However, if non-standard connections are used, e.g. transformer windings connected in wye and CTs in wye, the current inputs to the differential calculations in the relay must be modified to compensate for a 30° shift in the transformer and to subtract zero-sequence current as necessary. To accomplish this, the relay applies a connection compensation factor for each winding.

The unit includes five three-phase current inputs and three single-phase current inputs for restricted earth fault (REF) protection. It also includes six voltage inputs. Several examples for delta-connected high-side windings and wye connected low-side windings are shown here. These examples provide correct settings for two-winding transformer examples, but can also be applied to transformers with additional windings.

The device contains settings for transformer phase rotation (PHROT), CT connections (CTCONn), internal/external CT connection compensation (ICOM), and connection compensation (TnCTC).

Phase rotation setting (PHROT)

It is recommended that the CT secondary circuits are wired to the relay’s terminal block such that the system phase is connected to the same relay phase (i.e. connect system A-phase to the relay A-phase). This product uses the phase rotation setting to determine negative-sequence current (3I2). The phase differential element calculations do not use the phase rotation setting, but the setting must be correct for one to use the negative-sequence differential element in the relay, i.e. the system phase rotation must be known to select the connection compensation settings properly.

Current transformer connections (CTCONn)

The current transformer connection may be set for either wye (Y) or delta (Δ). In new installations, it is recommended to use wye-connected CTs whenever possible to maximise available protection, simplify overcurrent relay settings, CT wiring and troubleshooting. If CTs are...
That use wye-connected CTs. In general, wye-connected CTs are easier to draw, wire, and troubleshoot. Using the CTCONn setting in the relay will automatically calculate the TAPn setting if MVA is set to a value other than OFF. If MVA = OFF, the CTCONn setting can be used for metering and overcurrent elements.

**Internal/external CT connection compensation (ICOM)**

If ICOM = N, the traditional CT connections external to the relay must be used (e.g., transformer windings connected in wye and CTs in delta, or transformer windings connected in delta and CTs in wye) to accomplish the CT and transformer phase-shift compensation. The CTs must be connected such that the current entering the polarity marks of the relay windings are 180° out of phase for load and external faults. If ICOM = Y, the relay will compensate internally for the transformer and CT phase shifts.

**Internal connection compensation settings (TnCTC)**

With internal CT connection compensation enabled (ICOM = Y), the relay can correct for phase shifts in a transformer or CTs. It is best to wire all CTs in wye configuration to maximize available protection, simplify overcurrent protection, and CT wiring. The relay setting, CT connection (CTCONn, where n is the winding input), defines the CT connection as delta or wye. Where CTs are connected in wye as recommended, the relay setting for internal winding/CT connection compensation (ICOM) will need to be set to Y to accommodate for 30° phase shifts in the transformer. Setting ICOM equal to Y turns on the settings for connection compensation (TnCTC, where n is the winding input) to properly account for phase shifts in transformer winding connections and CT connections.

The relay can compensate in 30° increments with a setting range of 0 – 12. A setting of zero applies no phase shift compensation. A setting of twelve applies 360° of phase shift compensation, which results in 0° of compensation but the removal of zero-sequence currents. A setting of one applies a 30° phase shift in the counterclockwise direction for ABC system rotation, and a setting of eleven applies a 330° phase shift in the counterclockwise direction for ABC system rotation.

In all of the application examples, the following assumptions apply:

- CTs are connected in wye on both sides of the transformer (CTCONS = CTCONT = Y).
- The system phases connect to complementary labeled bushings on both the high side and low side of the

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**Fig. 5: ANSI standard delta-wye transformer, ACB system rotation.**

A-B-C connected to H1-H2-H3.

**Fig. 6: System phase angles for DABY connection, ACB system rotation.**

**Fig. 7: Winding compensation with delta winding as reference.**

**Fig. 8: Winding compensation with wye winding as reference.**
Application examples

Example 1

For the transformer nameplate drawing in Fig. 1, ABC phase rotation is assumed, and the high-side currents will lead the associated low-side currents by 30°. This is a DABY connection because the polarity of A-phase connects to the nonpolarity of B-phase. Because the CTs are connected in a wye configuration, the relay must compensate for the 30° phase shift.

The phasor diagram in Fig. 2 shows the A-phase load current flow through the transformer and the 180° shift of the A-phase current on the CT secondary as a result of the opposite CT polarity on the secondary of the transformer. The CT secondary current angles in the figure are the correct angles for a DABY transformer with ABC phase rotation.

For this example, there are multiple choices for winding compensation that will produce the correct 30° shift. The recommended method is to select the high-side winding as the reference winding and shift the low-side currents by the appropriate amount. In Fig. 3, the delta winding from neutral to A-phase is chosen as the reference. The wye current is adjusted by 30° in the counterclockwise direction (because of ABC rotation) to align with the reference. Therefore, setting TSCTC = 0 and TTCTC = 1 achieves the proper selection of winding compensation.

The appropriate settings are: PHROT = ABC, CTCONS = Y, CTCONT = Y, ICOM = Y, TSCTC = 0, TTCTC = 1

A second choice for winding compensation would be to select the wye winding as the reference and rotate the delta A-phase by the appropriate number of degrees to be in phase with the wye winding A-phase. As Fig. 4 shows, the A-phase-to-neutral on the delta winding must be rotated by 330° in the counterclockwise direction to align with the A-phase-to-neutral on the wye winding. One might think that the compensation settings would, therefore, be TSCTC = 11 and TTCTC = 0. However, winding two is a wye winding with wye-connected CTs; the proper selection would therefore be TTCTC = 12 to remove zero-sequence currents. Setting the winding compensation to twelve introduces a 360° phase shift and removes zero-sequence currents. Removal of the zero-sequence currents is important because phase-to-ground faults external to the differential zone of protection could cause a false assertion of the differential element. The false assertion results from the zero-sequence current source of the directly grounded or impedance-grounded wye transformer neutral creating an apparent, but incorrect, increase in the secondary phase currents to the relay.

In this case, the appropriate settings would be: PHROT = ABC, CTCONS = Y, CTCONT = Y, ICOM = Y, TSCTC = 11, TTCTC = 12

Example 2

For the transformer nameplate drawing in Fig. 5, ACB phase rotation is assumed and the high-side currents will lag the associated low-side currents by 30°. This is a DABY connection because the polarity of A-phase connects to the nonpolarity of B-phase. Because the CTs are connected in a wye configuration, the relay must compensate for the 30° phase shift.

The phasor diagram in Fig. 6 shows the A-phase load current flow through the transformer and the 180° shift of the A-phase current on the CT secondary as a result of the opposite CT polarity on the secondary of the transformer. The CT
secondary current angles in the figure are the correct angles for a DABY transformer with ACB phase rotation.

For this example, there are also multiple choices for winding compensation. The recommended method is to select the high-side winding as the reference winding, and to shift the low-side currents by the appropriate amount. In Fig. 7, the delta winding from neutral to A-phase was chosen as the reference. The wye current must be adjusted by 30° in the clockwise direction (because of ACB rotation) to align with the reference. Therefore, setting TSCTC = 0 and TTCTC = 1 achieves the proper selection of winding compensation. The winding compensation setting does not change, although the phase rotation changed. This is because, for ACB rotation, the phase-angle rotation was adjusted in the clockwise direction by the TnCTC setting.

The appropriate settings are:

PHROT = ACB, CTCONS = Y, CTCONT = Y, ICOM = Y, TSCTC = 0, TTCTC = 1

A second choice for winding compensation would be to select the wye winding as the reference and rotate the delta A-phase by the appropriate number of degrees to be in phase with the wye winding A-phase. As Fig. 8 shows, A-phase-to-neutral on the delta winding would need to be rotated by 330° in a clockwise direction to align with A-phase-to-neutral on the wye winding. Again, as in example 1, the compensation settings could be TSCTC = 11 and TTCTC = 12.

The appropriate settings are:

PHROT = ACB, CTCONS = Y, CTCONT = Y, ICOM = Y, TSCTC = 11, TTCTC = 12

Example 3

The transformer nameplate in example 3 is exactly like the nameplate in examples 1 and 2, but now the system phase connections to the H1, H2, and H3 terminals have changed. A-phase now connects to H3, and C-phase now connects to H1, and the system A-phase connects to the relay IAS input. This is a DACY connection because the polarity of A-phase connects to the nonpolarity of C-phase. For the nameplate diagram in the example and ABC system phase rotation, the high-side currents will lag the associated low-side currents by 30°, and the relay must account for this phase angle shift.

The phasor diagram in Fig. 10 shows the A-phase load current flow through the transformer and the 180° shift of the A-phase current on the CT secondary because of the opposite CT polarity on the secondary of the transformer. The CT secondary current angles in the figure are the correct angles for a DACY transformer with ABC phase rotation.

For this example, there are also multiple choices for winding compensation. The method recommended is to select the high-side winding as the reference winding and shift the low-side currents by the appropriate amount. In Fig. 11, the delta winding from neutral to C-phase was chosen as the reference simply because it is at the 12 o'clock position, although the A-phase could have been chosen as the reference again and the same results would have been obtained. The wye current must adjusted by 330° in the counterclockwise direction (because of the opposite CT polarity on the secondary of the transformer. The CT secondary current angles in the figure are the correct angles for a DACY transformer with ABC phase rotation.

For this example, there are also multiple choices for winding compensation. The method recommended is to select the high-side winding as the reference winding and shift the low-side currents by the appropriate amount. In Fig. 11, the delta winding from neutral to C-phase was chosen as the reference simply because it is at the 12 o'clock position, although the A-phase could have been chosen as the reference again and the same results would have been obtained. The wye current must adjusted by 330° in the counterclockwise direction (because of the opposite CT polarity on the secondary of the transformer. The CT secondary current angles in the figure are the correct angles for a DACY transformer with ABC phase rotation.

For this example, there are also multiple choices for winding compensation. The method recommended is to select the high-side winding as the reference winding and shift the low-side currents by the appropriate amount. In Fig. 11, the delta winding from neutral to C-phase was chosen as the reference simply because it is at the 12 o'clock position, although the A-phase could have been chosen as the reference again and the same results would have been obtained. The wye current must adjusted by 330° in the counterclockwise direction (because of the opposite CT polarity on the secondary of the transformer. The CT secondary current angles in the figure are the correct angles for a DACY transformer with ABC phase rotation.
The appropriate settings are: PHROT = ABC, CTCONS = Y, CTCONT = Y, ICOM = Y, TSCTC = 0, TTCTC = 11.

A second choice for winding compensation would be to select the wye winding as the reference, and rotate the delta A-phase by the appropriate number of degrees to be in phase with the wye winding C-phase.

As Fig. 12 shows, the C-phase to neutral on the delta winding would need to be rotated by 30° in the counterclockwise direction to align with C-phase-to-neutral on the wye winding and the compensation settings could be TSCTC = 1 and TTCTC = 12.

The appropriate settings are: PHROT = ABC, CTCONS = Y, CTCONT = Y, ICOM = Y, TSCTC = 1, TTCTC = 12.

Example 4

This transformer nameplate differs from the first three examples in that the polarity of the H1 winding now connects to the nonpolarity of the H3 winding. The system A-phase connects to the H1 winding, and the system C-phase connects to the H3 winding. This is a DACY connection because the polarity of A-phase connects to the nonpolarity of C-phase. For the nameplate diagram in the example and the ABC system phase rotation, the high-side currents will lag the associated low-side currents by 30°, and the relay must account for this phase angle shift. The phasor diagram in Fig. 14 shows the A-phase load current flow through the transformer and the 180° shift in the A-phase current on the CT secondary because of the opposite CT polarity on the secondary of the transformer. The CT secondary current angles in the figure are the correct angles for a DACY transformer with ABC phase rotation.

For this example, there are also multiple choices for winding compensation. The recommended method is to select the high-side winding as the reference winding and shift the low-side currents by the appropriate amount. In Fig. 15, the delta winding from neutral to A-phase was chosen as the reference. The wye current must be adjusted by 330° in the counterclockwise direction (because of ABC rotation) to align with the reference chosen. Therefore, the proper selection of winding compensation is TSCTC = 0 and TTCTC = 11.

The appropriate settings are: PHROT = ABC, CTCONS = Y, CTCONT = Y, ICOM = Y, TSCTC = 0, TTCTC = 11.

A second choice for winding compensation would be to select the wye winding as the reference, and rotate the delta A-phase by the appropriate number of degrees to be in phase with the wye winding C-phase. As Fig. 16 shows, A-phase-to-neutral on the delta winding would need to be rotated by 30° in the counterclockwise direction to align with A-phase-to-neutral on the wye winding. Compensation settings are TSCTC = 1 and TTCTC = 12.

The appropriate settings are: PHROT = ABC, CTCONS = Y, CTCONT = Y, ICOM = Y, TSCTC = 1, TTCTC = 12.

Example 5

This transformer connections of Fig. 17 are the same as Fig. 2 for example 1. However, the CTs connect in the traditional manner (e.g., transformer windings connect in wye and CTs in delta, or transformer windings connect in delta and CTs in wye). Because of the CT connections, internal compensation is not necessary. For the transformer nameplate drawing in Fig. 17, if ABC phase rotation is assumed, then the high-side currents will lead the associated low-side currents by 30°. This is a DABY connection because the polarity of A-phase connects to the nonpolarity of B-phase. The phasor diagram in Fig. 2 shows the A-phase load current flow through the transformer. The high-side current, Ia, connects to the relay’s IAS terminal. The IAT terminal of the relay connects to Ia – Ib, and the Ia – Ib current...
shifts 180° on the CT secondary because of the opposite CT polarity on the secondary of the transformer. The CT secondary current angles in the figure are the correct angles for a DABY transformer with ABC phase rotation. The appropriate settings are: PHROT = ABC, CTCONS = Y, CTCONT = D, ICOM = D

Conclusions
The relay winding compensation settings provide winding compensations in 30° increments to allow for most transformer applications, including mobile transformer applications. Care must be taken to connect the CTs and system phases to the transformer to provide proper targeting and metering quantities. The following guidelines must be applied whenever possible:

- All CTs should be connected in wye.
- The system phase must be connected to the corresponding relay phase.
- The Global Phase Rotation Setting (PHROT) must be set to the phase rotation of the system.
- The system connection diagram, system phase rotation, and transformer nameplate diagram must be used to determine proper winding compensation settings.
- The delta connection(s) must be identified as DAB or DAC by using system phase connections and relay phase connections.
- TnCTC = 12 must be set for any winding that needs no phase angle correction but is a grounded wye winding with wye-connected CTs.

Important points about delta connections:

- DABY transformers always result in the delta side leading the wye side for ABC system rotation.
- DABY transformers always result in the delta side lagging the wye side for ACB system rotation.
- DACY transformers always result in the delta side lagging the wye side for ABC system rotation.
- DACY transformers always result in the delta side leading the wye side for ACB system rotation.

SEL commissioning assistant software is available at no charge to help verify CT connections and compensation settings for SEL-487E relays.

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