Three-Phase Power Systems

Course No: E04-038

Credit: 4 PDH

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THREE-PHASE POWER SYSTEMS

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INTRODUCTION

Most of the electrical energy used in the world is alternating current or AC. The value of alternating current fluctuates between a maximum positive value and a minimum negative value with a zero reference which is named neutral or ground. This current is a sinusoidal wave. When only a single sine wave is generated, the electrical current is referred as single-phase current.

The other type of electrical energy used is DC current. Its magnitude is fixed with zero or ground as refence. Typical values are 12V dc (car batteries) or other values (4.5V) used in electronic devices like computers, etc.

DC or direct current is used mostly in small devices. There are some uses for DC in very high voltage transmission line and in DC drives, which are DC motors driven by an electronic system that allows variations of the motor speed by changing the DC voltage input to the motor.

DC in High voltage transmission lines is used by electrical companies in 500 KV and above.

Most of the AC power used is three phase power. This energy is produced in large generators coupled to rotating turbines (steam, hydraulic, wind, etc.). See Figure 1 for a typical balanced three phase waveform set.

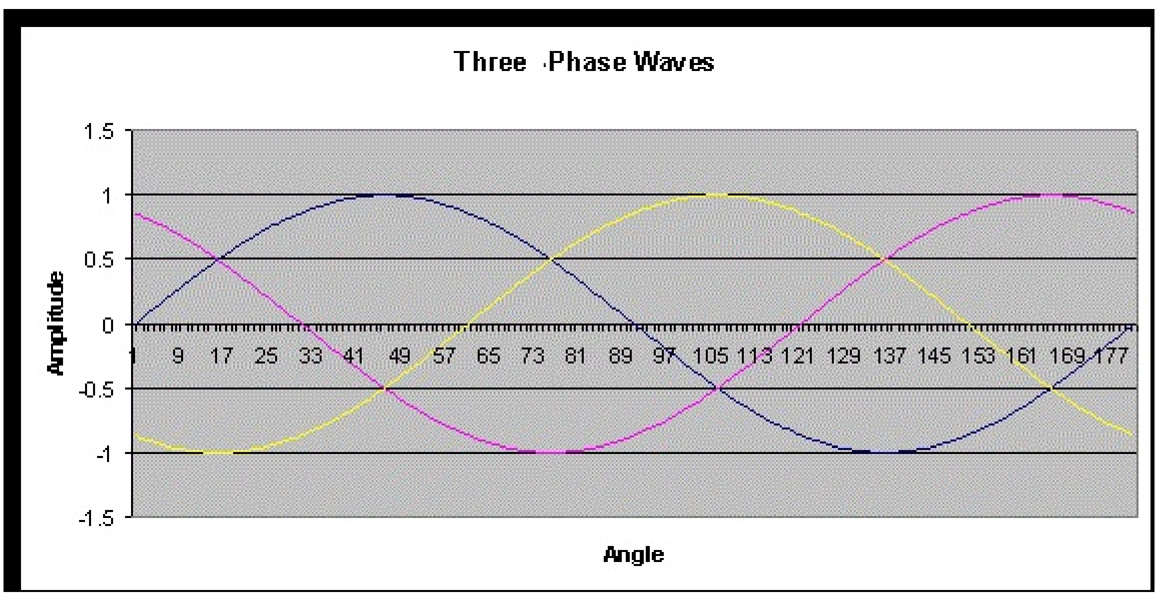

Figure 1

Three Phase alternating-current electrical energy is generated by three-phase generators and transmitted over three-phase circuit systems and wiring. We can see a three-phase circuit as three single-phase circuits consolidated into one circuit system with either three or four wires. Each one of the phases or waves generated can be separated using two wires only. Using these single waves, single-phase motors and other single-phase loads may be operated from a three-phase circuit. In industrial operation or whenever it is available, three phase circuits are preferable to use over single phase circuits. There are several reasons why three-phase is preferred to single-phase for service in so many applications. These reasons are as follows:

1. For specific horsepower or KVA rating, physical size of the three-phase motor or generator is smaller than that of the single-phase unit. The capacity of a three-phase generator or an induction motor is about 150% of that of a single- phase machine of comparable frame size.

2.

- For a single-phase system:
    - The power delivered by a single-phase circuit is pulsating. In Figure 2, sinusoidal wave patterns of voltage, current and power are shown for a resistance load. As the figure shows, the phase between the voltage and current is the same.
    - This means that the power factor of this system is unity (power factor is the cosine of the angle between voltage and current). At unity power factor, the power is zero twice each cycle.
- For a three-phase system:
    - The total power supplied to a balanced three-phase circuit is not a variable wave but is a constant value.
    - Adding the power for all phases together at any time, will create a constant value.
    - Mathematically, the above can be easily proven.
    - For balanced three phase circuit the addition at one point of all the three phase voltages or all currents at every instant adds to zero. See Figure 3.

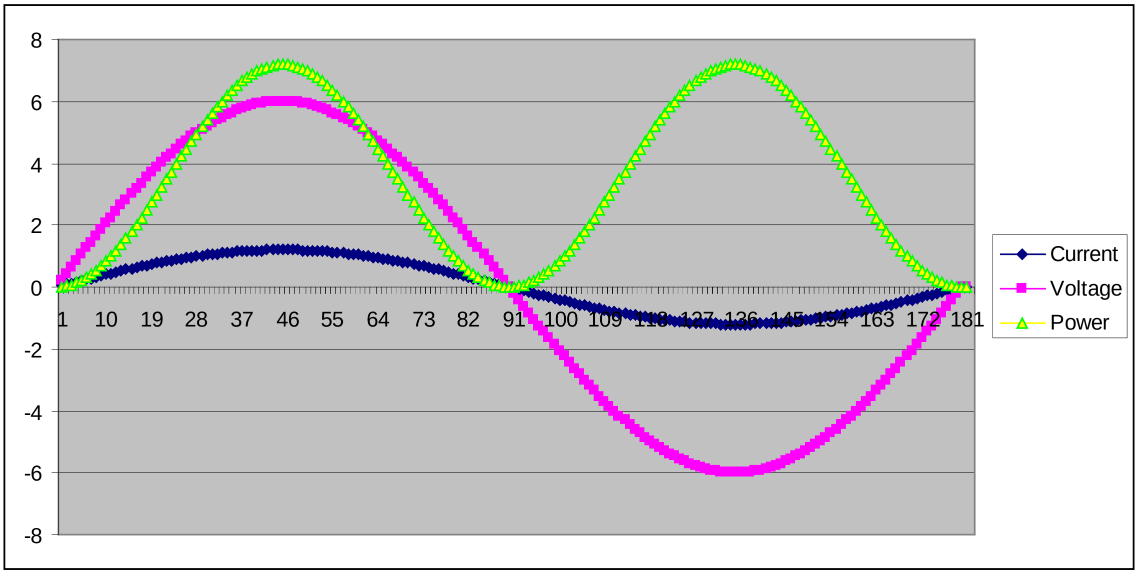

Figure 2

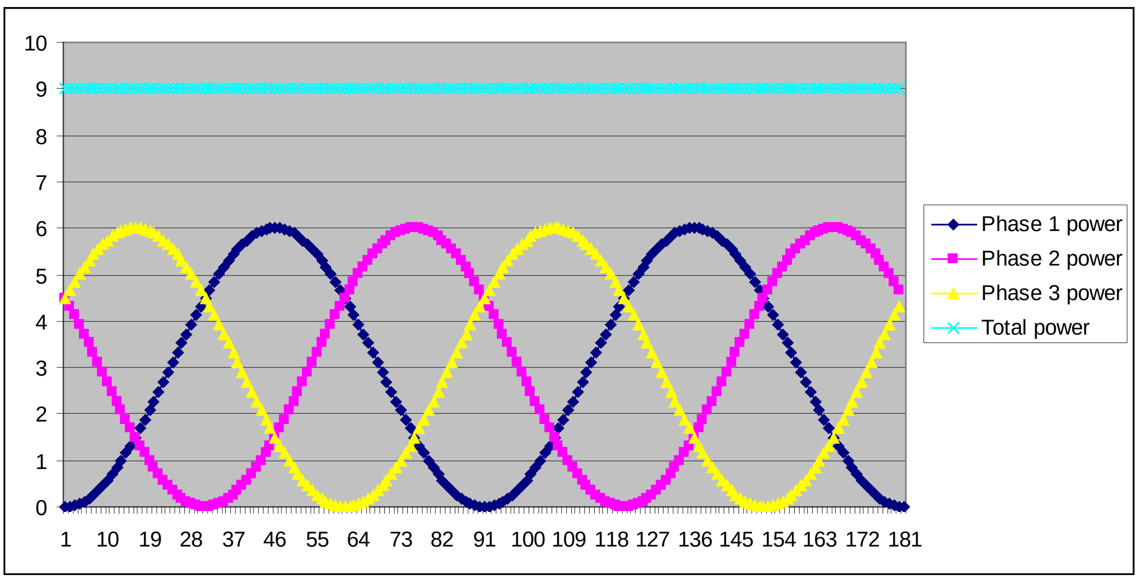

Figure 3

3. A balanced three-phase (with equal voltage between line wires) three-wire circuit uses only 75% of the copper required for a single-phase, two-wire circuit of the same kva, capacity, voltage rating, length of circuit, and efficiency of transmission.

THREE-PHASE VOLTAGE

A three-phase generator supplies a three-phase circuit with three separate voltages of the same frequency and magnitude but 120 electrical degrees apart. In Figure 4 an elementary a-c generator is shown with three conductors placed physically 120° apart.

Each small circle in the generator stator colored blue, yellow and red in Figure 4 represents a coil winding. The winding will wrap around the stator. Each circle has an opposite circle of the same color representing the same winding. The large outside circle in the figure represents the stator which is the non-moving component of the generator.

As the generator rotates, its stator windings will go through the magnetic field of the rotor and an electrical current will be generated in the coils of the stator windings. The induced voltages caused by this effect will be a three-phase voltage output produced by the a-c generator. The three voltages are 120 electrical degrees apart, following the physical separation of the windings. Each of the three windings wiring terminal is brought out connecting to three separate single phase. Two wire circuits are available to tap the generators produced current. The shown arrangement consists only of three single-phase circuits, with their individual voltages 120° apart. Each circuit is connected to one wire system.

Normally, generators have many coils for each winding system and their coil windings are interconnected with only three (or possibly four) conductors furnished to supply a three-phase circuit. Additionally, the rotor of the generator is not a physical magnet but an electromagnet created by copper windings wrapped around the rotor core and energized by an auxiliary circuit called the exciter. This type of generator is normally called a synchronous generator.

As indicated above, only two standard connections are used in three-phase work to feed systems used to connect single phase loads, such as motors, transformers, and other devices. The three phase connections can be made in several ways, as discussed in later sections of this course. The most common connections are the wye connection and the delta connection.

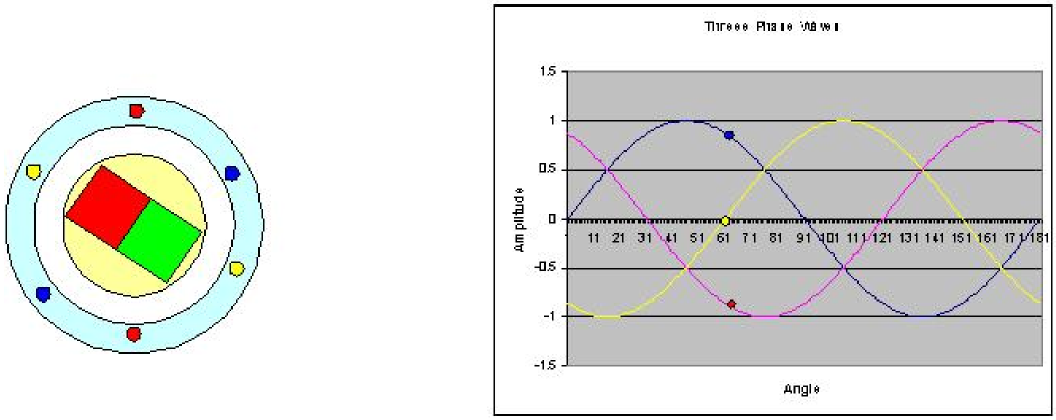

Figure 4

PHASE SEQUENCE

Conventions used here

Phase sequence is defined as the order in which the three generated electrical voltages or currents rotate, as indicated before; each voltage is separated from the next generated voltage by 120 degrees. We will assign subscript identification to the voltages as follows: Blue = B, Yellow = Y and Red = R. The reference or zero point is called O
The voltage generated in the blue winding is called V_B. The other voltages will then be V_Y and V_R. If we measure a voltage between the winding and neutral or zero level (ground), the Voltage will be designated as V_{BO} for voltage B, V_{YO} and V_{RO} for the other two. In the same manner, the voltage between B and Y is V_{BY}, between Y and R is V_{YR} and between R and B is V_{RB}

Analysis of phase sequence

To see the angle difference and sequence you can start with voltage V_{BO}. This voltage starts rising at zero degrees as shown in the sine wave. As voltage V_{BO} reaches 120 degrees, voltage V_{YO} starts rising from zero degrees, meaning that V_{BO} leads V_{YO} by 120 degrees. The same applies between the other two voltages. The sequence in our figure is BYR.
Understanding phase sequence is very important. For example, this is noted in one of the most important events when two generating systems are interconnected. Obviously, both systems must rotate in the same manner, just as if they were two gear boxes to be interconnected. In a gearbox, the gears would be destroyed by trying to connect them

when moving at different speed or sense of rotation. Electrically, phase differences in two interconnecting systems would produce short circuit conditions.
The importance of phase sequence is evident in rotating equipment. Specially, connecting rotating equipment, as in three phase motors. Motors need to rotate in the correct direction to properly move coupled rotating equipment. The rotation of the phases is the same as the rotation of the motor. Phasing of motors is executed before the motor is connected to the rotating equipment to have proper equipment functioning.

Determination of phase sequencing can be done in several ways. The most basic manner is to use an oscilloscope and look at the three wave forms checking the relative position of each with respect to the other. A more practical and simple way is to use a phase sequence indicator. The connection and sequence indication is shown in Figure 5. The phase that follows the capacitor in rotation is the one with the light on.

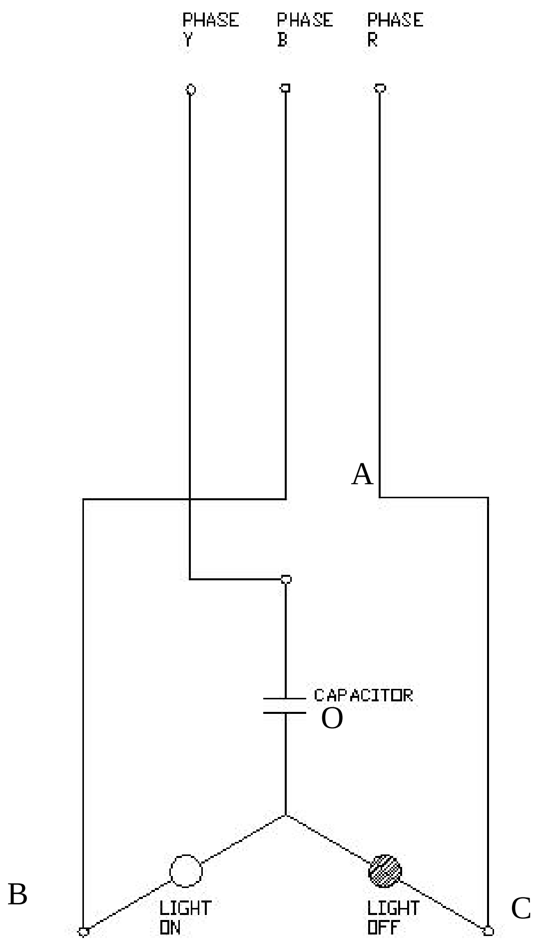

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Figure 5

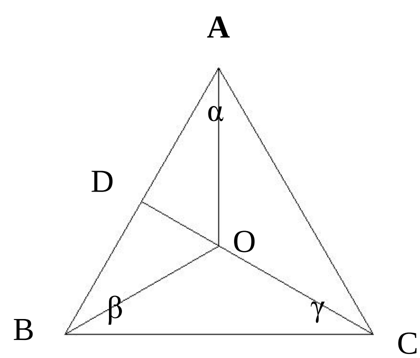
BASIC CONNECTIONS

Introduction

As indicated in a previous chapter, the most basic connections in a three-phase system are the delta and the wye connections; wye connections are also called star connections.
In a delta connection, there is no connected neutral and the three windings are connected as shown in Figure 8 and Figure 9.
Wye connections have one common connection point which is normally connected to the lowest potential point in the system, normally ground or zero reference voltage.

Wye and Delta Connections

The mathematical relationship of the voltages in a delta or wye connection can be resolved using trigonometric relations. See Figure 6 and Figure 7.



The center lines represent the voltage, all radiating from zero. The voltage of point A is V_{OA}. The voltage of point B is V_{OB}. The voltage of point C is $V_{OC.}$ Line AB represent the voltage between A and B. Line BC represents the voltage between B and C. Line CA represents the voltage between C and A.

Figure 6

With the above triangle of voltages, we can now find the equations that relate all these voltages for both wye and delta connections.

Definitions

The angle BAC is Alpha, the angle ABC is Beta, and the angle BCA is Gamma.
The angle BOA is 120 degrees because it is the phase difference between voltage V_{OA} and voltage V_{OB}. The same reasoning applies to angle BOC and COA both these angles are 120 degrees.

Currents in Delta systems

The first relationship that we want to find is the relationship between voltage between line to line and line to neutral.
We extend line CO to point D. This point divides segment AB in half because line CD is also bisector of angle gamma. Then we can write:

½ $I_{AB} = I_{BO} \cos 30$, $I_{AB} = 2\, I_{BO} \cos 30$
$\cos 30 = \sqrt{3}/2$
$I_{AB} = 2I_{BO} (\sqrt{3}/2)$
Simplifying
$\mathbf{I_{AB} = I_{BO} (\sqrt{3})}$ **Equation 1**
Or
$I_{PH} = \sqrt{3}\, I_L$
$\mathbf{I_L = I_{PH}/\sqrt{3}}$ **Equation 2**

Voltage between line to line is equal to 1.73 or 73% more than the voltage between line to neutral.

This can be written as

$I_{PH} = 1.73\, I_{LN}$ **Equation 3**

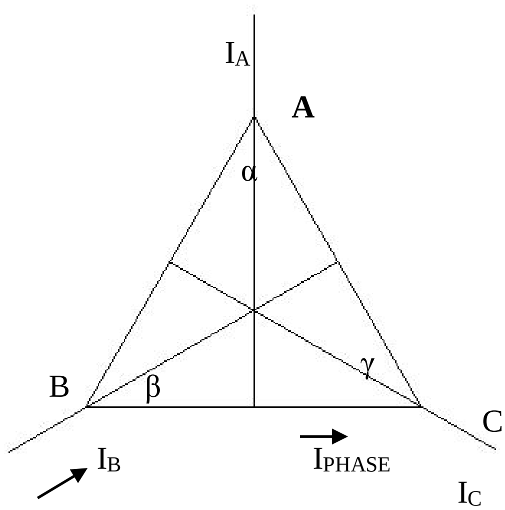


Figure 7

In any balanced wye system I_{line} or I_L is equal to I_{PHASE}. The sum of all the currents entering the neutral is zero.

$I_L = I_{PHASE}$ Same for I_A, I_B and I_C **Equation 4**

For a balanced Delta system

$I_L = I_{PHASE} \sqrt{3}$ **Equation 5**

Same relationships can be established for voltages.

- **$V_{PHASE} = V_{LINE}$** in a delta system
- **$V_{PHASE} = 1.73\ V_{LINE}$** In a wye system.

The Voltage V_{LINE} in a wye system is usually referred as the line to neutral voltage.

Wye to wye, wye to delta, delta to wye and delta to delta connections

1. Wye to wye

Figure 8 shows a typical connection between a wye supply and a wye connected resistive load. All the resistances in the load are equal and the supply is a 208 Volt Y connection. All the resistors are 10 ohms and represent resistive heater loads.

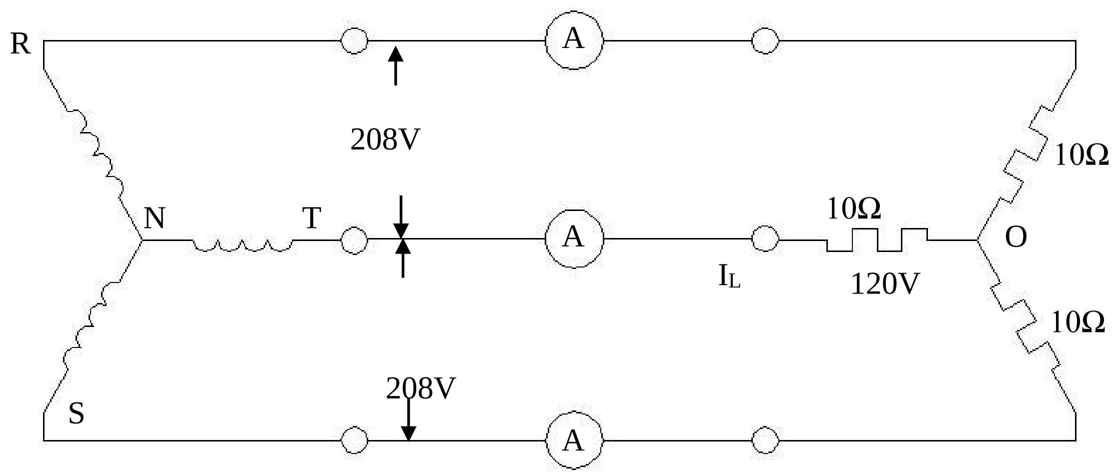


Figure 8

Let's calculate the voltage applied to the resistances.

$V_{PHASE} = 208V$,
$V_{LINE} = V_{PHASE}/\sqrt{3}$,
$V_{LINE} = 208/\sqrt{3}$ Volt,
$V_{LINE} = 120V$

The current going into the neutral of the supply is zero. You can prove it by applying Kirchhoff's current law, which indicates that the total current flowing into a node is zero. Since the loads are equal and the supply system is balanced, the currents across the resistors are equal.

The line current or I_L is

$I_L = V_L/R$, **Equation 6**

$I_L = 120/10 = 12$ A

The power at the one resistance will be

$P = I_L V_L = 12(120) = 1440$VA.

This load is resistive. There is no phase difference between the current and voltage, the VA value is in this case equal the to the value in watts.

The power dissipated by the resistor is also 1440 w

If the load was non-resistive, the power would be VL IL cos (θ) Where θ is the phase angle between the voltage and the current.

As you know from AC circuits, the value of the cosine of θ is called the power factor.

The power for the whole load is 3 times the power for one section, when the loads are balanced.

The total power for the whole load is the power taken by port AB + AC +BC.

The power for each of those is symmetrical thus the total power is three times the power for one.

Let's calculate the power for one section

$P = I_L V_{PH}$, $T_{otal\,=}$ $3 I_L V_{PH}$

$V_{PH} = V_L/\sqrt{3}$

$P = I_L V_L/\sqrt{3}$

$P_{Total} = 3 (I_L V_L/\sqrt{3})$

$P_{Total} = \sqrt{3} I_L V_L$ **Equation 7**

2. Delta to wye

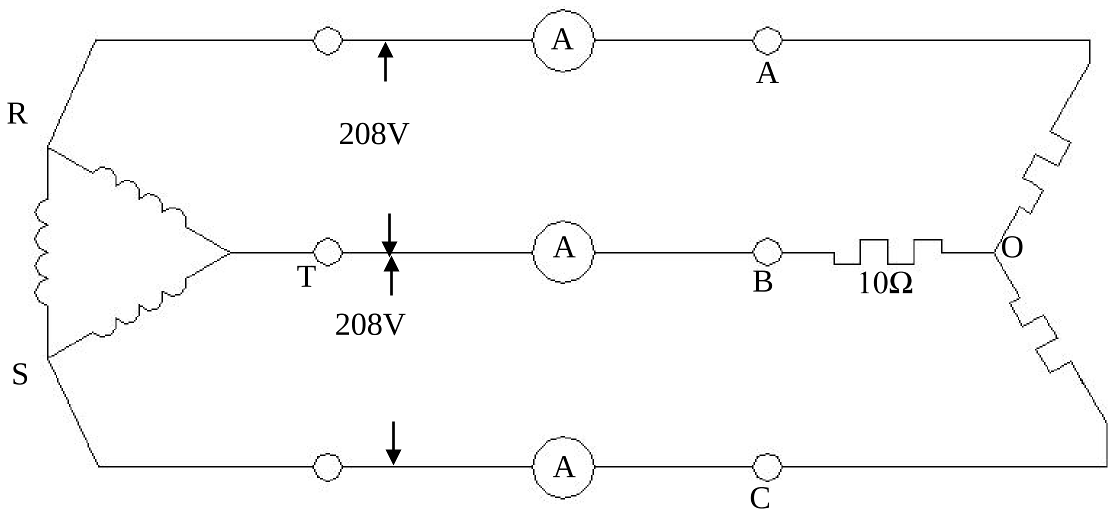


Figure 9
See Figure 9 above. In this case, the load current is equal to the line current.

The relation between the phase voltage and the load voltage can be found realizing that the load voltage is the line voltage which is:

V_{PHASE} = 208V,
$V_{LINE} = V_{PHASE}/\sqrt{3}$,
$V_{LINE} = 208/\sqrt{3}$ Volt,
V_{LINE} = 120V

Applying Ohm's law, we find the line current, just as in the case above:

$I_L = V_L/R$,
$I_L = 120/10 = 12$ A

Power calculations are identical to the above calculations:
The power for the whole load is 3 times the power for one section.
The total power for the whole load is the power taken by port AB + AC +BC.
The power for each of those is symmetrical thus the total power is three times the power for one.
$P_{Total} = 3\ I_L\ V_{PH}$
$P_{Total} = \sqrt{3}\ I_L\ V_L$
Or
$P_{Total} = (\sqrt{3})12(120) = 2494.15$ W

3. Delta to Delta
See Figure 10

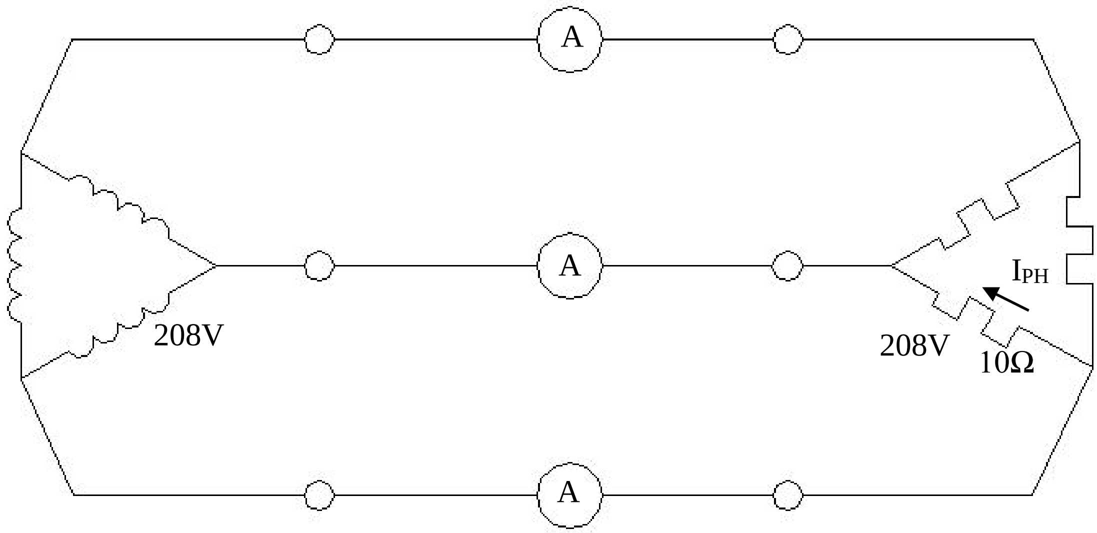


Figure 10

In this case the voltage across the resistor is three phase voltage and the load current is calculated as follows:

$I_{PH} = V_{PH}/R$
$I_{PH} = 208/10$ A
$I_{PH} = 20.8$ A

Let's calculate the power for one section
$P = I_{PH}\ V_{PH}$, $P_{Total} = 3\ I_{PH}\ V_{PH}$
$I_{PH} = I_L/\sqrt{3}$, $V_L = V_{PH}$
$P = (I_L/\sqrt{3})\ V_L$
$P_{TOTAL} = 3\ (I_L\ V_L/\sqrt{3})$
$P_{TOTAL} = \sqrt{3}\ I_L\ V_L$
$I_L = \sqrt{3}\ I_{PH} = 36$ A

We obtained the same result as that for the wye system.

If the system is not resistive, the current and voltage will be out of phase and the real or resistive value of the line current will be $I_L \cos(\theta)$.
The relation becomes:

$P_{TOTAL} = \sqrt{3}\ I_L\ V_L \cos(\theta) = 12{,}979.2$ VA or Watts in this case because we have a resistive load.
The same value can be obtained:
$P_{TOTAL} = 3\ I_{PH}\ V_{PH} \cos(\theta)$

Example

For a Delta-Delta configuration, the following parameters are measured:

The measurements obtained from the maintenance group are:

Input current to the load.

- Leg A = 20 A with an angle of 25°
- Leg B = 20 A with an angle of 25°
- Leg C = 20 A with an angle of 25°

Voltage:

- The system is a delta 480V, ungrounded.

a. Calculate the power for the whole load.
b. Calculate the resistance value of the load.
c. What is the power factor of the load?

Solution:

First observing the data, we can see that the system is a balanced system as the currents of each leg are equal.
Second, we know that the system is not resistive because the current is out of phase with the voltage; that information indicates that there is a load with non-pure resistive impedance. Maintenance does not tell us whether the angle is leading or lagging, and we do not know if the system is capacitive or inductive.
The power for the whole load is

a. Total = $\sqrt{3}\, I_L\, V_L \cos(\theta)$
Or substituting values
$T_{otal} = (\sqrt{3})20\,(480)\cos(25)$
$T_{otal} = 12548.4$ W
The resistance value of the load can be calculated by performing some manipulations:
We know that the resistive value of one leg is the leg voltage divided by the resistive part of the current on the leg.
The Value of the voltage leg is 480V,
The value of the leg current is the value of the line current divided by square root of three.

$I_{leg} = 20/\sqrt{3} = 13.87$A
The value of the Resistance is
$R = V/(I_{leg}\cos(\theta))$
$R = 480/(13.8\cos(25))$
c. $R = 38.2\ \Omega$

d. The power factor is cos (25) = .906

POWER MEASUREMENTS IN THREE PHASE SYSTEMS

The real power or power in watts of a three-phase system can be measured using two watt meters, known as the "Two Watt Meter Method"
This method can be used in the connections types explained in the previous sections.

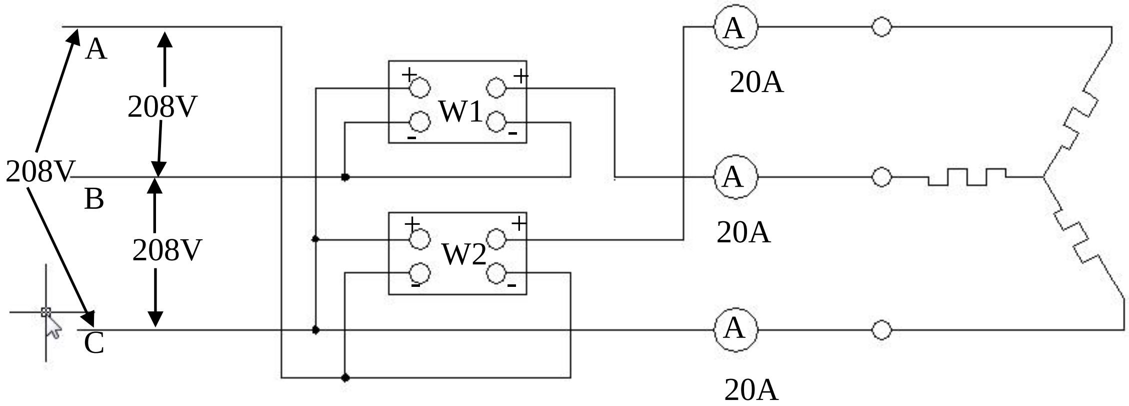


Figure 11

Please refer to Figure 11for the analysis that follows.
Figure 11 presents the typical connections for a two-watt power measuring method. The connections are for the power supplied from a three phase three wire system and delivering load to a wye connected load.
The wattmeters internally have two separate set of coils:

- Potential coils
- Current coils

- The current coils are connected in series with two of the three line leads.
- The potential coil is connected:
  - The positive pole interconnected between the two wattmeters, and to the third supply wire.
  - The negative pole is connected to the same phases as the current coils are connected.

1. When the system is balanced, the power factor is 1.0 and the voltages are equal, both wattmeters will read the same value for power.
Assume that the power factor is:

- Lagging
- Less than 1.0
- More than .5
- Phase sequence ABC

Wattmeter W1 will read more than W2.
The total power for the system is W1 + W2
2. When the power factor is 0.5, wattmeter 2 will read zero; the total power will be what wattmeter 1 reads.
When the power factor is less than 0.5, wattmeter 2 will read negative. To obtain the correct readings, the polarity of the potential coils for wattmeter 2 must be reversed to read a positive value.
The total power is still the algebraic addition of the two wattmeters; in this case the positive number of the reading from wattmeter 1 must be subtracted form the number at wattmeter 2.

Transformers and Transformer Connections

Transformers are one of the most useful and common electrical devices. In this course, we will mainly refer to the power transformation applications.
Power transformers are mainly for conversion of electrical energy into a useable form, for the customer, or for interconnection reasons in substations. Other uses include grounding transformers, used for grounding schemes in ungrounded or open systems, protection transformers such as PT or potential transformers, current transformers or CT, and other instrument transformers.
Power transformers are normally three phase; however single phase transformers are many times interconnected for three or two phase uses.
Some of the most used winding interconnections are presented below, as well as some grounding requirements for transformers, and later, a brief introduction of three phase transformer internal connections.
The main winding interconnections for single phase units presented here are:
Wye, delta, and zigzag.

First, we are going to use similar configurations as indicated above, this time applied to transformer connection. We will see how the windings are interconnected, starting with the wye connections.

- Wye connection is when one end of each winding is connected to a common point called neutral. This connection is also called the star connection.
- Delta connection, sometimes identified as a D connection, is when the windings are connected in series as to form a ring.
- Z-connection (zigzag) is a type of wye connection in which the windings are interconnected to each other to form a wye.

Power transformers normally have three types of windings, the primary, secondary and the tertiary.
The primary and secondary windings are used as the main transformer windings and serve to provide the bulk of transformation.
Benefits and characteristics of the three types of connections

Y connection

1. Preferred manner when a neutral is required
2. Used frequently for the highest voltages
3. Taps can be provided in the neutral for regulation using a less expensive tap changer than the ones used for the normal winding
4. When using a Y connection in the primary, the secondary preferable should be delta. The reason is that the
    1. Delta connection provides ampere turn balance for the zero sequence (related to fault) currents on the neutral and Y windings.
    2. Without the delta connection zero sequence currents would create a zero-sequence field in the transformer core (zero sequence currents do not exist in a delta system, these currents only exist in grounded or neutral connections).
    3. If the core is of the three yoke type, for example the zero sequence field would propagate to all the legs creating excessive heating.
    4. For yokes of 5 legs of for shell type transformers, a current in a ground fault condition could become so small that it would not be detected by the protective relay
    5. The delta connection requires $\sqrt{3}$ turns more than for a Y connection for the same voltage

Delta connection

- It is better in large transformers with low voltage and large currents both for step up and step down transformers in the high current side of the transformer. An application could be GSU or generator step up transformer in a generation plant.
- Currents called triple harmonics will flow around the ring in the delta connection; these currents are part of the magnetization currents that are required to prevent magnetization distortion in the core. Y connection would require a return path for the neutral connected to the winding
- In Y connected transformers a tertiary winding is sometimes used to prevent the above triple harmonic problem

More differences could be provided, but that information would be more appropriate for a transformer course due to the complexity of its explanation.

Delta and wye connections for transformer banks

Presented here, are the delta-delta and delta-wye connections for a bank. The connections could also be similarly done as wye-wye and wye-delta.

Delta-Delta connections

The connection in Figure 12 shows the windings connected in series both for the primary and for the secondary of the bank. This connection is called delta-delta or Δ Δ connection. It is the normal order in the connection the first word to be the primary and the second word the secondary. In this case both primary and secondary are the same.
The connection in Figure 12 is a common connection used in industry to supply motors and motor control centers that do not require neutrals.
In the past, the primary system for this type of application was 2400V; however, the trend is to increase the voltages in the industrial installations to save copper. Since a larger voltage can carry the same current using a smaller copper gauge, using a larger voltage reduces the size of conductor diameter and thus the cost. At this level of voltage (called medium voltage) the insulation cost is about the same for 2400 V than for 4160V. Usually this voltage level is referred as a 5 KV level of insulation.
The remaining observation is on the capacity of the bank. If one unit is 75KVA, the total bank capacity would be 225KVA (75 time 3).
There is a phase displacement between the primary current and the secondary current. In the connections shown in Figure 12 the displacement is 180 electrical degrees.
The symbol used to indicate this displacement is shown in Table 1 below.

Phasor Nomenclature

Winding Connection		Letter designation
High Voltage	Delta	D
	Star	Y
	Interconnected Star	Z
Low Voltage	Delta	d
	Star	y
	Interconnected Star	z
Phase displacement - Degrees	Group	Letter designation
0	I	O
180	II	6
-30	III	I
+30	IV	II

Table 1

This transformer is connected Dd6. See Table 1 for explanation.

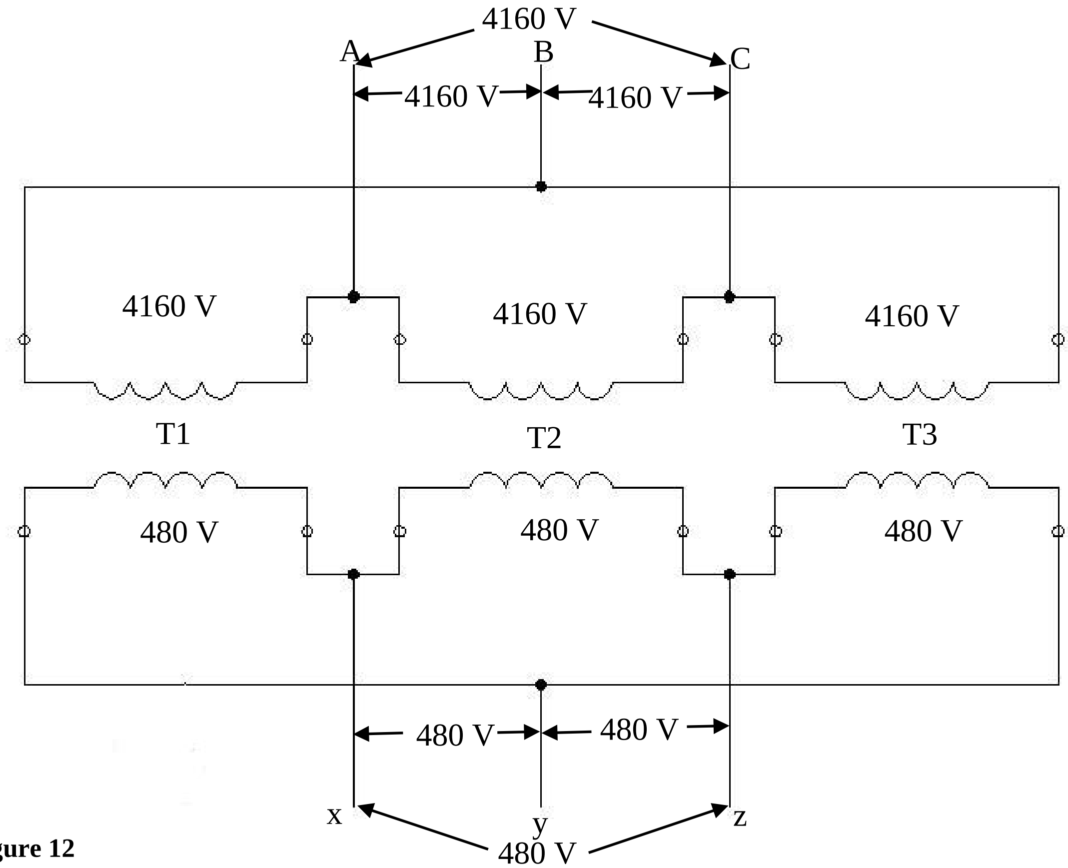


Figure 12

Delta Wye connection

The connection below is a delta primary. See Figure 13. All the windings are in series forming a ring. The secondary windings are connected as a star or wye connection.

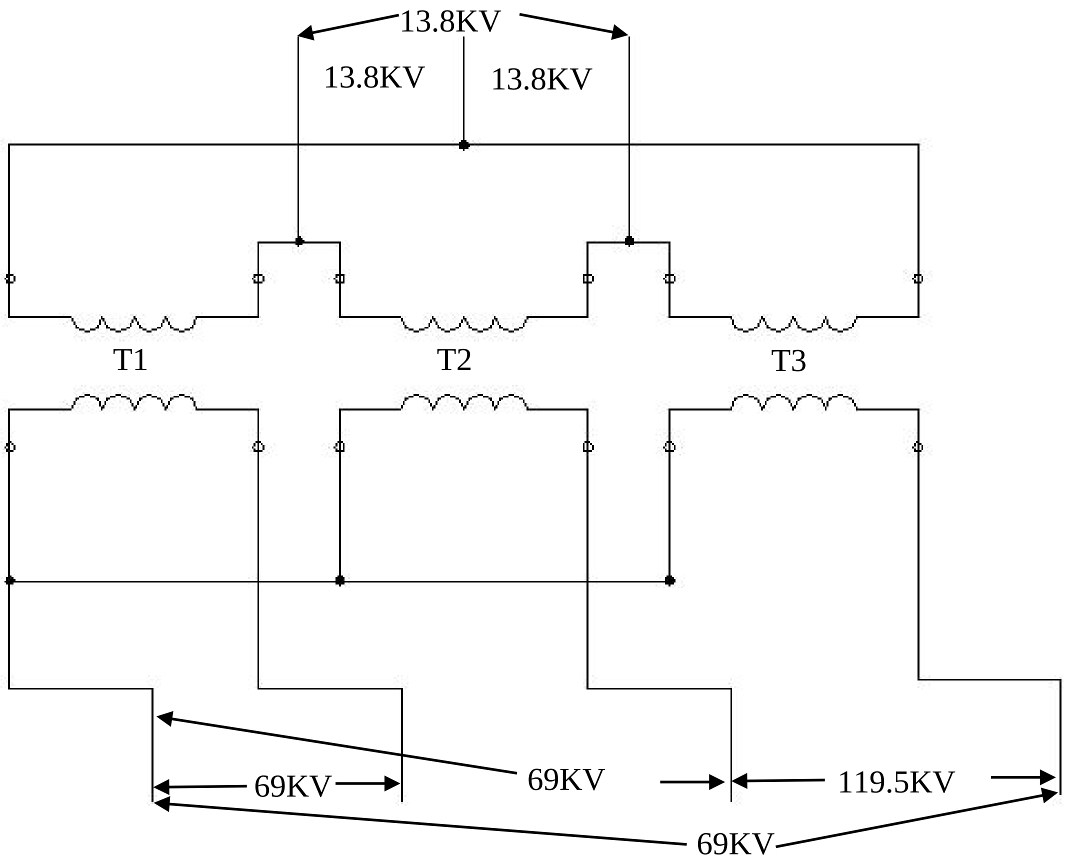


Figure 13

For example, the phase for this transformer is DyI. To determine the angle between primary and secondary, go to Table 1 to find the meaning of the letters.
D is primary delta (high voltage), y is the secondary (low voltage) and I is the phase angle which is in this case Group 3, -30 degrees.
Additional points of interest to this configuration are:

- Connection well adapted for step up transformers
- The voltage ratio is increased by the turns ratio and the square root of three or 1.73
- Insulation requirements for the secondary winding are reduced using a delta connection
- The coil voltage is only 58% of the line voltage (58% is equivalent to the inverse of square root of 3).
- Note that the phase to phase voltage is not 69KV, it is 119.5 KV

THREE PHASE CIRCUIT SYSTEMS

Introduction

Three phase systems are usually represented by single lines that depict the three wires. The system thus presented is called single line diagram.
Figure 14 below shows a typical three phase system shown with a single line diagram.

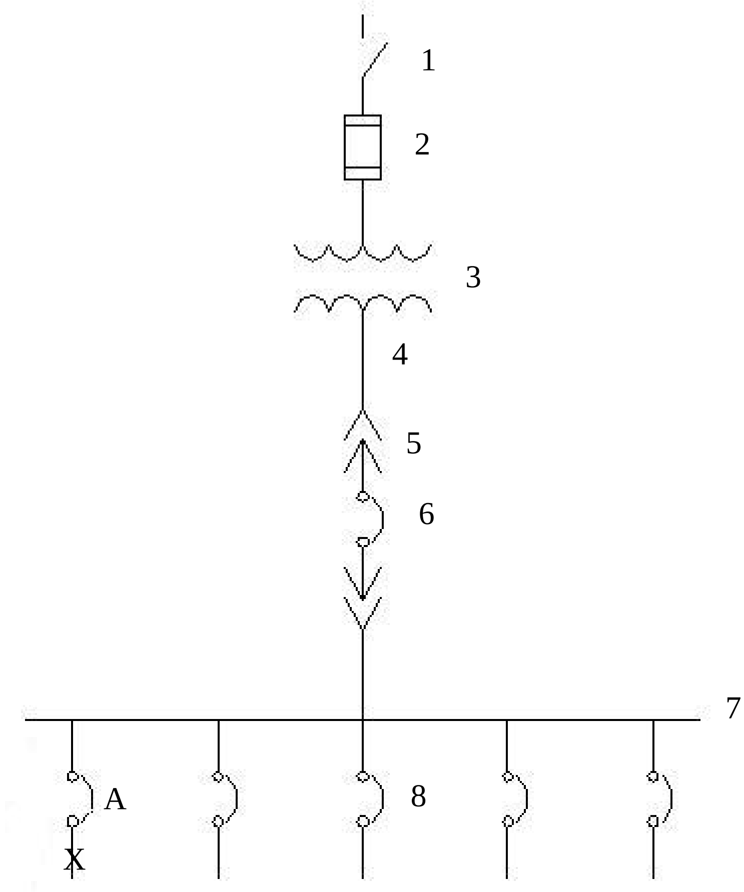


Figure 14

The symbols used in the above diagram are
1 = Air switch
2 = Fuse
3 = Transformer
4 = Connecting line
5 = Removable symbol
6 = Breaker
7 = Bus (metal conducting bars)
8 = Load breaker

The components above can be connected in many ways.
In a system design, the engineer will use the components above to feed the loads, connecting it to the supply systems, and placing the protection devices to comply with the electrical codes and the system protection requirements.

The design of a three-phase system is beyond the scope of this course, but an introduction to basic principles, such as electrical safety and protection, will be presented below.

Three Phase Systems Design Criteria

When designing an electrical system, the engineer must take into consideration that the system is suitably reliable, flexible, economical, has ease of maintenance, and is safe. The following factors are of basic importance:

- Building or facility function (small building, large industry, cogeneration facility)
- Needs and requirements of the client
- Knowledge of the power company requirements and electrical characteristics such as frequency, voltages, power factor requirements, installation of feeder costs, etc.
- The system basic loads
- Possible expansion plans or needs

After the system basic requirements are established, one of the engineer's first tasks is to sketch a single line diagram. This diagram will be the basis of the following electrical studies and settings:

- Load study
- Overload and short circuit study
- Protective device selection and settings
- Arc Flash design
- Coordination design

Load Study:

This study will determine the current and voltage characteristics of all the connected components of the system. It will also determine the amount of power used by each item of electrical equipment, its characteristics such as power factor voltage, etc., and the electrical location of the electrical equipment and how it is connected to the network. This will be basis for the design of the rest of the system, including protection settings and size of protective components.

Some data on typical load density could be used

- Fluorescent lighting at 3 to 6 VA per sq. ft.
- Incandescent lights at 6 to 12 VA per sq. ft.
- Air conditioning at 4 to 10 VA per sq. ft.

Other loads are determined by the magnitude of motor and heating loads.

Overload and Short Circuit Study:

After the one line diagram is completed, it should include all additional generation, capacitors for power factor correction, wiring, switchgear, and protective devices as well as all the loads including motor control centers and motors.
Additionally, data from the supply such as utility contribution and generators data (X/R ratio) should be known.
The best way to perform the calculations is to use the proper tools; there are many software manufacturers that can provide these tools. The software requires the input of all the information from the single line diagram. Revision by a Professional Engineer is recommended before accepting the results that the software produces. The methods and mathematical justification of Short Circuit calculations are beyond the scope of this course.

Protective Device Selection

Initially, the starting point for specification of the Protective devices is the selection of the size and type of protection equipment using various criteria. One of the most important criteria is the protection of the conductors and equipment. This is done using the protection requirements indicated in the National Electrical Code for lower voltages and the National Electrical Safety Code for the utility side.
Additionally, the results of the Short circuit calculations are used to set up the protection of the protection devices such as breakers, protection relays, and fuses. Additionally, revision of cable and conductor sizes is appropriate at this point. Initially, two basic needs, current and voltage, determine the conductor sizes (compliance with the National Electrical Code (NFPA 70) which also includes voltage drop requirements.

Arc Flash Design

The Arc Flash Studies are necessary for protection of personnel against accidental burns that could be caused by unexpected arc flashes occurring within electrical equipment protection cabinets and devices. The compliance and guidance documents are NFPA 70E and OSHA 1910 Arc Flash Warning Regulations and Standards. The Short Circuit Study information and input data is used to perform the Arc Flash Calculations. The results of this study provide information to label the cabinets with information that allows the operators and maintenance to proceed in correctly selecting the personal protection equipment and to determine if it is required. Use of PPE (Personal protection equipment) is included in the requirements wherever they are specified.

Coordination Design

This study defines which protection device should open the circuit in case of a fault. The purpose of this study is to set protection boundaries and open only the protection device needed to isolate a fault without disturbing the rest of the electrical system. A very simple case would be when a main breaker does not open because a lower branch circuit breaker clears the fault. In this case, the other branch circuits that depend on the main breaker do not lose power. See Figure 14 above. Breaker A would open to clear fault X, none of the other breakers would open in this case. If breaker A is not coordinated correctly, the main breaker would eventually open, leaving the system of Figure 14 with no power.

Examples

1.

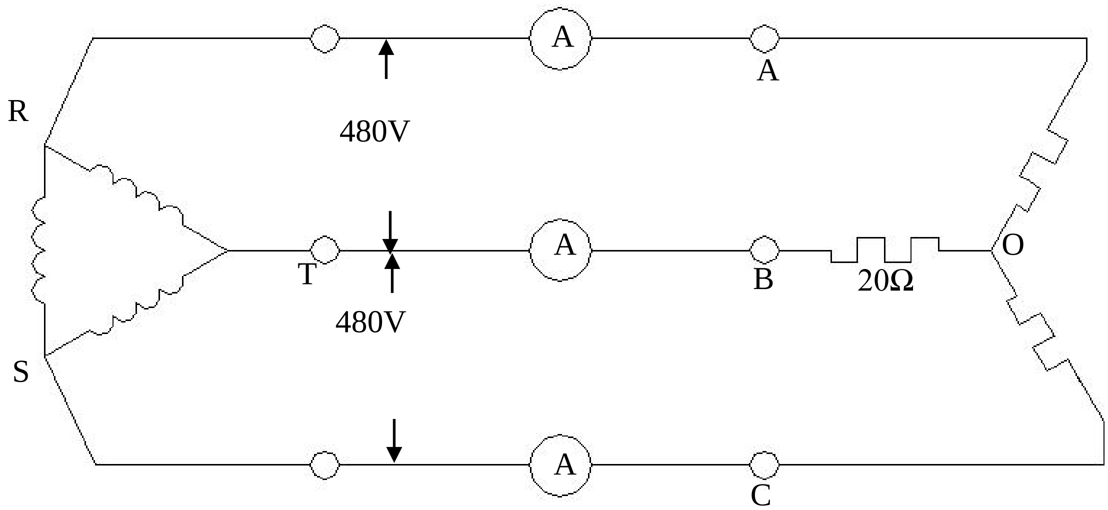


Figure 15

Given

$\mathbf{V}_{PHASE}$ = 480V,

R = 20 Ohm.

Calculate

$\mathbf{V}_{LINE}$

I_L

I_{PHASE}

P_{Total}

Calculations

$V_{LINE} = V_{PHASE}/\sqrt{3}$,

$V_{LINE} = 480/\sqrt{3}$ Volt,

V_{LINE} = 277V

Applying Ohm's law, we find the line current, just as in the case above:

$I_L = V_L/R$,

I_L = 277/10 = 27.7 A

$I_{PHASE} = I_L$ = 27.7A

Power calculations

$P_{Total} = 3\ I_L\ V_{PH}$ = 3(27.7A) (277) = 23018.7 VA or W because the load is resistive

2.

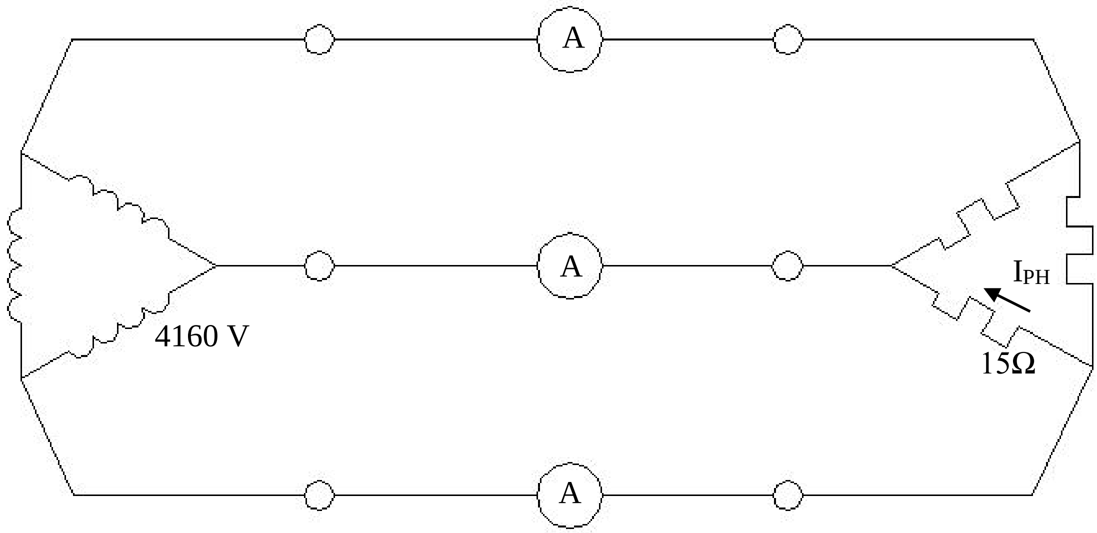


Figure 16
Given
$\mathbf{V}_{PHASE}$ = 4160V,
R = 15 Ohm

Calculate
$\mathbf{V}_{LINE}$
I_L
I_{PHASE}
P_{Total}
If the loads where each of an impedance of 15 Ohm at 45degrees lagging, calculate I_{PHASE}

Calculations
$V_{LINE} = V_{PHASE}$

V_{PHASE} = 4160Volt,
$I_{PHASE} = V_{PHASE}/R$
I_{PHASE} = 4160V/15 Ohm
I_{PHASE} = 277.3 A
$I_{LINE} = I_{PHASE}\sqrt{3}$
$I_{LINE} = 277.3\ A\sqrt{3}$
I_{LINE} = 480.4 A

For an impedance of 15 OHMS 45 degrees lagging, the impedance is inductive. Remembering the single-phase calculations, using Ohms Law we calculate:

$I_{PHASE} = V_{PHASE}/Z$
$I_{PHASE} = 4160/(15\angle 45) = 277.3\angle{-45}$ (Polar notation)

Expressed in complex rectangular notation:

I_{PHASE} = 195.9-j195.9 (Rectangular notation)

As you might remember it means that:
The real value is 195.9 A
The imaginary value is -195.9 A inductive.

3.

If a transformer is given with the notation Dy6
What does that mean?

Looking at Table 1:

- The letter D means that the primary or high voltage winding is connected in a Delta.
- The second letter is y, it means that the secondary or low voltage winding is connected in a Y or star connection.
- The third symbol is 6; looking at the table the 6 indicated that the phase shift between the windings is 180 degrees.

Table of Figures

