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## Shifting Transformers Damage Curves for Through-Fault Current Protection

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### Introduction

The purpose of this guide is to establish the rationale for shifting equipment damage curves based on winding connection when evaluating transformer through-fault current protection.

### ANSI Ø Shifts and Winding Connections

The ANSI standards specify that transformers connected  $\Delta$ - $\Delta$  or Y-Y shall have a phase shift of 0°. Transformers connected  $\Delta$ -Y or Y- $\Delta$  shall have a phase shift of 30°, and the low-voltage winding shall always lag the high-voltage winding.

Table 1 summarizes the winding connections covered in this guide. The last connection covers the neutral ground resistor (NGR) case common to industrial plants with MV distribution systems serving rotating equipment.

Primary-Side	Secondary-Side
$\Delta$	$\Delta$
$\Delta$	Y
$\Delta$	YG
Y	$\Delta$
Y	Y
Y	YG
YG	$\Delta$
YG	Y
YG	YG
$\Delta$	YG (w/NGR)

### Through-Fault Current Protection

Engineers must consider all possible fault scenarios on the secondary-side of the transformer in order to evaluate the level of through-fault current protection provided by a primary-side fuse, relay or circuit breaker. On a three-phase power system this would include; three-phase fault, single-line-to-ground fault, line-to-line fault and line-to-line-to-ground fault. It is common practice to view current distributions in per unit on the three-phase fault current base seen by the primary-side protective device.

### Three-Phase (3Ø) Secondary Fault

The primary-side relays would each see 1.0 A p.u. fault current on a 3-Ø primary fault current base, figure 1.

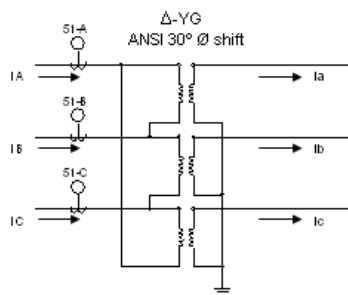


Fig 1 3-Ø Fault on the Secondary Terminals

### Single-Line-to-Ground (SLG) Secondary Fault

The primary-side phase A and C relays would see 0.58 A p.u. fault current on a 3-Ø primary fault current base, figure 2.

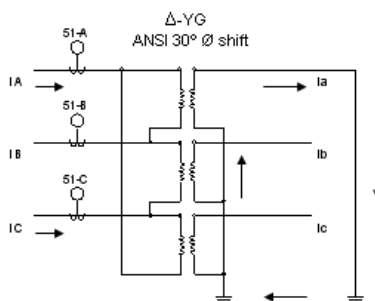


Fig 2 SLG Fault on the Secondary Ø-a Terminal

### Line-to-Line (LL) Secondary Fault

The primary-side phase A and C relays would see 0.50 A p.u. fault current and the phase B relay would see 1.0 A p.u. fault current on a 3-Ø primary fault current base, figure 3.

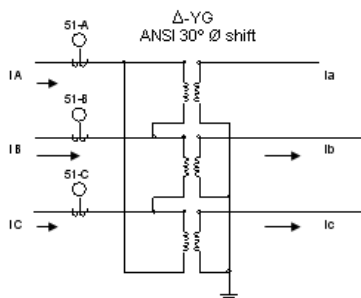


Fig 3 L-L Fault on the Secondary Ø b &amp; c Terminals

### Line-to-Line-Ground (LLG) Secondary Fault

The primary-side phase A and C relays would see 0.58 A p.u. fault current and the phase B relay would see 1.0 A p.u. fault current on a 3-Ø primary fault current base, figure 4.

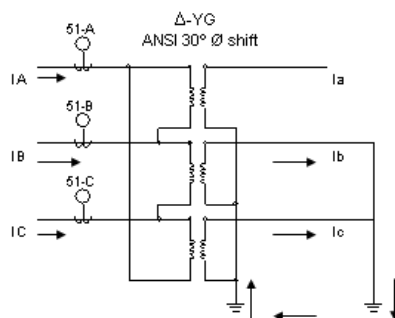


Fig 4 L-L-G Fault on the Secondary Ø b &amp; c Terminals

Transformer secondaries were faulted and primary currents were calculated for each fault type and summarized in Table 2 for winding configurations listed in Table 1.

Table 2 Fault Current Summary Table

Transformer			Primary Current - A p.u.				Calculated Curve Shift
Connection	Ø Shift	Ø	3-Ø	SLG	LL	LLG	
Δ-Δ	0°	A	1.00	0.00	0.00	0.00	0.87
		B	1.00	0.00	0.87	0.87	
		C	1.00	0.00	0.87	0.87	
Δ-Y	30°	A	1.00	0.00	0.50	0.50	no shift
		B	1.00	0.00	1.00	1.00	
		C	1.00	0.00	0.50	0.50	
Δ-YG	30°	A	1.00	0.58	0.50	0.58	0.58
		B	1.00	0.00	1.00	1.00	
		C	1.00	0.58	0.50	0.58	
Y-Δ	30°	A	1.00	0.00	0.50	0.50	no shift
		B	1.00	0.00	1.00	1.00	
		C	1.00	0.00	0.50	0.50	
Y-Y	0°	A	1.00	0.00	0.00	0.00	0.87
		B	1.00	0.00	0.87	0.87	
		C	1.00	0.00	0.87	0.87	
Y-YG	0°	A	1.00	0.00	0.00	0.00	0.87
		B	1.00	0.00	0.87	0.87	
		C	1.00	0.00	0.87	0.87	
YG-Δ	30°	A	1.00	0.00	0.50	0.50	no shift
		B	1.00	0.00	1.00	1.00	
		C	1.00	0.00	0.50	0.50	
YG-Y	0°	A	1.00	0.00	0.00	0.00	0.87
		B	1.00	0.00	0.87	0.87	
		C	1.00	0.00	0.87	0.87	
YG-YG	0°	A	1.00	1.00	0.00	0.00	0.87
		B	1.00	0.00	0.87	1.00	
		C	1.00	0.00	0.87	1.00	
Δ-YRG	30°	A	1.00	Note 1	0.50	Note 1	Note 1
		B	1.00	0.00	1.00	1.00	
		C	1.00	Note 1	0.50	Note 1	

1. Shifting of the damage curve is dependent upon the amp rating of the NGR relative to the transformer primary-side FLA. Shifting is To Be Determined by the engineer on a case by case basis. For a sample case study see Example 3.

#### Example 1

Plot the damage curve and set a primary-side 50/51 relay to protect a 1000kVA, 65°C, 4160-480/277V, Δ-YG, oil-filled, substation transformer with an impedance of 6.0%.

Consider secondary 3-Ø faults only when setting the primary-side 50/51 relay to protect the transformer during through-faults.

Solution

The protection is met based on the criteria given, see Figure 5.

Now examine the protection provided by the 50/51 relay shown in figure 1 for faults of all types using Table 1. For a secondary LL fault the primary relays in phases A and C would only see 50% of the fault current they would otherwise see for a 3-Ø fault. This is not a problem though because the B-phase relay would see 100% current, and the transformer would be protected.

The LLG fault is similar to the LL fault accept that the relays in phases A and C would see 58% current. But again the B-phase relay would see 100% current, so the transformer would be protected.

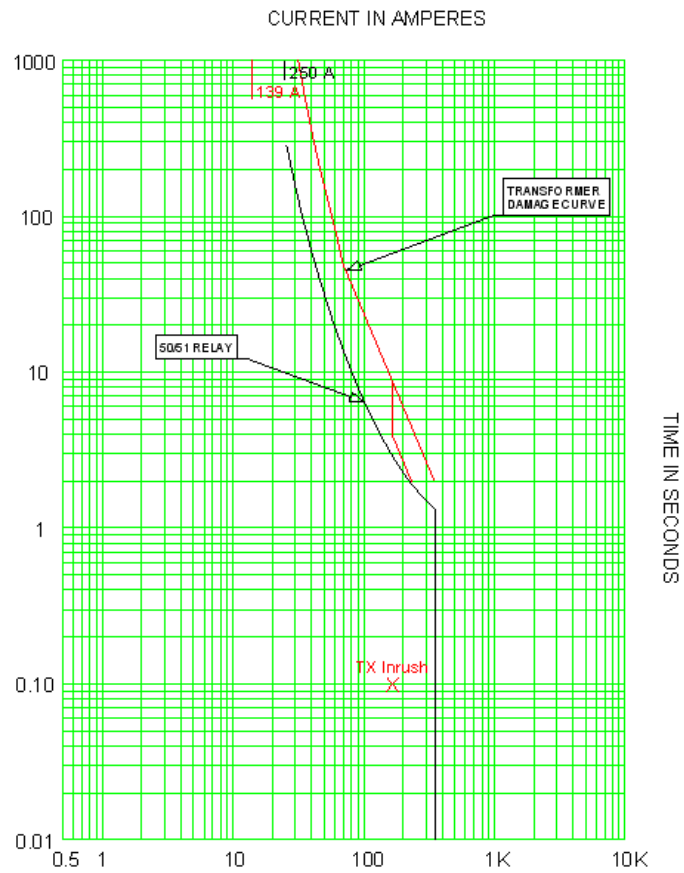
However for the SLG fault case, the A and C-phase relays would see 58% current with no current flowing in the B-phase! In order to evaluate the through-fault current protection afforded by the relays for a secondary SLG fault, the damage curve of Figure 5 would have to be shifted 58% to the left. It is common practice to show both damage curves on the TCC. After shifting it becomes apparent that the original relay settings are inadequate, see Figure 6.

#### Example 2

Repeat Example 1 but now consider secondary faults of all types when setting the primary-side 50/51 relay to protect the transformer during through-faults.

Solution

The protection is met based on the criteria given, see Figure 7.



Example 1(a).tcc Ref. Voltage: 4160 Current Scale  $\times 10^1$

Fig. 5 Example 1 Though-Fault Current Protection (3- $\phi$  Fault Only)

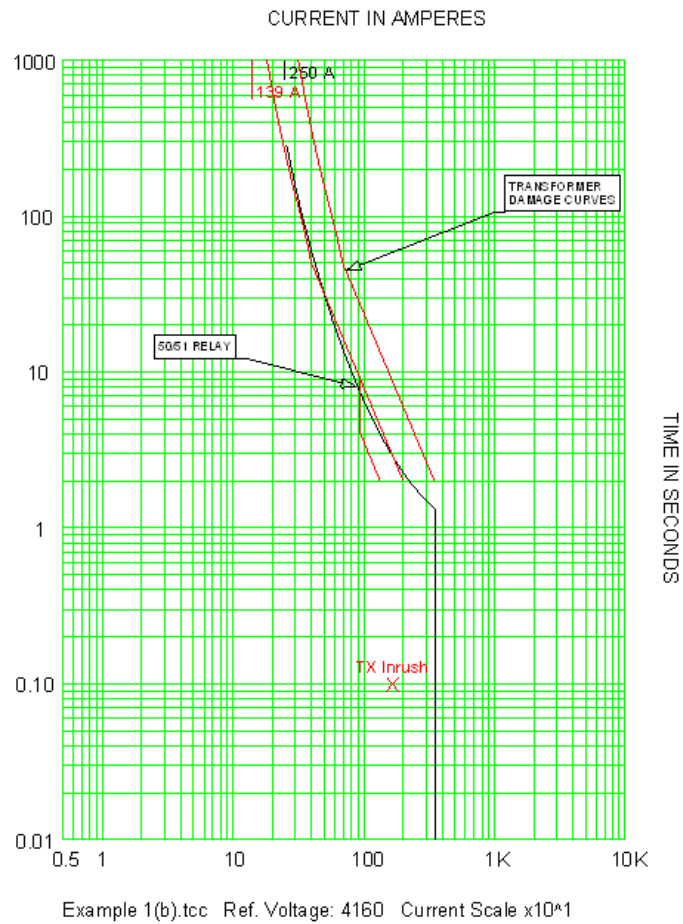


Fig. 6 Example 1 Though-Fault Current Protection (All Faults)

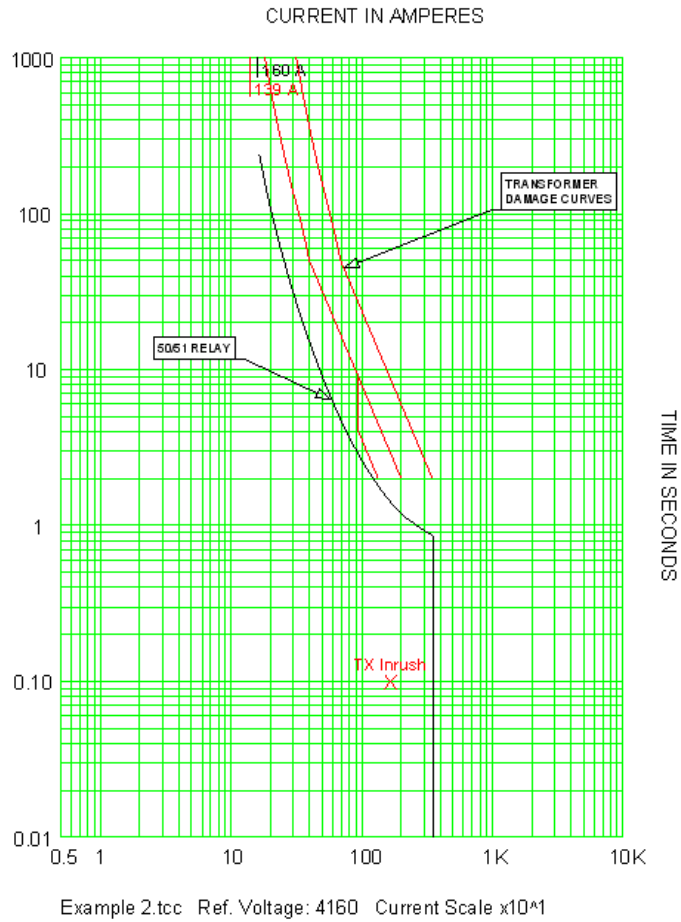


Fig. 7 Example 2 Though-Fault Current Protection (All Faults)

**Example 3**

Consider the case of a 5000kVA, 65°C, 13800-4160/2400V, Δ-YG, oil-filled, substation transformer with an impedance of 6.0%. The secondary neutral terminal is grounded through a 400A NGR.

Solution

Step 1 – Determine the primary FLA

$$FLA\ PRI = 5000kVA / (1.732 \times 13.8kV) = 209A$$

Step 2 – Determine the primary-side current distribution for a secondary-side SLG fault

$$I\ SLG\ SEC = 400\ amps$$

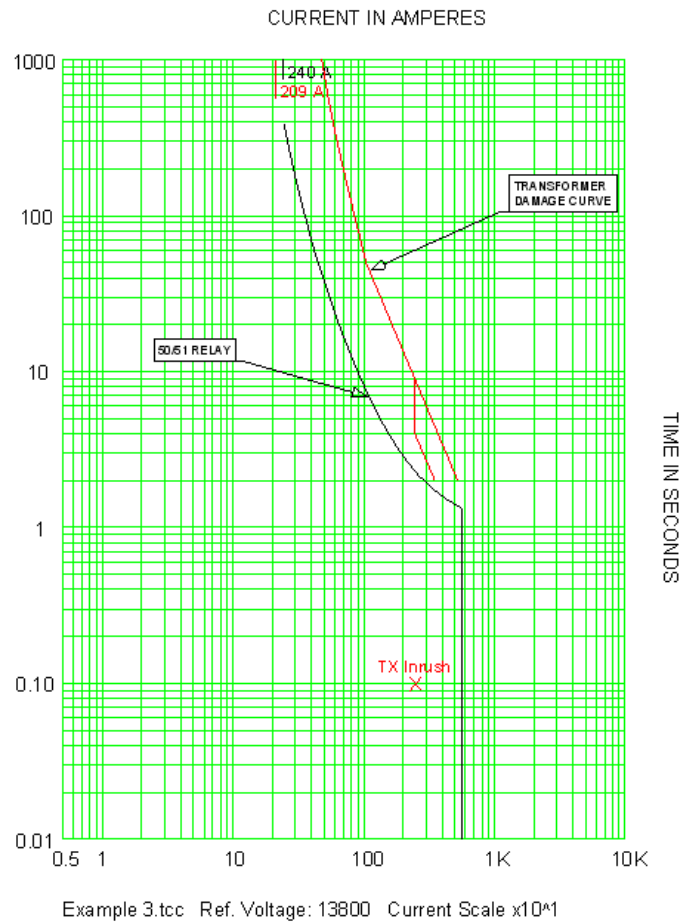
$$I\ FAULT\ PRI = 0.58 \times 400\ amps\ (4160V / 13800V) = 69\ amps$$

Step 3 – Determine the relationship between I FAULT PRI and FLA PRI

$$I\ FAULT\ PRI = 69 < FLA\ PRI = 209A$$

Conclusions

- No shifting is required, see Figure 8.
- The relay is not capable of distinguishing between a secondary-side SLG fault and an increase in load
- In this case it is common practice to protect the transformer using a 51G relay fed from a current transformer mounted in the secondary neutral bushing.
- If the transformer protection system includes a 51G relay there is no need to perform this calculation.

Fig. 8 Example 3 Though-Fault Current Protection ( $\Delta$ -YRG)

#### References

- the Application Guides offered by SKM Systems Analysis at [www.skm.com](http://www.skm.com)

The latest revision of:

- IEEE Std C57.12.00, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers
- IEEE Std C57.12.01, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those with Solid-Cast and/or Resin-Encapsulated Windings
- IEEE Std C37.91, IEEE Guide for Protective Relay Applications to Power Transformers

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