type. Upon restoring the ultra-high frequency overvoltage relay K6 interrupts, at the bridging member 93, the circuit for operating the stepping magnet SM of the control switch SS so that the spring 87 may return the armature 84 into its normal position thereby to condition the control switch SS to be operated another step in the event of reoperation of the stepping magnet SM. Also upon restoring the ultra-high frequency overvoltage relay K6 recompletes, at the bridging member 108 the circuit for energizing the winding 36 of the plate power relay K2, whereby the latter relay reoperates in order again to effect the supply of power to the plate power transformer T1 so that the respective tubes V2, etc., and the magnetron tube V1 are again operated in order to supply the ultra-high frequency power from the magnetron tube V1 via the transmission line 14 to the cavity 12.

In view of the foregoing, it will be understood that at this time the incident ultra-high frequency power that is supplied from the magnetron tube V1 via the transmission line 14 to the cavity 12 is at a given lower predetermined level by virtue of the circumstance that the control switch SS occupies its first control position short-

circuiting the resistor R11 so that the magnet coil L1 is excited with a greater current in its local exciting circuit. Also it will be appreciated that in the event the impedance mismatch is sufficiently severe, again an undue and dangerous amount of ultra-high frequency power willl be reflected back from the cavity 12 through the transmission line 14 to the magnetron tube V1 so as again to ignite the glow tube V9, whereby the circuit is recycled in the manner explained above. Specifically the ultra-high frequency overvoltage relay K6 is operated and then restored effecting restoration and then reoperation of the plate power relay K2 and driving of the control switch SS from its first control position into its second control position. Thus at this time incident ultra-high frequency power is supplied from the magnetron tube V1 via the transmission line 14 to the cavity 12 at a still lower given level by virtue of the exclusion of the resistors R11 and R12 from the local exciting circuit of the magnet coil L1 of the magnetron tube V1.

In view of the foregoing description of the mode of operation of the glow lamp V9 and the associated ultra-high frequency overvoltage relay K6, in conjunction with the plate power relay K2 and control switch SS, it will be understood that successive operations of the control switch SS are effected until the incident ultra-high frequency power level of the magnetron tube V1 is established, in view of the impedance mismatch, so that the amount of reflected ultra-high frequency power from the cavity 12 via the transmission line 14 to the magnetron tube V1 is not excessive and at a safe level so that damaging heating of the magnetron tube V1 is prevented.

Further it is pointed out that in the event of an extremely severe impedance mismatch that the glow lamp V9 is successively ignited so that the control switch SS is driven through its various control positions into its final position wherein the wiper 82 engages the contact in the associated contact bank completing a direct connection between the conductors 20 and 21, thereby short-circuiting the upper portion of the divider D4 in multiple with the glow lamp V9 and effecting the completion of a locking circuit for energizing the winding 79 of the ultra-high frequency overvoltage relay K6 so as to retain the latter relay in its operated position notwithstanding the subsequent extinguishing of the glow lamp V9 when the plate power relay K2 restores. Thus in this event the ultra-high frequency overvoltage relay K6 is locked in its operated position in order to prevent further reoperation of the plate power relay K2 so that the power circuit is locked out of service. In this connection, it is noted that the ultra-high frequency overvoltage relay K6 also includes a contact bridging member 109 that completes a circuit for illuminating an alarm lamp AL when the latter relay occupies its operated position; the circuit mentioned being bridged across the conductors 77 and 78. The continued illumination of the alarm lamp AL indicates that the control switch SS has been operated into its final position and that the power circuit has been locked out of service. The attendant then trips the oil circuit breaker K1 into its open position in order to remove power from the power supply buses 40, 41 and 42 bringing about the restoration of the plate power delay relay K3 and the ultra-high frequency overvoltage relay K6.

The attendant may again place the power supply circuit in operation by reclosing the oil circuit breaker K1. When the oil circuit breaker K1 is thus reclosed, the previously-traced circuit for operating the release magnet RM of the control switch SS is completed, whereby the armature 89 is operated so that the release pawl 88 is withdrawn from the ratchet wheel 86 so that the spring 83 may return the operating shaft 80 back into its home position. When the operating shaft 80 of the control switch SS is thus returned into its home position, the resistors R11, etc., are again inserted in the local exciting circuit for the magnet coil L1 of the magnetron tube V1. Also when the oil circuit breaker K1 is reclosed, the winding of the plate power delay relay K3 is energized so as to effect operation of the latter relay after the time interval previously noted. Also upon reoperating the plate power delay relay K3 interrupts, at the bridging member 96, the circuit for energizing the release magnet RM of the control switch SS and effects reoperation of the plate power relay K2 so that the magnetron tube V1 is reoperated. Of course in the event the severe impedance mismatch has not been corrected, the glow lamp V9 will be again successively ignited to effect successive recycling of the ultra-high frequency overvoltage relay K6 and the ultimate locking of the latter relay in its operated position and the continued illumination of the alarm lamp AL, in the manner explained above.

For purposes of instrumentation a plate voltmeter M1 is bridged between the output conductor 53 and ground potential; and a plate ammeter M2 is included in the output conductor 52. Also a magnet current ammeter M3 is included in the conductor 75 in series relation with the magnet coil L1; a filament voltmeter M6 is bridged across the conductor pair 65 for the purpose of measuring the voltage supplied to the primary winding 66 of the magnetron filament transformer T2; a filament hourmeter M7 is bridged across the filament supply conductors 46 and 47 and may comprise essentially a synchronous motor of the Telechron type; and a plate hourmeter M8 is bridged across the feed conductors 44 and 45 and may comprise essentially a synchronous motor of the Telechron type. Also an incident ultra-high frequency power wattmeter M4 and a reflected ultra-high frequency power wattmeter M5 are provided. More particularly two directional couplers 110 and 111 are respectively connected between the outer conductor 15 of the transmission line 14 and two conductors 112 and 113, which conductors 112 and 113 are respectively connected to two square law crystal detectors 114 and 115 that may be of the germanium crystal type. In turn, the detectors 114 and 115 are connected to a filter network that comprises two resistors 116 and 117 and two smoothing condensers 118 and 119, the midpoint between the resistors 116 and 117 and the midpoint between the smoothing condensers 118 and 119 being commonly connected together by a conductor 120, that is, in turn, connected both to ground potential and to the outer conductor 15 of the transmission line 14. The incident ultra-high frequency power wattmeter M4 is bridged between the outer extremities of the resistor 116 and the condenser 118 and the conductor 120; and the reflected ultra-high frequency power wattmeter M5 is bridged between the outer extremities of the resistor 117 and the condenser 119 and the conductor 120. In the operation of the meters M4 and M5, it is pointed out that the directional coupler 110 is arranged and poled with respect to the incident ultra-high frequency elec-

tromagnetic traveling wave in the transmission line 14 to derive a first ultra-high frequency current that is proportional to the incident voltage of the wave noted; while the directional coupler 111 is arranged and poled with respect to the reflected ultra-high frequency electromagnetic traveling wave in the transmission line 14 to derive a second ultra-high frequency current that is proportional to the reflected voltage of the wave noted. The first current mentioned derived by the directional coupler 110 is rectified by the square-law crystal detector 114 to produce a third ultra-high frequency pulsating current that is proportional to the square of the first current mentioned; and the second current mentioned derived by the directional coupler 111 is rectified by the square-law crystal detector 115 to produce a fourth ultra-high frequency pulsating current that is proportional to the square of the second current mentioned. The third and fourth currents mentioned are applied in opposition to each other to the extremities of the resistors 116 and 117, whereby the smoothing condensers 118 and 119 produce unidirectional voltages that are respectively proportional to the incident ultra-high frequency power and to the reflected ultra-high frequency power, which voltages are respectively applied to the meters M4 and M5 that may be of the voltmeter type. Accordingly the meters M4 and M5 effectively measure the respective incident ultra-high frequency power and the reflected ultra-high frequency power in the transmission line 14.

The construction and arrangement of the cooking oven 10 and the associated transmission line 14 provided with the bifurcated end terminating in the two arms embracing the oven 10 are disclosed and claimed in the copending application of George W. Schroeder, Serial No. 232,005, filed June 16, 1951.

In view of the foregoing, it is apparent that there has been provided an improved protective and control circuit network for an ultra-high frequency power supply system so as to prevent damage to the ultra-high frequency generator in the event of an impedance mismatch between the load and the generator and so as to establish automatically a safe ultra-high frequency power level of operation of the ultra-high frequency generator in view of the existing impedance mismatch between the generator and the load.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made therein, and it is intended to cover in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. In a radio frequency power supply system including a load, a radio frequency generator of the magnetron type provided with an input circuit and an output circuit and a magnet coil, a source of power, a power switch selectively operative to connect and to disconnect said source of power with respect to said input circuit, means for connecting said output circuit to said load, and an exciting circuit for said magnet coil, the radio frequency power supplied by said magnetron to said load via said output circuit being inversely proportional to the excitation of said magnet coil via said exciting circuit; the combination comprising means for setting a predetermined excitation of said magnet coil via said exciting circuit, means for closing said power switch, means including an element for testing the amount of radio frequency power reflected from said load back to said magnetron via said output circuit, a relay, means controlled by said element in response to testing of a certain amount of radio frequency power reflected from said load back to said magnetron via said output circuit for operating said relay, means controlled by operation of said relay for opening said power switch and for setting a higher given excitation of said magnet coil via said exciting circuit, means controlled by interruption of the supply of radio frequency power from said magnetron to said load via said output circuit for restoring said relay, and means controlled by restoration of said relay for reclosing said power switch.

2. In a radio frequency power supply system including a load, a radio frequency generator of the magnetron type provided with an input circuit and an output circuit and a magnet coil, a source of power, a power switch selectively operative to connect and to disconnect said source of power with respect to said input circuit, means for connecting said output circuit to said load, and an exciting circuit for said magnet coil, the radio frequency power supplied by said magnetron to said load via said output circuit being inversely proportional to the excitation of said magnet coil via said exciting circuit; the combination comprising a device successively operative from a normal position through a plurality of control positions into a final position, means controlled by said device in its normal position for setting a predetermined excitation of said magnet coil via said exciting circuit and controlled by said device in its successive control positions for setting successively higher given excitations of said magnet coil via said exciting circuit, means for closing said power switch, means for operating said device into its normal position, an element operative in response to the reflection of radio frequency power from said load back to said generator in a certain amount, a relay, means controlled by operation of said element for operating said relay, means controlled by operation of said relay for opening said power switch and for operating said device from its present position into the adjacent one of its positions and toward its final position, means normally controlled by interruption of the supply of radio frequency power from said magnetron to said load via said output circuit for restoring said relay, means controlled by restoration of said relay for reclosing said power switch so that said testing means again tests the amount of radio frequency power reflected from said load back to said magnetron via said output circuit, and means controlled by operation of said device into its final position for retaining operated said relay.

3. The combination set forth in claim 2, and further comprising release means for restoring said relay and for operating said device from its final position back into its normal position.

4. The combination set forth in claim 2, wherein said exciting circuit includes a plurality of series related resistors, and said device is in the form of a stepping switch arranged successively to remove said resistors from said exciting circuit in the successive control positions thereof.

5. In a radio frequency power supply system including a load, and a radio frequency generator operative to supply radio frequency power to said load; the combination comprising a device successively operative from a normal position through a plurality of control positions, means controlled by said device in its normal position

for setting said generator to supply radio frequency power in a predetermined amount to said load and controlled by said device in its successive control positions for setting successively said generator to supply radio frequency power in successively lower given amounts to said load, means for operating said device into its normal position, means for operating said generator, means including an element for testing successively the amount of radio frequency power reflected from said load back to said generator, and means controlled by said element in response to each testing of a certain amount of radio frequency power reflected from said load back to said generator for operating said device away from its normal position.

6. The radio frequency power supply system combination set forth in claim 5, wherein said generator essentially comprises a magnetron type tube.

7. The radio frequency power supply system combination set forth in claim 5, wherein said element essentially comprises a gaseous discharge type tube.

8. The radio frequency power supply system combination set forth in claim 5, wherein said device essentially comprises a switch of the step-by-step type.

9. In a radio frequency power supply system including a load, and a radio frequency generator operative to supply radio frequency power to said load; the combination comprising a device successively operative from a normal position through a plurality of control positions into a final position, means controlled by said device in its normal position for setting said generator to supply radio frequency power in a predetermined amount to said load and controlled by said device in its successive control positions for setting successively said generator to supply radio frequency power in successively lower given amounts to said load, means for operating said device into its normal position, means for initiating operation of said generator, means including an element for testing successively the amount of radio frequency power reflected from said load back to said generator, means controlled by said element in response to each testing of a certain amount of radio frequency power reflected from said load back to said generator for operating said device away from its normal position, and means controlled by operation of said device into its final position for arresting operation of said generator.

10. In a radio frequency power supply system including a load, a radio frequency generator operative to supply radio frequency power to said load, a source of power, and a power switch operable between open and closed positions, said power switch in its closed position connecting said source of power to said generator in order to effect operation thereof; the combination comprising a device successively operative from a normal position through a plurality of control positions into a final position, means controlled by said device in its normal position for setting said generator to supply radio frequency power in a predetermined amount to said load and controlled by said device in its successive control positions for setting successively said generator to supply radio frequency power in successively lower given amounts to said load, means for operating said power switch into its closed position, means for operating said device into its normal position, means including an element for testing successively the amount of radio frequency power reflected from said load back to said generator, means controlled by said element in response to each testing of a certain amount of radio frequency power reflected from said load back to said generator for operating said device away from its normal position, means controlled by operation of said device into its final position for operating said power switch into its open position, and additional means responsive to the supply of more than said predetermined amount of radio frequency power from said generator to said load for operating said power switch into its open position.

11. In a radio frequency power supply system including a source of power, a supply bus, a first switch operable between open and closed positions, said first switch in its closed position connecting said source of power to said supply bus, a load, a radio frequency generator operative to supply power to said load, and a second switch operable between open and closed positions, said second switch in its closed position connecting said supply bus to said generator in order to effect operation thereof; the combination comprising a first relay of the slow-to-operate type, means for operating said first switch into its closed position, means controlled by the supply of power to said supply bus for initiating operation of said first relay, means controlled by operation of said first relay for operating said second switch into its closed position, a device successively operative from a normal position through a plurality of control positions into a final position, means controlled by said device in its normal position for setting said generator to supply radio frequency power in a predetermined amount to said load and controlled by said device in its successive control positions for setting successively said generator to supply radio frequency power in successively lower given amounts to said load, means for operating said device into its normal position, means including an element for testing successively the amount of radio frequency power reflected from said load back to said generator, a second relay, means controlled by said element in response to each testing of a certain amount of radio frequency power reflected from said load back to said generator for operating said second relay, means controlled by operation of said second relay for operating said second switch into its open position and for operating said device away from its normal position, means normally responsive to the disconnection of said supply bus from said generator for restoring said second relay, means responsive to restoration of said second relay for reoperating said second switch into its closed position, and means controlled by operation of said device into its final position for retaining operated said second relay.

12. In a radio frequency power supply system including a source of power, a supply bus, a first switch operable between open and closed positions, said first switch in its closed position connecting said source of power to said supply bus, a load, a radio frequency generator operative to supply power to said load, and a second switch operable between open and closed positions, said second switch in its closed position connecting said supply bus to said generator in order to effect operation thereof; the combination comprising a first relay of the slow-to-operate type, means for operating said first switch into its closed position, means controlled by the supply of power to said

supply bus for initiating operation of said first relay, means controlled by operation of said first relay for operating said second switch into its closed position, a device successively operative from a normal position through a plurality of control positions into a final position, means controlled by said device in its normal position for setting said generator to supply radio frequency power in a predetermined amount to said load and controlled by said device in its successive control positions for setting successively said generator to supply radio frequency power in successively lower given amounts to said load, means including an element for testing successively the amount of radio frequency power reflected from said load back to said generator, a second relay, means controlled by said element in response to each testing of a certain amount of radio frequency power reflected from said load back to said generator for operating said second relay, means controlled by operation of said second relay for operating said second switch into its open position and for operating said device away from its normal position, means normally responsive to the disconnection of said supply bus

from said generator for restoring said second relay, means responsive to restoration of said second relay for reoperating said second switch into its closed position, means controlled by operation of said device into its final position for retaining operated said second relay, means for operating said first switch into its open position, means responsive to the removal of power from said supply bus for restoring said first and second relays, and means controlled by the restoration of said first relay for operating said device from its final position back into its normal position.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
2,374,008	Godsey	Apr. 17, 1945
2,498,719	Spencer	Feb. 28, 1950
2,498,720	Wild	Feb. 28, 1950
2,508,548	Spauldine	May 23, 1950
2,546,500	Hall	Mar. 27, 1951
2,595,748	Andrews	May 6, 1952
2,648,772	Dawson et al.	Aug. 11, 1953