General Description

Introduction

The system described in this manual is designed to power a CPI S-Band magnetron, 850-1000 kW, operating in a normal environment.

The system is a hard modulator system driven by a series resonance solid state power supply. The input line voltage is 220VAC 50/60 Hz and the maximum input line current is 20 amperes.

The system described in this manual consists of three main parts.

- The Main High Voltage Power Supply
- The Modulator System
- Control Panel

Our design objective is to incorporate the latest technology in both the power supply and the modulator to meet the magnetron requirements and to satisfy our customer's needs.

The customer requires a system that is flexible on both pulse width and PRF with emphasis being placed on reliability, size and cost.

The first objective was to design the system with a variable pulse width and variable PRF. In contrast with a line type modulator system where the pulse width is set by the pulse forming network and it becomes difficult to fine tune, the pulse width of this system can be set from 0.5 μsec to 2.0 μsec. The pulse selection is done through the modulator control system with four pre-selectable pulse widths: 0.5 μsec, 0.8 μsec, 1.0 μsec and 2.0 μsec.

The power supply section is self-contained in an enclosure as shown in Figure 1.0 (See Appendix). Our design is based on series resonance topology driving a full bridge IGBT circuit.

The modulator is a hard-tube type, utilizing IGBT technology, and is under an oil environment. The mechanical enclosure for the modulator is shown in Figure 2.0 (See Appendix).

System Specifications

The specifications for the system are outlined in the appendix along with the magnetron specifications.

General Technical Discussion

As previously mentioned, the whole system consists of the high-voltage power supply and the solid-state hard tube modulator.

The solid-state power supply contains the following sections:

A. Off-Line Power Factor, Filters, and Controls
B. Series Resonance Full Bridge Inverter
C. Series Resonance Frequency Modulation Controller
D. High Voltage Output Section
E. Low Voltage Power Supplies
F. Hard Tube Modulator Control
G. Filament Power Supply (control section)

The Modulator section contains the following sections:

A. IGBT Driver Card Array
B. PRF Driver
C. High Power Switch Section with Despike Network
D. Corner Cutter Section
E. Despike Network
F. Magnetron Peak Current Detector
G. Magnetron Filament Power Supply Section (Power Section)

Figure 4.0 shows the full system including the control panel and the magnetron connections. The following discussion is in reference to this figure.

The input voltage for the system is 220 VAC single phase and it enters the system via the rear panel of the high voltage power supply via terminals E2 and E3 of terminal strip.

The input line voltage enters the Power Factor Correction Module, which performs the rectification, inrush current limiting and pre-regulation of the input line voltage.

The power factor module provides a pre-regulate voltage level of 360 VDC. The above 360 VDC is applied to the input of the series resonance converter which, in turn, provides a final adjustable level of 0-900 VDC available at the modulator section.

The above DC output is sent to the modulator section via a connector leaving the back of the power supply section from terminal strip, terminals E7, E8, and E9 and terminating at J3 of the modulator. The above connector is a four wire connector including the system ground.

The input PRF, which is TTL level, enters the rear panel of the power supply marked J1, "PRF IN". It enters the Modulator Control Circuit, which transforms this input signal to a selectable pulse width level proper for triggering the modulator section of the system. The modulator control circuit performs additional functions and this will be discussed later under the power supply section.

Figure 3.0 shows the complete power supply section of the system. The left lower section of the above diagram shows the connectors for the external control panel. The power supply also provides the low voltage bias levels required by the modulator. The modulator section receives the trigger input from the modulator control circuit located in the power supply. The input pulse is TTL level and the output pulse from the modulator control to the modulator section is CMOS level.

The function of the modulator is to receive the input signal and provide a high power pulse of 36-38 kV at the cathode of the magnetron, thus causing the magnetron to oscillate at C-Band frequency under the selected pulse width set by the modulator control circuit.

The nominal cathode peak current under the above conditions is 50 Amperes peak. The above voltage and current levels result in a peak output power of 850 KW. In the meantime, the filament power supply requires programming according to the magnetron specifications.

For the stand-by condition, the filament voltage is set to 9.0 VDC at 24 Amps. At 001 duty cycle the heater voltage should be reduced to 7.0 VDC.

The cathode voltage is fed to the magnetron via the high voltage bushing located on top of the modulator. The following is an option. At the base of the high-voltage bushing, a wide band current transformer can be provided to monitor the peak cathode current. The calibration of the current transformer is set at 0.1volt per ampere of peak current.

For example, if we are looking at the scope displaying the current monitor output, a 5.5 volt peak pulse level will indicate 55 Amps peak magnetron current. A spark gap is required and supplied with each system, which prevents the magnetron from reaching much higher than normal pulse voltage levels. The voltage of the spark gap is set to 45 kVpk.

The spark gap should be connected between the cathode voltage and ground.

Mechanical

As previously mentioned, the mechanical outline drawings of both the power supply and modulator are shown in figures 1.0 and 2.0. The power supply is of a dry construction and can be mounted in any orientation. The modulator on the other hand is enclosed in an oil-filled container for insulating and cooling reasons. The modulator should be mounted in a horizontal position.

Power Supply Section

Technical Approach

For the power supply of the system, we feel that the series resonance converter topology is the best choice.

First, the efficiency of the system is greatly optimized under this topology and both the RFI and EMI levels are kept at a minimum. In contrast, with PWM systems, the series resonance converter operates smoothly with sine wave currents, rather than square wave excitation. Efficiency levels of 97% are easily attained under the chosen power supply topology with proper design techniques.

Schematic Diagram

Figure 3.0 shows the complete schematic of the power supply. There are several sections shown in the block diagrams; the relay section, the SRI Control, the Modulator Control , the Bridge Inverter, the low voltage power supplies, the filament power supply, the high voltage section and the input and output connections to the rest of the system. This is done to facilitate the technical description for the power supply that follows.

The input power enters the power supply at the command of the 24 VDC control voltage. This voltage is received from the control panel via pin 13 of the control connector J3 located at the rear panel of the power supply. Relays K1and K2, receives the +24 VDC level and allows the main power to enter the power supply. The control transformer T-3 when energized provides low voltage ac power for the gate drive of modulator section.

At the same time, the main voltage of 220 VAC is applied to the two low voltage power supplies in the upper section of the schematic. These two power supplies provide the +24 VDC and the +15 VDC needed by the system.

Next, the input line voltage enters the Power Factor Correction Circuit. The power factor module rectifies the input line voltage, regulates it, and limits the input inrush current to a reasonable level.

The final level of 360 VDC is applied to a capacitive input filter properly sized for the full power of the system and, finally, is applied to the full bridge circuit shown next to the power factor circuit. The full bridge circuit is driven by the SRI Control circuit, which generates, regulates and provides protection for the whole power supply system.

The SRI control circuit sends two drive pulses, noted as Drive A and Drive B. Both pulses are identical in amplitude and pulse-width and they occur in a time sequence dictated by the SRI Controller. These pulses are also frequency modulated, depending on the power demand of the system. This is the way the power supply regulates.

When the load demands more power, the drive pulses occur at a higher frequency and when the load demand diminishes, the frequency slows down to the point that the system meets its regulating requirements.

The two drive pulses are applied to the bridge circuit of the main inverter and they drive the main switches into full conduction during their on state and off during their off state. Turn-on and turn-off occur at zero current conditions. The schematic diagram of the full bridge driver circuit is shown on figure 6.0.

This alternating voltage waveform is impressed across the primary winding of the inverter transformer and with the proper turns ratio the output is rectified and filtered to a maximum level of 850 VDC.

The output voltage of the power supply is controlled by a potentiometer located at the control panel. The top arm of the potentiometer is connected to +10 VDC and the wiper is connected to one terminal of an operational amplifier. The other input terminal of the operational amplifier is connected to the feedback terminal of the output section of the power supply.

The design objective is to keep the two input terminals of the operational amplifier to an equal level. If the arm of the potentiometer is set to a higher voltage level, thus demanding higher output voltage from the power supply, the feedback signal is raised to the same corresponding level as the arm of the potentiometer. This is the way the system regulates against input and load variations.

Metering circuits are provided for the following parameters:

A: DC Output Power Supply Voltage DC Output Power Supply
B: C: Current Magnetron Average Current Magnetron Filament
D: E: Voltage System Input Voltage

The return section of the power supply goes through a sensing resistor whose level is detected and processed for over-current condition.

Mechanical Considerations

Figure 1.0 shows the mechanical configuration of the power supply. The enclosure is made of chemically treated aluminum alloy and is cooled with three fans located in the back section of the power supply frame.

The power level of the power supply system is set to a maximum of 4.0 kW. The maximum temperature rise of the power supply is 35 degrees Centigrade.

The average power of the system is given by the following equation:

Pav = Vpk Ipk duty cycle

The system operating at maximum duty cycle of .001 requires a power level of 36000 x 55 x .001 = 1980 watts. If we assume system efficiency, including both the power supply and modulator, of 75% the power level of the power supply becomes 2,640 watts, which is lower than the maximum power supply limit of 4000 watts.

Interface

In order for the system to operate properly and provide all the essential parameters on the monitors, a control panel in necessary.

In order to place the system in operation, the need of a +24 VDC power supply is essential. This power supply is shown in the power supply schematic on figure 3.0

The system has both local and remote capabilities. The control panel enables both the local and remote modes of the system. All the local functions are contained in the control panel located in the front section of the equipment cabinet. By placing the control switch in the remote position all functions can be controlled remotely via RS 232 interface, or via a control processor. Figure 9.0 shows the schematic of the control panel.

The power supply communicates with the modulator and monitors fault conditions relating to the magnetron misfiring, over-current and over-duty conditions.

Figure 4.0 is a functional diagram showing the power supply and modulator interconnected via the control panel.

Modulator Section

Technical Approach

Our design approach for reliable operation has been to limit the switching voltage level within the solid-state switch capability and to avoid stacking switches in series configuration. The design approach is shown in figure 8.0.

Schematic Diagram

For the discussion, which follows, we make reference to figure 8.0.

The control portion of the modulator system is designed on an open frame for easy access. The high voltage portion of the system is enclosed in oil environment for insulating and cooling reasons. Figure 8.0 shows the main sections that are contained in the modulator system. The dotted right section of figure 8 is the oil section and the left portion is the open construction assembly.

The PRF driver is set at the front section of the system. It receives its signal from the modulator control, designed to be slaved to an external PRF generator.

The only control that the external generator has over the modulator control is the frequency count. The rest of the pulse width processing and control is governed by the modulator control circuit. The hard modulator control circuit is shown in figure 7.0

The complete modulator system consists of three drive circuits, a supervisory control circuit governing the operating conditions of the drive circuits and the output section. The output section consists of three solid-state switch assemblies, three high voltage step-up pulse transformers, a dc filament power supply and a pulse-shaping network.

In order to generate the narrow pulses with proper rise and fall times, the pulse transformer design demands special consideration in selecting the proper magnetic material and proper winding configuration. This information is proprietary to Pulse Systems Inc.

The magnetron tube also requires proper rate of rise of the cathode voltage. This level has to be kept between 40 and 60 kV/μsec in order to avoid magnetron moding

The solid-state switch assembly is turned on during the positive portion of the drive pulse and kept off when the drive pulse goes to a negative bias level.

The output pulse-width of the system bears a close relationship to the drive pulse of the switch driver.

The pulse current is monitored via a wide-band current transformer and fed back to the peak over current detector, which removes the drive pulse from the switch driver circuit if the magnetron pulse current is out of specification.

The modulator control circuit has a provision and allows a number of peak over-current conditions within the time frame of one minute. This number is selectable via a switch assembly located in the modulator control circuit inside the power supply section of the system. Missing magnetron pulses and magnetron misfiring occurs quite often and the above-mentioned quality of the modulator control circuit is essential to allow the system to run and overcome the magnetron temporary miss occurrences.

If the abnormalities associated with magnetron continue on beyond the set limits, the system latches to the stand-by condition and a manual reset is required.

The magnetron average current level is also detected in the same way and controlled.

Mechanical Considerations

The modulator outline drawing is shown in Figure 2.0. The dry section of the modulator system has all the connectors necessary for all the interconnections between the power supply and modulator.

Connector J4 provides power for the magnetron heater power supply and the cooling fans. There are four pins in the J4 connector. Two for the heater power supply and two far the fan power.

The power supply shown on figure 3.0 shows the connections of J4 connector.

Connector J3 is the high voltage connector and it contains four wires. Three wires are dedicated to the high voltage (+850VDC) and one to the ground of the system.

Connector J2 provides the control power to the modulator and the communication between the modulator and power supply.

The drive power for the IGBT gate drive cards and all other communications are made possible through this connector.

The oil portion of the modulator system, the tank, has side connection for the dry electronic portion of the modulator system and top connections for the magnetron tube.

On the left side and along the centerline of the top cover, we see a high-voltage bushing with two posts, one for the cathode and one for the heater. The cathode terminal should be connected to a high voltage spark gap provided with the system.

Interface

The modulator connections to the power supply and to the rest of the system are shown in figure 4.0.

Magnetron Heater Power Supply

Technical Discussion

The magnetron heater power supply consists of three parts:

A. Forward Converter Circuit
B. Rectifier Circuit
C. Filter Section

The drive control circuit for the heater power supply is located inside the main power supply. It is a discontinuous mode, half bridge inverter operating at 35 KHz. The bus voltage for the heater power supply comes from the main bus of 360 VDC. Both the high voltage power supply and heater share the same source of 360 VDC.

The output stage of the heater power supply is located inside the oil filled modulator section.

The high voltage power transformer is designed with its secondary shielded and isolated for the full magnetron cathode voltage of 36 kvpk.

The secondary winding is a full wave center-tapped which is rectified and filtered to produce the 9.0 VDC at 24 Amps required for the magnetron heater circuit.

The filter section for the magnetron heater power supply is also located inside the oil filled section of the modulator section.

Operating Instructions

Unpacking and Inspection

First inspect package exterior for evidence of rough handling in transit. If none, proceed to unpack…carefully. After removing the supply from its shipping container, inspect it thoroughly for damage.

Correspondence

Each Pulse Systems power supply and modulator has an identification label that bears its model and serial number. When requesting engineering or applications information, reference should be made to this model and serial number, as well as, to the component symbol number (s) shown on the applicable schematic diagram, if specific components or circuit section are involved in the inquiry.

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Procedure for Setting All System Parameters

WARNING!

This procedure should only be attempted by qualified personnel who are knowledgeable in methods of safety testing and operating high voltage power supplies and related high voltage equipment.

Pulse System recommends that the transmitter should be installed in an equipment cabinet suitable for all components including the magnetron tube.

The power supply should be located at the bottom of the cabinet and the modulator directly above it.

Directly above the modulator, the magnetron tube should be mounted vertically with its cathode stem pointing in the down direction.

An air circulating system should be installed to cool the magnetron. The modulator and power supply systems are self cooled with their own fans and there is no need to provide anything other than a provision to circulate the air inside the cabinet.

After the system has been interconnected according to figure 4.0, the following steps should be followed.

First, the magnetron should be terminated to its RF load equipped with a loop or directional coupler.

The magnetron ground should be also returned to the top of the modulator ground stud.

A wide band current transformer should be installed to monitor the peak cathode current of the magnetron.

A PRF generator is also needed to provide the input PRF for the system.

Typically, the output of the generator should be 5.0 volts peak 2.0 µsec wide and a PRF capability between 100 and 1200 PPS.

After all interconnections to the system are completed, we turn to the control panel to power up and perform the initial check out of the whole system.

Before we apply power to the system, we make sure that the high voltage adjust potentiometer is set all the way counter clockwise. This ensures that when the power supply turns on, it will start at almost zero volts DC. This is only essential when we first set the system up and after we have completed all the steps, the system can return to its previous settings without further adjustments.

We now turn the main power breaker, located on the control panel, and set the local/remote switch to local control.

Next, we turn the power on switch to the on position and we notice the following:

A: The +24 VDC led turns on

B: The warm-up led turns on

C: The magnetron peak over-current and power supply over-current leds turn on momentarily

D: The magnetron filament voltmeter begins to move

At this point, we adjust the filament potentiometer to the right until the meter shows 9.0 VDC on the scale.

Nothing else is happening until the internal delay relay completes the preheat cycle of the magnetron set to five minutes. This allows the cathode of the magnetron to reach proper temperature and get ready for the radiate cycle.

After approximately five minutes from the time we turn the power on switch, the ready indicator turns on and now we are ready to place the system in the radiate mode.

After turning the radiate switch on we adjust the PRF generator to 100 PPS and set the system to 1.0 µsec.

We monitor the cathode peak current and RF on the oscilloscope and if possible the peak cathode voltage using a high voltage (50kv) probe connected to the cathode post of the modulator system.

We begin to raise the RF power adjust potentiometer and as we do this, we begin to see the negative cathode peak voltage waveform on the scope.

At the same time we notice that the power supply voltmeter and ammeter on the control panel begin to move indicating the power level of the power supply.

We are not going to see any peak cathode current or RF until we reach the heart-tree point of the magnetron tube set at 30-32 KV pulse.

When the power supply reaches the nominal level of 850 VDC we see the cathode peak current reaching 50-55 Amps peak and we also see the corresponding RF to follow.

The power supply voltage should be set to the level where the top level of the peak cathode current and RF look almost horizontal like perfect pulses.

We now can set the system in the proper pulse width and PRF to verify the full performance of the system.

One more adjustment has to be made in regard to the filament programming of the magnetron heater voltage. When we run the magnetron at 1.0 µsec and 1000 pulses per second the filament should be reduced to 7.0 volts and this can be done by adjusting the filament program potentiometer.

Performance Check-Out

The system has to operate within the specified conditions. The modulator will power the magnetron smoothly under all pulsing conditions. Because the power supply and modulator are quite adjustable in terms of voltage amplitude and pulse width, the output system performance could easily get out of specification and either the duty cycle or the peak cathode current of the magnetron can be exceeded. The two most important things to remember are the 50 Amps of peak cathode current and the 0.001 duty cycle. The peak cathode current is easily observed on the screen of the oscilloscope.

In the case of the duty cycle, each pulse condition has to be evaluated to ensure compliance with the magnetron specification. Since the product of the pulse width, in µsec, and the pulse repetition rate, in cycles, gives directly the value of the duty cycle, we have to mathematically evaluate it before proceeding with any pulse condition.

The pulse shape has to meet the specifications in terms of rise and fall time. Also an important parameter is the rate of rise of the cathode voltage. This parameter has been set by the manufacturer as the time of the steepest tangent, between the 70% point of the cathode voltage crossing the zero axis.

The corner-cutter is responsible for the rate of rise of the cathode voltage and is located inside the oil compartment of the modulator system.

Maintenance

Introduction

This sections covers information regarding the maintenance of the system. In general, the incorporation of solid-state devices makes the system an easier system to care for as time goes on. There is basically no component in the system that has a time limit or exhibits performance degradation as a function of time.

The Power Supply Section

Forced air-cooling fans located in the rear section cool the power supply section. The reliability of the selected fan is quite high and, so far, we have not encountered any problems in this area. Periodic examination to ensure that no build up of any foreign material is accumulating in any area near the cooling fan is essential.

Removing the power supply top cover for a quick examination is recommended every year to ensure that the air flow passages are clean, that no evidence of overheated parts is present, and that all other components are in normal operating condition.

The Modulator Section

The dry section of the modulator requires the same attention as the power supply in regard to the cooling fans. The oil filled section, does not require any maintenance and a slight air movement inside the cabinet is sufficient to keep this section cool. There should be no need ever to replace the oil of the modulator.