Three-Phase Voltages and Transformer Connections
Prerequisites:

- None

Objectives: Given the Construction Standards Manual, a system voltage and a customer voltage, you will be able to select and connect transformers.

Rationale: One of the most common connections line trade personnel are responsible for is the three-phase transformer bank. This module will enable you to build, maintain and troubleshoot transformer banks to provide a standard voltage to the customer.

Learning Objectives

- Explain system voltage configurations and line/coil values.
- Explain service voltage configurations and line/coil values.
- Describe the guidelines for connecting a closed transformer bank.
- Select and connect three transformers to provide single-phase and three-phase service voltage.
- Describe the guidelines for connecting an open transformer bank.
- Select and connect two transformers to build an open transformer bank.
- Describe the guidelines for paralleling three-phase banks.

Learning Methods

- Self-learning + On-the-job
- Self-learning + On-the-job
- Self-learning + On-the-job
- On-the-Job Demonstration and Practice
- Self-learning + On-the-job
- On-the-Job Demonstration and Practice
- Self-learning + On-the-job

EVALUATION METHODS

- Written test
- Written test
• Written test
• On-the-Job Evaluation
• Written test
• On-the-Job Evaluation
• Written test

STUDENT RESOURCES

• Construction Standards Manual

Learning Steps

1. Read the Learning Guide.
2. Follow the steps outlined in the Learning Guide.
3. Clarify any questions or concerns you may have.
4. Complete the Practice and Feedback.
5. Complete the Evaluation.
Lesson 1: System Voltage

Learning Objective: Explain system voltage configurations and line/coil values.

Learning Method: Self-learning + On-the-job

Evaluation Method: Written test

Introduction

An electrical system delivers power to customers in a variety of configurations. It is beneficial to study and understand these three-phase configurations, allowing us to perform the necessary construction and maintenance procedures associated with each.

Main line utilities offer the following common supply line voltages for distribution three-phase transformers:

- 2400V
- 4160V
- 14,400V
- 25,000V
Lesson 2: Service Voltage

Learning Objective: Explain service voltage configurations and line/coil values.
Learning Method: Self-learning + On-the-job
Evaluation Method: Written test

Introduction

The service voltages offered in 4-wire systems include:

- 120/208 Y GRD wye 4-wire
- 277/480 Y GRD wye 4-wire
- 347/600 Y GRD wye 4-wire
- 2400/4160 Y GRD wye 4-wire

The service voltages offered in 3-wire systems include:

- 240 delta 3-wire
- 480 delta 3-wire
- 600 delta 3-wire

The supply and service voltages for distribution three-phase transformer banks may be any combination of the above.
Lesson 3: Connecting a Closed Transformer Bank

Learning Objective: Describe the guidelines for connecting a closed transformer bank.

Learning Method: Self-learning + On-the-job

Evaluation Method: Written test

Introduction

There are three main procedures to follow when constructing a three-phase transformer bank.

First, ensure the correct transformers are chosen in order to utilize them effectively in the three-phase bank.

- The transformer should have double bushing primaries to make the primary connection easier, regardless of configuration.
- The transformer’s impedance must be within 7.5% of one another.
- Each transformer must have the same primary and secondary voltage ratings.
- If a tap changer is on the transformer, ensure the correct tap setting has been chosen.
- Be mindful of the polarity of each transformer. If possible, select three transformers with the same polarity to avoid confusion when connecting and maintaining the transformer bank.
- The secondary straps inside the tank must be terminated to provide the required secondary coil voltage rating.
- Remove the neutral straps from each transformer, if necessary.
- The transformers must provide the desired capacity (i.e. the three-phase capacity of a closed transformer bank is three times the smallest transformer).
- Choose the correct fuse size from the fusing charts in the Construction Standards Manual. Ensure you have the required arrestors, cutouts and secondary riser size.

Secondly, the transformer bank connections must be standard. Refer to and follow the Constructions Standards Manual carefully.

- Ensure the transformers are systematically connected to the supply line wires
• The primary rated coil voltage is the voltage that must be impressed on the primary coils to ensure the rated secondary voltage is delivered. (For example, if the supply line is 25kV and the transformers chosen have a primary rated coil voltage of 25kV, the transformers must be connected to the supply line wires in delta to ensure the applied voltage is 25kV across each of the primary coils. If 14.4kV primary rated coil transformers are chosen, the primary connections must be done in wye to ensure 14.4kV is applied to the primary coils.)

• Connect the secondary bushings correctly to ensure the proper service voltage.

• The case of each transformer and arrestor must be securely grounded.

• The midpoint of the secondary coil on the lighting transformer must be grounded to provide the correct single-phase voltage, if required.

Lastly, energize the transformer bank to conduct the final checks before the customer load is connected.

• Disconnect the bank from any load sources.

• Check the closure voltage if the bank has a delta connected secondary. Apply a voltmeter across the final open X3-X1 connection. The reading should be zero volts. If the primary is wye connected, the star point should be temporarily grounded while performing this check.

• Perform a voltage check to ensure the service voltage is correct.

• Perform a phase rotation check to verify the correct phase sequence (R, Y, B).

• In the case of a 4-wire delta connected secondary, the phase not connected to the lighting load transformer is referred to as the bastard phase or unwanted single-phase power. It is colour coded as the red phase. As far as we are concerned, it provides non-useable single-phase power. In the 120/240 4-wire delta three-phase transformer bank, the bastard phase is measured at 208 volts (120V x 1.73).

Example: A new business needs power to supply a lighting load, as well as supply their 208 volt three-phase motors. What are the possible connections for the supply and service voltages?

The future site of the business is in close proximity to a three-phase 25kV distribution line. The supply voltage, therefore, will be 25kV and the service voltage will be 120/208V three-phase. The capacity of the bank is agreed to be 75kVA.
On page A-08-00, Sheet 7 of 27, we find the following table for three-phase transformer bank configurations:

<table>
<thead>
<tr>
<th>TYPE OF SERVICE</th>
<th>25,000 VOLT WYE SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>* 120/240</td>
<td>OPEN GRD WYE</td>
</tr>
<tr>
<td>OR</td>
<td>OPEN GRD DELTA</td>
</tr>
<tr>
<td>* 240</td>
<td>WYE - USE DOUBLE BUSHING TRANSFORMERS</td>
</tr>
<tr>
<td>(GRD NOT USED ON SECONDARY)</td>
<td>GRD DELTA - ***</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>120/208 Y GRD WYE</th>
<th>4 WIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>277/480 Y GRD WYE</td>
<td>4 WIRE</td>
</tr>
<tr>
<td>347/600 Y GRD WYE</td>
<td>4 WIRE</td>
</tr>
<tr>
<td>* 2400/4160 Y GRD WYE</td>
<td>4 WIRE</td>
</tr>
<tr>
<td></td>
<td>GRD WYE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>277/480 Y HIGH RESISTANCE GRD WYE</th>
<th>3 WIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>347/600 Y HIGH RESISTANCE GRD WYE</td>
<td>3 WIRE</td>
</tr>
<tr>
<td>Xₐ NOT GROUNDED - GROUND THRU CUSTOMER RESISTOR</td>
<td>DELTA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>240 DELTA</th>
<th>3 WIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>480 DELTA OR WYE</td>
<td>3 WIRE</td>
</tr>
<tr>
<td>600 DELTA OR WYE</td>
<td>3 WIRE</td>
</tr>
<tr>
<td>1080 DELTA (OILFIELD)</td>
<td>3 WIRE</td>
</tr>
<tr>
<td>2400 DELTA</td>
<td>3 WIRE</td>
</tr>
<tr>
<td>WYE - USE DOUBLE BUSHING TRANSFORMERS</td>
<td>DELTA</td>
</tr>
</tbody>
</table>

* NOT RECOMMENDED FOR NEW CUSTOMERS
** TO LIMIT TELEPHONE INTERFERANCE BANK SIZE SHOULD BE RESTRICTED TO 75 kVA.
*** DO NOT INSTALL ARRESTORS. REMOVE ARRESTORS BEFORE RE-ENERGIZING.
In the top right hand corner of the table, the line supply voltage indicated is 25,000 volts.

The secondary voltage (120/208 volts) is located in the second box down on the left hand side. 120/208 Y GRD wye 4-wire states that the three-phase service voltage needed must be connected in wye, with the star point grounded. This connection provides 120 volt single-phase to ground, as well as 208 volts three-phase, phase to phase.

To the right of this box in the table are two possible service and supply voltage connections:

In the first box are two asterisks, which denote the transformer bank must be no greater than 75kVA to limit telephone interference. The second box has no such restrictions.

As decided in the example discussed previously, a 75kVA transformer bank is to be built; therefore, either configuration above is acceptable.

On Page A-08-00, Sheet 11 of 27, we find the following diagram:
The above diagram illustrates the connections to the supply and service...
Studying this section of the Construction Standards Manual is very beneficial in regards to the maintenance and construction procedures that you, as a lineman, are required to perform.

Although some of the supply voltages (line voltages of 14,400V and 2400V) are not used often, they must still be understood. At some point, maintenance procedures will have to be performed on these transformer banks.

**Floating Star Point (Y)**

In some instances, a floating star point connection may be required. This means the common ends of a star connection is not grounded or floating. The vectoral pull of each phase maintains a 120 degree separation between phases. If one transformer burns out with this connection, the 120 degree separation between phases is lost and low voltage will result. The benefit of this connection is a customer will call in a low voltage complaint before the other two transformers burn out from overload.
Lesson 4: Providing Single and Three-Phase Voltages

Learning Objective: Select and connect three transformers to provide single-phase and three-phase service voltage.

Learning Method: On-the-Job Demonstration and Practice

Evaluation Method: On-the-Job Evaluation
Skills Practice

1. **Select and connect three transformers:**

   1. Determine the desired secondary voltage requirements.
   2. Select three transformers with primary and secondary coil requirements as per the primary and secondary line values desired.
   3. Connect the transformer case grounds.
   4. Connect the primary coils to the primary line (in accordance with the Construction Standards Manual, Section A-08).
   5. Connect the secondary coils to the secondary line (in accordance with the Construction Standards Manual, Section A-08).
   6. Energize the transformer bank.
   7. Perform a voltage and rotation check.
   8. Identify the phases (bastard leg, etc.)
   9. Connect the customer.
Lesson 5: Describe an Open Transformer Bank

Learning Objective: Describe the guidelines for connecting an open transformer bank.

Learning Method: Self-learning + On-the-job

Evaluation Method: Written test

Introduction

---Note---

An open three-phase transformer bank can only deliver a delta configured secondary. It differs from a closed three-phase bank in that it only employs two transformers.

An open three-phase transformer bank may be utilized for emergency maintenance procedures, power for small three-phase loads and large lighting loads. Whatever the reason, certain guidelines must be followed when using these connections.

• The capacity of an open bank is reduced to 86% of two times the smallest transformer.
• When building an open bank requiring a wye connected primary, the star point must be grounded.
• A closure voltage check is not applicable to open delta secondary banks.

Single-Phase and Three-Phase Service Voltage

A customer requires a transformer bank to supply 20kVA three-phase 240 volt power and 20kVA single-phase 120 volt power.

After meeting with the utility, it is decided that, due to the small three-phase load, an open bank requiring two transformers will be built. The following job order was issued to the line crew.
The supply line voltage is 25kV and the service voltage is 120/240V 4-wire.

Once again, refer to the Construction Standards Manual, Page A-08-00, Sheet 7 of 27, and find the 25kV configurations (refer to the configuration page discussed previously in this module).

On the left hand side, the first service voltage is 120/240V 4-wire. Across from the service voltage is the supply and service voltage configurations (illustrated below).

Since we are only utilizing a 37.5 kVA transformer and a 15kVA transformer, we must build the top diagram of the open bank configuration.

On Page A-08-00, Sheet 14 of 27, we find the transformer connection schematic for the open wye-open delta (three-phase 4-wire) configuration.
1. The reference phase is 208 V to ground.
2. When using transformers with 4 secondary bushings, jumper X2 and X3, and X4 is connected as X3 shown above.
3. Transformers shown have additive polarity.
Lesson 6: Connecting an Open Transformer Bank

*Learning Objective:* Select and connect two transformers to build an open transformer bank.

*Learning Method:* On-the-Job Demonstration and Practice

*Evaluation Method:* On-the-Job Evaluation
Skills Practice

1. Select and connect two transformers.

   1. Determine the primary voltage and desired secondary voltage requirements.

   2. Select two transformers with primary and secondary coil requirements as per the primary and secondary line values desired.

   3. Connect the transformer case grounds.

   4. Connect the primary coils to the primary line (in accordance with the Construction Standards Manual, Section A-08)

   5. Connect the secondary coils to the secondary line (in accordance with the Construction Standards Manual, Section A-08)

   6. Energize the transformer bank.

   7. Perform a voltage and rotation check.

   8. Identify the phases (bastard leg, etc.)

   9. Connect the customer.
Lesson 7: Precautions When Paralleling Three-Phase Banks

Learning Objective: Describe the guidelines for paralleling three-phase banks.
Learning Method: Self-learning + On-the-job
Evaluation Method: Written test

Introduction

To parallel three-phase transformers and transformer banks successfully, the same criteria as single-phase transformer paralleling must be met.

Reference

For further information, refer to the Paralleling Transformers module.

In addition, the angular displacement of the banks must be the same. For example, if the voltage ratings, polarities and sources are the same, and impedances are within 7.5% of each other, a delta-delta bank can be paralleled with another delta-delta bank or wye-wye bank. It cannot be paralleled with either delta-wye or wye-delta banks because they have 30 degree angular displacements.
CAUTION

The requirements for identical angular displacement must be met when paralleling a three-phase transformer and three-phase transformer bank made up of three single-phase units, or when paralleling two banks, both made up of three single-phase units.
Summary

To summarize this module, you have learned:

- System and service voltage configurations.
- How to select and connect two or three transformers for single-phase and three-phase service.

Practice Feedback

Review the lesson, ask any questions and complete the self-test.

Evaluation

When you are ready, complete the final test. You are expected to achieve 100%.
Review Questions

1. The supply line voltage that main line utilities do not commonly employ is:
   (a) 2400V.
   (b) 4600V.
   (c) 14,400V.
   (d) 25,000V.

2. The supply line voltage that main line utilities do not commonly employ is:
   (a) 2400V.
   (b) 4160V.
   (c) 14,400V.
   (d) 24,000V.

3. Which of the following is not a 3-wire service voltage?
   (a) 240V delta
   (b) 480V delta
   (c) 600V delta
   (d) 2400/4160 Y GRD wye

4. Which of the following is not a 4-wire service voltage?
   (a) 277/480 Y GRD wye
   (b) 120/240 open GRD delta
   (c) 240 GRD delta
   (d) 347/600 Y high resistance GRD wye

5. After a transformer is energized, which of the checks below is not done?
   (a) Check the closure voltage when the bank has a delta connected secondary.
   (b) Perform a voltage check.
   (c) Ensure the transformer is connected to the correct supply line wires.
   (d) Perform a phase rotation check.
6. The impedance of the transformers must be within:
   (a) 1.5% of each other.
   (b) 2.5% of each other.
   (c) 5.5% of each other.
   (d) 7.5% of each other.

T / F 7. Single bushing transformers are preferred when building three-phase banks.

8. The correct capacity (in kVA) of a closed three-phase transformer bank is:
   (a) Three times the smallest transformer.
   (b) Three times the smallest transformer multiplied by 86%.
   (c) The capacity of all the transformers added together.
   (d) Three times the smallest transformer multiplied by 58%.

T / F 9. Choosing a transformer with a tap setting not at neutral is not a concern when building a three-phase bank as the supply voltage is the same for all three transformers.

T / F 10. The transformers used in the same three-phase bank must have the same polarity.

11. The correct capacity (kVA) of an open three-phase transformer bank is:
    (a) Two times the smallest transformer.
    (b) Two times the largest transformer.
    (c) The capacity of the transformer added together.
    (d) Two times the smallest transformer multiplied by 86%.

T / F 12. Double bushing transformers are preferred when building three-phase banks.
13. A floating star point connection may be required in some instances. If one transformer burnt out with this connection, it would result in:

(a) Interrupted service.
(b) Low voltage.
(c) The 120 degrees separation between phases being lost.
(d) All of these.

14. After a transformer bank is energized, which of the checks below is not required.

(a) Ensure the transformer is connected to the correct supply line wires.
(b) Perform a phase rotation check.
(c) Check the closure voltage when the bank has a delta connected secondary.
(d) Perform a voltage check.

T / F 15. A closure voltage check is required for open delta banks.

T / F 16. An open three-phase bank differs from a closed three-phase bank in that it only utilizes two transformers.

17. The capacity of an open bank is:

(a) 86% of two times the smallest transformer.
(b) 58% of the two transformers.
(c) The capacity of the two transformers added together.
(d) None of these

18. After energizing an open three-phase transformer bank with no lead attached to it:

(a) A voltage check is unnecessary.
(b) A closure voltage check is unnecessary.
(c) A phase rotation check is unnecessary.
(d) None of these
T / F 19. To parallel three-phase transformers and transformer banks successfully, the same criteria as single-phase transformer paralleling must be met.

T / F 20. Angular displacement of the banks must be the same in order to parallel them.
Review Question Solutions

1. 4600V.

2. 24,000V.

3. 2400/4160 Y GRD wye

4. 347/600 Y high resistance GRD wye

5. Ensure the transformer is connected to the correct supply line wires.

6. 7.5% of each other.

7. F

8. Three times the smallest transformer.

9. F

10. F

11. Two times the smallest transformer multiplied by 86%.

12. T

13. All of these.

14. Ensure the transformer is connected to the correct supply line wires.

15. F

16. T

17. 86% of two times the smallest transformer.

18. A closure voltage check is unnecessary.

19. T

20. T