# COMMAND RESONANT CHARGING SYSTEM FOR A 350 kW AVERAGE POWER LINE TYPE MODULATOR

R. M. Ness, B.L. Thomas, and G. Schofield
Maxwell Laboratories, Inc.
8888 Balboa Ave.
San Diego, CA 92123
(619) 279-5100

## Abstract

A command resonant charging system for a line type modulator has been designed, manufactured, and successfully tested which charges four parallel Pulse Forming Networks (PFNs) to voltages of up to 75 kV at rep-rates of up to 50 Hz. A phase controlled power supply provides charging of the 53.4 μF filter capacitor bank to voltages up to 45 kV. A solid state, series stack array of twenty matched SCRs is used as a command charging switch to initiate the resonant charging cycle. Both resistive and RC snubber networks are used across each stage of the switch assembly in order to ensure proper voltage division during both steady state and transient conditions. A master trigger generates 20 fiber optic signals which are transmitted through inexpensive plastic fiber to each of the 20 series switch stages. An on-board fiber optic receiver and trigger amplifier uses the energy stored in the RC snubber network capacitance to trigger the SCR switch, eliminating the need for high voltage trigger or power isolation transformers. A 1 H charging inductor is contained within a water cooled, oil insulated tank and also includes a 1:40 secondary winding for de-Qing purposes. An additional single SCR device is used as the de-Qing switch to halt the charging cycle and maintain precise regulation of the PFN charging voltage to variations of less than ± 0.2%. A compact high power resistor assembly is provided along with a capacitor array to dissipate any remaining stored energy in the charging inductor at the time of de-Qing. The resistor assembly is made up of an array of 4 (parallel) by 6 (series) ceramic disk resistors which are sandwiched between 7 water cooled cold plates. Diagnostics are provided to monitor the PFN voltage, charging current, and de-Qing current and built-in interlocks automatically shut the modulator down in the case of a PFN over-voltage or charge over-current condition, or if the resonant charging control electronics are not ready. Additional design details and test results are presented in the paper.

## Introduction and Resonant Charging System Requirements

This paper describes the resonant charging system for a 350 kW average power, line type modulator, as shown in Figure 1, which provides pulsed energy to a high power klystron rf tube. A separate paper at this conference provides more detail on the design and testing of the overall 350 kW line type modulator system[1].

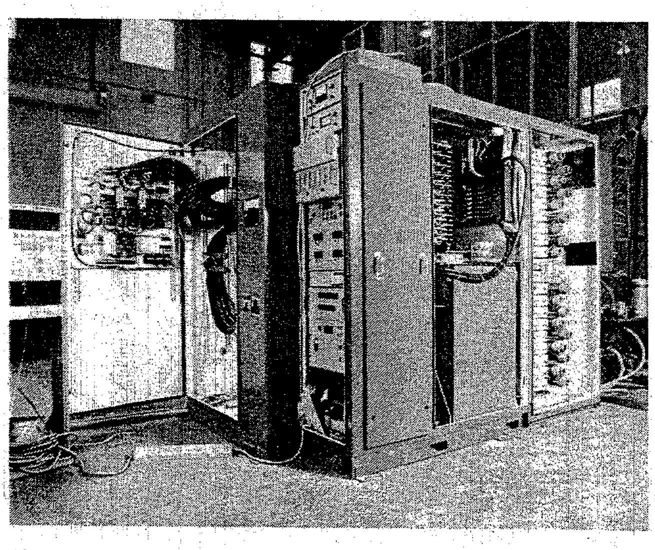

Figure 1. 350 kW Average Power, Line Type Modulator with Resonant Charging System in Center of Photo.

## Electrical Requirements and Design Goals

The electrical requirements for the resonant charging subsystem were tiered down from the overall modulator requirements. From the subsystem voltage allocations, the PFN capacitors were required to charge to a maximum of 75 kV for the full modulator output voltage of 600 kV. Since the resonant charging cycle would provide a ring-up voltage gain of at least 1.8, ~42 kV was then required from the high voltage power supply subsystem. With the final values used for the filter capacitor bank and PFN capacitance of 54 μF and 2.71 μF, respectively, the calculated voltage ring-up was actually closer to 1.9.

The overall requirement for pulse-to-pulse voltage amplitude stability of less than ± 0.2% (1200 V at the full 600 kV output) was passed down directly to the resonant charging subsystem since the determining factor is the regulation of the PFN charging voltage. This regulation was dependent upon the accuracy of the voltage monitoring device and the electronics which were used for de-Qing.

A further requirement for the voltage regulation was that the resonant charging subsystem accommodate sudden "high line" or "low line" power conditions where the input voltage may fluctuate ±5% of the nominal line values. This was dealt with by picking the nominal de-Qing threshold such that a -5% low line condition would result in no de-Qing at all while a +5% high line condition would result in earlier (than normal) de-Qing.

The last major parameter tiered down from the overall requirements is the charging cycle time. Given the modulator rep-rate of 50 Hz, a maximum of 20 ms was available for resonant charging between output pulses. In reality, less time was available because some time was required for the de-Qing process to occur and for all de-Qing transient waveforms to decay. Since the PFN capacitance was determined by the amount of energy required in the output pulse and the high voltage power supply filter bank capacitance was based upon requirements for minimizing the input line harmonics, only the charging inductance remained for determining the LC time constant associated with the charging cycle. In the preliminary design stage, charging inductances in the range of 0.1 to 10 H were examined, corresponding to charging times of ~1.6 to 16 ms. Since the peak charging current would only be on the order of 200 A with the worst case (0.1 H inductance) and this is well within large power SCR current ratings, the inductance did not need to be increased strictly to reduce the charging current level. Trade-off considerations and results, as well as the charging inductance selected for this application, will be discussed later in the section on the details of the charging inductor.

## Other Requirements and Design Drivers

In addition to the electrical requirements passed down from the overall modulator, other design drivers and considerations had to be applied to the resonant charging subsystem. Because the customer desired that the modulator footprint be minimized, packaging of the resonant charging subsystem and its components was critical. As will be described in the following sections, major components, such as the de-Qing resistor assembly, were designed and fabricated specifically to minimize the space requirements, as well as meet the electrical requirements.

Long lifetime, reliability, and maintainability were also very important to the user and were applied to the design and manufacturing process wherever possible. A specific lifetime of 50,000 hours was requested by the customer, implying that the major components survive more than $9 \times 10^9$ shots at the full 50 Hz rep-rate. Since power dissipation to the ambient air environment was to be limited, water cooling was used for eliminating heat generated within the resonant charging subsystem, specifically within the charging inductor, de-Qing switch, and de-Qing resistor.

## Resonant Charging Subsystem Description

The Resonant Charging Subsystem is responsible for charging the PFNs to their required voltages on a rep-rated basis and regulating the charge voltage so that the output pulse amplitude will also be controlled to the desired precision ($<\pm 0.2\%$). The major components or assemblies in this subsystem, as shown in the simplified schematic diagram of Figure 2, include the de-spiking networks, command charging switch assembly, charging inductor with de-Qing secondary winding, charging diode, diagnostic monitors, and control electronics.

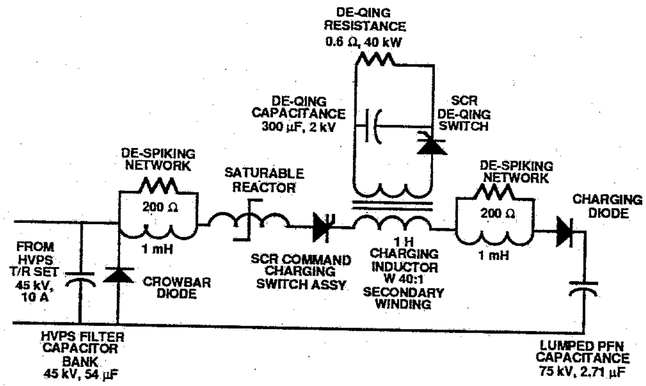


Figure 2. Simplified Schematic Diagram of 350 kW Average Power, Resonant Charging System.

## High Voltage Power Supply (HVPS) and Filter Capacitor Bank

Although not included in our previous description of the resonant charging subsystem, some mention of the HVPS and filter capacitor bank are required in order to understand their relevance to the resonant charging cycle. As mentioned in the referenced paper[1], the HVPS subsystem is responsible for generating ~45 kV, 10 A dc power (regulated to ~2-3%). Adjustment of the HVPS phase controller controls the output voltage on the filter capacitor bank which adjusts the PFN charging voltage in a linear fashion. As a result, the modulator output voltage is also controlled according to the phase controller setpoint.

The filter capacitor bank is made up of eight Maxwell capacitors for a combined rating of 54 µF and 45 kV. In order to achieve a voltage ring-up of ~1.8 during the resonant charging, this filter capacitance must be at least ten times the lumped capacitance of the four parallel PFNs, or ten times 2.71 µF. Since the filter capacitance has actually been increased over that amount (in order to further reduce the ac input power line harmonics) to ~20 times the total PFN capacitance, the voltage ring-up is closer to 1.9 than 1.8. At the full rated voltage, the filter capacitance bank stores ~55 kJ of energy while approximately 7600 J is stored in the four PFNs.

## De-Spiking Network

Two de-spiking networks are used in the resonant charging circuit. Each is made up of a ~1 mH inductor in parallel with a 200 Ω ceramic resistor. The inductance in the first de-spiking network was selected in order to limit the di/dt impressed upon the command charging switch in the case of a fault on the primary side of the charging inductor. Given the 150 A/µs maximum di/dt rating of the charging switch SCRs and the ~45 kV maximum voltage of the high voltage power supply, an inductance of at least 300 µH is needed to protect the SCRs from a fault. The value of 1 mH was selected to allow some engineering margin.

Since one of the primary functions of the de-spiking network is to protect the command charging switch in a fault condition, the design of the network must ensure that it will also survive the same fault conditions. From computer simulations, we were able to calculate the peak fault current and fault action subjected on the de-spiking inductor. These values were found to be ~5.7 kA and 77.1 x $10^3$ $A^2$-sec, respectively. From standard fuse calculations, we also determined the action required to melt or to fuse, based upon a given wire size. Using 8 AWG wire sized for the normal rms current, it was found that the action required for melting was approximately three orders of magnitude larger than that expected in the fault. As a result, there was little possibility that the wire would melt in a fault and damage or destroy the de-spiking inductance.

The inductor is wound on an 9" o.d. form made from PVC pipe with the resistor located on the inductor axis. A second section of larger diameter (10" o.d.) PVC pipe was also used to surround the inductor windings. In the case of a short circuit fault, this housing would contain the expected radial magnetic pressure of ~125 psi associated with the inductor windings and prevent the inductor from "un-winding" and failing (or at least requiring significant maintenance).

In order to help minimize corona from the floating de-spiking networks, aluminum toroids were assembled at the ends of the units. The toroids, as well as the de-spiking resistor, were held in compression against the PVC pipe with fiberglass studs.

## Command Charging Switch Assembly

Given the requirements for a long lifetime and the time available for the resonant charging cycle (up to almost 20 ms at the full 50 Hz rep-rate), the choice of SCRs for use as the command charging switch was an ideal solution. While many previous line type modulators have used thyratrons as the command charging switch, SCRs have the following advantages, particularly in this current application:

- SCRs are more suited to the ms duration waveforms associated with resonant charging than thyratrons which must operate in the long pulse mode.
- SCRs do not require isolated auxiliary power (as compared to thyratrons which need heater and reservoir power) which must be provided to the floating, high voltage, series switch.
- SCRs also have much simpler trigger requirements (10's of volts as compared to 1000's of volts for thyratrons).

The SCR devices for this application were selected primarily based upon their fault current ($I_{TSM}$) and voltage capabilities. Table 1 shows the SCR capabilities and requirements for this application.

**TABLE 1: SCR CAPABILITIES AND REQUIREMENTS FOR THIS APPLICATION**

| Parameters | Capabilities | Requirements |
|---|---|---|
| Voltage | 4000 V | 2500 V |
| Peak Current (Normal) | 13 kA | 75 A |
| Peak Current (Fault) | 13 kA | 5.68 kA |
| RMS Current | 1260 A | 25 A |
| Average Current | 800 A | 11 A |
| Maximum di/dt (Fault) | 150 A/µs | 50 A/µs |
| Maximum di/dt (Normal) | 150 A/µs | 0.05 A/µs |
| Action (Fault) | 700 x $10^3$ $A^2$-sec | 77.1 x $10^3$ $A^2$-sec |

As can be seen from the data in the table, the normal peak, rms, and average current levels were far below the device capabilities. As required by the modulator specifications, the command charge switches were de-rated by 150% with respect to operating voltage. Twenty series connected devices, each rated at 4000 V, were therefore used to made up the switch array which was rated for operation up to ~50 kV. Powerex T9G04008 devices were selected since they had more than enough current capability and could be obtained in the 4000 V rating.

A simplified schematic diagram of each of the twenty individual charging switch stages is shown in Figure 3. The following paragraphs describe the functions of the various components.

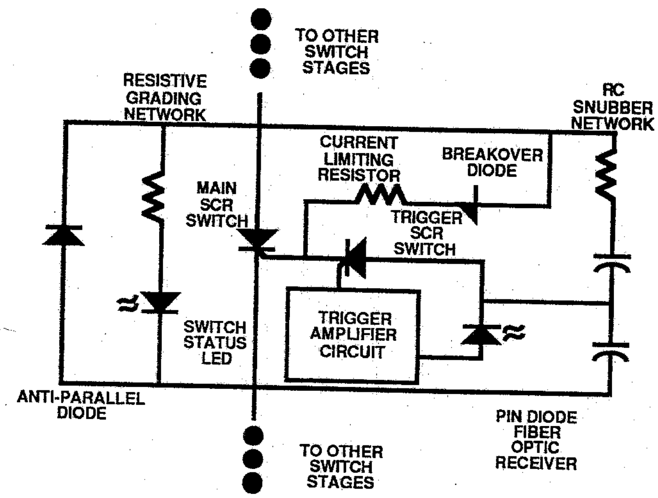


Figure 3. Simplified Schematic Diagram of One of Twenty Command Charging Switch Stages Showing Switch Trigger Circuitry.

In order to ensure proper operation of the solid state switch assembly and prevent damage to the SCRs, voltage division among the series connected devices must be maintained during both steady state and transient conditions. This was achieved through three separate, multi-tiered approaches. The first technique was to obtain devices which were matched to minimize variations in leakage current, turn-on time, and reverse recovery charge. Powerex was able to help with this effort by performing initial tests on this device family to quantify the level of possible matching and to then provide this service in conjunction with the normal testing of the devices.

In addition to the device matching, voltage grading networks across each switch stage were used to ensure proper voltage division along the stack. A purely resistive grading network maintained equal voltage division among the devices during dc or steady state conditions while the RC grading network performed the same function during the transient periods. An LED in series with each resistor in the purely resistive network also enables identification of failed (shorted) SCRs.

The last technique was to provide a strong, fast risetime (~100's of ns) trigger source to the SCRs with little variation (jitter) between the individual trigger signals sent to each particular stage. This requirement was complicated by the need for voltage isolation between the trigger source electronics (at ground level) and the floating high voltage switch. In previous applications of solid state switch assemblies with multiple, series, floating devices, trigger transformers have often been used for this isolation[2]. The disadvantage of this approach is the limitation associated with the large leakage inductance usually resulting from the voltage insulation requirement which can degrade the trigger pulse risetime. Fiber optics have also been used for trigger isolation of solid state switches but in most cases, require isolated "housekeeping" electrical power at the receiver for the amplification of the light signal into a sufficient electrical pulse for triggering of the devices.

The solution for this particular application was to trigger the overall switch through fiber optic signals to each stage which, in turn, trigger a small circuit that derives its power from the RC snubber capacitor energy and discharges this energy into the main SCR gate. In this resonant charging application, a small "on-board" circuit on each SCR switch stage provided several stages of amplification between the PIN diode fiber optic receiver and the gate of the main SCR. This general technique has apparently been used for some time in the utility industry in the application of large static power converters and for high-voltage direct-current (HVDC) power transmission systems[3]. The referenced paper describes such a large rectifier/inverter system which connects a 345 kV power network in New Mexico with a 230 kV network in Texas through a HVDC tie.

In this case, the application was somewhat complicated by the fact that the switch must operate over a voltage range equivalent to that required by the overall modulator output (-200 to -600 kV). To achieve this, the total RC snubber capacitance was split into two series capacitors which form a capacitive voltage divider. This voltage divider generated a trigger voltage of ~35 V for the SCR from the total voltage across the device of ~2050 V per stage at the maximum operating levels. These capacitor values were also carefully chosen so that a sufficient trigger pulse of ~12 V was generated at the lower end of the modulator operating range corresponding to a switch stage voltage of ~680 V.

Breakover Diodes (BODs) from ABB[4] were also implemented in each of the "on-board" trigger circuits to ensure that the SCR was triggered in the case of a forward over-voltage condition before any damage can be done. These devices are small thyristor elements without the gate connection which turn on in a controlled manner. When connected across the SCR anode and gate, they can turn the SCR on if the anode voltage exceeds the BOD threshold by "breaking over" and applying voltage to the SCR gate through a current limiting resistor. Thus, if a fiber optic receiver or link failed, the SCR would not be put in jeopardy since the breakover diode would also discharge the snubber capacitance (in a controlled fashion) into the SCR gate and turn the device on.

Inexpensive fiber optic transmitters, receivers, and plastic cable were used for delivery of the trigger pulses and proved to be more than adequate in meeting the requirements. In order to ensure low jitter between SCR stages, the master trigger pulse was generated from a power MOSFET circuit at ground level in the Resonant Charging Electronics chassis driving 20 individual fiber optic transmitters in parallel.

The 20 SCR devices were sandwiched between 1/2 inch thick aluminum buswork plates. Four fiberglass threaded rods, along with Belleville washers, were used to put the entire assembly in compression, as required for proper thermal transfer from the SCR packages. Given the low average and rms currents, thermal losses in the devices were minimal and the surface area of the buswork plates was more than enough for power dissipation.

A photograph of the command charging switch assembly is shown in Figure 4. The RC snubber networks can be seen on the left side with the SCRs and trigger printer circuit boards in the center and the resistive grading network and bypass diodes on the right.

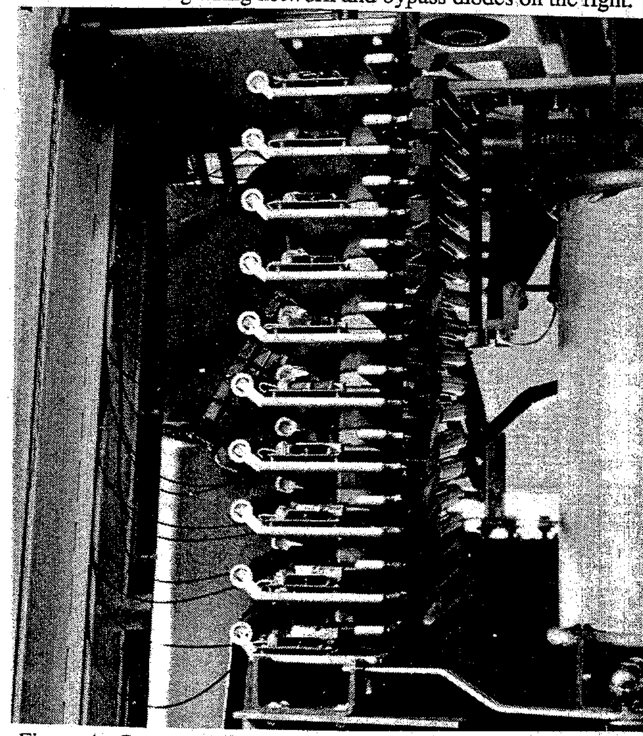

Figure 4. Command Charging Switch Assembly.

Charging Inductor

As mentioned in the subsystem requirements section, charging inductances in the range of 0.1 to 10 H were examined. Conversations with potential vendors for this item indicated that an optimum inductance value existed based upon cost and size of the unit. Lower values would have cost more due to higher manufacturing labor costs associated with multiple air gaps in the core of the unit while higher inductance values would have required more material dollars needed for the additional core material. The optimum value was found to be ~1 H, which would correspond to a resonant charging cycle (half-sinusoid) duration of ~5 ms.

The charging inductor was then procured according to a detailed specification with the primary parameters listed in Table 2.

**TABLE 2: CHARGING INDUCTOR SPECIFICATIONS**

| Parameters | Value |
|---|---|
| Inductance | 1 H |
| Resonant Charge Time | 4.8 mS |
| Peak Current (Normal) | 75 A |
| RMS Current | 25 A |
| Average Current | 11 A |
| Peak De-Qing Current | 1800 A |
| RMS De-Qing Current | 285 A |
| Average De-Qing Current | 90 A |
| Filter Voltage | 50 kV |
| PFN Voltage | 80 kV |
| Saturated Inductance | > 50 mH |
| Leakage Inductance | < 30 mH |
| Inductor Q | > 150 |
| Turns Ratio | 40:1 |
| Size | 32" x 30" x 54" tall |
| Weight | ~ 2500 lb. |

In summary, the procured charging inductor was a 1 H inductor with a 1:40 secondary winding for the de-Qing circuit. The iron-core inductor was oil insulated and contained within its own tank. Connections for the de-Qing winding, as well as the high voltage bushings for the main winding, were located on the top of the tank. Cooling water was circulated through tubing wound around the inside diameter of the tank.

Charging Diode

The Charging diode assembly was a set of 30, series-connected, GEC DS412SE40, 4000 V ($V_{RRM}$) diodes in a clamped heat sink assembly. MOVs are connected in parallel with the diodes to assist with voltage sharing.

De-Qing Network

The de-Qing circuit was made up of a single SCR de-Qing switch, a capacitor bank, and a water cooled resistor assembly which form the slightly over-damped circuit used to stop the resonant charging cycle. The de-Qing SCR requirements and the capabilities of the Powerex T7202035 device which was chosen are shown in Table 3. A water cooled heat sink clamp assembly was used to remove the heat dissipated within the de-Qing SCR during normal operation.

**TABLE 3: DE-QING SCR CAPABILITIES AND REQUIREMENTS FOR THIS APPLICATION**

| Parameters | Capabilities | Requirements |
|---|---|---|
| Voltage | 2000 V | 1250 V |
| Peak Current (Normal) | 7000 A (~8 ms) | 1800 A (~2.5 ms) |
| RMS Current | 550 A | 285 A |
| Average Current | 350 A | 90 A |
| di/dt (repetitive) | 150 A/μs | 22.5 A/μs |
| dV/dt | 300 V/μs | 40 V/μs |

Six parallel Maxwell 50 μF, 2 kV capacitors form the overall de-Qing capacitance. Since these units normally operate at voltages less than or equal to 800 V, their normal lifetime of $5 \times 10^7$ shots at 2 kV can be extrapolated to approximately $5 \times 10^{10}$ shots at 800 V, meeting the overall modulator lifetime requirements.

The requirements for the de-Qing resistor were determined from circuit simulations and calculations. A ~0.6 Ω resistance was needed capable of voltages up to 800 V and peak currents up to 1300 A. In normal operation, it would dissipate ~20 kW while in the worst case (a +5%, or "high line" ac input), the power would increase to 40 kW. Given the additional requirements for compactness, water cooling, reliability, maintainability, and long lifetime, a somewhat unique design was required.

The resulting design for the de-Qing resistor assembly was made up of a 6 (series) by 4 (parallel) array of ~4.4" o.d. x 1" thick, 0.4 Ω, ceramic resistor slugs which are sandwiched between commercially available ("off the shelf"), water cooled, cold plate, heat sinks. This compact assembly measured ~6" deep x 24" wide x 14" tall and was mounted to the inside wall of the enclosure on an insulating plate with the remainder of the de-Qing circuit, as shown in Figure 5. The large number of water cooled cold plates allowed heat to be removed from the compact assembly effectively without having to design the resistor with a large overall surface area or immerse it in oil (or something else) to improve the heat transfer. In addition, the multiple series connection of resistors allowed one section to be used as a current shunt to monitor the current through the de-Qing resistor.

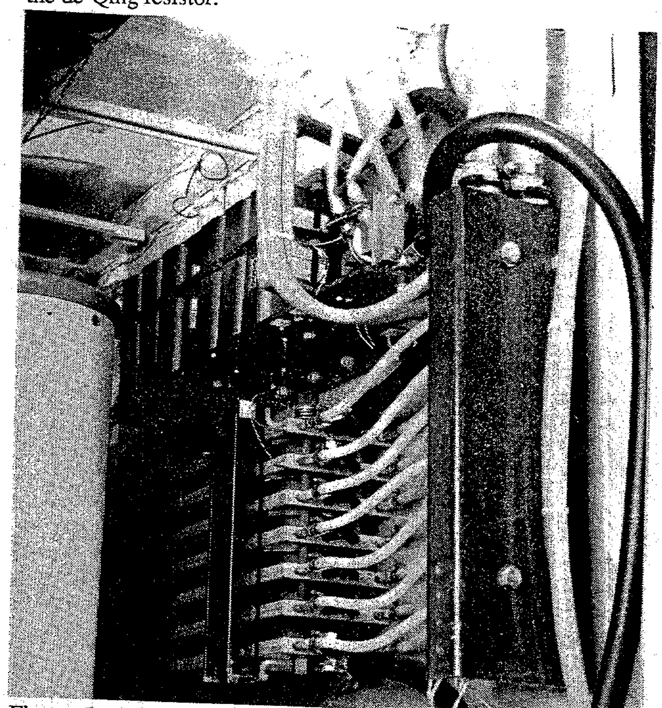

Figure 5. De-Qing Circuit Assembly with De-Qing Resistor on Bottom and De-Qing Capacitors and Switch on Top.

Worst case, one-dimensional heat flow calculations indicated that the core temperature of the resistor slugs at 40 kW dissipation would be ~145 degrees C, assuming ~10 gpm of 30 degree C cooling water flowing through the assembly. This temperature is well within the manufacturers temperature rating of 225 degrees C.

The problem of slug height mismatch causing poor electrical and thermal connections with the heat sink plates was addressed in two approaches. Instead of procuring standard height tolerance (±0.06 inches) resistors, the entire batch of resistors was procured at slightly higher cost (~5-10%) with thicknesses matched to within ±0.01 inches. In addition, a special thermal (and electrical) interface pad material, known as THERMSTRATE[5], was used between the resistors and cold plates which would "mold" to irregularities in the resistor surface under pressure and temperature. The entire resistor and heat sink assembly was held in compression with fiberglass threaded rods and spring washers.

## Resonant Charging Controls

The Resonant Charging Electronics are located in a shielded enclosure on the wall of the modulator enclosure. This chassis holds seven printed circuit boards and several power supplies. These printed circuit boards generate the command charge trigger fiber optic signals from a master trigger input, interface the modulator control signals with the resonant charging electronics, and monitor the PFN voltage, PFN charging current, and de-Qing current for trouble-shooting diagnostics and interlock circuitry. Latching interlocks are used to shutdown the modulator in the case of an unsafe condition and must be manually reset by the operator once the fault has been corrected. Other interlocks are included to monitor other resonant charging system critical items, such as auxiliary electronics power supply status and cooling circulation and temperature for the charging inductor and de-Qing circuit.

A compensated voltage divider was used to monitor the PFN voltage for diagnostics and de-Qing purposes. A 0.1 Ω resistive shunt in the current return to the HVDC filter capacitor bank provided the charging current signal. As mentioned previously, one of the sections in the de-Qing resistor array assembly was used as a current shunt for monitoring the de-Qing current.

## Resonant Charging System Testing Results

Typical resonant charging current and (PFN) voltage waveforms are shown in Figure 6. In this case, the modulator was operating at the full rated rep-rate of 50 Hz and a HVPS output voltage of 38.5 kV, representing ~95% of the rated modulator output voltage. This, in turn, corresponds to an average power of over 300 kW delivered to the load.

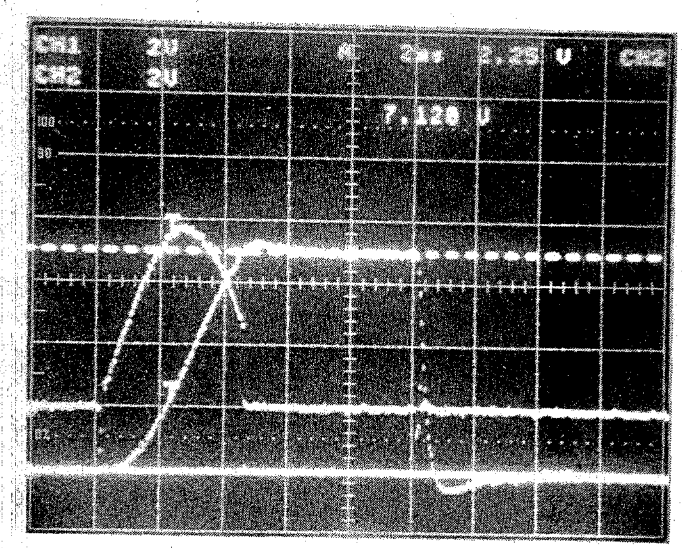


Figure 6. Oscilloscope Photo of Typical Resonant Charging Current (upper trace, 20 A / division) and PFN Charging Voltage (lower trace, 20 kV / division) During 50 Hz Rep-Rated Operation ($V_{Filter}$=38.5 kV).

Figure 7 shows an expanded view of the top of the PFN charging voltage waveform where ~50 charging cycles have been overlaid in order to look at the variation in regulation. From the photo, we can see that the spread in voltage at the end of the charging waveform just prior to thyratron triggering is approximately one tenth of a division, or 20 mV. Since ± 0.2% of 5.7 V (the amplitude of the waveform as defined by the offset) is equivalent to ± 11 mV, we can say that the resonant charging system has met the regulation requirements.

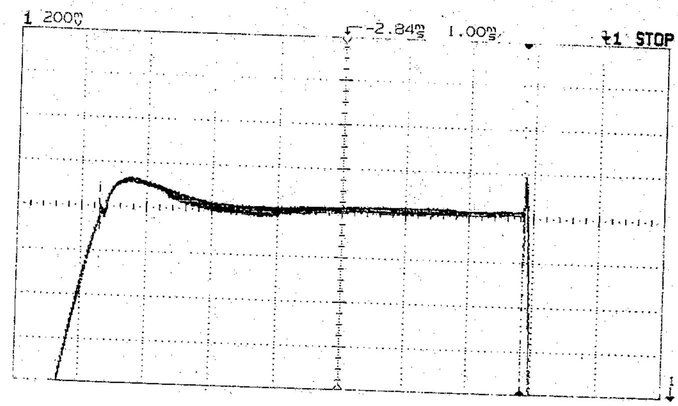


Figure 7. Expanded View of the Top of the PFN Charging Voltage Waveform ( 2 kV / division, $V_{Filter}$=30 kV). The Baseline of the Waveform is Offset -5.7 V from the Center of the Screen.

## Summary

A 350 kW average power command resonant charging system for a line type modulator has been demonstrated which charges the modulator PFNs to voltages of up to 75 kV with regulation of better than ± 0.2%. Unique features of the resonant charging system included the following:

- A 50 kV, solid state, SCR command charging switch assembly using fiber optics and energy stored in the RC snubber capacitors to trigger the SCR switches, eliminating the requirement for additional isolated power to the floating, series switch.
- A charging inductor selected to minimize both size and cost while meeting all of the necessary electrical requirements.
- A compact, water cooled, de-Qing resistor assembly capable of dissipating up to 40 kW.

## Acknowledgments

The authors would like to acknowledge the work of certain individuals who have contributed to the successes associated with this program and whose help was greatly appreciated. Technical discussions and advice from Ed Chu have been extremely worthwhile throughout the program during the design, manufacture, and testing phases. The work of Terry Houston and Troy Bekel has also been invaluable in the fabrication, assembly, and testing of the modulator. Jerry Sherbondy at Powerex was also very helpful with regards to the selection and matching of the SCRs in the command charging switch.

## References

[1] R.M. Ness, B.L. Thomas, and G. Schofield, "A 350 kW Average Power Thyratron Switched Line Type Modulator", 21st International Power Modulator Symposium, Costa Mesa, California, 1994.

[2] W.F.J. Crewson, J.L. Matilaine, "30 kV, 100 kW (Avg.), 10 MW (Peak) Repetitive Solid-State Switch", Conference Record of the 1986 Seventeenth Power Modulator Symposium, Seattle, Washington, 1986, pp. 224-225.

[3] "HVDC Back-to-Back Tie Blackwater Station - Energy Exchange Between Eastern and Western Power Networks, USA", Brown Boveri Corporation Publication #CH-A 030 882 E, p. 6.

[4] "Semiconductor Components for the Power Electronics Industry", Brown Boveri Corporation Publication #CH-E 3.40591.8 E, pp. 28-30.

[5] Manufactured by Power Devices Inc., Thermal Interface Products Group, Laguna Hills, CA, 92653.