POWER FACTOR CORRECTION

INTRODUCTION

Modern electronic equipment can create noise that will cause problems with other equipment on the same supply system. To reduce system disturbances it is therefore essential to correct for this, which requires an understanding of the problems poor power factors can cause, the requirements of correcting the power factor, and the methods of power factor correction.

WHAT IS POWER FACTOR?

A resistive load is ideal for an ac source. It will draw current from the ac line in a sine wave that is in phase with the line voltage. The classical definition of power factor is:

$$\text{Power Factor} = \frac{\text{Real Power}}{\text{input voltage x input current}}$$

The real power is expressed in watts. The rms voltage multiplied by the rms current is expressed in volt-amps-reactive (VA or VAr).

Power factor is a unit-less number between 1 and 0, where a power factor of 1 would indicate the current and voltage are exactly in phase. The power factor for a linear load is the cosine of the phase angle.

A resistive load will have a power factor of 1. The power factor for an inductive load will be less 1 because the current will lag behind the voltage.

Wiring, circuit breakers, and transformers that are used to supply power must be appropriately sized to the VA rating of the load. The power factor of an inductive load can be improved by adding a proportional amount of capacitance across it. This will counteract the inductance and a power factor of 1 can be achieved.

Most modern equipment uses a switch mode power supply to convert the high voltage ac to lower dc voltages. These power supplies use a rectifier and capacitor connected in series to the ac line, see **Figure 1**. This nonlinear load on the ac line causes large peak currents at the peaks of the ac line voltage. This can cause the line voltage to be clipped at the peak, see **Figure 2**. The wiring, circuit breakers, and transformers must therefore be rated to handle the large peak current. The current will be almost in phase with the voltage, but the current will not be sinusoidal. The modern definition of power factor uses only the first or fundamental harmonic of the line current for the real power calculation.

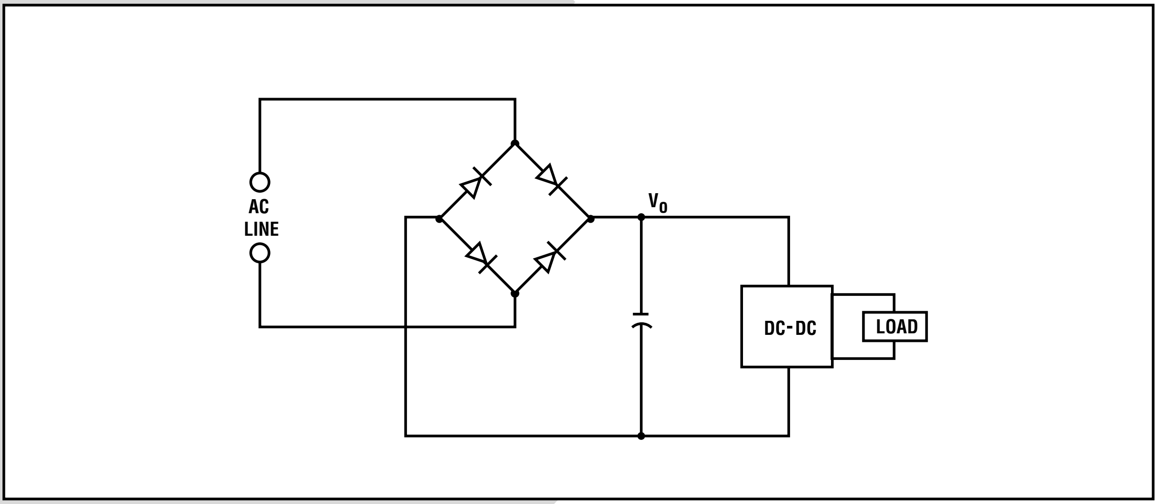


FIGURE 1: Typical switch mode power supply circuit

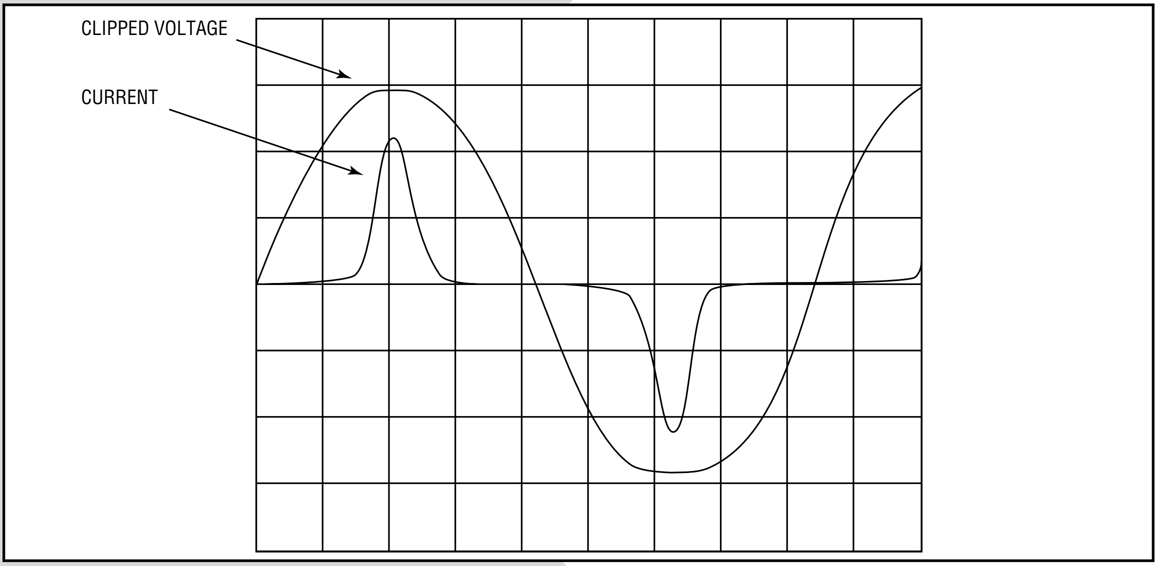


FIGURE 2: Typical wave forms for a switch mode power supply

The power factor of most off line switch mode power supplies is about 0.65.

The high peak currents and clipping of the voltage can cause problems for other equipment connected to the supply system. These problems are so prevalent with today's electronic equipment that the International Electrotechnical Commission (IEC) found it necessary to regulate the current harmonics of household appliances and similar electrical equipment (IEC 1000-3-2). Most European communities require electronic equipment to conform with IEC 1000-3-2.

IEC REQUIREMENTS

The maximum current allowed by IEC 1000-3-2 for each harmonic is shown in Table 1, note that the harmonic limits are not proportional to the power used. The minimum power factor required can be calculated for various input power levels, see Table 2. This calculation shows that some type of power factor correction must be incorporated in power supply designs at 500 watts and above.

Other regulations, such as EN60555-2, are being considered and may impose a mA/watt specification that would require a power factor greater than 0 .7 for all equipment regardless of input power.

Table 1 IEC 1000-3-2 Harmonic current limits

Harmonic	Maximum Current (amperes)
2	1.08
3	2.30
4	.43
5	1.14
6	.30
7	.77
even 8<n<40	.23x8/n
9	.40
11	.33
13	.21
odd 15<n<39	.15x15/n

Table 2 Input power vs. minimum power factor at 170 Vrms

Input Power (watts)	Minimum Power Factor
250	.435
500	.695
1000	.888
2500	.979
5000	.995

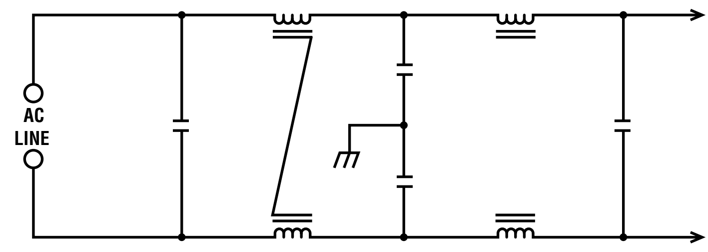


FIGURE 3: For typical passive input filter

POWER FACTOR CORRECTION METHODS

Passive input filtering can achieve a .7 power factor for power levels below 500 watts. **Figure 3** shows a typical circuit. Each design will require unique values for the inductors and capacitors. This filter will operate at the line frequency and will require relatively large inductors and capacitors. A passive filter would be too large and heavy for most designs above 500 watts or with power factors greater than .7. An active low frequency approach can be implemented up to about 1000 watts. **Figure 4** shows a typical design and the current wave form.

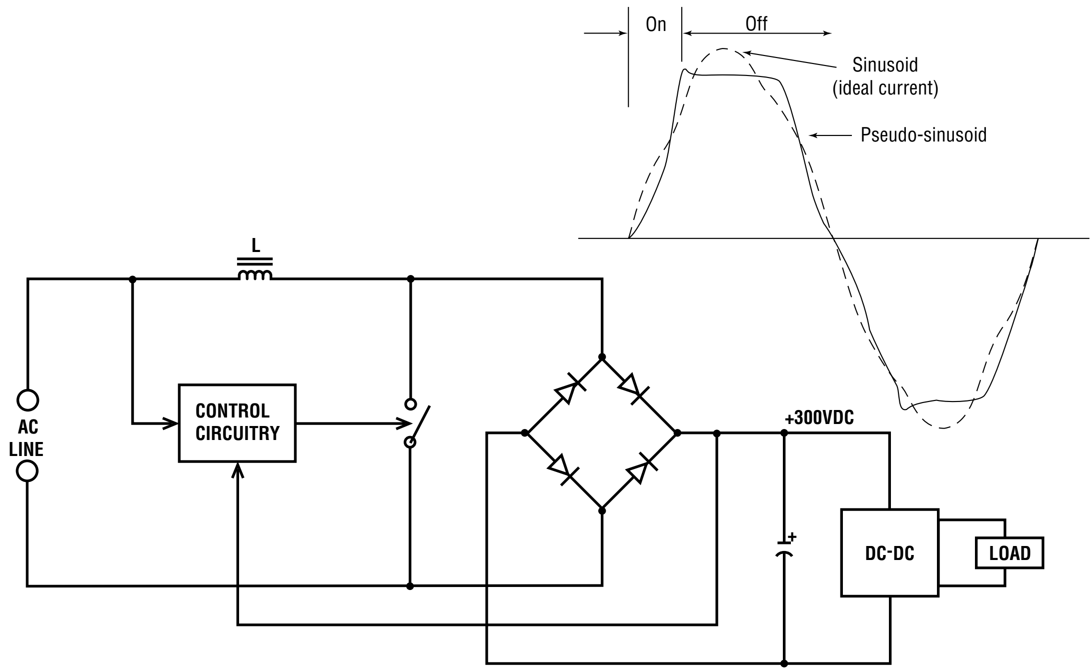


FIGURE 4: Active low frequency PFC

Power factors as high as .95 can be achieved with an active low frequency design. The inductor is operated at the line frequency and its size and weight will limit the usefulness of this topology.
Active high frequency has become the most popular method of correcting the power factor. The boost topology is used with a dual control loop to maintain a sinusoidal input current and a regulated output voltage, see **Figure 5**. This implementation has the advantages of power factors greater than .99, a wide input voltage range, regulated dc bus, small size, and a holdup time that is independent from the input voltage.

ACTIVE HIGH FREQUENCY EXAMPLE

The following specifications are used for a design example of an active high frequency power factor corrected front end.

Maximum output power = 3000 watts
Input voltage range = 170 - 270 Vrms
Line frequency = 47 - 65 Hz
Switching frequency = 100KHz
Output voltage = 400Vdc
Holdover time = 30ms minimum

The boost topology requires that the output voltage be greater than the highest expected input voltage. The 270Vrms input requires the output to be greater than 382Vdc, an output of 400Vdc is acceptable.

The inductor value controls the amplitude of the 100KHz current ripple. This can greatly affect the amount of distortion and thus the amount of EMI filtering required on the input. A good starting point for the inductor value would be to set Ip-p equal to 20% of the peak line current.

$$L \geq \frac{5 \times V_{in}^2 \times (1 - 1.414 \times V_{in} / V_o)}{P_{in} \times f}$$

In this case V_{in} = 170Vrms, V_o = 400Vdc, P_{in} = 3400 watts, and f = 100KHz. The inductor must be greater than 170uH while allowing for operation into saturation. A Micrometals E220-18 core with 48 turns of two #16 wires will provide a conservative choice for the inductor.

The value of the output capacitor can be determined from the holdover time requirement.

$$Co\ min = \frac{2 \times P_{out} \times t}{V_o^2 - V_o\ min^2}$$

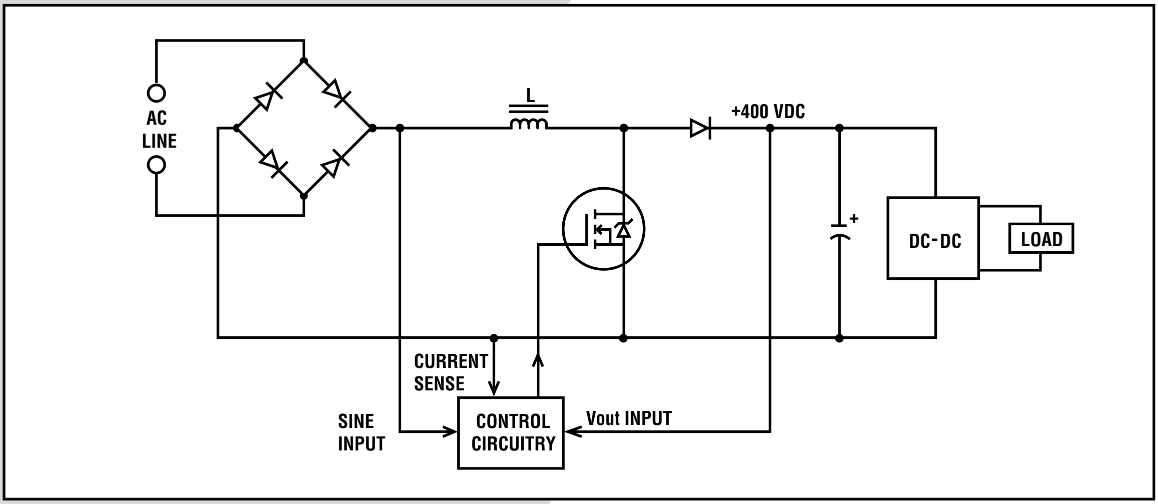


FIGURE 5: Active high frequency PFC

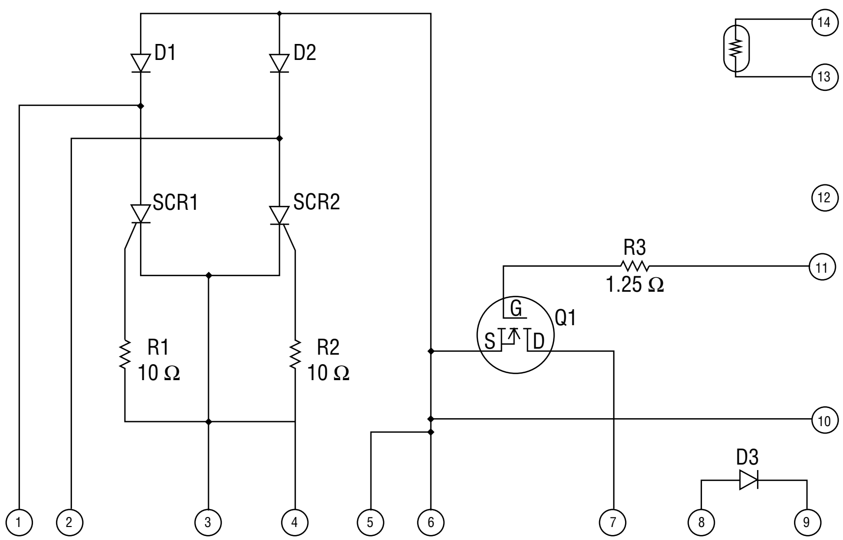
Assuming the load will be dc-dc converters that can maintain their outputs with a minimum input voltage of 240Vdc, then the output capacitance should be 1800uF. Four United Chemi-Con 35x50 450V 470uF capacitors would suffice.

A power module that contains all the power semiconductors needed to implement this circuit at currents up to 20Arms has been developed by BI Technologies. This module, model 7700, contains a rectifier bridge with SCRs to limit the inrush current, an ultra fast 24 amp output diode, a temperature sensing switch, and a 500V .1ohm FET. This module significantly reduces the labor involved with mounting the components to the heat sink, simplifies the design, and saves space. **Figure 6** shows a schematic of the module.

Several IC manufacturers offer a control chip specifically for active high frequency power factor correction. Linear Technology, Micro Linear, and Unitrode are popular sources. These manufactures have detailed data sheets and application notes that delineate how to utilize their ICs.

FET switching times must be fast enough to insure that the FET turns off when the PWM is at maximum duty cycle. A gate driver such as the Unitrode UC3710 or a similar discrete design must be used.

The air flow and heat sink design must be sufficient to keep the inductor and power module within their rated temperatures. The power module contains a thermal switch that can be used to shut down the supply in case of over temperature.



Pin Designation

Pin 1: AC1
Pin 2: AC2
Pin 3: Bridge Output
Pin 4: SCR Gates
Pin 5: Ground
Pin 6: Ground
Pin 7: FET Drain
Pin 8: Ultra Fast Anode
Pin 9: Ultra Fast Cathode
Pin 10: Gate Ground
Pin 11: Gate Drive
Pin 12: N.C.
Pin 13: TH1
Pin 14: TH2

FIGURE 6: Schematic of BI model 7700 PFC module

APPLICATION NOTES

Figure 7 shows a schematic for the 3000 watt design.

CONCLUSIONS

Power factor correction will reduce the harmonic currents in the supply system and reducing these currents will benefit the utility companies and other equipment users on the supply system. The reduction in noise and cleaner sine wave will create a more ideal power distribution system.

Active high frequency PFC will continue to grow in popularity due to its ideal sine wave input current. Power supply manufactures who incorporate power factor correction will dominate the European market as more communities require compliance to the latest legislation.

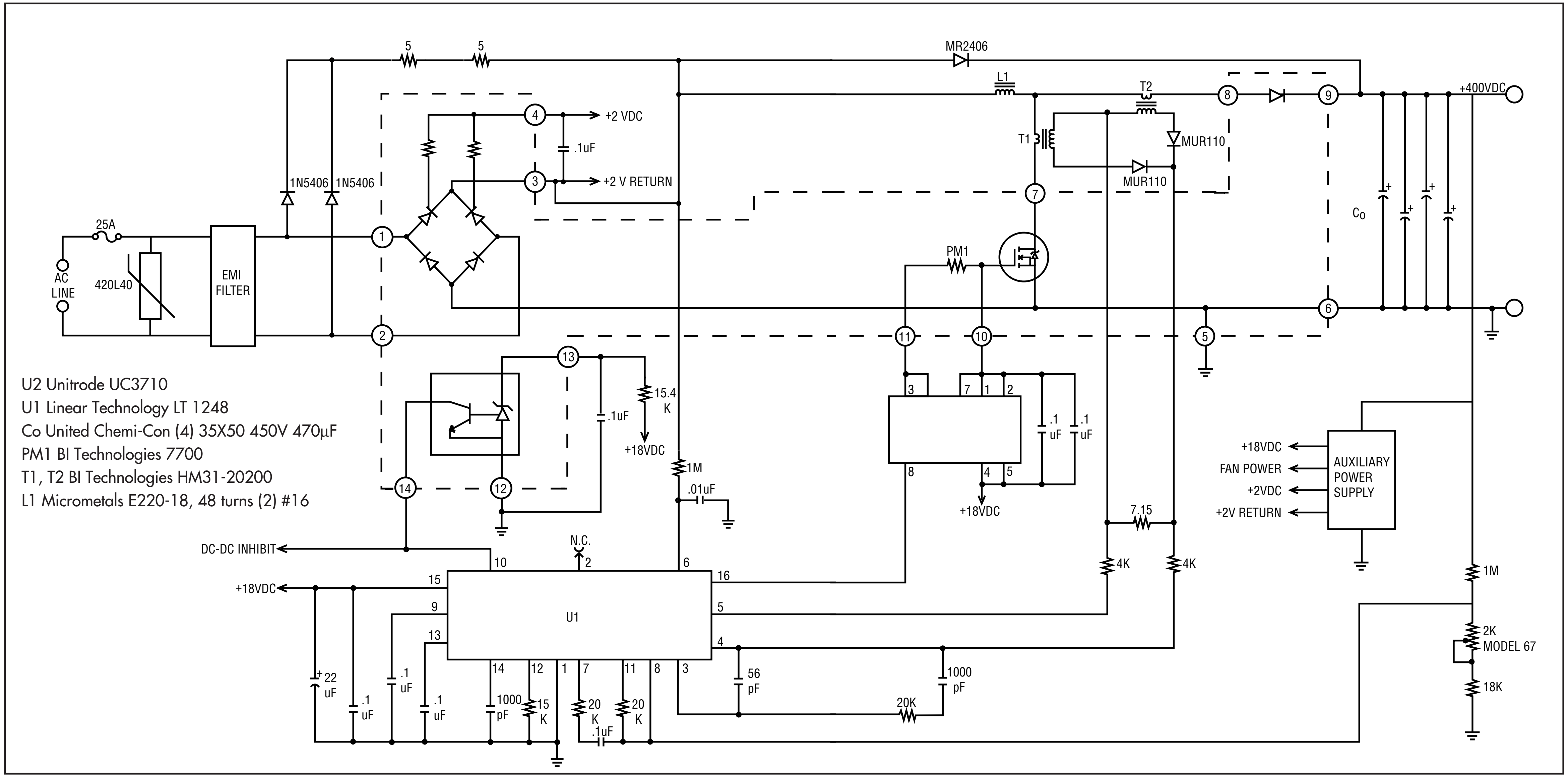


FIGURE 7: 3000 watt PFC front end