



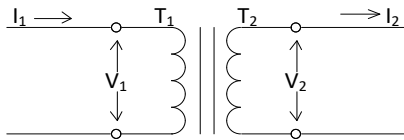
# Review of Wye/Delta Transformer Connections and How They Affect Measured Current and Voltage

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## Introduction

The transformer is arguably one of the key technologies that led to AC winning over DC in the contest to distribute electricity across the US and the world. The concept is easy, but the details are confusing, which often leads to incorrectly configured differential protection. In this paper, transformer configurations, an example of incorrectly configured differential protection, and tools to help ensure proper configuration are discussed.

A single-phase transformer is shown in Figure 1.



$$V_2 = V_1 \times (T_2 \div T_1)$$

$$I_2 = I_1 \div (T_2 \div T_1)$$

Figure 1. Single-Phase Transformer

Voltage  $V_2$  on the secondary side is equal to Voltage  $V_1$  on the primary side multiplied by the ratio of secondary turns  $T_2$  to primary turns  $T_1$ . Current  $I_2$  from the secondary side is equal to  $I_1$  in the primary side divided by the ratio of secondary turns  $T_2$  to primary turns  $T_1$ . This example ignores the losses inside the transformer due to things like winding resistance and energizing current.

Three-phase transformers connected in Wye/Wye configuration are almost as easy to understand. A Wye/Wye configured transformer is shown in Figure 2.

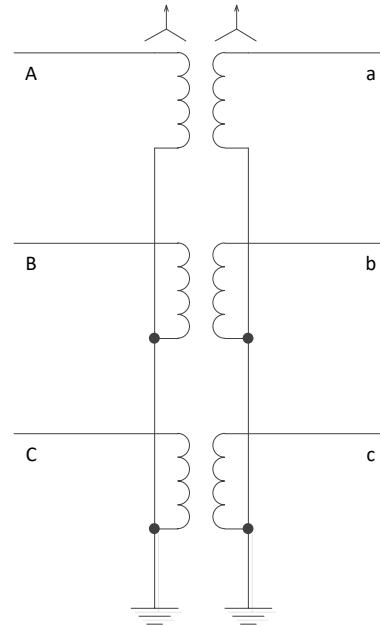


Figure 2. Wye/Wye Transformer

In this configuration, each of the three phases acts as a single phase. Load on the phase A secondary is supplied by the current from the phase A primary. The magnitude of voltage on the phase B secondary is dependent on the magnitude of voltage on the phase B primary.

Even with a Delta/Delta connection, as shown in Figure 3, things remain fairly straightforward.

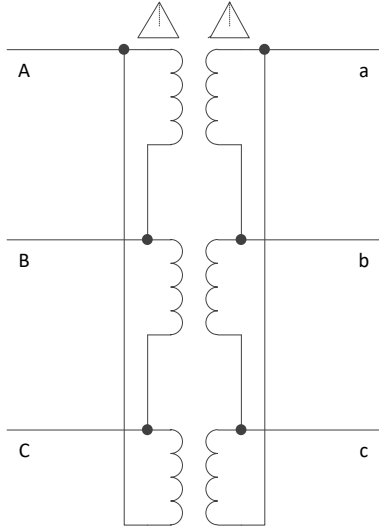


Figure 3. Delta/Delta Configuration

For the Delta/Delta configuration, the reference voltages are  $V_{ab}$ ,  $V_{bc}$ , and  $V_{ca}$  instead of  $V_a$ ,  $V_b$ , and  $V_c$ . This adds the constraint that  $V_{ab} + V_{bc} + V_{ca}$  must equal zero. With Wye/Wye,  $V_a$  could go to zero without affecting  $V_c$ . With Delta/Delta,  $V_{ab}$  cannot go to zero without affecting  $V_{ca}$ . Still, voltage in is equal to voltage out scaled by the turns ratio and the same is true for current.

Things are more complicated when transformers are connected in Wye/Delta or Delta/Wye configurations as shown in Figure 4. Early in my career, I would remain quiet when there were discussions about Delta/Wye transformers. Others seemed to understand the details behind the 30-degree phase shift, however, I have realized that many others did not understand as well. This lack of understanding has led to many incorrectly configured differential relays and has made it difficult to take advantage of the data in modern protective relays to help identify and correct the protection configuration.

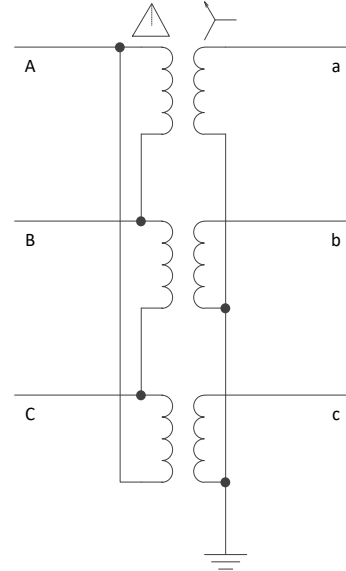


Figure 4. Delta/Wye Configuration

### Identify Transformer Configurations

For Delta/Wye and Wye/Delta transformers there are 2 most common configurations out of a possible 24. To properly set up differential protection, the transformer's configuration must be understood. Connecting three single-phase transformers as Delta/Wye is explored in the following example.

The transformer configuration is a simple isolation transformer with a ratio of 1:1. This means the line-to-line voltage on each side of the transformer is equal. Because the transformer is connected line-to-line on the delta side and line-to-neutral on the wye side, the single-phase transformer has a 1.732:1 ratio to give a 1:1 voltage ratio for the rated line voltage. Figure 5 shows phase A of the transformer.

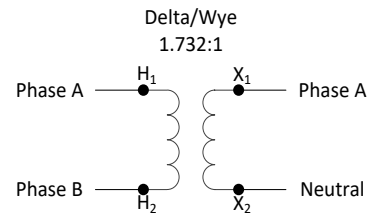


Figure 5. Phase A of a Delta/Wye Transformer

On the wye side of the transformer,  $X_1$  is connected to phase A and  $X_2$  is connected to neutral. On the delta side,  $H_1$  is connected to phase A. Because there is no neutral on the delta side,  $H_2$  must be connected to one of the other phases. In this example, it is connected to phase B. The windings for phase B and C are connected in a similar manner and the completed assembly is shown in Figure 6.

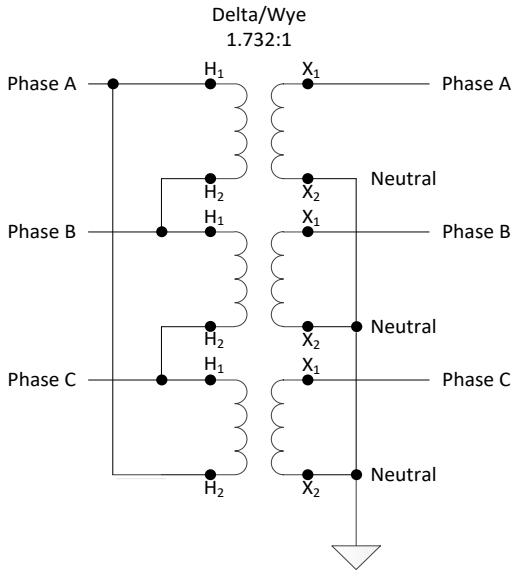


Figure 6. Delta/Wye Transformer

This configuration rotates the delta voltage in a lagging direction as shown in Figure 7.  $V_{AB}$  on the delta side of the transformer equals  $V_a$  scaled by the turns ratio of the transformer winding.

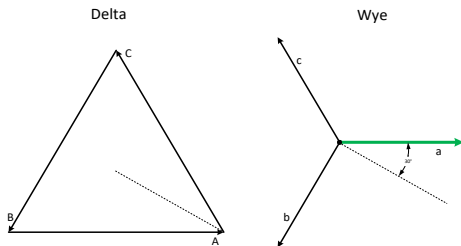


Figure 7. Delta Voltage Lagging

This connection tells us something about the current as well. Current flowing out of phase A on the delta side is the current flowing in the delta phase A winding minus the current flowing in the delta phase C winding.

This is one of two very common connections when building transformers and is often described as having the delta side lagging 30

degrees. The other common configuration is with  $H_2$  of phase A connected to phase C instead of phase B. This results in the delta side rotating in a leading direction as shown in Figure 8 and this is often described as having the delta side leading by 30 degrees.

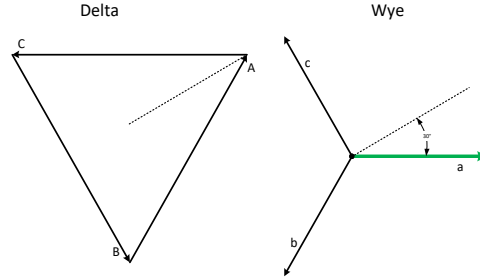


Figure 8. Delta Voltage Leading

The description of lagging by 30 degrees and leading by 30 degrees is convenient, but can be a point of confusion that will be explained later in this paper. Although the most common connection for Delta/Wye transformers is leading or lagging by 30 degrees, they can be built to lead or lag by any multiple of 30. Figure 9 shows a transformer with the delta side connections shifted by one phase which makes the delta side lag by 150 degrees.

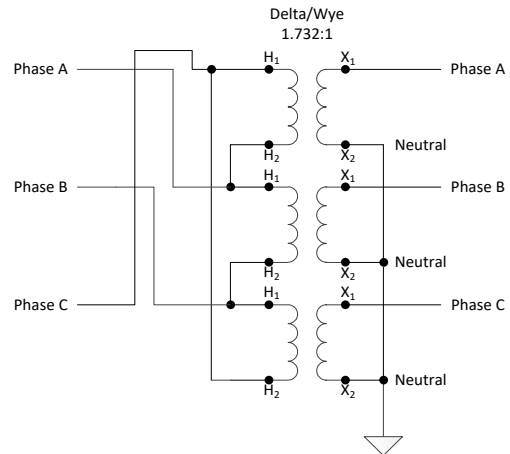


Figure 9. Delta/Wye Transformer with Delta Lagging by 150 Degrees

The IEEE Standard C57.12.70-2011 provides a basis for identifying and labeling Wye/Wye, Delta/Wye, and Wye/Delta transformers, among other things. Transformers are assigned a code based on the winding type of the primary, the winding type of the secondary, and the angle by which secondary lags the primary in multiples of 30 degrees. For example, the transformer in Figure 8 is identified as a Dy1. The primary is delta(D), the secondary is wye(y), and the

secondary lags by 30 degrees ( $1 \times 30 = 30$ ). The transformer in Figure 7 is identified as a Dy11. The secondary side leads by 30 or lags by 330 degrees, therefore the number used in the identifier is 11 ( $11 \times 30 = 330$ ). The angle descriptor always references the degrees by which the secondary lags the primary in units of 30. Although any multiple of 30 degrees is

possible, 30 degrees leading or 30 degrees lagging are the most common. Table 1 shows four such configurations. IEEE Standard C57.12.00-2000 states that transformers should be connected so that lower voltage lags the higher voltage. This means that a step-up or step-down transformer identifier should end in "1".

Table 1. Common Transformer Configurations

	<p>Dy1</p>	<p>Used for applications where low voltage side is wye configured. Wye lags delta by 30 degrees.</p>
	<p>Yd1</p>	<p>Used for applications where low voltage side is delta configured. Delta lags wye by 30 degrees.</p>

**Beyond Labels: What Does the Math Say?**

Now that the transformer types have been described, the simple example shown in Figure 10 may be explored. A generator operating at 480 V is connected to the distribution system by a 480 V to 13.2 kV Wye/Delta transformer.



Figure 10. Distribution System Example

Following IEEE convention, the 480 V side lags the 13.2 kV side by using a Yd11 transformer.

On the load side, the distribution is connected to the load by a 13.2 kV to 208 V Delta/Wye transformer. Following IEEE convention, the 208 V side lags the 13.2 kV side by using a Dy1 transformer. Table 2 shows the voltage and current of the generator, distribution, and load for a balanced system. Consistent with the Yd1 and Dy1 definitions, the distribution leads the generator by 30 degrees and the load lags the distribution by 30 degrees. At this point, it appears to follow the equations from Figure 1. The step-down transformer is 13.2kV:208V or 63.5:1. The magnitude of the current measured on the transformer delta side is equal to 27.5 times the current on the wye side and the angle is different by 30 degrees. It is easy to mistake the relationship for the equation in Figure 1 with the addition of a 30-degree phase shift.

Table 2. Voltage and Current for Generator, Distribution, and Load in a Balanced System

	Generator						Distribution						Load					
	Vpp		Vpn		I		Vpp		Vpn		I		Vpp		Vpn		I	
	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle
Phase A	480	30	277	0	216.7	0	13.2kV	60	n/a	n/a	7.87	30	208	30	120	0	500	0
Phase B	480	270	277	240	216.7	240	13.2kV	300	n/a	n/a	7.87	270	208	270	120	240	500	240
Phase C	480	150	277	120	216.7	120	13.2kV	180	n/a	n/a	7.87	150	208	150	120	120	500	120

To demonstrate how this is not accurate, the same system is evaluated with a single-phase load. Table 3 shows that a single-phase load of 500 A at 0 degrees on phase A results in 4.54 A at 0 degrees flowing in phase A of the distribution. In table 2 the ratio of load current to distribution current is 63.5:1, whereas in table 3

the ratio is 110:1. Phase A in table 2 shows a 30-degree phase shift that is not present in table 3. The most apparent difference is that phase C of distribution has 4.54 A flowing even though there is no phase C load. Clearly, the currents in the distribution are not a result of load current divided by the ratio of the line voltages.

Table 3. Voltage and Current for Generator, Distribution, and Load with a Single-Phase Load

	Generator						Distribution						Load					
	Vpp		Vpn		I		Vpp		Vpn		I		Vpp		Vpn		I	
	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle
Phase A	480	30	277	0	144.2	0	13.2kV	60	n/a	n/a	4.54	0	208	30	120	0	500	0
Phase B	480	270	277	240	72.07	180	13.2kV	300	n/a	n/a	0	n/a	208	270	120	240	0	n/a
Phase C	480	150	277	120	72.07	180	13.2kV	180	n/a	n/a	4.54	-180	208	150	120	120	0	n/a

With a balanced three-phase load, the currents appear to follow the inverse of the ratio of the line voltages, however, the same is not true when the load is single phase. To understand why, a closer look at the transformer is needed. A typical Dy1 transformer is shown in Figure 11.

helpful mnemonic device: the current from the Delta side is **A** minus **B**. Table 4 shows the mathematical relationship between currents and voltages on this step-down transformer.

Table 4. Voltage and Current Relationships in a Step-Down Transformer

Voltage	Current
$V_{AB\Delta} = -V_{aY} \times 110$	$I_{A\Delta} = (I_{aY} - I_{bY}) \div 110$
$V_{BC\Delta} = -V_{bY} \times 110$	$I_{B\Delta} = (I_{bY} - I_{cY}) \div 110$
$V_{CA\Delta} = -V_{cY} \times 110$	$I_{C\Delta} = (I_{cY} - I_{aY}) \div 110$

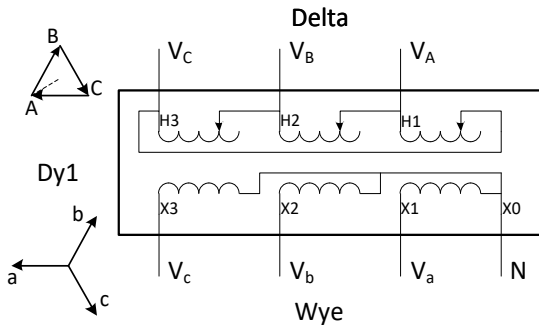


Figure 11. Typical Delta/Wye Transformer

The transformer is labeled as 13.2kV:208Y120. The phase A voltage on the delta side,  $V_{AB}$ , is connected phase-to-phase at 13.2 kV. The phase A voltage on wye side,  $V_a$ , is connected phase-to-neutral at 120 V. This means the windings of the transformers have a 110:1 ratio instead of the approximate 63.5:1 ratio of the system voltage. This also means that current flowing into H1 is equal to the current flowing out of X1 divided by 110. The phase A current on the wye side is the current from X1. On the delta side, the phase currents are not supplied by a single winding on the transformer. Phase A current on the delta side is a combination of the current in the  $V_A$  winding (H1) minus the current in the  $V_B$  winding (H2). This configuration is also commonly labeled as DAB, which can be a

Given this information, current in the single-phase load may be verified. The load is 500 A at 0 degrees on phase A. From Table 4,  $I_{A\Delta}$  on the delta side is shown in Equation 1.

$$I_{A\Delta} = (I_{aY} - I_{bY}) \div 110$$

Equation 1.

Because  $I_{bY}$  is equal to zero:

$$I_{A\Delta} = (I_{aY} - 0) \div 110$$

$$I_{A\Delta} = 4.54@0$$

From Table 4,  $I_{C\Delta}$  is shown in Equation 2.

$$I_{C\Delta} = (I_{cY} - I_{aY}) \div 110$$

Equation 2.

Because  $I_{cY}$  is equal to zero:

$$I_{C\Delta} = (0 - I_{aY}) \div 110$$

$$I_{C\Delta} = 4.54@180$$

These equations produce the single-phase load currents as shown in Table 3. Next, these equations are tested with the results from the 3-phase loads (Table 2). In the 3-phase load example, 500 A on each phase results in 7.87 A on the delta side of the step-down transformer. Using the current equations from Table 4,  $I_{A\Delta}$  on the delta is shown here:

$$I_{A\Delta} = (500@0 - 500@240) \div 110$$

The subtraction is shown graphically in Figure 12.

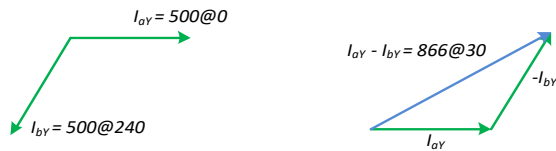


Figure 12.  $I_A$  on Delta Side

Putting these results back into the equation for  $I_{A\Delta}$  on the delta side gives the following results.

$$I_{A\Delta} = 866@30 \div 110$$

$$I_{A\Delta} = 7.87@30$$

With the three-phase load, the equation provided the expected result again.

Figure 13 shows the details of the transformer between the generator and the distribution system. This transformer is a Yd11. Note that this looks the same as the transformer shown in Figure 11.

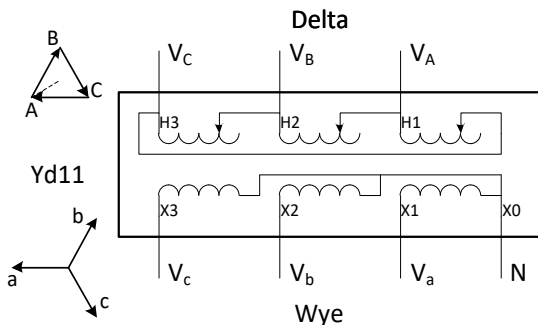


Figure 13. Wye/Delta Transformer

In this case, the wye side is 480 V instead of 208 V. As mentioned above, IEEE Standard C57.12.00-2000 states that voltage on the low side should be lagging. Thus, the transformer configuration is the same whether stepping up with a wye-to-delta or stepping down with a delta-to-wye. The difference is in the step-up transformer, the wye side is identified as primary so the transformer is Yd11. In the stepdown

transformer, the delta is the primary so the transformer is Dy1. Table 5 provides the current and voltage relationships for the step-up transformer.

Table 5. Voltage and Current Relationships in a Step-up Transformer

Voltage	Current
$V_{AB\Delta} = -V_{bY} \times 47.6$	$I_{A\Delta} = (I_{aY} - I_{bY}) \div 47.6$
$V_{BC\Delta} = -V_{cY} \times 47.6$	$I_{B\Delta} = (I_{bY} - I_{cY}) \div 47.6$
$V_{CA\Delta} = -V_{aY} \times 47.6$	$I_{C\Delta} = (I_{cY} - I_{aY}) \div 47.6$

Because the two transformers are the same except for ratio, it may seem as though the phase A generator current should be the same as the phase A load current with the exception of the scale. However, that is not entirely accurate. Using the current equations from Table 5, let's look at the generator current resulting from the single-phase load identified earlier. The equations are shown below.

$$I_{A\Delta} = (I_{aY} - I_{bY}) \div 47.63 = 4.54@0$$

$$I_{B\Delta} = (I_{bY} - I_{cY}) \div 47.63 = 0$$

$$I_{C\Delta} = (I_{cY} - I_{aY}) \div 47.63 = 4.54@180$$

This is more complicated than before, when the wye currents were known and the delta were being solved for.  $I_b$  and  $I_c$  from the wye side must be equal in magnitude and angle. As long as that condition is met, for any magnitude of  $I_b$  on the wye side there is a magnitude of  $I_a$  on the wye side that satisfies the equation. From a classical three equations and three unknowns approach this means  $I_{A\Delta}$ ,  $I_{B\Delta}$ , and  $I_{C\Delta}$  are not independent equations. To solve for  $I_{bY}$ , all three equations must be rewritten.

The first equation is rewritten as:

$$I_{bY} = I_{aY} - 216.2@0$$

The second equation is rewritten as:

$$I_{bY} = I_{cY}$$

The third equation is rewritten, after substituting  $I_{bY}$  for  $I_{cY}$  to be:

$$I_{bY} = I_{aY} + 216.2@180$$

Because  $+216.2@180$  and  $-216.2@0$  are equal, the first and third equations are slightly different forms of the same equation. This means a third equation is still needed. The final piece of

information is that a delta-connected distribution cannot provide a zero-sequence load to the generator. This means the zero-sequence current on the generator is zero, which adds the following equation.

$$I_{aY} + I_{bY} + I_{cY} = 0$$

Now there is enough information to solve the problem. Following the equations for  $I_{aY}$  and  $I_{cY}$  are substituted to get the following equation.

$$216.2@0 + 3I_{bY} = 0$$

$$I_{bY} = I_{cY} = 72.07@180$$

$$I_{aY} = 144.1@0$$

At the beginning of this section, the transformers were identified as Yd11 and Dy1. With these labels, the relationship between the delta side and the wye side appeared to be explained by a simple 30-degree shift leading or lagging.

However, after analyzing unbalanced loads on the example system, it is obvious that this is an oversimplification. Current on the delta side of a transformer is a combination of two currents from the wye side. The magnitude and angle of the wye side currents determine the angle of the delta side currents. When the magnitudes and angles are balanced, the delta current is shifted by plus or minus 30 degrees. When the magnitudes and angles are not balanced, the current magnitude and angles must be calculated. Table 6 provides the equations for Dy1, Dy11, Yd1, and Yd11 at any turns ratio. As seen previously, additional constraints may apply. Delta currents, when summed, must equal zero. Depending on the system configuration, wye currents, when summed, may have to equal zero as seen in the generator currents in the example.

Table 6. Voltage and Current Equations for Wye/Delta and Delta/Wye Transformers

Transformer Type		Phase	Voltage	Current
Dy1 or Yd11	DAB	A	$V_{ab\Delta} = -V_{bY} \times N \times \sqrt{3}$	$I_{a\Delta} = (I_{aY} - I_{bY}) \div (N \times \sqrt{3})$
		B	$V_{bc\Delta} = -V_{cY} \times N \times \sqrt{3}$	$I_{b\Delta} = (I_{bY} - I_{cY}) \div (N \times \sqrt{3})$
		C	$V_{ca\Delta} = -V_{aY} \times N \times \sqrt{3}$	$I_{c\Delta} = (I_{cY} - I_{aY}) \div (N \times \sqrt{3})$
Dy11 or Yd1	DAC	A	$V_{ab\Delta} = V_{aY} \times N \times \sqrt{3}$	$I_{a\Delta} = (I_{aY} - I_{cY}) \div (N \times \sqrt{3})$
		B	$V_{bc\Delta} = V_{bY} \times N \times \sqrt{3}$	$I_{b\Delta} = (I_{bY} - I_{aY}) \div (N \times \sqrt{3})$
		C	$V_{ca\Delta} = V_{cY} \times N \times \sqrt{3}$	$I_{c\Delta} = (I_{cY} - I_{bY}) \div (N \times \sqrt{3})$

*N* is the ratio of the line to line voltage on delta side of transformer to line to line voltage on wye side.

The proper equations to produce the current and voltage relationships for wye/delta transformers have been evaluated. Although developing equations can be difficult, using them is relatively easy. In the next section, the equations in Table 6 are used to check and correct some settings on a transformer differential relay that trips when the load is increased.

### Troubleshooting Differential Configuration

In this example, a small power plant has a transformer with differential protection that is configured as shown in Figures 14 and 15.

### Transformer Setup

**Transformer Circuits**

**CT Circuit 1**

Transformer Connection  
DAC

Ground Compensation  
No

Differential Circuit  
Primary

Polarity  
Normal

Phase Relationship  
A

**CT Circuit 2**

Transformer Connection  
WYE

Ground Compensation  
No

Differential Circuit  
Primary

Polarity  
Normal

Phase Relationship  
A

IEC Transformer Setup  
IEC Setup

**Transformer Taps**

Tap Calculation Mode  
Automatic

MVA Rating  
2.00

Calculate Taps

**CT Circuit 1**

kV Rating  
0.46

Tap  
6.00

**CT Circuit 2**

kV Rating  
13.80

Tap  
2.00

**CT Settings (Set on Sensing Transformers View)**

**CT Circuit 1**

CT Connection  
WYE

Phase CT Ratio  
800

**CT Circuit 2**

CT Connection  
WYE

Phase CT Ratio  
80

Figure 14. Relay Settings: Transformer Setup

### Power System

**Nominal Settings**

Frequency  
60 Hz

Secondary Phase Voltage (V)  
69.30 Vpn

Secondary Phase Current CT1 (A)  
5.00

Secondary Phase Current CT2 (A)  
5.00

Secondary Aux Voltage (V)  
69.30 Vpn

Power Polarity  
Normal

**Phase Rotation Setup**

Rotation  
ACB

**Power Line Parameters**

**Positive Sequence Impedance**

Z1 Line Magnitude (Ohm)  
24.00

Z1 Line Angle (°)  
80.0

**Zero Sequence Impedance**

Z0 Line Magnitude (Ohm)  
8.00

Z0 Line Angle (°)  
80.0

**Line Length**

Line Length  
100.00

**67-1 Maximum Torque Angle**

**Positive Sequence**

Z1 Angle (°)  
80.0

**Zero Sequence**

Z0 Angle (°)  
80.0

**Negative Sequence**

Z2 Angle (°)  
80.0

**67-2 Maximum Torque Angle**

**Positive Sequence**

Z1 Angle (°)  
80.0

**Zero Sequence**

Z0 Angle (°)  
80.0

**Negative Sequence**

Z2 Angle (°)  
80.0

Figure 15. Relay Settings: Power System

The system is identified as using ACB rotation. The transformer steps up from 460 V to 13.8 kV with DAC for the 460 V winding and WYE for the 13.8 kV side. As previously discussed, this means the transformer is connected so that phase A current on the delta side is from the phase A current minus phase C current on the wye side. This is also known as the Dy11 configuration. When the transformer was loaded

to approximately 85 A on the wye side, the relay tripped on differential. The plant is over 100 years old, so some of the drawings are incorrect, and some do not exist altogether. The customer first suspected they may have CTs flipped, but they sought assistance in determining if that was the true cause. Figure 16 shows a few cycles of fault and pre-fault waveforms for delta and wye current.

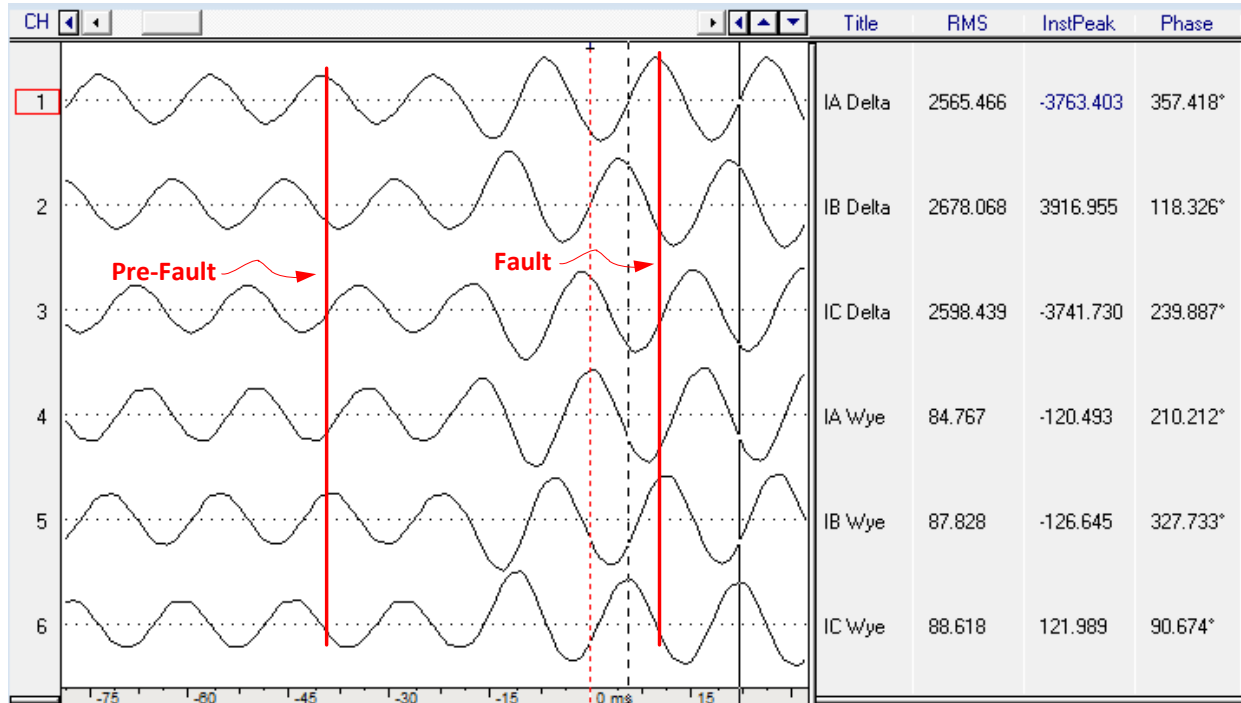


Figure 16. Fault and Pre-fault Waveforms for Wye and Delta

At first glance, the waveforms more closely resemble those of an added load than a faulted transformer. The waveforms are pretty clean and there is little, if any, change in phase relationship from pre-fault to fault currents. Because of this, incorrect settings that describe the transformer and CT configuration are suspected. They are Transformer Connection, Polarity, Phase CT Ratio, and Tap. Previously, the current on the delta side of a transformer was shown to be a composite of the current in A and B, or A and C depending on the transformer configuration. Thus, when comparing the currents in and out of the transformer, the difference must be considered. In the relay, that setting is named Transformer Connection. The normal CT connection for differential applications is with polarity away from the transformer. Differential will work correctly with both polarities towards the transformer. However, if one side is towards and the other side is away the relay the differential will not work correctly. With modern relays, flipped CTs can typically be resolved by adjusting settings, but some may require the CTs to be rewired. Ideally, the Phase CT Ratio scales the current on both sides to be equivalent at the secondary side, but conflicting requirements often prevent that from happening. The Tap setting is used to effectively balance the CT secondary currents. The Phase CT Ratio and the Tap must be set correctly together in order to properly compare transformer currents.

Figure 17 shows a phasor representation of the delta and the wye current after the relay picked up. Because the delta side current is approximately 30 times the wye side current, it is not practical to show these as primary currents. The phasors are shown scaled by the rating of the transformer, which is 2 MVA.

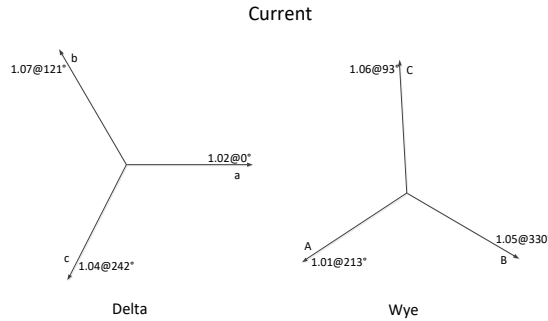


Figure 17. Delta and Wye Current Phasor (After Relay Pickup)

When connected normally, with both polarities away from the transformer, the current measured on the delta side is 180 degrees from the current measured on the wye side in addition to an angle shift caused by the transformer. In Figure 17, phase A delta is at 0 degrees and phase A wye is at 213 degrees (180+33). Looking at phases B and C, there is a 209 and 211 degree shift respectively between the wye and delta sides as well. This shows that the CTs are connected as expected and the relay does not have a flipped CT. The figure also shows that phase C is lagging phase A by about 120 degrees followed by phase B at about 240 degrees. This confirms that the system has ACB rotation as identified in Figure 15. It does introduce some confusion though. With the 180-degree shift taken into account, the wye side of the transformer is leading the delta side by about 30 degrees. From the previous table, this is a Dy11. At this point, one may wonder whether the definition holds true for reverse rotation. There are not many ACB systems and most standards are not very clear on this subject. The IEEE standards mentioned previously do not address reverse rotation. With the lack of system documentation, it is unclear if the transformer was connected in accordance with the standard. So, it is best to follow the math. The phase A current on the delta side must be a result of the difference of two currents on the wye side. The most common choices are A – B and A – C. Figure 18 shows the currents for phase A delta, phase A – B wye, and phase A – C wye. For now, the phasors remain scaled by the 2 MVA rating.

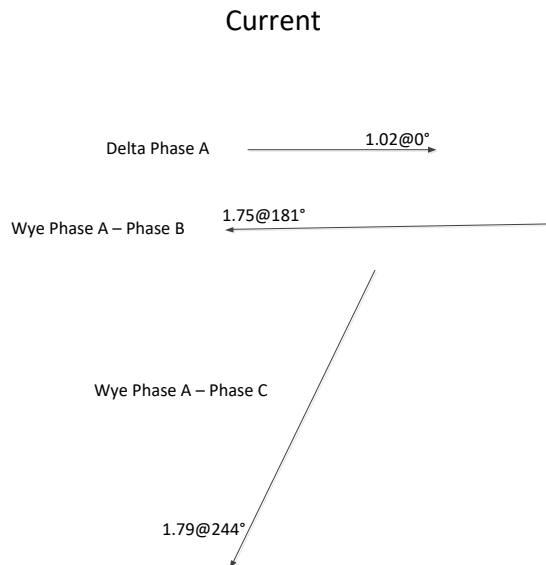


Figure 18. Phase A Delta, Phase A-B Wye, and Phase A-C Wye Currents

One of the resulting wye-side phasors should be 180 degrees opposite of the delta-side phase A phasor. It is confirmed that the A – B current from the wye side of the transformer is 181 degrees opposite of the phase A current from the delta side. This means that the transformer is connected as DAB. For

completeness, the DAB current calculations from Table 6 are performed. The calculated delta currents should be very close to the measured delta currents shifted by 180 degrees.

$$N = 460 \div 13800 = 0.0\bar{3}$$

$$I_{a_{\Delta}} = (84.8@212.8 - 87.8@330.3) \div (0.0\bar{3} \times \sqrt{3})$$

$$I_{a_{\Delta}} = 2556@181$$

$$I_{b_{\Delta}} = (87.8@330.3 - 88.6@93.3) \div (0.0\bar{3} \times \sqrt{3})$$

$$I_{b_{\Delta}} = 2685@-58$$

$$I_{c_{\Delta}} = (88.6@93.3 - 84.8@212.8) \div (0.0\bar{3} \times \sqrt{3})$$

$$I_{c_{\Delta}} = 2594@64$$

Table 7 shows the calculated delta currents as well as the measured delta currents.

*Table 7. Calculated and Measured Delta Currents*

	Delta Currents	
	Measured	Calculated
<b>Phase A</b>	2565@0	2555@181
<b>Phase B</b>	2678@121	2685@-58
<b>Phase C</b>	2598@242	2594@64

Each of the calculated currents are within 1% and 2 degrees of the measured current. If the incorrect equations were selected, the angles would be off by about 60 degrees as seen in Figure 18. The results show, with certainty, that the setting in Figure 14 that shows the delta side of the transformer as a DAC is incorrect. The DAC setting contributed to the unexpected trip, so the setting should be changed to DAB. However, that may not be the only cause of the nuisance trip. Phase CT ratios and taps should be evaluated as well. The relay software is capable of calculating recommended taps using the transformer voltages, CT ratios, and transformer MVA rating. The following equation confirms that the CTs and tap settings used creates an equivalency between the delta and wye side currents.

$$V_{\Delta} \times CT_{\Delta} \times Tap_{\Delta} = V_Y \times CT_Y \times Tap_Y$$

$$460 \times 800 \times 6 = 13800 \times 80 \times 2$$

$$2208000 = 2208000$$

This proves that the combination of CT and tap settings match the system configuration. Changing the circuit 1 transformer connection from DAC to DAB solves the problem and the transformer should be able to be loaded without tripping.

## Summary

- Wye/Delta and Delta/Wye transformers are more complicated than Wye/Wye and Delta/Delta transformers.
- Many people do not have a good understanding of Delta/Wye transformers. Do not be shy about asking for help.
- Thirty degree leading and lagging provides a good way to identify transformers, but may cause confusion in understanding them.
- Each phase current from a delta winding is the result of two phases from the wye winding.
- Incorrect transformer definition can result in unexpected differential trips.
- Using the Delta/Wye equations can be helpful when evaluating and correcting a differential configuration.

## Author Biography

Todd Martin is a Relay Application Engineer for Basler Electric Company. He has been employed by Basler for 28 years, with more than 19 years of engineering experience in digital, analog, and firmware design for protective relays. Todd received a BSEE and a MBA from the Southern Illinois University at Edwardsville, Illinois.