Power PE Technical Study Guide Errata

This product has been updated to incorporate all changes shown in the comments on the webpage and email comments as of November, 26 2017. If you have purchased this product prior to this date and wish for the latest version then please email Justin Kauwale at contact@engproguides.com.

The following changes have been incorporated into the product as shown below.

November 22, 2017: Circuits pages 27-33 have been updated. The updated pages are attached. The previous version incorrectly stated the power factor values for the waveform and phasor descriptions.

November 26, 2017: Circuits pages 35-36 have been updated. The updated pages are attached. The previous version incorrectly stated that the negative and positive sequence components had the same magnitude.

November 26, 2017: Devices page 18 has been updated. The updated page is attached. The half wave rectifier ripple factor and average and rms values were incorrect.

$$Z_{AB,delta} = \frac{Z_A * Z_B + Z_A * Z_C + Z_B * Z_{BC}}{Z_C};$$

$$Z_{BC,delta} = \frac{Z_A * Z_B + Z_A * Z_C + Z_B * Z_{BC}}{Z_A};$$

$$Z_{AC,delta} = \frac{Z_A * Z_B + Z_A * Z_C + Z_B * Z_{BC}}{Z_B};$$

If you assume that the impedances are balanced, then the above equations reduce to the following.

$$Z_{delta} = 3Z_{wye};$$

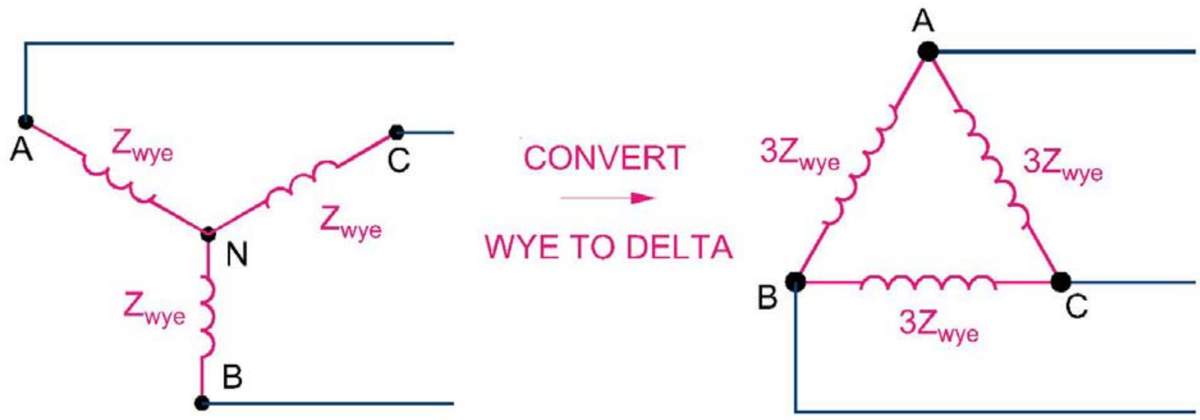

Figure 27: Convert wye to delta in a balanced circuit.

3.7 Power Factor

The term power factor describes the relationship between the apparent power and real power. Power factor describes how much of the apparent power provided is being used for real power. Real power can best be understood by remembering that power is the multiplication of current and voltage. If you imagine a waveform, where current and voltage are perfectly in sync, then current and voltage will always be positive at the same time and will always be negative at the same time. Thus, the multiplication of current and voltage will always be positive. This is best shown in the next waveform section. Apparent power is the multiplication of the current and voltage at all times. Real power is the multiplication of the current and voltage when the value is positive. Reactive power is the multiplication of the current and voltage when the value is negative.

3.7.1 Waveform – Current & Voltage

In the following graph, current and voltage are in phase. This corresponds to a power factor of 1.0. The current and voltage waveforms cross the X-axis at the same time. In this graph the real power is 100% of the apparent power.

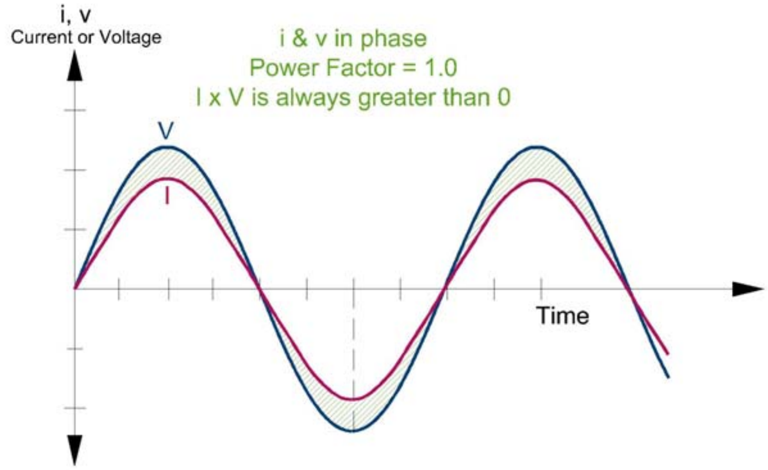

Figure 28: Current and voltage waveforms with a power factor of 1.0.

In the following graph, current and voltage are out of phase by a factor of 0. This corresponds to a power factor of 0. The current waveform is negative when the voltage is positive for 50% of the time. Thus, the multiplication of the current and voltage will be negative for 50% of the time and positive 50% of the time. The real power will be 0% of the apparent power and the reactive power will be 100% of the apparent power.

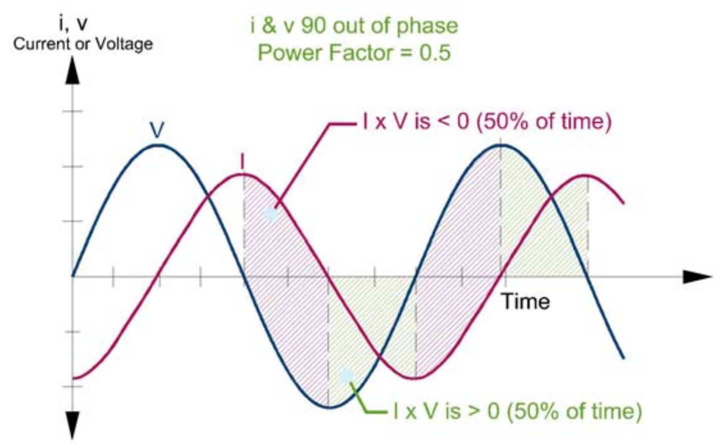

Figure 29: Current and voltage waveforms with a power factor of 0.707.

The next graph shows a negative power factor. When the voltage waveform crosses to the negative, the current waveform crosses to the positive. Thus, the multiplication of current and voltage will always be negative. This corresponds to a power factor of -1. In this scenario, the real power will be 100% of the apparent power and the reactive power will be 0% of the apparent power, similar to a power factor of 1. The only difference is that power is flowing the opposite way. With a power factor of 1, the load is completely resistive. But a power factor of -1 means that the load is now generating power and the power is 100% real.

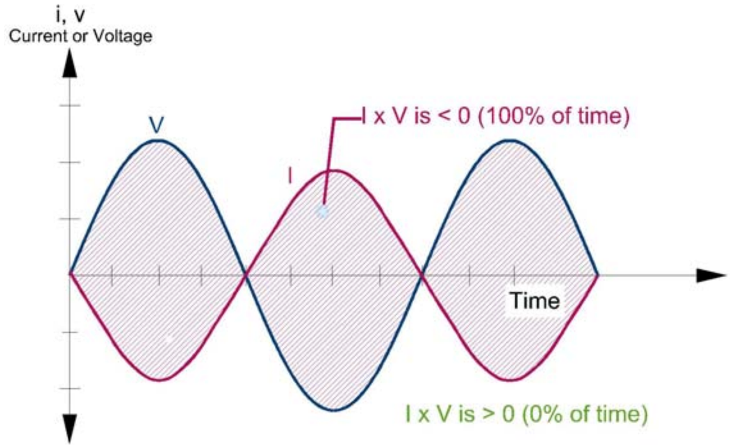

Figure 30: Current and voltage waveforms with a power factor of -1. The load is now generating power.

Next, you should understand that the timing of the voltage and current waveforms can be one of two cases. The current can either be ahead of behind the voltage waveform. These two scenarios correspond to two types of power factors, (1) leading power factor and (2) lagging power factor. The terms leading and lagging are in terms of the current waveform and the voltage waveform with the current as the reference point. A leading power factor describes a current waveform that leads the voltage waveform. A lagging power factor describes a current waveform that lags the voltage waveform.

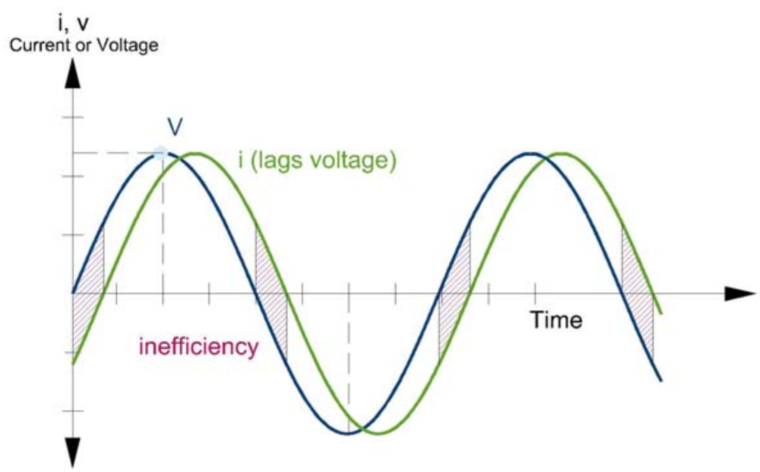

Figure 31: Current and voltage waveforms with a ***lagging*** *power factor. Current reaches its peak* ***after*** *voltage.*

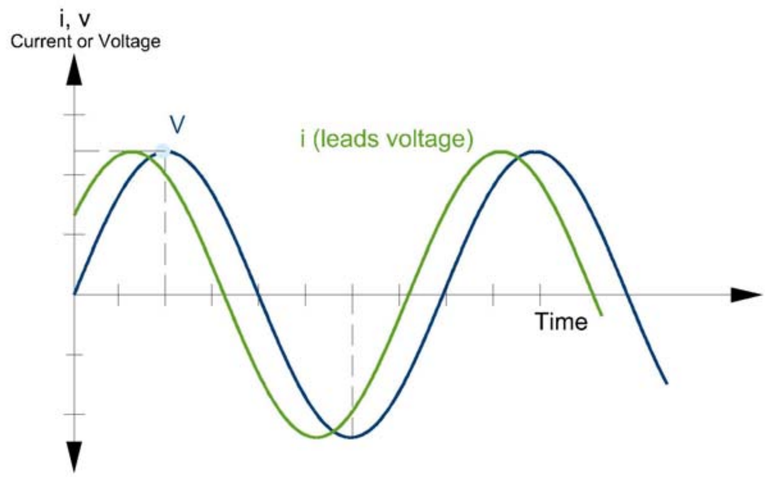

*Figure 32: Current and voltage waveforms with a **leading** power factor. Current reaches its peak **before** voltage.*

3.7.2 Phasor – Current & Voltage

Another way to look at power factor is to look at the current and voltage phasors. You should be able to understand both methods, such that you can use both on the exam. The power factor fraction can be represented as an angle on the phasor diagram.

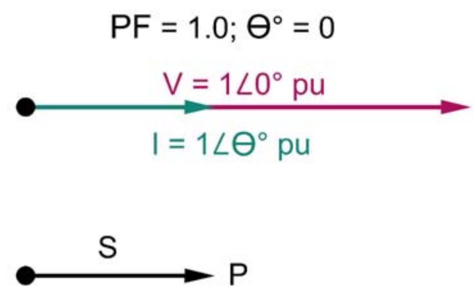

Figure 33: Power factor of 1.0 corresponds to a power factor angle of 0 degrees.

A power factor of 1.0 corresponds to a power factor angle of 0 degrees on a phasor diagram. This shows that the current and voltage phasors are exactly in phase with each other. Also shown is that the apparent power (S) is 100% comprised of real power (P).

A power factor 0.0 corresponds to a power factor angle of 90 degrees on a phasor diagram. This shows that the current and voltage phasors are completely out of phase with each other. Also shown in the below figure is that the apparent power is 100% comprised of reactive power.

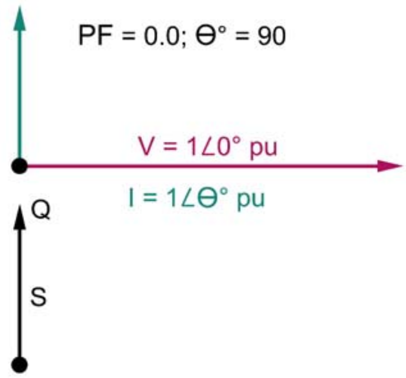

Figure 34: A power factor of 0.0, corresponds to a power factor angle of 90 degrees.

Next, this phasor diagram shows a power factor of 0.707, which corresponds to a power factor angle of 45 degrees. This diagram also shows that the resulting apparent power is comprised of 70.7% real power and 29.3% reactive power.

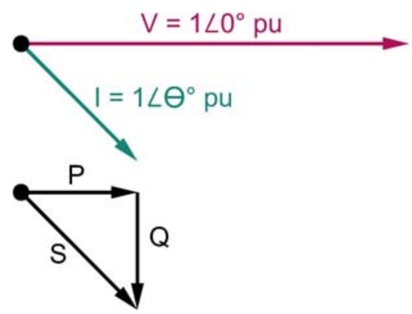

Figure 35: A power factor of 0.707 corresponds to a power factor angle of 45 degrees.

The last important thing to understand with phasor diagrams is how to draw a leading and lagging power factor. Remember that leading and lagging are in terms of current. Current either leads or lags voltage. Thus, power factor angle equation is in terms of the voltage phase angle minus the current phase angle.

$$\theta_{PF} = \theta_v - \theta_i$$

<u>Lagging Power Factor</u>

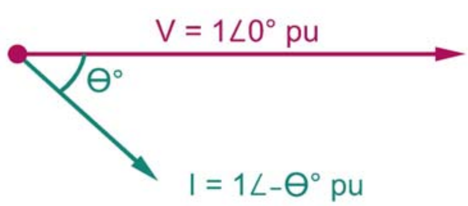

Figure 36: In a lagging power factor, the current phasor lags behind the voltage phasor.

In a lagging power factor, if the voltage phasor is selected to have a phase angle of 0 degrees, then the current phasor angle will be negative and so the power factor angle will be positive.

$$Lagging\ Power\ Factor \rightarrow \theta_{PF} = \theta_v - \theta_i$$

$$Lagging\ Power\ Factor \rightarrow \theta_{PF} = 0 - (-\theta) = +\theta$$

Leading Power Factor

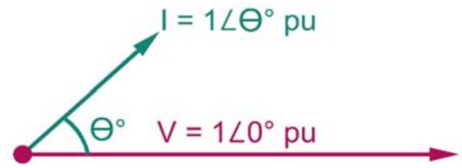

Figure 37: In a leading power factor, current leads the voltage phasor.

In a leading power factor, if the voltage phasor is selected to have a phase angle of 0 degrees, then the current phasor angle will be positive and so the power factor angle will be negative.

$$Leading\ Power\ Factor \rightarrow \theta_{PF} = \theta_v - \theta_i$$

$$Leading\ Power\ Factor \rightarrow \theta_{PF} = 0 - (+\theta) = -\theta$$

3.7.3 Apparent Power, Real Power and Reactive Power

Real power is the power that is used for useful, actual work. This could be used to turn a motor, turn on a light or to power a computer. Real power is given in units of kilowatts (kW), watts (W) or megawatts (MW) and is designated by the variable, "P". Real power is consumed at any resistor, X_R. On a phasor diagram, real power is the power shown on the real axis. On a waveform diagram, real power is the instantaneous current multiplied by the instantaneous voltage at that same point in time. On the exam, you will not need to plot the waveforms to find power at a certain point in time, but you will have to find the effective real power, which will just be called real power through the following equation.

$$P = I * V * \cos(\theta)$$

$$I = RMS\ of\ current\ waveform; V = RMS\ of\ voltage\ waveform;\ \theta = power\ factor\ angle$$

Reactive power is developed by any reactor or inductor, X_L. Reactive power is not consumed, it moves back and forth in the circuit. Reactive power is given the variable, "Q" and is shown in units of kilovar (kVAR), megavar (mVAR) or var (VAR). Similar to real power, you will not need to plot the waveform of reactive power, but you will need to find the effective reactive power, which will just be called reactive power through the following equation.

$$Q = I * V * \sin(\theta)$$

$$I = RMS\ of\ current\ waveform; V = RMS\ of\ voltage\ waveform;\ \theta = power\ factor\ angle$$

The following diagrams are provided for you to use during the exam. The diagrams will allow you to quickly access any equations and visually see the concepts that were previously discussed. The first diagram includes the equations for apparent, real and reactive power.

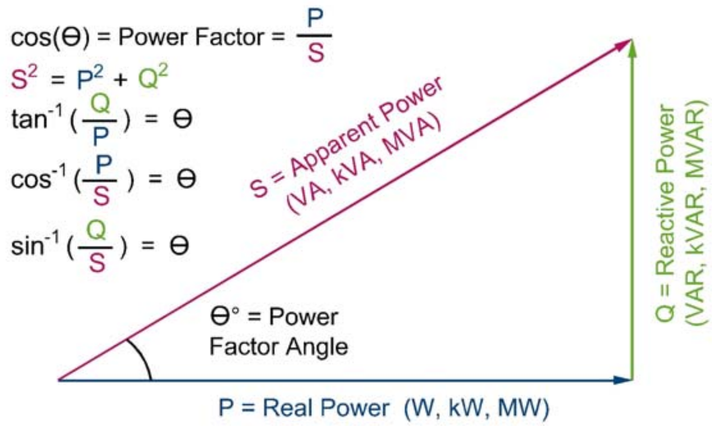

Figure 38: Power factor triangle

The second diagram shows the power factor triangle with leading and lagging power factors. It also includes the inductor and capacitor effect.

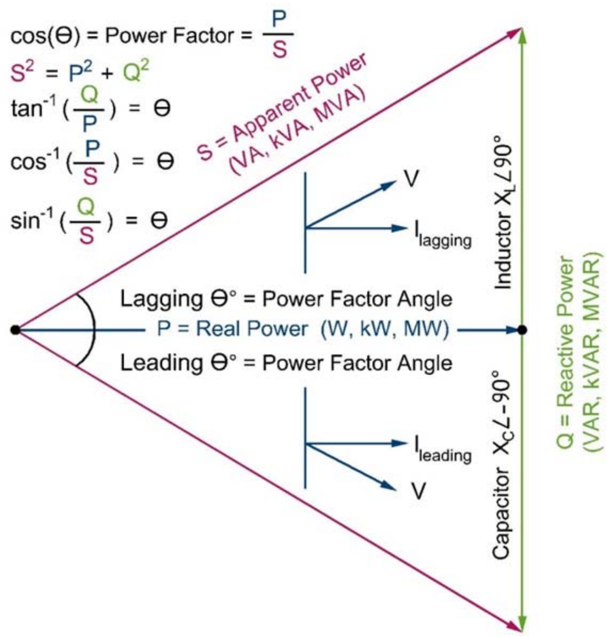

Figure 39: Power factor

4.2 POSITIVE, NEGATIVE AND ZERO COMPONENTS

The premise of the symmetrical components technique is that any unbalanced load can be expressed as a set of three balanced components called, (1) Positive-sequence, (2) Negative-sequence and (3) Zero-sequence. The following figure shows an unbalanced load that has different magnitude phasors and phasors that are not 120 degrees apart.

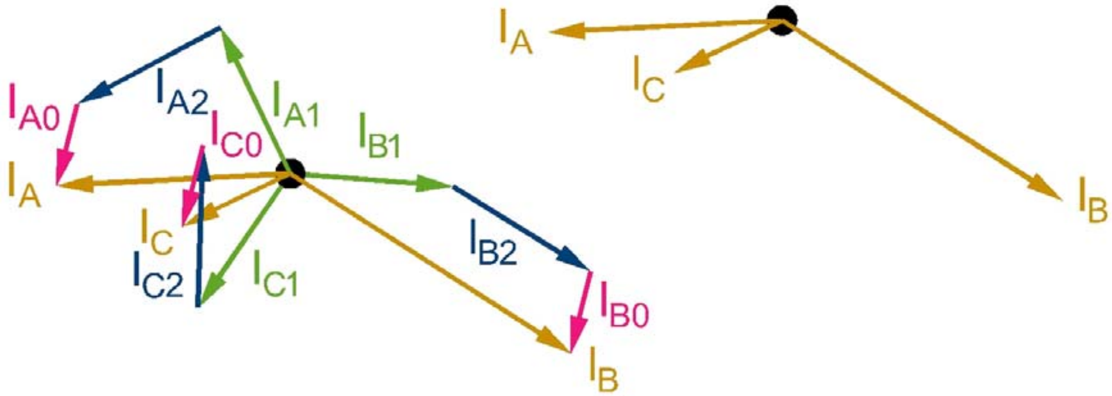

Figure 40: An unbalanced load can be broken down into three sets of symmetrical components. The right figure is the unbalanced load. The left are the symmetrical components that can create the unbalanced load.

The figure above reconstructs the unbalanced load with three sets of symmetrical components. The individual sets of components can be seen below for clarity.

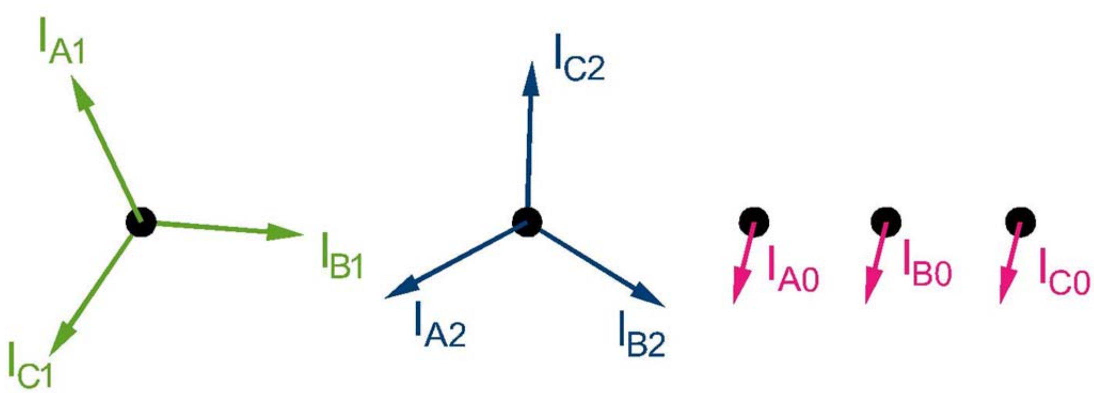

Figure 41: These phasors show the positive, negative and zero components, from left to right, that were used to construct the unbalanced loads.

The positive-sequence components are symmetrical and have the same magnitudes and are 120 degrees apart from one another. The sequence of the components is also in the same order as the original unbalanced load (clockwise: A-B-C). The negative sequence components are a different magnitude from the positive sequence, but each negative sequence component is the same magnitude. In addition, the negative sequence is arranged in an opposite sequence from the positive sequence (counterclockwise: A-B-C). In addition, the negative sequence is at a different starting angle from the positive sequence. Finally, the zero sequence consists of equal magnitude and phase angle phasors.

As you can see, each phase is equal to the sum of each phase's positive, negative and zero sequences. These equations are shown in terms of current (I) but they are also the same for voltage (V) and impedance (Z).

$$I_A = I_{A1} + I_{A2} + I_{A0}$$

$$I_B = I_{B1} + I_{B2} + I_{B0}$$

$$I_C = I_{C1} + I_{C2} + I_{C0}$$

Another important set of equations is the opposite version, where the symmetrical components are in terms of the phase components.

The zero component is equal to 1/3 the sum of the phase components.

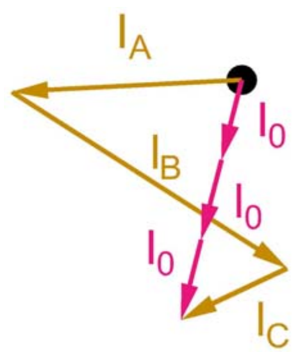

Figure 42: The zero-component is equal to the sum of the phase components divided by 3.

$$I_{A0} = I_{B0} = I_{C0} = \frac{I_A + I_B + I_C}{3}$$

The "A" positive sequence component is equal to the sum of the phase A component, the B component rotated 120 degrees and the C component rotated 240 degrees, all divided by 3.

$$I_{A1} = \frac{I_A + aI_B + a^2 I_C}{3}$$

$$where\ a = 1\angle 120°\ and\ a = 1\angle 240°$$

The three-phase, half-wave rectifier and full-wave rectifier RMS values are much more difficult to calculate and outside the scope of this book. These values will be provided to you.

Three-Phase, Full-Wave Rectifier

$$Three\ Phase\ Full\ Wave\ Rectifier \rightarrow V_{rms} = 0.96 * V_{max}$$

$$Three\ Phase\ Full\ Wave\ Rectifier \rightarrow V_{avg} = \left(\frac{3}{\pi}\right) * V_{max}$$

$$Ripple\ Factor = 10\%$$

Three-Phase, Half-Wave Rectifier

$$Three\ Phase\ Half\ Wave\ Rectifier \rightarrow V_{rms} = 0.838 * V_{max}$$

$$Three\ Phase\ Half\ Wave\ Rectifier \rightarrow V_{avg} = 0.827 * V_{max}$$

$$Ripple\ Factor = 17\%$$

4.2.4 Full-Wave Rectifier with Capacitor

In order to address the DC bus ripple, capacitors are installed to smooth the waveforms into a more consistent value.

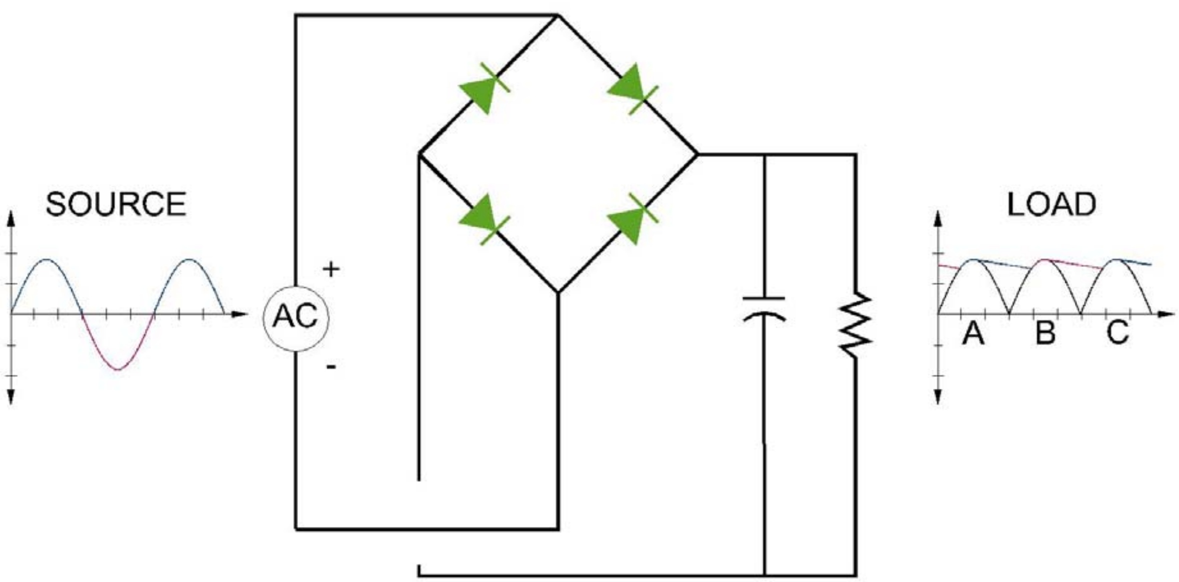

Figure 17: A full-wave rectifier with a smoothing capacitor.

A capacitor can greatly reduce the ripple factor. A capacitor can reduce the ripple factor down to 5 percent for a three-phase, full-wave rectifier.