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INTERFACING PULSED POWER SYSTEMS TO SWITCHING POWER SUPPLIES

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INTERFACING PULSED POWER SYSTEMS TO SWITCHING POWER SUPPLIES*

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Abstract

In many modern pulsed power systems traditional power supplies have been replaced by high frequency switching power supplies. These supplies offer lightweight, smaller footprints and improved efficiencies over traditional power supplies. Applications of switching power supplies for pulsed power range from large single shot capacitor banks to high pulse rate laser systems. This paper will discuss issues in interfacing switching power supplies to pulsed power systems. Simple protection networks can be used to avoid damage to power supplies in normal operation and in fault situations. Design of these networks also impact power supply voltage accuracy. The networks typically also incorporate safety dump systems to remove energy from capacitors.

I. INTRODUCTION

Switching power supplies are now used extensively in pulsed power systems. These supplies offer a flexible, modular approach to capacitor charging. They can be



Figure 1. Typical modern switching power supplies.

used to charge large high energy capacitor banks or high average power, high pulse rate modulators. Figure 1 shows examples of typical modern switching power supplies.

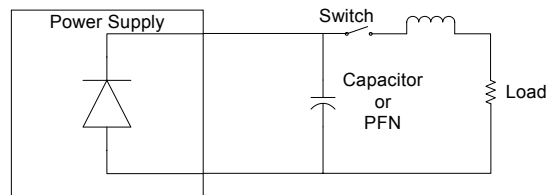


Figure 2. Basic pulsed power system connected to a switching power supply.

Pulsed power systems consist of a power supply that charges an energy storage device, typically a capacitor over a long period of time and then discharges the energy to a load over a short period of time. The charging time may range from fractions of a millisecond to minutes. Care must be taken in the design of these systems to avoid allowing some of the very high peak powers to “leak” back into the power supply and cause damage either in normal operation or in a fault mode. The output of

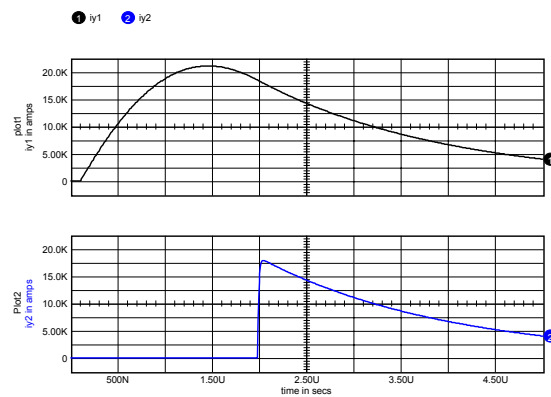


Figure 3. Spice waveforms representing currents flowing in load (top) and power supply output (bottom) with out protection circuits

switching power supplies typically has diode bridges that will conduct if the output of the power supply is reverse biased. For example in figure 2, if the circuit is under damped, the voltage on the capacitor will reverse and without protection high currents will flow in the power

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supply diodes causing failure. Even in cases where the load does not cause voltage reversal, a fault in the load may cause voltage reversal leading to power supply failure.

Consider the waveform shown in figure 3. This waveform represents what might happen to a power supply configured with out protection. The upper trace shows the current through the load. The lower trace shows the current through the power supply output diodes. The output diodes would die a rapid death under these conditions.

II. PROTECTING THE POWER SUPPLY

The power supply must be protected from voltage reversal by isolating the supply. This may be done either by a passive protection network or with an isolation switch.

An isolation switch at first offers an attractive option because the power supply is completely removed from the circuit. But there can be problems associated with this. Faults can occur when a switch pre-fires during charge, which can lead to failure of the power supply and the switch. This problem may be avoided if switches are used that have a very low probability of pre-firing, such as solid state switches or if a solid state isolation switch is used that can be rapidly opened under fault conditions.

A very robust method uses a passive, resistive and diode network, that is shown in Figure 4. When the capacitor reverses, the diode and resistor R_2 start to conduct. The resistor R_2 limits the peak current in the protection diode. A small amount of current also flows in the resistor R_1 and the power supply output diodes. This

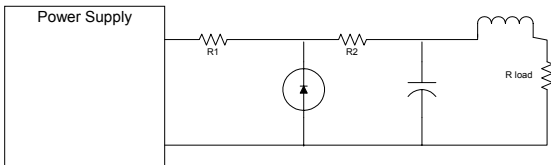


Figure 4. Power Supply Protection Network

current is driven by the voltage drop across the protection diode and should be very small. It is very important to use care in routing wiring using this technique. Inductive voltage drop in the R_2 protection diode loop can be significant. If R_1 and its return are not connected very close to the diode significant current can be developed in R_1 which may lead to failures in the power supply.

As an example, a protection network is added to the circuit simulated in figure 2 so that it is configured as shown in figure 4. Now the current has fallen to a little over one kiloamp and is not flowing in the power supply, as compared to the 17 kA flowing in the power supply without the protection network. The current flowing in the power supply is much lower then this and depends on the

forward drop in the protection diode and is also reduced by the resistance in series with the power supply output.

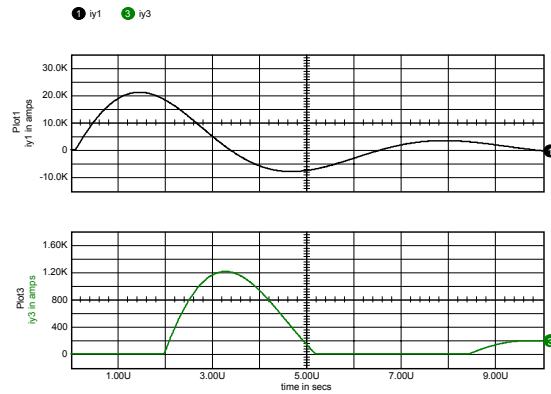


Figure 5. Waveforms using protection network shown in figure 4. The upper trace is the load current and the lower trace is the protection diode current.

Often the resistors can be used for safety discharge of the capacitor by placing a dump relay in parallel with the diode. When using this safety discharge technique make sure there is a resistor of at least 50 ohms between the dump relay and the cables. If the relay is placed across the cable with out any resistors the other end of the cable will go through 100% voltage reversal at a very fast rate and probably destroy the power supply.

A disadvantage of using this network is the losses in the resistor during charging¹. A large resistor allows a small protection diode or even not using a protection diode. But the large resistor will increase losses and could also impact power supply regulation. The power supply regulation problem can be avoided by using an external voltage monitor circuit connected directly to the capacitor. Care must be taken to avoid charging the system with the external monitor disconnected or an over voltage situation can develop. Also external monitors add cost and complexity to systems. A small resistor value reduces the regulation and power issues but will increase the size of the protection diode and may also impact the output waveform.

III. GROUNDED SWITCH OPERATION

In many cases it is better to have the switch tied to ground in a pulsed power system. For instance with a thyratron, the filament, reservoir, bias and trigger supplies require complex isolation transformer systems to float them at high voltage. This also introduces new issues into interfacing power supplies to pulsed power systems. Figure 6 shows a typical grounded switch configuration. The power supply is connected typically by coaxial cable to the high voltage end of the switch and charges the energy storage capacitor. A return path must be provided for capacitor charging either through the load or by a diode bypassing the load. After the power supply finishes charging the capacitor the supply is shutoff and the switch is closed. If the resistor in series with the power supply is not used then severe reversal of the coaxial cable will occur. Also high voltage reversal on the cable may destroy the power supply. The obvious solution is to use a resistor in series with the cable that matches or is greater

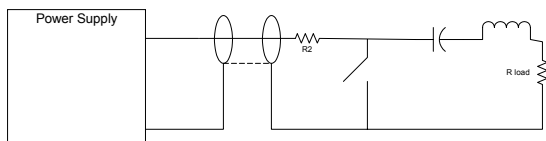


Figure 6. Switching power supply in grounded switch configuration

then the cable impedance. This prevents the voltage reversal and absorbs the energy in the cable. In high pulse rate systems the energy stored in the cable can be significant and impact system efficiency. For instance a pulse generator running at 1000 Hz with 5 m of cable at 40 kV will dissipate 400 watts in the resistor. This must be considered when deciding the location of the main switch in a pulsed power system.

IV. POWER SUPPLY SIZE

Capacitor charging power supplies are typically characterized by their charging rate in kJ/sec. This number is used because the instantaneous charge rate varies from zero to twice the average charge rate. This can impact the sizing of power feeds to the power supplies specially in systems charging at times long compared to the line frequency. In high rep-rate pulsed power systems the power supply input filter capacitor smooths out the demand on the AC line but at low pulse rates the demand on the line will ramp from very low levels to twice the average charge rate.

For example assume a 100 kJ capacitor bank will be charged in 10 seconds. This will require a 10 kJ/sec power supply. At the start of charge the real power demanded from the wall will be very low because the voltage on the capacitor bank is low. As the voltage linearly ramps up the power into the capacitor will ramp up linearly too greater than 20 kVA. The reactive power on the AC line would be:

$$10 \text{ kJ/sec} \times 2 / (90\% \text{ efficiency}) / (85\% \text{ PF})$$

This gives a peak complex power demand of 26 kVA.

For high pulse rate applications the user must consider not only the charge rate but dead time and dwell time requirements. These can significantly eat into the time available to charge the capacitors. Prior to discharging the capacitor we recommend the power supply be inhibited. The inhibit should continue through the discharge and allow complete recovery of the output switch prior to charging at the end of t_D .

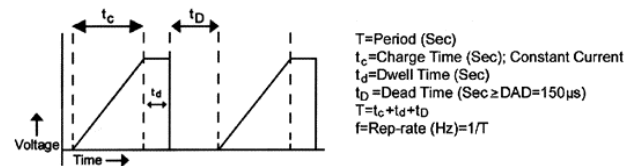


Figure 7. Timing parameters in high rep-rate systems

Another factor to consider when specifying a power supply is maximum charge voltage vs. operating charge voltage. Power supply charge rates are normally rated at their maximum charge voltage. Charging rate must be linearly reduced with reduced charge voltage. Thus a 10 kJ, 30 kV, power supply will produce 6.6 kJ/sec maximum charge rate at 20 kV.

V. SUMMARY

Switching capacitor charging power supplies have reduced the size and cost of power supplies for pulsed power systems. Using simple interfacing techniques it is possible to use switching power supplies without concern for failure in normal operation or in fault modes.

VI. REFERENCES

¹ O. I. Elgerd, Control System Theory, McGraw-Hill Book Company, New York, 1967, pp. 449-451.