

Design Guidelines for a Power Factor Correction (PFC) Circuit Using a Capacitor and an NTC Thermistor

Objective

Ametherm In rush current Limiters are used in many applications today that require suppression of surge current, when power is first is first applied to the system. One of the popular applications of Ametherm in rush current limiters is in power factor correction circuits. This article provides a solution for finding the correct power factor correction (PFC) circuit for an inductive circuit. This solution is suitable for applications such as ballasts, LED drivers, and HVAC.

Background

The power factor (PF) describes the characteristics of AC circuits in florescent lamps, appliances, transformers, relays, and motors. It is a ratio between the power that does the actual work and the power that is delivered to the equipment. It is a dimensionless entity with a value varying, theoretically, between 0 and 1. A practical value of the PF, in the real world, varies between 0.65 and 1. When its value is less than 1, additional power is required to operate electrical components such as transformers, induction motors, or high-intensity discharge lighting.

Mathematically speaking, PF or $\cos(\alpha) = \text{true power in W} / \text{apparent power} - \text{rms voltage} \times \text{rms current (as measured)}$, or X_R/Z where the angle α denotes the phase angle between the voltage and the current waveform.

Apparent power (in volt-ampere(VA)) denotes a quantity where voltage is multiplied by current. Real power, however, is measured with the help of a watt meter.

As shown in Figure 1 below, Z is the vector addition of X_R (reactive power or real power) and X_L (inductive power or apparent power).

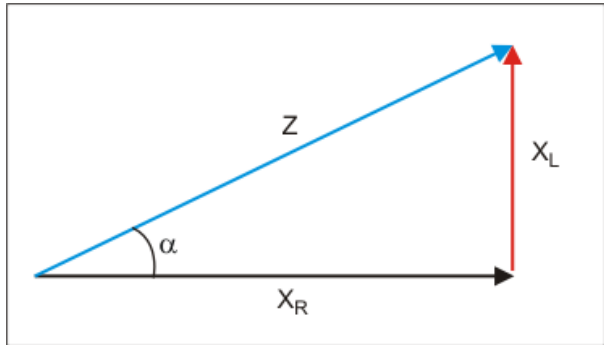


Figure 1: Z is the vector addition of X_R and X_L

Figure 2 shows how larger inductive loads (requiring large reactive power) result in a larger angle α (measured between X_R and Z). This implies that large inductive loads result in a smaller quantitative PF value.

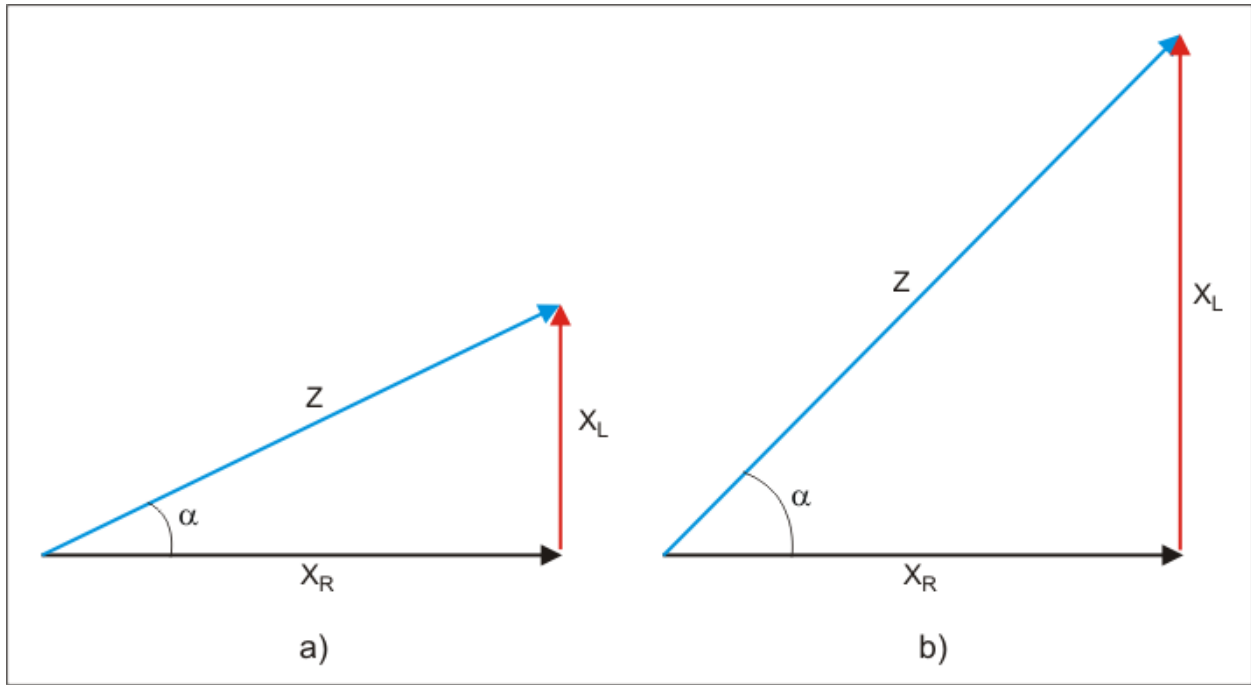


Figure 1: The $\cos \alpha$ for b) has a smaller value than the $\cos \alpha$ for a)

Note:

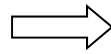
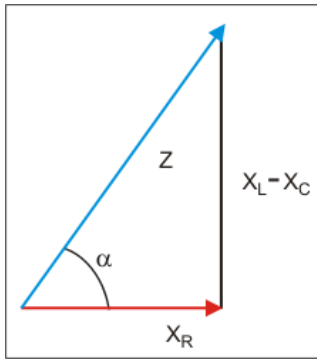
Most equipment built today carries an inductive load, as opposed to a resistive load. When that occurs, the voltage and current become out of phase due to the resistance. The product of the voltage and current is called the apparent power. This is commonly referred to in VA instead of watts, since watts are reserved for real power.

Real power can be considered as resistive power, which is dissipated as heat. A reactance from the inductive load does not dissipate power, but stores energy in the electric or magnetic field.

Alternatively, the PF is the ratio of real power to apparent power.

Theory of Mitigating an Inductive Load With a Capacitor

When both inductance and capacitance are present in an electrical circuit, X_L and X_C are added or subtracted algebraically, because they are out of phase by 180° . The vector triangle or phasor triangle is as shown below:



Where $P_F = \frac{X_R}{Z}$

$$Z = \sqrt{X_R^2 + (X_L - X_C)^2} = \text{impedance}$$

Glossary, Symbol, and Formulas:

Inductive reactance = $X_L = 2\pi fl$

Capacitive reactance = $X_C = \frac{1}{2\pi fc}$

Problem Statement

The following circuit exhibits the typical behaviour of an inductive circuit where the inductive component of the current lags the voltage in the main line.

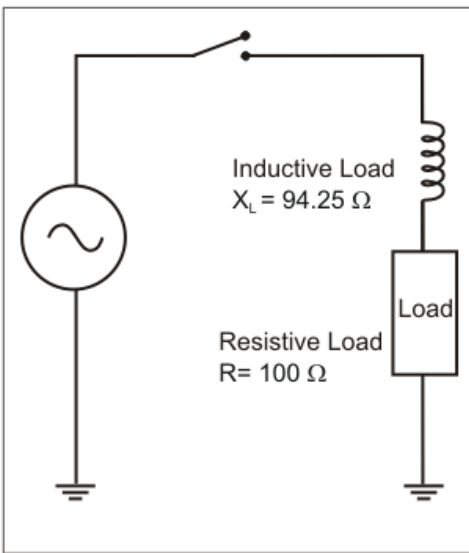


Figure 3

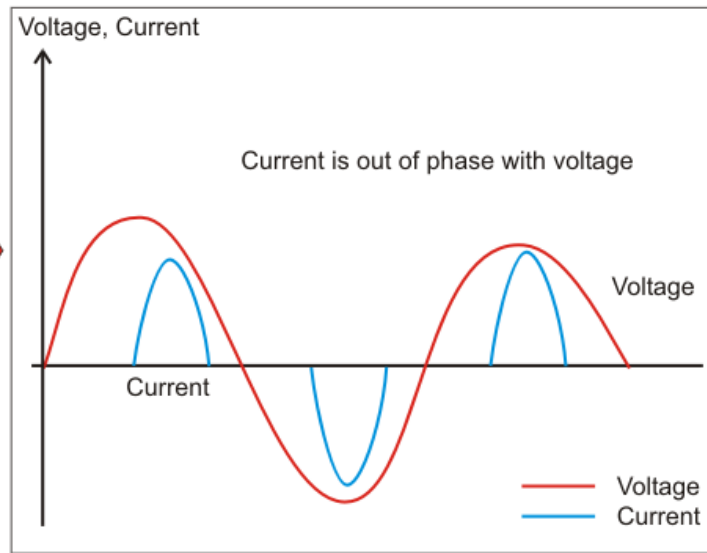
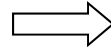
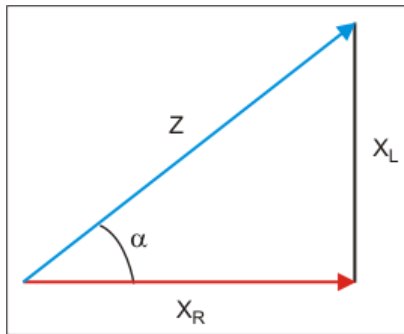


Figure 4

Figures 3 and 4: The inductive component of the current lags the voltage in the main line

The first step is to determine the PF for the above circuit, which is calculated using the phasor diagram, as shown in Figure 5.



$$Z = \sqrt{X_L^2 + X_R^2}$$

$$\cos \alpha = \frac{X_R}{Z}$$

Figure 5: Phasor diagram

Using the values from Figure 3:

$$Z = \sqrt{(100)^2 + (94.25)^2}$$

$$Z = \sqrt{18,883.06} = 137.42 \Omega$$

$$\cos \alpha = \frac{100}{137.42} = 0.7277 \approx 43.30^\circ$$

So, the total steady state current is input voltage / impedance = $\frac{277 \text{ VAC}}{137.42 \Omega} = 2.02 \text{ A}$.

Hence the apparent power = $2.02 \text{ A} \times 277 \text{ VAC} = 559 \text{ VA}$.

Real power = $I^2 R = (2.02)^2 (100 \Omega) = 408 \text{ W}$.

Alternatively, PF is calculated as real power / apparent power: $\frac{408}{559} = 0.73$, which is considered a poor value.

Solution

A power factor correction (PFC) circuit is able to correct this poor PF.

In order to correct this condition, a parallel capacitor is added across the inductive load. This is shown in Figure 6, with the resultant phasor diagram shown in Figure 7. The capacitive current attempts to lead the voltage by 90° and cancels the lagging inductive current, which is about 43.30° .

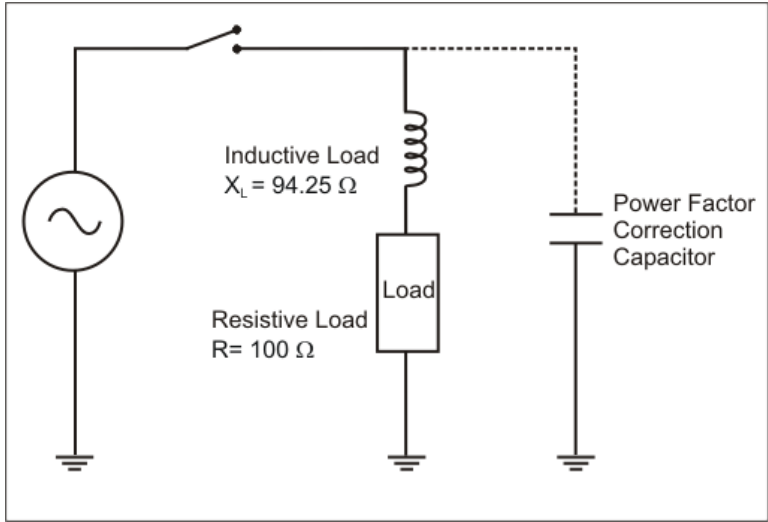


Figure 6: A parallel capacitor is added across the inductive load

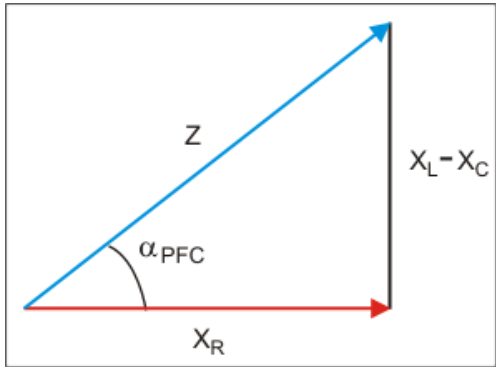


Figure 7: Phasor diagram

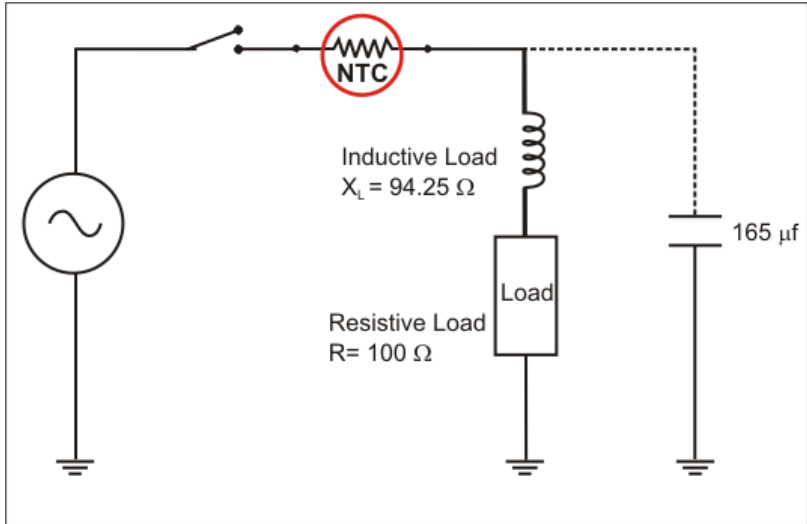


Figure 8: An NTC thermistor is added to limit the inrush current

Next, turning on the capacitor will act like a short and induce a huge inrush current. The best way to limit the inrush current is to introduce an NTC thermistor, as shown in Figure 8. Note that this NTC thermistor must handle 2.02 A of steady state current.

Let's consider a target (design) PF value for the PFC circuit of 0.8

$$\text{So, } \cos(\alpha_{PFC}) = R/Z = 0.8$$

$$\implies Z = R/0.8 = 100 \Omega / 0.8 = 125 \Omega.$$

From the phasor diagram (Figure 5),

$$Z^2 = R^2 + K^2,$$

$$\text{where } X_L - X_C = K.$$

This implies:

$$125^2 = 100^2 + K^2.$$

$$\text{So, } K^2 = 5625,$$

$$\text{or } K = 75 \Omega.$$

Since $X_L = 94.25 \Omega$, X_C is derived as $94.25 \Omega - 75 = 19.25 \Omega$

The capacitance value is obtained by using $X_C = 1 / 2 \pi f C$,

$$\text{or } C = 1 / 2 \pi f X_C = 1 / 2(3.1415)(50)(19.25) = 165 \mu\text{f}.$$

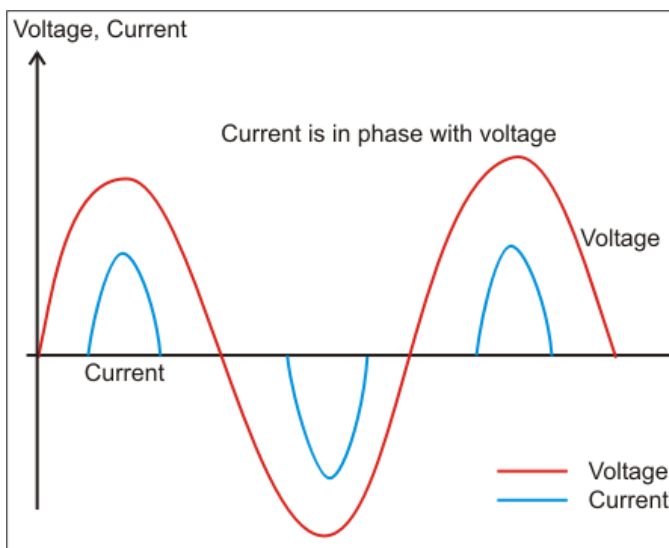


Figure 9: The current is in phase with the voltage

The energy needed to block the inrush current without self destruction is $E = \frac{1}{2} C V^2$

$$= \frac{1}{2} (2.77 \times 1.414V)^2 (165 / 1,000,000) = 12.70 \text{ J.}$$

Selection of Thermistor

Ametherm offers a number of thermistors. In order to handle this inrush current, the best selection is:

Thermistor type: SL10 10003 (See Appendix A)

UL File: E209153

CSA File: CA110863

Rated for 277 VAC & 3.0 A

APPENDIX A

Electrical Specification

Resistance at 25 °C	10 Ω ± 20 %
Max Steady State Current	3 A
Max Rec. Energy Rating	17 J
Actual Failure Instantaneous Energy	35 J
Dissipation Constant	11 mW/°C
Body Temperature at 100% Max Current	151 °C
Thermal Time Constant	30 sec
Max Cap at 277 V	220 µf
Material Type	C

Current and Energy Derating Curve

