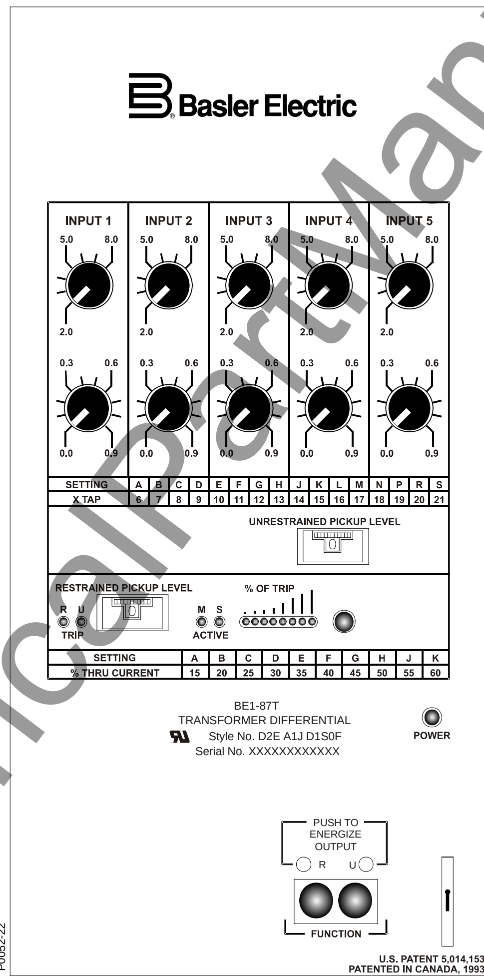
INSTRUCTION MANUAL

FOR

TRANSFORMER DIFFERENTIAL RELAY

BE1-87T



Basler Electric

Publication: 9171300990
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INTRODUCTION

This instruction manual provides information about the operation and installation of the BE1-87T Transformer Differential relay. To accomplish this, the following information is provided:

- General Information and Specifications
- Controls and Indicators
- Functional Description
- Installation
- Test Procedures

WARNING!

To avoid personal injury or equipment damage, only qualified personnel should perform the procedures in this manual.

NOTE

Be sure that the relay is hard-wired to earth ground with no smaller than 12 AWG copper wire attached to the ground terminal on the rear of the unit case. When the relay is configured in a system with other devices, it is recommended to use a separate lead to the ground bus from each unit.

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REVISION HISTORY

The following information provides a historical summary of the changes made to the BE1-87T instruction manual (9171300990). Revisions are listed in reverse chronological order.

Manual Revision and Date	Change
R, 09/07	• Replaced magnetic type targets with electronic type targets. • Updated power supply burden data and output contact ratings. • Updated front panel illustrations to show laser graphics. • Moved content of Section 6, *Maintenance* to Section 4, *Installation.* • Added GOST-R certification to Section 1, *General Information.*
Q, 10/05	• In Section 1, General Information, Specifications, corrected values for Maximum Current per Input for 1 Ampere CT Units. • In Section 5, Test Procedures, corrected values inside CAUTION box for 1 AMP CT on page 5-14.
P, 05/03	• Added a thumbscrew to the figure on the manual front cover. • Added "not all styles" to the Power Supply Output heading on page 3-4 as well as added "NOTE" and a text box around the second last paragraph on page 3-4. • Added the new thumbscrew to Figure 4-1 and changed the height dimensions in Figure 4-2. • Clarified the terminal numbers on Figure 4-6b. • Added a shorting bar between terminals 6 & 7 in Figure 4-11. • Added a shorting bar and normally open contact and normally closed contact effecting terminals 1, 2, & 5 in Figure 4-12. • Step 13 was corrected on pages 4-31 and 4-39 to include R_w in the formulas. • Values were changed to Table 5-4 under Option 1-0 for Unrestrained Trip.
N, 09/00	• Corrected Table 1-3 to show power supply ranges. • Changed instruction manual front cover, Figures 4-1, 4-3, and 4-5 to show new unit case covers. • Changed Figure 4-32 per markup.
M, 04/99	• Table 3-1 changed mid range nominal volt 125 Vac to 120 Vac. • Corrected Figures 4-24, 4-31a, and A-3 • Corrected page 4-38, Step 10; added note to page 4-39, Step 13, and corrected Steps 14 and 16. • Page A-2, changed 3-Phase fault ratio current to 3-phase fault current. • Page A-3, corrected formulas for Figure A-3. • Under Section 4, *Procedure One, Verify CT Performance,* changed the procedure to the ANSI accuracy class method. This forced changes in the following steps: 12, 13, 14, 16, 18, 20, and 21. • Under Section 4, *Procedure Two, Verify CT Performance,* changed the procedure to the ANSI accuracy class method. This forced changes in the following steps: 12, 13, 14, and 16. • Added ECO revision information to Table 8-1. • Added Setting Note 7 *(ANSI Accuracy Class Method)* to Appendix A.
L, 05/97	• To delete the part number from the front cover of the manual.

Manual Revision and Date	Change
K, 03/97	• Deleted all references to Service Manual 9171300620. • Changed the Title of Section 2 from “Controls and Indicators” to “Human-Machine Interface”. • Replaced the Power Supply Options paragraphs with a new Power Supply paragraph explaining the new power supply design. • Deleted Figure 3-2 and added Table 3-1, *Wide Range Power Supply Voltage Ranges.* • Changed Power Supply Status Output for Type G power supply on the formerly page 3-6 (now page 3-4) from terminals 9 and 20 to terminals 9 and 19. • Added information to Section 4 to help the user understand the procedures better. • Deleted all NOTES FOR USERS OF SENSING INPUT TYPE F RELAYS and added Section 7, *Difference Data.* • Changed previous Section 7, *Manual Change Information,* to Section 8. • Added an Appendix A to clarify the setting procedures. • Added an index to help the user find information easier. • Changed the format of the manual.
J, 01/96	• Deleted “Difference Data” (formerly Section 7) and included notes for users of Type F relays. • Moved all information regarding relay settings and checking relay setting from Section 5, *Testing and Setting,* to Section 4, *Installation.* Section 5 now contains information on test procedures. • Combined 50 and 60 Hz Verification Tests. • Various editorial changes. • Reformatted instruction manual as Windows Help file for electronic documentation.
I, 01/95	• Added outline (box) to Figure 5-8 to highlight the figure. • Page 5-42, Step 5, changed, “should be less than 4.45” to, “must be less than 4.45”. • Added note to page 5-43, Step 10 and corrected the formula in Step 10. • Page 5-45, Step 18, corrected formula and high side results; and Step 19, changed last sentence from H (13 x tap) to S (21 x tap). • Page 5-46, Steps 20 and 21, corrected figure references.
H, 12/94	• Page 1-6, changed *Specification for Restrained Output, Pickup Accuracy.* • Changed Section 5, *Testing and Setting, Verification Tests* (all models): Steps 1, 4, 5, and 8; and Table 5-4. • Page 5-50, *Jumper Positions Wye-Delta 1*, Step 3: Corrected Input 2 terminal identifications. • Page 5-51, *Jumper Positions Delta2-Delta2*, Step 2: Corrected verification statement.
G, 09/94	• Changed all sections to reflect new Option 1-1. • Added to Section 5 four examples for testing relays to clarify test procedures. • Added to Section 5 one procedure for setting relays. • Corrected typographical and illustration errors.

Manual Revision and Date	Change
F, 03/93	• Changed formula pages 5-4, 5-10, 5-16, and 5-22 from I = the square root of K over t, to I = K over the square root of t.
E, 01/93	• Manual was revised to incorporate a revision in the relay that made sensing input type F obsolete and included the 1 A, 60 hertz and 5 A, 50 hertz model relays. • Section 5, *Test Setup,* diagrams were changed to clarify relay connections. • Added three relay Internal Connection diagrams. • Changed unrestrained maximum time to trip, reference old Tables 5-4 and 5-8 (new Tables 5-4, 5-8, 5-12, and 5-16). • Renamed Section 7, *Manual Change Information* to Section 8, *Manual Change Information* and added new Section 7, Difference Data to support BE1-87T relays with Sensing Input Type F.
D, 06/92	• Manual was revised to include the 1 A, 50 Hz model relay and reformatted to a new Instruction Manual style. • Additional connection diagrams were included in Section 4 and test plug information was added to Section 6. • Minor typographical errors were also corrected.
C, 03/91	• Table 5-1 was expanded and Figure 5-4 Test Setup illustration was added. • Miscellaneous editing.
B, 03/91	• Manual (with the exception of Section 2) was rewritten for ease of use.
A, 06/90	• Figure 3-1 (Functional Block Diagram) corrected. • Formula in caution note (formerly on p. 4-17, now on p. 5-2) corrected. • Miscellaneous editing.

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CONTENTS

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SECTION 1 • GENERAL INFORMATION

INTRODUCTION

These instructions provide information concerning the operation and installation of BE1-87T Transformer Differential Relays. To accomplish this, the following is provided:

- Specifications
- Functional characteristics
- Mounting information
- Setting procedures and examples

WARNING!

To avoid personal injury or equipment damage, only qualified personnel should perform the procedures presented in these instructions.

These instructions may be used in place of all earlier editions. For change information, see Section 8.

NOTE FOR USERS OF SENSING INPUT TYPE F RELAYS

Users of BE1-87T relays with Sensing Input Type F (three-phases three inputs per phase) will find Difference Data in Section 6 of this manual that describes features specific to these relays. The three-phase, three inputs per phase design, previously available as Sensing Input Type F, has been modified and is now available as Sensing Input Type G. Due to differences in components and output terminal connections, Type G relays *are not* compatible with earlier versions of the BE1-87T with Sensing Input Type F. There are also differences in the output connections as described in Section 6, *Difference Data.*

DESCRIPTION

BE1-87T Transformer Differential Relays provide primary protection for power transformers and are available in either Single-Phase or Three-Phase configurations. The solid-state BE1-87T compares the currents entering and leaving the protected transformer. If a fault is detected, the relay initiates a trip signal to isolate the power transformer. This limits damage to the transformer and minimizes the impact on the power system.

BE1-87T relays use three types of restraint:

- Percentage of through-current
- Second harmonic
- Fifth harmonic

Selectivity in differential relaying is based on the ability to distinguish between internal and external faults. This is achieved by comparing the currents into and out of a power transformer. Comparing these currents often requires more than two inputs. For example:

- Power transformers may have a significant portion (greater than 10 %) of the current flowing in a third or tertiary winding.
- Power transformers can have multiple breakers for a given winding (e.g., ring bus or breaker-and-a-half bus).

BE1-87T relays are available with up to five restraint inputs for the single-phase unit and up to three restraint inputs per phase for the three-phase unit.

APPLICATION

In general, power transformers have different values of current flowing through their primary, secondary, and tertiary windings. These currents have specific phase relationships depending upon the connections of the individual windings (e.g., wye/delta). As inputs to a differential relay, these currents must be compensated or scaled so that the relay can compare the inputs and determine when an unbalance exists. Under ideal operating conditions, the scaled vector sum of these currents is zero.

Because it is practically impossible to match the magnitudes of these detected currents from the various power windings using standard CT ratios, the currents are matched within the relay by scaling each of the applied currents by an appropriate factor called a Tap Setting. This is set by means of the front panel **INPUT** dials. By selecting suitable tap ratios, the applied currents are scaled within the relay to achieve the desired balance for normal operating conditions. BE1-87T relays offer a range of available tap settings for inputs between 0.4 A to 1.78 A (Sensing Input Range Options 2 and 4 for a 1 A CT) or 2.0 to 8.9 A (Sensing Input Range Options 1 and 3 for a 5 A CT). These settings are independently adjustable in increments of 0.02 A for Sensing Input Range Options 2 and 4, or 0.1 A for Sensing Input Range Options 1 and 3. These small increments allow more precise scaling of the applied currents and usually eliminate the need for installing auxiliary ratio-matching CTs.

Single-Phase

BE1-87T Single-Phase relays require phase angle compensation to be accomplished externally by proper connection of the system CT secondaries. A wye/delta transformer requires that the CT secondaries be connected in delta for the wye winding and in wye for the delta winding. This type of connection also eliminates the zero-sequence component of current which could cause a false trip (operation) during external ground fault conditions on the wye system.

Three-Phase

BE1-87T Three-Phase relays can provide zero-sequence filtering and compensation for phase shifts introduced by the connections of the power transformer. This 30° Phase Shift compensation (either ±30° or no compensation) is field selectable. Additionally, this feature allows sharing the transformer differential relay CTs with other relays or instrumentation.

BE1-87T relays use the highest input current (in per unit values) to operate on maximum restraint. The relay does not have a conventional operate winding in the internal magnetics. Operating current is developed within the electronics of the relay.

Percentage Restraint

A primary concern in differential relay applications is security against high current levels caused by faults outside the protected zone. Inevitable differences in the saturation characteristics between current transformers require a compensating decrease in relay sensitivity. It is also necessary to be able to adjust the sensitivity to compensate for transformer voltage taps or CT mismatches. This is accomplished by providing a restraint factor proportional to the current flowing through the protected zone (through-current).

BE1-87T relays maintain sensitivity at a specified ratio of trip current to through current. This ratio, generally referred to as slope, is front-panel adjustable in 5 % increments from 15 to 60 %.

Second-Harmonic Restraint

Magnetizing inrush current presents another problem unique to transformer differential relays. Relays must be capable of detecting the small differences in current caused by the shorting of a limited number of turns, yet remain secure against the occurrence of magnetizing currents many times the transformer rating (as seen at one set of terminals).

Although magnetizing inrush is usually associated with the energizing of the transformer, any abrupt change in the energizing voltage may produce this phenomenon. Common causes are the transients generated during the onset, evolution and removal of external faults. Desensitizing the relay only during energization is therefore insufficient.

Magnetizing inrush produces an offset sine wave rich in all harmonics. BE1-87T relays use the second harmonic to restrain operation because it predominates and because it does not occur in significant magnitude or duration at other times.

Three-phase BE1-87T relays use second-harmonic sharing. The second-harmonic content of all three phases is summed together to derive the restraint for each phase. As a result, the second-harmonic inhibit range and the associated factory setting, is higher than on single-phase relays.

Fifth-Harmonic Restraint

Power transformer overexcitation causes additional exciting current to flow into one set of terminals. This presents an apparent differential (or operating) current not attributable to an internal fault. Although potentially damaging, overexcitation is not an internal fault and, therefore, is not an appropriate condition for transformer differential relay operation. One of the principal components in the complex waveform produced during overexcitation is the fifth harmonic. BE1-87T relays use fifth-harmonic restraint to inhibit the differential relay operation.

Unrestrained Trip

Severe internal transformer faults may cause CT saturation. Under such circumstances, harmonic-restraint transformer differential relays may fail to trip because of the extremely high harmonic content in the waveform. Lack of operation can result in severe transformer damage.

BE1-87T relays provide an independent unrestrained tripping function. When set above the possible inrush current magnitude, this function provides high-speed protection for the most severe internal faults.

OPTIONS

Push-To-Energize Output Pushbuttons

Two **PUSH-TO-ENERGIZE OUTPUT** switches are available as a means to verify external output wiring without the inconvenience of having to test the entire relay. Option 2-S provides a small pushbutton switch for each isolated output function (Restrained and Unrestrained) and may be actuated by inserting a thin, non-conducting rod through access holes in the front panel. Refer to Figure 2-1 through 2-4 for location.

Appropriate power must be applied to Power Supply terminals 3 and 4 (shown in Figures 4-7 through 4-10) for these pushbuttons to operate the output relays. However, it is not necessary to apply currents to the sensing inputs of the relay for these switches to function.

Auxiliary Output Contacts

Three types of auxiliary output contacts are available: Normally open, normally closed and SPDT. The contacts can be made to respond to a restrained trip, an unrestrained trip or both. Refer to the **Functional Description: Auxiliary Relay Option** for further information.

Power Supply

Various power supply options are available to allow the BE1-87T to be used with standard supply voltages. See the Style Number Identification Chart, Figure 1-1, for details.

MODEL AND STYLE NUMBER

The electrical characteristics and operational features of the BE1-87T Transformer Differential Relay are defined by a combination of letters and numbers that make up its Style Number. The Model Number together with the Style Number, describe the options included in a specific device and appear on the front panel, drawout cradle and inside the case assembly.

Upon receipt of a relay, be sure to check the Style Number against the requisition and the packing list to ensure that they agree.

Style Number Example

The Style Number Identification Chart (Figure 1-1) defines the electrical characteristics and operational features included in BE1-87T relays. For example, if the Style Number were **G1E-A1Y-D1S0F**, the device would have the following:

BE1-87T Model Number (designates the relay as a Basler Electric, Class 100, Transformer Differential Relay)

G Three-phase sensing with three inputs per phase

1 2.0 to 8.9 A Sensing Range at 60 Hz

E One unrestrained output contact and one restrained output contact

A1 No intentional delay in the outputs

Y 48/125 Vdc switchable

D Current operated targets

1 Percent I_{OP} display and high-speed trip

S Push-to-Energize outputs

0 No auxiliary output

F Semi-flush mounting

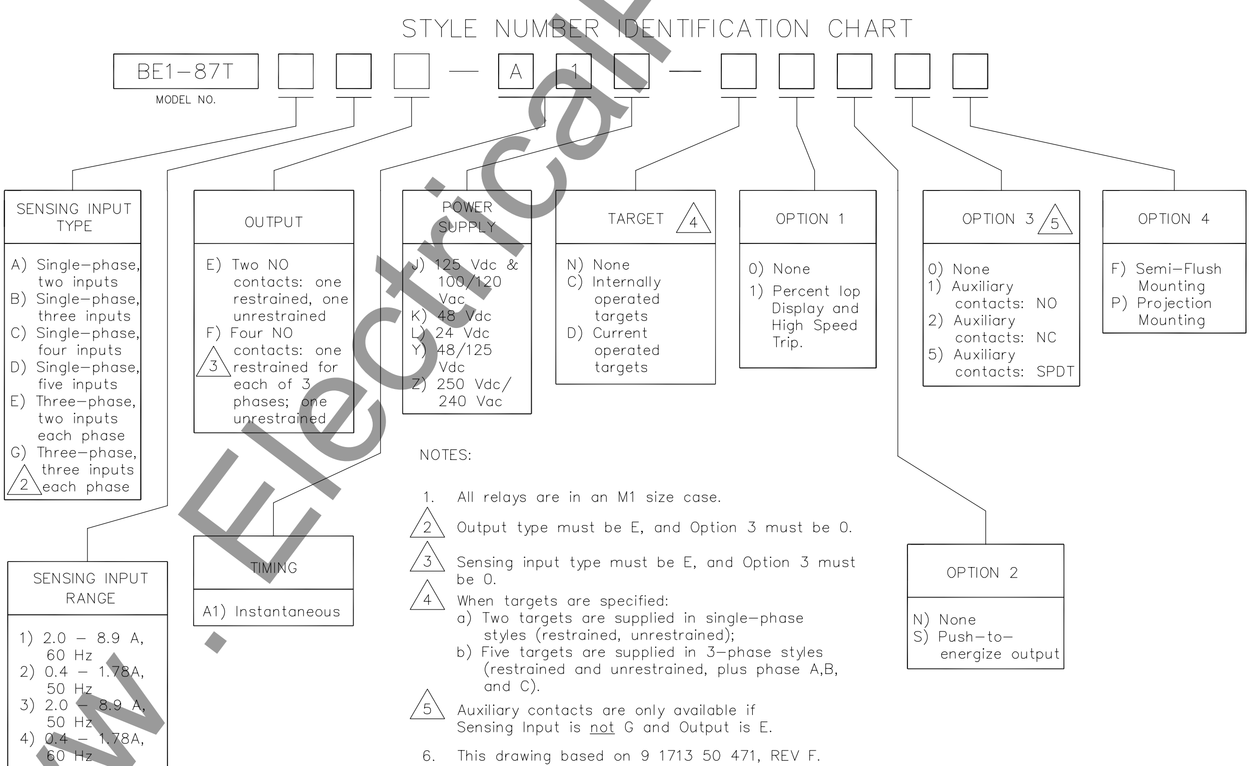

Figure 1-1. Style Number Identification Chart

SPECIFICATIONS

The BE1-87T relay is available in either single-phase or three-phase configurations and with the following features and capabilities.

Current Sensing Inputs The unit is designed to operate from the secondary of current transformers rated at either 1 A or 5 A. Frequency range is ±5 Hz of nominal.

Maximum Current Per Input

1 Ampere CT Units: 4 A continuous; 50 A or 50 X tap (whichever is less) for 1 second.

5 Ampere CT Units: 20 A continuous; 250 A or 50 X tap (whichever is less) for 1 second.

For ratings other than one second, the rating may be calculated as:

$$I = \frac{K}{\sqrt{t}}$$

Where:

t is the time (in seconds) that the current flows

K = 50 A or 50 X tap, whichever is less (1 Amp CT Units), or

K = 250 A or 50 X tap, whichever is less (5 Amp CT Models)

Current Sensing Burden Less than 0.02 ohm per phase.

Tap Setting Control (Scaling) Front panel rotary switches, labeled INPUT, permit scaling the sensed input current (or tap setting) over the range of:

1 Ampere CT Units: 0 . 4 to 1 . 78 in 0 . 02 A increments.

5 Ampere CT Units: 2 . 0 to 8 . 9 A, in 0 . 1 A increments.

Restrained Output

Pickup Range: Front panel thumbwheel switches adjust pickup of the restrained output as a percentage of the through current. The range is 15 to 60 % of the operating current in 5 % increments.

Pickup Accuracy: ±6 % of pickup ±100 mA (5 Ampere Units) or ±20 mA (1 Ampere units).

Minimum Pickup: 0.35 ±6 % of tap setting. Refer to Table 1-1 and Figure 1-2. Table 1-1 provides calculated intersection points of the slope characteristic and the minimum pickup (in multiples of tap) as shown in Figure 1-2. The calculation was derived from the formula:

$$Maximum\ I_{Restraint} = \frac{Minimum\ Pickup}{Percent\ of\ Slope}$$

For example:

$$\frac{Minimum\ Pickup}{Percent\ of\ Slope} = \frac{0.35}{20\ \%} = 1.75$$

The relay operates when the per unit difference current (operating current) is above the 0.35 pu or the slope line in Figure 1-2. Calculation examples are found in Section 5.

Table 1-1. Multiples of Tap

Front Panel Setting %	15	20	25	30	35	40	45	50	55	60
Maximum Restraint Current At Minimum Pickup In Multiples of Tap	2.33	1.75	1.40	1.17	1.00	0.875	0.778	0.700	0.636	0.583

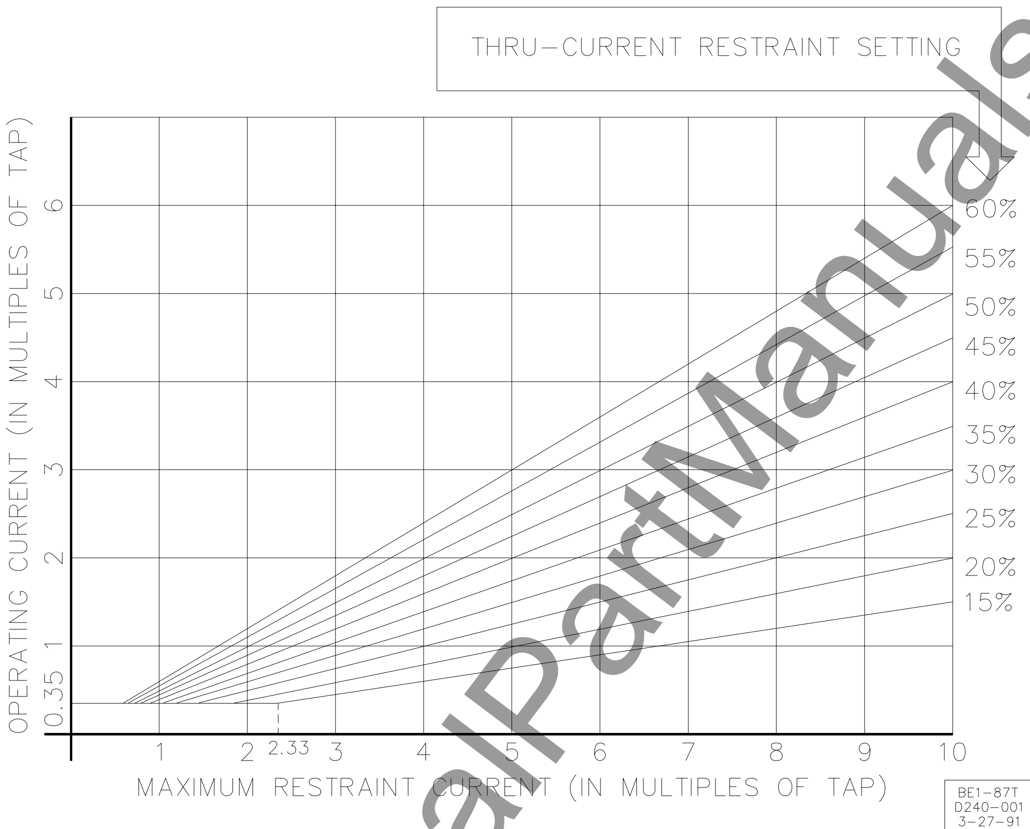

Figure 1-2. Percentage Restraint Characteristic

Second-Harmonic Restraint — Inhibit of the restrained output occurs when the second-harmonic component exceeds a pickup setting, which is internally adjustable over the range of 8 % to 15 % of the operating current for single-phase Units or 11 to 27 % for three-phase units. The factory setting is 12 % for single-phase units and 18 % for three-phase units.

Fifth-Harmonic Restraint — Inhibit of the restrained output occurs when the fifth-harmonic component exceeds a pickup setting which has an internally adjustable range of 25 to 45 % of the operating current. The factory setting is 35 %.

Unrestrained Output

Pickup Range — Front panel thumbwheel switches adjust the pickup point of the unrestrained output over a range of 6 to 21 times the tap setting in increments of 1 x Tap.

Pickup Accuracy — ±3 % of the front panel setting.

Outputs Output contact are rated as follows.

Resistive

120/240 Vac	Make 30 A for 0.2 seconds, carry 7 A continuously and break 7 A.
250 Vdc	Make and carry 30 A for 0.2 seconds, carry 7 A continuously and break 0.3 A.
500 Vdc	Make and carry 15 A for 0.2 seconds, carry 7 A continuously and break 0.1 A.

Inductive

120/240 Vac, 125/250 Vdc	Make and carry 30 A for 0.2 seconds, carry 7 A continuously and break 0.3 A, (L/R = 0.04).

Target Indicators Target indicators may be either internally-operated or current-operated (operated by a minimum of 0.2 A through the output trip circuit). When the target is current-operated, the associated output circuit must be limited to 30 A for 0.2 seconds, 7 A for 2 minutes and 3 A continuously.

Single-Phase Units	Either an internally-operated or a current-operated target is supplied (as selected by the Style Number) for each trip output (i.e., the restrained and the unrestrained functions).
Three-Phase Units	Either internally operated or current operated targets (as selected) indicate the function (restrained or unrestrained) that caused the trip, and the tripped phase (A, B, C).

Harmonic Attenuation Refer to Table 1-2.

Table 1-2. Harmonic Attenuation

Parameter (50 Or 60 Hz Models)	Minimum Attenuation at Indicated Fundamental				
	50/60 Hz	**100/120 Hz**	**150/180 Hz**	**250/300 Hz**	**500 Hz**
Through Current	0	0	0	0	12 dB
Operating Current	0	0	0	0	12 dB
2nd Harmonic Restraint	12 dB	0	12 dB	12 dB	12 dB
5th Harmonic Restraint	12 dB	12 dB	12 dB	0	12 dB

Timing (For 60 Hz units only) Refer to Figure 1-3 for Unrestrained Response Times and Figure 1-4 for Restrained Response Times.

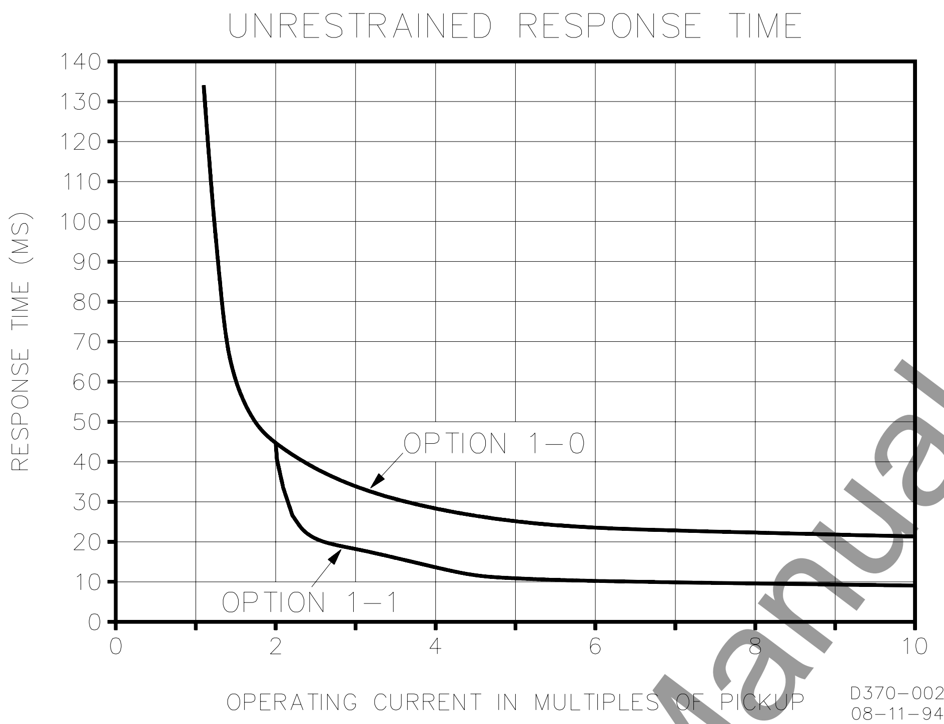

Figure 1-3. Unrestrained Response Times

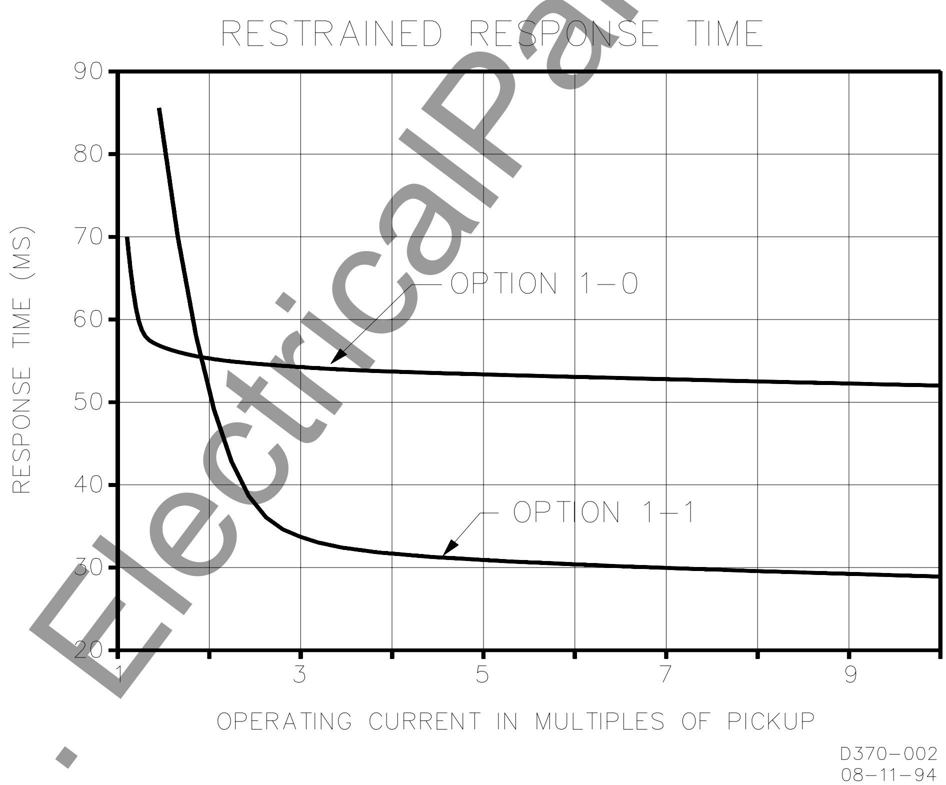

Figure 1-4. Restrained Response Times

Isolation In accordance with IEC 255-5 and ANSI/IEEE C37.90-1989, one minute dielectric (high potential) tests, as follows:

All circuits to ground: 2121 Vdc

Input to output circuits: 1500 Vac or 2121 Vdc

Power Supply Refer to Table 1-3.

Table 1-3. Power Supply Specifications

Type	Nominal Input Voltage	Input Voltage Range	Burden at Nominal (Energized)	Burden at Nominal (De-energized)
J (Mid Range)	125 Vdc 120 Vac	62 – 150 Vdc 90 – 132 Vac	9.0 W 21.0 VA∗	6.4 W 19.8 VA
K (Mid Range)	48 Vdc	24 - 60 Vdc	8.5 W	6.2 W
L† (Low Range)	24 Vdc	12 - 32 Vdc	9.0 W	6.4 W
Y (Mid Range)	48 Vdc 125 Vdc	24 - 60 Vdc 62 – 150 Vdc	8.5 W 9.0 W	6.2 W 6.4 W
Z (High Range)	250 Vdc 240 Vac	140 – 280 Vdc 190 – 270 Vac	9.5 W 28.0 VA*	6.4 W 26.0 VA

∗ *At 55 - 65 Hz.*

† *Type L power supply may require 14 Vdc to begin operation. Once operating, the voltage may be reduced to 12 Vdc.*

Surge Withstand Capability Qualified to ANSI/IEEE C37.90.1-1989, Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems, and IEC 255-5 Impulse Test and Dielectric Test.

Radio Frequency Interference (RFI) Maintains proper operation when tested in accordance with IEEE C37.90.2-1987, Trial-Use Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

UL Recognition UL Recognized per Standard 508, UL File No. E97033. Note: Output contacts are not UL Recognized for voltages greater than 250 V.

GOST-R Certification Gost-R certified, No. POCC US.ME05.B03391; complies with the relevant standards of Gosstandart of Russia. Issued by accredited certification body POCC RU.0001.11ME05.

Patent Patented in U.S., 1991, U.S. Patent No. 5014153.

Patented in Canada, 1993.

Shock In standard tests, the relay has withstood 15 g in each of three mutually perpendicular axes without structural damage or degradation of performance.

Vibration In standard tests, the relay has withstood 2 g in each of three mutually perpendicular axes swept over the range of 10 to 500 Hz for a total of six sweeps, 15 minutes each sweep, without structural damage or degradation of performance.

Operating Temperature	-40°C (-40°F) to 70°C (158°F)
Storage Temperature	-65°C (-85°F) to 100°C (212°F)
Weight	22.3 lbs (10.1 kg) maximum (three-phase unit)
	19.5 lbs (8.85 kg) maximum (single-phase unit)
Case Size	All units are supplied in an M1 case size. See Section 4, *Installation* for case dimensions.

SECTION 2 • CONTROLS AND INDICATORS

LOCATION OF CONTROLS AND INDICATORS

Table 2-1 lists and briefly describes the operator controls and indicators of the BE1-87T Transformer Differential Relay. Reference the call-out letters A through M to Figures 2-1 to 2-3; N through Q to Figure 2-5. Exploded views of controls that are mounted inside the relay (call-out letters B, D and I) are shown in Figure 2-4.

Table 2-1. Controls and Indicators

Letter	Control or Indicator	Function
A	**INPUT** (or TAP) Switches	Front panel **INPUT** switches are used to scale the transformer currents. There are two of these rotary switches for each input.
	1 Ampere CT Units	Each of the upper switches is calibrated to represent the tenths and units digits (0.4 through 1.6) of tap value. Each of the lower switches is calibrated to represent two-hundredths of tap value for each increment. Always add the setting of the lower switch to that of the upper switch. For example, if a setting of 1.02 is desired, the upper switch must be at 1.0 and the lower switch must be at 0.02. The total setting range for each input is 0.4 to 1.78.
	5 Ampere CT Units	Each of the upper switches is calibrated to represent the units digit (2 through 8) of tap value. Each of the lower switches is calibrated to represent tenths of tap value. Always add the setting of the lower switch to that of the upper switch. For example, if a setting of 5.0 is desired, the upper switch is set to 5.0, the lower switch must be at 0.0. The total setting range for each input is 2.0 to 8.9.
B	30° Phase Shift Jumpers (three-phase units ONLY)	These jumpers control the internal phase shift of the relay, either +30°, -30°, or 0°, depending upon the position of the jumpers provided for each input on the Analog #2 Board, shown in Figure 2-4. Additional information is in Section 4.
C	**UNRESTRAINED PICKUP LEVEL** Switches	This thumbwheel switch establishes the desired pickup setting for all phases of the unrestrained output. The adjustment range is from 6 to 21 times the phase tap setting, in increments of 1.
D	CALIBRATE Switch (three-phase units ONLY)	A two-position switch is located on each Analog #1 Board and is easily accessible on the right side of the relay when it is withdrawn from the case. In the **CALIBRATE** position, these switches inhibit the harmonic share feature when calibrating the 2nd Harmonic Restraint. In the **NORMAL** position, the relay will operate normally.
E	**POWER** Indicator	This LED will illuminate when operating power is supplied to the internal circuitry of the relay.

Letter	Control or Indicator	Function
F	**PUSH-TO-ENERGIZE OUTPUT** Switches Option	Two momentary pushbutton switches are accessible by inserting a 1/8 inch diameter non-conducting rod through access holes in the front panel. Switch **R**, when actuated, closes the Restrained Output Relay contacts. Switch **U**, when actuated, closes the Unrestrained Output Relay contact(s). **NOTE** The optional Auxiliary Relay contacts (Option 3-1, 3-2 or 3-5) will also be operated by the **PUSH-TO-ENERGIZE** switches if enabled by the two internal Auxiliary Relay Control Switches. (Refer to **LETTER I**.)
G	**FUNCTION** Targets Option	Electronically-latched LED targets that indicate an unrestrained or restrained output has occurred.
H	Target Reset Switch	Resets the electronically-latched targets.
I	Auxiliary Relay Control Switches Option	Two internal slide switches, **S1** and **S2**, enable the optional Auxiliary Output Relay to close only when a restrained output occurs (**S1** ON), only when an unrestrained output occurs (**S2** ON), or to close when either output occurs (**S1** and **S2** ON). When shipped from the factory, the Auxiliary Relay will be configured with **S1** and **S2** ON. **NOTE** The switches are located on the mother board and are only accessible by withdrawing the relay case.
J	**ELEMENT** Targets Option (three-phase units ONLY)	Electronically-latching LED targets indicate the phase that caused a trip operation.
K	**RESTRAINED PICKUP LEVEL** Switches	Thumb-wheel switches (one per phase element) are used to adjust the desired percent of allowable through-current restraint from 15 to 60 % in 5 % increments. (Through-current is the greatest relative individual input current.) The through-current restraint characteristic is individually adjustable for phases A, B, and C. In a three-phase unit, all three switches are typically kept at identical settings.
L	**UNREST. TRIP** Indicator	Red LED lights when there is an unrestrained pickup.
M	**REST. TRIP** Indicator	Red LED lights when there is a restrained pickup.
N	**M** Indicator	Red LED lights when the **% OF TRIP** pushbutton P is pressed and the restraint current is below the slope characteristic kneepoint as defined in Table 1-1. That is, the relay will operate at minimum pickup (0.35 times tap).

Letter	Control or Indicator	Function
O	**S** Indicator	Red LED lights when the **% OF TRIP** pushbutton P is pressed and the restraint current is above the slope characteristic kneepoint as defined in Table 1-1. That is, the relay will operate based on the restraint characteristic.
P	Percent of Trip Pushbutton	Pushbutton that is used to activate the **% of TRIP** LEDs.
Q	**% OF TRIP** Indicators Option	When the **% OF TRIP** pushbutton P is pushed, eight LEDs, shown in Figure 2-5, are used to indicate the approximate percentage of operating current to: Minimum pickup (LED **M** also lights); or Slope characteristic pickup (LED **S** also lights). The eight LEDs represent the following approximate percentages. 1 LED: 3% (Yellow LED) 2 LEDs: 7% (Yellow LED) 3 LEDs: 11% (Yellow LED) 4 LEDs: 20% (Red LED) 5 LEDs: 40% (Red LED) 6 LEDs: 60% (Red LED) 7 LEDs: 80% (Red LED) 8 LEDs: 100% (Red LED) A bar chart above the LEDs shows the relative percentage of trip.

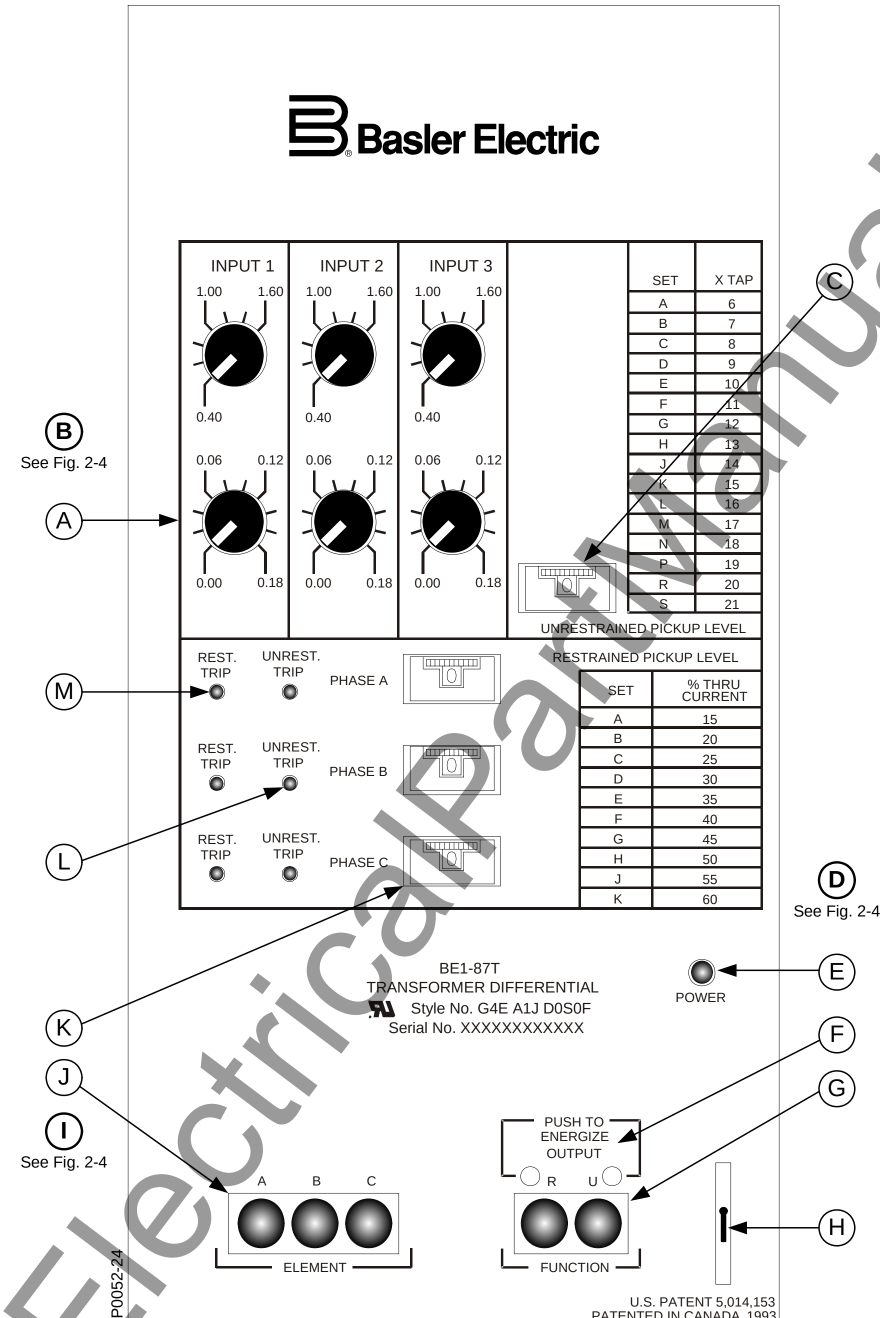

Figure 2-1. Sensing Input Range 1 or 3 Three-Phase, Three Inputs

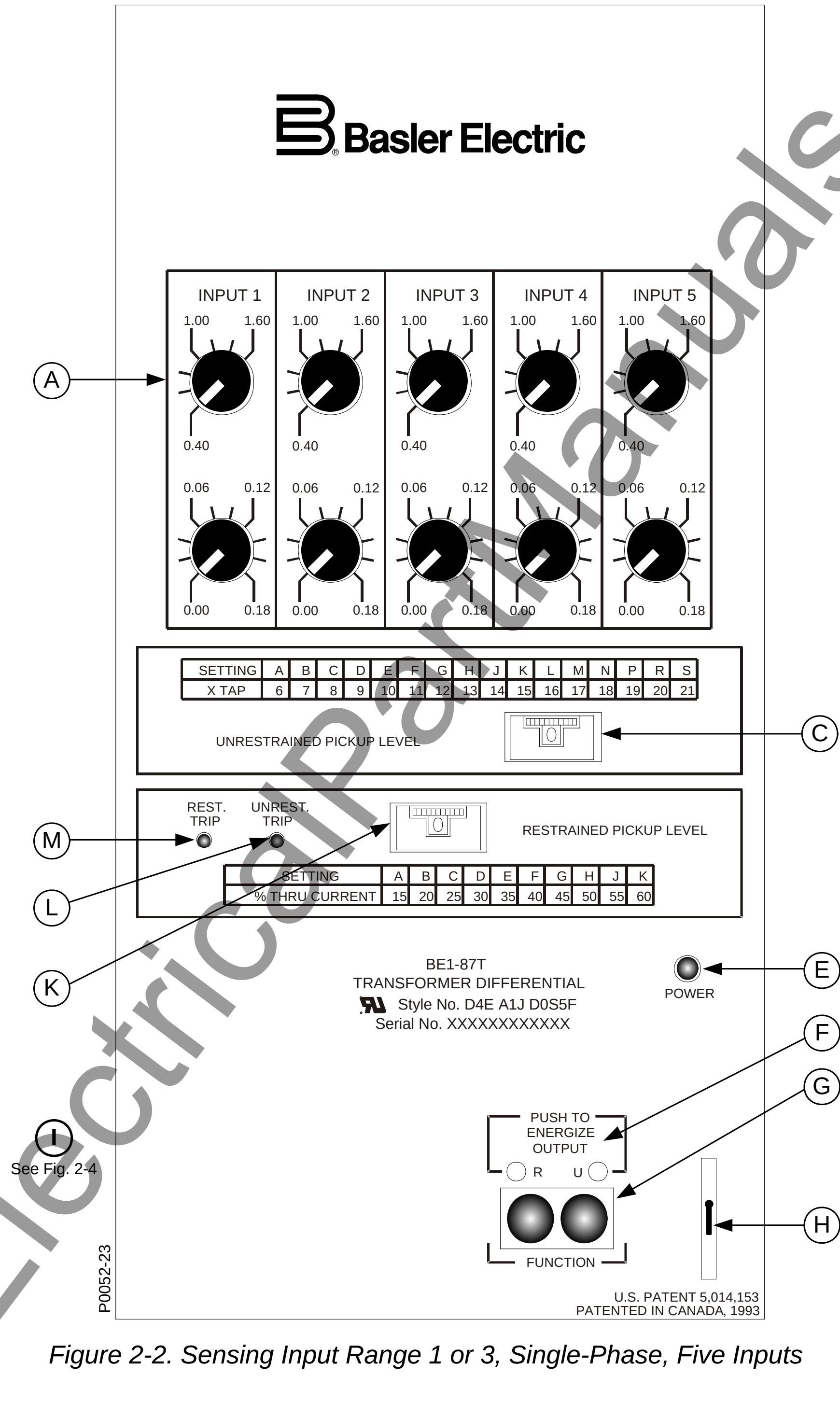

Figure 2-2. Sensing Input Range 1 or 3, Single-Phase, Five Inputs

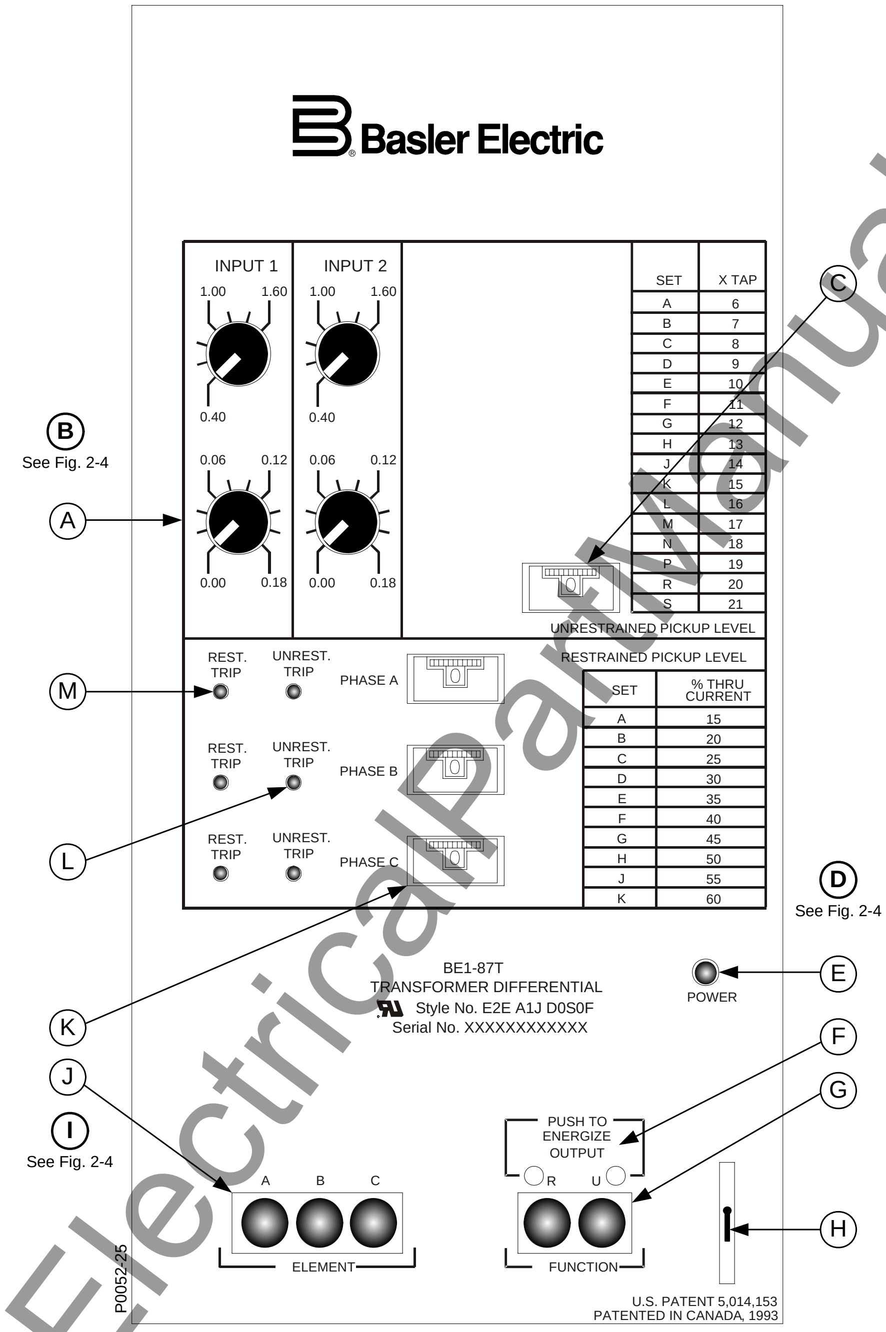

Figure 2-3. Sensing Input Range 2 or 4 Three-Phase, Two Inputs

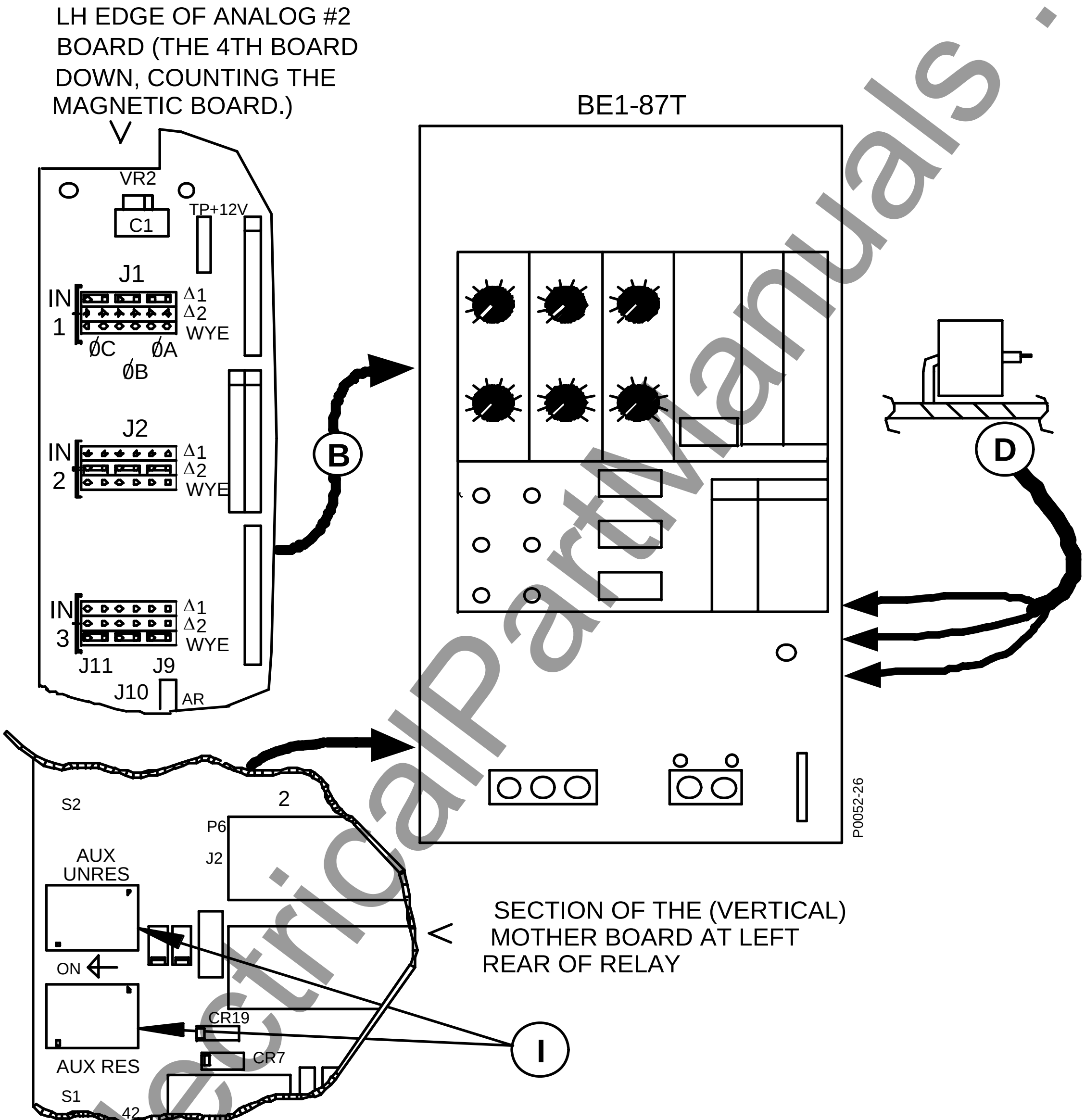

Figure 2-4. Controls Mounted Inside the Relay

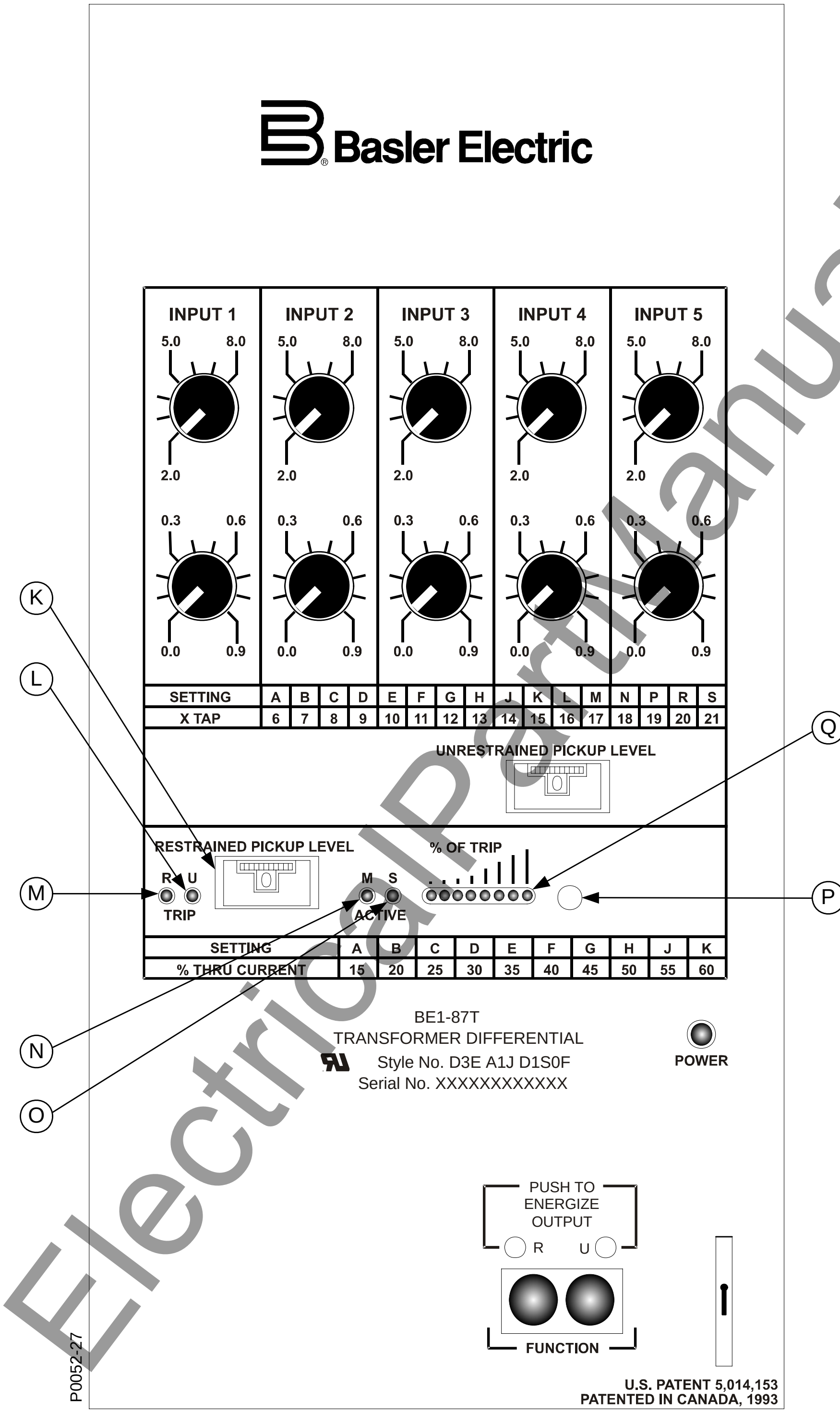

Figure 2-5. Sensing Input Range 2 or 4, Option 1-1, Single-Phase, Five Inputs, % OF TRIP Option

SECTION 3 • FUNCTIONAL DESCRIPTION

GENERAL

BE1-87T relays are solid-state devices that protect transformers by providing output contact closure when the scaled current into the protected transformer does not equal the scaled current out, within defined limits. These relays are harmonically restrained to prevent tripping during initial energization and external fault conditions. A through-current restraint also provides security against tripping for external faults. An unrestrained tripping element is included to provide a high-speed trip in the event of a particularly severe fault within the transformer.

DESCRIPTION

The functional block diagrams of Figures 3-1 and 3-2 illustrate the overall operation of the BE1-87T Transformer Differential Relay. (Figure 3-1 shows Phase A or single-phase functions; Figure 3-2 shows the additional functions for phases B and C.) Since the three phases are functionally similar, only phase A is shown in detail in Figure 3-1. Note that in a three-phase unit, there may be one restrained output for each phase (Output Type Option E in the third position of the Style Number), or one restrained output that serves for all three phases (Option F in the third position). When Target Option C or D is specified for a three-phase Unit (in the seventh position), an individual target is supplied for each phase.

Current Transformers

In the protected zone of the power system, CTs with a 1 ampere or 5 ampere secondary winding supply the sensing current for each input. This is not shown in Figure 3-1 or Figure 3-2. Other relays may be connected ahead of the BE1-87T. Sensing currents are, in turn, applied to relay internal input transformers. These transformers provide system isolation.

Scaling

Input currents are scaled by the front panel **INPUT** rotary switches that introduce resistances to the internal CT secondaries. The switches are calibrated in 0.02 ampere increments from 0.4 to 1.78 ampere for 1 ampere CT units (Options 2 or 4 in the second position of the Style Number), and in 0.1 ampere increments from 2.0 to 8.9 amperes for 5 ampere CT models (Options 1 or 3 in the second). The many graduations of adjustment are provided to allow each input to approach an ideal representation of the actual operating per unit value.

Summing

Analog signals representing each input contribution are vector summed (shown as *Summing* in Figure 3-1). This summing process produces the operating current (I_{OP}) that is the phasor sum of the input currents.

Ideally, and with perfectly matched CTs, a transformer without an internal fault should cause I_{OP} to be exactly zero on a continuous basis. When not zero, a fault would be indicated. However, saturation effects caused by heavy through-current or magnetic inrush can cause a temporary imbalance even though no internal fault has occurred. To prevent a false trip under such conditions, various types of restraint are used. Each restraint is specific to a potential cause of misoperation. These are individually discussed in the topic *Restrained Trip Output*.

30° Internal Phase Shift (Three-Phase Relays ONLY)

For three-phase units, the inputs to the *Summing* function are first routed through the *30° Phase Shift* circuit. There the signals may be advanced or retarded by 30° or passed through unchanged. Compensating phase shift direction (shown as the *Phase Shift Setting* circuit in Figure 3-1) is determined by the position of three jumpers on the internal Analog #2 Board. (The location of these jumpers is shown in Figure 2-4.) The internal phase shift will accomplish the corresponding zero sequence blocking. The current magnitude will be increased by $\sqrt{3}$ and must be taken into account in the tap setting (explained later in detail in Section 4).

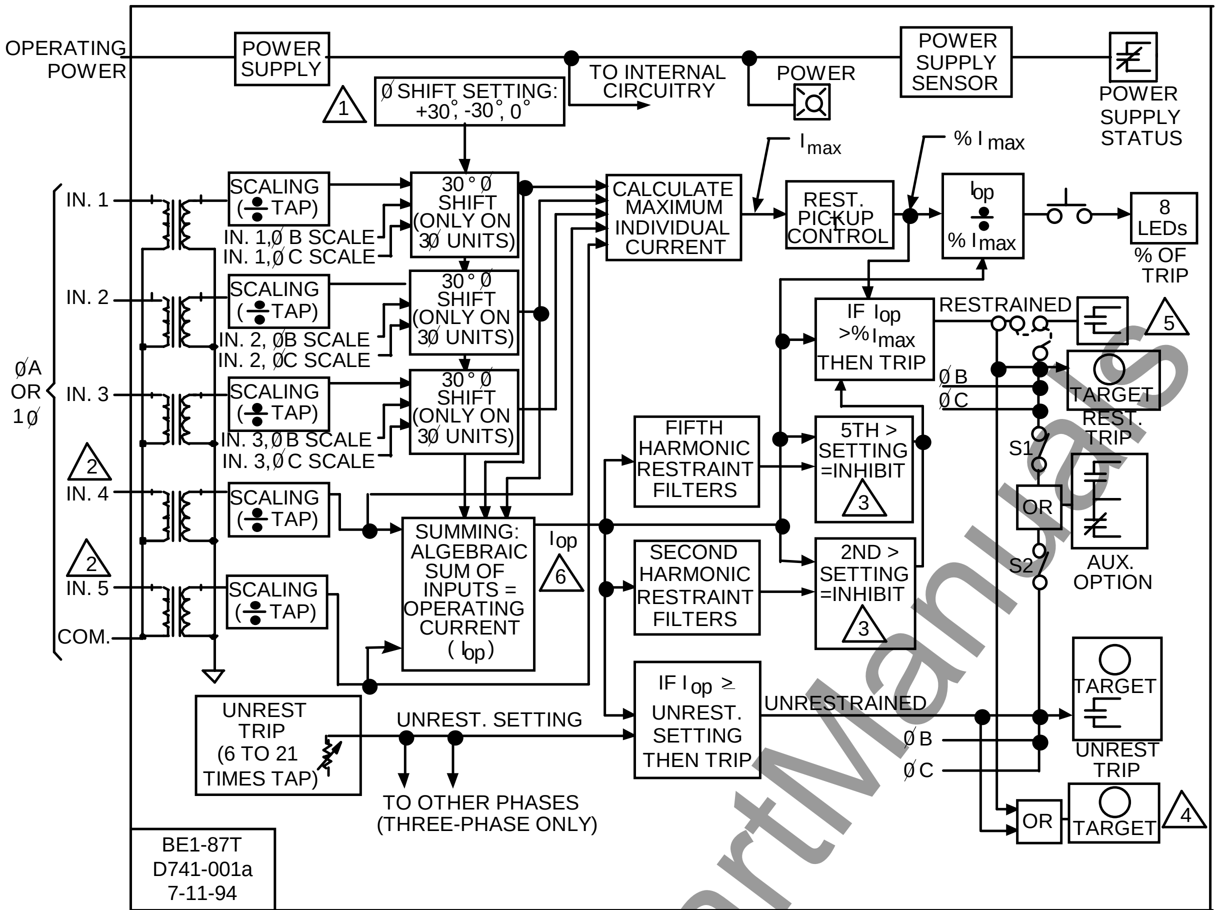

Figure 3-1. Functional Block Diagram

NOTES

1. Present in three-phase units ONLY.
2. Inputs 4 and 5 are available in single-phase units ONLY.
3. The settings are calibrated to a specified percentage of the harmonic to the fundamental. See **Harmonic Restraints** for factory settings.
4. Phase Targets are supplied on three-phase units ONLY.
5. Restrained Trip Contact:
   - One contact for single-phase units.
   - One contact or one contact per phase available on three-phase units.
6. Three-phase units use the sum of the second harmonic from each phase to restrain each phase.
7. Phase Targets are supplied on three-phase units ONLY.
8. Restrained Trip Contact:
   - One contact for single-phase units.
   - One contact or one contact per phase available on three-phase units.

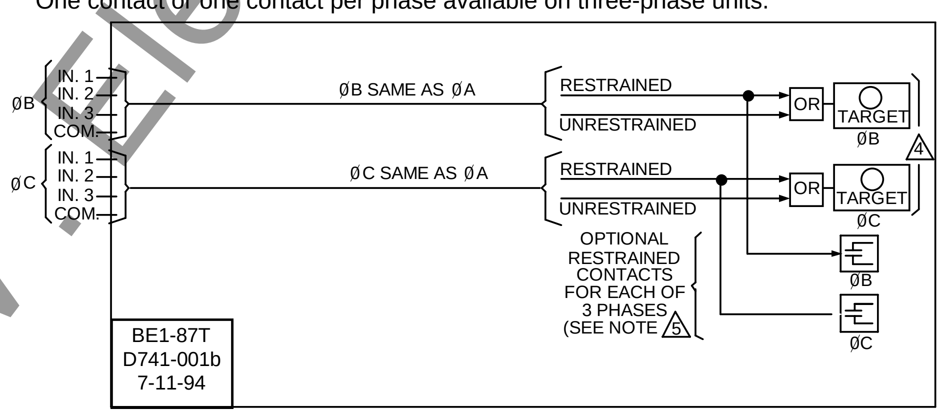

Figure 3-2. Functional Block Diagram, Phase B and Phase C

Restrained Trip Output

Restrained trip output contacts are subject to three types of restraint (i.e., inhibit) signals:

- Percentage restraint
- Second-harmonic restraint
- Fifth-harmonic restraint

These signals are developed within the relay in response to external conditions and block the restrained output contacts from closing.

Percentage Restraint

Percentage restraint developed from the maximum through current and the slope setting determines the minimum operating current I_{OP} (Figure 3-1) in a comparator where I_{OP} must be greater than $\%I_{MAX}$ to produce a Restraint Trip output. The I_{OP} desired trip level is adjustable on the front panel **RESTRAINED PICKUP LEVEL** switches shown in Figures 2-1 through 2-3.

Comparators in the *Calculate Max. Individual Current* circuit determine which input (of a particular phase) is receiving the greatest current. That input is chosen and then called the I_{MAX} signal. The I_{MAX} output is then scaled by the front panel **RESTRAINED PICKUP LEVEL** switches (shown as the *Restrained Pickup Control* in Figure 3-1). The resulting signal ($\%I_{MAX}$), that represents the percentage of through-current is extended to the *Then Trip* comparator and the I_{OP} *Divided By* $\%I_{MAX}$ function.

The *Then Trip* circuitry compares the operating current (I_{OP}) to $\%I_{MAX}$. If the operating current is greater than $\%I_{MAX}$ (and there is no *5th* or *2nd* harmonic restraint to cause an inhibit as described below), a *Restrained Trip* output is produced.

I_{OP} *Divided By* $\%I_{MAX}$ contains eight comparators and compares I_{OP} to the preset percentage levels of $\%I_{MAX}$. If I_{OP} is greater than the preset percent of $\%I_{MAX}$ for a specific comparator, the LED associated with that comparator lights. The eight LEDs represent the following approximate percentages:

First LED:	3%
Second LED:	7%
Third LED:	11%
Fourth LED:	20%
Fifth LED:	40%
Sixth LED:	60%
Seventh LED:	80%
Eighth LED:	100%

NOTE

As each successive LED lights, all previous or lesser percentage value LEDs will also light.

Harmonic Restraints

Development of a restrained trip output may be inhibited by either of two harmonic restraints. These are generated by bandpass filters tuned to the second and fifth harmonics of the operating current. Comparators monitor these signals. When the fifth-harmonic content exceeds 35% of the operate current (indicating overexcitation of the transformer) or when the second-harmonic content exceeds 12% (single-phase) or 18% (three-phase) of the operate current (indicating a magnetic inrush condition), an inhibit signal is developed that blocks operation of the *Restrained Trip* output contact. (Stated percentages represent the factory setting.)

Unrestrained Trip Output

I_{OP} is also compared against a reference established by the front panel **UNRESTRAINED PICKUP LEVEL** switch is shown in Figures 2-1 through 2-5. When this reference is exceeded, the *Unrestrained Trip* output relay is energized. An unrestrained trip is not affected by through-current or harmonic inhibits.

Auxiliary Relay Option

Auxiliary relays (Option 3-1, 3-2 or 3-5 in the tenth position of the Style Number) are accompanied by two switches, **S1** and **S2**, which allow the relays to respond to a restrained trip (**S1** ON) or to an unrestrained trip (**S2** ON), or both (**S1** and **S2** ON). These switches (letter I of Figure 2-4 and described in Table 2-1) are located on the mother board and are shipped in the ON position. Auxiliary relays may be disabled by opening both switches (**S1** and **S2** OFF).

Power Supply

Relay operating power is developed by a wide-range, isolated, low-burden, switching power supply that delivers ±12 Vdc to the relay's internal circuitry. The power supply is not sensitive to the input power polarity. A front panel LED power indicator lights to indicate that the power supply is functioning properly.

Style number designations and input voltage ranges for the available power supply models are provided in Section 1, *General Information*.

Power Supply Status Output (Optional)

The *Power Supply Status* output relay has normally closed (NC) contacts. The relay is energized by the presence of nominal voltage at the output of the power supply. Normal operating voltage then keeps the relay continuously energized and its contacts open. However, if the power supply voltage falls below requirements, the *Power Supply Status* output relay will de-energize and close the contacts.

The Power Supply Status output is not associated with any magnetically latched target. The **POWER** LED on the front panel provides a visual indication of the normal operating status of the power supply.

NOTE

Sensing Input Types A through E (first position of the Style Number) have paddle-operated shorting bars included in the relay case (terminals 19 and 20) so that the *Power Supply Status* output terminals can provide a remote indication that the BE1-87T has been withdrawn from its case or that it has been taken out of service by removing the connection plugs. Sensing Input Type G relays do NOT have shorting bars on the Power Supply Status output. Sensing Input Type G units use terminal 9 (lower terminal block) and terminal 19 (upper terminal block) for the *Power Supply Status* output.

Target Indicators (Optional)

When the Target option is specified as either C or D, shown in the seventh position of the Style Number, electronically latched indicators, labeled **FUNCTION**, are incorporated in the front panel. The electronically latched and reset targets consist of red LED indicators. The appropriate target is tripped when either a restrained (**R**) or unrestrained (**U**) output occurs. Latched targets are reset by operating the target reset switch on the front panel. If relay operating power is lost, any illuminated (latched) targets are extinguished. When relay operating power is restored, the previously latched targets are restored to their latched state.

When targets are specified for three-phase relays, three additional **ELEMENT** targets are incorporated to indicate the phase involved. Only the **FUNCTION** targets, restrained (**R**) or unrestrained (**U**) are available for single-phase units.

Relays can be equipped with either internally operated targets (Type C) or current operated targets (Type D). Both target types are reset by operating the target reset switch.

- Type C target (referred to as internally operated) is actuated by an integral driver circuit that responds directly to the relay internal logic. This type of target is tripped regardless of the amount of current flowing through the associated output contact.
- Type D target (referred to as current operated) is actuated when a minimum of 0.2 A flows through the associated output contacts. To accomplish this, a special reed relay is placed in series with the contact to signal the target indicator. (The series impedance of the reed relay is less than 0.1 ohm.) Current in the output circuit must be limited to 30 amperes for 0.2 seconds, 7 amperes for 2 minutes and 3 amperes continuously.

> **NOTE**
>
> Prior to September 2007, the BE1-87T target indicators consisted of magnetically latched, disc indicators. These mechanically latched target indicators have been replaced by the electronically latched LED targets in use today.

% of Trip

When the % of trip pushbutton Q is pushed, eight LEDs, shown in Figure 2-5, are used to indicate the percentage of operating current to: Minimum pickup (LED M also lights); or Slope characteristic pickup (LED S also lights). The eight LEDs represent the following percentages:

1 LED: 3% (Yellow LED)

2 LEDs: 7% (Yellow LED)

3 LEDs: 11% (Yellow LED)

4 LEDs: 20% (Red LED)

5 LEDs: 40% (Red LED)

6 LEDs: 60% (Red LED)

7 LEDs: 80% (Red LED)

8 LEDs: 100% (Red LED)

A bar chart above the LEDs shows the relative percentage of trip.

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SECTION 4 • INSTALLATION

GENERAL

When not shipped as part of a control or a switchgear panel, the relay is shipped in a sturdy carton to prevent damage during transit. Immediately upon receipt of a relay, check the model and Style Number against the requisition and packing list to see that they agree. Visually inspect the relay for damage that may have occurred during shipment. If there is evidence of damage, immediately file a claim with the carrier and notify the Regional Sales Office, or contact a sales representative at Basler Electric, Highland, Illinois.

In the event the relay is not to be installed immediately, store the relay in its original shipping carton in a moisture- and dust-free environment. For more information, see *STORAGE* in Section 4. When the relay is to be placed in service, it is recommended that the *VERIFICATION TESTS*, shown in Section 5, be performed prior to installation.

RELAY OPERATING PRECAUTIONS

Before installation or operation of the relay, note the following precautions.

1. A minimum of 0.2 A in the output circuit is required to ensure operation of current-operated targets.
2. The relay is a solid-state device and has been type tested in accordance with the requirements defined under *Dielectric Test.* If a wiring insulation test is required on the panel assembly in which the relay is to be installed, it is suggested that the connection plugs (or paddles) of the relay be removed and the cradle withdrawn from the case so as not to produce false readings during the wiring insulation test.
3. When the connection plugs are removed, the relay is disconnected from the operating circuit and will not provide system protection. Always be sure that external operating (monitored) conditions are stable before removing a relay for inspection, testing, or servicing. Be sure that connection plugs are in place before replacing the front cover.

CAUTION

To prevent possible false tripping, the upper connection plug should be in place prior to removing or installing the lower connection plug.

4. Thumbwheel switches should not be changed while the relay is in service. Momentary undesired indications and outputs may occur.

WARNING!

The **TEST PROCEDURES** require familiarity with solid-state relay circuits. To avoid personal injury or equipment damage, do not proceed unless qualified in this area.

MOUNTING

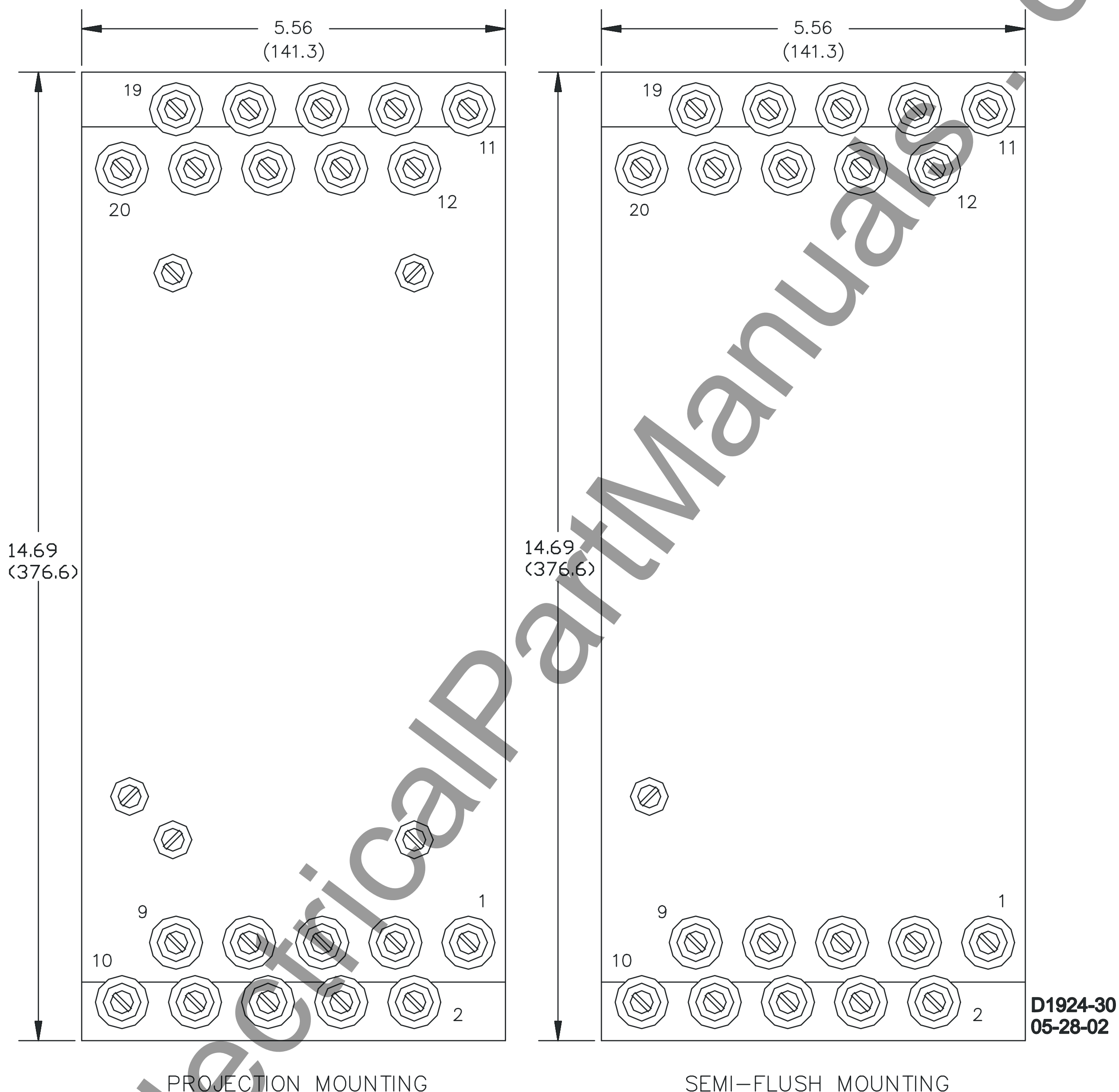
Because the BE1-87T, Transformer Differential Relay, is of solid-state design. It does not have to be mounted vertically. Any convenient mounting angle may be chosen. The BE1-87T relay is supplied in a standard M1 size drawout case and can be either semi-flush or projection mounted (Option 4). Refer to Figures 4-1 through 4-6 for outline dimensions and panel drilling diagrams.

NOTE

Several procedures in this manual require the removal of printed circuit boards. Refer to the topic **RELAY DISASSEMBLY** before installing the BE1-87T.

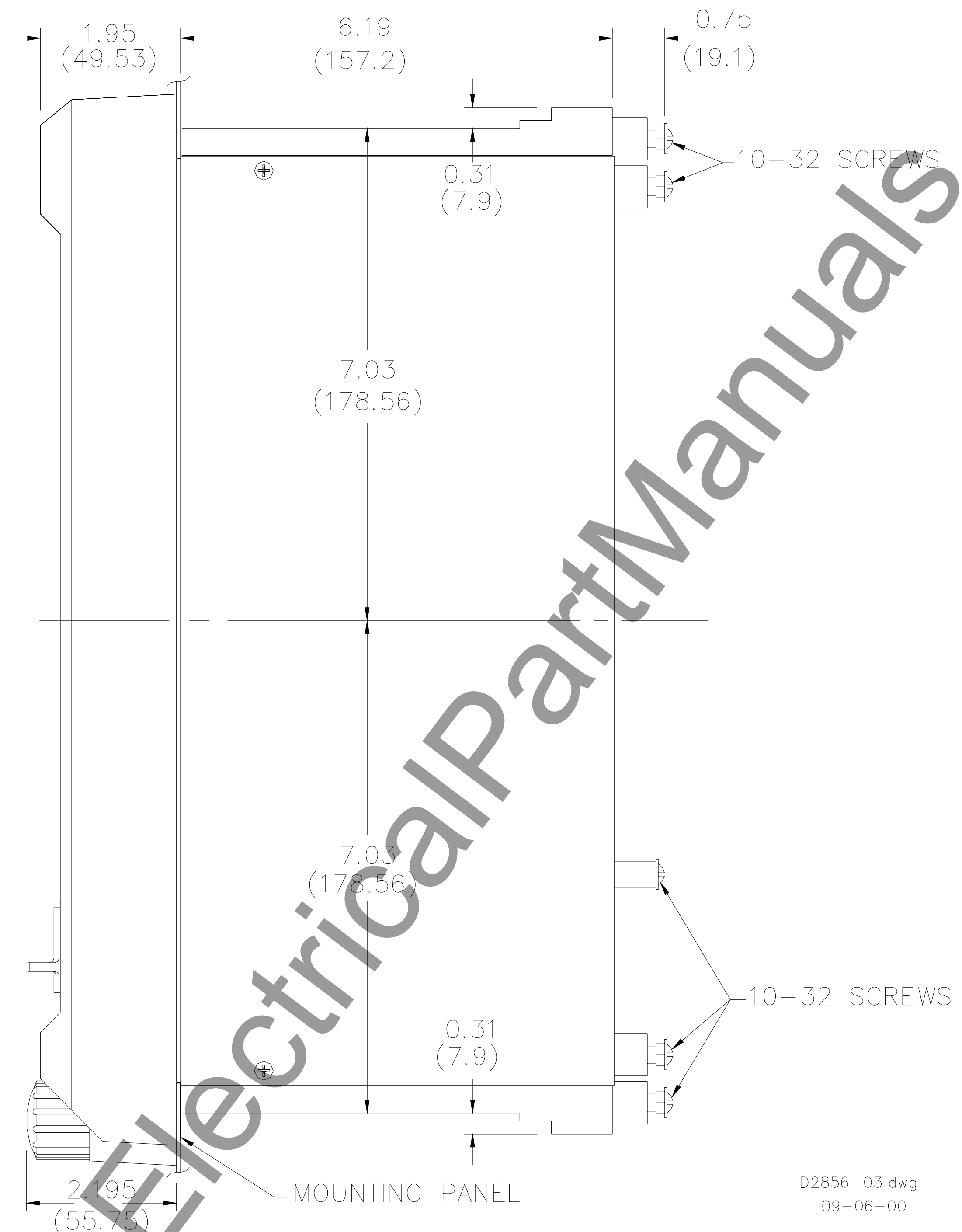
Inches (Millimeters)

Figure 4-1. Outline Dimensions, Front View



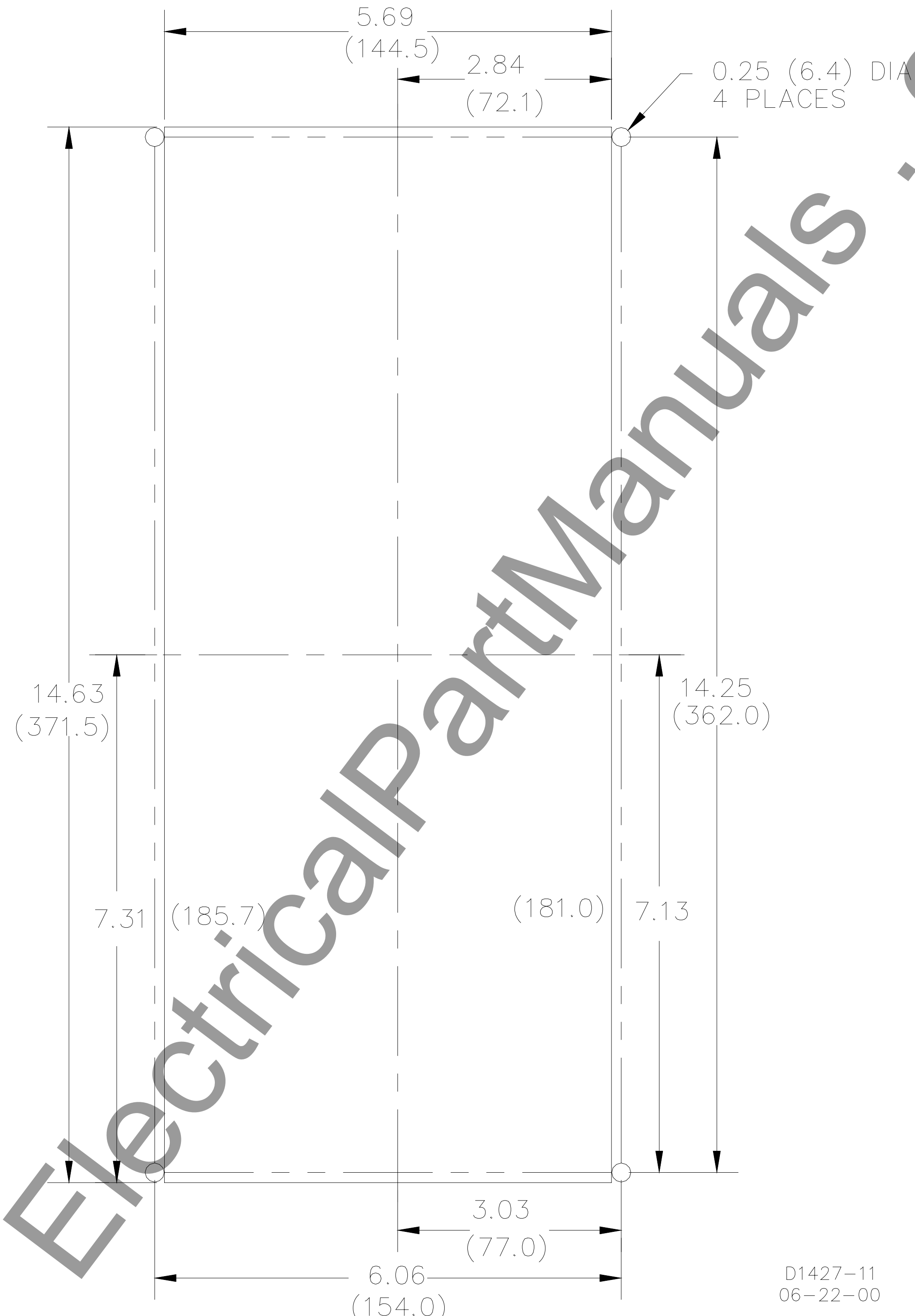
Inches (Millimeters)

Figure 4-2. Outline Dimensions, Rear View



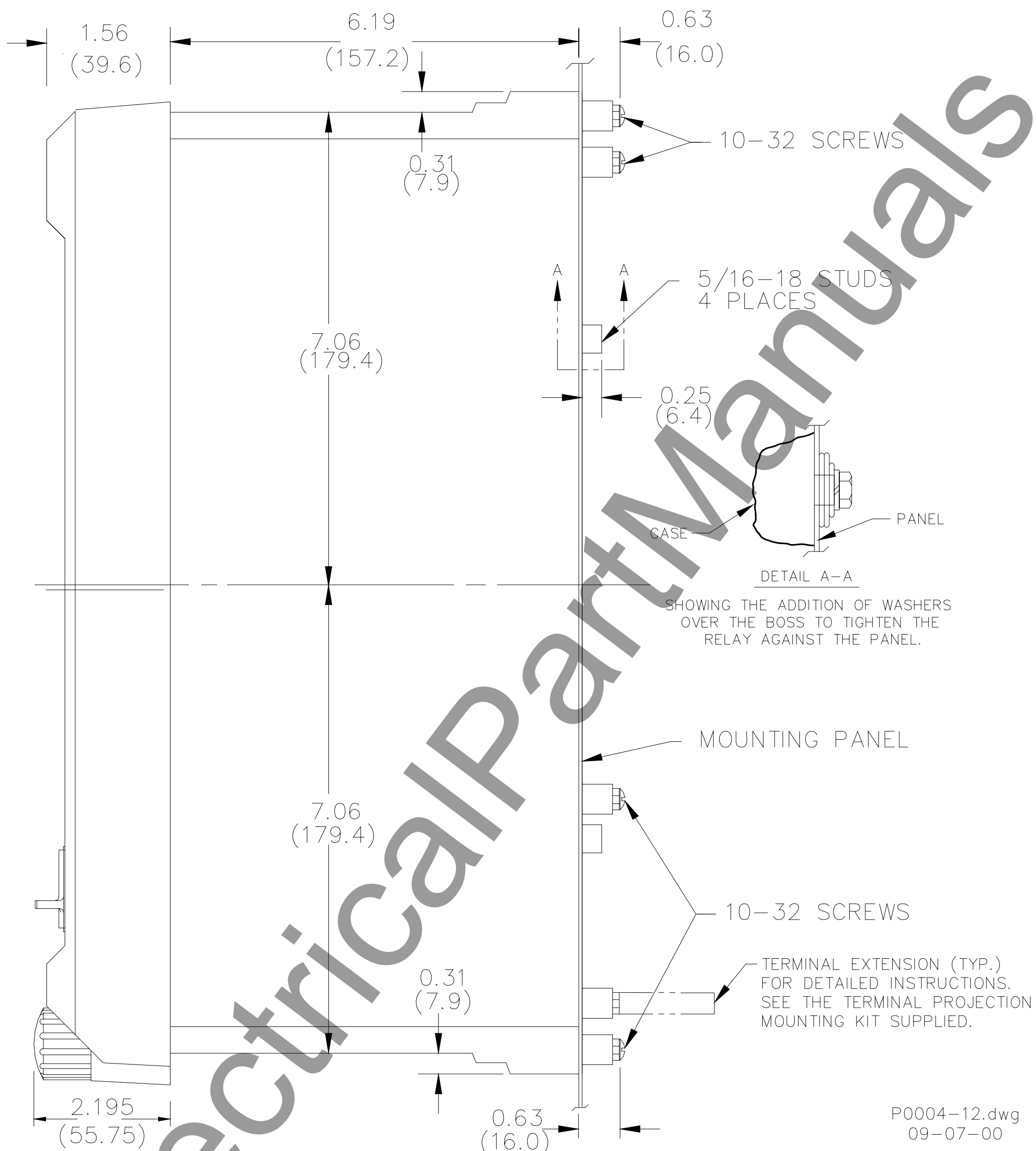
Inches (Millimeters)

Figure 4-3. Outline Dimensions, Side View (Semi-Flush Mounting)



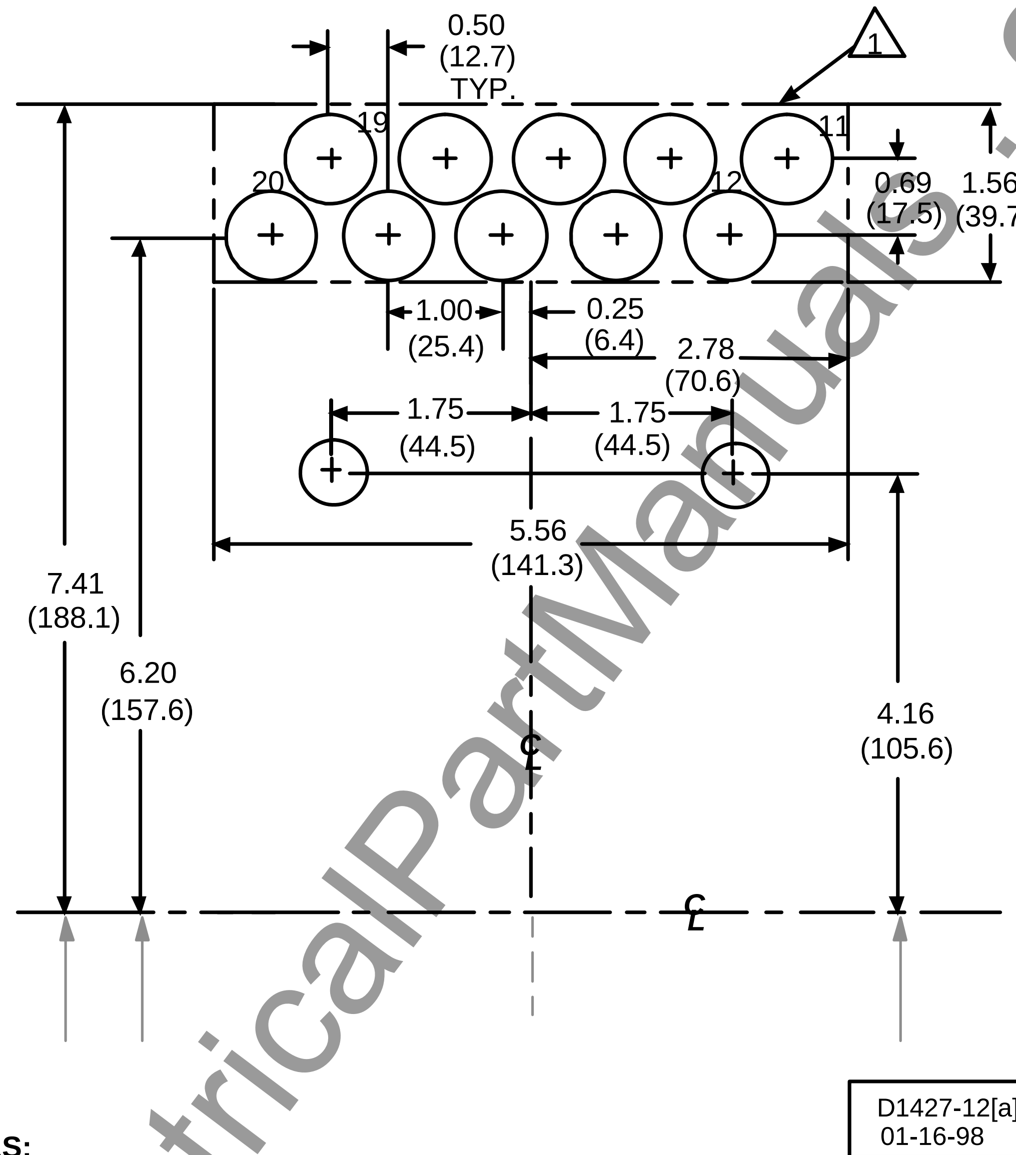
Inches (Millimeters)

Figure 4-4. Panel Drilling Diagram (Semi-Flush Mounting)



Inches (Millimeters)

Figure 4-5. Outline Dimensions, Side View (Projection Mounting)

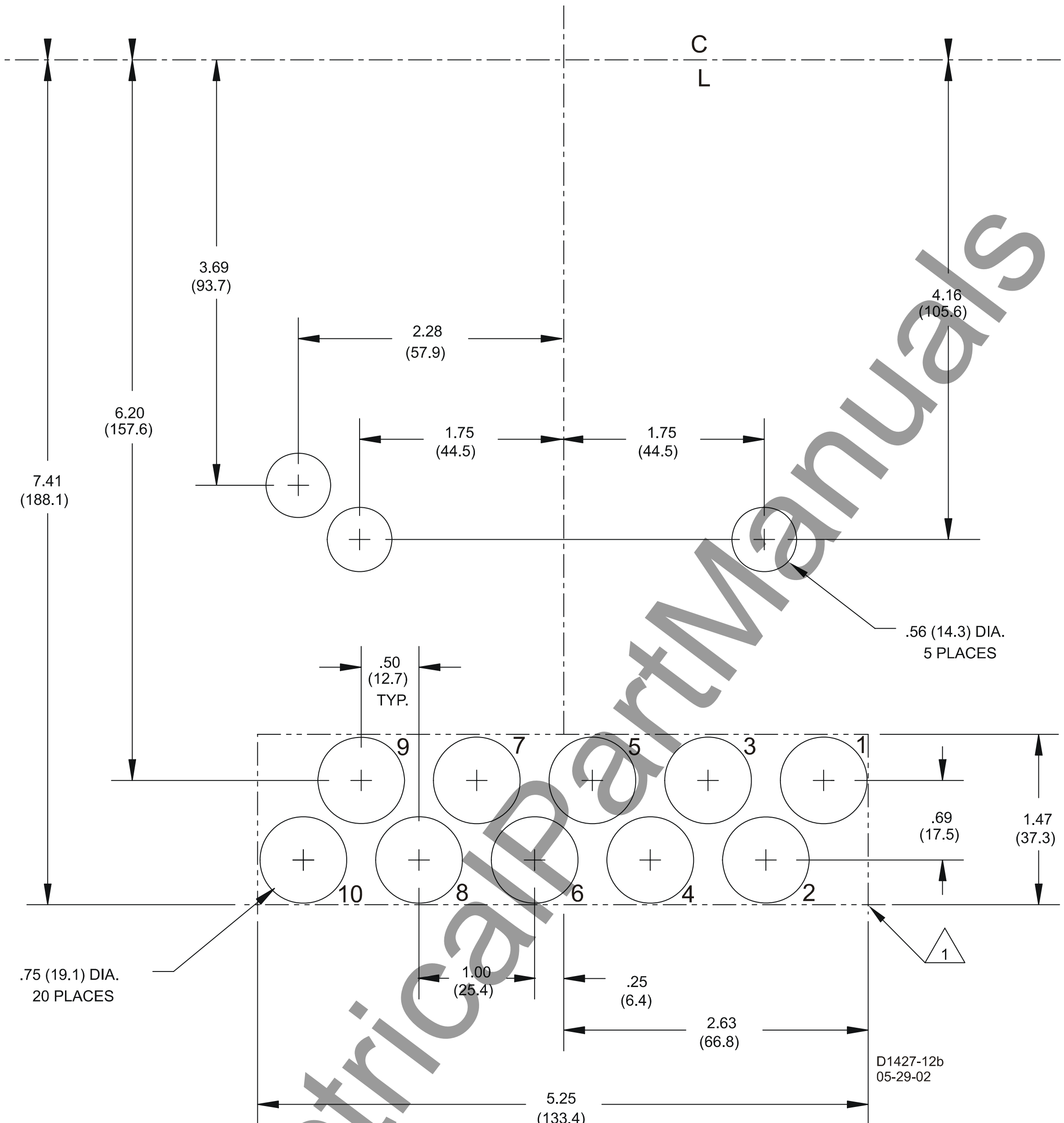


NOTES:

1. OPTIONAL RECTANGULAR CUTOUT MAY REPLACE 10 DRILLED HOLES.
2. TERMINAL NUMBERS SHOWN ARE AS VIEWED FROM REAR OF RELAY.
3. BOTTOM HALF OF PANEL DRILLING DIAGRAM (FROM CENTERLINE DOWN) IS SHOWN IN FIGURE 4-6b.

Inches (Millimeters)

Figure 4-6a. Panel Drilling Diagram-Top Half (Projection Mounting)



NOTES:

1. OPTIONAL RECTANGULAR CUTOUT MAY REPLACE 10 DRILLED HOLES.
2. TERMINAL NUMBERS SHOWN ARE VIEWED FROM REAR OF RELAY.
3. TOP HALF OF PANEL DRILLING DIAGRAM (FROM CENTERLINE UP) IS SHOWN IN FIGURE 4-6a.

Inches (Millimeters)

Figure 4-6b. Panel Drilling Diagram-Bottom Half (Projection Mounting)

DIELECTRIC TEST

In accordance with IEC 255-5 and ANSI/IEEE C37.90-1989, one minute dielectric (high potential) tests may be performed as follows.

All circuits to ground:	2121 Vdc
Input to output circuits	1500 Vac or 2121 Vdc

Note that this device employs decoupling capacitors to ground at all the output terminals, and at the power supply terminals (3, 4). Accordingly, a leakage current of approximately 15 milliamperes per 1000 Vac is to be expected.

CONNECTIONS

Incorrect wiring may result in damage to the relay. Be sure to check the model and Style Number against the options listed in the Style Number Identification Chart (Figure 1-1) before connecting and energizing a particular relay.

NOTE

Be sure the relay case is hard-wired to earth ground with no smaller than 12 AWG copper wire attached to the ground terminal on the rear of the relay case. When the relay is configured in a system with other protective devices, it is recommended to use a separate lead to the ground bus from each relay.

Except as noted above, connections should be made with a minimum wire size of 14 AWG. Figures 4-7 through 4-10 show case terminals designations for four typical relay configurations. Figures 4-11 through 4-14 show the internal connections of the BE1-87T. Control circuit connections are shown in Figures 4-15 through 4-18.

CAUTION

To prevent possible false tripping, the upper connection plug should be in place prior to removing or installing the lower connection plug.

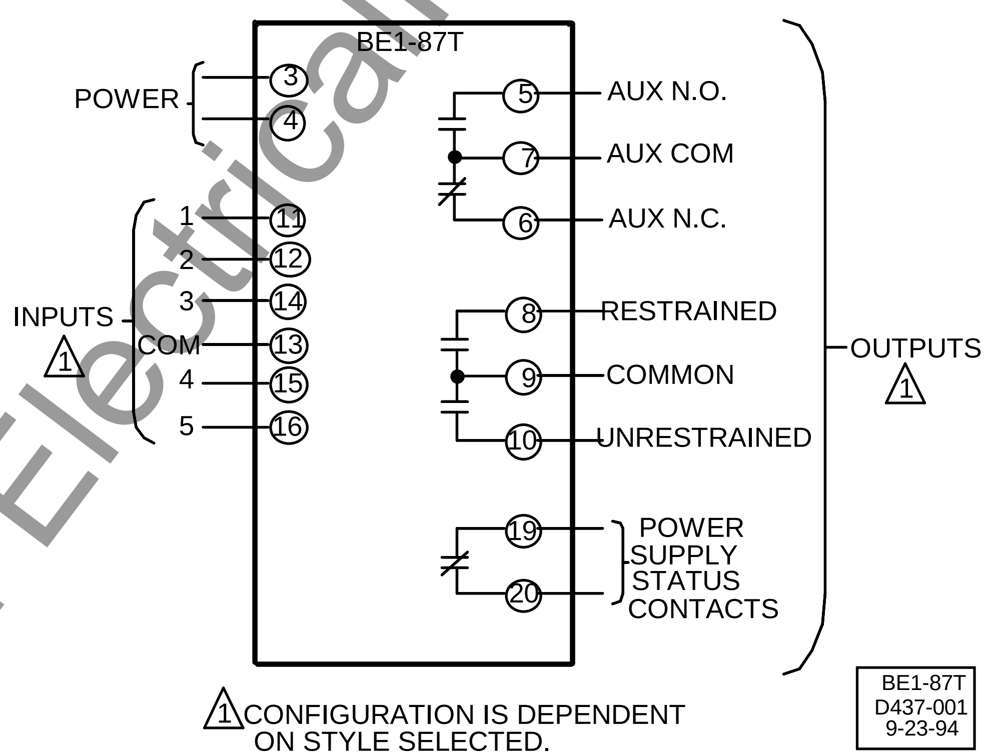


Figure 4-7. Case Terminals: Single-Phase

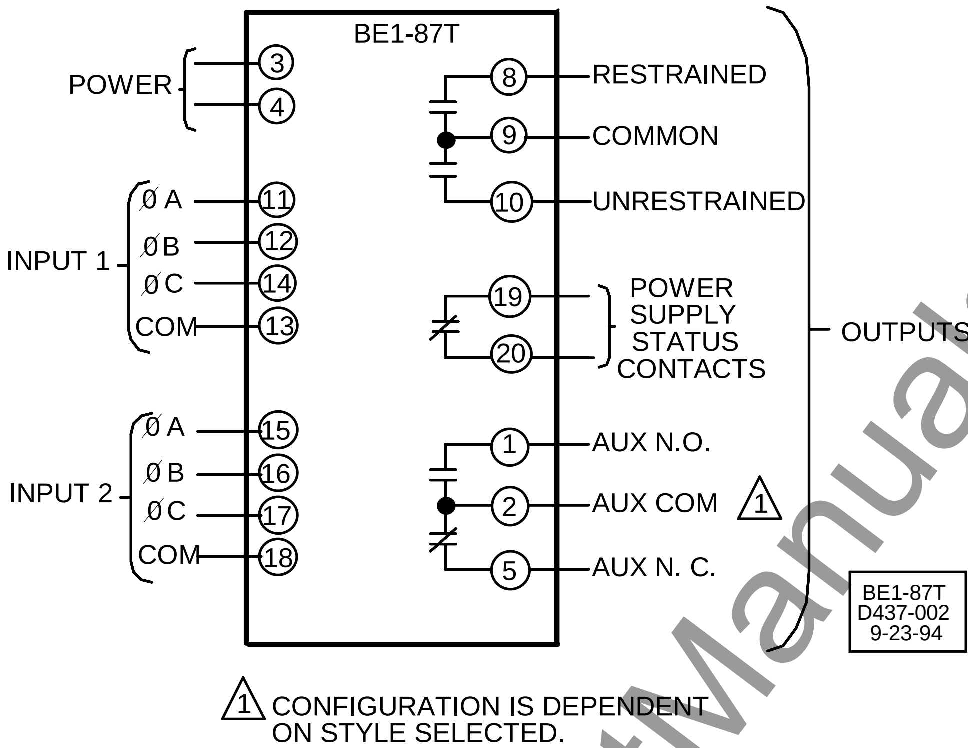


Figure 4-8. Case Terminals: Three-Phase, Two Input (Sensing Input Type E), Output Option E

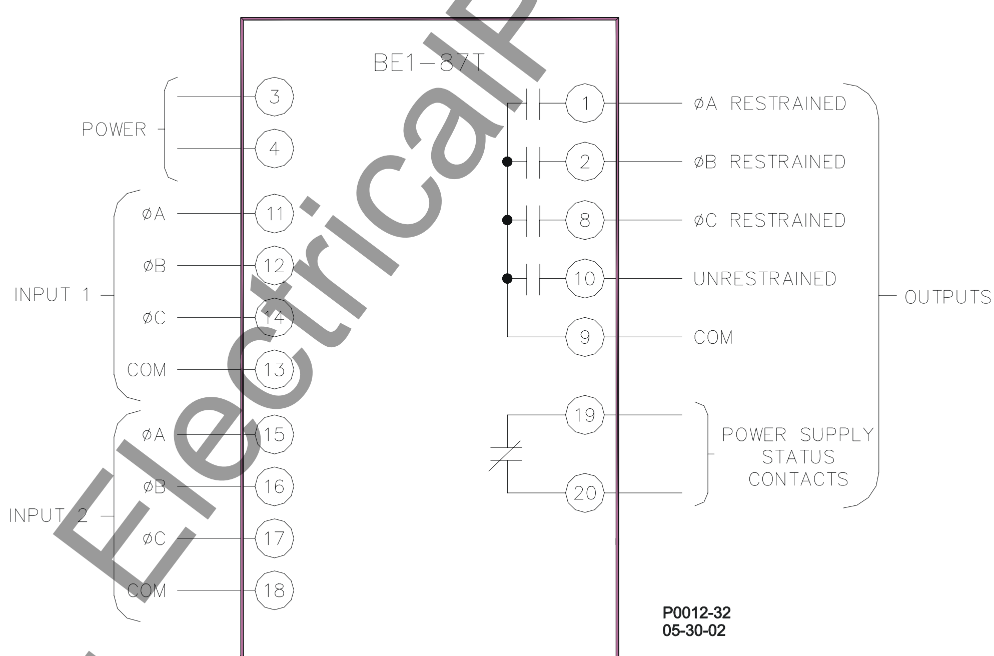


Figure 4-9. Case Terminals: Three-Phase, Two Input (Sensing Input Type E), Output Option F

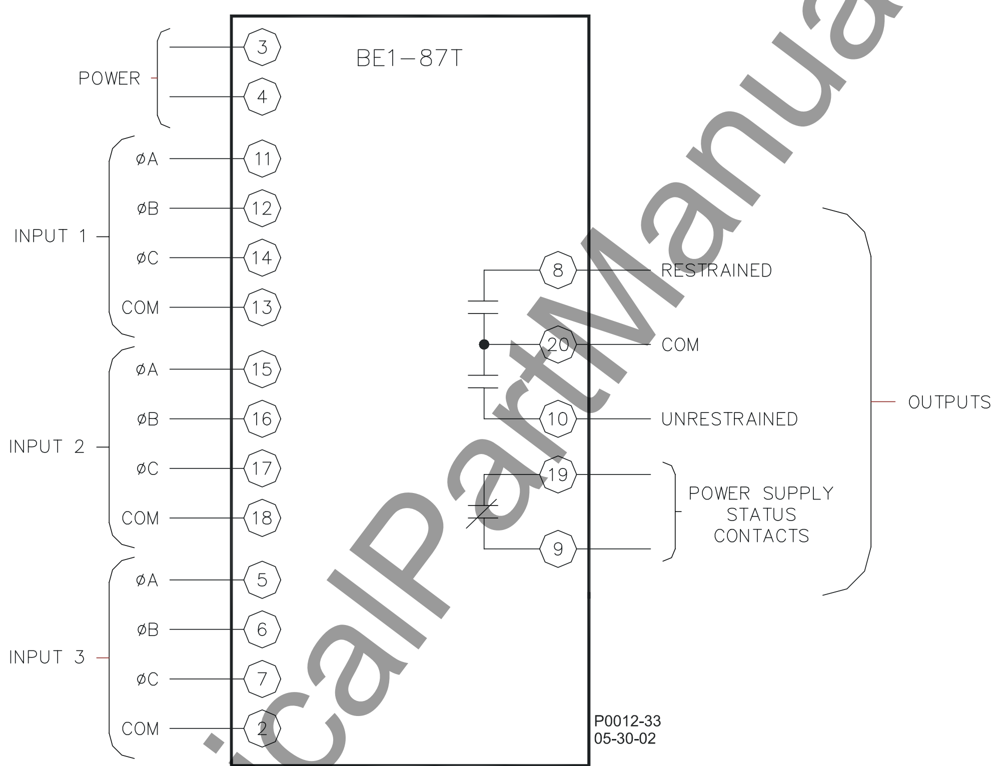


Figure 4-10. Case Terminals: Three-Phase, Three Input (Sensing Input Type G), Output Option E

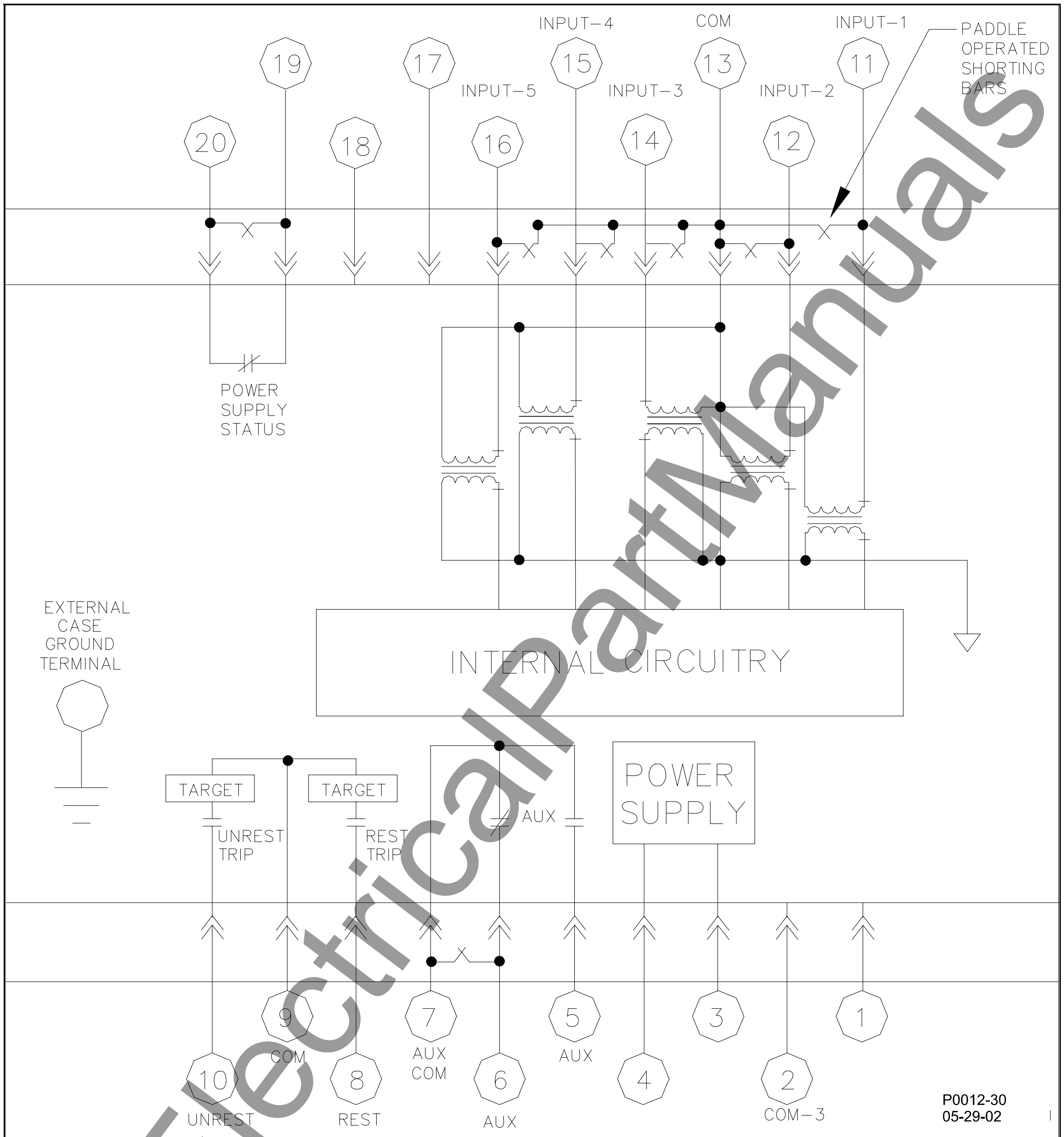


Figure 4-11. Internal Connections: Single-Phase, Five Input (Sensing Input Type D), Output Option E

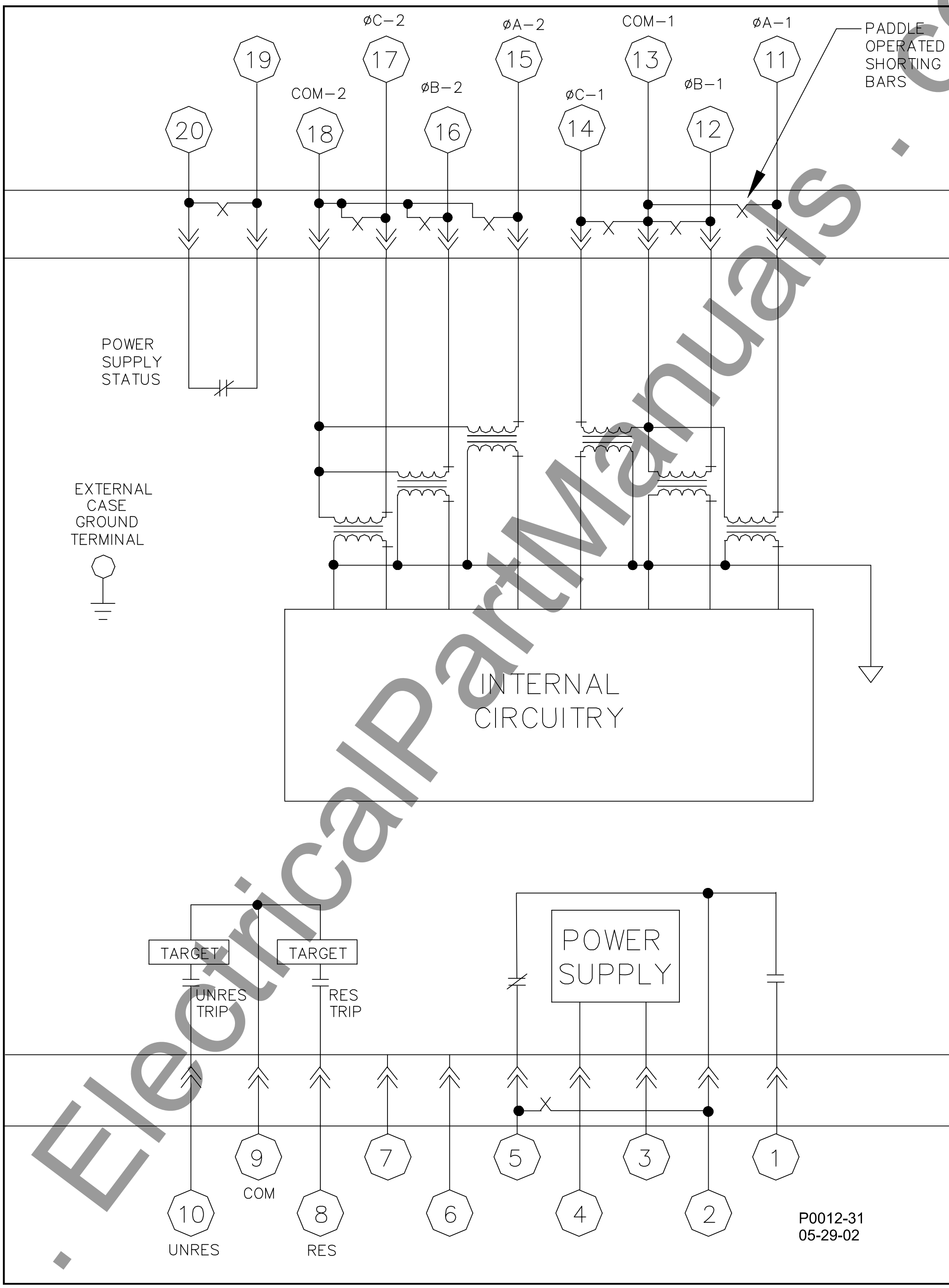


Figure 4-12. Internal Connections: Three-Phase, Two Input (Sensing Input Type E), Output Option E

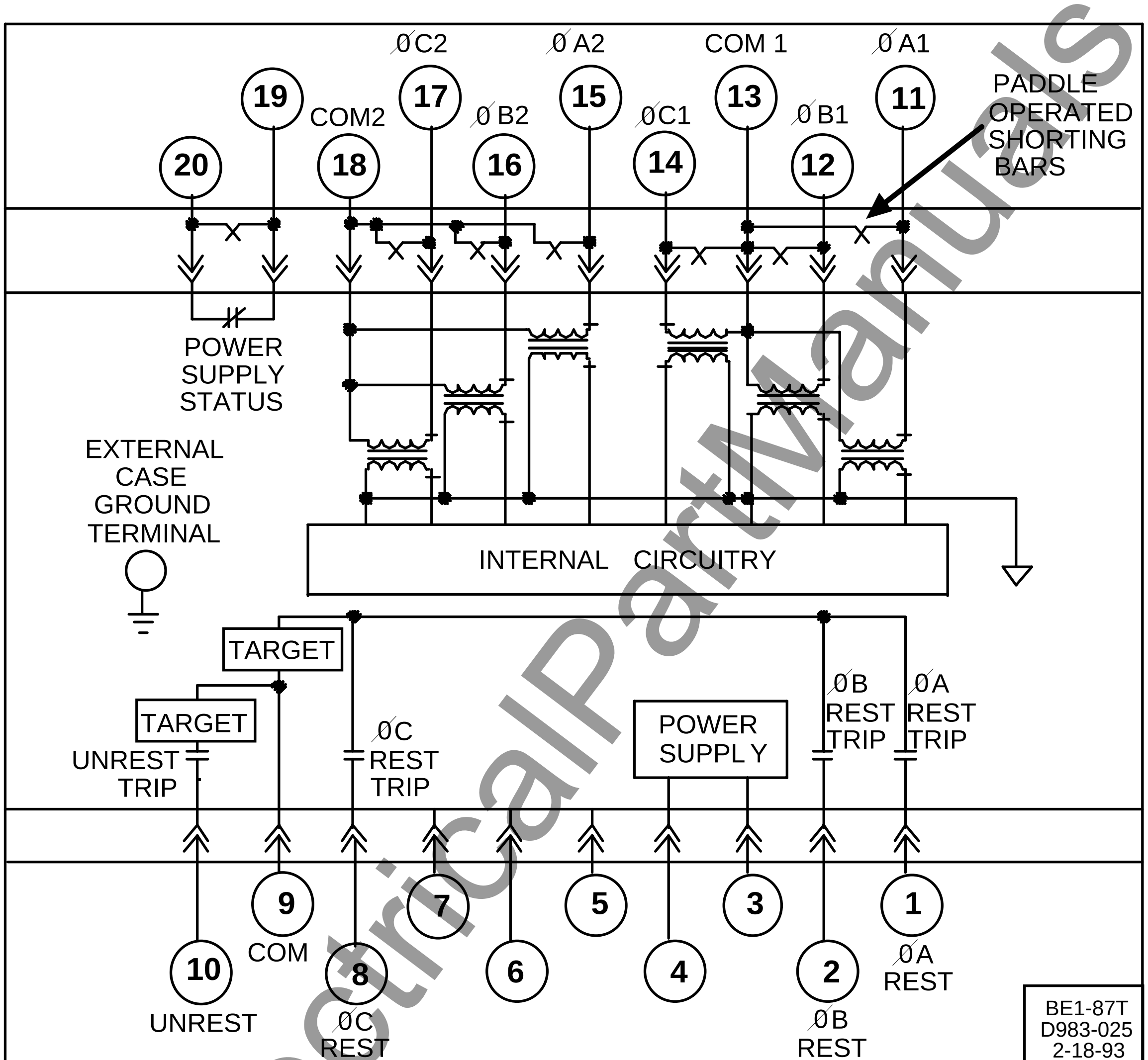


Figure 4-13. Internal Connections: Three-Phase, Two Input (Sensing Input Type E), Output Option F

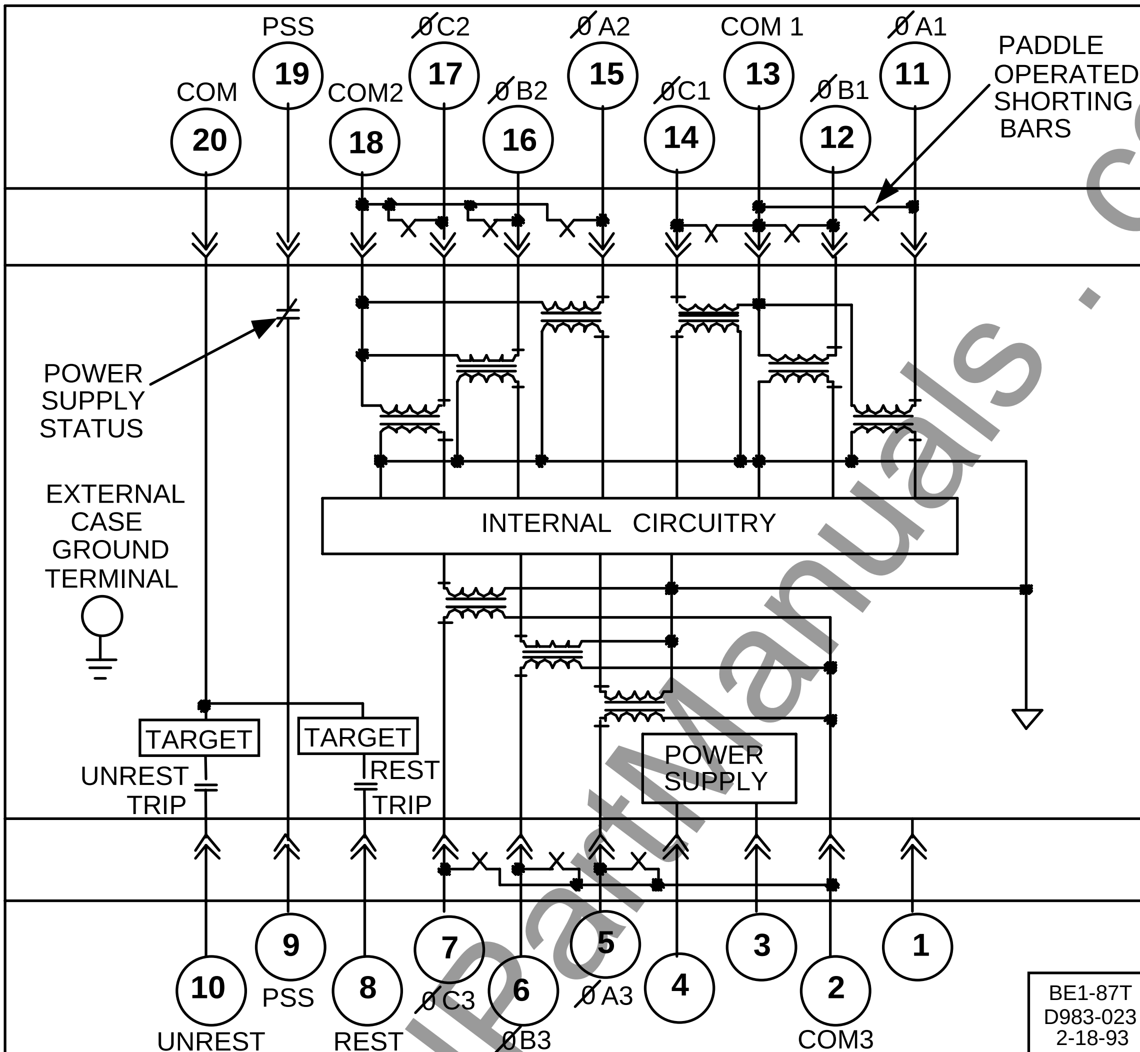


Figure 4-14. Internal Connections: Three-Phase, Three Input (Sensing Input Type G), Output Option E

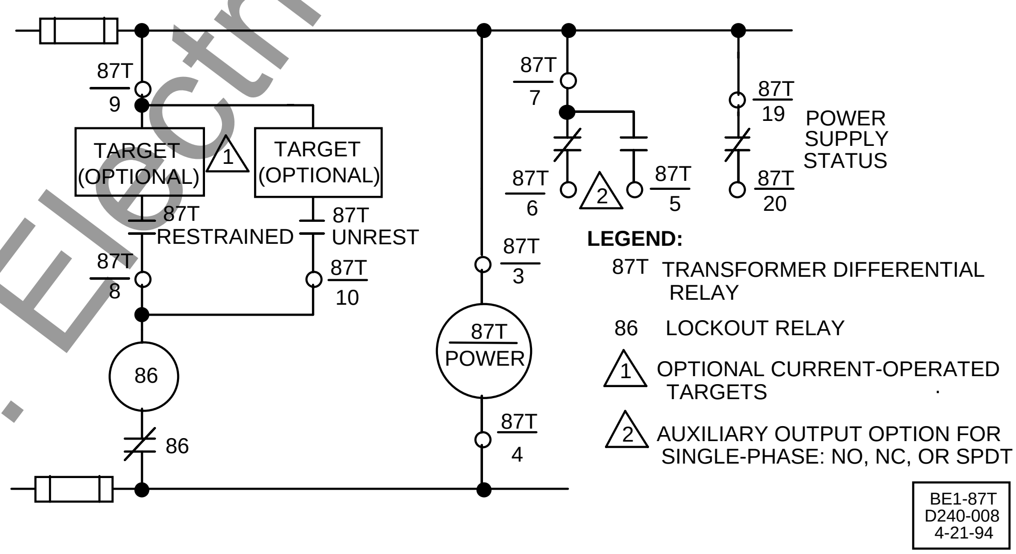


Figure 4-15. Control Circuits: Single-Phase, Output Option E

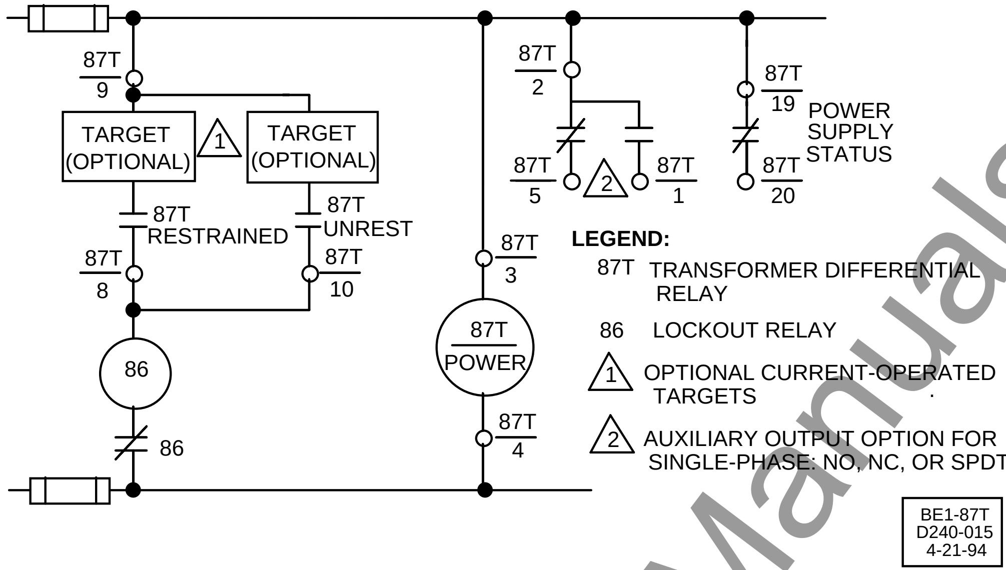


Figure 4-16. Control Circuits: Three-Phase, Two Input (Sensing Input E), Output Option E

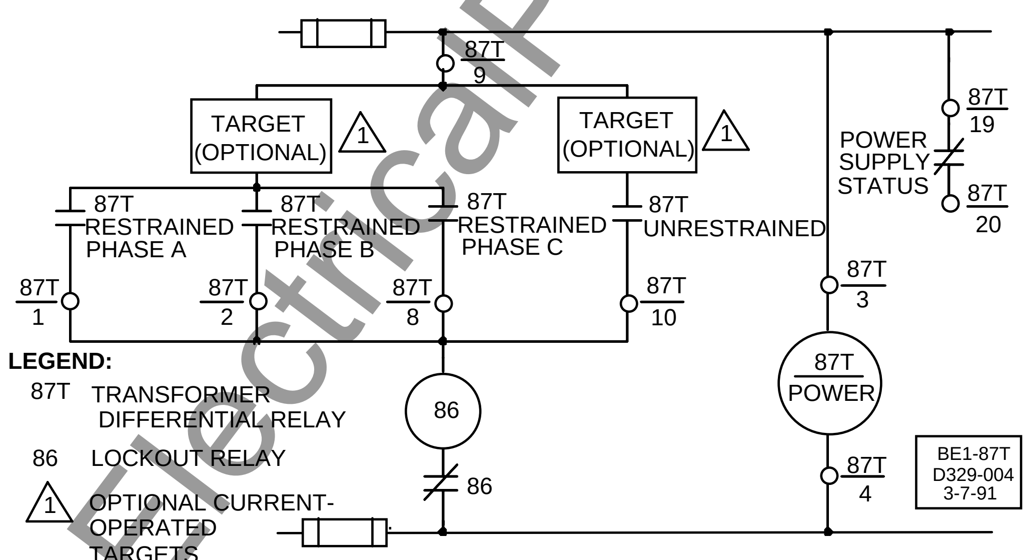


Figure 4-17. Control Circuits: Three-Phase, Two Input (Sensing Input E), Output Option F

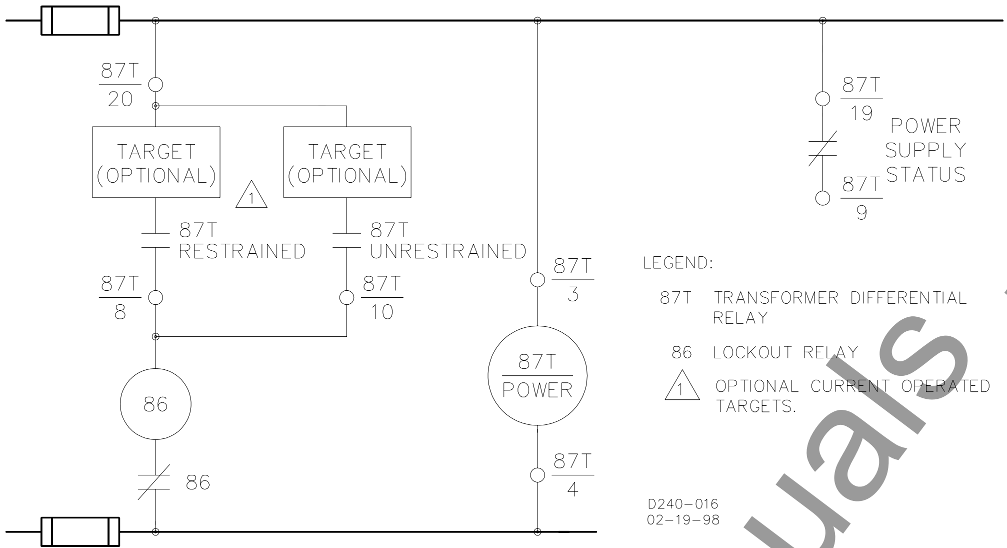


Figure 4-18. Control Circuits: Three-Phase, Three Input (Sensing Input G), Output E

RELAY DISASSEMBLY

Precautions

The following procedures require the removal and handling of the internal printed circuit boards. Figure 4-19 shows the location of major components and assemblies. Because some of the components are vulnerable to electrostatic charge, the following precautions should be observed.

CAUTION

1. Always remove power from the BE1-87T by removing the connection plugs before removing or installing a printed circuit board.
2. Always neutralize static body charge before placing a printed circuit board on—or removing one from—metal surfaces. This can be accomplished by placing your hand on the metal surface before handling the boards.
3. Never hand a printed circuit board to another person whose static body charge has not been neutralized.
4. Testing or troubleshooting should always be done on a conductive and grounded (static-controlled) surface.
5. Never test printed circuit boards with an ohmmeter. The test current from the ohmmeter may exceed component ratings.
6. Printed circuit boards or integrated circuits should be transported only in electrically conductive containers. The use of ordinary plastic bags may result in damage from static charge buildup.

Circuit Board Removal Procedure

Step 1. Remove the front cover and connection plugs.

CAUTION

To prevent possible false tripping, the upper connection plug should be in place prior to removing or installing the lower connection plug.

Step 2. Withdraw the cradle assembly (see Figure 4-19).

Step 3. Remove the four screws that attach the front panel to the cradle assembly, and remove the front panel.

Step 4. With a slight side-to-side rocking motion, withdraw Analog Board #1.

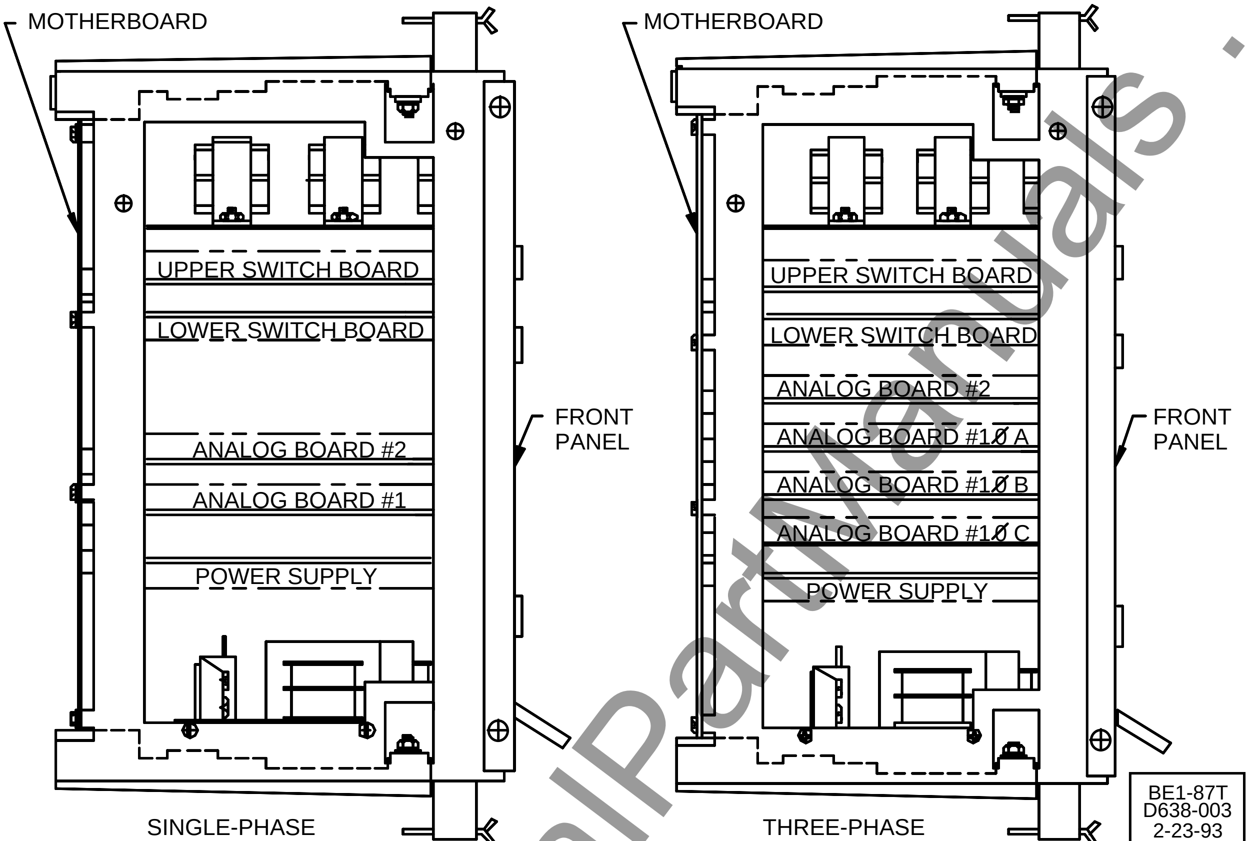


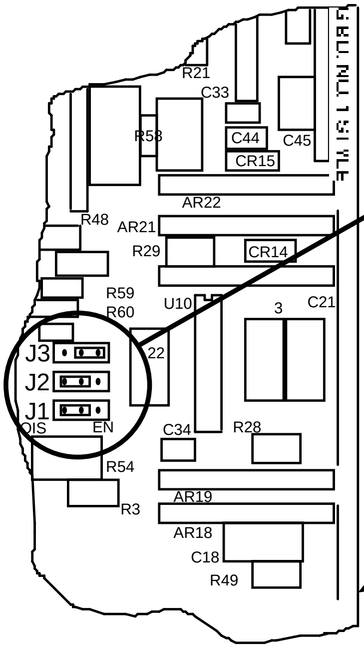
Figure 4-19. Side View of Cradle Assembly

DISABLING UNUSED INPUTS

To eliminate the possibility of a spurious input from induced currents within the relay, special internal jumpers have been provided to disable any inputs that are not connected to CT wires.

CAUTION

Disabling unused inputs requires disassembly of the relay and must be done when the relay has been taken out of service. Access to the input-disabling jumpers requires the removal of the Analog #1 Board, shown in Figure 4-19. To avoid personal injury or equipment damage, do **NOT** proceed unless thoroughly familiar with the instructions in sections **RELAY OPERATING PRECAUTIONS** and **RELAY DISASSEMBLY: Precautions**.



NOTE:

FOR ALL 2-INPUT RELAYS (BOTH SINGLE- AND THREE-PHASE), ALL JUMPERS MUST BE IN THE DISABLE POSITION AT ALL TIMES.

FOR OTHER RELAYS, SEE CHART BELOW.

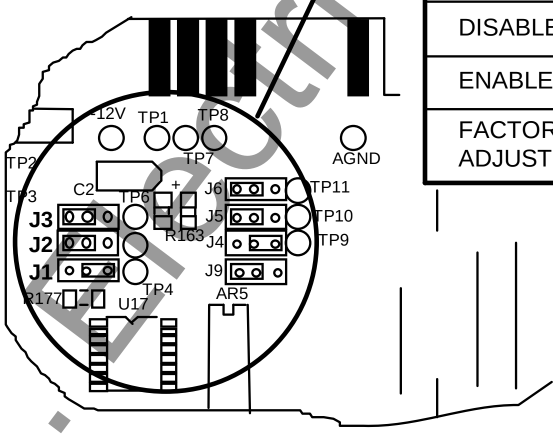
OBJECTIVE	JUMPER	POSITION
DISABLE INPUT 3	J3	
ENABLE INPUT 3	J3	
DISABLE INPUT 5	J2	
ENABLE INPUT 5	J2	
DISABLE INPUT 4	J1	
ENABLE INPUT 4	J1	

RIGHT-HAND EDGE OF ANALOG BOARD #1
(LOOKING FROM FRONT OF RELAY.)

BE1-87T
D641-001
9-21-94

Figure 4-20. Unused Input-Disabling Jumpers, Analog #1 Board: Option 1-0

OBJECTIVE	JUMPER	POSITION
DISABLE INPUT 3	J1 & J4	
ENABLE INPUT 3	J1 & J4	
DISABLE INPUT 5	J3 & J6	
ENABLE INPUT 5	J3 & J6	
DISABLE INPUT 4	J2 & J5	
ENABLE INPUT 4	J2 & J5	
FACTORY ADJUSTMENT	J9	NOT FIELD ADJUSTABLE



BE1-87T
D1924-12
9-21-94

Figure 4-21. Unused Input-Disabling Jumpers, Analog #1 Board: Option 1-1

Single-Phase Units

Single-Phase Units with Option 1-0

Three Input-Disabling Jumpers are located on each Analog Board #1 as shown in Figure 4-20.

Single-Phase Units with Option 1-1

Three additional Input-Disabling Jumpers are also located on each Analog Board #1 as shown in Figure 4-21. J9 is a factory adjustment and is not intended to be changed in the field.

BE1-87T single-phase units are shipped with all inputs enabled.

Three-Phase Units

Three-Phase Units with Option 1-0

Three Input-Disabling jumpers are located on each Analog Board #1 as shown in Figure 4-20.

Three-Phase Units with Option 1-1

Three additional Input-Disabling jumpers are also located on each Analog Board #1 as shown in Figure 4-21. J9 is a factory adjustment and is not intended to be changed in the field.

For Three-Phase Units with Input Sensing Type E (two inputs per phase)

The jumpers shown in Figures 4-20 and 4-21 are shipped in the disabled position and no further adjustment should ever be necessary.

For Three-Phase Units with Input Sensing Type G (three inputs per phase)

The jumpers shown in Figures 4-20 and 4-21 are shipped with Input 3 enabled, and Inputs 4 and 5 disabled. If only two inputs are actually used (which must be Inputs 1 and 2), it is important to disable the unused input of each phase by means of the internal Input-Disabling jumpers provided on each of the three Analog Boards #1 as shown in either Figure 4-20 or Figure 4-21. J9 in Figure 4-21 is a factory adjustment and is not intended to be changed in the field.

SENSING CONNECTION DIAGRAMS

Each connection diagram provides, as an example, typical transformer terminal markings and voltage diagrams that might be found on a transformer nameplate with the winding interconnections shown. The designations for high side and low side windings are for illustrative purposes only. For example, a diagram for a delta-wye transformer is applicable to a wye-delta transformer if the winding interconnections are the same. The phase shifts shown in the voltage diagrams assume A-B-C Phase sequence (rotation).

Each connection diagram shows the CT circuit safety ground located at the switch board panel terminal block as recommended in ANSI Standard C57.13.3.

Single-Phase Input Sensing Connections

Typical single-phase input sensing connections are illustrated in Figure 4-22.

Single-phase units may also be used in three-phase configurations, one on each phase. Figure 4-23 through Figure 4-26 show several typical three-phase sensing examples using three BE1-87T single-phase relays. Many other configurations are possible.

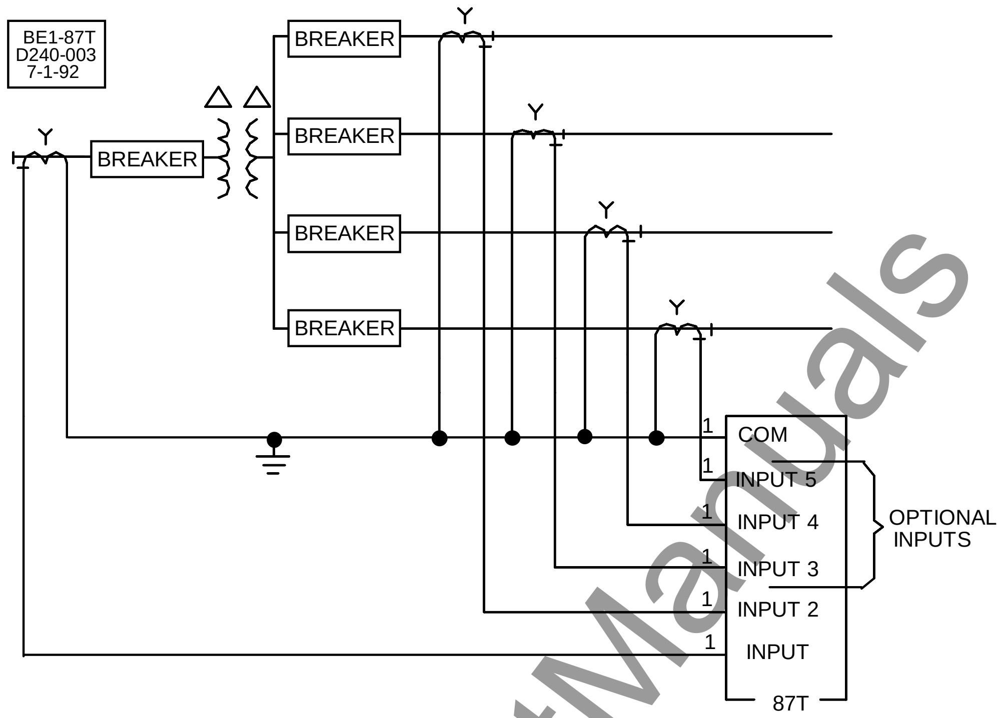


Figure 4-22. Typical Single-Phase Sensing Connections

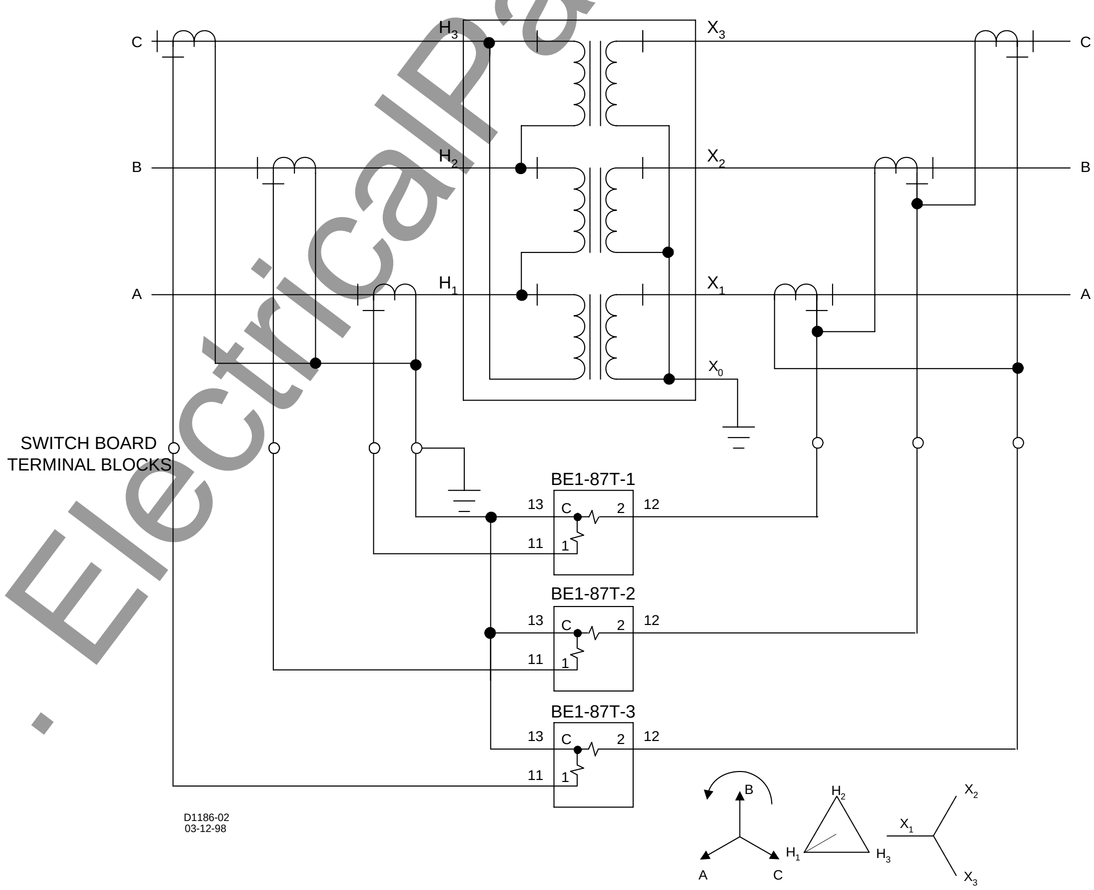


Figure 4-23. Single-Phase Connections, Delta-Wye Configuration

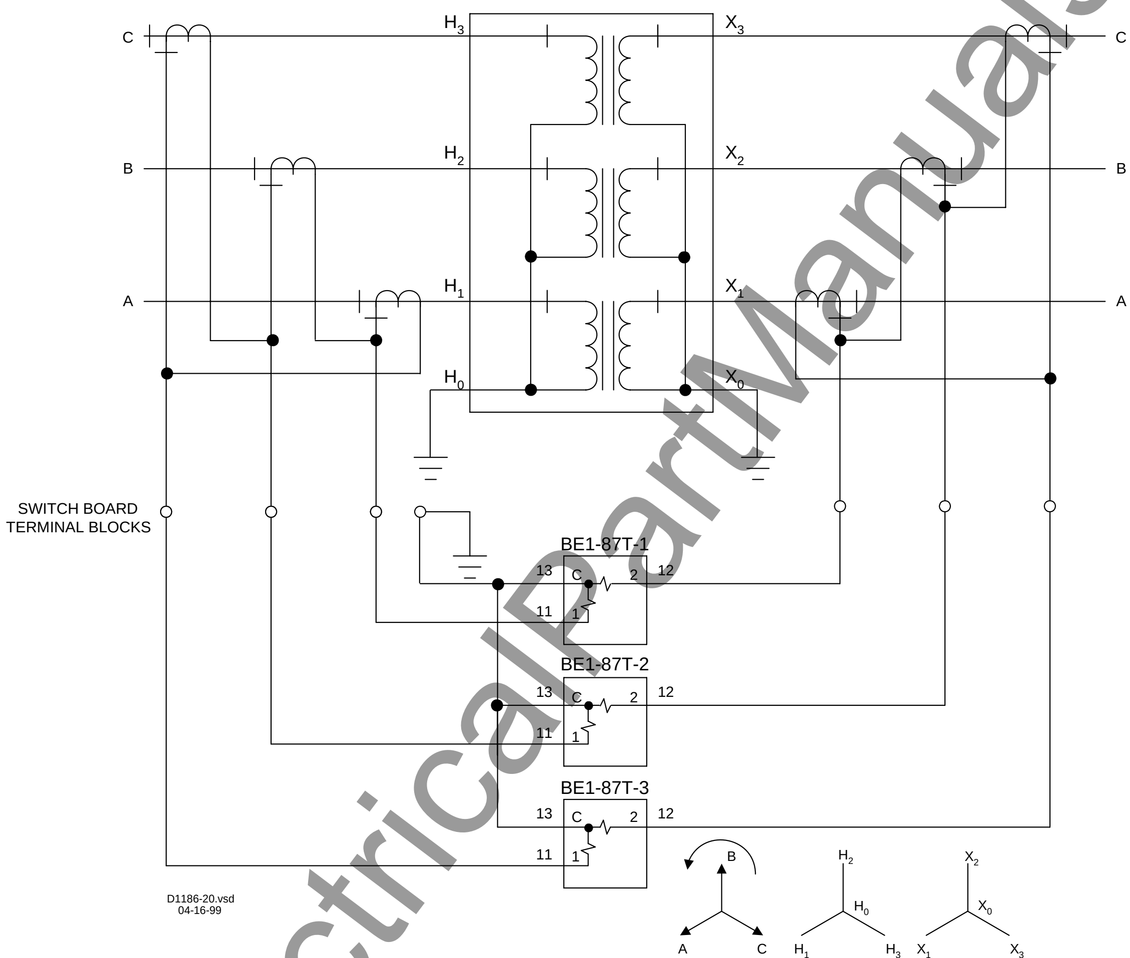


Figure 4-24. Single-Phase Connections, Wye-Wye Configuration

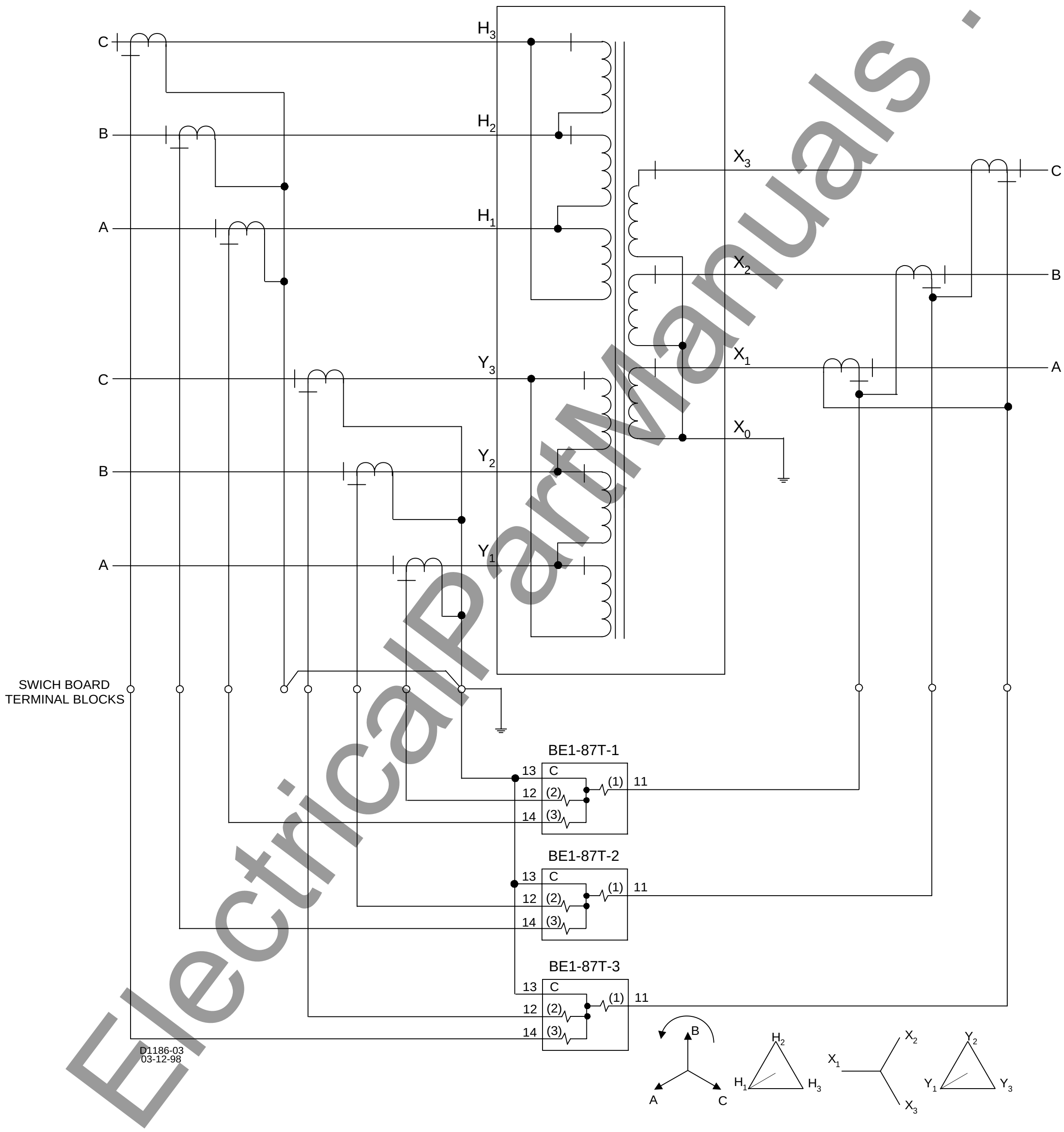


Figure 4-25. Single-Phase Connections, Delta-Delta-Wye Configuration

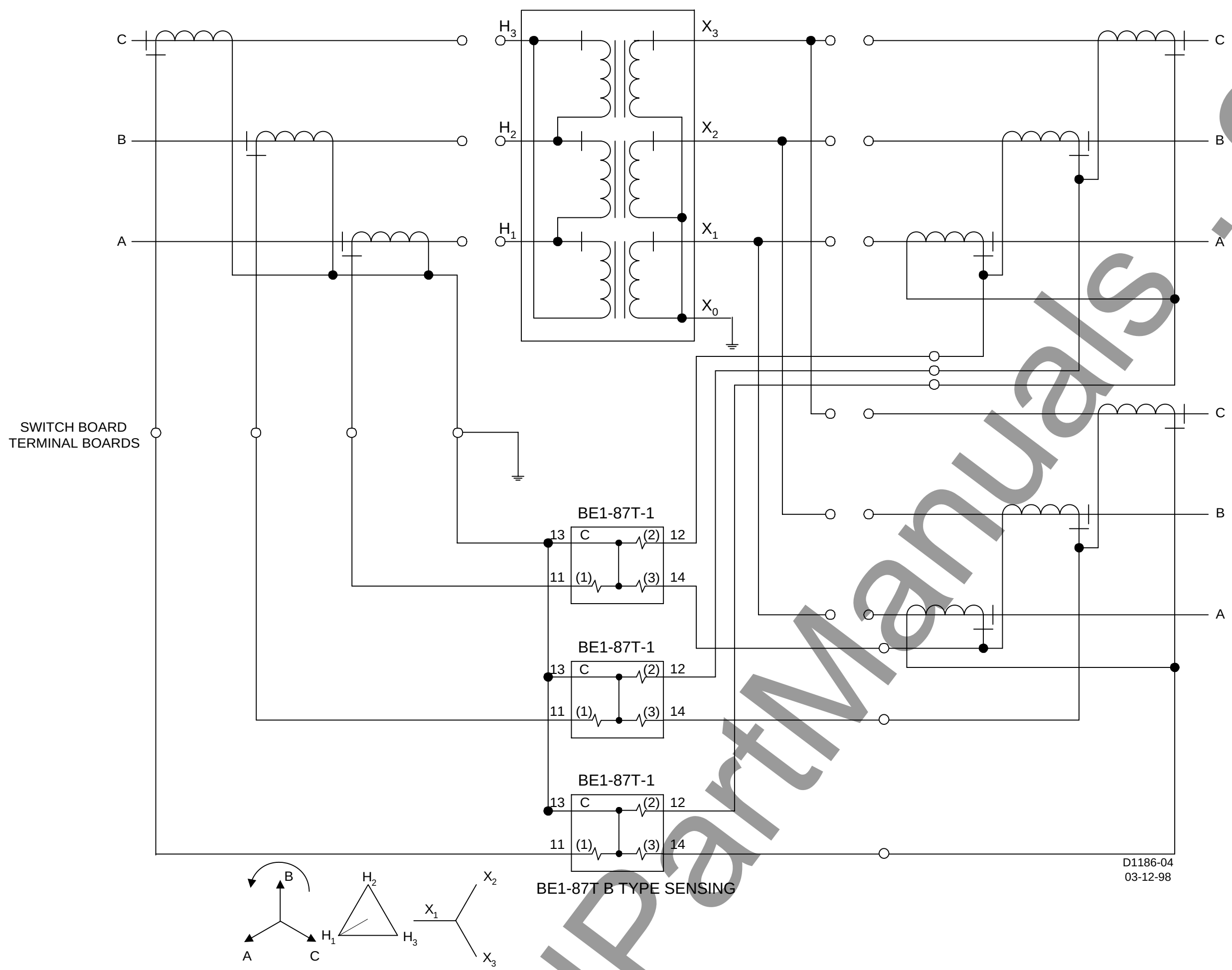


Figure 4-26. Single-Phase Connections, Delta-Wye Configuration With Two Load Busses

Three-Phase Input Sensing Connections

Phase Shift Compensation

Three-phase units must be connected in a way that will negate any phase shift introduced by the protected power transformer. This is accomplished by one of two methods:

1. By connecting the system CTs to complement the power transformer connections (i.e., a wye/delta CT can negate the phase shift of a delta/wye power transformer, and vice versa).
2. By utilizing the internal 30° Phase Shift Compensation that is a feature of three-phase BE1-87T relays.

Advantages of Internal Phase Compensation

Three-phase units provide for internal phase angle compensation. Among the advantages of this method is the ability to connect all the CTs in wye. This not only simplifies the connections but also facilitates sharing the CTs with other devices. Furthermore, the wye connection reduces the burden on the CTs.

A set of movable jumpers (Figure 4-27) determines the direction of the compensating internal phase shift for each input. Because each jumper can be shifted +30°, -30°, or 0°; a total of 60° is achievable between two inputs for special applications. In this way, the appropriate direction of phase shift can be matched to the shift in the protected transformer. This alleviates the need for an extra set of external CTs in most applications.

Figures 4-28 through 4-32 illustrate the use of internal phase shift in lieu of matching by external CT connections. These are typical of the many combinations that can occur.

CAUTION

Assigning 30° Phase Shift Compensation requires disassembly of the relay, and must be done when the relay has been taken out of service. Access to the 30° Phase Shift jumpers requires the removal of the Analog #2 Board, shown in Figure 4-27. To avoid personal injury or equipment damage, do **NOT** proceed unless thoroughly familiar with the instructions in the sections on **RELAY OPERATING PRECAUTIONS** and **RELAY DISASSEMBLY: Precautions**.

30° Phase Shift Compensation Adjustment Procedure

The position of a set of movable jumpers on Analog Board #2 determines the state of the internal compensation. To gain access to these jumpers, it is necessary to remove Analog Board #2. Refer to the topic *RELAY DISASSEMBLY* for instructions on gaining access to the circuit board then adjust the jumpers shown in Figure 4-27 as follows:

- In cases where no phase shift is wanted, all three jumpers (ϕA, ϕB, and ϕC) shown in Figure 4-27 are in the **WYE-WYE** position. (Relays are shipped with all jumpers in this position.)
- If one of the inputs requires a shift in phase, the jumpers for all three phases are moved as follows:

  1. The Δ2 position develops A-B, B-C, C-A.
  2. The Δ1 position develops A-C, B-A, C-B.

NOTE

The result of each of these vector differences has a magnitude of the square root of three times each component.

The internal phase shift compensation is performed electronically as shown in the chart of Figure 4-27. The internal compensation can apply to any power transformer with any combination of wye, delta or autotransformer winding connections.

A procedure to check the differential balance is described later in this section, *CHECKING THE RELAY SETTINGS AND SYSTEM INPUTS.*

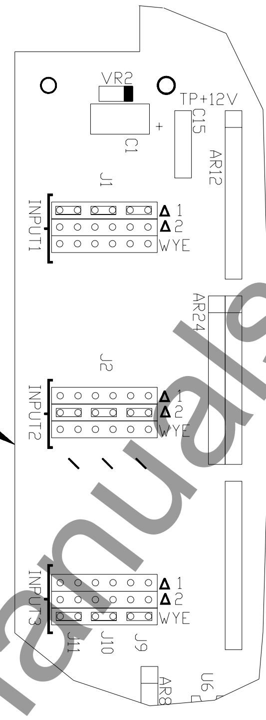
30° PHASE COMPENSATION CHART

POSITION	INTERNAL RELAY SIGNALS			PHASE SHIFT*
WYE	I_a	I_b	I_c	0°
Δ2	$I_a - I_b$	$I_b - I_c$	$I_c - I_a$	+30°
Δ1	$I_a - I_c$	$I_b - I_a$	$I_c - I_b$	-30°

*APPLIES FOR A-B-C ROTATION AND BALANCED CURRENTS.

LEFT-HAND EDGE OF ANALOG BOARD #2 (LOOKING FROM FRONT OF RELAY)

ALTHOUGH NINE INDIVIDUAL JUMPERS ARE SHOWN (EACH SHORTING A PIN-PAIR), IN PRACTICE THERE WILL ALWAYS BE THREE JUMPERS AT A GIVEN POSITION, AS ILLUSTRATED.



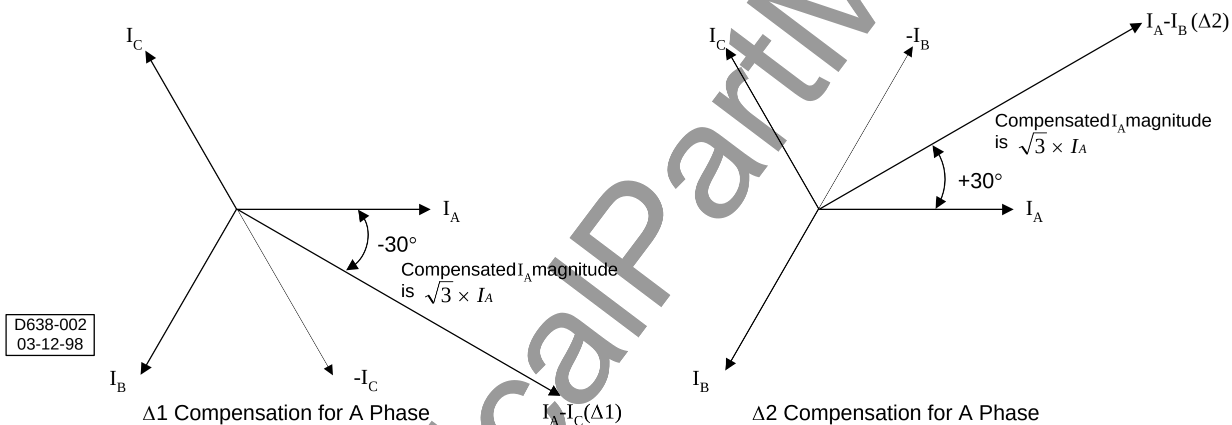
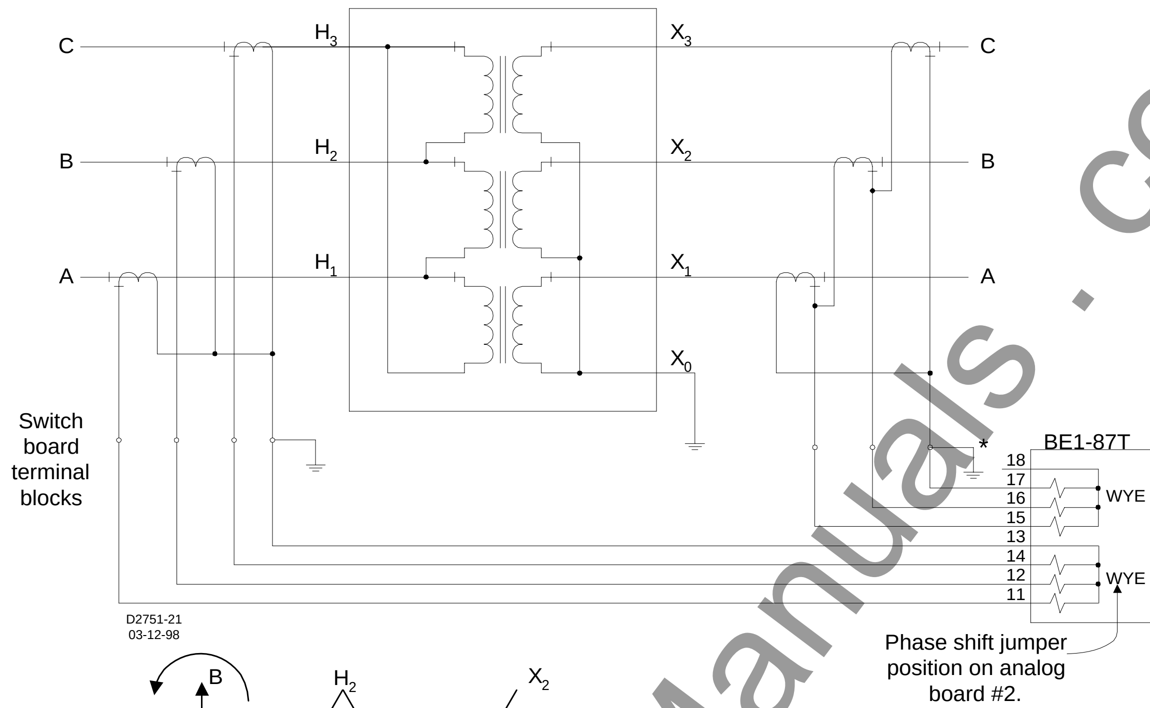
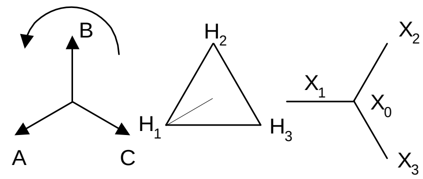


Figure 4-27. 30° Phase Shift Compensation Jumpers

The transformer in the example shown in Figure 4-28a and 4-28b has a delta connection on the primary winding. The currents in each winding of the delta are A, B and C respectively as reflected from the wye connected secondary winding. The delta connection of the transformer windings causes the current flowing in the phase leads connected to the delta winding to be A-B, B-C and C-A respectively. The CT currents on the wye side must be combined similarly to provide A-B, B-C and C-A to compensate. This is done in Figure 4-28a by connecting the wye side CTs in delta such that the currents sent to the relay are A-B, B-C and C-A. This is shown in Figure 4-28b by selecting phase compensation jumper position Δ2 for the wye side input.





*An alternative to grounding one corner of the delta connected CTs is to connect the ground to a lead connected to terminal 18.

Figure 4-28a. Three-Phase Connections, Delta-Wye Configuration, CT Compensation

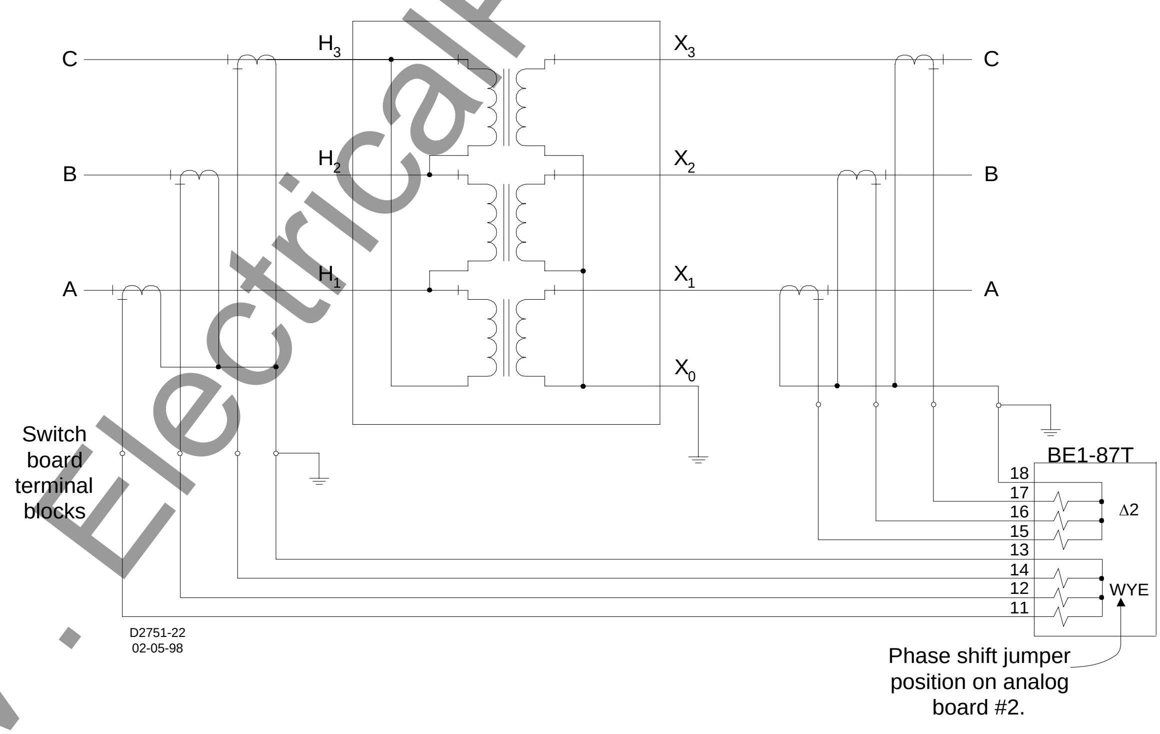


Figure 4-28b. Three-Phase Connections, Delta-Wye Configuration, Internal Phase Compensation

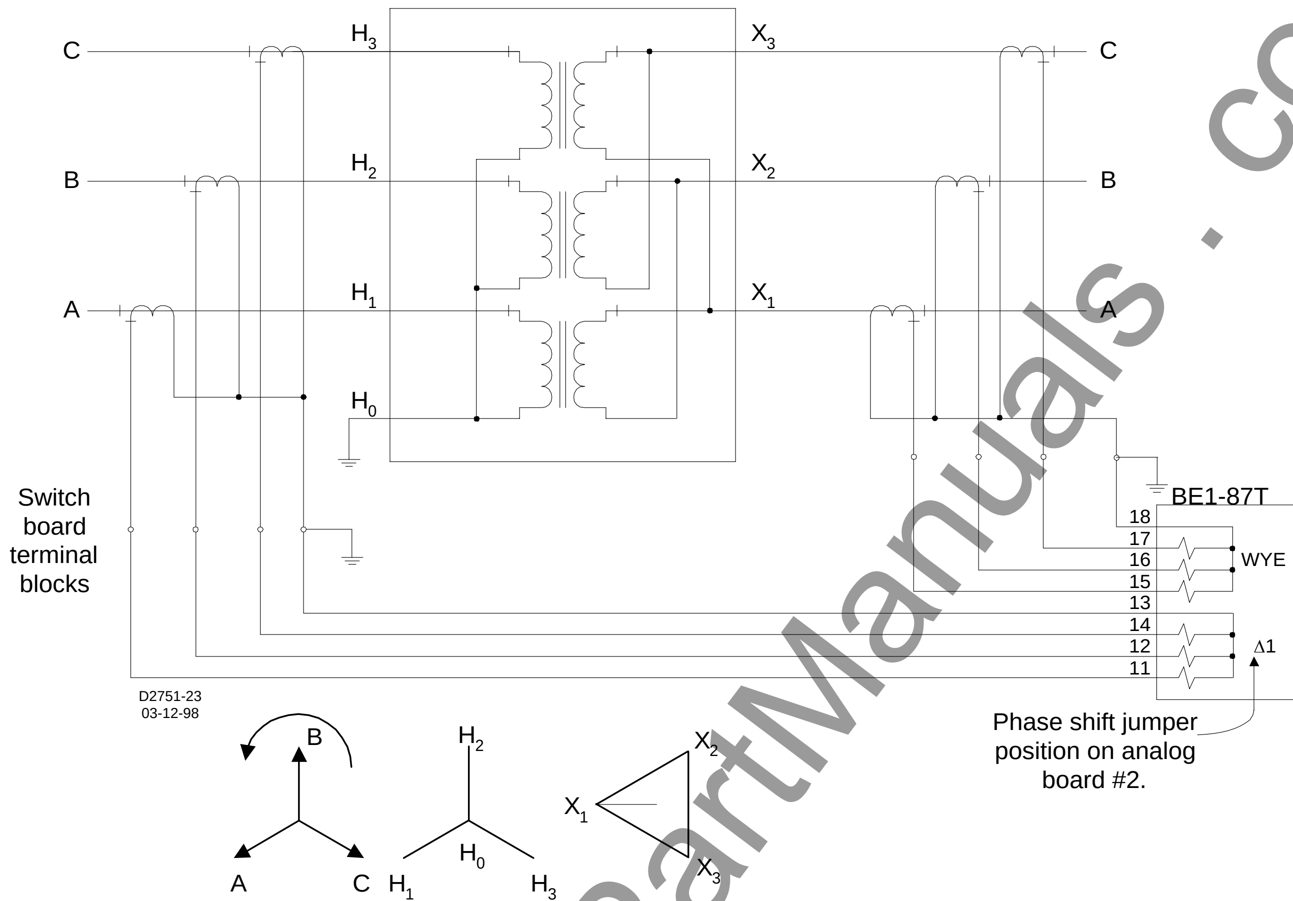


Figure 4-29. Three-Phase Connections, Wye-Delta Configuration, Internal Phase Compensation

The transformer in the example shown in Figure 4-29 has a delta connection on the secondary winding. The currents in each winding of the delta are A, B and C respectively as reflected from the wye connected primary winding. The delta connection of the transformer windings causes the current flowing in the phase leads connected to the delta winding to be A-C, B-A and C-B respectively. The CT currents on the wye side must be combined similarly to provide A-C, B-A and C-B to compensate. This is shown in Figure 4-27 by selecting phase compensation jumper position Δ1 for the wye side input.

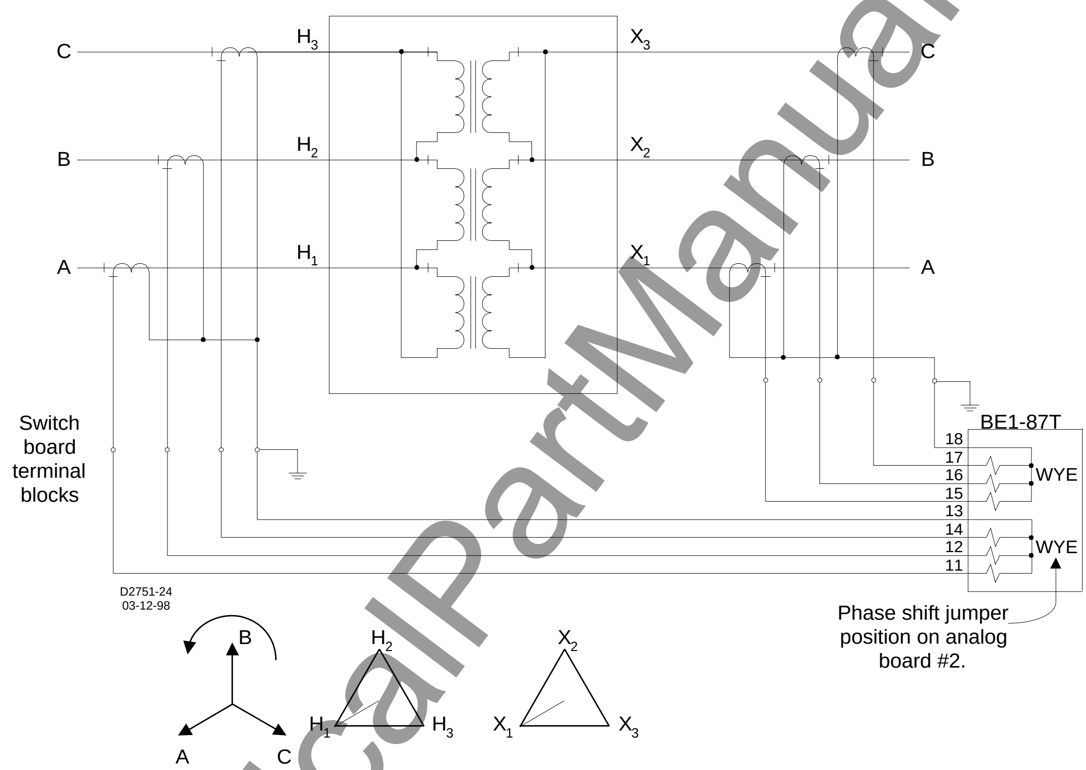
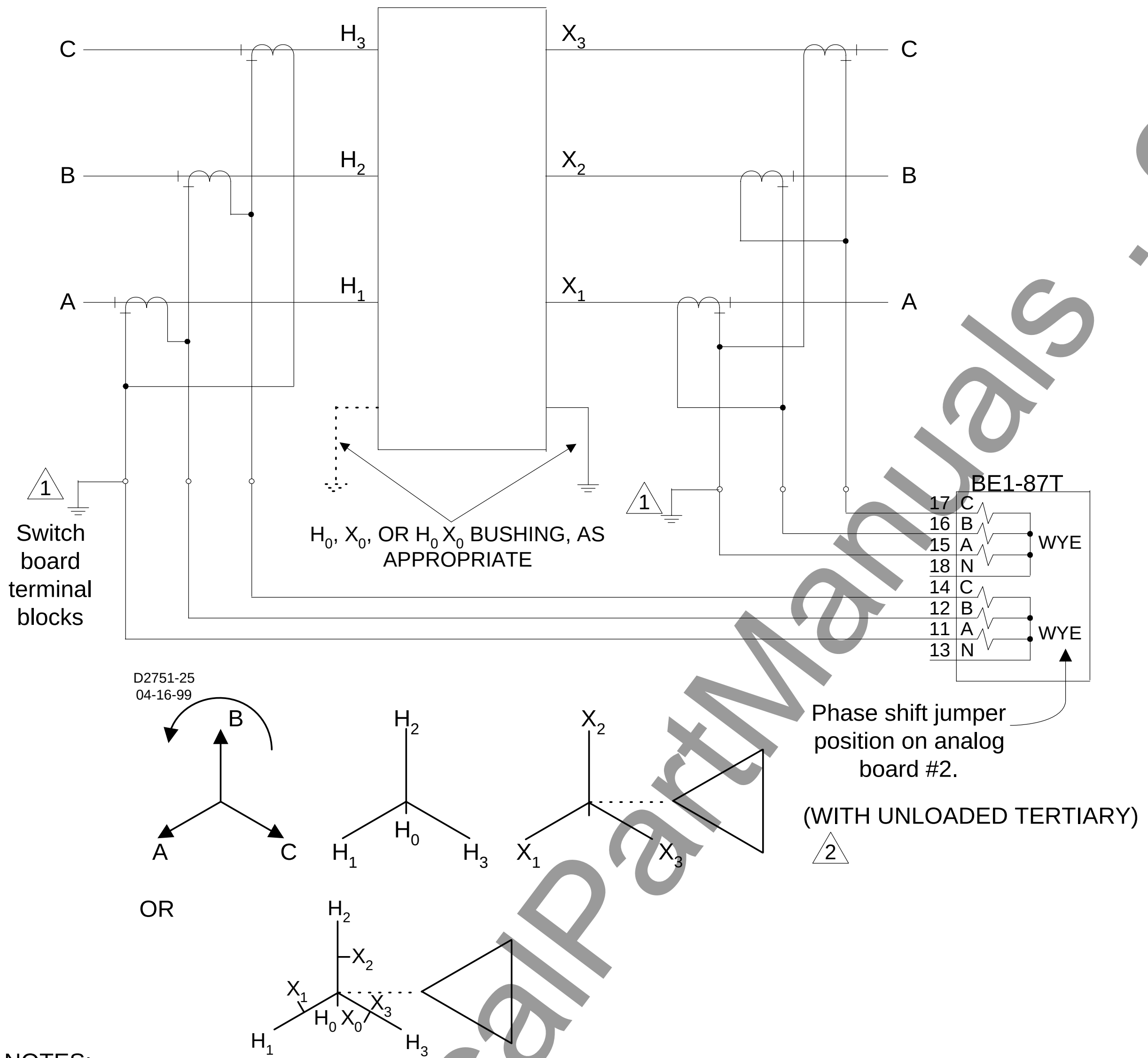


Figure 4-30. Three-Phase Connections, Delta-Delta Configuration

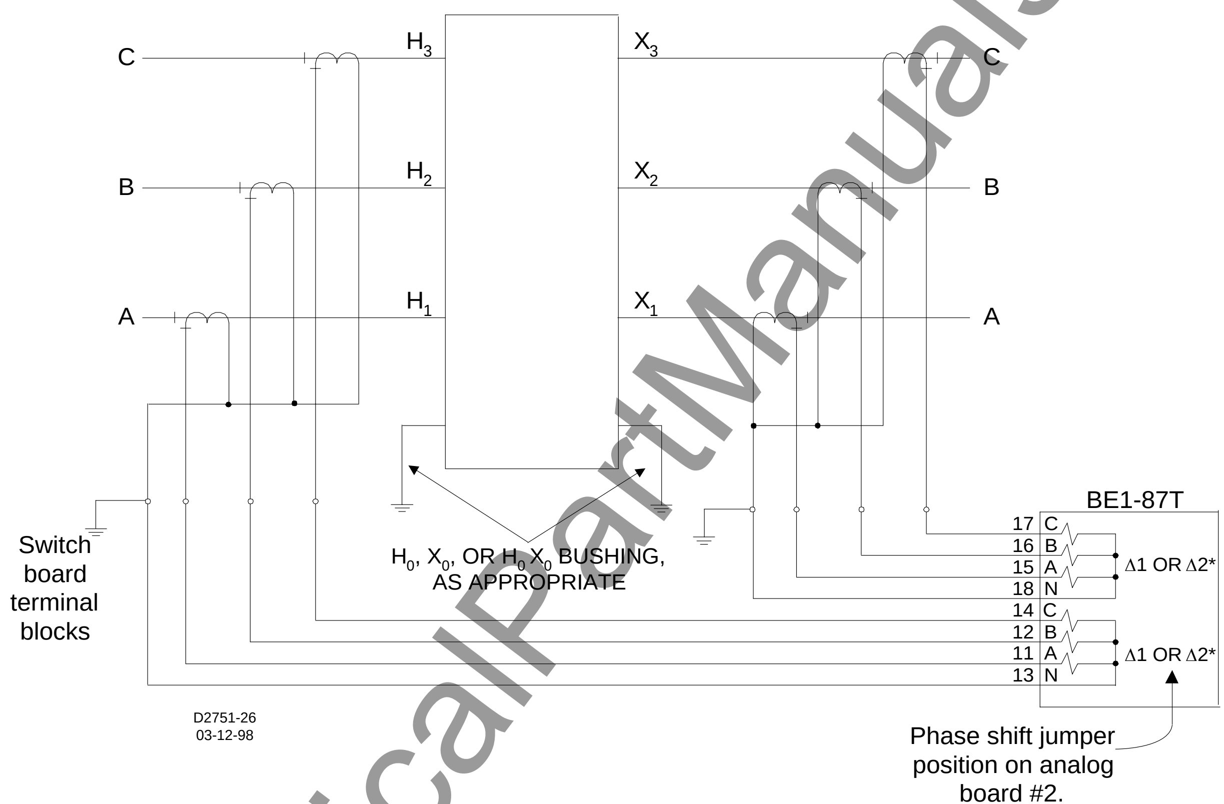


NOTES:

1. AN ALERNATIVE TO GROUNDING THE CORNER OF THE THE DELTA CONNECTED CTs IS TO CONNECT THE GROUND TO LEADS CONNECTED TO TERMINALS 13 AND18.
2. IF THERE IS NOT A DELTA TERTIARY, OR IF THE WYE WINDING IS UNGROUNDED, IT IS UNNECESSARY TO DELTA SHIFT THE CURRENTS FOR ZERO SEQUENCE BLOCKING.

Figure 4-31a. Three-Phase Connections, Wye-Wye or Autotransformer Configuration, CT Compensation

The Wye-Wye or Autotransformer does not require phase shift compensation. However, it is necessary to Delta compensate the currents to block zero sequence currents being supplied by the transformer bank. This is shown in Figure 4-31a by connecting the CTs in Delta. In Figure 31b, compensation is shown by internal phase compensation jumper setting.



NOTES:

*THE BE1-87T MUST USE THE SAME PHASE COMPENSATION JUMPER POSITION ON ALL INPUTS.

Figure 4-31b. Three-Phase Connections, Wye-Wye or Autotransformer Configuration, Internal Phase Compensation

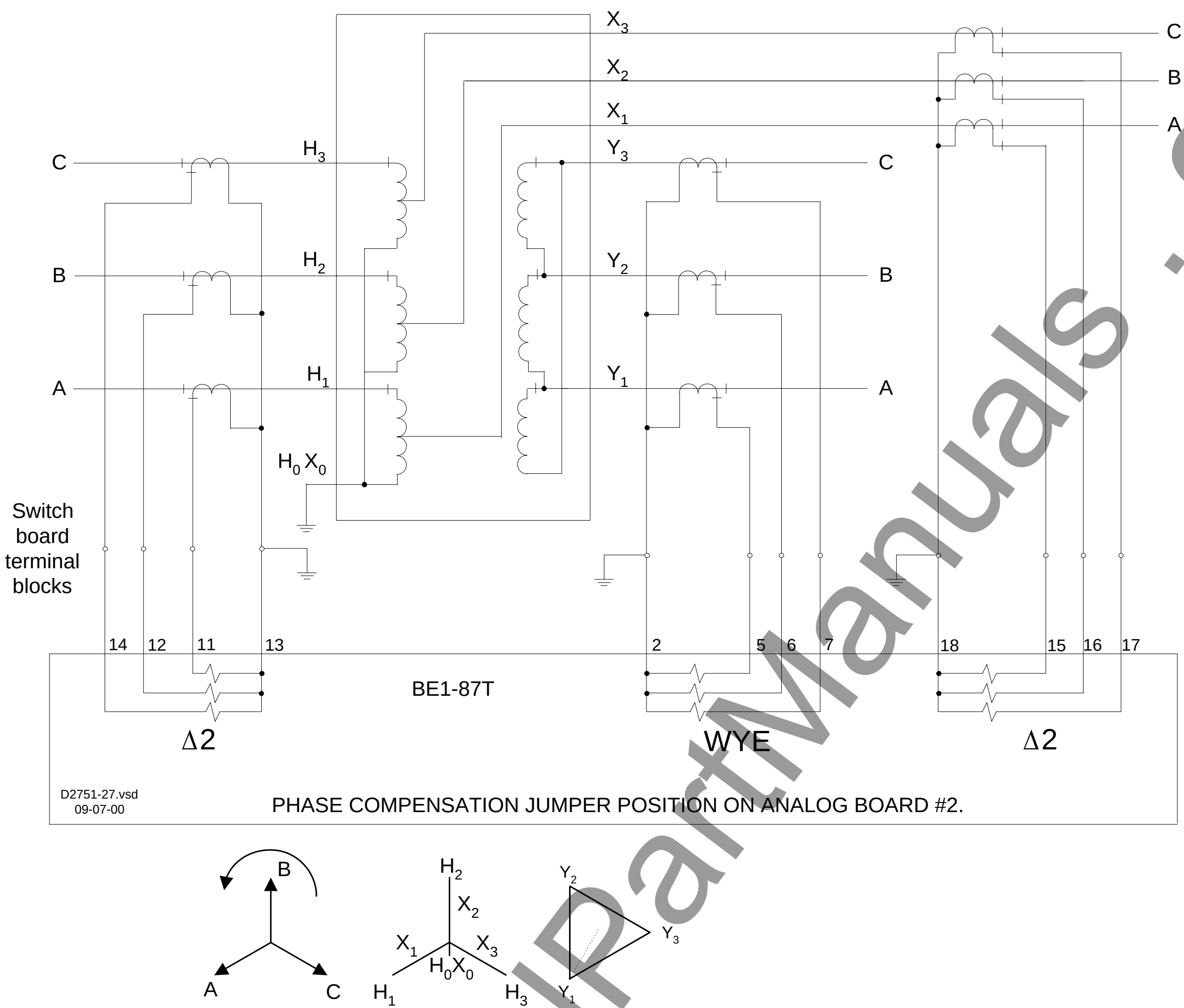


Figure 4-32. Three-Phase Connections, Autotransformer With Loaded Delta Tertiary

The transformer in the example shown in Figure 4-32 has a delta connection on the tertiary winding. The currents in each winding of the delta are A, B, and C respectively as reflected from the wye or auto connected winding. The delta connection of the transformer windings causes the current flowing in the phase leads connected to the delta winding to be A-B, B-C and C-A respectively. The CT currents on the wye or auto windings must be combined similarly to provide A-B, B-C and C-A to compensate. This is shown in Figure 4-32 by selecting phase compensation jumper position Δ2 for these inputs. This also provides zero sequence blocking for these inputs since this transformer configuration is a source of zero sequence currents.

SETTING THE BE1-87T

The following setting procedures include two examples:

1. Using the MVA rating of the highest-rated winding for all the other windings when making the calculations.
2. Using the top kVA rating of the transformer.

Each procedure can be used as a means to understand the principles involved, and by replacing the variables of the example, can become a procedure of general application. Variable abbreviations and definitions are provided in Table 4-1*, List Of Variables.*

Method

Both procedures determine:

1. The matching tap and slope settings required to implement the restrained function, and
2. The unrestrained pickup setting as a multiple of the BE1-87T tap setting (i.e., the **INPUT** switches).

The matching tap procedure is conventional, providing tap values proportional to the normal currents as seen by the relay. An exception occurs with multiple-winding banks where zero-balance current is assumed in each pair of windings, successively.

NOTE
The dc component of the input current is effectively blocked by the gapped cores of the input CTs. Therefore, for offset fault currents or magnetic inrush, the dc component of the waveform can be ignored in fault current calculations.

Procedure One

Refer to Figure 4-33 for a one-line drawing of this example. Refer to Figure 4-32 for the three-line representation of this transformer.

<u>*Tap and Phase Shift Settings*</u>

Step 1. Determine the primary current (I_P) of each winding:

$$I_P = \frac{\text{(MVA rating of transformer) (X 1,000)}}{(\text{V}_{\text{LINE - LINE}})(\sqrt{3}\ )}$$

Use the MVA rating of the highest-rated winding for all the other windings when making the calculations. (This procedure assures that the taps follow the voltage ratios. Refer to Appendix A, *Setting Note 1*.)

HIGH	TERTIARY	LOW
$I_P = \frac{250{,}000}{345\sqrt{3}}$	$I_P = \frac{250{,}000}{13.2\ \sqrt{3}}$	$I_P = \frac{250{,}000}{138\sqrt{3}}$
$I_P = 418$	$I_P = 10{,}935$	$I_P = 1{,}046$

Step 2. Determine the CT secondary current (I_S)of each winding:

$$I_S = \frac{I_P}{\text{CT ratio}}$$

HIGH	TERTIARY	LOW
$I_S = \frac{418}{120}$	$I_S = \frac{10{,}935}{600}$	$I_S = \frac{1046}{240}$
$I_S = 3.49$	$I_S = 18.22$	$I_S = 4.36$

Table 4-1. List of Variables

D_P	The driving input number, a procedural term designating the current input terminal whose tap is the first selected. (The setting procedure is simplified if the driving input is the input of least current, I_M)
I_E	Maximum external fault current in multiples of tap (the larger of three-phase or line-ground values)
I_D	Driving input relay current used for matching in amperes
I_F	The larger of I_{F3} and I_{FG}
I_{F3}	Relay input current at the maximum external three-phase fault level in secondary amperes
I_{FG}	Relay input current at the maximum external line-ground fault level in secondary amperes
I_M	The input with the least minimum current
I_P	CT primary current in amperes
I_R	Relay input current in amperes
I_S	CT secondary current in amperes
I_T	Rated self-cooled current of the power transformer in multiples of tap
M_N	Current mismatch, with power transformer on its neutral tap
MR	Multiple rating CT, i.e., a tapped CT
M_T	Total mismatch, including the maximum transformer tap excursion
N	Total number of CT turns available
N_A	Number of CT turns in use
R_L	One-way lead resistance in ohms
R_W	CT winding resistance in ohms
R_R	Relay resistance in ohms
S	Restrained slope setting (from 15 to 60%)
S_F	Saturation factor, which equals V_B/V_{CE}
T	Relay current tap (0.4 to 1.78 for 1 A CT, 2 to 8.9 for 5 A CT)
T_D	Desired tap, based on the current ratio
V_B	The larger of V_{B3} or V_{BG}
V_{B3}	The CT burden voltage with I_{F3} flowing
V_{BG}	The CT burden voltage with I_{FG} flowing
V_C	Base accuracy class CT voltage rating
V_{CE}	Accuracy class CT effective voltage where not all turns are used, which equals $V_C(N_A/N)$
x TAP	Unrestrained pickup setting, in multiples of tap (6 to 21)

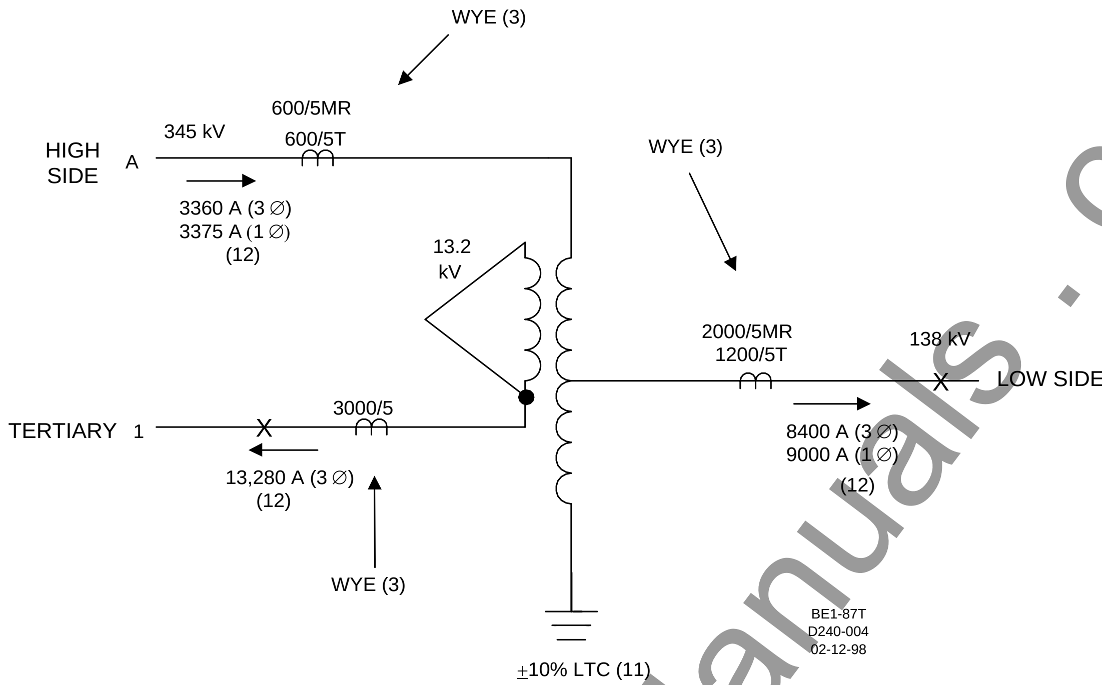


Figure 4-33. Application Example: Autotransformer With Tertiary Winding (See Figure 4-32 for 3-phase connections.)

SPECIFICATIONS	HIGH SIDE	TERTIARY	LOW SIDE
KV	345	13.2	138
MVA	200/250	40/50	200/250
CT Ratio	600/5 (*MR*) 600/5 (*T*)	3000/5	2000/5 (*MR*) 1200/5 (*T*)
CT Accuracy Class	C400	C800	C400
CT Resistance (ohms)	0.3	1.5	0.6
One-Way Lead Burden (ohms)	0.7	0.7	0.7
CT Connection (Three-Phase)	WYE	WYE	WYE

NOTE

Three-phase is the most common application of the BE1-87T. Using single-phase relays requires a Delta connection for the High side and Low side CTs (I_A-I_B to match the tertiary connection in the example detailed in Figure 4-32).

Step 3. ***Three-Phase Units Only:*** Adjust the phase compensation jumpers on Analog Board #2, shown in Figure 2-4 and Figure 4-27, (or use the procedure listed *in TESTING THREE-PHASE UNITS WITHOUT CHANGING JUMPERS*, in Section 5).

Because of the grounded winding in this example, as shown in Figure 4-33 and 4-32, the high-side and low-side zero-sequence currents must be canceled. Δ2 position is selected to align the High side and Low side secondary current phasors with the tertiary phasors which lead by 30° in this example:

	HIGH	TERTIARY	LOW
Jumper Position:	Δ2	WYE	Δ2

Step 4. Determine the relay current (I_R):

$$I_R = I_S \times \text{Conversion Factor}$$

Three-Phase Units only: When using either Δ2 or Δ1 jumper positions, shown in Figure 2-4, multiply the secondary current I_S by the conversion factor (square-root of three) just as if the CTs were connected in delta. Remember that, if system CTs are connected in delta, the same square-root-of-three conversion factor must be applied.

HIGH (INPUT 1)	TERTIARY (INPUT 2)	LOW (INPUT 3)
$I_R = 3.49\sqrt{3}$	$I_R = (18.22)(1)$	$I_R = 4.36\sqrt{3}$
$I_R = 6.04$	$I_R = 18.22$	$I_R = 7.55$

Step 5. Determine the spread ratio of the relay currents (largest/smallest):

Spread = 18.22/6.04 = 3.0

Step 6. Determine the Driving Input**Error! Bookmark not defined.** (*DP*), which we define as the input assigned to the smallest current in Step 4:

$$DP = I_M$$

$DP =$ **HIGH (INPUT 1)**

Step 7. Determine the Driving Input Tap (T_1), which must be less than the 4.45 capability of the BE1-87T:

HIGH

$$T_1 = 2.0$$

Choosing the 2.0 setting for the minimum inputs will yield maximum sensitivity.

Step 8. Determine the Desired Tap (T_D):

TERTIARY

$$T_{D2} = T_1\left(\frac{I_{R2}}{I_{R1}}\right) = 2.0\left(\frac{18.22}{6.04}\right) = 6.03$$

LOW

$$T_{D3} = T_1\left(\frac{I_{R3}}{I_{R1}}\right) = 2.0\left(\frac{7.55}{6.04}\right) = 2.50$$

Step 9. Select taps by rounding T_D to the nearest tenth:

HIGH	TERTIARY	LOW
T = 2.0	*T* = 6.0	*T* = 2.5

Step 10. Determine the CT mismatch (M_N):

HIGH – LOW

$$M_N = 100\frac{\left(\frac{I_1}{I_3}\right)-\left(\frac{T_1}{T_3}\right)}{\text{(the smaller of the above)}}$$

$$= 100\frac{\left(\frac{6.04}{7.55}\right)-\left(\frac{2.0}{2.5}\right)}{\text{(the smaller of the above)}}$$

$$= 100\frac{0.80 - 0.80}{0.80}$$

$$= 0\%$$

HIGH – TERTIARY

$$M_N = 100\frac{\left(\frac{I_2}{I_1}\right)-\left(\frac{T_2}{T_1}\right)}{\text{(the smaller of the above)}}$$

$$= 100\frac{\left(\frac{18.22}{6.04}\right)-\left(\frac{6.0}{2.0}\right)}{\text{(the smaller of the above)}}$$

$$= 100\frac{3.02 - 3.0}{3.0}$$

$$= 0.6\%$$

LOW – TERTIARY

$$M_N = 100\frac{\left(\frac{I_3}{I_2}\right)-\left(\frac{T_3}{T_2}\right)}{\text{(the smaller of the above)}}$$

$$= 100\frac{\left(\frac{18.22}{7.55}\right)-\left(\frac{6.0}{2.5}\right)}{\text{(the smaller of the above)}}$$

$$= 100\frac{2.41 - 2.40}{2.40}$$

$$= 0.4\%$$

Step 11. Determine the total mismatch (M_T):

$$M_T = M_N + \text{LTC}$$

Add the maximum CT mismatch M_N (based on the power transformer in the neutral tap position) to the total permissible tap excursion from neutral. In this example, a ±10% load tap change (LTC) must be accommodated. Therefore:

$$M_T = 0.6 + 10 = 10.6\ \%$$

Verify CT Performance

> **NOTE**
> This procedure uses the ANSI accuracy class method. See *Appendix A*, *Setting Note 7* for more information.

Step 12. Determine the maximum CT secondary fault current for external faults (I_{F3} for three-phase, and I_{FG} for line-to-ground). Refer again to Figure 4-33 for this example. The maximum fault current is recorded for each set of terminals for all combinations of external faults.

HIGH

$$I_{F3} = \frac{3360}{120} = 28\text{ A}$$

$$I_{FG} = \frac{3375}{120} = 28\text{ A}$$

TERTIARY

$$I_{F3} = \frac{13{,}280}{600} = 22\text{ A}$$

LOW

$$I_{F3} = \frac{8400}{240} = 35\text{ A}$$

$$I_{FG} = \frac{9000}{240} = 38\text{ A}$$

Step 13. Determine the worst case burden voltage for a three-phase fault (V_{B3}).

- For wye-connected CTs:

$$V_{B3} = I_{F3}(R_L + R_R)$$

- For delta-connected CTs, based on a three-phase fault (refer to *Appendix A*, *Setting Note 2*):

$$V_{B3} = I_{F3}(R_W + 3R_L + 3R_R)$$

Where:

I_{F3} = determined in Step 12
R_R = relay resistance in ohms (< 0.05 ohm)
R_W = winding burden
R_L = one-way lead resistance in ohms

Neglecting R_R, use R_L from Figure 4-33:

HIGH	TERTIARY	LOW
$V_{B3} = 28(0.7)$	$V_{B3} = 22(0.7)$	$V_{B3} = 35(0.7)$
$= 19.6$	$= 15.4$	$= 24.5$

Step 14. Determine the burden voltage for a line-to-ground fault (V_{BG}).

- **For wye-connected CTs:**

$$V_{BG} = I_{FG}(2R_L + R_R)$$

Where:

I_{FG} = determined in Step 12

R_L = one-way lead resistance in ohms

R_R = relay resistance in ohms (< 0.05 ohm)

- **For delta-connected CTs:** V_{BG} is a function of the proportion of positive-sequence to zero-sequence currents but may be approximated by the same equation.

Neglecting R_R, use R_W and R_L from Figure 4-33:

HIGH	TERTIARY	LOW
$V_{BG} = 28(2(0.7))$	NONE	$V_{BG} = 38(2(0.7))$
$= 39.2$		$= 53.2$

Step 15. Determine the effective CT accuracy class (V_{CE}):

$$V_{CE} = \frac{\text{(Base Accuracy) (Number of CT Turns in Use)}}{\text{Maximum Ratio}}$$

$$= V_C\left(\frac{N_A}{N}\right)$$

HIGH	TERTIARY	LOW
$V_{CE} = (400)\frac{600}{600}$	$V_{CE} = (800)\frac{3000}{3000}$	$V_{CE} = (400)\frac{1200}{2000}$
$= 400$	$= 800$	$= 240$

Step 16. Determine the saturation factor (S_F):

Note: V_B is the largest burden voltage from steps 13 and 14.

$$S_F = \frac{V_B}{V_{CE}}$$

HIGH	TERTIARY	LOW
$S_F = \frac{39.2}{400}$	$S_F = \frac{15.4}{800}$	$S_F = \frac{53.2}{240}$
$= 0.1$	$= 0.02$	$= 0.22$

NOTE
Maximum recommended S_F=0.5.

Instantaneous (Unrestraint) Unit Setting

Step 17. Determine the maximum external fault multiple (I_E).

- **For wye-connected CTs and with WYE jumpers on Analog Board #2, shown in Figure 2-4:**

$$I_E = \frac{I_F}{T} = \frac{Maximum\ Relay\ Fault\ Current}{Corresponding\ Tap}$$

- **For delta-connected CTs, or with Δ1 or Δ2 jumpers on Analog Board #2, shown in Figure 2-4, (and based on a phase-to-phase fault): (**Refer to *Appendix A, Setting Note 3*.**)**

$$I_E = \frac{I_{F3}(\sqrt{3})}{T}$$

HIGH	TERTIARY	LOW
$I_E = \frac{28(\sqrt{3})}{2.0}$ $= 24$	$I_E = \frac{22}{6.0}$ $= 3.7$	$I_E = \frac{35(\sqrt{3})}{2.5}$ $= 24$

Step 18. Determine the unrestrained pickup level in multiples of tap (**X TAP**): Refer to *Appendix A, Setting Note 4.*

$$(\mathbf{X\ TAP}) = 0.7 \times I_E(Max.)$$

HIGH	TERTIARY	LOW
I_E not maximum	I_E not maximum	**X TAP** = (0.7)24 = 16.8

Note
The restrained element will not operate due to the large 2nd harmonic component present in the highly distorted current.

Step 19. Using the results of Step 18, set the **UNRESTRAINED PICKUP LEVEL** control. Referring to the table on the BE1-87T front panel, select the tap position (**X TAP**) that is higher than the result obtained in Step 18. Therefore, for this example, select **SET** position **P** (=**19 X TAP**) which is higher than the above result of 18.2 A.

Slope Setting

Step 20. Determine the multiples of self-cooled current (I_T): Refer to *Appendix A, Setting Note 5.*

$$I_T = \frac{I_R(\mathrm{MVA}_{\mathrm{SELF\text{-}COOLED}})}{T(\mathrm{MVA}_{\mathrm{FORCED\text{-}COOLED}})}$$

Where:

I_R = relay current (from Step 4)

T = the input tap (from Step 9)

$\mathrm{MVA}_{\mathrm{SELF\ COOLED}}$ and $\mathrm{MVA}_{\mathrm{FORCED\ COOLED}}$ are given in Figure 4-33.

HIGH	TERTIARY	LOW
$I_T = \frac{(6.04)(200)}{(2.0)(250)}$	$I_T = \frac{(16.8)(40)}{(6.0)(50)}$	$I_T = \frac{(7.55)(200)}{(2.5)(250)}$
$= 2.42$	=2.24	=2.42

Step 21. Select the restrained slope setting.

The recommended restrained slope setting (*S*) is a function of the total mismatch and the power transformer exciting current. This provides an ample security margin with respect to the characteristic kneepoint of the BE1-87T. Refer to Figure 4-34.

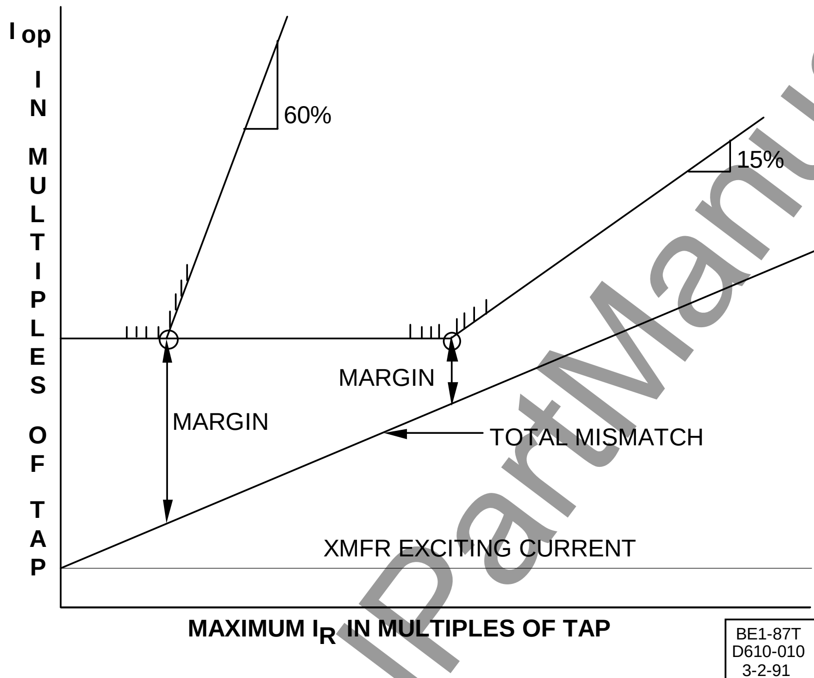


Figure 4-34. Slope Needed to Accommodate Total Mismatch with Adequate Margin

Specifically, if the maximum saturation factor S_F (from Step 16) exceeds 0.5, set the **RESTRAINED PICKUP LEVEL** to setting **K** which is equal to 60 as shown in the table on the front panel.

For all other cases including this example, use the following equation:

$$S = 3 + \frac{35(M_T + 3)}{23 - 4I_T}$$

Where:

S = restrained slope setting

M_T = total mismatch in percent

I_T = rated self-cooled current of the power transformer in multiples of tap

For a three-winding transformer application, such as this example, the maximum of the three values of M_T and of I_T is used.

M_T is 10.6 (from Step 11) and I_T is 2.42 (Step 20):

$$S = 3 + \frac{35(10.6 + 3)}{23 - 4(2.42)}$$

$$= 38.8$$

Because the maximum saturation factor S_F for this example is less than 0.5 (from Step 16), use the next highest slope. Select position **F** which = 40%.

For examples of suitable slope settings, see Table 4-2.

Table 4-2. Examples of Suitable Slope Settings

Maximum Mismatch in % (M_T)	**Current Rating of Power Transformer in Multiples of TAP (I_T)**	**Recommended Minimum RESTRAINED PICKUP LEVEL Setting* (Slope)**
2.5	1.5	15
2.5	2	20
5	2	25
10	1.5	30
12.5	1.5	35
15	1.5	40
15	2	45
15	2.5	50
20	1.5	55
20	2	60

* $S_F = V_B/V_{CE}$
If $S_F > 0.5$, set the RESTRAINED PICKUP LEVEL setting (slope) to $S = 60\%$.

Procedure Two

Refer to Figure 4-35 for a one-line drawing of this example.

Data

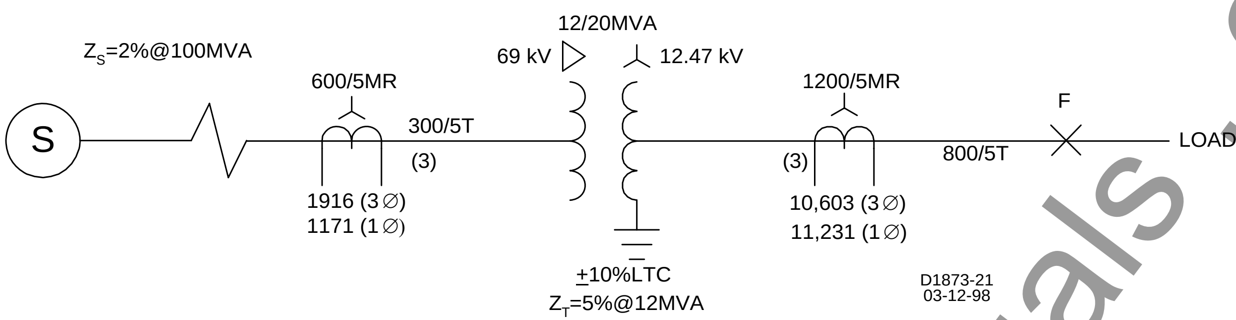


Figure 4-35. Two Winding Transformer Relay Setting Calculation Example

SPECIFICATIONS	HIGH SIDE	LOW SIDE
KV	69	12.47
MVA	12/20	12/20
CT Ratio	600	1200
CT Tap	300	800
CT Accuracy Class	400	800
CT Resistance (ohms)	0.18	0.48
One-Way Lead Burden (ohms)	0.7	0.7
XFMR Connection*	DELTA	WYE
CT Connection	WYE	WYE
Input #	1	2
Fault Current (Three-Phase)	1,916	10,603
Fault Current (Single-Phase)	1,171	11,231

* Standard connection: High voltage leads low voltage by 30°.

Tap and Phase Shift Settings

Step 1. Determine the full load primary current (I_P) of each winding:

$$I_P = \frac{(\text{MVA rating of transformer})(\times 1{,}000)}{(V_{\text{LINE - LINE}})(\sqrt{3})}$$

Use the top kVA rating of the transformer when making the calculations:

HIGH

$$I_P = \frac{20{,}000}{69\sqrt{3}}$$

$$I_P = 167.35$$

LOW

$$I_P = \frac{20{,}000}{12.47\sqrt{3}}$$

$$I_P = 925.98$$

Step 2. Determine the CT secondary current (I_S):

$$I_S = \frac{I_P}{\text{CT ratio}}$$

HIGH	LOW
$I_S = \frac{167.35}{60}$	$I_S = \frac{925.98}{160}$
$I_S = 2.79$	$I_S = 5.79$

Step 3. ***Three-Phase Units Only:*** Adjust the phase compensation jumpers on Analog Board #2, shown in Figure 2-4 (or use the procedure listed in **TESTING THREE-PHASE UNITS WITHOUT CHANGING JUMPERS,** in Section 5). Because of the grounded winding in this example, as shown in Figure 4-35, the high-side and low-side zero-sequence currents must be canceled. Because the CTs are connected in wye and the high-side currents lead the low-side currents by 30°, select the Δ2 position. This connection advances the low side phasors by 30° to match the phasors from the high-side.

	HIGH	LOW
Jumper Position:	WYE	Δ2

On single-phase units, the zero-sequence currents must be canceled by connecting the low side CTs in delta.

Step 4. Determine the relay current (I_R):

$$I_R = I_S \text{ x Conversion Factor}$$

Three-Phase Units Only: When using either Δ1 or Δ2 jumper positions, shown in Figure 2-4, multiply the secondary current I_S by the conversion factor (square root of three) just as if the CTs were connected in delta. If the system CTs are connected in delta (either three-phase or single-phase units), the same square root-of-three conversion factor must be applied.

HIGH	LOW
$I_R = (2.79)\ (1)$	$I_R = 5.79\sqrt{3}$
$I_R = 2.79$	$I_R = 10.02$

Step 5. Determine the spread ratio of the relay currents (largest/smallest) which must be less than the 4.45 capability of the BE1-87T:

Spread = 10.02/2.79 = 3.59

If the spread exceeds 4.45, consider changing CT ratios or use auxiliary CTs.

Step 6. Determine the Driving Input (*DP*) which we define as the input assigned to the smallest current in Step 4.

DP=I_M
DP=HIGH (INPUT 1)

Step 7. Determine the Driving Input Tap (T_I).

If both relay currents are between 2.0 and 8.9 amperes, the tap settings can be set equal to the relay currents (to the nearest 0.1 ampere). However, choosing the 2.0 tap setting for the minimum input will yield maximum sensitivity.

T_1 = 2.00

Step 8. Determine the desired Tap (T_D) for Input 2:

$$T_{D2} = (T_1)\ \frac{I_{R2}}{I_{R1}}$$

$$= 2.0\left(\frac{10.02}{2.79}\right)$$

$$= 7.18$$

Step 9. Select taps by rounding T_D to the nearest tenth:

T_1 = 2.0

T_2 = 7.2

Step 10. Determine the CT mismatch (M_N):

$$M_N = 100\left|\frac{\text{Current Ratio - Tap Ratio}}{\text{the smaller of the above}}\right|$$

$$= 100\left|\frac{\frac{I_{R1}}{I_{R2}} - \frac{T_1}{T_2}}{Smaller}\right|$$

$$= 100\left|\frac{\frac{2.79}{10.02} - \frac{2.0}{7.2}}{\text{Smaller}}\right| = 100\left|\frac{0.2784 - 0.2778}{0.2778}\right|$$

$$= 0.216 \text{ or } 0.22\ \%$$

Step 11. Determine the total mismatch (M_T):

$$M_T = M_N + LTC$$

Add the maximum CT mismatch M_N (based on the power transformer in the neutral tap position) to the total permissible tap excursion from neutral. In this example, a ±10 % load-tap change (LTC) must be accommodated. Therefore:

$$M_T = 0.22 + 10 = 10.22\%$$

Verify CT Performance

> **NOTE**
> This procedure uses the ANSI accuracy class method. See *Appendix A*, *Setting Note 7* for more information.

Step 12. Determine the maximum CT secondary fault current for external faults at F (I_{F3} for three-phase, and I_{FG} for single-phase). Refer again to Figure 4-35 for this example:

HIGH	**LOW**
$I_{F3} = \frac{1916}{60} = 32\ \text{A}$	$I_{F3} = \frac{10603}{160} = 66\ \text{A}$
$I_{FG} = \frac{1171}{60} = 19.5\ \text{A}$	$I_{FG} = \frac{11231}{160} = 70\ \text{A}$

Step 13. Determine the worst case CT burden voltage for a three-phase fault (V_{B3}).

- **For wye-connected CTs:**

$$V_{B3} = I_{F3}(R_L + R_R)$$

- **For delta-connected CTs, for three-phase fault:**

$$V_{B3} = I_{F3}(R_W + 3R_L + 3R_R)$$

Note that the wye connection produces a lower burden on the CTs (see *Appendix A*, Note 2).

Where:

I_{F3} = determined in Step 12 R_L = one-way lead resistance in ohms

R_W = winding burden R_R = relay resistance in ohms (< 0.05 ohm)

Neglecting R_R, use R_W and R_L from Figure 4-35:

HIGH	**LOW**
$V_{B3} = (32)(0.7) = 22.4\ \text{V}$	$V_{B3} = (66)(0.7) = 46.2\ \text{V}$

Step 14. Determine the worst case burden voltage for a line-to-ground fault (V_{BG}).

- **For wye-connected CTs:**

$$V_{BG} = I_{FG}(2R_L + R_R)$$

Where:

I_{FG} = determined in Step 12

R_L = one-way lead resistance in ohms

R_R = relay resistance in ohms

- **For delta-connected CTs:**

V_{BG} is a function of the proportion of positive-sequence to zero-sequence currents but may be approximated by the same equation (for worst case).

Neglecting R_R, use R_W and R_L from Figure 4-35:

HIGH∗

$$V_{BG} = 19.5(0.7) = 13.6\ \text{V}$$

LOW

$$V_{BG} = 70\,(2(0.7)) = 98.0\ \text{V}$$

> **NOTE∗**
>
> Since a phase-to-ground fault looks like a phase-to-phase fault on the delta side of a delta/wye transformer, each CT only has to carry one times the one way lead burden.

Step 15. Determine the effective CT accuracy class (V_{CE}):

$$V_{CE} = \frac{\text{(Base Accuracy) (Number of CT Turns in Use)}}{\text{Maximum Ratio}} = V_C\left(\frac{N_A}{N}\right)$$

HIGH

$$V_{CE} = (400)\frac{300}{600} = 200$$

LOW

$$V_{CE} = (800)\frac{800}{2000} = 533.3$$

Step 16. Determine the saturation factor (S_F):

VB is the largest of the burden voltages calculated in steps 13 and 14.

$$S_F = \frac{V_B}{V_{CE}}$$

HIGH

$$S_F = \frac{22.4}{200} = 0.11$$

LOW

$$S_F = \frac{98.0}{533.3} = 0.18$$

> **NOTE**
>
> Maximum Recommended S_F = 0.5.

Larger saturation factors will make the relay insecure for external faults. The only solution is to increase the CT quality.

Instantaneous (Unrestraint) Unit Setting

Step 17. Determine the maximum external fault multiple (I_E).

- **For wye-connected CTs and with WYE jumpers on Analog Board #2, shown in Figure 2-4:**

$$I_E = \frac{I_F}{T} = \frac{\text{Maximum Relay Fault Current}}{\text{Corresponding Tap}}$$

- **For delta-connected CTs, or with Δ1 or Δ2 jumpers on Analog Board #2, shown in Figure 2-4, (and based on phase-to-phase fault):** (See Setting Note 3.)

$$I_E = \frac{I_{F3}(\sqrt{3})}{T}$$

HIGH	LOW
$I_E = \frac{32}{2.0} = 15.96$	$I_E = \frac{66(\sqrt{3})}{7.2} = 15.9$

Step 18. Determine the unrestrained pickup level in multiples of tap (**X TAP**): (See Setting Note 4.)

$$(\textbf{X TAP}) = 0.7 \times I_E(Max.)$$

HIGH	LOW
X TAP $= (0.7)15.96 = 11.17$	I_E not maximum

This calculation assumes that the CTs carrying the maximum fault saturate severely, yielding only 30% of the expected ratio current. This leaves 70% of the fault current as a false differential current.

> **NOTE**
>
> The restrained element will not operate due to the large 2nd harmonic component present in the highly distorted current.

Step 19. Using the results of Step 18, set the **UNRESTRAINED PICKUP LEVEL** control.

Referring to the table on the BE1-87T front panel, select the tap position (**X TAP**) that is higher than the result obtained in Step 18. Therefore, for this example, select **SET** position G (=**12 X TAP**) which is higher than the above result of 11.17 X TAP.

If this value exceeds 21 (max setting), raise the tap settings toward the upper end of the tap range. If after the highest tap has been reached the unrestrained trip settings still exceeds 21, security is affected. The user should remember that the 70% saturation is conservative. A close look at the system L/R and CT performance is recommended. Chances are that the risk will be tolerable.

<u>*Slope Setting*</u>

The slope equation determines the slope setting required to maintain a margin of about 12% of I_{OP} at the breakpoint of the slope characteristic. This margin varies slightly with the actual taps but remains secure over the tap range.

Step 20. Determine the multiples of self-cooled current (I_T): Refer to *Appendix A*, *Setting Note 5.*

$$I_T = \frac{I_R(\text{MVA}_{\text{SELF-COOLED}})}{T(\text{MVA}_{\text{FORCED-COOLED}})}$$

Where:

I_R = relay current (from Step 4)

T = the input tap (from Step 9)

$\text{MVA}_{\text{SELF COOLED}}$ and $\text{MVA}_{\text{FORCE COOLED}}$ are given in Figure 4-35.

HIGH

$$I_T = \frac{(2.79)(12)}{(2.0)(20)} = 0.84$$

LOW

$$I_T = \frac{(10.02)(12)}{(7.2)(20)} = 0.84$$

Step 21. Select the restrained slope setting.

The recommended restrained slope setting (*S*) is a function of the total mismatch and the power transformer exciting current. This provides an ample security margin with respect to the characteristic kneepoint of the BE1-87T. Refer to Figure 4-34.

Specifically, if the maximum saturation factor S_F (from Step 16) exceeds 0.5, set the **RESTRAINED PICKUP LEVEL** to setting **K**, which is equal to 60 as shown in the table on the front panel.

For all other cases, including this example, use the following equation:

$$S = 3 + \frac{35(M_T + 3)}{23 - 4I_T}$$

Where:

S = restrained slope setting

M_T = total mismatch in percent

I_T = rated self-cooled current of the power transformer in multiples of tap

M_T is 10.2 (from Step 11) and I_T is 0.84 (Step 20):

$$S = 3 + \frac{35(10.2 + 3)}{23 - 4(0.84)} = 26.5\%$$

Because the maximum saturation factor S_F for this example is less than 0.5 (from Step 16), use the next highest slope. Select position **D**, which = 30%.

For examples of suitable slope settings, see Table 4-2.

CHECKING THE RELAY SETTINGS AND SYSTEM INPUTS

Steps 1 and 2 check that the current inputs from the power transformer are correct and consistent with the BE1-87T settings. The remaining steps check that the relay settings are within acceptable parameters.

> **CAUTION**
>
> Do **NOT** install connection plugs, apply power, remove circuit boards or carry out any of the other instructions given unless you are thoroughly familiar with the instructions in the sections on **RELAY OPERATING PRECAUTIONS** on page 4-1 and **RELAY DISASSEMBLY: Precautions** on page 4-11.

Step 1. Insert the cradle assembly into the relay case, then:

Three-Phase Units with Sensing Input Type G: Remove the lower connection plug first. Then remove the upper connection plug. Insert two Test Plugs (P/N 10095 or equivalent) in place of the top and bottom connection plugs. For further information, refer to *TEST PLUG* in Section 6, *MAINTENANCE*. Terminal 20 (trip output common) shown in Figure 4-10, must be isolated for this test.

All other styles: Replace the top connection plug with a Test Plug (P/N 10095 or equivalent). For further information, refer to *TEST PLUG* in Section 6, *MAINTENANCE*. Terminal 9 (trip output common) shown in Figures 4-7 through 4-9 must be isolated for this test.

Step 2. Using an ammeter and phase angle meter, measure the magnitude and phase angle of each current input, testing two inputs at a time. Begin with Inputs 1 and 2.

> **CAUTION**
>
> When more than two inputs are present, all inputs not being tested must be shorted to ground.

Single-Phase Units: Relay must not trip when the current to each input (of the pair being tested) is equal to the other in magnitude and the two currents are 180° out of phase (e.g., Inputs 1 and 2 measured, with Inputs 3, 4 and 5 shorted). For input terminal numbers, see Table 4-3.

Three-Phase Units: Relay must not trip when the current to Input 1 is equal to that of Input 2 in magnitude and the phase angle is as shown in Table 4-4. If there are three inputs per phase, interchange Inputs 2 and 3 and repeat the procedure, this time with magnitudes and phase angles as shown in Table 4-4. (Testing may require six synchronized current sources.)

Step 3. Using the Test Plug, reestablish all input connections and verify that the front panel **REST. TRIP** and **UNREST. TRIP** LEDs are extinguished.

This assures that the **X TAP** settings and jumper settings (refer to Figures 4-20, 4-21 and 4-27) are within acceptable parameters and that the differential current is below pickup.

If the **REST. TRIP** or **UNREST. TRIP** LEDs light, recheck the system current inputs and relay settings.

If actual waveforms, as sensed by the BE1-87T are desired, a procedure using a circuit board Extender Card shown in Figure 5-1 and an oscilloscope is available.

Table 4-3. Single-Phase Input Terminals

	Input 1	Input 2	Input 3	Input 4	Input 5
Terminals:	11 & 13	12 & 13	14 & 13	15 & 13	16 & 13

Table 4-4. Input Conditions For Non-Trip Three-Phase Sensing

30° Phase Shift Compensation Jumper Settings		Input 1 *		Input 2 *	
(Ref. Figure 4-27)	Phase	Terminals	Phase Angle	Terminals	Phase Angle
WYE-WYE, Δ1-Δ1, or Δ2-Δ2. (In these cases, input currents are equal and 180° out-of-phase.)	A	11 & 13	$I\angle\theta$	15 & 18	$I\angle\theta+180^\circ$
	B	12 & 13	$I\angle\theta+240^\circ$	16 & 18	$I\angle\theta+60^\circ$
	C	14 & 13	$I\angle\theta+120^\circ$	17 & 18	$I\angle\theta+300^\circ$
Input 1 is Δ1, Input 2 is WYE.	A	11 & 13	$I\angle\theta$	15 & 18	$I(\sqrt{3})\angle\theta+150^\circ$
	B	12 & 13	$I\angle\theta+240^\circ$	16 & 18	$I(\sqrt{3})\angle\theta+30^\circ$
	C	14 & 13	$I\angle\theta+120^\circ$	17 & 18	$I(\sqrt{3})\angle\theta+270^\circ$
Input 1 is WYE, Input 2 is Δ1.	A	11 & 13	$I\angle\theta$	15 & 18	$I\div(\sqrt{3})\angle\theta+210^\circ$
	B	12 & 13	$I\angle\theta+240^\circ$	16 & 18	$I\div(\sqrt{3})\angle\theta+90^\circ$
	C	14 & 13	$I\angle\theta+120^\circ$	17 & 18	$I\div(\sqrt{3})\angle\theta+330^\circ$
Input 1 is Δ2, Input 2 is WYE.	A	11 & 13	$I\angle\theta$	15 & 18	$I(\sqrt{3})\angle\theta+210^\circ$
	B	12 & 13	$I\angle\theta+240^\circ$	16 & 18	$I(\sqrt{3})\angle\theta+90^\circ$
	C	14 & 13	$I\angle\theta+120^\circ$	17 & 18	$I(\sqrt{3})\angle\theta+330^\circ$
Input 1 is WYE, Input 2 is Δ2.	A	11 & 13	$I\angle\theta$	15 & 18	$I\div(\sqrt{3})\angle\theta+150^\circ$
	B	12 & 13	$I\angle\theta+240^\circ$	16 & 18	$I\div(\sqrt{3})\angle\theta+30^\circ$
	C	14 & 13	$I\angle\theta+120^\circ$	17 & 18	$I\div(\sqrt{3})\angle\theta+270^\circ$

NOTES:
1. Table 4-4 is for reference only and applies to three-phase units with Input 3 at zero amperes.
2. * For A-B-C rotation.

MAINTENANCE

BE1-87T relays require no preventative maintenance other than a periodic operational check. If the relay fails to function properly, contact Technical Sales Support at Basler Electric to coordinate repairs.

STORAGE

This protective relay contains aluminum electrolytic capacitors which generally have a life expectancy in excess of 10 years at storage temperatures less than 40°C (104°F). Typically, the life expectancy of a capacitor is cut in half for every 10°C rise in temperature. Storage life can be extended if, at one-year intervals, power is applied to the relay for a period of 30 minutes.

TEST PLUG

Test plugs (Basler p/n 10095) provide a quick, easy method of testing relays without removing them from their case. Test plugs are simply substituted for the connection plugs. This provides access to the external stud connections as well as to the internal circuitry.

Test plugs consist of a black and red phenolic molding with 20 electrically separated contact fingers connected to 10 coaxial binding posts. The 10 fingers on the black side are connected to the inner binding posts (black thumbnuts) and tap into the relay internal circuitry. The 10 fingers on the red side of the test plug are connected to the outer binding posts (red thumbnuts) and also connect to the relay case terminals.

When testing circuits connected to the bottom set of case terminals, the test plug is inserted with the numbers 1 through 10 facing up. When using the test plug in the upper part of the relay, the numbers 11 through 20 are face up. It is impossible, due to the construction of the test plug, to insert it with the wrong orientation.

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SECTION 5 • TEST PROCEDURES

OVERVIEW

BE1-87T Transformer Differential Relays are calibrated and tested for correct operation at the factory and all calibration pots are sealed.

Immediately upon receipt of the relay, or after extended service, it is recommended that the **Verification Tests** provided in this section be performed. These comprehensive tests verify all operating parameters including calibration.

BE1-87T relay **Verification Tests** are divided into two groups based on the current CT ampere rating and the nominal operating frequency: (See the first position of the Style Number and the Sensing Input Range Option as shown in Figure 1-1.)

Five Amperes CT, 60 Hz Units (Range 1) and Five Amperes CT, 50 Hz Units (Range 3)

One Ampere CT, 60 Hz Units (Range 4) and One Ampere CT, 50 Hz Units (Range 2)

Within each group are separate tests that can be performed individually to make it easier to focus on a particular problem. However, all of these tests should be performed prior to putting the relay into service.

To help field users understand the verification procedures, four examples for restrained pickup testing are provided before the actual **Verification Tests** begin. Two examples are for increasing one input from balance and two examples are for decreasing one input from balance. These examples are not a necessary part of verification testing, but are provided for clarification.

For routine assurance that the BE1-87T is operating correctly, the simplified **OPERATIONAL TESTS** may be performed.

Before starting a test program, check the Style Number of the relay against the Style Number Identification Chart, Figure 1-1, to identify the specific features and options to be tested. For location of the switches and controls, refer to Figures 2-1 and 2-2 for Input Range 1 or 3, and Figures 2-3 and 2-4 for Input Range 2 or 4.

NOTE

LEDs and targets (if provided) should be checked for proper operation and targets reset after they have been tripped. Current-operated (Type D) targets will only operate when a minimum of 0.2 A is present in the trip circuit.

Similarly, the auxiliary contacts (if present) should be checked for proper operation. Switches **S1** and **S2**, located on the mother board and shown in Figure 2-4 allow the auxiliary output to operate in conjunction with a restrained trip, an unrestrained trip, or both.

EQUIPMENT REQUIRED

The following test equipment (or equivalent) is required for either the **Operational Tests** or the **Verification Tests:**

1. Two current sources with independently regulated current outputs. Must be able to produce outputs 180° out of phase. If harmonic testing is desired, harmonic capability is also required.
2. Counter, 0 to 0.5 second range.
3. Two Test Plugs, Basler p/n 10095 (see *Test Plug* in Section 4, *Installation*).
4. Extender Card, Basler p/n 9165500100, as shown in Figure 5-1.
5. Phase angle meter or oscilloscope with an ungrounded plug or ground isolation transformer.

CAUTION

If an oscilloscope or meter is to be connected to the internal relay circuitry, it must be isolated from ground. The internal circuits are not grounded to the case or isolated from the power inputs source.

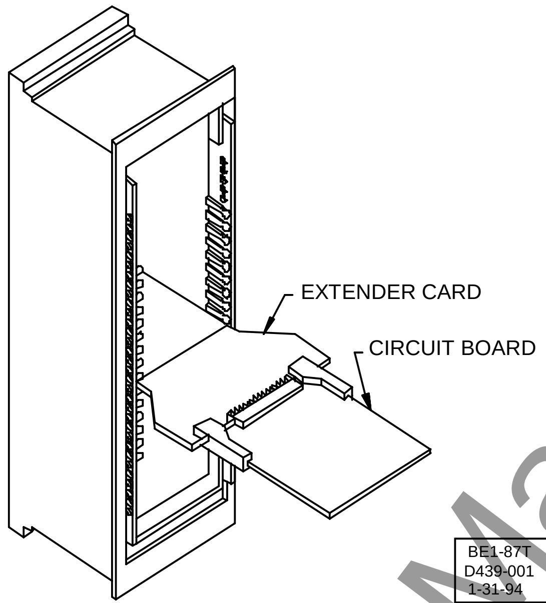


Figure 5-1. Illustrating Use of Extender Board

RESTRAINED PICKUP TESTING EXAMPLES

Increasing One Input from Balance

The formula to determine the unbalance value at which the restrained trip occurs is:

$$\text{unbalance} > \frac{slope}{100} \ (\text{maximum restraint})$$

or 0.35 pu, whichever is greater

Where:

unbalance = absolute value of (I_1 - I_2) in per unit (pu) i.e. $\left|\frac{I_1}{T_1} - \frac{I_2}{T_2}\right|$

slope = the **RESTRAINED PICKUP LEVEL** setting (15 to 60)

maximum restraint = larger of I_1 or I_2 in pu i.e. $\frac{I_1}{T_1} \ or \ \frac{I_2}{T_2}$

By increasing the I_1 input current from balance: (The balance current is $I_1 = I_2 \times \frac{T_1}{T_2} \ Amps$

1) *When:*

$$I_{1balance} > \frac{0.35}{\dfrac{\left(\dfrac{slope}{100}\right)}{1-\left(\dfrac{slope}{100}\right)}} \quad \text{OR} \quad \frac{I_2}{T_2} > \frac{0.35}{\dfrac{\left(\dfrac{slope}{100}\right)}{1-\left(\dfrac{slope}{100}\right)}} \ (\text{in pu})$$

This means the pu restraint current is to the right of the intersection of the slope characteristic with the 0.35 MPU horizontal line (see Figure 1-2).

the minimum trip point is established as:

$$I_{1trip\ min} = \frac{I_{1balance}}{1 - \frac{slope}{(100)}} \quad \text{(in pu)} \qquad \text{(Equation 1)}$$

OR $$I_{1trip\ \min} = \frac{I_2}{1-s} \times \frac{T_1}{T_2} \quad \text{(in Amps)} \qquad \text{(Equation 1a)}$$

2) *When:*

$$I_{1balance} < \frac{0.35}{\left[\frac{\left(\frac{slope}{100}\right)}{1 - \left(\frac{slope}{100}\right)}\right]} \quad \text{(in pu)}$$

the minimum trip point is established as:

$$I_{1trip\ min} = I_{1balance} + 0.35 \quad \text{(in pu)} \qquad \text{(Equation 2)}$$

OR $$I_{1trip\ \min} = T_1\left(\frac{I_2}{T_2} + 0.35\right) \quad \text{(in Amps)} \qquad \text{(Equation 2a)}$$

Example One:

Assume:

$$tap_1 = 2,\ tap_2 = 3.8,\ slope = 15\%$$

$$Inputs:\ I_1 = 2A\ (1\ pu)\ \left(\frac{I_1}{T_1} = \frac{2}{2} = 1\ pu\right)$$

$$I_2 = 3.8A\ (1\ pu)\ \left(\frac{I_2}{T_2} = \frac{3.8}{3.8} = 1\ pu\right)$$

Check:

$$I_{1balance} <\ > \frac{0.35}{\left[\frac{\left(\frac{slope}{100}\right)}{1 - \left(\frac{slope}{100}\right)}\right]} \quad \text{(in pu)}$$

$$1 <\ > \frac{0.35}{\left(\frac{0.15}{1 - 0.15}\right)}$$

$$1 < 1.983$$

Therefore: Use Equation 2 or 2a.

From Figure 1-2 (the percentage restraint characteristic of the BE1-87T at 15% slope), the minimum current where trip occurs is:

$$I_{1trip} = 1\ \text{pu} + 0.35$$
$$= 1.35\ \text{pu}$$

In terms of current, the trip current is:

$$I_{1trip} = 1.35 \text{ pu} \times tap$$
$$= (1.35)(2.0)$$
$$= 2.70 \text{ A} \pm 6\% \pm 100 \text{ mA}$$

Using Equation 2a:

$$I_{1trip} = 2\left(\frac{3.8}{3.8} + 0.35\right)$$
$$= 2.7 \text{ A}$$

Example Two:

Assume:

$$tap_1 = 2,\ tap_2 = 3.8,\ slope = 15\%$$

$$Inputs\text{: } I_1 = 6A\ (3\ pu)\ \left(\frac{I_1}{T_1} = \frac{6}{2} = 3\ pu\right)$$

$$I_2 = 11.4A\ (3\ pu)\ \left(\frac{I_2}{T_2} = \frac{11.4}{3.8} = 3\ pu\right)$$

Check:

$$I_{1balance} < > \frac{0.35}{\left[\frac{\left(\frac{slope}{100}\right)}{1 - \left(\frac{slope}{100}\right)}\right]} \quad \text{(in pu)}$$

$$3 < > \frac{0.35}{\left(\frac{0.15}{1 - (0.15)}\right)}$$

$$3 > 1.983$$

Therefore: Use Equation 1 or 1a.

From Figure 1-2 (the percentage restraint characteristic of the BE1-87T at 15% slope), the minimum current where trip occurs is:

$$I_{1\,trip} = \frac{3 \text{ pu}}{1 - 0.15}$$
$$= 3.53 \text{ pu}$$

In terms of current, the trip current is:

$$I_{1trip} = 3.53 \text{ pu} \times \text{tap}$$
$$= (3.53)(2.0)$$
$$= 7.06 \text{ A} \pm 6\% \pm 100 \text{ mA}$$

Using Equation 1a:

$$I_{1trip\,\min} = \frac{11.4}{1 - 0.15} \times \frac{2}{3.8}$$
$$= 7.06 \text{ A}$$

Decreasing One Input from Balance

The formula to determine the unbalance value at which the restrained trip occurs is:

$$\text{unbalance} > \frac{slope}{100} \ \text{(maximum restraint)}$$

$$\text{or } 0.35 \text{ pu, whichever is greater}$$

Where:

unbalance **-** absolute value of I_1 **-** I_2 in per unit (pu)

slope = the **RESTRAINED PICKUP LEVEL** setting (15 to 60)

maximum restraint = larger of I_1 or I_2 in pu $=I_r$

By decreasing the I_2 input current from balance:

The balance current is $I_2 = I_1 \times \frac{T_2}{T_1}$

1) *When:*

$$I_{2balance} > \frac{0.35}{\left(\frac{slope}{100}\right)} \ \text{(in pu)} \quad \text{OR} \quad \frac{I_1}{T_1} > \frac{0.35}{\left(\frac{slope}{100}\right)}$$

the value of $I_{2\ \text{trip max.}}$ is defined as:

$$I_{2trip} = I_{2balance} \ 1 - \left(\frac{slope}{100}\right) \ \text{(in pu)}$$ (Equation 3)

OR $$I_{2trip\max} = \left(1 - \frac{slope}{100}\right) \times I_1 \times \frac{T_2}{T_1}$$ (Equation 3a)

2) *When:*

$$I_{2\,balance} < \frac{0.35}{\left(\frac{slope}{100}\right)} \quad \text{(in pu)}$$

the maximum trip point is established as:

$$I_{2\,trip} = I_{2\,balance} - 0.35 \quad \text{(in pu)}$$ (Equation 4)

OR $$I_{2trip\max} = T_2\left(\frac{I_1}{T_1} - 0.35\right)$$ (Equation 4a)

Example Three:

Assume:

$tap_1 = 2$, $tap_1 = 3.8$, slope = 15%.

Inputs: $I_1 = 2$ A (1 pu)

$I_2 = 3.8$ A (1 pu)

Check:

$$I_{2balance} < \ > \frac{0.35}{\left(\frac{slope}{100}\right)} \quad \text{(in pu)}$$

$$1 < \ > \frac{0.35}{0.15}$$

$$1 < 2.333$$

Therefore: Use Equation 4 or 4a.

From Figure 1-2 (the percentage restraint characteristic of the BE1-87T at 15% slope), the minimum current where trip occurs is:

$$I_{2\ trip} = 1 \text{ pu} - 0.35$$
$$= 0.65 \text{ pu}$$

In terms of current, the trip current is:

$$I_{2\ trip} = (0.65 \text{ pu})\ (\text{Tap})$$
$$= (0.65)\ (3.8)$$
$$= 2.47 \text{ A} \pm 6\% \pm 100 \text{ mA}$$

Using Equation 4a:

$$I_{2trip} = 3.8\left(\frac{2}{2} - 0.35\right)$$
$$= 2.47 \text{ A}$$

Example Four:

Assume:

$tap_1 = 2,\ tap_2 = 3.8,\ slope = 15\%.$

Inputs: $I_1 = 6$ A (3 pu)

$I_2 = 11.4$ A (3 pu)

Check:

$$I_{2\ balance} < \ > \frac{0.35}{\left(\frac{slope}{100}\right)} \quad \text{(in pu)}$$

$$3 < \ > \frac{0.35}{0.15}$$

$$3 < 2.333$$

Therefore: Use Equation 3 or 3a.

From Figure 1-2 (the percentage restraint characteristic of the BE1-87T at 15% slope), the minimum current where trip occurs is:

$$I_{2\ trip} = 3 \text{ pu } (1 - 0.15)$$
$$= 2.55 \text{ pu}$$

In terms of current, the trip current is:

$$I_{2\ trip} = 2.55 \text{ pu } (\text{Tap})$$
$$= (2.55)\ (3.8)$$
$$= 9.69 \text{ A} \pm 6\% \pm 100 \text{ mA}$$

Using Equation 3a:

$$I_{2trip} = (1 - 0.15) \times 6 \times \frac{3.8}{2}$$
$$= 9.69 \text{ A}$$

NOTE

The relay operates on maximum restraint. By reducing the current of one input, the published trip/non-trip regions are as defined by Figure 1-2.

TEST SETUP DIAGRAMS

Refer to the appropriate test setup diagram under "Related Topics."

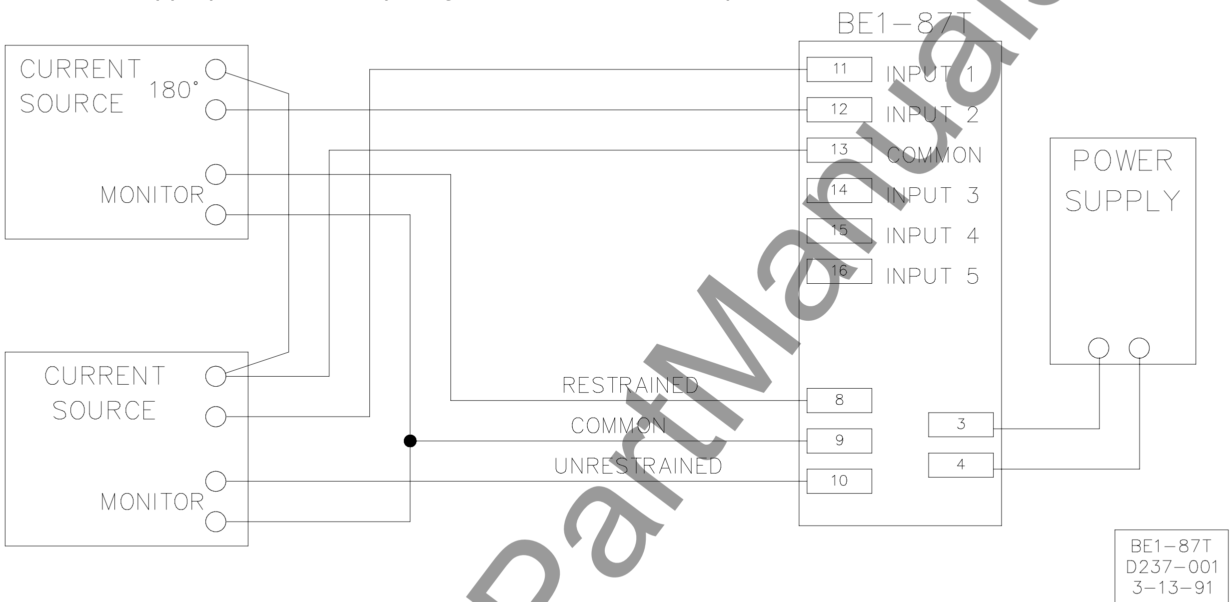


Figure 5-2. Test Setup: Single-Phase

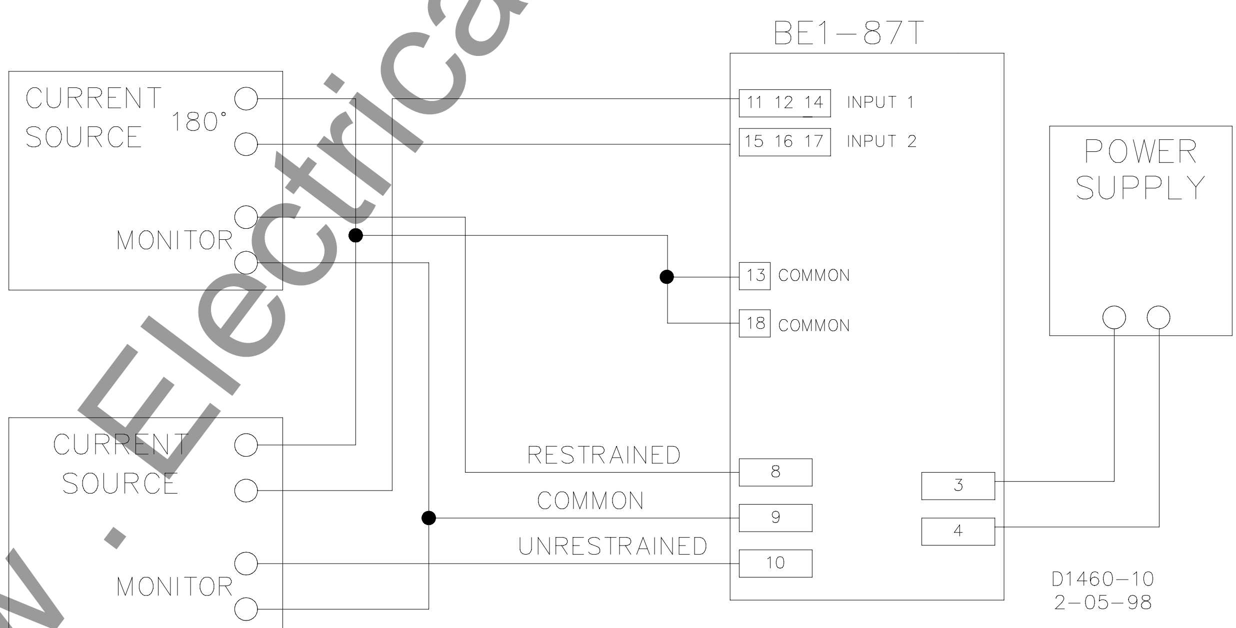


Figure 5-3. Test Setup: Three-Phase, Sensing Input Type E, Output Option E

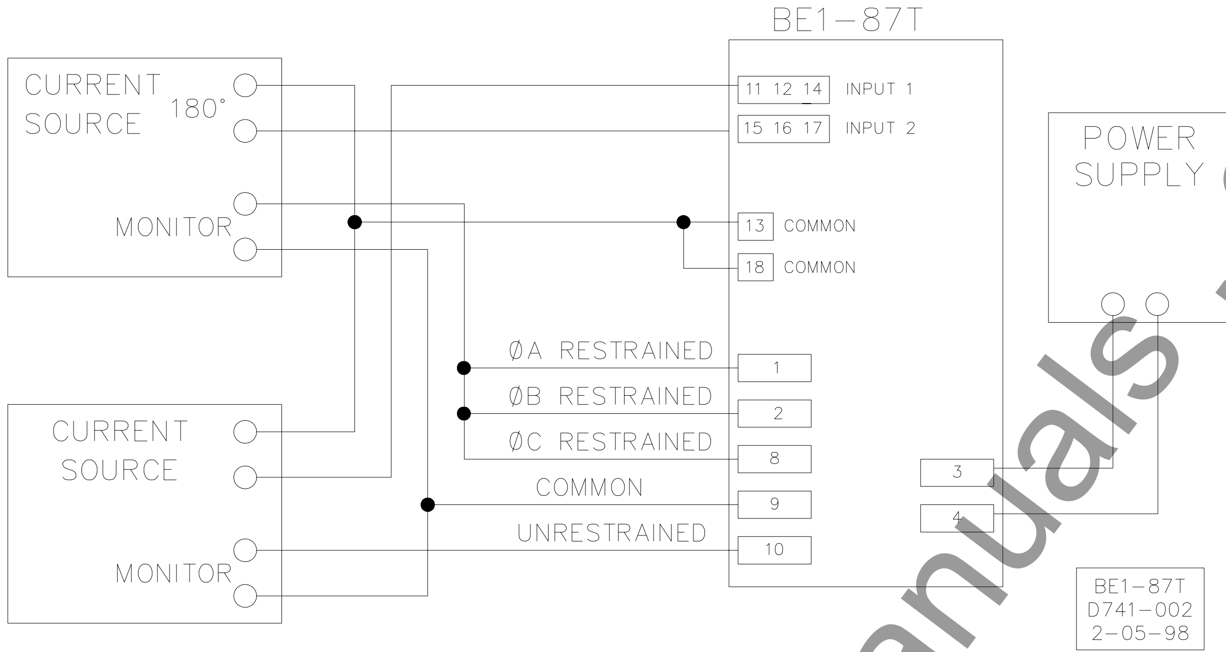


Figure 5-4. Test Setup: Three-Phase, Sensing Input Type E, Output Option F

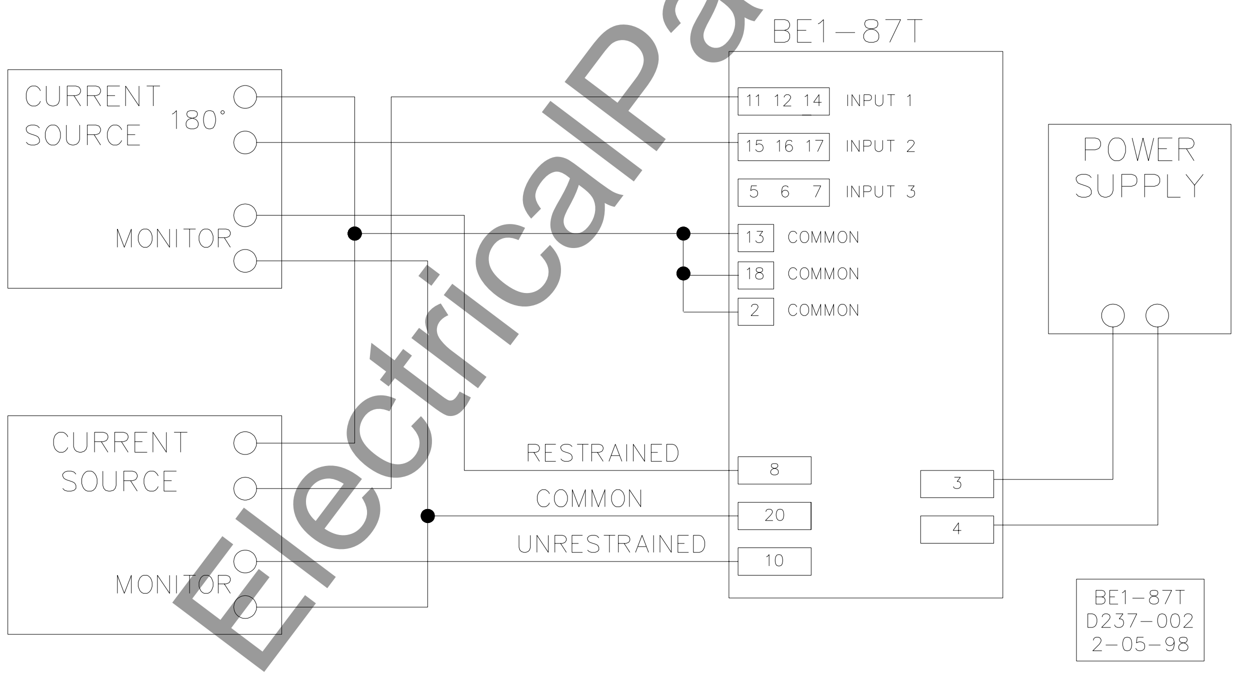


Figure 5-5. Test Setup: Three-Phase, Sensing Input Type G, Output Option E

VERIFICATION TESTS: 5 AMP CT, 50 OR 60 HZ UNITS

CAUTION

Current supplied to the BE1-87T input terminals must not exceed 20 A continuous or 250 A for 1 second. Whenever 20 A must be exceeded, provisions must be made to cut off the sensing current automatically after a suitable time interval. Sensing current can be calculated by using the following equation:

$$I = \frac{K}{\sqrt{t}}$$

Where: K = 250 or 50 x tap, whichever is less
t = the time (in seconds) that the current flows

Restrained Pickup Verification

Step 1. Connect the relay as appropriate (refer to Figures 5-2 through 5-5) beginning with input terminals 11 and 13 for the initial tests. Do not apply power at this time.

Step 2. Observing the precautions provided in Section 4, *RELAY DISSASSEMBLY*, remove the relay from its case. Then remove the front panel to gain access to the printed circuit boards.

Step 3. Remove the Analog #1 board (one per phase) as shown in Figure 4-19. Connect the Input-Grounding jumpers to the disabled position. Refer to Figure 4-20 for relays with Option 1-0 and Figure 4-21 for relays with Option 1-1 for correct positioning. For further information, see *Grounding Unused Inputs* in Section 4.

After testing is complete (and prior to placing the relay in service), it may be necessary to reposition the jumpers.

Step 4. ***Three-Phase Units Only:*** Check that all of the 30° Phase Shift Compensation jumpers on the Analog Board #2, shown in Figure 4-27, are in the WYE position. If not, reposition these jumpers accordingly.

NOTE

It is possible to test three-phase units without changing the 30° Phase Shift Compensation jumpers from the in-service positions. Refer to *Testing Three-Phase Relays without Changing Jumpers*, at the end of this section.

Step 5. Replace all circuit boards and reassemble the relay.

Step 6. Refer to Table 1-1 and Figure 1-2 for multiples of tap and percentage restraint characteristics. Set the **RESTRAINED PICKUP LEVEL** switches and the **INPUT 1** and **INPUT 2** tap switches to the values shown in Table 5-1.

Step 7. Apply power to the relay. Apply input current as indicated in Table 5-1 for each input, then reduce the Input 2 current or increase the Input 1 current until the **REST. TRIP** LED lights. This should occur as the input current being adjusted reaches the level given in the Trip Amperes column for the respective input.

Step 8. If the relay has more than two inputs, reconnect the relay by substituting the Input 3 terminals for the Input 2 terminals. Then repeat Steps 6 and 7, using the Input 2 values of Table 5-1 for Input 3.

If there are more than three inputs (as in some single-phase units), continue substituting every higher-numbered input for Input 2, each time comparing the input under test against Input 1 as in Steps 6 and 7.

Step 9. ***Three-Phase Units Only***: Repeat Steps 6, 7 and 8 for phases B and C. (Refer to Figures 5-2 through 5-5, as appropriate, for the terminal numbers of the phase B and C inputs.)

Table 5-1. Restrained Pickup Test: 5 A, 50 or 60 Hz

	Input 1, Tap = 2.0		**Input 2, Tap = 3.8**		**Increasing Input 1**	**Decreasing Input 2**
% Slope	**Amperes**	**X Tap**	**Amperes**	**X Tap**	**Trip Amperes**	**Trip Amperes**
15	2.0	1	3.8	1	2.70 ±0.26	2.47 ±0.25
15	4.0	2	7.6	2	4.71 ±0.38	6.27 ±0.48
15	6.0	3	11.4	3	7.06 ±0.52	9.69 ±0.68
15	10.0	5	19.0	5	11.76 ±0.81	16.15 ±1.07
25	2.0	1	3.8	1	2.70 ±0.26	2.47 ±0.25
25	4.0	2	7.6	2	5.33 ±0.42	5.70 ±0.44
25	6.0	3	11.4	3	8.00 ±0.58	8.55 ±0.61
25	10.0	5	19.0	5	13.33 ±0.90	14.25 ±0.96
50	2.0	1	3.8	1	4.00 ±0.34	1.90 ±0.21
50	4.0	2	7.6	2	8.00 ±0.58	3.80 ±0.33
50	6.0	3	11.4	3	12.00 ±0.82	5.70 ±0.44
50	10.0	5	19.0	5	20.00 ±1.30	9.50 ±0.67
30	2.0	1	3.8	1	2.86 ±0.27	2.47 ±0.25
30	6.0	3	11.4	3	8.57 ±0.61	7.98 ±0.58
35	2.0	1	3.8	1	3.08 ±0.28	2.47 ±0.25
35	6.0	3	11.4	3	9.23 ±0.65	7.41 ±0.54
40	2.0	1	3.8	1	3.33 ±0.30	2.28 ±0.24
40	6.0	3	11.4	3	10.00 ±0.70	6.84 ±0.51
60	2.0	1	3.8	1	5.00 ±0.40	1.52 ±0.19
60	6.0	3	11.4	3	15.00 ±1.00	4.56 ±0.37

Input (or Tap) Switch Verification

Each input is scaled using a combination of two rotary switches. Verify the switches as follows.

Step 1. Determine the Sensing Input Type (the first digit of the Style Number shown on the front panel):

- **A** Single-phase, two inputs
- **B** Single-phase, three inputs
- **C** Single-phase, four inputs
- **D** Single-phase, five inputs
- **E** Three-phase, two inputs each phase
- **G** Three-phase, three inputs each phase

Step 2. Connect the input being tested to the current source, as shown in the appropriate **TEST SETUP**, Figures 5-2 through 5-5.

Step 3. Set the input under test to the 3.9 tap position as shown in Table 5-2. Set the **RESTRAINED PICKUP LEVEL** switch to position **A** (15%). Apply current to the input under test, increasing the current until the **REST. TRIP** LED lights. At this point, the input current should be 1.36 A ±6% ±100 mA.

Step 4. Repeat Step 3 for the additional tap positions shown in Table 5-2. This verifies the accuracy of all the binary combinations of the rotary switches.

Step 5. Test the other inputs by reconnecting to the next pair of terminals for your relay and repeating Steps 3 and 4. (The successful completion of these tests will verify the electrical integrity of all the tap switches.)

Table 5-2. Input Verification∗: 5 A, 50 or 60 Hz

Tap† Position	Input Current Range at Pickup
3.9	1.18 - 1.55 A
4.3	1.31 - 1.70 A
6.4	2.01 - 2.47 A
7.8	2.47 - 2.99 A

∗ Pickup occurs at 0.35 x Tap. See Figure 1-2.
† The setting of the upper and lower **INPUT** switches of the input being tested. (Reference *LOCATION OF CONTROLS AND INDICATORS*.)

Unrestrained Pickup Verification

Step 1. Set the **INPUT** 1 (tap) switches to the 2.0 A position. Connect the relay as appropriate (refer to Figures 5-2 through 5-5) using terminals 11 & 13 (Input 1 for both single-phase and three-phase units).

Step 2. Set the **UNRESTRAINED PICKUP LEVEL** switch to position **A** (**6 x TAP**). Increase the input current until the **UNREST. TRIP** LED lights (disregard the **REST. TRIP** LED). This should occur at 12.0 A ±3% as indicated in Table 5-3.

Step 3. Repeat Step 2 using the other **UNRESTRAINED PICKUP LEVEL** switch positions given in Table 5-3.

Step 4. ***For Three-Phase Units Only:*** Repeat Steps 1 through 3 for phase B of input 1 (terminals 12 & 13) and Phase C of input 1 (terminals 14 & 13).

Table 5-3. Unrestrained Pickup Verification: 5 A, 50 or 60 Hz

Unrestrained Pickup Level	Input 1 Tap Position	Input Current at Pickup ±3%
A (6 x TAP)	2.0	12.0 A
J (14 x TAP)	2.0	28.0 A
S (21 x TAP)	2.0	42.0 A

Second-Harmonic Restraint Verification

Step 1. Set the **INPUT 1** (tap) switches to the 2.0 A position. Connect the relay as appropriate (refer to Figures 5-2 through 5-5) using terminals 11 & 13 (Input 1 for both single-phase and three-phase units).

Step 2. ***Three-Phase Units Only:*** Set the **Calibrate** toggle switch **S2** (letter D of Figure 2-4) to the **CAL** position on each of the three Analog #1 boards. These three toggle switches are readily accessible on the right side of the relay when withdrawn from the case. (It is not necessary to pull out the circuit boards.)

> **NOTE**
>
> With two current sources in parallel, apply the fundamental frequency and then add the required harmonic.

Step 3. Apply 2.0 A at 50 or 60 Hz, as appropriate for the style, to Input 1. The **REST. TRIP** LED should be illuminated.

Step 4. Increase the second-harmonic current until the **REST. TRIP** LED extinguishes, indicating that the inhibit point has been reached. Note the magnitude of the second-harmonic component at the inhibit point.

Step 5. To calculate the second-harmonic inhibit percentage, divide the second-harmonic current measured in Step 4 by the current applied in Step 3. (Divide the harmonic current by the fundamental current.) Factory setting is 12.0 ±3% for single-phase units and 18.0 ±3% for three-phase units.

Step 6. ***Three-Phase Units Only:*** Repeat Steps 1 through 5 for phase B (terminals 12 & 13) and phase C (terminals 14 & 13).

Step 7. ***Three-Phase Units Only:*** Upon completion of above testing, return the three calibrate toggle switches **S2** (letter D of Figure 2-4) to the **NORM** position.

Fifth-Harmonic Restraint Verification

Step 1. Set the **INPUT 1** (tap) switches to the 2.0 A position. Connect the relay as appropriate (refer to Figures 5-2 through 5-5) using terminals 11 & 13 (Input 1 for both single-phase and three-phase).

Step 2. Apply 2.0 A at 50 or 60 Hz, as appropriate for the style, to Input 1. The **REST. TRIP** LED should be illuminated.

Step 3. Increase the fifth-harmonic current until the **REST. TRIP** LED extinguishes indicating that the inhibit point has been reached. Note the magnitude of the fifth-harmonic component at the inhibit point.

Step 4. To calculate the fifth-harmonic inhibit percentage, divide the current measured in Step 3 by the current applied in Step 2. (Divide the harmonic current by the fundamental current.) Factory setting is 35.0 ±3% for both single-phase and three-phase units.

Step 5. ***Three-Phase Units Only:*** Repeat Steps 1 through 4 for phase B (terminals 12 & 13) and phase C (terminals 14 & 13).

Response Time Verification

Step 1. Connect the relay as appropriate (refer to Figures 5-2 through 5-5).

Step 2. Set the **RESTRAINED PICKUP LEVEL** switch (phase A) to **A** (15%). Place all of the **INPUT** switches on the 2.0 A tap position.

Step 3. Apply 2.0 A at 50 or 60 Hz, as appropriate for the style, to Input 1 (terminals 11 & 13 on both single- and three-phase styles) and to Input 2 (terminals 12 & 13 on Single-Phase and terminals 15 & 18 on three-phase).

Step 4. Perform a restrained trip at 2 x Pickup by stepping the Input 2 current 3.4 A. Note the time interval between initiation of the simulated fault and the closure of the restrained output contact. The trip time should be less than that shown in Table 5-4.

Step 5. Repeat Step 4 at I_{OP} = 10 x Pickup. Note that, with Input 1 at 2.0 A, Input 2 current should be stepped to 9.0 A. The trip time should be less than that shown in Table 5-4.

Step 6. ***Three-Phase Units Only:*** Repeat Steps 1 through 5 for Phases B and C.

Step 7. Place the **UNRESTRAINED PICKUP LEVEL** switch to the **A** setting (**6 X TAP**). Place all of the **INPUT** switches to the 2.0 A tap position.

Step 8. With 0.0 A at Input 1 (terminals 11 & 13), apply 24 A (2 x Pickup) to Input 2 (terminals 12 and 13 on single-phase and terminals 15 & 18 on three-phase). Note the time interval between initiation of the simulated fault and the closure of the unrestrained output contact. The interval should be less than that shown in Table 5-4.

Step 9. Repeat Steps 7 and 8 at 10 x Pickup. Note that, with Input 1 at 0.0 A, it will be necessary to step the Input 2 current to 120.0 A for an unrestrained trip. The trip time should be less than that shown in Table 5-4.

Step 10. ***Three-Phase Units Only:*** Repeat Steps 8 and 9 for phases B and C.

Table 5-4. Timing: 5 A, 50 or 60 Hz

		Option 1-0 Timing Maximum		Option 1-1 Timing Maximum
Function	**Differential Current**	**50 Hz**	**60 Hz**	**50 or 60 Hz**
Restrained Trip	2 x Pickup	81 ms	70 ms	49 ms
Restrained Trip	10 x Pickup	73 ms	67 ms	37 ms
Unrestrained Trip	2 x Pickup	70 ms	57 ms	57 ms
Unrestrained Trip	10 x Pickup	32 ms	28 ms	10 ms

VERIFICATION TESTS: 1 AMP CT, 50 OR 60 HZ UNITS

CAUTION

Current supplied to the BE1-87T input terminals must not exceed 4 A continuous or 50 A for 1 second. Whenever 4 A must be exceeded, provisions must be made to cut off the sensing current automatically after a suitable time interval. This can be calculated by using the following equation:

$$I = \frac{K}{\sqrt{t}}$$

Where: K = 50 or 50 x tap, whichever is less
t = the time (in seconds) that the current flows

Restrained Pickup Verification

Step 1. Connect the relay as appropriate (refer to Figures 5-2 through 5-5) beginning with input terminals 11 and 13 for the initial tests. Do not apply power at this time.

Step 2. Observing the precautions provided in Section 4, *RELAY DISASSEMBLY*, remove the relay from its case. Then remove the front panel to gain access to the printed circuit boards.

Step 3. Remove the Analog #1 board (one per phase) shown in Figure 4-19. Connect the Input-Grounding jumpers to the disabled position. Refer to Figure 4-20 for relays with Option 1-0 and Figure 4-21 for relays with Option 1-1 for correct positioning. For further information, see *Grounding Unused Inputs* in Section 4.

After testing is complete (and prior to placing the relay in service), it may be necessary to reposition the jumpers.

Step 4. ***Three-Phase Units Only:*** Check that all of the 30° Phase Shift Compensation jumpers on the Analog Board #2, shown in Figure 4-27, are in the **WYE** position. If not, reposition these jumpers accordingly.

NOTE

It is possible to test three-phase units without changing the 30° Phase Shift Compensation jumpers from the in-service positions. Refer to *Testing Three-Phase Relays without Changing Jumpers* at the end of this section.

Step 5. Replace all circuit boards and reassemble the relay.

Step 6. Refer to Table 1-1 and Figure 1-2 for multiples of tap and percentage restraint characteristics. Set the **RESTRAINED PICKUP LEVEL** switches and the **INPUT 1** and **INPUT 2** tap switches to the values shown in Table 5-5.

Step 7. Apply power to the relay. Apply input current as indicated in Table 5-5 for each input. Then reduce the Input 2 current or increase the Input 1 current until the **REST. TRIP** LED lights. This should occur as the input current being adjusted reaches the level given in the Trip Amperes column for the respective input.

Step 8. If the relay has more than two inputs, reconnect the relay by substituting the Input 3 terminals for the Input 2 terminals. Then repeat step 6 and 7 using the Input 2 values of Table 5-5 for Input 3.

If there are more than three inputs (as in some single-phase units), continue substituting every higher-numbered input for Input 2, each time comparing the input under test against Input 1 as in Steps 6 and 7.

Step 9. ***Three-Phase Units Only:*** Repeat Steps 6, 7 and 8 for phases B and C. (Refer to Figures 5-2 through 5-5, as appropriate, for the terminal numbers of the phase B and C inputs of the relay under test.)

Table 5-5. Restraint Pickup Test: 1 A, 50 or 60 Hz

	Input 1, Tap = 2.0		Input 2, Tap = 3.8		Increasing Input 1	Decreasing Input 2
% Slope	**Amperes**	**X Tap**	**Amperes**	**X Tap**	**Trip Amperes**	**Trip Amperes**
15	0.4	1	0.76	1	0.540 ±0.052	0.494 ± 0.050
15	0.8	2	1.52	2	0.941 ±0.076	1.254 ± 0.095
15	1.2	3	2.28	3	1.412 ±0.105	1.938 ± 0.136
15	2.0	5	3.8	5	2.353 ±0.161	3.230 ± 0.214
25	0.4	1	0.76	1	0.540 ±0.052	0.494 ± 0.050
25	0.8	2	1.52	2	1.067 ±0.084	1.140 ± 0.088
25	1.2	3	2.28	3	1.600 ±0.116	1.710 ± 0.123
25	2.0	5	3.8	5	2.667 ± 0.180	2.850 ± 0.191
50	0.4	1	0.76	1	0.800 ± 0.068	0.380 ± 0.043
50	0.8	2	1.52	2	1.600 ± 0.116	0.760 ± 0.066
50	1.2	3	2.28	3	2.400 ± 0.164	1.140 ± 0.088
50	2.0	5	3.8	5	4.00 ± 0.260	1.900 ± 0.134
30	0.4	1	0.76	1	0.571 ± 0.054	0.494 ± 0.050
30	1.2	3	2.28	3	1.714 ± 0.123	1.596 ± 0.116
35	0.4	1	0.76	1	0.615 ± 0.057	0.494 ± 0.050
35	1.2	3	2.28	3	1.846 ± 0.131	1.482 ± 0.109
40	0.4	1	0.76	1	0.667 ± 0.060	0.456 ± 0.047
40	1.2	3	2.28	3	2.000 ± 0.140	1.368 ± 0.102
55	0.4	1	0.76	1	0.889 ± 0.073	0.342 ± 0.041
55	1.2	3	2.28	3	2.667 ± 0.180	1.026 ± 0.082

Input (or Tap) Switch Verification

Each input is scaled using a combination of two rotary switches. Verify the switches as follows.

Step 1. Determine the Sensing Input Type (the first digit of the Style Number shown on the front panel):

- **A** Single-phase, two inputs
- **B** Single-phase, three inputs
- **C** Single-phase, four inputs
- **D** Single-phase, five inputs
- **E** Three-phase, two inputs each phase
- **G** Three-phase, three inputs each phase

Step 2. Connect the input being tested to the current source as shown in the appropriate diagram, Figures 5-2 through 5-5.

Step 3. Set the **INPUT** under test to the **0.78** tap position as shown in Table 5-6. Set the **RESTRAINED PICKUP LEVEL** switch to position **A** (15%). Apply current to the input under test, increasing the current until the **REST. TRIP** LED lights. At this point, the input current should be 0.273 A ±6% ±20 mA.

Step 4. Repeat Step 3 for the additional tap positions shown in Table 5-6. This verifies the accuracy of all the binary combinations of the rotary switches.

Step 5. Test the other inputs by reconnecting to the next pair of terminals for your relay and repeating Steps 3 and 4. (The successful completion of these tests will verify the electrical integrity of all the tap switches.)

Table 5-6. Input Verification∗: 1 A, 50 or 60 Hz

Tap† Position	Input Current Range at Pickup
0.78	0.24 - 0.31 A
0.86	0.26 - 0.34 A
1.28	0.40 - 0.49 A
1.56	0.49 - 0.60 A

∗ Pickup occurs at 0.35 x Tap. See Figure 1-2.
† The setting of the upper and lower **INPUT** switches of the input being tested. (Reference Figures 2-1 to 2-4.)

Unrestrained Pickup Verification

Step 1. Set the **INPUT 1** (tap) switches to the **2.0** A position. Connect the relay as appropriate (refer to Figures 5-2 through 5-5, as appropriate) using terminals 11 & 13 (Input 1 for both single-phase and three-phase units).

Step 2. Set the **UNRESTRAINED PICKUP LEVEL** switch to position **A** (**6 X TAP**). Increase the input current until the **UNREST. TRIP** LED lights (disregard the **REST. TRIP** LED). This should occur at 2.4 A ±3% as indicated in Table 5-7.

Step 3. Repeat Step 2 using the other **UNRESTRAINED PICKUP LEVEL** switch positions given in Table 5-7.

Step 4. ***For Three-Phase Units Only:*** Repeat Steps 1 through 3 for Phase B of input 1 (terminals 12 & 13) and Phase C of input 1 (terminals 14 & 13).

Table 5-7. Unrestrained Pickup Verification, 1 A, 50 or 60 Hz

Unrestrained Pickup Level	Input 1 Tap Position	Input Current at Pickup ±3%
A (6 X TAP)	0.4	2.4 A
J (14 X TAP)	0.4	5.6 A
S (21 X TAP)	0.4	8.4 A

Second-Harmonic Restraint Verification

Step 1. Set the **INPUT 1** (tap) switches to the **0.4** A position. Connect the relay as (refer to Figures 5-2 through 5-5, as appropriate) using terminals 11 & 13 (Input 1 for both single-phase and three-phase units).

Step 2. ***Three-Phase Units Only:*** Set the Calibrate toggle switch **S2** (letter J of Figure 2-4) to the **CAL** position on each of the three Analog #1 boards. These three toggle switches are readily accessible on the right side of the relay when withdrawn from the case. (It is not necessary to pull out the circuit boards.)

> **NOTE**
>
> With two current sources in parallel, apply the fundamental frequency and then add the required harmonic.

Step 3. Apply 0.4 A at 50 or 60 Hz, as appropriate for the style, to Input 1. The **REST. TRIP** LED should be illuminated.

Step 4. Increase the second-harmonic current until the **REST. TRIP** LED extinguishes indicating that the inhibit point has been reached. Note the magnitude of the second-harmonic component at the inhibit point.

Step 5. To calculate the second-harmonic inhibit percentage, divide the second-harmonic current measured in Step 4 by the current applied in Step 3. (Divide the harmonic current by the fundamental current.) Factory setting is 12.0 ±3% for single-phase units and 18.0 ±3% for three-phase units.

Step 6. ***Three-Phase Units Only:*** Repeat Steps 1 through 5 for phase B (terminals 12 & 13) and phase C (terminals 14 & 13).

Step 7. ***Three-Phase Units Only:*** Upon completion of above testing, return the three calibrate toggle switches **S2** (letter D of Figure 2-4) to the **NORM** position.

Fifth-Harmonic Restraint Verification

Step 1. Set the **INPUT 1** (tap) switches to the **0.4** A position. Connect the relay as appropriate (refer to Figures 5-2 through 5-5) using terminals 11 & 13 (Input 1 for both single-phase and three-phase).

Step 2. Apply 0.4 A at 50 or 60 Hz, as appropriate for the style, to Input 1. The **REST. TRIP** LED should be illuminated.

Step 3. Increase the fifth-harmonic current until the **REST. TRIP** LED extinguishes indicating that the inhibit point has been reached. Note the magnitude of the fifth-harmonic component at the inhibit point.

Step 4. To calculate the fifth-harmonic inhibit percentage, divide the current measured in Step 3 by the current applied in Step 2. (Divide the harmonic current by the fundamental current.) Factory setting is 35.0 ±3% for both single-phase and three-phase styles.

Step 5. ***Three-Phase Units Only:*** Repeat Steps 1 through 4 for phase B (terminals 12 & 13) and phase C (terminals 14 & 13).

Response Time Verification

Step 1. Connect the relay as appropriate (refer to Figures 5-2 through 5-5).

Step 2. Set the **RESTRAINED PICKUP LEVEL** switch (phase A) to **A** (15%). Place all of the **INPUT** switches on the **0.4** A tap position.

Step 3. Apply 0.4 A at 50 or 60 Hz, as appropriate for the style, to Input 1 (terminals 11 & 13 on both single- and three-phase styles) and to Input 2 (terminals 12 & 13 on single-phase and terminals 15 & 18 on three-phase).

Step 4. Perform a restrained trip at 2 x Pickup by stepping the Input 2 current to 0.68 A. Note the time interval between initiation of the simulated fault and the closure of the restrained output contact. The trip time should be less than that shown in Table 5-8.

Step 5. Repeat Step 4 at I_{OP} = 10 x Pickup. Note that, with Input 1 at 0.4 A, Input 2 current should be stepped to 1.8 A. The trip time should be less than that shown in Table 5-8.

Step 6. ***Three-Phase Units Only:*** Repeat Steps 1 through 5 for Phases B and C.

Step 7. Place the **UNRESTRAINED PICKUP LEVEL** switch to the **A** setting (**6 X TAP**). Place all of the **INPUT** switches to the **0.4** A tap position.

Step 8. With 0.0 A at Input 1 (terminals 11 & 13), apply 4.8 A (2 x Pickup) to Input 2 (terminals 15 & 18 on three-phase). Note the time interval between initiation of the simulated fault and the closure of the unrestrained output contact. The interval should be less than that shown in Table 5-8.

Step 9. Repeat Steps 7 and 8 at 10 × Pickup. Note that, with Input 1 at 0.0 A, it will be necessary to step the Input 2 current to 24 A for an unrestrained trip. The trip time should be less than that shown in Table 5-8.

Step 10. ***Three-Phase Units Only:*** Repeat Steps 8 and 9 for phases B and C.

Table 5-8. Timing, 1 A, 50 or 60 Hz

Function	Differential Current	Option 1-0 Timing Maximum 50 Hz	Option 1-0 Timing Maximum 60 Hz	Option 1-1 Timing Maximum 50 or 60 Hz
Restrained Trip	2 x Pickup	81 ms	70 ms	49 ms
Restrained Trip	10 x Pickup	73 ms	67 ms	37 ms
Unrestrained Trip	2 x Pickup	64 ms	52 ms	57 ms
Unrestrained Trip	10 x Pickup	32 ms	28 ms	10 ms

OPERATIONAL TEST PROCEDURES

The functional tests given below provide a simplified method of checking the relay trip performance relative to the front panel settings, and indirectly, the calibration. Individual steps of the procedure are designed as a series of tests that are performed in the sequence shown (rather than stand alone). For a more comprehensive test, refer to *Verification Tests: 5 Amp CT* or *Verification Tests: 1 Amp CT* earlier in this section.

CAUTION

Do not proceed unless familiar with the **Relay Operating Precautions**, the procedures described in **Relay Disassembly** and the procedures listed in the **RESTRAINED PICKUP TESTING EXAMPLES** at the beginning of this section.

These tests may be performed by removing the BE1-87T to a test station or with the relay installed.

CAUTION

If testing an installed relay, be sure to isolate the current inputs and the relay outputs from the system. Basler electric test plugs (p/n 10095) are recommended for this purpose to isolate the relay as well as simplify the test setup. (For further information, see *Test Plug* in Section 4, *INSTALLATION.*

Restrained Pickup

NOTE

When making restrained pickup tests, always **decrease** one current starting from a balanced input. Since percentage restraint is derived from the maximum current at any one input, an increase of any current increases restraint. By contrast, a decrease of one current has no effect on restraint.

Step 1. Connect the relay as appropriate (refer to Figures 5-2 through 5-5). Apply the tap value to Input 1 and to Input 2.

Step 2. With Input 1 constant, decrease Input 2 until the **REST. TRIP** LED lights. Ensure that this measurement is within ±6% of the calculated current. Return Input 2 to tap value.

Step 3. With Input 2 constant, decrease Input 1 until the **REST. TRIP** LED lights. Ensure that this measurement is within ±6% of the calculated current. Return Input 1 to tap value.

Unrestrained Pickup

Step 4. Set the front panel **UNREST PICKUP LEVEL** switch to the desired multiple of the tap setting (**X TAP**) which is the pickup level.

Step 5. Increase the input test current until the **UNREST. TRIP** LED lights. Ensure that this measurement is within ±3% of calculated pickup. **Do NOT exceed the thermal rating!**

Second-Harmonic Inhibit

Step 6. ***For 50 and 60 Hz Units:*** Apply tap value (1 pu) to Input 1. The **REST. TRIP** LED should be illuminated.

For Three-Phase Units: Set **CALIBRATE** switch S2 to **CAL** Position (see Figure 2-4).

Step 7. ***For 50 Hz Units:*** Holding the 50 Hz current constant at tap value, add a 100 Hz (I_{100}) current in parallel with I_{50}. Increase I_{100} until the **REST. TRIP** LED extinguishes. The inhibit percentage is $100 \times \frac{I_{100}}{I_{50}}$ at the point where the LED extinguishes.

Expected Values: 12±3% for single-phase

18±3% for three-phase

For 60 Hz Units: Holding the 60 Hz current constant at tap value, add a 120 Hz (I_{120}) current in parallel with I_{60}. Increase I_{120} until the **REST. TRIP** LED extinguishes. The inhibit percentage is $100 \times \frac{I_{120}}{I_{60}}$ at the point where the LED extinguishes.

Expected Values: 12±3% for Single-Phase

18±3% for Three-Phase

Fifth-Harmonic Inhibit

Step 8. ***For 50 and 60 Hz Units:*** Apply tap value (1 pu) to Input 1. **REST. TRIP** LED should be illuminated.

For Three- Phase Units: Return S2 to the **NORMAL** position.

Step 9. ***For 50 Hz Units:*** Holding the 50 Hz current constant at tap value, add a 250 Hz (I_{250}) current in parallel with I_{50}. Increase I_{250} until the **REST. TRIP** LED extinguishes. The inhibit percentage is $100 \times \frac{I_{250}}{I_{50}}$ at the point where the LED extinguishes.

Expected Values: 35±3% for single-phase or three-phase units.

For 60 Hz Units: Holding the 60 Hz current constant at tap value, add a 300 Hz (I_{300}) current in parallel with I_{60}. Increase I_{300} until the **REST. TRIP** LED extinguishes. The inhibit percentage is $100 \times \frac{I_{300}}{I_{60}}$ at the point where the LED extinguishes.

Expected Values: 35±3% for single-phase or three-phase units.

TESTING THREE-PHASE UNITS WITHOUT CHANGING JUMPERS

The simplest way to test three-phase units using only two test currents is to set all jumpers to the **WYE** position. Then each comparison circuit is tested independently when the respective phase currents are applied. This is not acceptable from two points of view:

- Requires changing the relay settings (jumpers) from the in-service position.
- Does not verify that the jumpers have been properly set.

It is possible to completely test the BE1-87T with the jumpers set to the in-service position and still use only two input current sources. When the jumpers are in the positions shown in Table 5-9, the respective current inputs are compared.

Table 5-9. Input Signals to Comparison Circuits Based On Jumper Positions

Jumper	Ain	Bin	Cin
WYE	I_A	I_B	I_C
Jumper	**Ain**	**Bin**	**Cin**
Δ1	I_A-I_C	I_B-I_A	I_C-I_B
Δ2	I_A-I_C	I_B-I_C	I_C-I_A

The following connections can be used to verify proper relay jumper positions on a three-phase unit or to test an in-service relay without changing the jumpers. These tests only require two input current sources (180° out of phase). In most cases, the specified input pair will properly test only two of the three phases within the relay. In order to test all three of the relay phases, two of the three connection pairings should be tested. This confirms relay operation.

Jumper Positions WYE-WYE

Step 1. Connect Input 1 current to terminals A and B.

Connect Input 2 current to terminals A and B.

This verifies the A- and B-phase differential circuits which respond together, as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The C-phase differential circuit sees no current and does not respond.

Step 2. Connect Input 1 current to terminals A and C.

Connect Input 2 current to terminals A and C.

This verifies the A- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The B-phase differential circuit sees no current and does not respond.

Step 3. Connect Input 1 current to terminals B and C.

Connect Input 2 current to terminals B and C.

This verifies the B- and C-phase differential circuits which respond together, as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The A-phase differential circuit sees no current and does not respond.

Jumper Positions WYE-Δ1

Step 1. Connect Input 1 current to terminals A and B.

Connect Input 2 current to terminals A and N.

This verifies the A- and B-phase differential circuits which respond together, as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The C-phase differential circuit sees no current and does not respond.

Step 2. Connect Input 1 current to terminals A and C.

Connect Input 2 current to terminals N and C.

This verifies the A- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The B-phase differential circuit sees no current and does not respond.

Step 3. Connect Input 1 current to terminals B and C.

Connect Input 2 current to terminals B and N.

This verifies the B- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The A-phase differential circuit sees no current and does not respond.

Jumper Positions WYE-Δ2

Step 1. Connect Input 1 current to terminals A and B.

Connect Input 2 current to terminals N and B.

This verifies the A- and B-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The C-phase differential circuit sees no current and does not respond.

Step 2. Connect Input 1 current to terminals A and C.

Connect Input 2 current to terminals A and N.

This verifies the A- and C-phase differential circuits which respond together, as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The B-phase differential circuit sees no current and does not respond.

Step 3. Connect Input 1 current to terminals B and C.

Connect Input 2 current to terminals N and C.

This verifies the B- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The A-phase differential circuit sees no current and does not respond.

Jumper Positions Δ1-Δ1

Step 1. Connect Input 1 current to terminals A and N.

Connect Input 2 current to terminals A and N.

This verifies the A- and B-phase differential circuits which respond together. The C-phase differential circuit sees no current and does not respond.

Step 2. Connect Input 1 current to terminals B and N.

Connect Input 2 current to terminals B and N.

This verifies the B- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The A-phase differential circuit sees no current and does not respond.

Step 3. Connect Input 1 current to terminals C and N.

Connect Input 2 current to terminals C and N.

This verifies the A- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The B-phase differential circuit sees no current and does not respond.

> **NOTE**
>
> The same test connections are used for Δ1-Δ1 and Δ2-Δ2. The proper jumper position is confirmed by which relay differential circuits respond for the specific condition.

Jumper Positions Δ2-Δ2

Step 1. Connect Input 1 current to terminals A and N.

Connect Input 2 current to terminals A and N.

This verifies the A- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The B-phase differential circuit sees no current and does not respond.

Step 2. Connect Input 1 current to terminals B and N.

Connect Input 2 current to terminals B and N.

This verifies the A- and B-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The C-phase differential circuit sees no current and does not respond.

Step 3. Connect Input 1 current to terminals C and N.

Connect Input 2 current to terminals C and N.

This verifies the B- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The A-phase differential circuit sees no current and does not respond.

Jumper Positions Δ1-Δ2

Step 1. Connect Input 1 current to terminals A and N.

Connect Input 2 current to terminals N and B.

This verifies the A- and B-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The C-phase differential circuit sees no current and does not respond.

Step 2. Connect Input 1 current to terminals C and N.

Connect Input 2 current to terminals N and A.

This verifies the A- and C-phase differential circuits which respond together as provided earlier in the **Verification Tests: 5 Amp CT** or **Verification Tests: 1 Amp CT** in this section. The B-phase differential circuit sees no current and does not respond.

Step 3. Connect Input 1 current to terminals B and N.

Connect Input 2 current to terminals N and C.

This verifies the B- and C-phase differential circuits which respond together as provided earlier in the Verification Tests: 5 Amp CT or Verification Tests: 1 Amp CT in this section. The A-phase differential circuit sees no current and does not respond.

SECTION 6 • DIFFERENCE DATA

GENERAL

This section provides the information necessary to support BE1-87T, Transformer Differential Relays, with sensing input type F (three-phases, three inputs each phase). Sensing input type F relays have a style number with the first character F (refer to Style Number Identification Chart, Figure 6-1). Sensing input type F relays require the lower connection plug to be removed before the upper connection plug. This procedure prevents false trips. During installation, the lower connection plug should be installed last.

DIFFERENCES

Revision P to BE1-87T relays made sensing input type F obsolete and created sensing input type G, for three-phase, three inputs for each phase. Primary differences between sensing input types F and G are:

- Sensing input type G relays do not require a specific procedure for removing and installing connection plugs.
- Sensing input type F relays have the normally closed power supply status (PSS) output at terminals 19 and 20 and have shorting bars across the PSS terminals (refer to Figure 6-2).
- Sensing input type F relays have terminal 9 for the common terminal on restrained and unrestrained outputs.
- Sensing input type G relays have the normally closed PSS output at terminals 9 and 19 and have NO shorting bars across the PSS terminals (refer to Figure 4-7).
- Sensing input type G relays have terminal 20 for the common terminal on restrained and unrestrained outputs.

COMPATIBILITY

Revision P relays with sensing input type G are NOT compatible with previous versions of the relays with sensing input type F.

CONNECTIONS

Sensing input type F relays (three-phase, three inputs per phase) provide protection for transformers requiring three differential inputs per phase. Be sure to check the model and style number against the options listed in the *Style Number Identification Chart* before connecting and energizing a particular relay.

NOTE

Be sure the relay case is hard-wired to earth ground with no smaller than 12 AWG copper wire attached to the ground terminal on the rear of the relay case. When the relay is configured with other protective devices, it is recommended to use a separate lead to the ground bus for each relay.

Connections should be made with 14 AWG stranded wire or better except as noted for the ground wire. Figure 6-3 shows case terminal designations for sensing input type F relays. And Figure 6-4 shows the test setup. Refer to the test procedures in Section 4 for testing sensing input type F relays. Testing procedures are the same with the exception of terminal connections and the procedures for removing connection plugs.

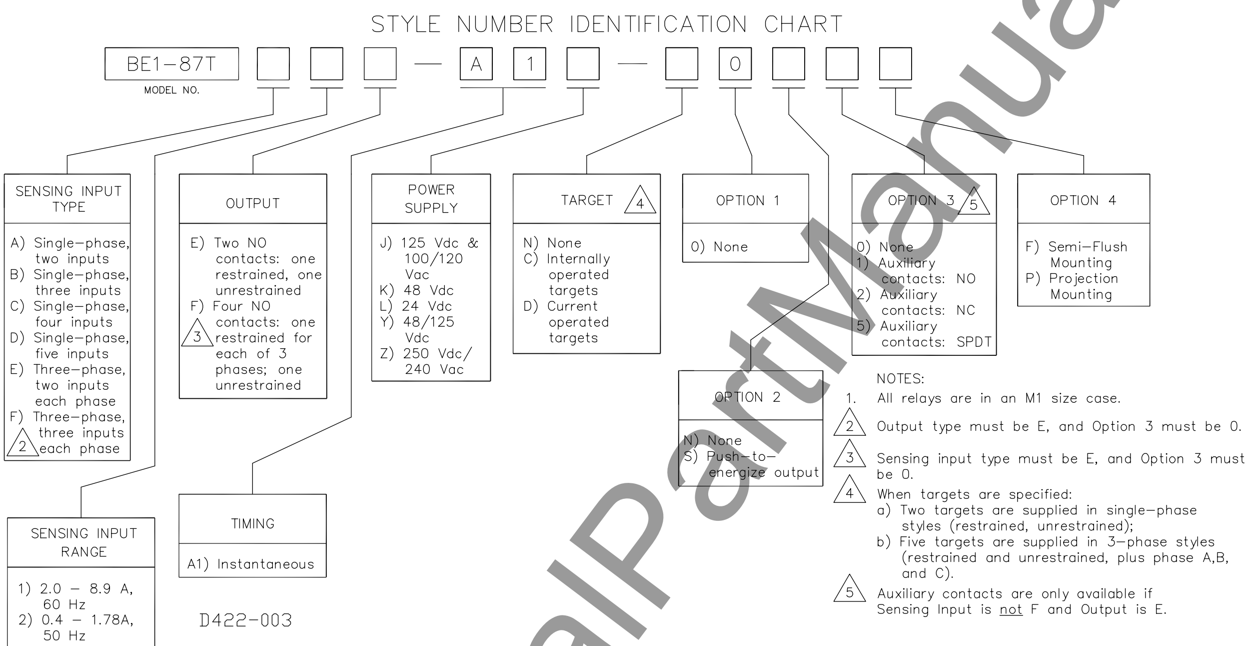


Figure 6-1. Style Number Identification Chart

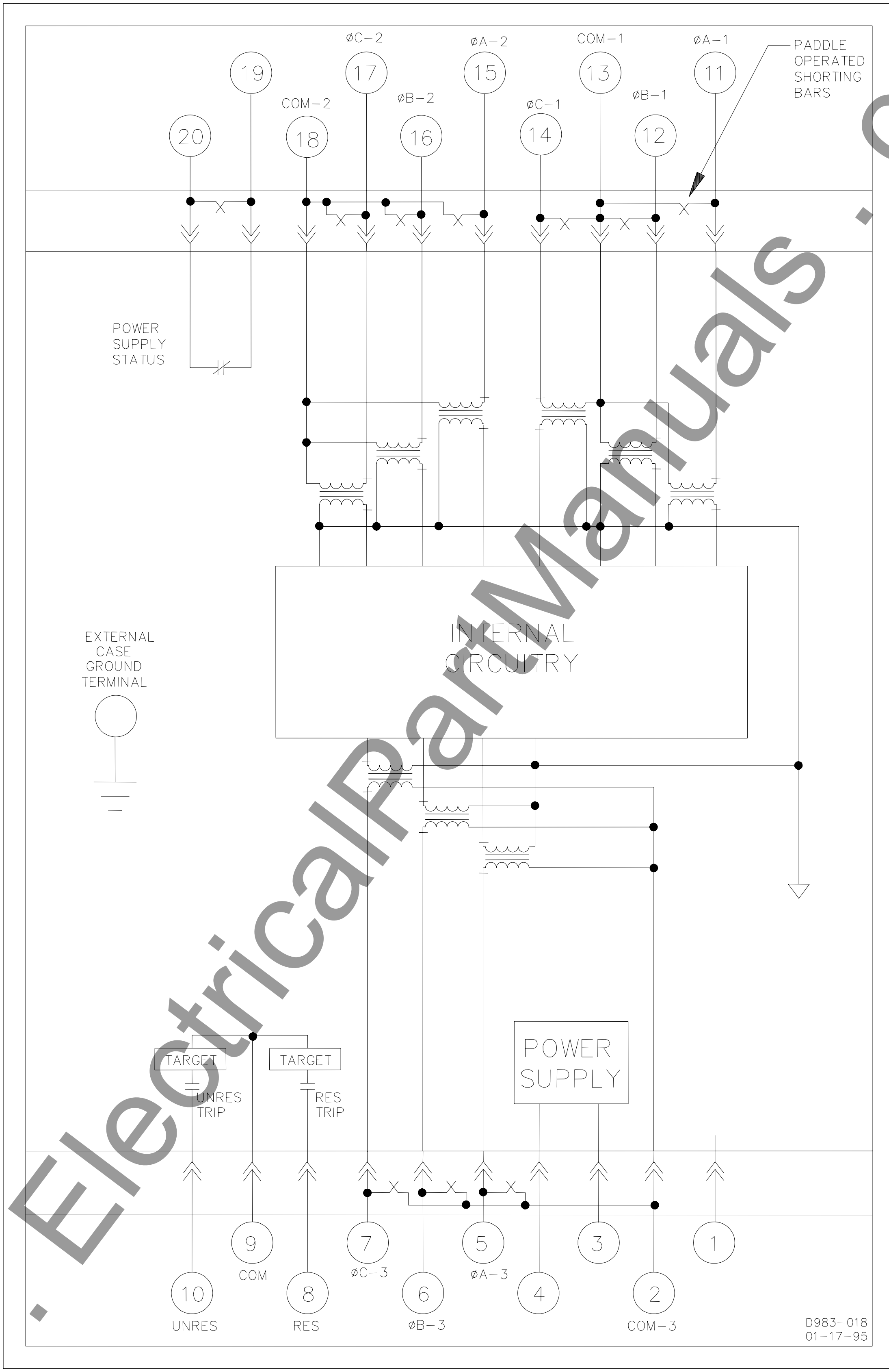


Figure 6-2. Typical Internal Connections, Three-Phase, Sensing Input Type F, Output Option E

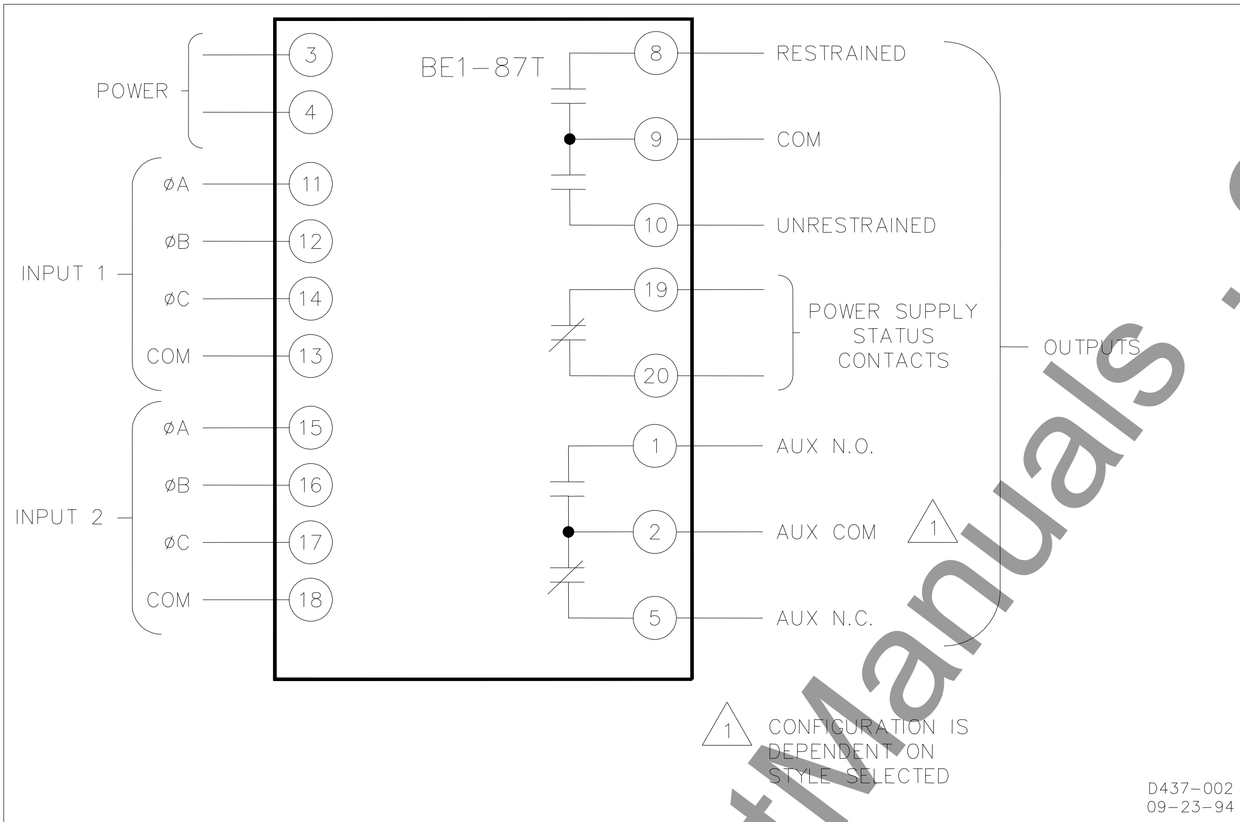


Figure 6-3. Case Terminals, Sensing Input Type F, Output Option E

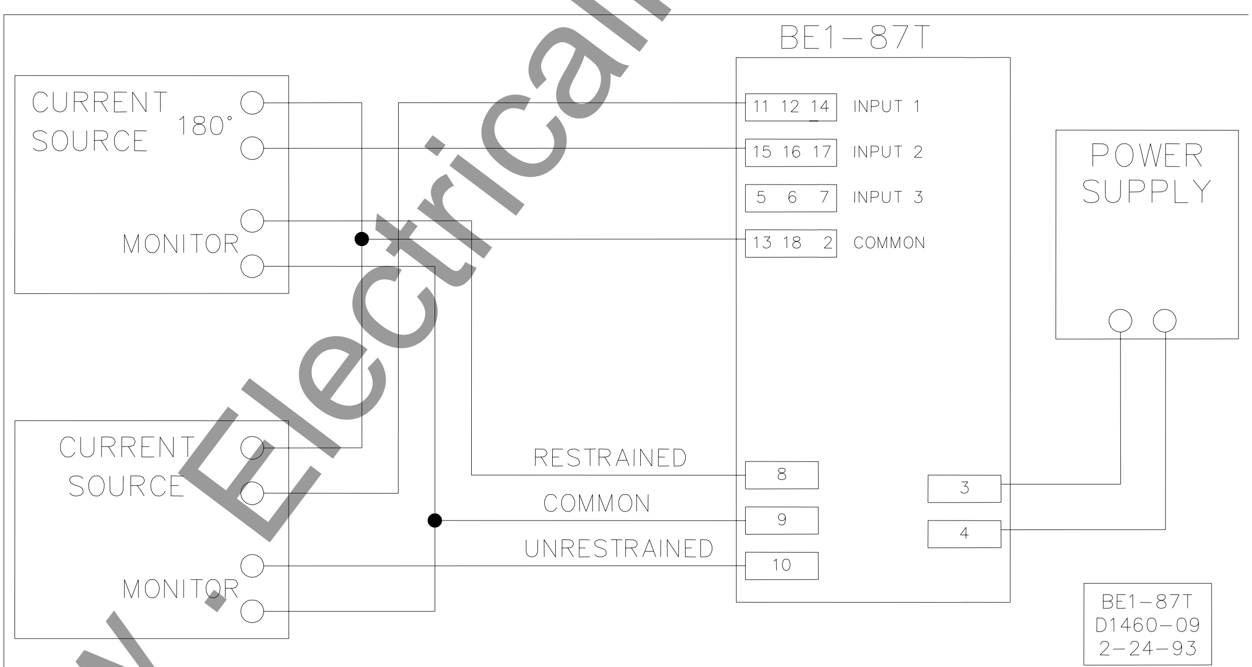


Figure 6-4. Test Setup, Sensing Input Type F, Output Option E

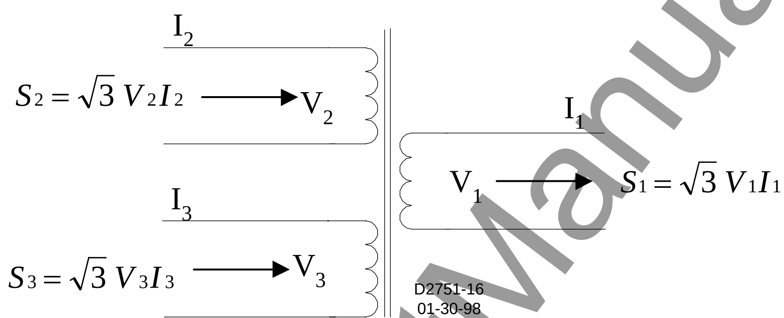
APPENDIX A • SETTING NOTES

INTRODUCTION

These setting notes are to clarify several of the settings steps in Section 4, *Installation*.

SETTING NOTE 1

The procedure outlined in Step 1 assumes that S_2 or S_3 is zero and yields the correct magnitude and ratios. This note is to point out that the relay taps are determined by the windings turn ratios. The use of the MVA rating is only a convenient way of calculating the currents (i.e. taps) in proportion to their voltage rating. It does not mean that the windings will necessarily carry the maximum rating.



$$S_1 = S_2 + S_3$$

$$V_1 I_1 = V_2 I_2 + V_3 I_3$$

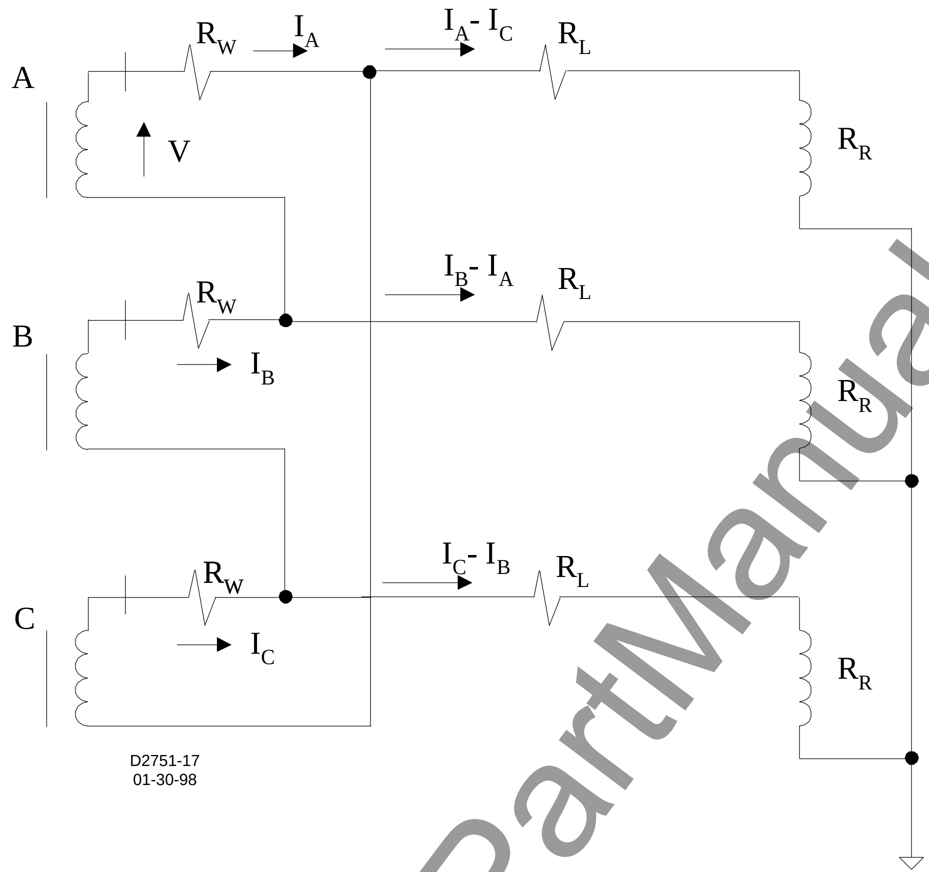
$$I_1 = \frac{V_2}{V_1} \times I_2 + \frac{V_3}{V_1} \times I_3$$

$$= \frac{S_1}{\sqrt{3}\, V_1}$$

S = Winding Rating (MVA)

Figure A-1. Multi-winding Transformer

SETTING NOTE 2



$I_A+I_B+I_C=0$
$I_A=-(I_B+I_C)$

$V=I_AR_W+(I_A-I_C)(R_L+R_R)-(I_B-I_A)(R_L+R_R)$

$=I_A(R_W+R_L+R_R+R_L+R_R)-I_B(R_L+R_R)-I_C(R_L+R_R)$

$=I_A(R_W+2R_L+2R_R)-(I_B+I_C)(R_L+R_R)$

Since $I_A=-(I_B+I_C)$

$V=I_A(R_W+3R_L+3R_R)$

Where:

I_A = 3-Phase fault current

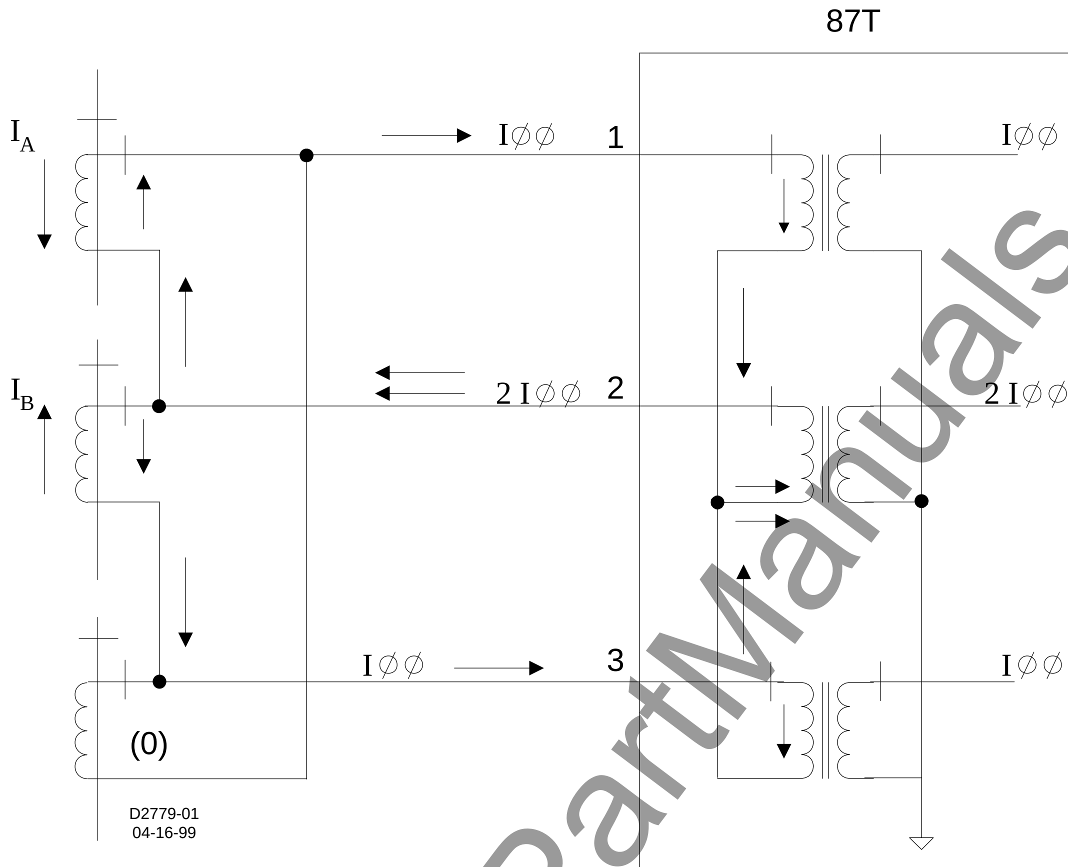
R_R = Relay burden

R_L = Lead burden

R_W = Winding burden

Figure A-2. CT Burden-Delta Connected CTs 3-Phase Fault

SETTING NOTE 3



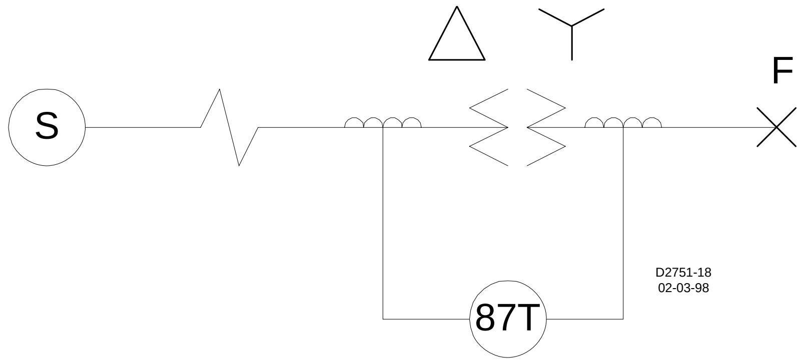
Assuming Z_1=Z_2, $I\phi\phi = \frac{\sqrt{3}}{2} \times I_{3\phi}$

Phase 2 carries twice the fault current returning from the relay to the CTs. Therefore, the maximum current is:

$$
\begin{aligned}
I_{MAX} &= 2 \times I\phi\phi \\
&= 2 \times \left(\frac{\sqrt{3}}{2} I_{3\phi} \right) \\
I_{MAX} &= \sqrt{3} \times I_{3\phi}
\end{aligned}
$$

Figure A-3. Phase-Phase Fault Delta Connected CTs

SETTING NOTE 4



1) Find the maximum pu fault current for external faults (ie).

2) Assume that one of the input CTs saturates to 70%.

3) Set unrestraint pickup >.7 X IE.

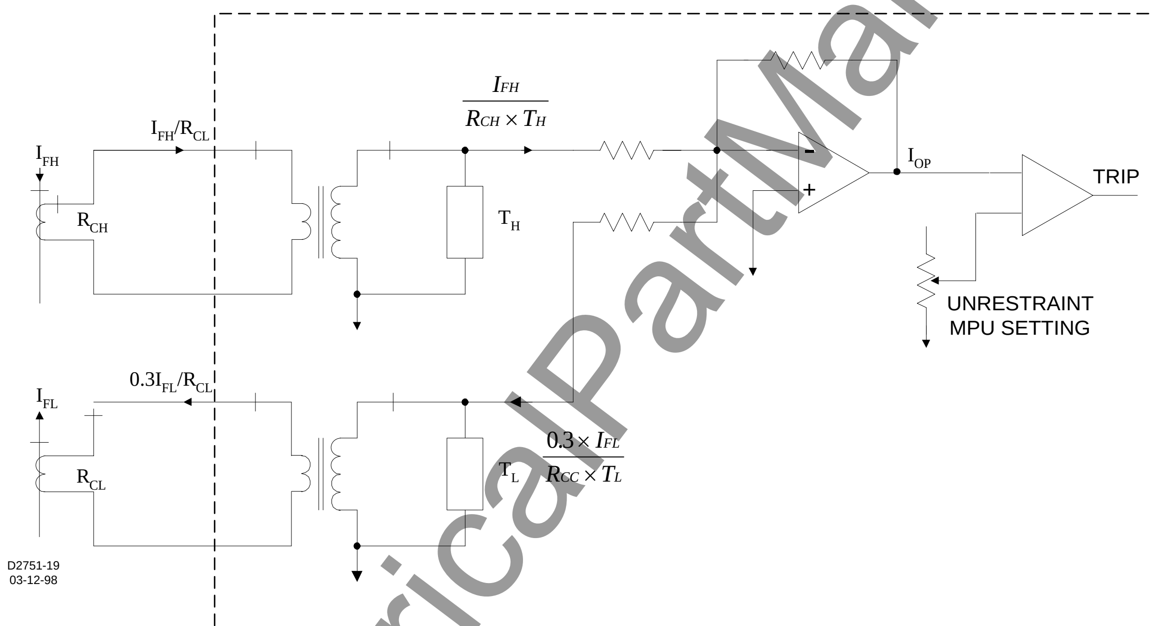


Figure A-4. Unrestraint Tap Setting

SETTING NOTE 5

Slope Margin

The slope formula accounts for an operating current bias due to magnetizing current in one winding. The magnetizing current is assumed to be 4% of the OA rating. Step 20 is used to scale this magnetizing ratio to the corresponding ratio of relay operate current: 4 x I_T%.

The formula further assumes a conservative margin corresponding to an operation current of 23% of tap. The actual margin varies with the tap settings, as given by the following equation:

$$Margin = 35 - 4 \times I_T - \left(M_T + 3\right) \times \frac{35}{S}$$

The margin variations for different tap settings (I_T) can be evaluated with this equation. The following plots show the calculated slope and the resulting margin for M_T varying from 1 to 11% and I_T varying from .5 to 2 (plot shows $10 \times I_T$).

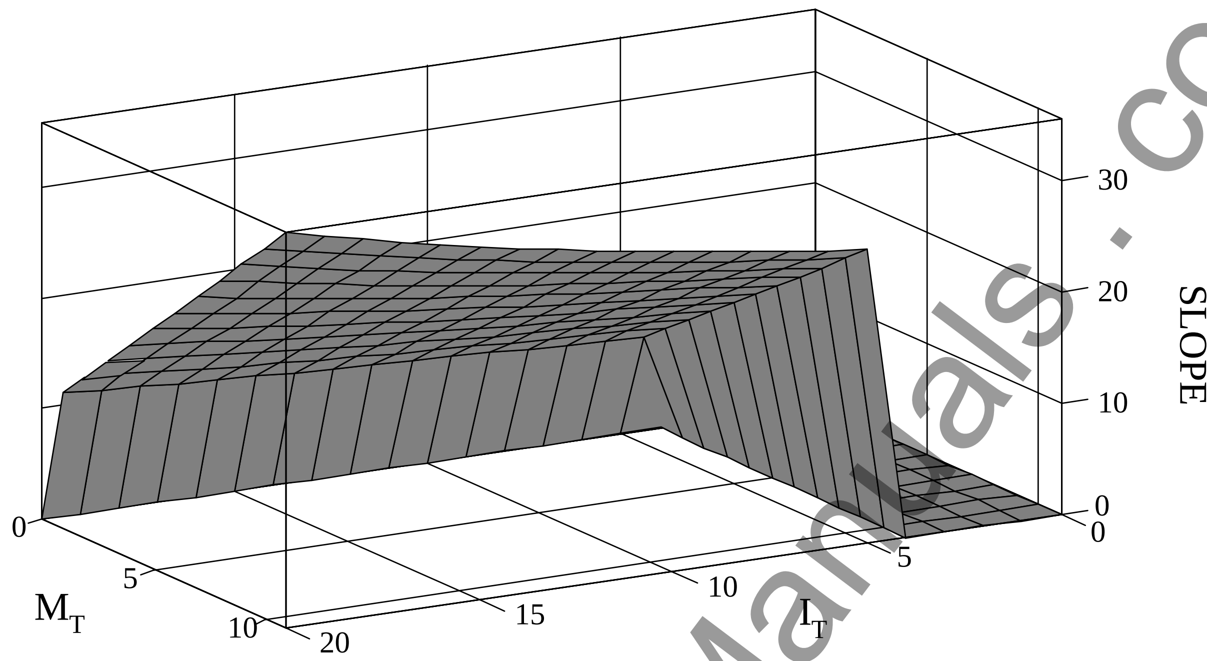


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Figure A-5. BE1-87T Slope vs. M_T and I_T

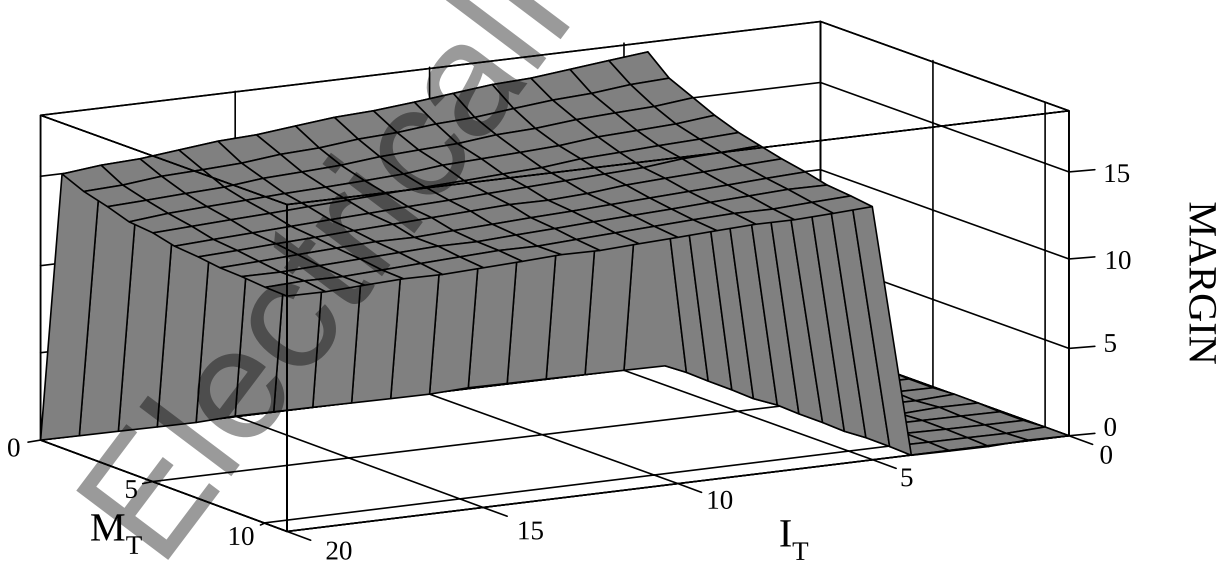

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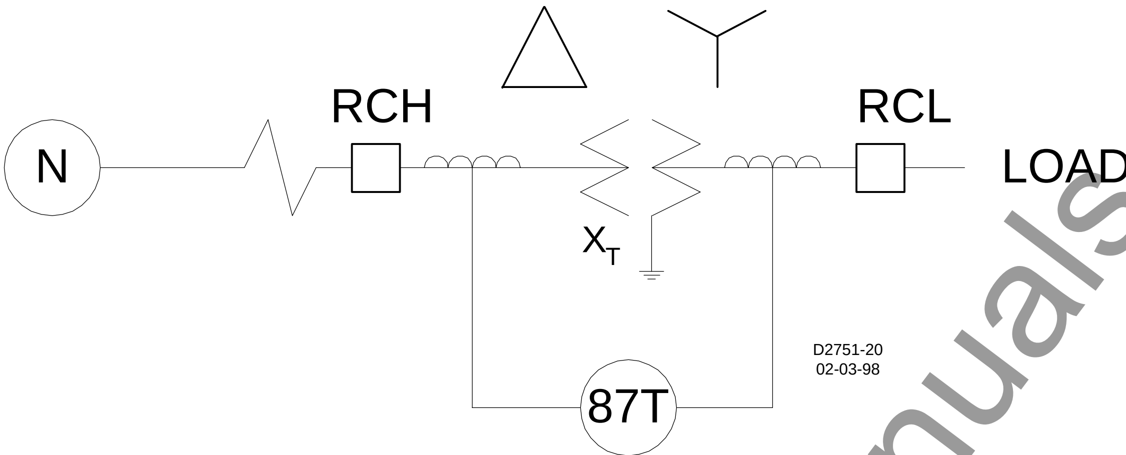
Figure A-6. BE1-87T Margin vs. M_T and I_T

SETTING NOTE 6

Inrush vs. Unrestraint Tap



Compare the unrestraint pickup setting defined in NOTE 4 to the transformer in rush current.

The UR tap is set at 70% of IE, the maximum pu through fault current. $\left(I_E = \frac{I_{F3}}{T \times RCH} \right)$

The worst case 3-Phase fault occurs when the source impedance is negligible (X_S=0):

Then $I_F = \frac{1}{X_T}$ pu at the transformer OA base.

For a X_T=6%, $I_F = \frac{1}{.06}$
$= 16.7\,PU$

The unrestraint tap MPU would be set for $0.7 \times 16.7 = 11.7\ pu$. (Note that 11.7 pu value is different from the relay UR tap setting.) The inrush current is generally assumed to be less than 10 times the nominal transformer current (10 pu on the OA base).

For this worst case example, the maximum inrush current is below the UR threshold. For significant source impedance values, we assume that the inrush current will decrease in proportion to the decrease in the fault current and thus maintain security with the recommended settings.

SETTING NOTE 7

CT Performance Evaluation: Saturation Factor

The secondary current delivered by a current transformer to a relay circuit is always less than the current available from an ideal CT. The ideal or ratio current (Ist=IP/RCT) is reduced by the excitation current (Ie) to yield the actual current (Is). This relationship is illustrated in the CT equivalent circuit shown in Figure 1.

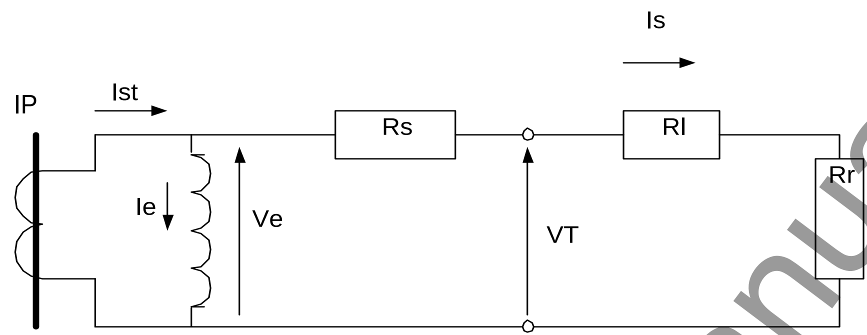


Figure 1. CT Equivalent Circuit

For relaying applications, the CT performance is considered acceptable if the ratio correction is less than 10%. The ratio error is defined in C57.13-1993, Section 8.1.10 as Ie/Is. This criterion is expressed in the ANSI C accuracy class which is defined in the following sentence. Under steady state (symmetrical current) conditions, the excitation current must be less than 10 amperes for a relay current of 100 amperes into the specified standard burden. Since fault currents necessarily start with some degree of transient DC offset, good design practice requires that the ratio error remain below 10% during the initial transient offset period, if possible, particularly when fast tripping is in effect. It has been generally accepted that a design for a saturation factor (SF) of 0.5 or less is acceptable. The following analysis provides two definitions of the saturation factor using a C200 application as an example.

Saturation Factor Defined from the ANSI C Classification

In Figure 2, the CT terminal voltage increases linearly with the secondary current along the V=ZBxI line where ZB is the total CT burden (leads plus relays for a particular fault and connection). A terminal voltage (VT) corresponds to the maximum fault current. This voltage is lower than the maximum voltage (VC) that the C200 CT can support. Saturation will occur (i.e. ratio error will exceed 10%) for secondary currents in excess of IFs where the corresponding terminal voltage crosses the accuracy class limit VC (point C in Figure 2). We can define a measure of the degree of saturation with the saturation factor (SF):

$$SF = \frac{IF}{IFs}$$

By examination of triangles OAB and OCD, the same saturation factor can be expressed as:

$$SF = \frac{VT}{VC}$$

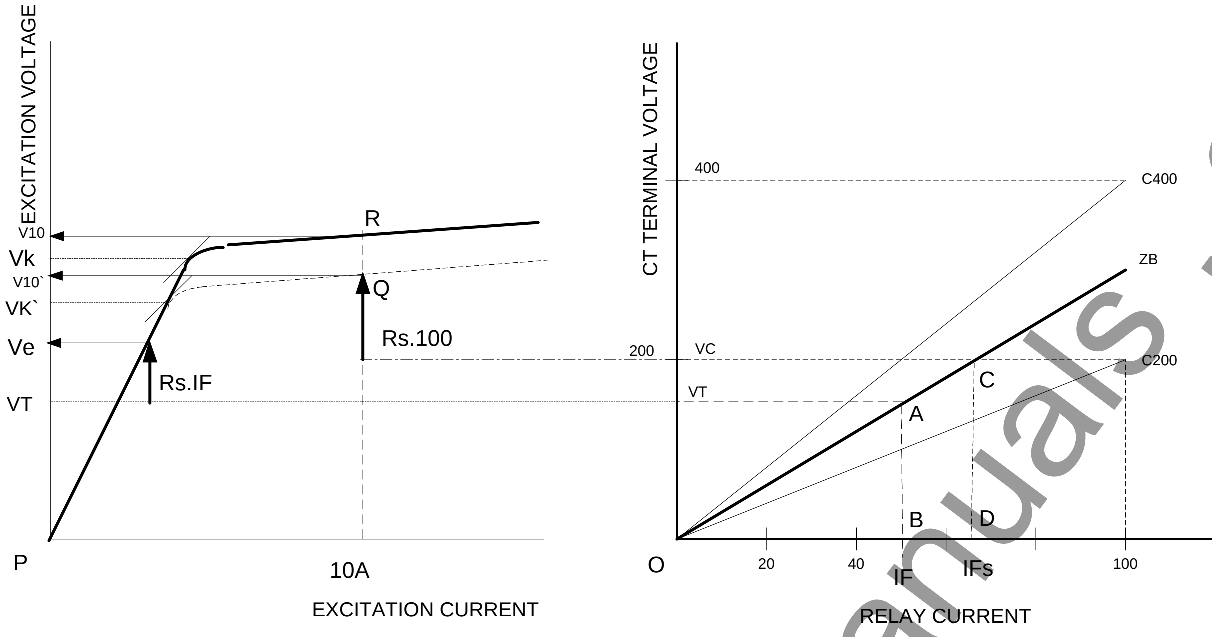


Figure 2. CT Terminal and Excitation Voltages

This first definition of saturation relates the CT terminal voltage to the accuracy class of the CT (effective class in the case of multi-ratio CTs). It is practical and easy to calculate since it requires only readily available data. An application is considered reasonably secure when SF is less than 0.5

Saturation Factor Defined from the CT Excitation Curve

The definition of the saturation factor given above appears to be conservative because it assumes the worst case ratio error. However, a closer look is required since it neglects the CT internal resistance. It corresponds to an excitation voltage on a curve passing through point Q in Figure 2 at which the excitation current is 10 amperes (the maximum error allowed by the accuracy class definition). The Rsx100 term represents the voltage drop across the CT internal resistance. A new SF which takes the internal CT resistance into account can be defined on the excitation curve, as:

$$SF` = \frac{Ve}{V10`}$$

Where Ve is the internal excitation voltage (VT+Rs.IF) at the maximum fault current IF and V10` is the voltage of the curve passing through point Q where the exciting is 10A. This voltage is practically close to the knee-point voltage VK` which would yield nearly the same (a slightly more conservative) result.

Since in all likelihood, the excitation voltage capability of the CT will be higher (passing through point R in Figure 2 for instance), the saturation factor defined on the excitation curve appears to be lower, i.e. - more favorable. A detailed analysis can be performed to compare the two saturation factor definitions.

Saturation Factor Definitions Compared

Using the equivalent circuit in Figure 1 and the ANSI Accuracy Class definition that the CT must be able to source 20 times nominal current into a standard burden Zc, we now develop a comparative analysis between the two definitions:

$$SF = \frac{VT}{VC} \qquad SF` = \frac{Ve}{V10`}$$

$$SF = \frac{ZB.IF}{100.Zc} \qquad SF` = \frac{IF.(ZB + Rs)}{100.(Zc + Rs)}$$

To compare the two expressions, we take the ratio SF`/SF

$$\frac{SF`}{SF} = \frac{Zc}{ZB} \cdot \frac{(ZB + Rs)}{(Zc + Rs)}$$

Since this expression varies with the ratio of the actual relay circuit burden (ZB) to the accuracy class burden (Zc) and the CT internal resistance (Rs), it is best visualized with a surface plot showing simultaneous variations of the parameters. The following example is based on a C200 (Zc=2) with Rs varying from 0.1 to 0.8 ohms and ZB varying from 0.1 to 2 times ZC ohms. (Load angles are neglected).

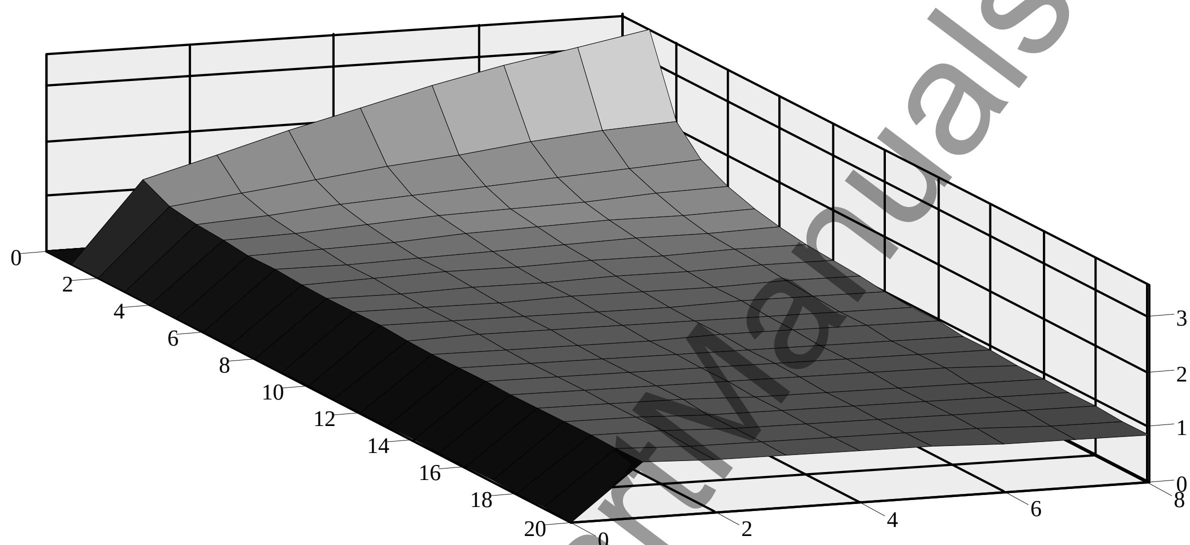


Figure 3. SF`/SF Ratio

The 0 to 20 axis represents the variations X10 of ZB (20 is 2xZC). The 0 to 8 axis represents the variations x10 of Rs in ohms. The vertical axis (0 to 4) shows that for ZB values equal to or greater than the burden value Zc, the two saturation factor equations are nearly identical. The ANSI Accuracy Class method yields the larger, more conservative result. For low values of ZB and large values of Rs, the Excitation Curve method yields a larger saturation factor. Since the Excitation Curve method is closely following the CT characteristics, it may be said that the ANSI Class method which neglects the CT internal resistance, is too optimistic in this range and should be discarded in favor of the Excitation Curve method. The absolute values of SF and SF` are compared in Figure 4 for the particular case where Zc=2, ZB=0.5 and Rs=0.8 when IF varies from 0 to 100A.

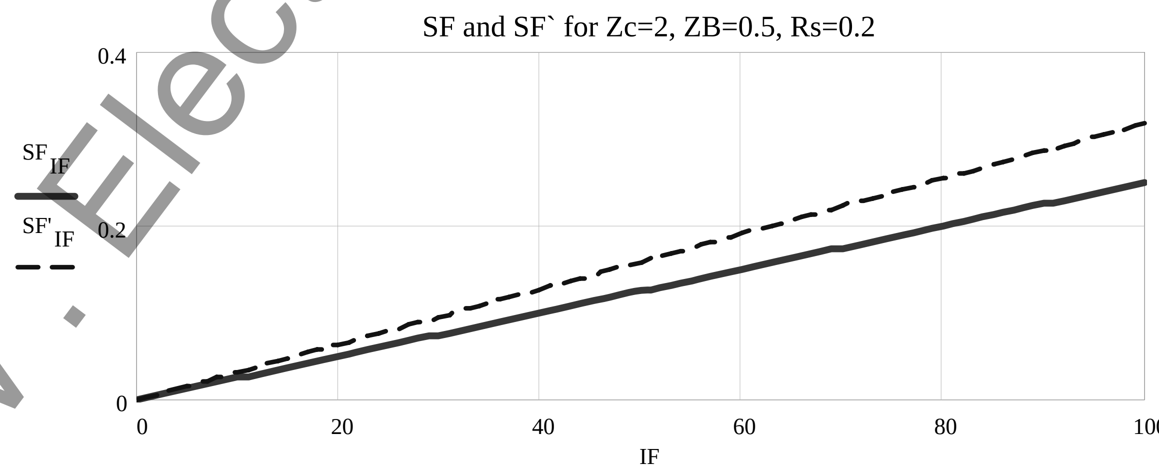


Figure 4. Comparing SF and SF`

Figure 5 illustrates how a lower Rs value reduces the difference between SF and SF`.

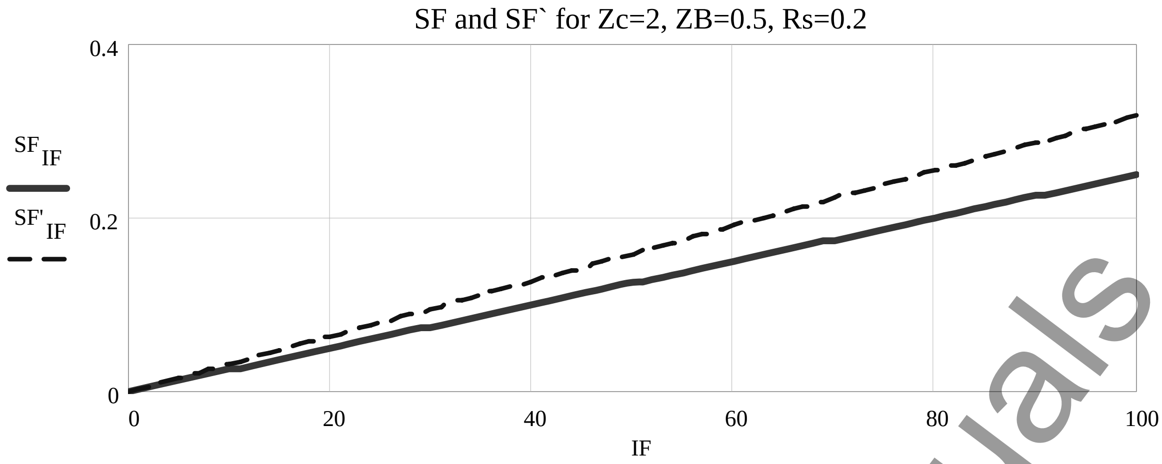


Figure 5. Reducing the Difference between SF and SF'

Conclusion

This analysis shows that the easy to apply SF based on the ANSI Accuracy Class may yield optimistic results in cases where the CT internal resistance is significant. The Excitation curve method, requiring more data, yields more accurate results and should be used when the SF is marginal.

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