



Simulation Based Study and Calculation of Required KVAR for Power Factor Improvement.

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ABSTRACT:

In today's technological world, the power becomes very essential element in households and industries. Most of the loads are inductive type or mixed type which consumes more power and thus losses generated. Hence the power factor gets degrade. So part of the power get wasted and cannot be utilized. This paper is all about how to improve the power factor near unity so that the losses can be minimized. For this, first of all the simulation based study is carried out and based on this, later the practical hardware testing will be done which will include the atmega328p development board for programming which will be programmed in such a way that it will improve the power factor from 0.8 to 0.95. This paper includes the simulation in Proteus8 for reading the phase shift between voltage and current waveforms and based on the result calculation of the KVAR needed to compensate the required power factor is done.

Keywords: Power Factor, Power Factor Correction, Proteus8, Capacitor Bank, 3 Phase Load, Current Transformer, Potential Transformer.

1. Introduction

The **power factor** correction means bringing the power factor of an **AC circuit** nearer to one (1) by using the equipment which absorbs or supply the reactive power to the circuit. Usually, the power factor correction can be done by using the capacitor in the circuit. The power factor correction will not change the amount of true power, but it will reduce the apparent power and the total current drawn from the load.

The phase shift between the voltage and the current of the circuit is known as the power factor. It is represented by the cosine of the angle ϕ . The power factor represents the fraction of total energy use for doing useful work, and the remaining energy is stored in the form of magnetic energy in the inductor and capacitor of the circuit. The value of power factor lies between -1 to +1. The most economical value of power factor lies between 0.9 to 0.95. If the value of power factor lies below 0.8 (approx), then it draws more current from the load. The large current increases the losses and requires a large conductor, thus increases the cost of the system. The loss can be reduced by correcting the power factor of the system.

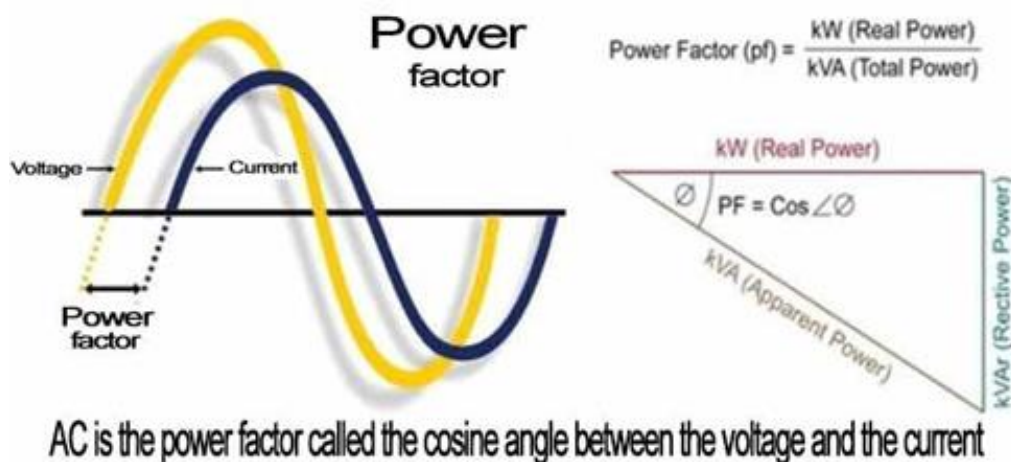


Figure 1: Power Triangle

Figure 1 show the power triangle of power factor where power factor is the ratio of active power to the apparent power which is nothing but $\cos\phi$.

2. Design Methodology

Our proposed scheme consists of Simulation based study of power factor correction using Proteus8 design software.

Proteus 8 Professional: The **Proteus Design Suite** is a proprietary software tool suite used primarily for [electronic design automation](#). The software is used mainly by electronic [design engineers](#) and technicians to create [schematics](#) and electronic prints for manufacturing [printed circuit boards](#).

It was developed in [Yorkshire](#), England by Labcenter Electronics Ltd and is available in English, French, Spanish and Chinese languages.

The design consists of:

- Voltage and current sensor circuit(ZCD)

A. Voltage and Current Sense Circuit (ZCD)

Figure 2 shows the voltage and current sensor circuit. It is a zero cross detector circuit by using LM2903 IC, which compares the input voltage to the zero reference. We get square waveform at the output of the comparator in synchronise with the input waveform. We use current transformer to sense the current and is converted to the voltage by using resistor in parallel with the CT. The output of current and voltage waveform are then fed to the EX-OR gate 4070 to get the phase difference between current and voltage. The ZCD shown in figure 2 is consist of voltage source and current source available in the design suit. Just to make sure that the circuit is giving the phase shift, the phase shifted current source is used i.e. by changing some parameters inside the current source the phase shift is generated.

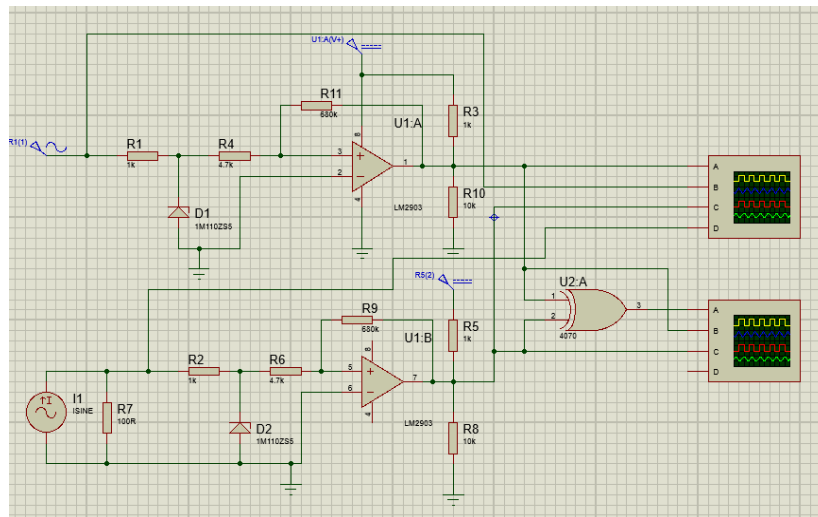


Figure 2: Voltage and Current Sense Circuit (ZCD)

The waveforms for the above ZCD is shown in the following figure.

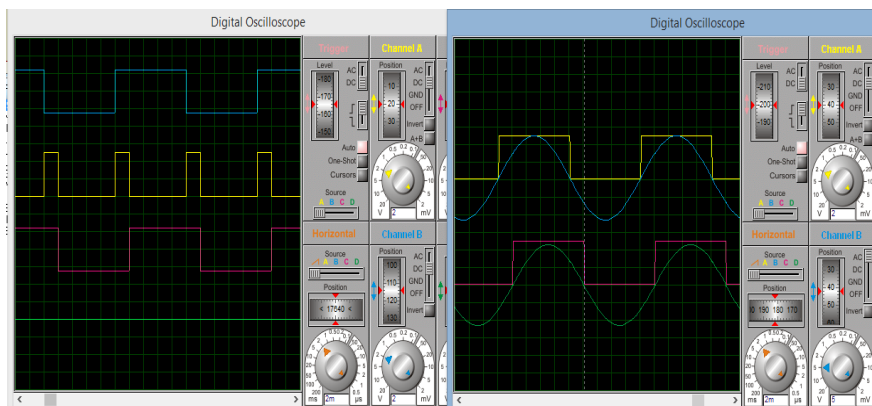


Figure 3: Voltage and Current Waveforms and phase shift between Voltage and current

3. Practical circuit:

In practical circuit we are using the 3 phase voltage source consists of R Y B and Neutral terminal. Here in this circuit we are using only single phase supply means R phase and Neutral provides 230V ac. Which is then fed to voltage or potential step down transformer to get the voltage square wave in synchronized with input supply. To do this we are using a zero cross detector using LM2903 IC. The current transformer is used to sense the current waveform by using inductor in series with the phase for generating the phase shift. The figure shows as follows.

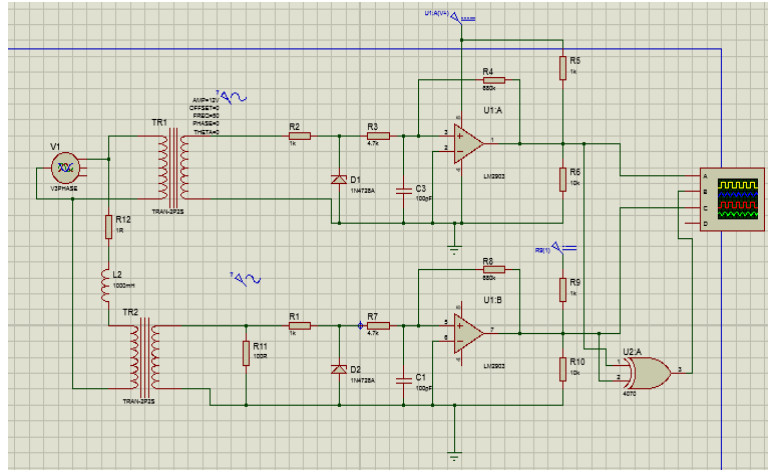


Figure 4: Single phase Voltage and Current Sense Circuit (ZCD)

And the waveform are shown in following figure.

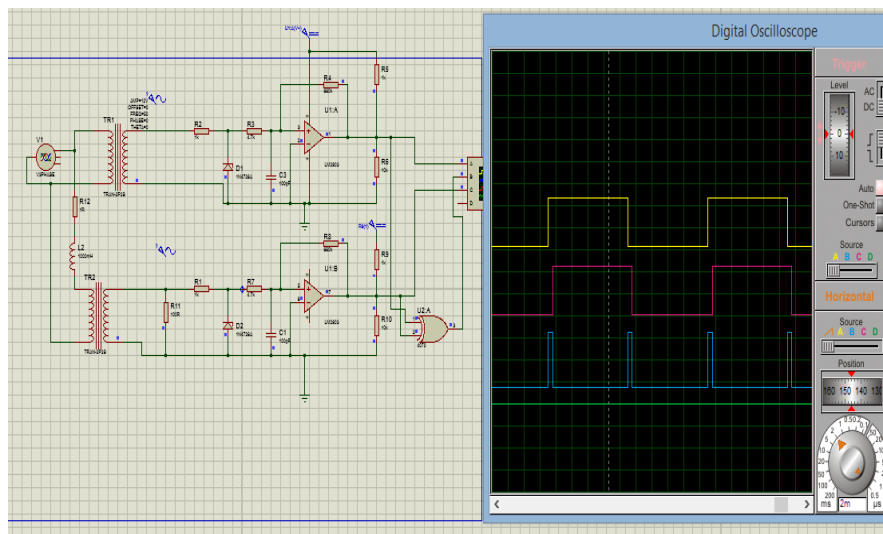


Figure 5: Voltage and Current Waveforms and phase shift between Voltage and current

4. Calculation of the Phase Angle

Phase shift is a small difference between two waves; in math and electronics, it is a delay between two waves that have the same period or frequency. Typically, phase shift is expressed in terms of angle, which can be measured in degrees or radians, and the angle can be positive or negative. For example, a +90 degree phase shift is one quarter of a full cycle; in this case, the second wave leads the first by 90 degrees. You can calculate phase shift using the frequency of the waves and the time delay between them.

Calculation between phase angle ϕ° in degrees (deg), the time delay Δt and the frequency f is: **Phase angle (deg) $\phi^\circ = 360^\circ \cdot f \cdot \Delta t$**

In our case the waveform is shown the phase difference or time delay is 5 ms. Hence the phase angle is calculated as:

$$\text{Phase angle (deg) } \phi^\circ = 360^\circ \times 50 \times 0.0005$$

$$= 9^\circ$$

$$\text{Power factor (PF)} = \cos \phi^\circ$$

$$= \cos(9^\circ)$$

$$= 0.98$$

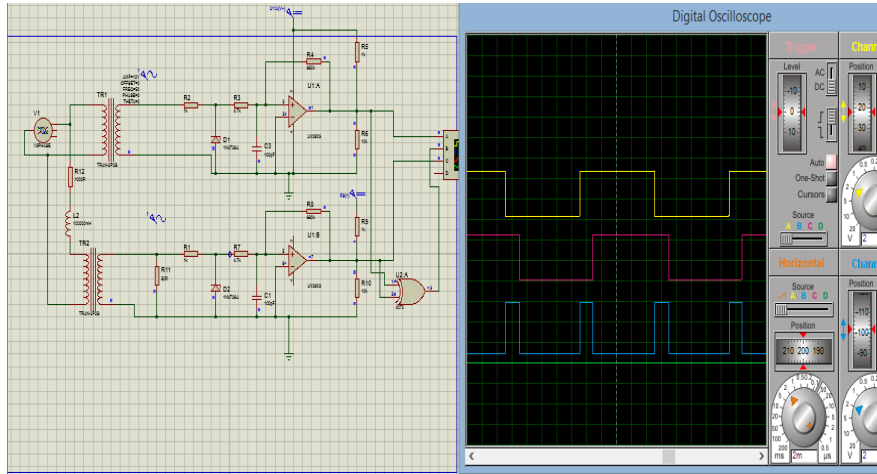


Figure 6: Voltage and Current Waveforms and phase shift between Voltage and current

Here in above figure the time delay is generated between voltage and current waveform is 2ms. It is due to the change in load.

$$\text{Phase angle (deg)} \phi^\circ = 360^\circ \times 50 \times 0.002$$

$$= 36^\circ$$

$$\text{Power factor (PF)} = \cos \phi^\circ$$

$$= \cos(36^\circ)$$

$$= 0.80$$

The power factor correction capacitor should be connected in parallel to each phase load.

The power factor calculation does not distinguish between leading and lagging power factors.

The power factor correction calculation assumes inductive load.

4.1 Single phase circuit calculation:

Power factor calculation:

$$PF = |\cos \phi| = 1000 \times P_{(kW)} / (V_{(V)} \times I_{(A)})$$

Apparent power calculation:

$$|S_{(kVA)}| = V_{(V)} \times I_{(A)} / 1000$$

Reactive power calculation:

$$Q_{(kVAR)} = \sqrt{(S_{(kVA)})^2 - P_{(kW)}^2}$$

Power factor correction capacitor's capacitance calculation:

$$S_{\text{corrected (kVA)}} = P_{(kW)} / PF_{\text{corrected}}$$

$$Q_{\text{corrected (kVAR)}} = \sqrt{(S_{\text{corrected (kVA)}})^2 - P_{(kW)}^2}$$

$$Q_c \text{ (kVAR)} = Q_{(kVAR)} - Q_{\text{corrected (kVAR)}}$$

$$C_{(F)} = 1000 \times Q_c \text{ (kVAR)} / (2\pi f_{(Hz)} \times V_{(V)}^2)$$

4.2 Three phase circuit calculation

For three phase with balanced loads:

Calculation with line to line voltage

Power factor calculation:

$$PF = |\cos \phi| = 1000 \times P_{(kW)} / (\sqrt{3} \times V_{L-L(V)} \times I_{(A)})$$

Apparent power calculation:

$$|S_{(kVA)}| = \sqrt{3} \times V_{L-L(V)} \times I_{(A)} / 1000$$

Reactive power calculation:

$$Q_{(kVAR)} = \sqrt{(|S_{(kVA)}|^2 - P_{(kW)}^2)}$$

Power factor correction capacitor's capacitance calculation:

$$Q_c (kVAR) = Q_{(kVAR)} - Q_{\text{corrected (kVAR)}}$$

$$C_{(F)} = 1000 \times Q_c (kVAR) / (2\pi f_{(Hz)} \times V_{L-L(V)}^2)$$

Calculation with line to neutral voltage

Power factor calculation:

$$PF = |\cos \phi| = 1000 \times P_{(kW)} / (3 \times V_{L-N(V)} \times I_{(A)})$$

Apparent power calculation:

$$|S_{(kVA)}| = 3 \times V_{L-N(V)} \times I_{(A)} / 1000$$

Reactive power calculation:

$$Q_{(kVAR)} = \sqrt{(|S_{(kVA)}|^2 - P_{(kW)}^2)}$$

Power factor correction capacitor's capacitance calculation:

$$Q_c (kVAR) = Q_{(kVAR)} - Q_{\text{corrected (kVAR)}}$$

$$C_{(F)} = 1000 \times Q_c (kVAR) / (3 \times 2\pi f_{(Hz)} \times V_{L-N(V)}^2)$$

5. Power Factor Calculation

In **power factor calculation**, we measure the source voltage and current drawn using a voltmeter and ammeter respectively. A wattmeter is used to get the active power.

Now, we know $P = VI \cos \phi$ watt

$$\text{From this } \cos \phi = \frac{P}{VI} \text{ or } \frac{\text{Wattmeter reading}}{\text{Voltmeter reading} \times \text{Ammeter reading}}$$

Hence, we can get the electrical power factor.

Now we can calculate the reactive power $Q = VI \sin \phi$ VAR

This reactive power can now be supplied from the capacitor installed in parallel with the load in local. The reactive power of a capacitor can be calculated using the following formula:

$$Q = \frac{V^2}{X_C} \Rightarrow C = \frac{Q}{2\pi f V^2} \text{ farad}$$

In **power factor improvement**, the reactive power requirement by the load does not change. It is just supplied by other devices, thus reducing the burden on the source to provide the required reactive power.

Let us consider one example of 3phase load of 10kw has power factor is of 0.8, to make it 0.99 the KVAR (capacitor) calculation is as follows: (this is the simplest method to calculate the KVAR)

$$\text{KVAR} = P (\tan \theta_1 - \tan \theta_2)$$

Now from above example we have,

$$\cos \theta_1 = 0.8, \text{ and } \cos \theta_2 = 0.99$$

$$\text{therefore } \theta_1 = \cos^{-1}(0.8) = 36.86^\circ$$

$$\theta_2 = \cos^{-1}(0.99) = 8.10^\circ$$

now, KVAR = $10(\tan(36.86) - \tan(8.10))$

$$= 10(0.70 - 0.14)$$

$$= 10(0.60)$$

$$\text{KVAR} = 6$$

Hence we have to add 6 KVAR capacitor in the load to compensate the power factor to 0.99.

The lookup table for fix load 10KW for different power factor is as follows:

Power (Kw)	Power Factor(Pf)	Desired Pf	Kvar
10	0.5	0.99	15.89
10	0.55	0.99	13.75
10	0.6	0.99	11.91
10	0.65	0.99	10.26
10	0.7	0.99	8.77
10	0.75	0.99	7.39
10	0.8	0.99	6.07
10	0.85	0.99	4.77
10	0.9	0.99	3.41
10	0.95	0.99	1.86

Figure 7: Lookup table for Calculation of KVAR

6. Result & Conclusion

Engineers use different techniques to improve power quality for such electrical installations. Power factor improvement for linear loads can be brought about by reactive power compensation to compensate for the leading or lagging VARs. However, nonlinear loads generating harmonics require power factor correction techniques like tuned or active harmonic filters to mitigate these harmonics and improve power quality. Such power factor correction techniques rely on the use of power electronics, controlled using analog or digital controllers.

Digital power factor correction control design using Proteus⁸ lets you make use of multirate simulation to design and tune digital control algorithms, enabling you to tailor the input current waveforms, thus keeping losses low while improving the power quality to a desired value. This approach also enables you to test and verify controllers in the presence of varying loads and input voltages before deploying the control algorithms on hardware.

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