INRUSH CURRENT

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The inrush current phenomenon for a PWM switching power supply comes in two parts. The first involves the charging of the input capacitors and/or filter elements. The second is the power converter input current time profile which is supposed to be controlled by the soft start circuitry which in turn controls the PWM and charging rate of the output filter and load elements. Each of these is discussed in the following.

1) The input power line filter may consist of a capacitor across the power line or, more generally, a 2 or 4 pole LC differential filter which will generally be under damped. Refer to Figure 1 for a functional example of a forward converter complete with the input line filter. If the power is applied as a step with a rise time of 1 µsecond or less, the initial inrush current can be 50 amps or more on an unlimited 28 V power bus. This could occur if power were applied with a switch on an aircraft power bus. Where the input filter is only a capacitor, the initial surge current will be a single surge lasting the duration of the input step. Where an underdamped line filter is involved, the initial inrush current will be an exponentially damped sinusoid

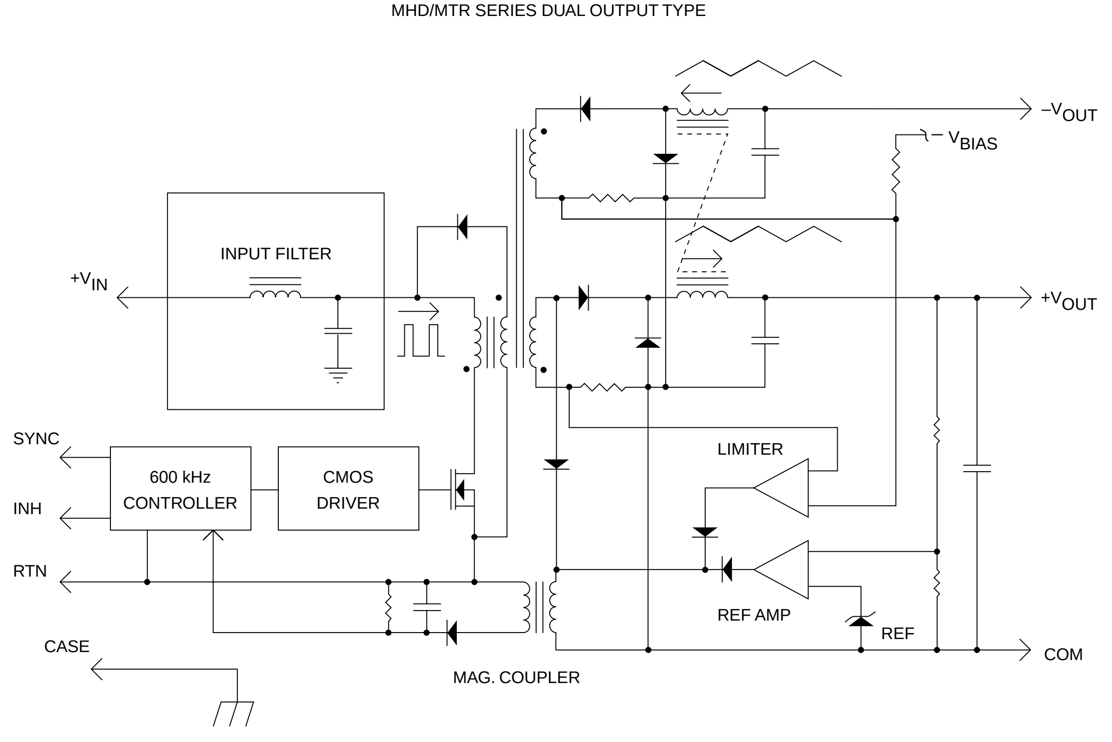


FIGURE 1: FORWARD CONVERTER WITH INPUT LINE FILTER

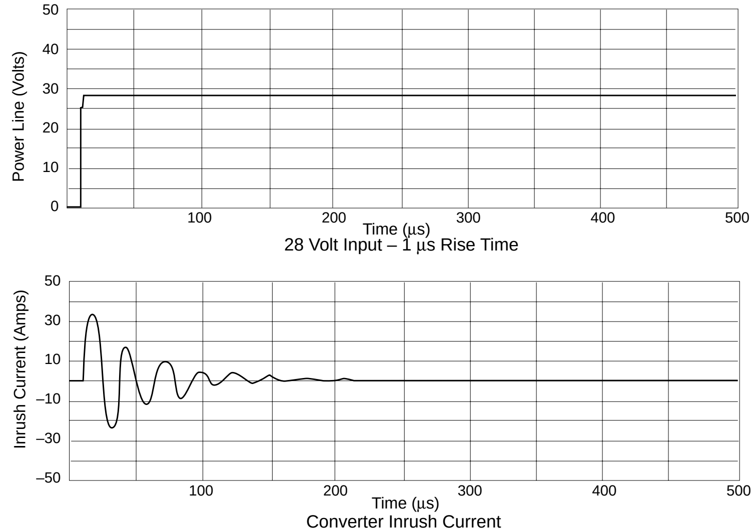


FIGURE 2: 1 µS RISE TIME

lasting for as long as a few hundred µseconds. Using a current limited supply or ramping up the input line voltage will reduce the inrush surge amplitude. Using a ramp with a 100 µsecond rise time or longer will reduce the surge currents to reasonable limits. Refer to Figures 2, 3, and 4 for examples of inrush current.

Figure 5 illustrates the input filter model used in the examples. For an input capacitor only, the 100 µsecond ramp reduces the surge to about 1% of that where the rise time is 1 µsecond. Where a current limited supply is used, beware that starting a single or several PWM supplies can cause problems with

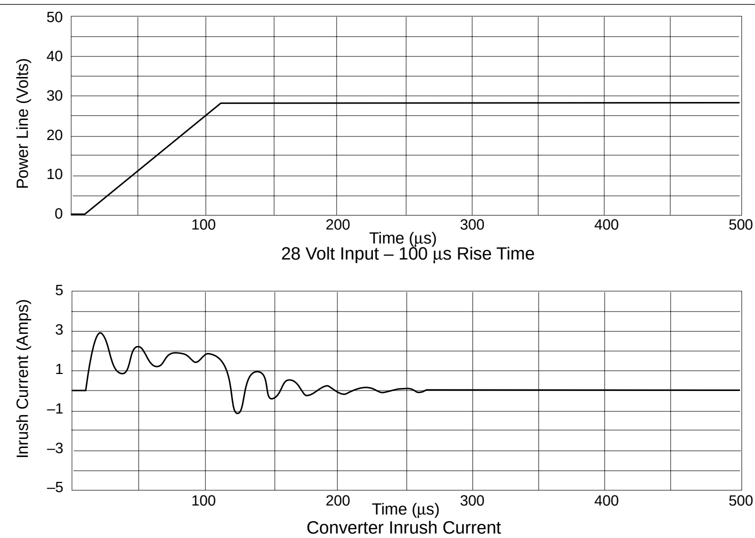


FIGURE 3: 100 µS RISE TIME

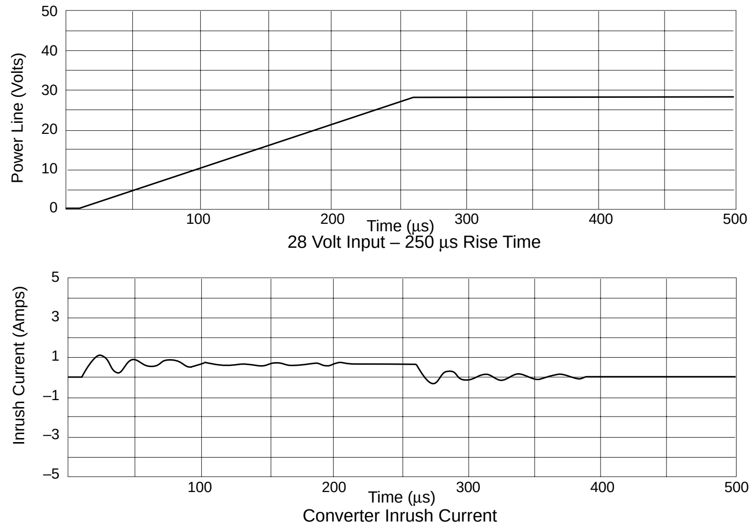


FIGURE 4: 250 µS RISE TIME

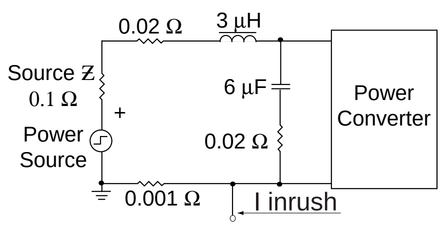


FIGURE 5: INPUT FILTER MODEL

hangup and possible damage to the supplies due to their negative input impedance characteristic. Refer to the following paragraphs for further explanation on this issue.

Figures 6 and 7 show the circuit for a simple power ramp circuit and its starting voltage profile in response to a step application of the 28 volt power line. The circuit utilizes a HEX 5 N channel FET in the return line configured as an integrator controlled by a current source. The integrator time constant is determined by the voltage across R_T, about 6 volts, and the sum of C_T and the FET Drain Gate capacitance, on the order of 1000 PF total. As configured, the turn on voltage ramp rise time is about 200 µseconds. Once timed out, the FET becomes a closed switch, and is full on with its R_{ds} in series with the 28 volt return line. Alternately, a P channel FET could be used in the high line with the circuit reconfigured to change active component polarities, or an N channel FET source follower could be used in the high line. The latter has the disadvantage of requiring a charge pump or other means to provide the FET with gate enhancement above the +28 volt line.

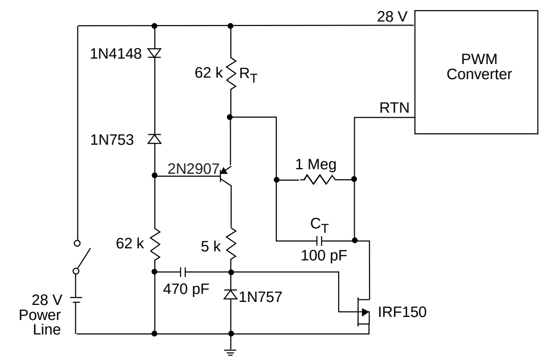


FIGURE 6: CONTROLLED RAMP VOLTAGE STARTING CIRCUIT – 200 µS RAMP

2) The input starting current profile of the power converter will follow that due to the filter elements by a few hundred µseconds to a few milliseconds, and can last from a few to 10's of milliseconds. Refer to the figures for examples. A properly designed forward or flyback converter will have a smooth inrush profile where the current will not exceed the normal values for a step or ramp start similar to that discussed earlier. For a ramp or slow start, the input current when the PWM begins to control will be on

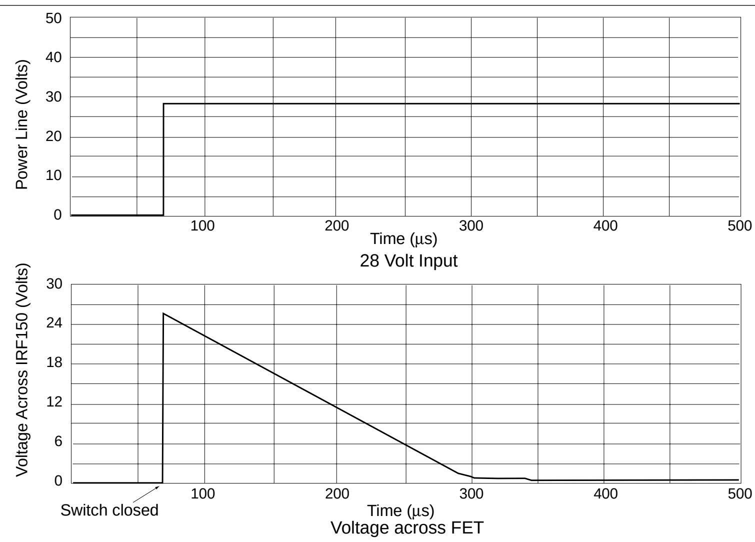


FIGURE 7: VOLTAGE ACROSS NCH FET IN RAMP START CIRCUIT

the order of 2.5 times the normal value at 28 V, and will decline smoothly as the line voltage comes up. This is because of the negative input impedance characteristic where the input line current is inversely proportional to the input line voltage. This means that for a constant load, the product of input voltage and current is constant as a function of line voltage except for small differences in conduction losses over the input range. Then, where a current limited power source is to be used, the limit current must be set based on maximum load and the low line starting voltage, usually 11 to 15 volts for 28 volt devices. Where the input line is applied as a step, depending on the individual part and type of soft start, the input current may rise monotonically rather than beginning at a high value and then decreasing as the line voltage rises. Where this is important, it is best to assume the latter case unless the user has proven it to be otherwise.

3) Some examples of output voltage and input current starting profiles follow. All were taken from lab data using a step start from a HP Model 602A, 200 watt switching power supply.

Figure 8 shows the starting profiles for an MCH2805S flyback converter with current mode control. This part starts at just under 12 volts and has a 0.5 watt load. The efficiency should be about 70% at this load such that the input power will be 0.71 watts. When starting occurs at about 12 volts, the input current will be about 0.71 watts/12 volts = 0.06 amps, in agreement with the measured value. At 28 volts, the current decreases to 0.025 amps due to the incrementally negative input impedance. The starting profiles with the load paralleled with 1000 µfd is also shown and is well behaved with the current mode control, but requires some additional time to start. Also, due to the large capacitance, there is some overshoot of output voltage. Note that the surge for charging the input capacitor has occurred at time zero on the graph and is not shown.

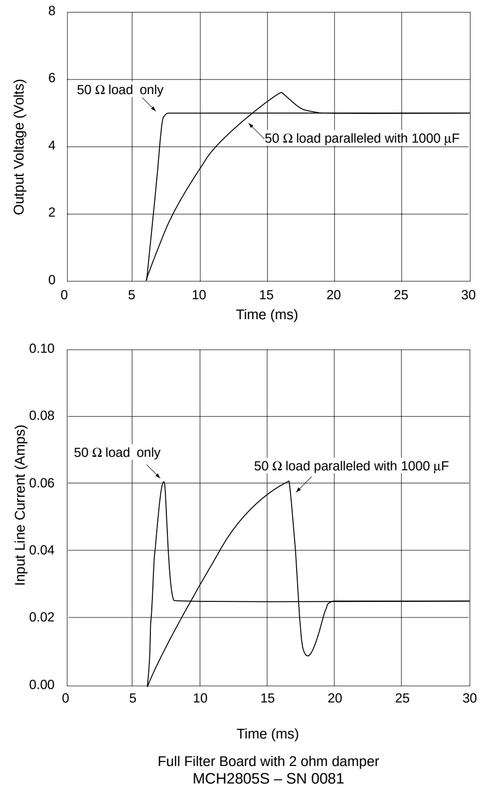
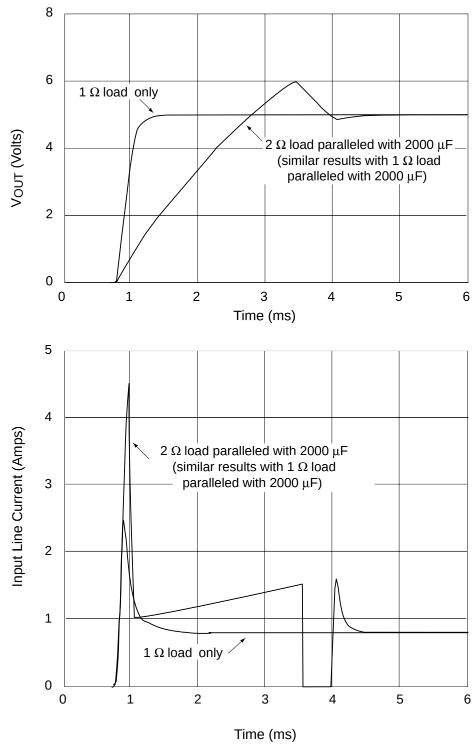


FIGURE 8: STARTING PROFILE – MCH2805S

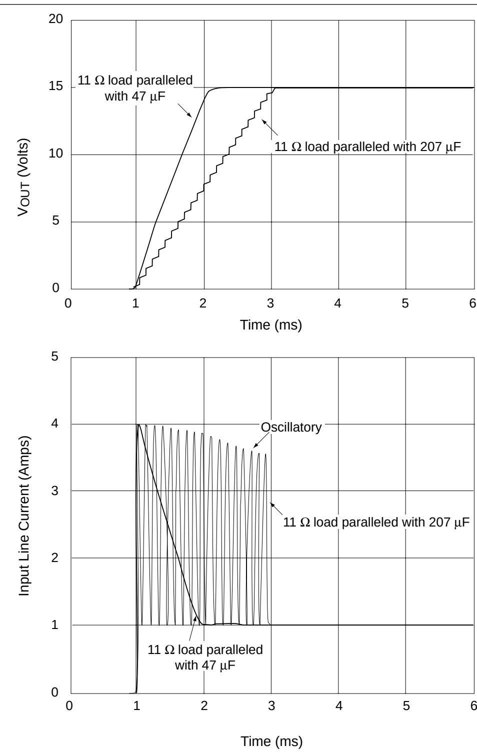


Step start at 28 V, load on +5 only
MTR2805D – SN 0044

FIGURE 9: STARTING PROFILE – MTR2805D

Figure 9 shows the starting profiles for an MTR2805D with a 1 ohm load on the positive output only, and also a 2 ohm load paralleled with a 2000 µfd capacitor. The MTR is a voltage mode forward converter, and the large capacitor significantly modifies the control loop characteristics. The input current peak is defined by the peak output power at current limit. Large capacitive loads should be used with flyback rather than forward power converters whenever possible, since the former doesn't have the disadvantage of a low frequency 2nd order output filter inside its control loop.

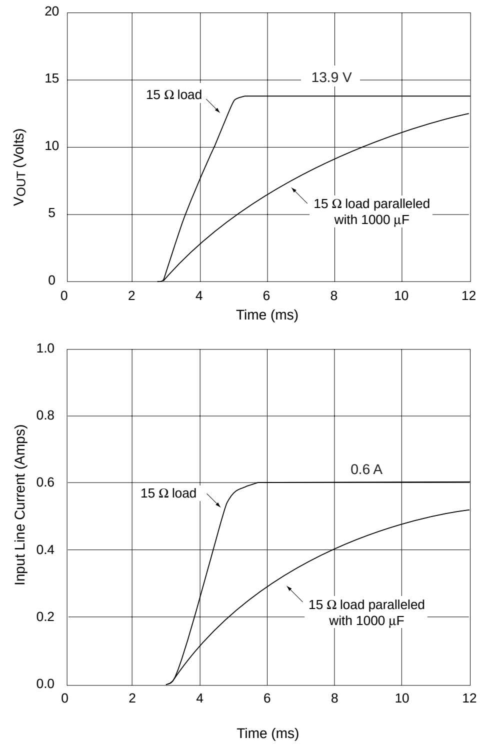
Figure 10 shows the starting profiles for an MTR2815S with about a 20 watt load and two different values of paralleled capacitors. The first with a 47 µfd paralleled capacitor has a smooth and orderly starting profile. The second with a larger 207 µfd capacitor shows an oscillatory behavior where starting is controlled by the current limit loop which causes the ON/OFF behavior on the way up. This by itself should not cause any type of damage during startup.



28 V ⌐ start
MTR2815S – SN 0068

FIGURE 10: STARTING PROFILE – MTR2815S

Figure 11 shows the starting profile of an MHV2815DF with nearly full load, and with an added 1000 µfd capacitor across the load. This is a continuous flyback device with current mode control, and a good soft start. The input current is monotonic and well behaved with and without the added capacitive load.



Profile on +15 V output only, 28 V start
Inrush current is measured across a 0.1Ω resistor in series with input return.
MHV2815DF – SN 0012

FIGURE 11: STARTING PROFILE – MHV2815DF

APPLICATION NOTE

If you are using Interpoint power converters, make sure the power source is large enough for starting as well as for continuous operation. For starting, the following procedure should work safely.

1) Determine the maximum continuous output power in watts. Add a safety factor, like 30%. Then multiply by 1.3 to add the safety factor.

2) Divide this figure by the decimal efficiency to get the maximum input power. Look for the efficiency curves on the data sheet. If you can't find it, use a figure like 70%, and divide by 0.7. If you are not sure, talk to one of the Interpoint Application Engineers.

3) Now you have the maximum input power. Divide this by the low line voltage at which the PWM starts working to get the maximum input current you will need. you can determine this voltage on the bench by turning the power source voltage up slowly and monitoring the power converter output. You may want to apply an additional safety factor like maybe 10%. Do this by multiplying the low line starting voltage by 0.9. Now divide this voltage into the maximum input power you found in step 2), and you have the maximum current you will require. If several power converters are involved, go through the previous procedure on each, and then add the line currents. The answer you get is the minimum current capacity you need from your power source at current limit. If you get an answer like 7.5 amps, then the actual line current at 28 volts will be more like 3.5 amps due to the negative input impedance characteristics of the power converters. If you have a supply with an adjustable current limit, be sure to set the limit at 7.5 amps or more, not the 3.5 amp normal line voltage operating current. The lower current limit may cause hangup and damage to the supplies.

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