

Three-Phase Transformer Configurations

EXERCISE OBJECTIVE When you have completed this exercise, you will know how to connect three-phase transformer banks in wye-wye, delta-delta, wye-delta, and delta-wye configurations. You will determine what are the voltage, current, and phase relationships between the primary windings and the secondary windings of a three-phase transformer bank for each of these configurations. You will be familiar with the different uses of three-phase transformer banks in three-phase ac power circuits.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Common three-phase transformer configurations
- Voltage, current, and phase relationships of the four common three-phase transformer configurations
- Summary of the characteristics of the four common three-phase transformer configurations
- Uses of three-phase transformer banks

DISCUSSION

Common three-phase transformer configurations

Many **three-phase transformer configurations** are possible when connecting the primary and secondary windings of a three-phase transformer bank. Each configuration presents different characteristics. When connecting a three-phase transformer bank in a circuit, it is therefore important to determine which characteristics are advantageous to the circuit, and to choose the appropriate three-phase transformer configuration accordingly.

The four most common three-phase transformer configurations are wye-wye, delta-delta, wye-delta, and delta-wye configurations. Each of these configurations is shown in Figure 3. The letter (A, B, or C) beside each winding in Figure 3 identifies one of the transformers in a three-phase transformer bank. This allows the primary and secondary windings of each transformer in the three-phase transformer bank to be easily located in the diagrams of Figure 3.

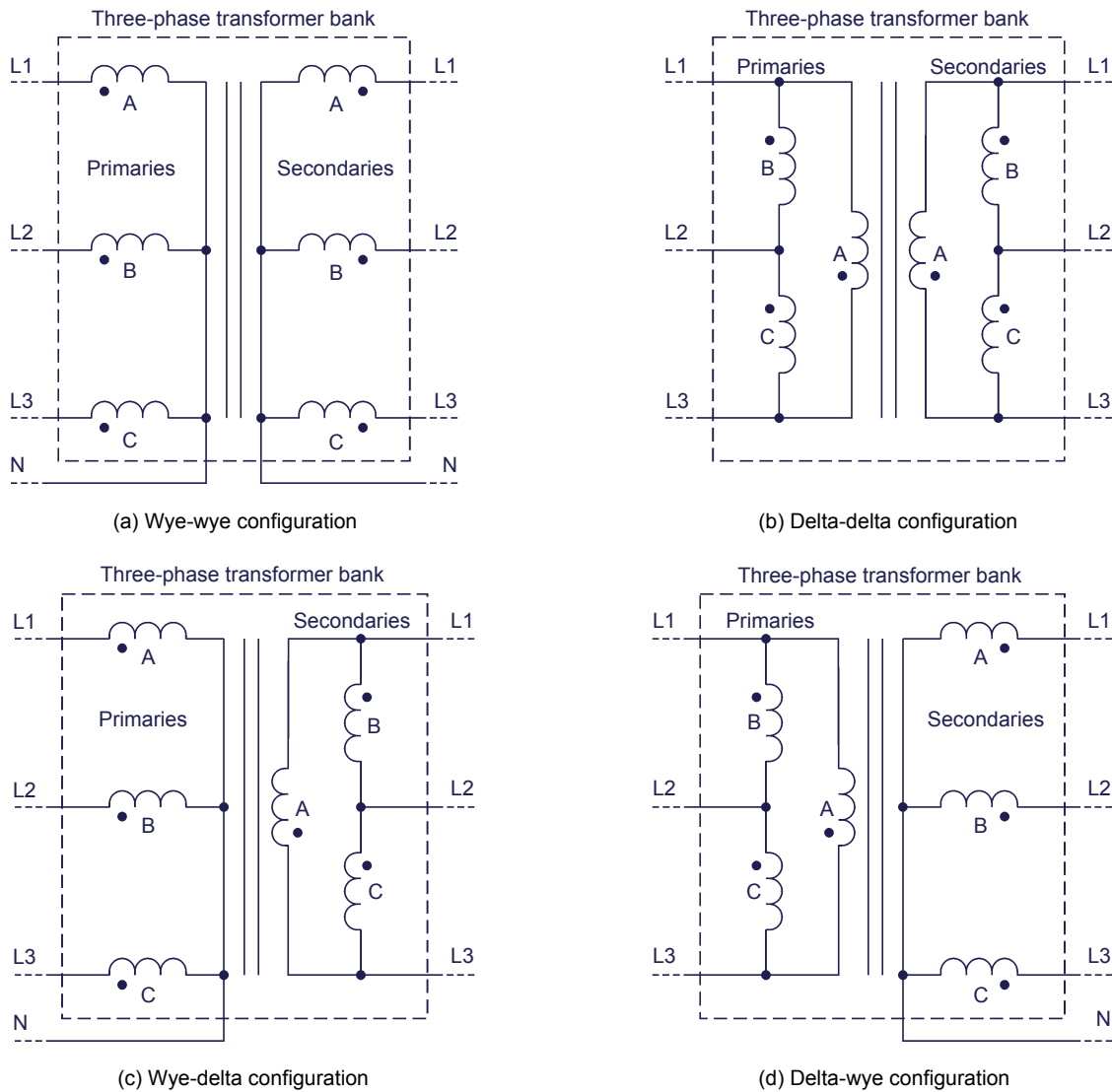


Figure 3. The four most common three-phase transformer configurations.

As you can see from the figure, wye-connected windings use 4 wires, while delta-connected windings use only 3 wires. When setting up a three-phase transformer bank in a wye-delta or delta-wye configuration, this property allows the number of wires in a three-phase ac circuit to be modified from 4 wires to 3 wires, or from 3 wires to 4 wires, respectively. Either of these configurations can be a significant advantage, depending on the requirements of the particular application in which it is used.

Voltage, current, and phase relationships of the four common three-phase transformer configurations

The most determining characteristics of each three-phase transformer configuration mentioned in the previous section (i.e., the wye-wye, delta-delta, wye-delta, and delta-wye configurations) are their respective voltage, current, and phase relationships between the primary windings and the secondary

windings. The following three sections discuss these relationships for each three-phase transformer configuration. Note that, as wye-wye and delta-delta configurations have similar voltage, current, and phase relationships, both configurations are covered in the same section. Also note that, in the following sections, the turns ratio of each transformer in the three-phase transformer bank is assumed to be equal to 1:1. This allows observation of the effects each configuration has on the voltage, current, and phase relationships of the three-phase transformer bank, independently of the turns ratio.

Wye-wye and delta-delta configurations

When a three-phase transformer bank is connected in either a wye-wye or a delta-delta configuration, the voltage, current, and phase relationships between the primary windings and the secondary windings are identical to the relationships found in a conventional single-phase power transformer. This means that the values of the line voltages and currents at the secondary are equal to those of the line voltages and currents at the primary (neglecting transformer losses). Also, the line voltage sine waves at the secondary are in phase with the line voltage sine waves at the primary. The same is true for the line current sine waves at the secondary with respect to the line current sine waves at the primary.

Wye-delta configuration

When a three-phase transformer bank is connected in a wye-delta configuration, the values and phases of the line voltages and currents at the secondary are different from those at the primary. Thus, in a wye-delta configuration, the value of the line voltages at the secondary is equal to that of the line voltages at the primary divided by $\sqrt{3}$. Conversely, the value of the line currents at the secondary is equal to that of the line currents at the primary multiplied by $\sqrt{3}$. Furthermore, the line voltage sine waves at the secondary lag behind those at the primary by 30° . The same is true for the line current sine waves at the secondary with respect to the line current sine waves at the primary.

Delta-wye configuration

When a three-phase transformer bank is connected in a delta-wye configuration, the values and phases of the line voltages and currents at the secondary are different from those at the primary. Thus, in a delta-wye configuration, the value of the line voltages at the secondary is equal to that of the line voltages at the primary multiplied by $\sqrt{3}$. Conversely, the value of the line currents at the secondary is equal to that of the line currents at the primary divided by $\sqrt{3}$. Furthermore, the line voltage sine waves at the secondary lead those at the primary by 30° . The same is true for the line current sine waves at the secondary with respect to the line current sine waves at the primary.

Summary of the characteristics of the four common three-phase transformer configurations

The following table gives a summary of the different characteristics of the four three-phase transformer configurations presented in the previous section (i.e., the wye-wye, delta-delta, wye-delta, and delta-wye configurations).

Table 1. Summary of the characteristics of three-phase transformer configurations.

Three-phase transformer configuration	Line voltage relationship ($E_{Pri.}:E_{Sec.}$)	Line current relationship ($I_{Pri.}:I_{Sec.}$)	Phase shift (Sec. with respect to Pri.)	Number of wires (Pri.:Sec.)
<p>Wye-wye configuration</p>	1: 1	1: 1	0°	4: 4
<p>Delta-delta configuration</p>	1: 1	1: 1	0°	3: 3
<p>Wye-delta configuration</p>	$\sqrt{3}: 1$	$1:\sqrt{3}$	-30° (30° lag)	4: 3
<p>Delta-wye configuration</p>	$1:\sqrt{3}$	$\sqrt{3}: 1$	30° (30° lead)	3: 4

Remember that the line voltage and current relationships presented in Table 1 are valid only when the turns ratio of the transformers in the three-phase transformer bank is equal to 1:1. When the turns ratio of the transformers in the three-phase transformer bank is not 1:1, the actual line voltages at the secondary can be found by multiplying the primary line voltages by the voltage ratio appropriate to the configuration of the three-phase transformer bank and the inverse of the turns ratio ($N_{Sec.}/N_{Pri.}$) of the transformers. Similarly, the actual line currents at the secondary can be found by multiplying the primary line currents

by the current ratio appropriate to the configuration of the three-phase transformer bank and the turns ratio ($N_{Pri.}/N_{Sec.}$) of the transformers.

Uses of three-phase transformer banks

Three-phase transformer banks are used in three-phase ac power circuits for basically the same reasons as single-phase power transformers in single-phase ac circuits, i.e., to step-up or step-down the voltages in the circuit and to provide electrical isolation between the primary windings and the secondary windings. However, the special properties of certain three-phase transformer configurations presented in the previous sections allow three-phase transformer banks to be used in a few additional applications. The primary uses of three-phase transformer banks in three-phase ac power circuits are summarized below.

1. Three-phase transformer banks allow the voltages in the three-phase ac power circuit to be stepped-up (i.e., to be increased) or stepped-down (i.e., to be decreased).
2. Three-phase transformer banks provide electrical isolation between the primary windings and the secondary windings.
3. Three-phase transformer banks connected in a wye-delta or in a delta-wye configuration allow the number of wires in the three-phase ac power circuit to be decreased from 4 to 3, or increased from 3 to 4, respectively.
4. Three-phase transformer banks connected in a wye-delta or in a delta-wye configuration allow the incoming line voltages and currents to be phase shifted -30° or 30° , respectively.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and connections
- Voltage, current, and phase relationships in a wye-wye configuration
- Voltage, current, and phase relationships in a wye-delta configuration
- Voltage, current, and phase relationships in a delta-delta configuration
- Voltage, current, and phase relationships in a delta-wye configuration

PROCEDURE

WARNING



High voltages are present in this laboratory exercise. Do not make or modify any banana jack connections with the power on unless otherwise specified.

Set up and connections

In this section, you will set up a circuit containing a three-phase transformer bank connected in a wye-wye configuration. You will then set the measuring equipment required to study the voltage, current, and phase relationships of the three-phase transformer bank.