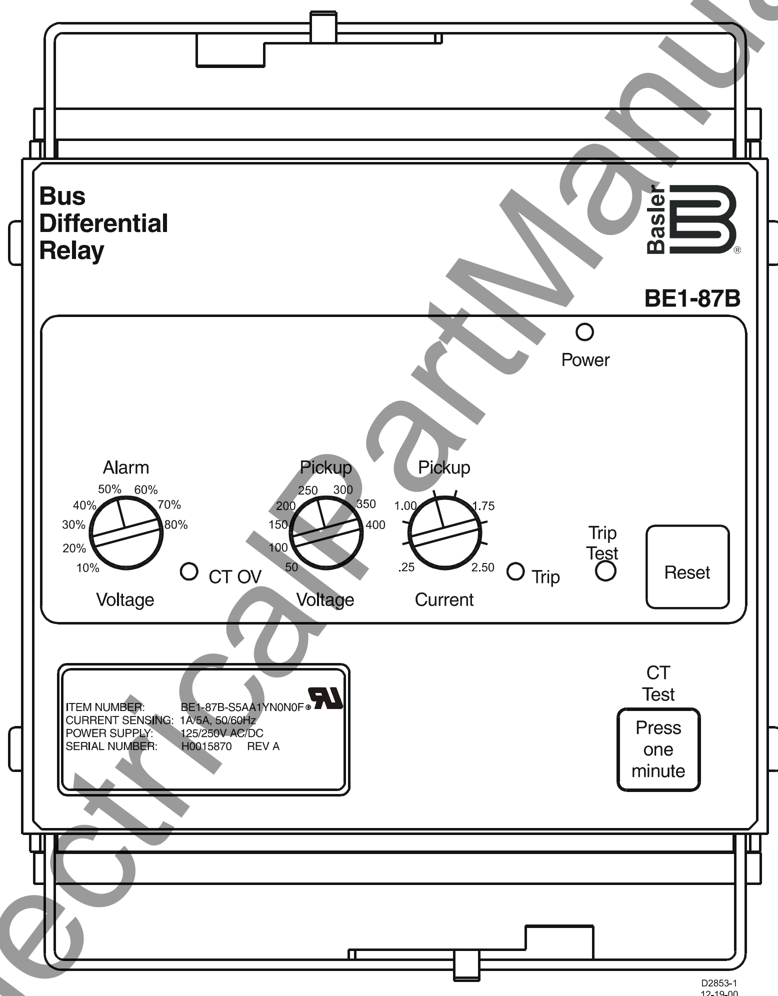
INSTRUCTION MANUAL

FOR

BUS DIFFERENTIAL RELAY

BE1-87B



Basler Electric

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INTRODUCTION

This manual provides information concerning the operation and installation of a BE1-87B Relay. To accomplish this, the following is provided.

- Specifications
- Functional Description
- Installation Information
- Testing Procedures

WARNING!

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

CAUTION

Meggers and high potential test equipment should be used with extreme care. Incorrect use of such equipment could damage components contained in the device.

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February 2007

It is not the intention of this manual to cover all details and variations in equipment, nor does this manual provide data for every possible contingency regarding installation or operation. The availability and design of all features and options are subject to modification without notice. Should further information be required, contact Basler Electric, Highland, Illinois.

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PRODUCT REVISIONS

The following information provides a historical summary of the changes made to the hardware and instruction manual of the BE1-87B Bus Differential Relay. All revisions are listed in chronological order.

Hardware Version	Change
—	Initial release.
A	Enhanced temperature stability and SWC immunity in single-phase relays.
B	New circuit board design released for single-phase relays.
C	Applied Revision A enhancements to three-phase relays with new circuit board design.
D	Improved immunity to ESD.
E	CT Test pushbutton changed to "pillow-type" switch. Optional case cover with CT Test pushbutton access introduced.
F	Improved relay stability during cycling of operating power.
G	Corrected labeling for CR1 and CR3 polarity on the SCR circuit board.
H	Not released to production.
I	Revision designator I not used.
J	Improved stability of Relay Trouble output contacts during power-up/power-down.

Manual Version	Change
—	Initial release.
A	Corrected various errors in the illustrations.
B	Added and updated drawings throughout the manual to accommodate the three-phase version of the BE1-87B.
C	*Section 1:* Added UL recognition to specifications. Changed voltage rating specification from "75% of tap setting" to "300 Vac for 1 hour". *Section 2:* Corrected equation reference under *Sample Calculation*. *Section 4:* Revised Figures 4-1 and 4-2 to show proper position of the Reset button access on the S1 case. Changed all power supply status references from "Relay Trouble Alarm" to "Power Supply Status".
D	Updated drawings, as required, to reflect changes to the cases and overlays as a result of "pillow-type" switch implementation for CT Test pushbutton. Updated the style chart with front cover with CT test access option.
E	Corrected the terminal numbering in Figure 2-5. Changed the Power Supply Status Contacts label to Relay Trouble Contacts in Figures 4-13 and 4-14. Corrected various minor errors throughout the manual.
F	Information was added to Section 2, *Application*. Moved CT circuit testing information from Section 3, *Human-Machine Interface* to Section 5, *Testing*. Moved illustration of Figure 3-3 to Section 4, *Installation* and added terminal designations. Added metric equivalents and mounting depth dimension to Figure 3-4 and moved illustration to Section 4, *Installation*. Corrected various minor errors throughout manual.

Manual Version	Change
G	Clarified wording of timing specification in Section 1, *General Information* and removed Figure 1-3. Reworded first paragraph of Section 2, *Application* and last paragraph of *Sample Calculation* sub-section. Removed the polarity marks from terminals 15 and 16 of Figures 4-14 and 4-15.
H	Added *Two Different Ratio CTs* paragraph to Section 2, *Application*. Added information to *Internal Faults* paragraphs in Section 2, *Application*. Improved Figure 2-7.
J	Improved Figure 2-7.
K	Added option "R" mounting type to Style Number. Updated Output Contact ratings in Section 1. Added 19" Horizontal Rack-Mount Front and Side views to Section 4, *Installation*. Added GOST-R certification to Section 1, *General Information*, *Specifications*.
L	Updated *Intentional Delay Jumper* instructions on pages 2-11 and 3-5.

CONTENTS

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SECTION 1 • GENERAL INFORMATION

TABLE OF CONTENTS

Figures

Tables

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SECTION 1 • GENERAL INFORMATION

GENERAL

The BE1-87B is a high-speed, high-impedance, solid-state differential relay. It was designed specifically for bus differential protection. Because of the relay's high impedance, it can be used in other applications, such as the protection of shunt reactors. Contact your local Basler Applications Engineer for information about additional applications.

FEATURES

The BE1-87B offers high-speed fault protection, which may be applied to individual elements or zones of ac power systems. It operates in less than 7 milliseconds for fault levels of 1.5 times the current pickup and less than 5.5 milliseconds for fault levels above six times the current pickup. This high-speed operation minimizes potential damage to the protected equipment. Response characteristics for sensing input ranges one and two are shown in Section 5, *Testing*.

Standard Features

Available in single-phase or three-phase models

- S1 and M1 double ended drawout cases and 19" rack-mount
- Percent of pickup voltage alarm
- Differential logic test
- LED trip output indicators
- Power supply status
- Ten position incremental adjust for the voltage and current pickup settings

MODEL AND STYLE NUMBER

The electrical characteristics and operational features included in a specific relay are defined by a combination of letters and numbers, which constitutes the device's style number. The style number together with the model number describes the features and options in a particular device and appears on the front panel as the item number. They also appear in the drawout cradle, and inside the case assembly. The model number BE1-87B designates the relay as a Basler Electric Class 100, high-impedance bus differential relay.

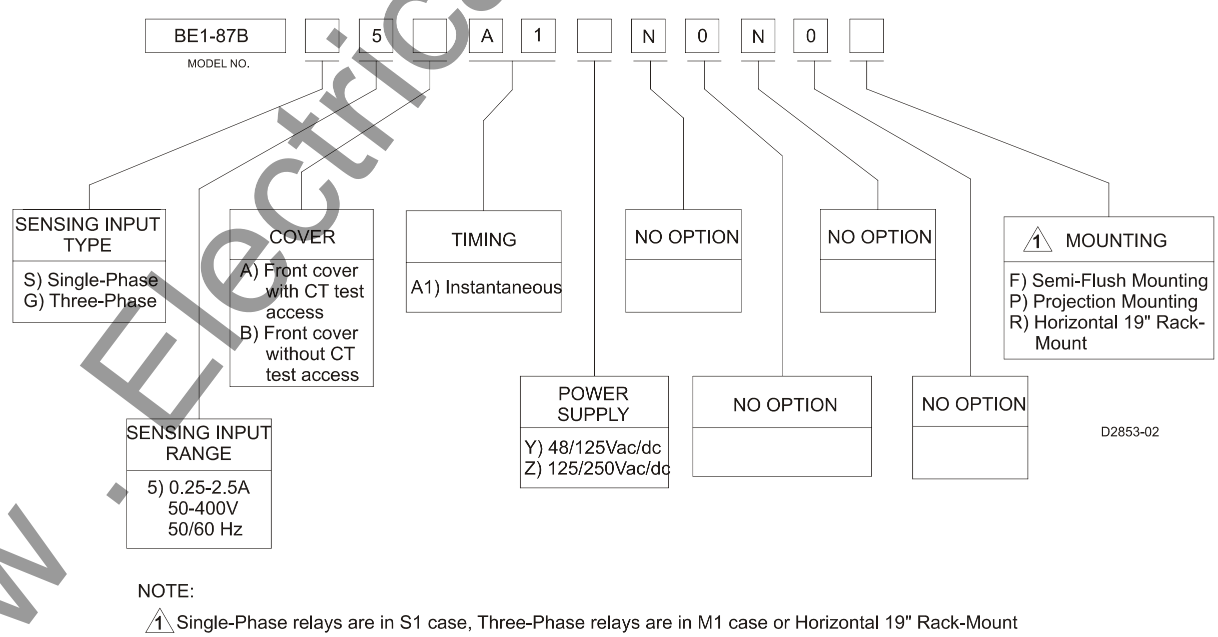

Figure 1-1. BE1-87B Style Chart

Style Number Example

The style number identification chart defines the electrical characteristics and operation features included in the BE1-87B relay. For example, if the style number were BE1-87B S5AA1YN0N0F, the device would have the following:

<u>*BE1-87B*</u>

S.......... Single-phase current sensing
5.......... 5 ampere current sensing input range
A.......... Front case cover with CT test button access
A1........ Instantaneous timing
Y.......... 48/125 Vac/Vdc power supply
N .... No Option
N .... No Option
N .... No Option
0.......... No Option
F.......... Semi-flush case mounting

SPECIFICATIONS

Timing

A maximum of seven milliseconds at 1.5 times the pickup setting.
A maximum of 5.5 milliseconds above six times the pickup setting.
Figure 1-2 illustrates typical response times.

Figure 1-2. Typical Pickup Current Response Time without a Trip Delay

Power Supply

Power for the internal circuitry may be obtained from either an ac or a dc external power source as indicated in Table 1-1.

Table 1-1. BE1-87B Power Supply Specifications

Type	Nominal Input Voltage	Input Voltage Range	Burden at Nominal (Maximum)
Y	48/125 Vdc 110Vac	24 to 150 Vdc 90 to 132 Vac	7.5 W 15.0 VA
Z	125/250 Vdc 110/230Vac	60 to 250 Vdc 90 to 230 Vac	7.5 W 20.0 VA

Current and Voltage Settings

Voltage Alarm Pickup:	10 to 80% in 10% increments
Voltage Pickup:	50 to 400 V in 50 V increments
Current Pickup:	0.25 to 2.5 A in 0.25 A increments

Frequency

Nominal 50 or 60 Hz, ± 5 Hz

Pickup Accuracy

±5% of the setting over the operating ranges for both current and voltage. Pickup accuracy over the ±5 Hz nominal frequency variation is within ±8% of the nominal frequency value.

Output Contacts

Output contacts are rated as follows.

Resistive

120 Vac:	Make, break, and carry 7 Aac continuously
250 Vdc:	Make and carry 30 Adc for 0.2 s, carry 7 Adc continuously, break 0.3 Adc
500 Vdc:	Make and carry 15 Adc for 0.2 s, carry 7 Adc continuously, break 0.3 Adc

Inductive

120 Vac, 125 Vdc, 250 Vdc:	Break 0.3 A (L/R = 0.04)

Current Rating

Continuous:	10 A rms
1 second, symmetrical:	160 A rms
5 cycles, symmetrical:	480 A rms
2 cycles, fully offset:	215 A

Voltage Rating

The nature of the BE1-87B relay's application is that voltage is not applied continuously. For calibration and test purposes, it may be of value to apply input voltage for a longer duration than the few milliseconds that would typify an internal or external power system fault. For test and calibration purposes, the BE1-87B has been designed to withstand 300 Vac for a maximum duration of 60 minutes.

Targets

LED indication (Trip LED) is latched with an internal, mechanical latching relay. Reset is accomplished by pressing the Reset button on the front panel.

Isolation

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

All circuits to ground:	2000 Vac or 2828 Vdc
Each circuit to all other circuits:	2000 Vac or 2828 Vdc.

Surge Withstand Capability (SWC)

Oscillatory and Fast Transient:	Qualified to IEEE C37.90.1-1989

Impulse Test

Qualified to IEC 255-5.

Radio Frequency Interference

Maintains proper operation when tested for interference in accordance with IEEE C37.90.2 1995.

Electrostatic Discharge (ESD)

In accordance with IEEE C37.90.3, contact discharges of 8 kilovolts and air discharges of 15 kilovolts were applied with no misoperation occurring.

UL Recognition

Recognized per Standard 508, UL File Number E97033.

Note that 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.

Environment

Temperature

Operating Range:	–40°C to 70°C (–40°F to 158°F)
Storage Range:	–40°C to 85°C (–40°F to 185°F)

Humidity

Qualified to IEC 68-2-38, First Edition 1974

Shock

Qualified to IEC 255-21-2, Class 1.

Vibration

Qualified to IEC 255-21-1, Class 1.

Weight

1-phase Relay:	14.3 lb (6.5 kg) maximum
3-phase Relay:	19.2 lb (8.8 kg) maximum

Case Size

1-phase Relay:	S1
3-phase Relay:	M1 or 19" Rack-Mount

Case dimensions are provided in Section 4, *Installation*.

SECTION 2 • APPLICATION

TABLE OF CONTENTS

Figures

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SECTION 2 • APPLICATION

APPLICATION

The BE1-87B solid-state, high-speed, high-impedance differential relay is available in single or three-phase models. The relay was specifically designed to provide high-speed differential protection for high voltage buses, critical medium, and low voltage buses. Because of its design and sensitivity, the relay can also be used for shunt reactor protection. While bus schemes require three-phase protection, shunt reactors may be protected with only one single-phase relay for ground faults. Regardless of the scheme employed or the equipment protected, the following applications apply to the BE1-87B relay.

Application with Lightning Arresters

The BE1-87B is a high-speed relay designed to operate in a half-cycle or less. As a result, applying the relay to a bus with lightning arresters must be addressed. The relay pickup current range is adjustable between 0.25 to 2.5 amperes rms. If lightning arresters will be connected to the bus, use the 2.5 ampere sensitivity setting so as to prevent the possibility of a differential operation during a normal arrester operation. If no lightning arresters are used, start with the 0.5 ampere sensitivity setting and adjust as the application dictates.

CAUTION

If lightning arresters are added to an existing bus, as might be the case when adding a transformer, be sure to increase the Pickup Current setting of the BE1-87B to the 2.5 ampere setting.

Application with a Lockout Function

Contacts from the lockout relay (86) should be connected across terminals 5 and 6 (single-phase or phase A for 3-phase models), 3 and 4 (phase B), and 1 and 2 (phase C) of the BE1-87B relay to short-circuit the SCRs in the input circuit after a trip output has been initiated. This allows the relay to continue operation as a conventional overcurrent relay and at the same time protect against exceeding the short-time rating of the internal SCRs. The relay can be used in any application where the total secondary current is not more than the current waveform of a fully-offset fault with 215 amperes rms symmetrical available, provided the lockout relay (86) has an operate time of 1 cycle or less (16 milliseconds).

CAUTION

If the BE1-87B relay control power (power supply voltage) is removed, relay terminals 5 and 7 (single-phase model) or 5 and 7, 3 and 7, and 1 and 7 (three-phase model) should be shorted by pulling the connection plug. If this is not done, the BE1-87B relay could be damaged due to continuous fault current flowing through the relay SCRs.

Current Source for High Impedance Differential Relaying

Predictable current transformer (CT) performance is critical to the effective operation of a high impedance differential scheme. Where practical, the following current transformer guidelines should be applied when using the BE1-87B relay.

- All CTs should be of toroidal design and be fully distributed around the core.
- All CTs should have the same full ratio value and be connected to the full ratio taps.
- All CTs should have the same voltage rating, accuracy class, and thermal rating.
- The CTs should be dedicated to the differential application.
- When adding to an existing differential scheme, at least one set of CTs in the new breaker should be ordered with the same ratio and accuracy class as the differential CTs used in the existing scheme.
- CTs cannot have primary or secondary voltage limiting devices, as the resulting short-circuit could cause an unwanted operation of the differential.

BE1-87B FLEXIBILITY

Because of the flexible wide range design of the BE1-87B, it is possible to apply the relay in situations where the current sensing input circuit is less than ideal. It should be noted, however, that the possibility of less sensitive settings, equipment overvoltage, or false operation could result. Careful review of the following application notes is recommended:

- It is possible to use a mixture of multi-ratio CTs, however, it is essential that the tapped value has the same turns ratio as the other parallel CTs in the circuit. When taps are selected other than full ratio, use the highest available tap setting that will allow all CTs in the scheme to have the same turns ratio. Tap settings other than full ratio require a calculation of the peak voltage developed across the full winding resulting from autotransformer action. The resulting voltage should not exceed the insulation breakdown values of the connected equipment. The equation for this calculation is derived in the paragraph on operating principles in this section and repeated in the paragraphs on *Calculation of Settings*.
- All CTs used in the differential circuit should have negligible leakage reactance on the connected taps. Most, if not all, multi-ratio internal, bushing, and column type CTs made in the last 30 years meet this requirement. All CTs wound on toroidally shaped cores meet this requirement if the windings (on the tap used) are completely distributed around the core (consult your CT manufacturer if you have questions). It may be possible to use CTs that do not meet this requirement if the leakage reactance is known. The leakage reactance is added algebraically to the resistance of the CT circuit in question. Less sensitive protection will occur as a result of a higher pickup setting.
- It may be possible, although not recommended, to use the differential circuit CTs jointly for other functions as long as an accurate impedance of the other function is known. The performance of the system under these conditions can be calculated by algebraically adding the other impedance to the CT winding and cable resistance. Less sensitive protection will occur as a result of a higher pickup setting. Also, consideration must be given to the hazards of false operation due to extra connections and errors in testing the added devices. To ensure proper relay setting, all cable and CT secondary winding resistances should be evaluated before a decision is made to add other devices to the BE1-87B CT circuits.

Bus Protection Application

Three single-phase BE1-87B relays or one three-phase BE1-87B relay and an auxiliary lockout relay (86), provide a complete multi-phase and ground bus fault protection package. Typical external connections to the relays are shown in Figures 2-1 and 2-2. The connections are illustrated for a bus with three circuits, but the protection can easily be extended if more circuits are added to the bus. For additional circuits, it is only necessary to connect the CTs associated with the added circuits to the respective junction points and to connect the contacts of the lockout relay in the respective trip circuits. The relay voltage tap setting is based on the maximum voltage that can be developed across the differential junction point during an external fault. Calculation of the maximum voltage is easily made and methods for doing so are given in the paragraph under calculation of settings. A sample calculation for a bus differential scheme is also provided.

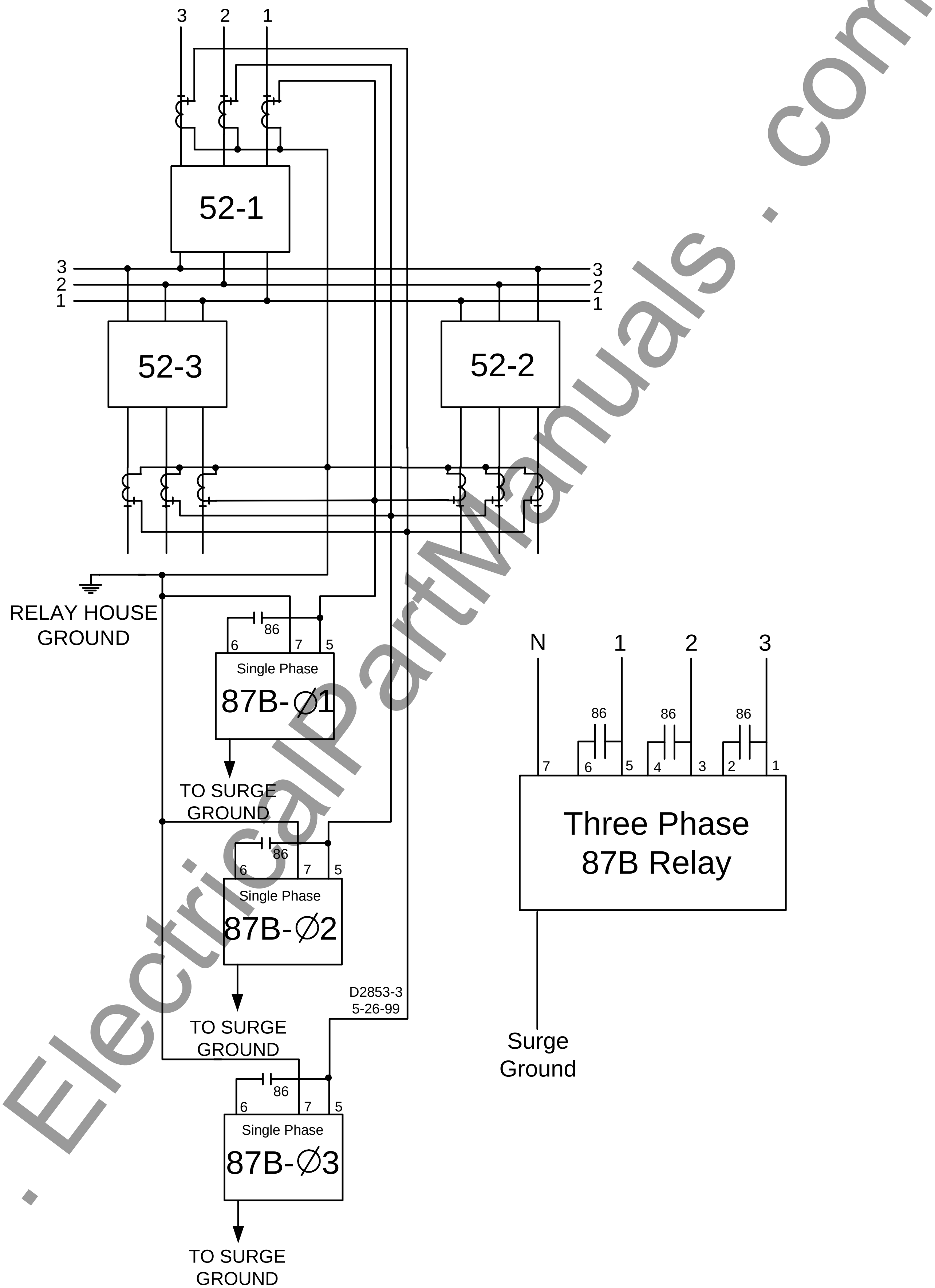


Figure 2-1. External AC Connections for Bus Protection

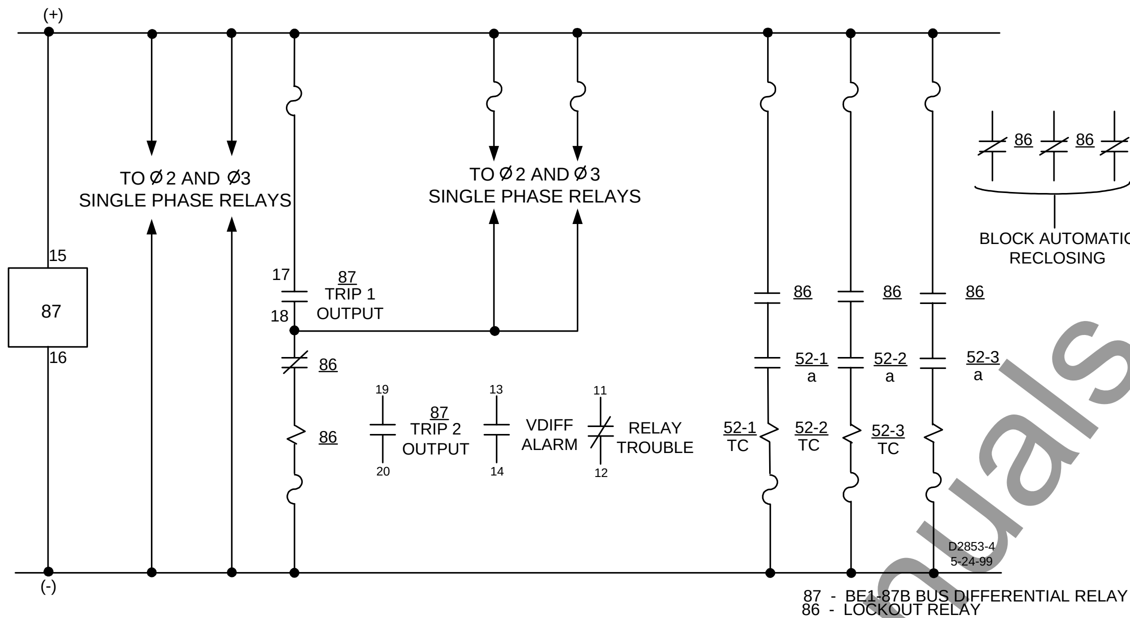


Figure 2-2. External DC Connections for Bus Protection

Shunt Reactor Protection Application

Differential protection of shunt reactors may be provided by using only one single-phase BE1-87B relay, three single-phase relays, or one three-phase relay. Typical ac external connection diagrams for these schemes are shown in Figures 2-3 and 2-4. The dc connections will be similar to those shown in Figure 2-2. Only ground fault protection will be provided when one relay is applied. Application of either three-phase arrangement will provide both multi-phase and phase-to-ground fault protection. Calculation of the voltage tap setting is basically the same as for the bus application. The procedures for calculating the voltage tap setting for either scheme are provided under Calculation of Settings.

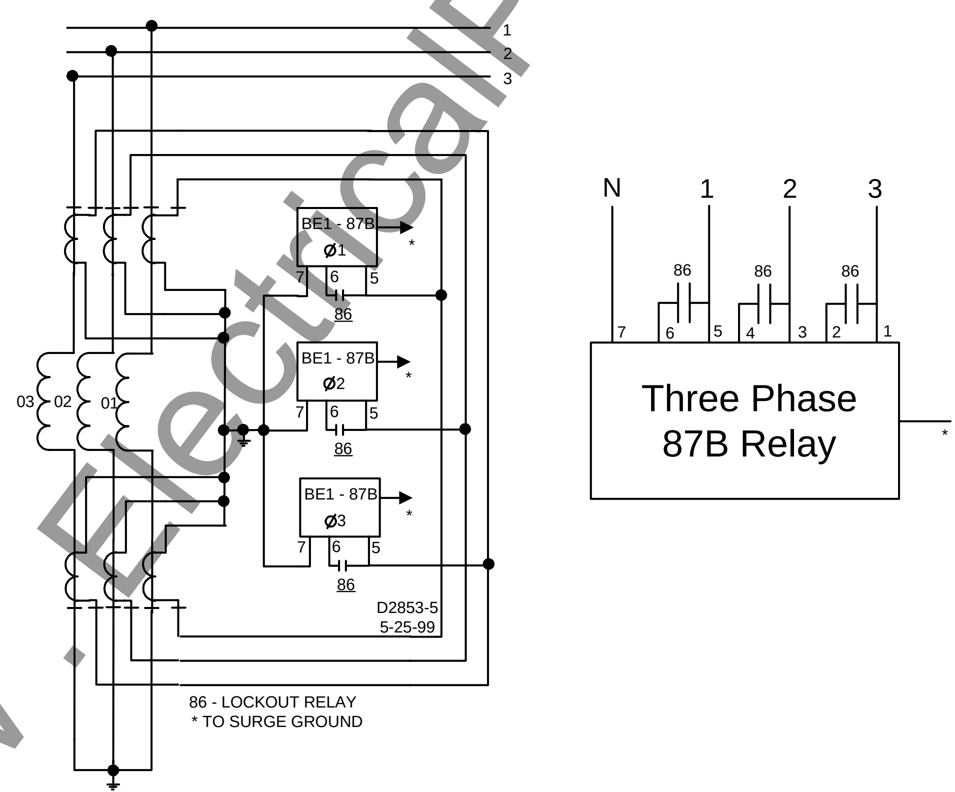


Figure 2-3. External AC Connections for Shunt Reactor Protection,
Multi-Phase and Line-to-Ground Faults

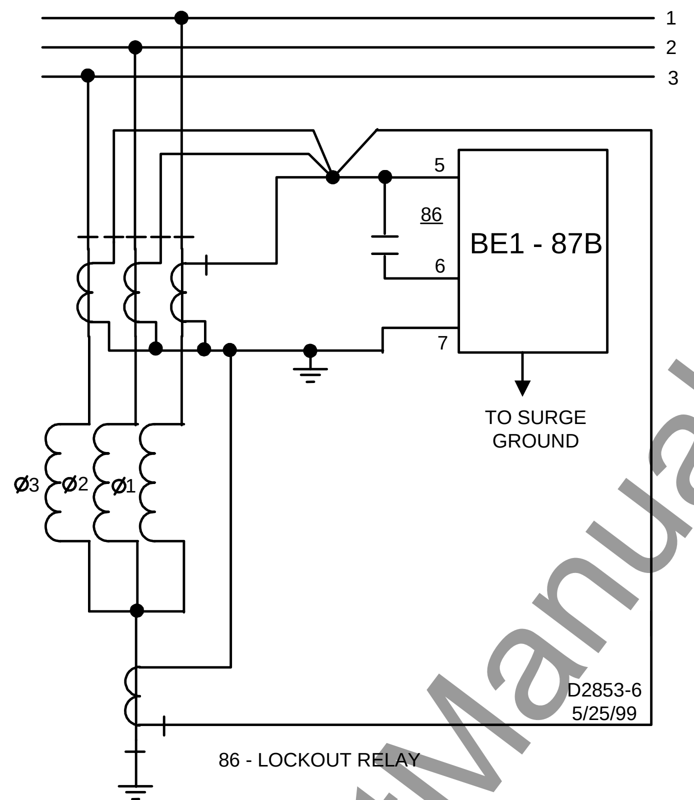


Figure 2-4. External AC Connections for Shunt Reactor Protection, Ground Faults

Mixing Two Different Ratio CTs

While high impedance bus protection is best configured with all CTs having a common ratio, it is possible to utilize two different ratio CTs within one bus protection zone. The process by which this is accomplished is detailed in the paper *"Bus Protective Relaying, Methods and Application"* located at www.basler.com.

General Settings Guidelines

To obtain the maximum setting sensitivity, the CT loop resistance should be minimized so that the lowest possible voltage setting can be selected. For switchyard applications where there is a large distance between the breaker and the relay panel, it may be desirable to locate the differential junction in the switchyard since the resistance of the fault CT loop may otherwise be too large. To minimize the impedance from the current transformers to the junction point, all the secondary windings should be paralleled in the switchyard and as close as possible to the current transformers. Optimally, the junction point should be equidistant from all current transformers.

NOTE

The cable resistance from the junction point to the relay is not included as a part of the fault CT loop resistance. It is permissible to locate junction points at the panel, providing that the relay setting gives the desired sensitivity.

OPERATING PRINCIPLES

The BE1-87B high impedance, differential relay operates on the instantaneous value of CT secondary voltage to which the relay is connected. All the CTs in the differential circuit must have the same turns ratio. If all CTs have the same turns ratio, the voltage developed across the relay during normal system conditions is very small. The diagram in Figure 2-1 illustrates typical external ac connections to the relay for use in a bus differential scheme. As shown in the diagram, a typical differential connection is used consisting of the CT circuits from each bus device connected in wye and paralleled at one location (summing point) on a per-phase basis. Three single-phase BE1-87B relays or one three-phase relay provide complete protection of the bus. The relay will generate a trip output when the instantaneous voltage applied across 5 and 7,or 3 and 7, or 1 and 7 of the three-phase model (A, B, and C respectively), exceeds the voltage pickup setting (V_{DIFF}) and the fault current is greater than the current sensitivity setting.

External Faults

If the differential protection scheme is to perform satisfactorily, then it must not trip for faults external to the zone of protection. For example, Figure 2-5 shows a one-line diagram for a three input differential scheme. The BE1-87B must not operate for a fault at F1. Since the CTs in the faulted feeder (CT 3) will see the most current, assume they will saturate completely, thus causing the magnetizing reactance to drop to zero. The total current from the other CTs (CT 1 and 2) is forced through the parallel combination of the high impedance relay (5,000 Ω) and the saturated CT secondary. The saturated CT secondary winding resistance is in series with any resistance of the CT leads and connection cables (the total of which presents a much lower resistance than the 5,000 Ω).

Therefore, nearly all the secondary fault current will flow through the saturated CT. A voltage drop V_R caused by the flow of the fault current in this parallel path will appear across the BE1-87B relay. For this fault, the highest voltage that could be developed at the relay would occur when the associated CT (CT3) saturates completely, and the others (CT1 and CT2) did not saturate at all. When a CT with a distributed toroidal winding (on the tap used) saturates completely, it produces no voltage and the impedance, as seen at the secondary winding, is very nearly equal to the winding resistance (very small impedance). Thus the highest peak voltage that can be developed across the relay during an external fault will be equal to the voltage produced by the total secondary fault current flowing through the control cable resistance plus the winding resistance of the CT associated with the faulted feeder. Refer to the example case in Figure 2-5 while applying Equation (1):

$$\text{Vpeak} = 2\sqrt{2}\ (I_F)(R_S + 2R_L) \qquad \text{(EQUATION 1)}$$

I_F = rms symmetrical value of fault current in the fault CT in secondary amps.

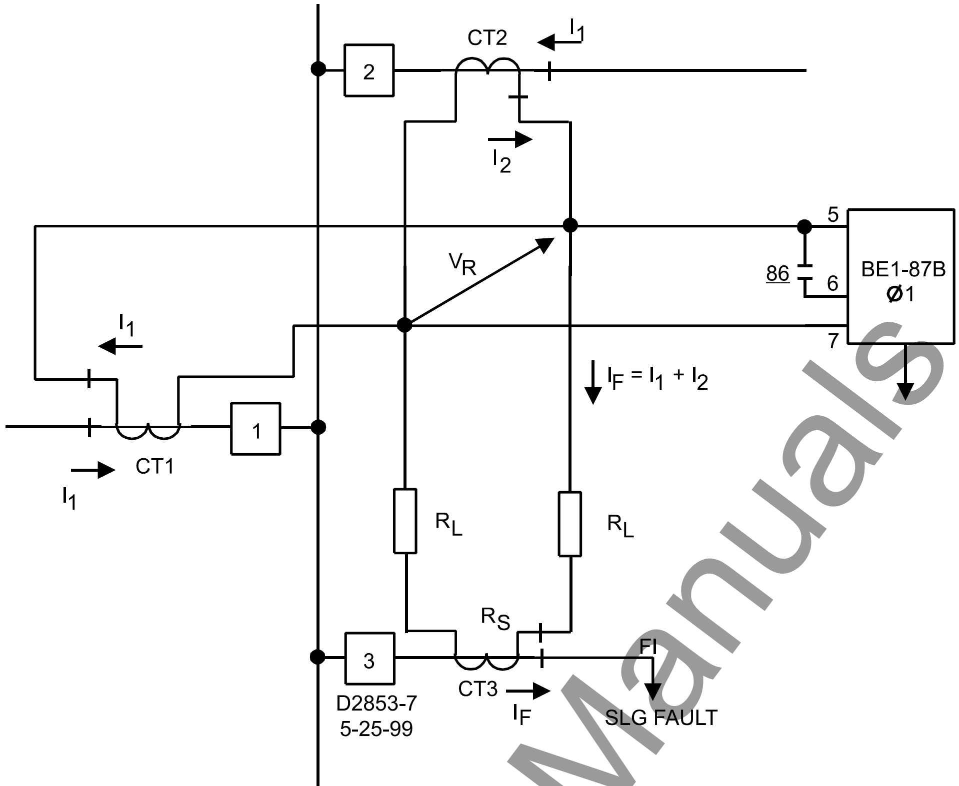
R_S = CT secondary winding resistance plus any lead resistance (at highest expected operating temperature)

R_L = Cable resistance from junction point to CT (at highest expected operating temperature)

Equation (1) above yields the peak voltage developed at the relay for a completely offset wave of current having an rms symmetrical value of I_F secondary amperes. Because the BE1-87B relay is calibrated in symmetrical rms volts, Equation (2) below, which yields the rms voltage value, is used in the paragraphs on *Calculation of Settings*.

$$V_R = I_F (R_S + 2R_L) \qquad \text{(EQUATION 2)}$$

The pickup voltage of the BE1-87B must be set above this value of rms voltage and above the rms value of the other voltages obtained in a similar manner on all the circuits of the bus. Because the peak voltage is proportional to the fault current, the highest possible value of expected fault current in rms symmetrical amperes should be used in making the evaluation.



NOTE: CT3 ASSUMED TO BE COMPLETELY SATURATED

R_S CT SECONDARY WINDING RESISTANCE PLUS ANY LEAD RESISTANCE (AT HIGHEST EXPECTED OPERATING TEMPERATURE).

R_L CABLE RESISTANCE FROM JUNCTION POINT TO CT (AT HIGHEST EXPECTED OPERATING TEMPERATURE)

I_F RMS VALUE OF THE CURRENT IN THE PRIMARY OF CT3 DIVIDED BY THE SECONDARY TURNS.

V_R VOLTAGE ACROSS BE1-87B

Figure 2-5. Illustration of Single Line-to-Ground Fault at Location F1

Internal Faults

During internal faults on the bus, all of the CTs will be operating into the relatively high impedance of the BE1-87B. Under these conditions, the maximum fundamental frequency voltage that can be produced will be limited to values as dictated by the CT secondary fundamental frequency excitation characteristics. Examination of a typical CT secondary excitation characteristic will show that the available fundamental frequency voltage flattens off beyond the knee of the curve. However, the peak voltages that can be produced are not indicated on the standard excitation curve.

The concept of how the CT responds during an internal fault is given in greater detail in the paper *"Bus Protective Relaying, Methods and Application"* located at www.basler.com. Let us summarize the matter to say that, for internal faults, the peak voltages will always be greater than indicated by the average, and will continue to increase in magnitude as the excitation is increased. Because the peak voltages during internal faults will be much greater than the peak voltages experienced during external faults, and because the BE1-87B relay operates as a function of the instantaneous voltage, the relay can be set to be selective between internal and external faults. An indication of the peak voltages that a CT can produce can be determined by a simple modification to the CT secondary excitation characteristic.

The modification is shown by the lines CPB in Figure 2-6, which now define the excitation characteristics as a function of the peak voltages. Studies have shown that the peak voltages produced will be at least equal to or greater than those established by the modified characteristics. These characteristics are useful in determining the minimum internal fault for which the relay will operate. The method for making the modifications, and their uses in determining the sensitivity, are provided in the *Calculation of Settings, Minimum Fault to Trip* sub-section in this chapter.

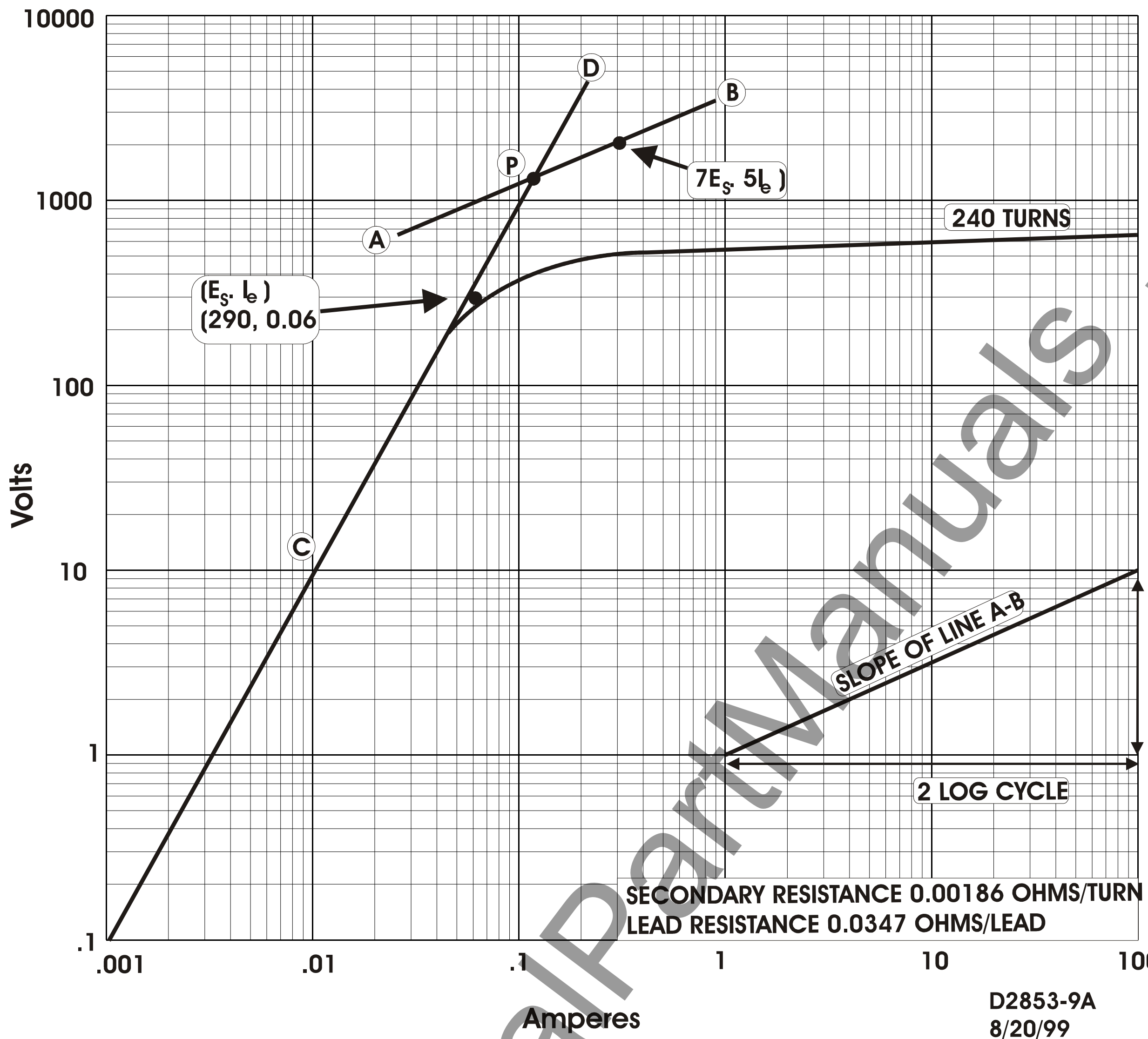
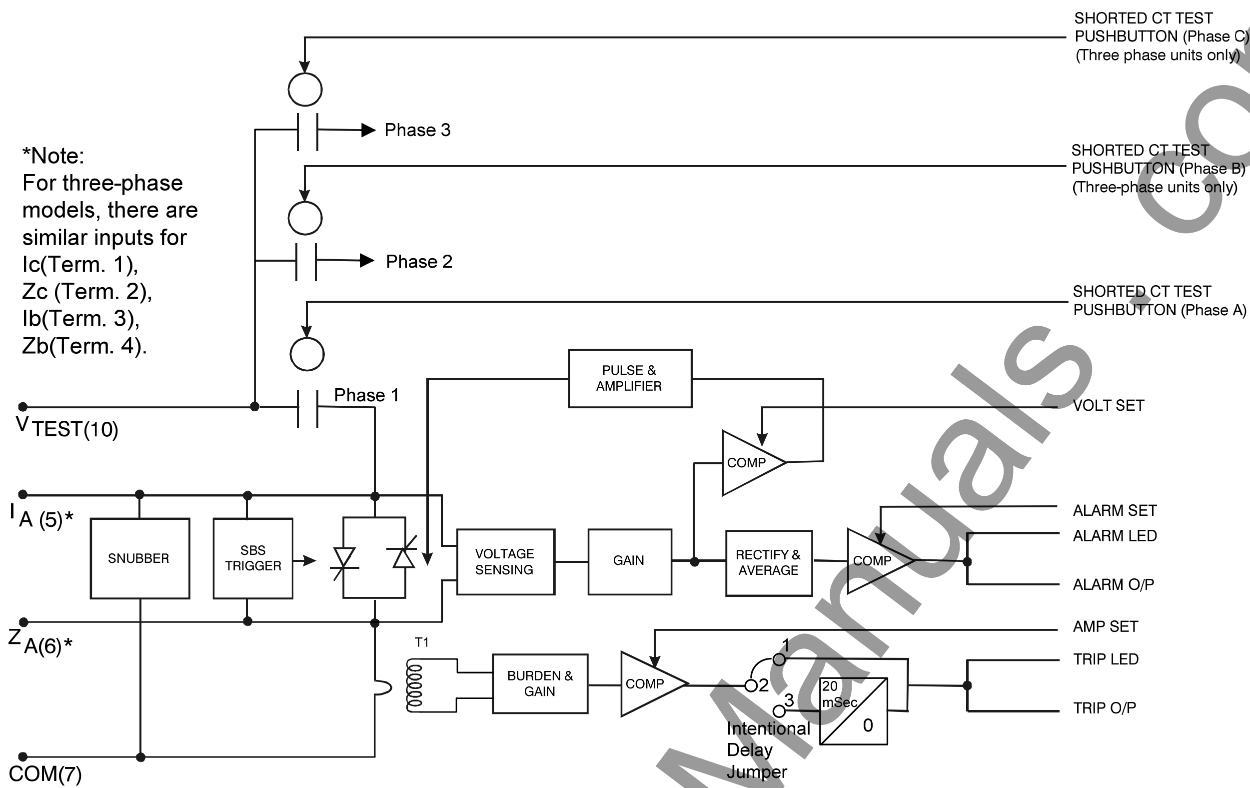


Figure 2-6. Typical Secondary Excitation for 1200/5 Bushing Current Transformer

Figure 2-7 illustrates, in simplified form, the internal connections of the BE1-87B relay. When an internal fault occurs, the peak voltage developed in the secondary of the feeder CTs will appear across the relay input network via phase A, phase B, or phase C. Under normal conditions, while operating power is available to the relay, the SCR firing is accomplished via the voltage sensing circuitry by the pulse amplifier. When the SCRs fire, the CT circuits will be shorted and the total secondary fault current will flow through the SCR circuits and the primary of current transformer T1. If the total secondary fault current, and hence the primary current of T1 is above the pickup level of the relay, a trip output will be provided via the output relay.

When relay-operating power is not available, the BE1-87B can no longer trip the output contacts. However the SBS (Silicon Bilateral Switch) circuitry provides voltage protection for the SCRs and the relay internal circuitry. When the peak voltage exceeds the switching voltage of the SBS, it will conduct, causing the corresponding SCR to be triggered to the ON condition. During subsequent half cycles, the SCRs will be triggered alternately. Note that the SBS, across the SCRs, exhibits high impedance in the OFF state and will turn ON and conduct when a switching voltage above the relay maximum setting is reached. The SBS acts only as a failsafe, triggering the SCRs in the event control power (power supply voltage) is lost and a fault has occurred.



Snubber Impedance (27 - j8040) + SBS Trigger (8700 + j0) =
A Net 60Hz Input Impedance of 3.95 - j3.30 K or 5.15 K $\angle$-40º

Figure 2-7. Simplified Internal Connection Diagram for BE1-87B Relay

For convenience, the BE1-87B relay voltage settings are calibrated in terms of rms symmetrical volts and all calculations for settings are made in terms of rms symmetrical quantities. The relay responds to the instantaneous value of applied voltage, and this maximum instantaneous value can be two times the square root of two or 2.83 times V_{DIFF} for fully offset waveforms. As soon as the relay operates, the shorting action of the SCR path reduces this voltage to a very low level. Thus the maximum peak voltage that can be produced in the differential circuit will be limited to the value calculated in Equation 3 below.

$$V_R = 2\sqrt{2}\ (V_{DIFF}) = (2.83)\,(V_{DIFF}) \qquad \text{(EQUATION 3)}$$

V_R = maximum instantaneous peak voltage that can be developed in the differential circuit

V_{DIFF} = BE1-87B voltage set point in rms symmetrical volts

($2\sqrt{2}$) = conversion of rms symmetrical volts to corresponding peak volts of a fully offset voltage wave

Where CTs with taps set on other than the full winding are involved, the voltage developed across the full winding of these CTs can be greater than the differential circuit voltage as a result of the autotransformer action. For example, consider the simple circuit of Figure 2-8. The voltage in the differential circuit, and consequently across CT1 and CT2, will be limited to V_R. But the voltage across the full winding of CT3 will be greater by the ratio of the total number of turns of the CT to the actual turns used.

$$V_F = \frac{N_1}{N_2}(V_R) = \frac{(2.83)\,(V_{DIFF})\,(N_1)}{N_2} \qquad \text{(EQUATION 4)}$$

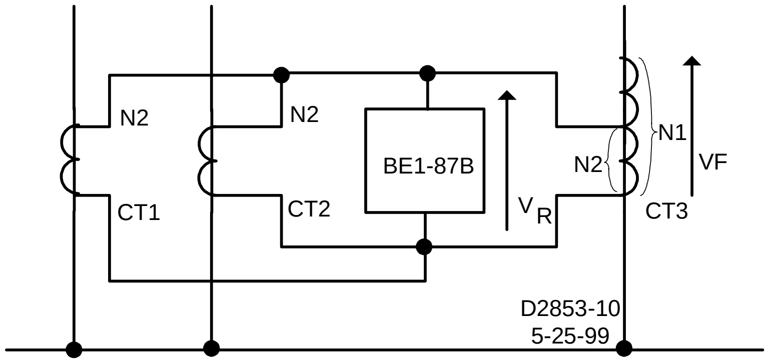
V_F = voltage across the full winding

N_1 = total number of CT secondary turns

N_2 = number of CT secondary turns used, i.e. tap settings

2.83 = $2\sqrt{2}$ (peak value of fully offset wave)

The voltage across the full winding (V_F) should not exceed the insulation breakdown of the connected equipment. The value of the actual peak voltage that can be produced for any relay tap setting and mixed multi-ratio CT combination may be evaluated using Equation (4).



$$VF = \frac{N1}{N2} VR$$

V_F = VOLTAGE DEVELOPED ACROSS FULL WINDING
V_R = MAXIMUM INSTANTANEOUS VOLTAGE
NI = TOTAL NUMBER OF CT TURNS
N2 = NUMBER OF CT TURNS USED (TAP SETTING)

Figure 2-8. Voltage Appearing Across Full Winding of CT

CHARACTERISTICS

Operation of the BE1-87B relay is initiated as a function of the instantaneous voltage developed across terminals 5 and 7 (single-phase model) of the relay. However, an output will not be produced unless the total secondary fault current that flows through the relay after the SCRs fire is greater than the pickup current setting. In this fashion both voltage and current are required to produce an output. The voltage selector switch setting and current selector switch setting determine the voltage and current requirements needed to produce an output.

Differential Voltage Pickup

The BE1-87B pickup voltage selector switch allows for a setting range of 50 to 400 volt rms symmetrical in 50-volt increments. This sets the voltage level at which the back to back internal SCRs will trigger. The SCRs will trigger whenever the instantaneous value of the applied voltage is equal to twice the peak value of the rms symmetrical pickup voltage setting. Refer to Equation 3.

NOTE

The voltage V_R is equal to the peak voltage of a fully offset voltage wave having an rms symmetrical value equal to the pickup voltage selector switch setting. Because of this the SCRs will fire whenever an rms symmetrical voltage greater than twice the voltage selector switch setting is applied, or whenever the corresponding peak voltage is exceeded on an instantaneous basis as in the case of an internal fault. When the SCRs fire, provided the total secondary fault current that flows in the relay is greater than the pickup current setting, the relay will produce an output.

Differential Pickup Current

Pickup current is defined as the rms value of a symmetrical sinusoidal current that must flow into the 87B in order to provide a contact output. The BE1-87B has a pickup current selector switch that allows for a range of 0.25 to 2.5 amperes rms in 0.25 ampere increments. However, the relay internally operates off of the instantaneous peak of this sinusoidal current. For example, if the relay is set at 1 amp, the current sensing element monitors for instantaneous current riding above 1.414 amps.

Alarm Voltage Pickup

The BE1-87B is equipped with a differential voltage alarm function. The function is used to detect steady state voltage imbalances across the input sensing circuit of the relay (Terminals 5 and 7, 3 and 7, and 1 and 7 for the three-phase model). The setting range for the alarm pickup is 10% to 80% of the rms differential voltage pickup setting (V_{DIFF}) in increments of 10%. When the rms voltage across the sensing input terminals exceeds the voltage pickup setting times the voltage alarm percentage setting (V_{DIFF} x % set), the CT OV LED illuminates and the alarm output contact closes (Terminals 13 and 14). When the input voltage falls below the alarm voltage threshold, the CT OV LED turns OFF and the alarm output contacts open. The response time of the alarm contacts and the LED is intentionally slow to prevent nuisance alarms (approximately one second). If the Shorted CT Test Circuit is used, set the alarm unit at minimum (10%).

Example:

A relay with a differential pickup voltage (V_{DIFF}) setting of 200 volts rms symmetrical and an imbalance alarm voltage setting of 10%, will alarm at 20 volts rms (200 x 0.1 = 20 volts).

Trip Test Pushbutton

The Trip Test pushbutton is recessed behind the front panel and is accessed through a small opening. Insert a small, nonconductive tool through the front panel to depress the Trip Test pushbutton. Trip test simulates a trip condition and verifies the operation of both output trip contacts and the trip LED. Upon releasing the Trip Test pushbutton, the trip output contacts will reset, but the LED remains lit. To clear the Trip LED indication, press the Reset button.

CAUTION

Activation of the Trip Test button will trip the lockout device (86) and the bus breakers unless appropriate steps are taken.

CT Test Pushbutton

The CT Test pushbutton is a “pillow-type” button located on the face of the relay. The button can be accessed by either removing the standard cover to actuate or through the external button actuators of the optional cover. The CT Test pushbutton provides a method for testing the “health” of the entire current circuit by injecting a calculated value of external test voltage across the current circuit. If the current circuit is healthy, the voltage across the relay will be high enough to light the Alarm LED and close the alarm output contacts, terminals 13 and 14. If there is a short circuit in the current circuit, all of the test voltage will be dropped across an external test resistor and neither the LED nor the alarm output will operate. If this occurs, further current circuit tests should be performed. This function is available only when power is applied to the relay and the CT diagnostic test source assembly (9282300014) is connected to terminals 7 and 10 of the relay. The *Test Circuit Calculations* sub-section provides details on applying this feature.

Power LED

This LED lights when normal operating power is applied to relay terminals 15 and 16.

Intentional Delay Jumper

A user-settable jumper is located on the Control circuit board to select either no intentional delay (jumper position 1 to 2), or a 20-millisecond delay∗ (jumper position 2 to 3) added to the trip response time. For applications having a tap within the zone of protection that is protected by a high-speed fuse, the 20 millisecond intentional delay∗ is intended to prevent tripping the bus for a fault on the fused tap. The current detector circuit reset time is approximately 1 millisecond so that the ac and dc components of the differential current, as reproduced at the CT secondary, must drop below pickup in less than 19 milliseconds. A secondary error may occur due to the fast dropout of the primary current when the fuse operates.

∗ Actual intentional time delay is a function of pickup current. For currents exceeding twice the pickup setting, intentional time delay is 20 milliseconds. For currents less than twice the pickup setting, intentional time delay is 25 milliseconds.

Operating Times

The BE1-87B operates in less than 7 milliseconds (1/2 cycle) for faults 1.5 times the current pickup. The BE1-87B operates in less than 5.5 milliseconds for fault levels above 6 times the current pickup. High-speed operation minimizes potential damage to the protected equipment. Refer to Figures 1-2 and 1-3 in Section 1, *General Information* for illustrations of response times.

CALCULATION OF SETTINGS

The BE1-87B relay is set based on the maximum possible voltage that can be produced in the differential circuit as a result of a fault external to the zone of protection. Determination of the maximum voltage for this condition is subject to simple calculations, and thus, the relay setting is easily determined. The relay has a setting range 50 to 400 volts rms in 50-volt steps.

It is first necessary to calculate the maximum voltage that can be produced in the differential circuit for an external fault. Once that value is determined, the appropriate voltage setting can be selected. If a mixture of multi-ratio CTs is used (not recommended) or if the CTs are applied on taps other than full ratio, calculations must be performed to determine if excessive voltages will be produced across the full winding of the CT. Last, the minimum internal fault for which the relay will just operate will be calculated.

Calculation of Voltage Differential Settings

The minimum acceptable differential voltage setting can be determined using the following equation.

$$V_{DIFF} = 1.25\,(R_S + PR_L)\,\frac{I_F}{N}$$ (EQUATION 5)

V_{DIFF} = minimum acceptable voltage tap setting. Since V_{DIFF} in general will not come out exactly equal to one of the available settings, the next higher setting should be used. The available voltage settings are 50 to 400 volts rms in 50-volt increments.

R_S = dc resistance of fault CT secondary windings and leads to the CT makeup box (at maximum expected operating temperature).

R_L = single conductor dc resistance of the current circuit cable for a one-way run from the differential junction point to the fault CT makeup box (at maximum expected operating temperature).

P = one (1.0) for three-phase faults and (2.0) for single-phase to ground faults.

I_F = maximum external fault current in the fault CT in primary symmetrical rms amperes.

N = CT ratio.

1.25 = margin for safety.

The following comments may be made with respect to the evaluation of Equation 5.

- It is only necessary to calculate three-phase and single-phase-to-ground faults. If the results yield a satisfactory application, the application will also be satisfactory for multi-phase faults.
- For single-phase-to-ground faults, the differential circuit is such that the CT secondary fault current will flow through both of the fault CT cables; thus the multiplier P must be set equal to two. On the other hand, the CT secondary currents during a balanced three-phase fault will result in 0 current in the return cable; thus only the one-way cable resistance is involved, and P is set equal to one.
- If the single-phase-to-ground fault current at a given location is greater than or equal to the three-phase fault current, the calculations need only be made for the single-phase-to-ground faults.
- The resistance of the CTs and connecting cables will increase with increasing temperature; therefore, if adequate margin is to be maintained at all times, Equation 5 should be evaluated using resistance values corresponding to the maximum expected operating temperature (see sample calculation in this section).

The methods to be used in calculating the voltage tap setting using Equation 5 will to some extent be dependent on the type of application. The following paragraphs discuss different areas in which the BE1-87B relay may be applied.

Bus Protection

Two methods will be outlined for evaluating Equation 5 in order to determine an appropriate relay voltage tap setting.

Method 1. The first method offers a simplified conservative approach to the problem and requires that equation 5 be evaluated only once. With this method, it is assumed that a single-phase-to-ground fault with a current magnitude equal to the maximum interrupting rating of the breaker occurs on the feeder associated with the CT having the longest cable run from the differential junction point. Under these assumptions, the effect of the fault current, I_F, is maximized, and so is the effect of cable resistance, because the highest value of resistance is used and P is set equal to 2. Thus, the highest possible value of V_{DIFF} will be obtained.

Method 2. The second method offers an exact approach but requires that Equation 5 be evaluated a number of times in order to obtain the maximum V_{DIFF}. With this method, calculations must be made for the maximum single-phase-to-ground fault and the maximum three-phase fault just off each of the n feeders on the bus. Therefore, Equation 5 must be evaluated 2n times using the associated value of cable resistance and P = 1 or P = 2, as required.

In general, Method 2 will produce a lower voltage tap setting than Method 1, but Method 1 is simpler to utilize. The user should begin with Method 1. If the voltage setting resulting from the use of this method results in adequate sensitivity, a unique advantage is realized in that the setting does not require recalculation following future changes in the power system that result in higher fault current magnitudes. If the sensitivity resulting from the use of Method 1 does not prove adequate, then Method 2 should be used. Each method is outlined below.

Method 1 (Simplified Conservative Approach)

a. Use the maximum interrupting rating of the circuit breaker as the maximum single-phase-to-ground symmetrical fault current (I_F).

b. R_L is based on the distance from the differential junction point to the most distant CT.

c. Calculate V_{DIFF} substituting the values of current and resistance from a. and b. and set P = 2.

d. Select the highest available voltage setting that just accommodates the voltage calculated in c. above.

Method 2 (Exact Approach)

a. Determine the maximum three-phase and single-phase-to-ground fault currents for faults just off each of the n breakers on the bus.

b. R_L is the one-way dc resistance of the cable from the associated CT to the differential junction point.

c. For each breaker in turn, calculate V_{DIFF} separately, utilizing the associated maximum external three-phase symmetrical fault current in the fault CT, with P = 1 and the maximum external single-phase-to-ground symmetrical fault current in the fault CT, with p = 2.

d. Use the highest V_{DIFF} resulting from the calculations and select the next highest available voltage setting that just accommodates this value.

Shunt Reactor Protection

Depending on the type of protection required, shunt reactors may be protected by the BE1-87B relay in one of two ways (see Figures 2-3 and 2-4). Since the shunt reactors contribute no current to an external fault, Equation 5 should be evaluated using the highest magnitude of current that can flow in the reactor under any system condition, exclusive of a fault in the reactor. If the differential junction point is located near the reactors, the resistance of the CT connecting cables can probably be ignored, and Equation 5 need only be evaluated using the CT resistance and the maximum expected current. If the cable resistance cannot be ignored, use the maximum expected reactor current and P = 2. After a value of VDIFF has been calculated, select the next higher available voltage setting that just accommodates this voltage.

Application with Mixed Multi-Ratio CTs

Where CTs are used on other than their full windings, (not recommended) the application should be evaluated after a voltage setting has been selected to determine that excessive voltages are not developed across the full windings of these CTs as a result of autotransformer action. It is desirable to limit the peak value of the voltage to less than the insulation breakdown of the connected equipment. Refer to Equation 4 under Operating Principles for information on how to calculate the peak voltage across the full winding.

See Figure 2-8 for an illustration of terms from Equation 4. If V_F is less than the insulation breakdown, and if the current rating of the CT is not exceeded, the application is permissible. Equation (4) should be evaluated for the CT having the highest N1/N2 ratio. If the condition of Equation (4) is met for this CT, then it will also be met for the remaining CTs.

Current Element Setting

The setting of the current element is based upon four factors.

1. The current setting needs to be set so that the relay will operate at minimum fault levels. The main application where this will be of concern will be when one wishes to ensure operation of the relay for ground faults on impedance grounded systems. This matter is discussed in the *Minimum Fault to Trip* sub-section.
2. The current setting should be set high when there are surge arresters in the zone of protection. This factor was discussed in the *Application with Lightning Arresters* sub-section.
3. The third factor is hard to quantify. It is possible for noise to be induced on the bus differential CT circuit by the magnetic fields generated by out-of-zone fault currents. This includes magnetic fields generated by both the primary fault currents and by secondary fault currents where CT leads are in the same conduit at the differential relay CT leads. Due to the high impedance of the bus differential circuit, the induced voltage can be high enough to cause the relay voltage element to transiently pick up. However, this induced voltage cannot carry any appreciable current after the BE1-87B SCRs are turned on. If the BE1-87B voltage element operates but current in the CT string remains low (less than the BE1-87B current element setting) after the SCRs turn on, the relay will not trip. Hence, the current element is set at some level that will prevent induced pickup of the relay for this condition. A typical setting for this purpose is 0.5 amperes.
4. The current should be set high enough so that if the BE1-87B CT Test feature is used (to test for CT short-circuits), the current that is induced in the relay by the test will be less than the current setting of the relay by a comfortable margin. This matter is discussed in the *CT Test Circuit Calculations* sub-section.

Minimum Fault to Trip (Voltage Element)

NOTE

In the following sensitivity analysis, relay impedance is rounded to 5000 ohms for simplicity and the algebraic addition of current magnitudes rather than a more exact phasor addition of currents is used. A comparison of the simplified calculation approach to the more exact calculation approach results in a minimum fault sensitivity value that is higher than when the more exact approach is used. Hence, the simplified approach is a more conservative method for finding minimum sensitivity.

After the differential voltage setting has been established, a check should be made to determine the minimum internal fault current that will just cause the voltage element of the relay to operate. This current level should be compared to the current element setting. The greater of these two quantities determines the relay minimum fault-to-trip. The minimum fault-to-trip should be less than the bus minimum fault duty. This will be an issue mainly with impedance-grounded systems. The following expression can be used to determine the minimum internal fault current required for a particular tap setting.

$$I_{MIN} = \left[\sum_{x=1}^{n} (I)x + I_R \right] N \quad \text{(EQUATION 6)}$$

I_{min} = minimum rms symmetrical internal fault current required to operate the BE1-87B relay

n = number of CTs (number of circuits)

I = secondary excitation current of individual CT at a voltage equal to (VDIFF)

I_R = current in the relay at pickup setting

N = CT ratio on tap used

The excitation currents, (I)1, (I)2,……(I)n will be a function of the peak voltages that can be produced in the secondary of the respective CTs. It is possible to determine the currents with the aid of the secondary excitation characteristic for the respective CT. But it is first necessary to modify the characteristics so that they are plotted as a function of the peak voltages that can be produced. The procedure for doing so is provided in the following paragraphs.

1. Determine the knee point coordinates of the standard excitation curve (E_S and Ie). These points will be indicated on the given characteristic, or they can be found graphically by determining the point where a 45-degree line is tangent to the knee of the excitation curve.
2. Calculate and plot the following point on the same sheet with the excitation curve:

   $V = (7)(E_S)$

   $I = (5)(Ie)$ (EQUATION 7)
3. Draw a line having a slope of ½ through the point (V, I) calculated and plotted in step 2. A slope of ½ corresponds to one log cycle on the vertical axis (voltage) and two log cycles on the horizontal axis (current) (See line A-B in Figure 2-6).
4. Extend the lower part of the excitation curve in a straight line until it intersects line A-B drawn in step 3 (see line C-D in Figure 2-6).

The curve (CPB) formed by these two lines now represents the modified excitation characteristics as a function of the peak voltages that can be produced. After the curve has been drawn, calculate the following corresponding excitation current I.

$$V_S = 2\sqrt{2}\,(V_{DIFF}) \qquad \text{(EQUATION 8)}$$

V_S = voltage coordinate for determining I

V_{DIFF} = differential voltage setting of the BE1-87B

NOTE

The first term in Equation 6 reduces the nI if all the CTs have the same characteristics. The second term in Equation 6 represents the current (I_R) drawn by the relay just at the operating point. It can be calculated as follows:

$$I_R = \frac{(2)(V_{DIFF})}{5000} \qquad \text{(EQUATION 9)}$$

SAMPLE CALCULATION

The various steps for determining the setting of the BE1-87B in a typical bus application will be demonstrated with the aid of a worked example. Assume the protected zone includes five breakers, all rated at 69 kV, 1500 MVA, and 1200 amperes, with a maximum interrupting rating of 12,500 amperes. The excitation curve for the 1200/5 bushing CTs in these breakers is shown in Figure 2-6.

A current sensitivity setting of 0.5 amperes will be used. The voltage tap setting will be determined by using Method 1 described in the preceding paragraphs. The value of R_S from Figure 2-6 is (0.0019) (240) + 2 (0.0347) = 0.525 Ω. It is assumed that this resistance corresponds to the maximum expected operating temperature. It is further assumed that the longest CT cable run is 442 feet, and number 10 AWG copper wire is used. The one-way cable resistance at 25 degrees C is 0.450 Ω. The resistance value of the wire at 25 degrees C or at any temperature T1 may be corrected to any temperature T2 by means of the following equation.

$RT2 = [1 + \rho 1\,(T2-T1)]\,RT1$

RT2 = Resistance in ohms at T2, degrees C

RT1 = Resistance in ohms at T1, degrees C

$\rho 1$ = Temperature coefficient of resistance at T1

For standard annealed copper, $\rho 1$ = 0.00385 at T1 = 25 degrees C. If the maximum expected operating temperature is assumed to be 50 degrees C, then the following applies.

$RT2 = [1 + 0.00385\,(50-25)]\,0.450$

$= (1.096)(0.450) = 0.493\ \Omega$

Substituting the various quantities in Equation 5 yields:

$V_{DIFF} = 1.25\,[.524 + 2\,(0.493)]\,12500/240$

$= 98.31$ volts

Since 98.31 volts is not an exact equal to one of the V_{DIFF} setting, select the next higher available setting, which is 100 volts.

V_{DIFF} = 100 volts

Since the CTs are all used on the full winding (suggested practice), there is no need to check that excessive voltages will be produced in the CT circuits. Now that V_{DIFF} setting has been selected, the sensitivity may be calculated following the procedure outlined in the section under Minimum Fault to Trip.

From Figure 2-6, the knee point coordinates E_S and Ie, are 290 volts and 0.06 ampere. From Equation 7:

V = (7) (E_S) = (7) (290) = 2030 volts

I = (5) (Ie) = (5) (0.06) = 0.30 ampere

Plot this point (V, I) on the graph of Figure 2-6 and draw the lines A-B and C-D. This gives the modified secondary excitation characteristics. Calculate the voltage V_S using Equation 8.

V_S = (V_{DIFF})

= 2.83 (100)

= 283 volts

From the modified curve, the current Ie corresponding to V_S = 283 volts is 0.05 ampere.

The relay current from Equation 9 is:

$$I_R = \frac{(2)(V_{DIFF})}{5000}$$

$$I_R = \frac{(2)(100)}{5000} = 0.04 \text{ amperes}$$

The sensitivity of the relay voltage element or the minimum fault level of the voltage element from Equation 6 is:

I_{min} = [(5) (.05) + 0.04] (240) = 70 amperes.

With the relay set at 0.25 amperes sensitivity, 60 amperes of primary current are required to produce 0.25 ampere secondary from the 1200/5 CTs. Therefore, the minimum current sensitivity of the relay is 60 amperes primary. If a higher minimum current sensitivity is used, the minimum current required for pickup will be correspondingly higher. For example, with a 1200/5 CT ratio, 120 amperes of primary current are required to produce 0.50 ampere secondary with the relay set at 0.50 ampere sensitivity.

CT TEST CIRCUIT CALCULATIONS

General

Operating parameters for the CT Test Circuit are defined by the user application. That is, the Pickup Voltage setting for the specific bus protection application is required before operating parameters for the test circuit can be determined. The Alarm Voltage should be set to 10% to minimize the voltage magnitude required from the external CT Diagnostic Test Source.

Definition of Terms

- V DIFF – symmetrical rms voltage setting of the relay.
- V ALARM – unbalance differential Voltage setting of the relay (V DIFF X 10%).
- V TEST- external test source voltage for shorted CT test circuit (V ALARM X 1.5). The multiple of 1.5 compensates for voltage drop across R TEST and guarantees operation of V ALARM during test of a Healthy CT circuit. The multiplier was derived through the iterative process.
- Ie - secondary excitation current from the CT excitation curve.
- Z CT –V TEST/Ie.
- Z PCT – parallel equivalent impedance of n CTs.
- Z BUS – parallel equivalent of the relay input impedance (5k) with Z PCT.
- Z TOTAL – Z BUS + Z PCT.
- I HT – Test current value for a HEALTHY current circuit.
- V R TEST –voltage drop across R TEST during a HEALTHY test.

- V Z BUS – voltage drop across Z BUS during HEALTHY test.
- % V ALARM – ratio of V Z BUS to V ALARM setting. As a rule of thumb, use a minimum ratio of 110% to insure enough voltage for guaranteed operation.
- I UHT – test current value for an UNHEALTHY current circuit.

Calculation Steps

Perform the following calculations to determine the appropriate secondary test voltage for the user specific application.

1. Determine the V DIFF setting.
2. Using the 10% Alarm Voltage setting, determine the alarm value (V DIFF X .1 = V Alarm).
3. Calculate V test by Multiplying V Alarm times 1.5 (accounts for test circuit V drop and provides guaranteed operation of V Alarm for healthy CT circuit).
4. From the user specific CT saturation curves, find Ie corresponding to the test source voltage (30 or 60) for the connected ratio (full ratio is recommended for bus differential protection).
5. Calculate the CT impedance (CTZ) (don't worry about the reactive component) V Test/Ie.
6. Calculate parallel CT impedance (PCTZ) by dividing CTZ by the number of breakers in the bus application (assumes all CTs on the bus are the same ratio and accuracy class).
7. Solve for Z Bus (relay input Z in parallel with the PCTZ) -- (PCT Z) (5000)/(PCT Z) + (5000).
8. Calculate I Healthy Test Current, I HT, by dividing the Test Source voltage V Test, by (Zbus+100) (value of external R Test resistor=100 ohms).
9. Solve for voltage drop across the 100-ohm resistor (R x I).
10. Solve for voltage drop across Z Bus.
11. Solve for % V ALARM, V Z Bus/V ALARM setting. As a rule of thumb, use a minimum ratio of 110% to insure enough voltage for guaranteed operation.
12. Divide Test Source Voltage by 100 = I UHT.
13. Verify that the Pickup Current setting of the relay is above the I Test Unhealthy.

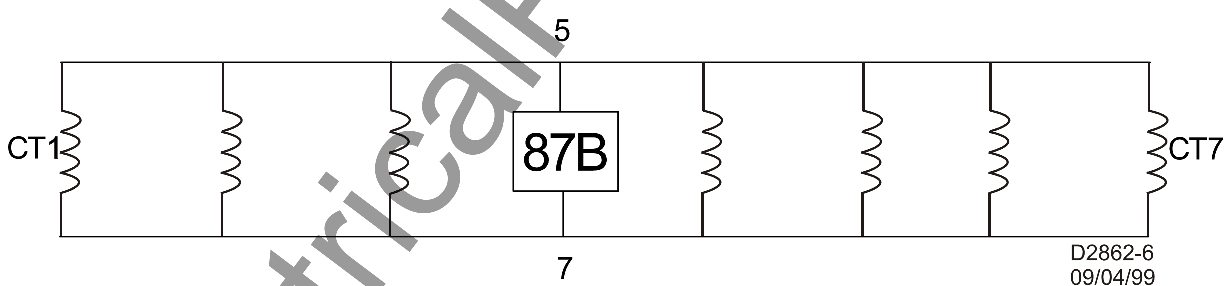


Figure 2-9. Voltage Appearing Across Full Winding of CT

Example Calculation

The following calculations are based on a seven-breaker bus as shown in Figure 2-9. For this example, 1200/5 CTs are used, all on the same ratio and same accuracy class as per Figure 2-6.

Based on a V Diff setting of 150 volts and an Alarm setting of 10 %, "V Alarm = (150) x .1 = 15 volts". "V Test = V Alarm X 1.5 or 15 X 1.5 = 22.5 volts".

The user must select the 30 or 60-volt secondary taps based on the V Test calculation. If V Test is 30 volts or less, choose the 30-volt tap and if higher choose the 60-volt tap. In our example, V Test = 22.5 volts, therefore the 30 volt tap will be selected.

1. From a CT excitation curve, find Ie at 30 volts for full ratio. At 30 volts on the 240 /1 curve, Ie is approximately equal to .017 amps:

   CTZ = V Test / Ie or 30 / .017 = 1765 ohms/CT (ignoring any reactive component)

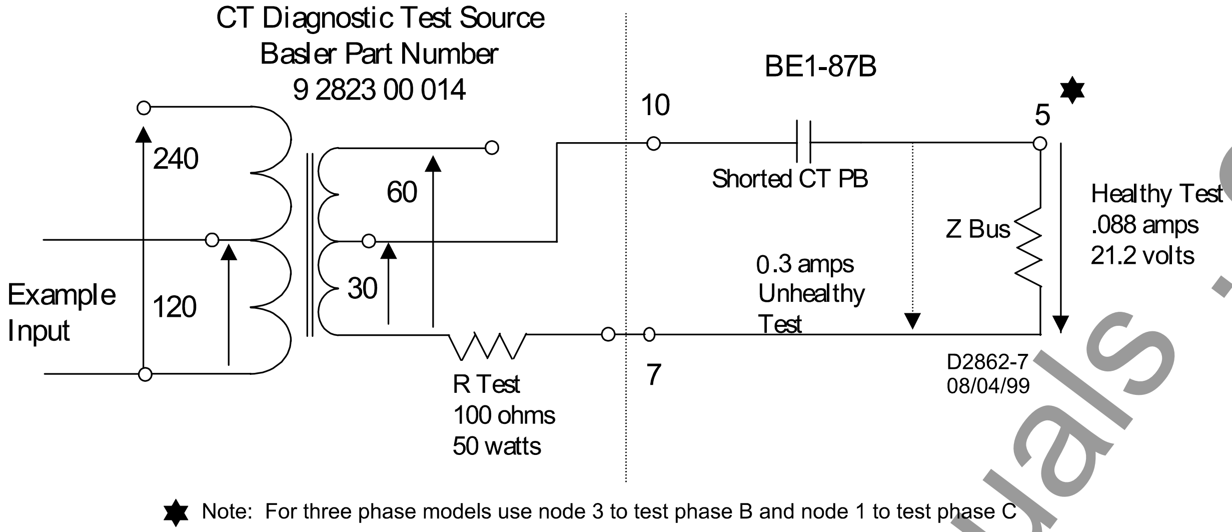


Figure 2-10. Voltage Appearing Across Full Winding of CT

2. In our example case, 7 CTs are in parallel with a relay input impedance of 5k ohms resulting in an equivalent impedance of 240 ohms (refer to Figure 2-9).

   Z Bus = CTZ / nCTs or 1765/7 = (252 X 5000) / (252 + 5000) = 240 ohms

3. Find the total current for a healthy CT test using V Test = 30 volts and R Test = 100 ohms.

   Z Total = R Test + Z Bus or 100 + 240 = 340 ohms.

   I HT = V Test / Z Total or 30/340 = 0.088 amp.

4. Find the total current for an unhealthy CT circuit (Z Bus shorted out):

   I UHT = V Test / R Test or 30/100 = 0.3 amp.

5. To guarantee security of the relay during the Shorted CT Test, set the relay Pickup Current to 0.5 amperes (For additional information see the paragraph in Section 3 entitled *Shorted CT Test Circuit*.)

6. Check the voltage drop across R Test and Z Bus:

   V R Test = 100 X .088 = 8.8 volts and V Z Bus = 240 X .088 = 21.2 volts.

7. Verify that the ratio between V Z Bus and V Alarm is 110% or higher:

   % V Alarm = V Z Bus / V Alarm X 100 or 21.2/15 X 100 = 141%.

8. If the %V Alarm is below 110%, raise V Test to 60 volts and repeat all calculation steps. A %V Alarm less than 110% may result in indication of an unhealthy CT circuit when in fact there is nothing wrong.

SECTION 3 • HUMAN-MACHINE INTERFACE

TABLE OF CONTENTS

Figures

Tables

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SECTION 3 • HUMAN-MACHINE INTERFACE

FRONT PANEL CONTROLS AND INDICATORS

For physical reference to the devices listed in the following paragraphs, refer to Figures 3-1 and 3-2. Figure 3-1 shows the single-phase version of the BE1-87B and Figure 3-2 shows the three-phase version of the BE1-87B. Controls and indicators of a 19" rack-mount relay are identical to Figure 3-2, except rotated 90 degrees.

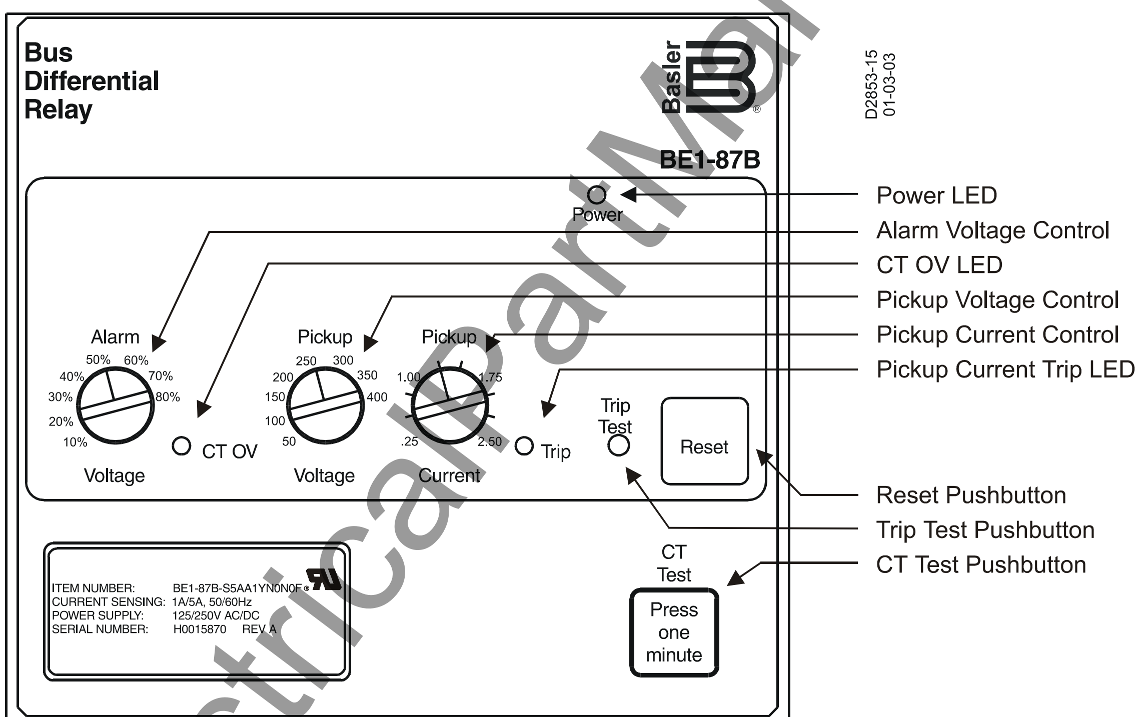

Figure 3-1. BE1-87B Controls and Indicators (Single-Phase Version)

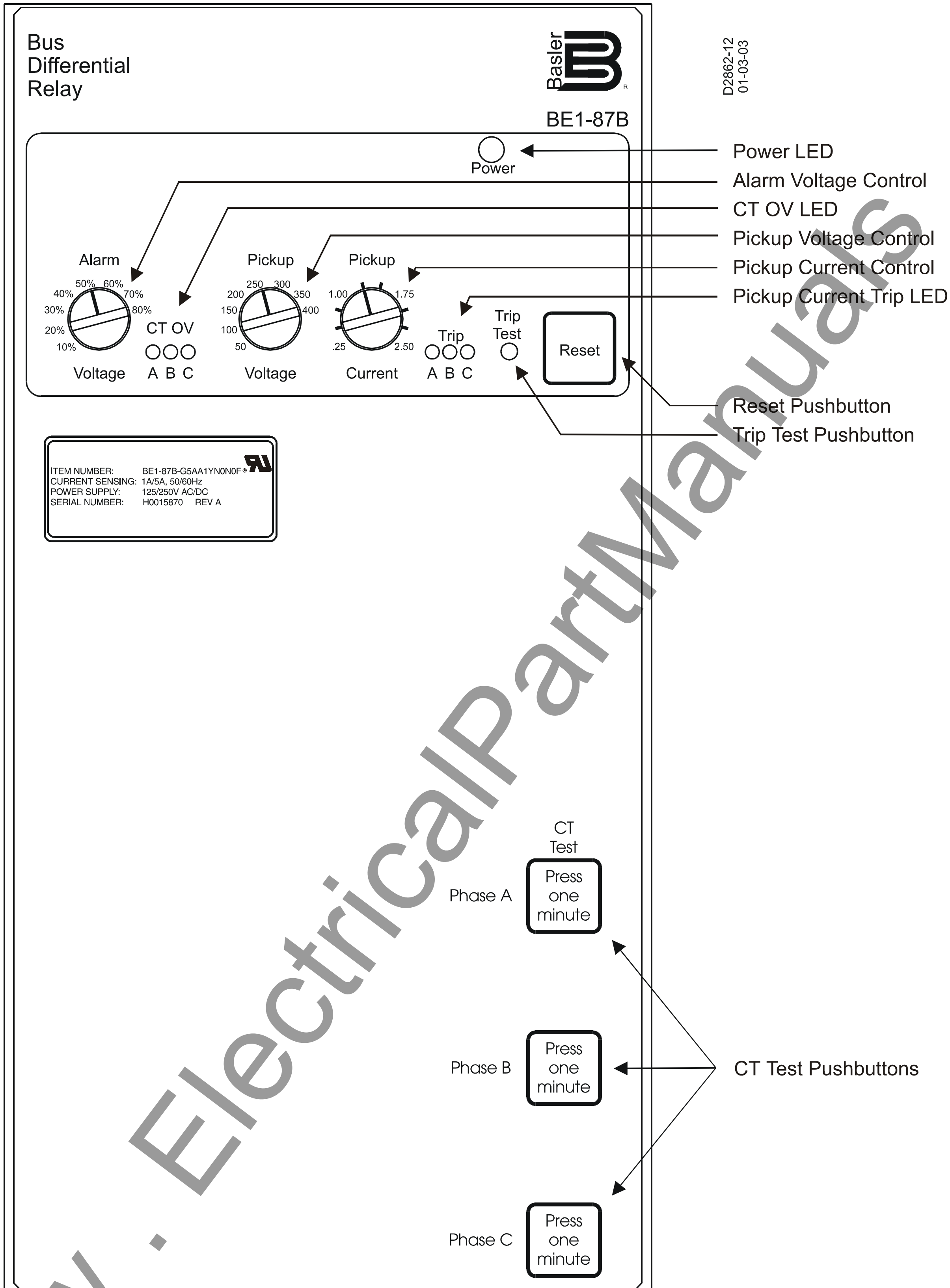

Figure 3-2. BE1-87B Controls and Indicators (Three-Phase Version)

Power LED

This indicator lights when nominal operating power is applied to the relay at terminals 15 and 16.

Alarm Voltage Control and CT OV LED

The Alarm Voltage rotary select switch allows for a setting range of 10% through 80% of the Pickup Voltage in 10% increments. The Alarm Voltage element detects unbalance voltages across the sensing inputs of the relay (Terminals 5 and 7, Single-Phase Units). If the unbalance voltage exceeds the Voltage Alarm Setting (10 to 80 % of Pickup Voltage), the Alarm Output Contact closes (Terminals 13 and 14), and the CT OV LED lights. When the voltage input falls below the Alarm setting, the Alarm Relay drops out and the CT OV LED turns OFF. The response time of the alarm contacts and the LED is intentionally slow to prevent nuisance alarms.

Example

With the Alarm Voltage setting at 10% and a Pickup Voltage setting of 150 volts, the Alarm output contacts will close when the input voltage exceeds 15 volts (0.1 X 150).

Pickup Voltage Control

This rotary control allows for a pickup voltage setting range of 50 to 400 volts rms in 50-volt increments. This sets the voltage at which the back-to-back internal SCRs trigger. The SCRs are triggered when the input voltage exceeds twice the setting of the Pickup Voltage switch to allow for a fully offset voltage signal. Table 3-1 describes input impedance while the device is triggered (low impedance) and while it is not triggered (high impedance).

Table 3-1. Input Impedance While Triggered and Not Triggered

Impedance State	**Input Impedance in Ohms**	
	60 Hz nominal	**50 Hz Nominal**
High Impedance (Triggered)	4000 - j3300 5100 ∠ -40°	4500 - j3100 5500 ∠ -35°
Low Impedance (Not Triggered)	0.05	0.05

Example

With the pickup voltage set at 150 volts rms, the input SCRs will trigger when the input voltage is increased to 300 volts rms (calibration and routine maintenance tests) or when the instantaneous voltage exceeds 2.83 times the rms pickup voltage (fully offset, peak value). Refer to Section 2, *Operating Principles* for more information.

Pickup Current Control

This rotary control allows for a pickup current setting of 0.25 to 2.50 amperes rms in 0.25 ampere increments. This setting determines the level of current into the sensing input (Terminals 5 and 7) that causes the two trip output contacts to close and the Trip LED to light. Note that relay operation is based on the instantaneous peak value of the sinusoidal current detected at the sensing input.

Example

When the Pickup Current Control is set at 1 amperes rms, output contact closure occurs when the current sensing element detects an instantaneous current value of 1.414 amperes.

When the input current falls back below this setting, the output contacts open, but the Trip LED remains lit until the Reset button is pressed. The Trip LED maintains correct status indication even if power is lost and then restored.

Pickup Current Trip LED

This indicator lights when the level of current flowing through the relay sensing input exceeds the setting of the Pickup Current Control. The Pickup Current Trip LED remains lit until the Reset button is pressed. LED status is maintained when the relay is de-energized. When operating power is re-applied, the LED lights and remains lit until the Reset button is pressed.

Reset Pushbutton

Pressing the Reset button turns off the Pickup Current Trip LED.

Trip Test Pushbutton

The Trip Test pushbutton is recessed behind the front panel and is accessed through a small opening. It is actuated by using a nonconductive tool small enough to fit through the front panel. It is used to simulate a trip condition, to verify operation of both output trip contacts, and to verify that the trip LED lights. Upon releasing this pushbutton, the output trip contacts open but the Trip LED remains lit. The test operator must depress the reset switch to clear the Trip LED.

NOTE
The Trip Test pushbutton is functional only when operating power is applied to the relay.

CT Test Pushbutton

This pushbutton control is used in conjunction with the optional Basler CT Diagnostic Test Source (P/N 9282300014) to verify the health of the CT input circuit. The condition of the CT input circuit is tested by depressing the CT Test Pushbutton for one minute or until the CT OV LED lights. A healthy CT input circuit is indicated by a lit CT OV LED and closed Alarm output contacts. A shorted CT input circuit is indicated by the CT OV LED remaining off and the Alarm output contacts remaining open.

Details about CT input circuit testing are provided in the CT Test sub-section of Section 5, *Testing*.

CIRCUIT BOARD CONTROLS

The BE1-87B relay has one circuit board control, the Intentional Delay Jumper. The jumper's location is illustrated in Figure 3-3 and its function is described in the following paragraphs.

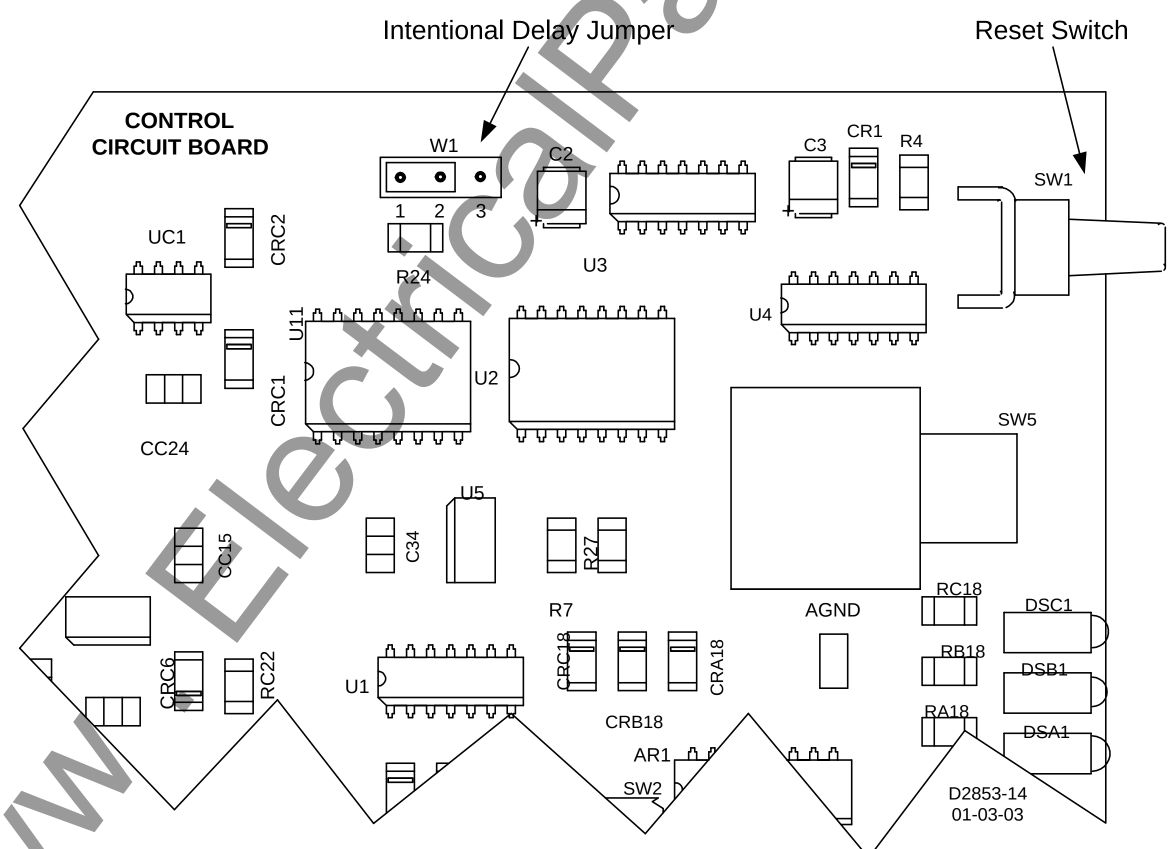

Figure 3-3. Intentional Delay Jumper Location

Intentional Delay Jumper

A user-settable jumper is located on the Control circuit board and is used to select either no intentional delay (jumper position 1 to 2), or a 20-millisecond delay∗ (jumper position 2 to 3) added to the trip response time. For applications having a tap within the zone of protection that is protected by a high-speed fuse, the 20 millisecond intentional delay∗ is intended to prevent tripping the bus for a fault on the fused tap. The current detector circuit reset time is approximately 1 millisecond so that the ac and dc components of the differential current, as reproduced at the CT secondary, must drop below pickup in less than 19 milliseconds. A secondary error may occur due to the fast dropout of the primary current when the fuse operates.

∗ Actual intentional time delay is a function of pickup current. For currents exceeding twice the pickup setting, intentional time delay is 20 milliseconds. For currents less than twice the pickup setting, intentional time delay is 25 milliseconds.

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SECTION 4 • INSTALLATION

TABLE OF CONTENTS

Figures

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SECTION 4 • INSTALLATION

GENERAL

When not shipped as part of a control or switchgear panel, the relays are shipped in sturdy cartons to prevent damage during transit. Upon receipt of a relay, check the model and style number against the requisition and packing list to see that they agree. Inspect the relay for damage that may have occurred during shipment. If there is evidence of damage, file a claim with the carrier and notify the regional sales office, or contact the 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. When the BE1-87B is to be placed in service, it is recommended that the procedures outlined in Section 5, *Testing* be performed prior to installation.

Relay Operating Precautions

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

1. The relay is a solid-state device. If a wiring insulation test is required, remove the connection plugs and withdraw the cradle from its case.
2. 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, test, or service.

Be sure that the relay case is hard wired to earth ground using the ground terminal on the rear of the unit. It is recommended to use a separate ground lead to the ground bus for each relay.

MOUNTING

Relay

Because the relay is of solid-state design, it does not have to be mounted vertically. Any convenient mounting angle may be chosen. Relay outline dimensions and panel drilling diagrams are shown in Figures 4-1 through 4-14. Dimensions are shown in inches with millimeters in parenthesis.

> **NOTE**
> All relay dimensional drawings show cases with optional CT Test pushbutton access.

CT Diagnostic Test Source Assembly

Mounting and drilling dimensions for the optional CT Diagnostic Test Source (Basler part number 9282300014) are shown in Figure 4-15. Dimensions are shown in inches with millimeters in parenthesis.

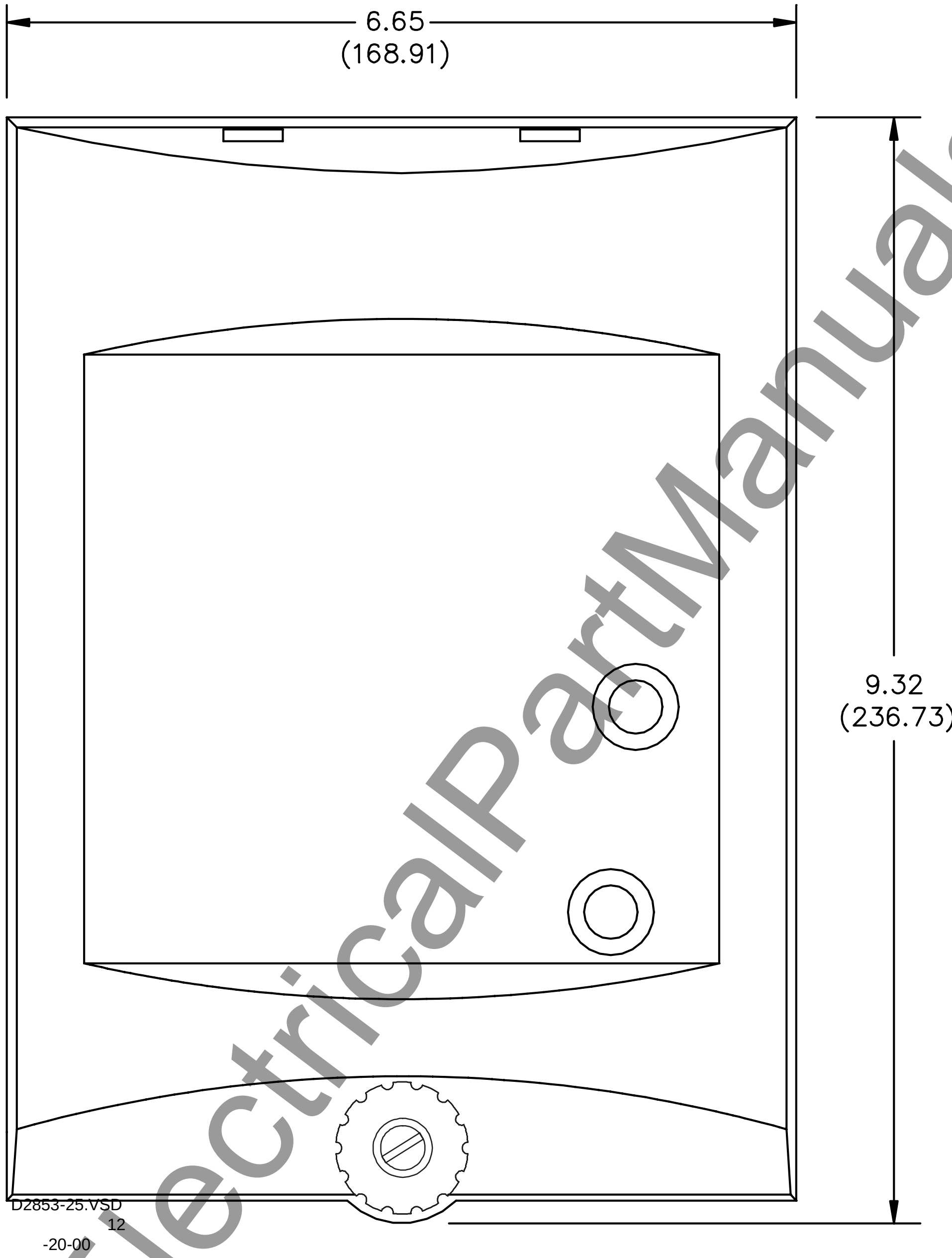

Figure 4-1. S1 Case, Outline Dimensions, Front View

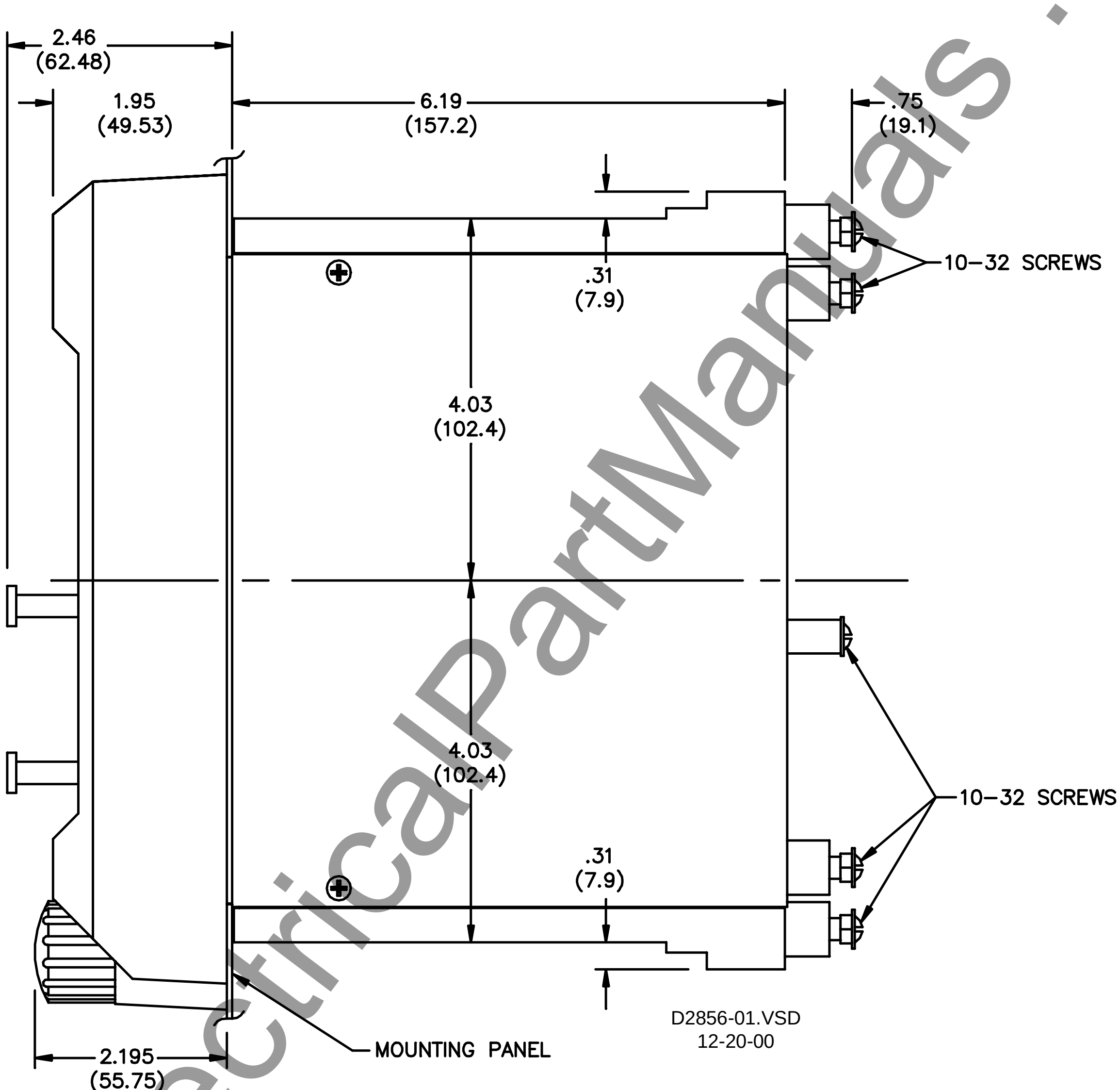

Figure 4-2. S1 Case, Double-Ended, Semi-Flush Mounting, Side View

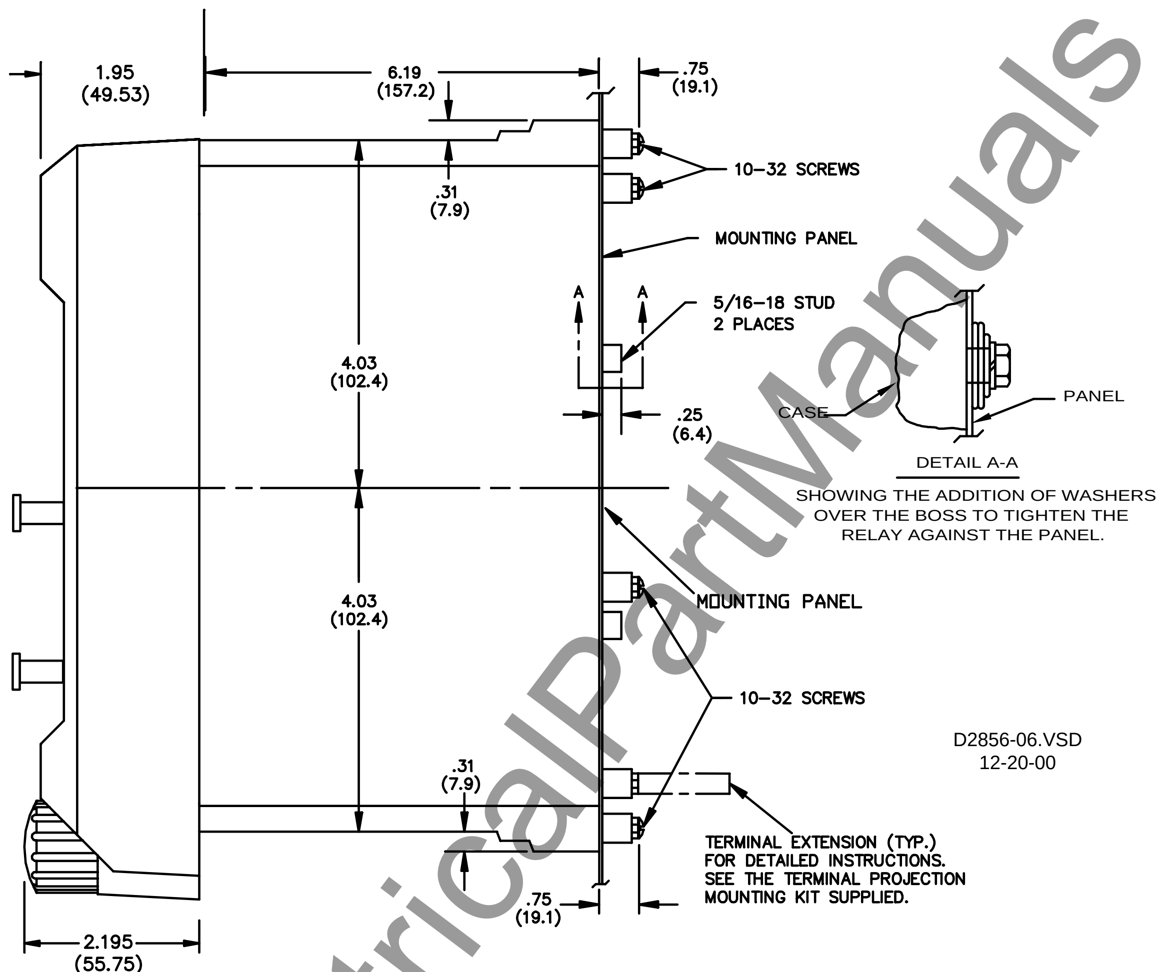

Figure 4-3. S1 Case, Double-Ended, Projection Mounting, Side View

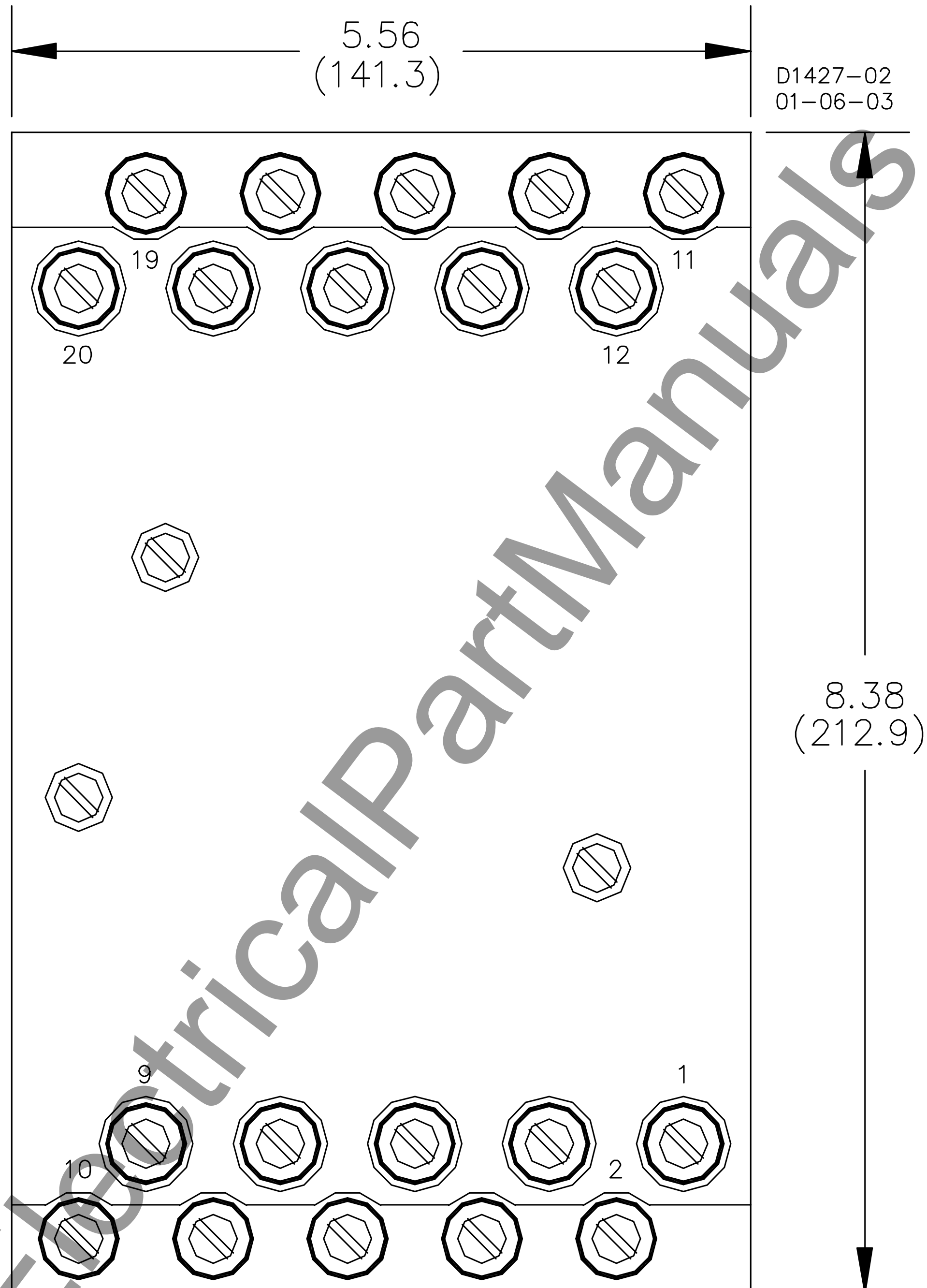

Figure 4-4. S1 Case, Double-Ended, Outline Dimensions, Rear View

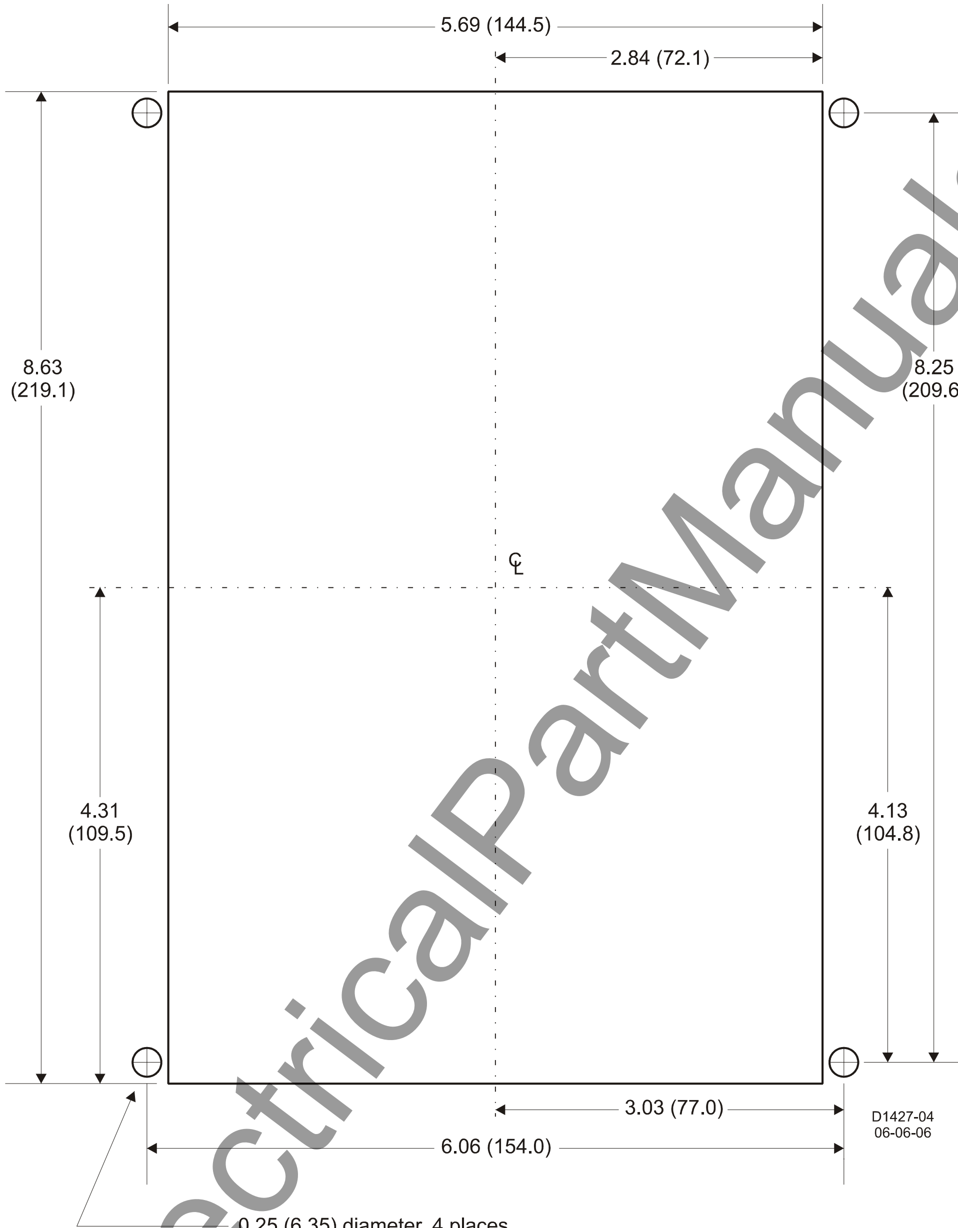

Figure 4-5. S1 Case, Panel Drilling Diagram, Semi-Flush Mounting

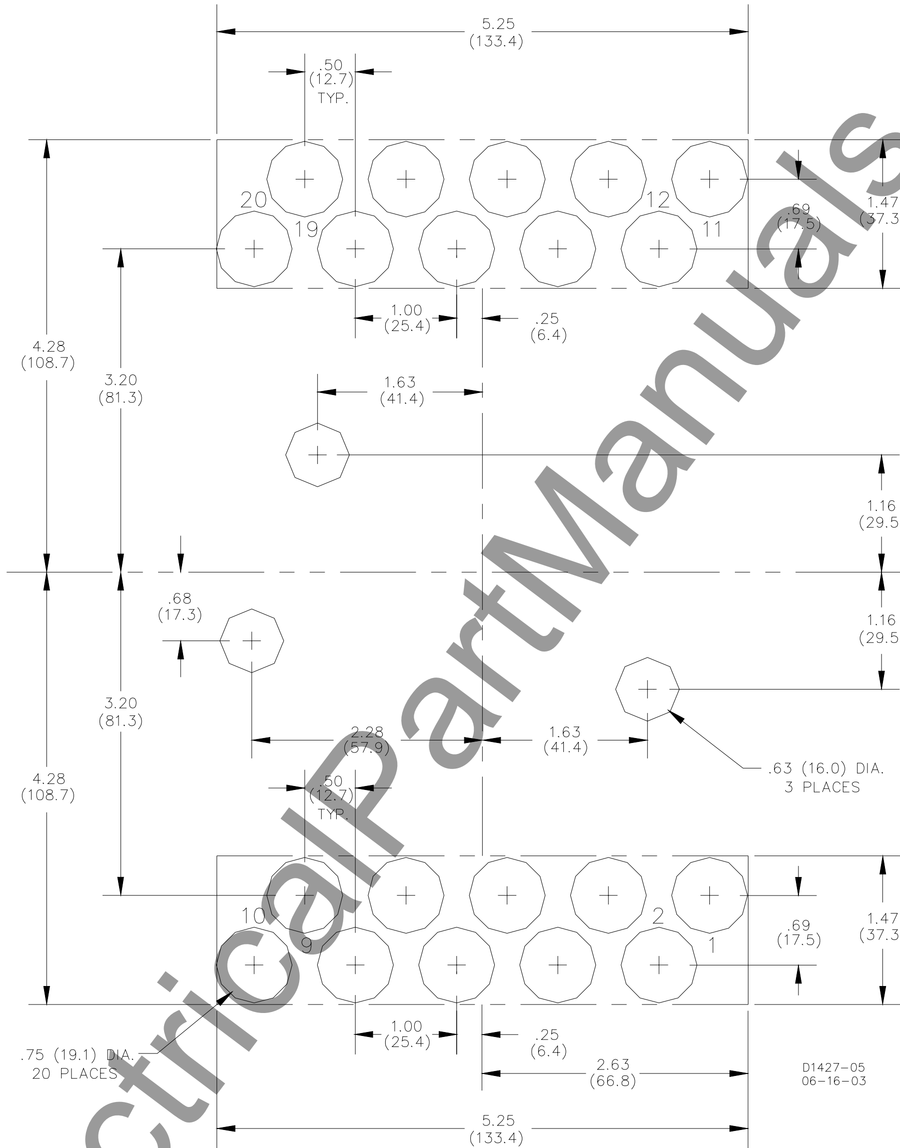

Figure 4-6. S1 Case, Panel Drilling Diagram, Projection Mounting

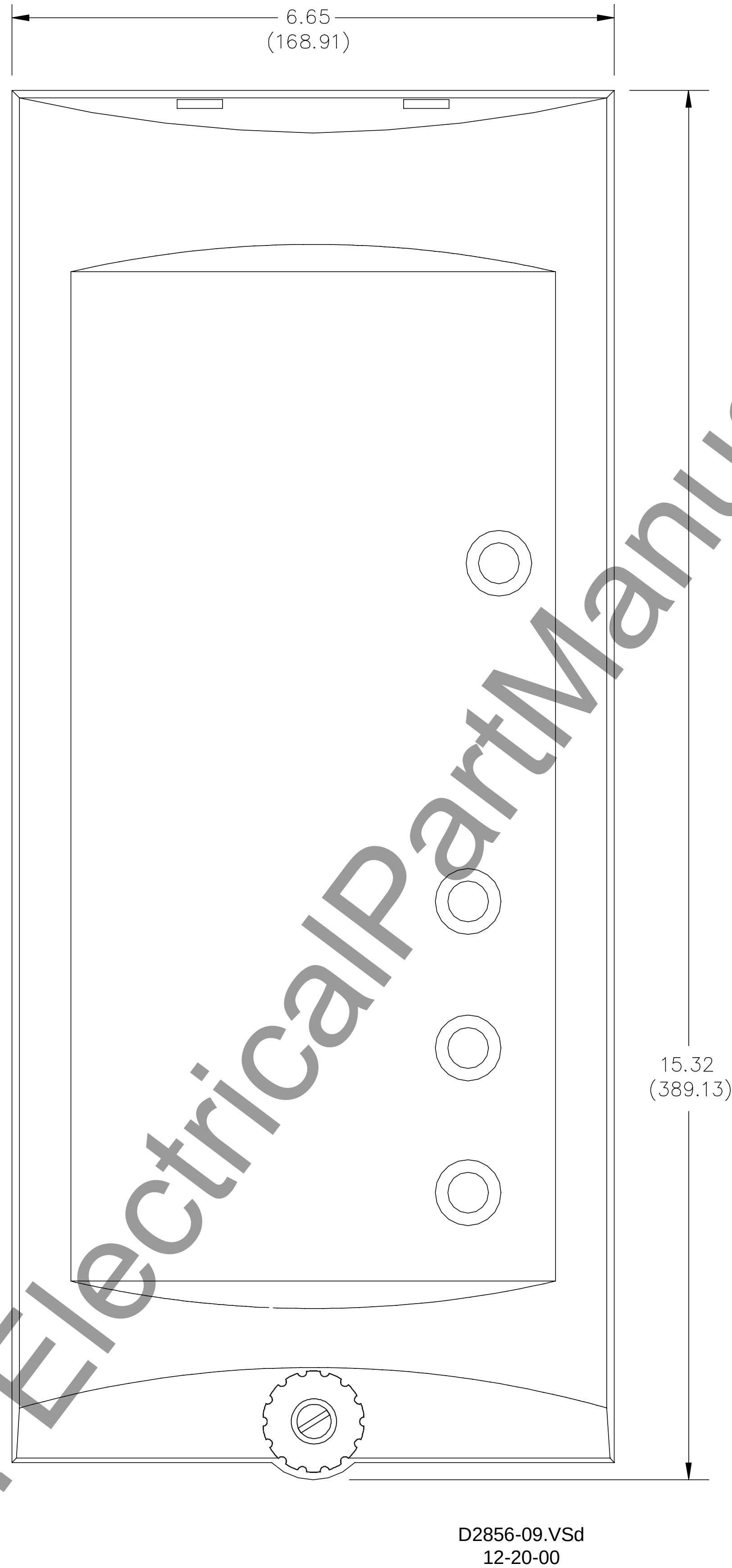

Figure 4-7. M1 Case, Outline Dimensions, Front View

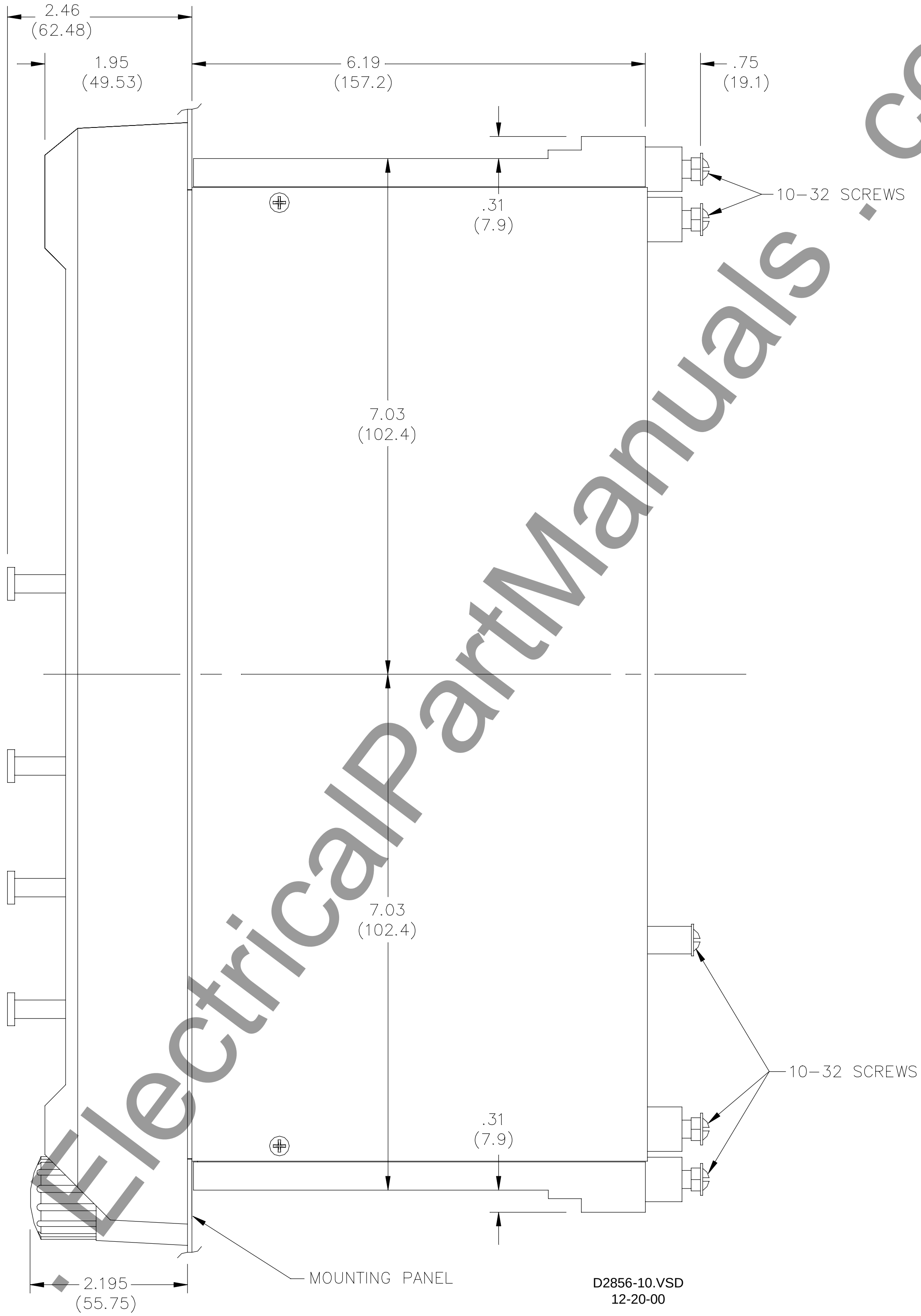

Figure 4-8. M1 Case, Semi-Flush Mounting, Outline Dimensions, Side View

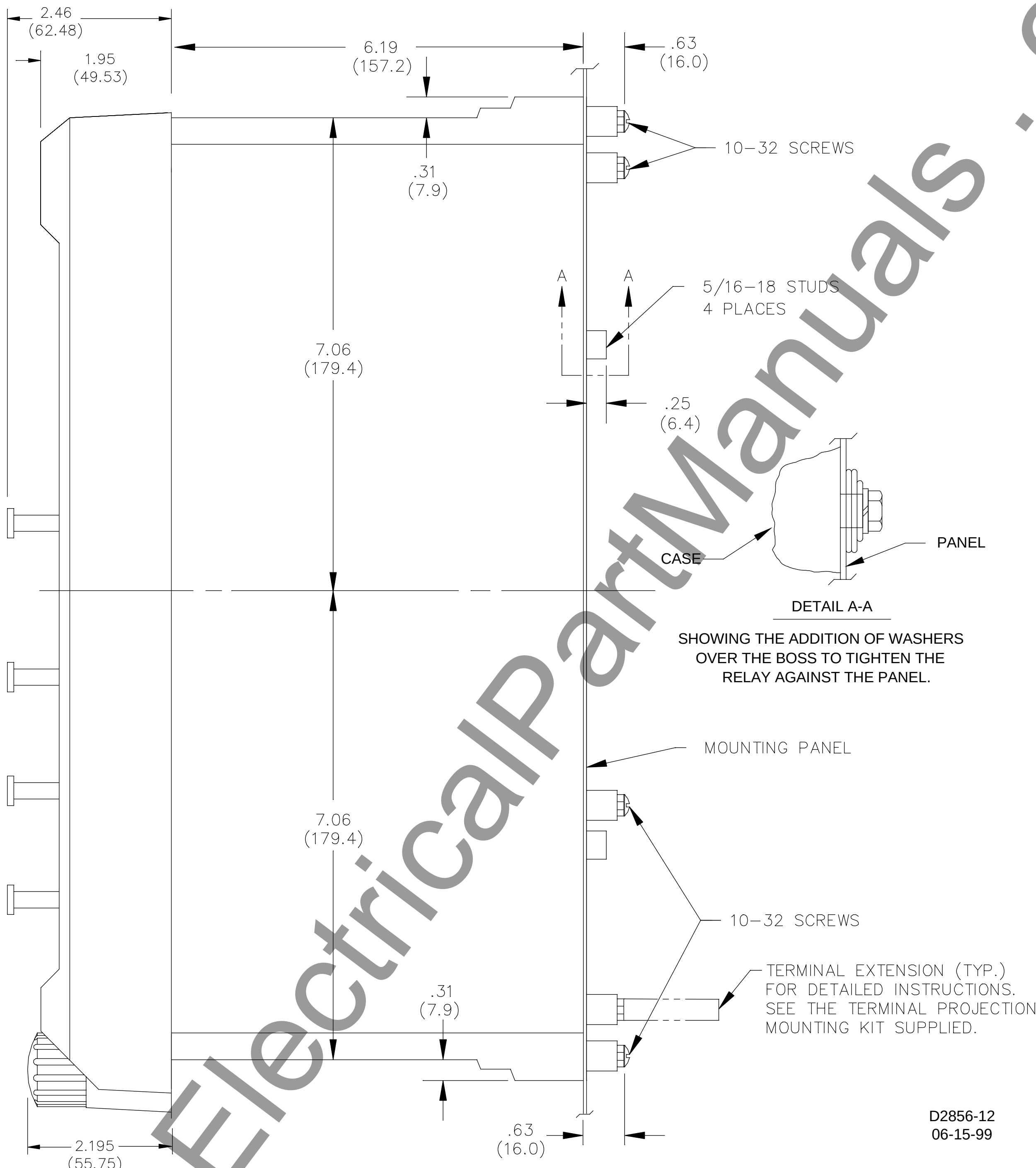

Figure 4-9. M1 Case, Double-Ended, Projection Mounting, Side View

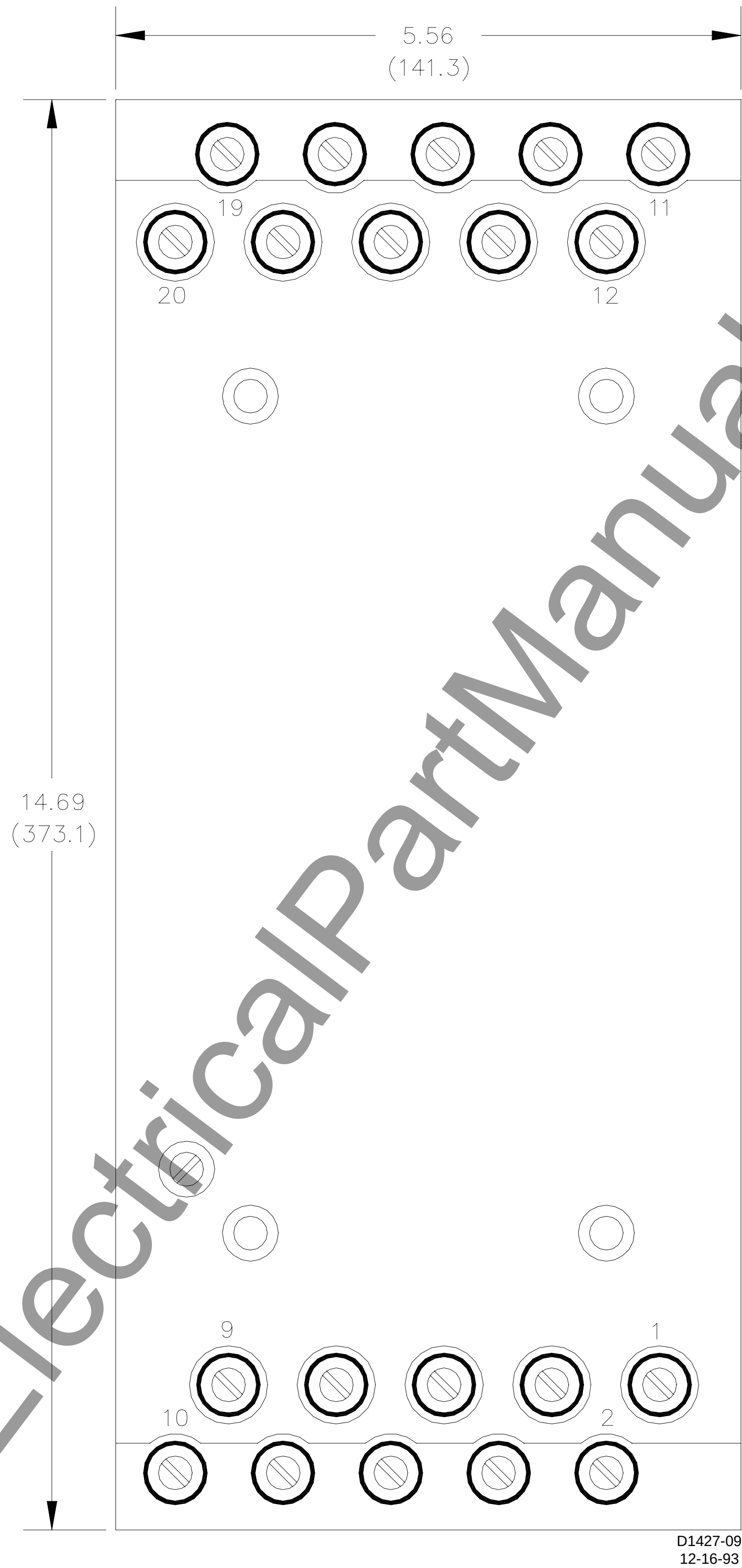

Figure 4-10. M1 Case, Double-Ended, Projection Mounting, Outline Dimensions, Rear View

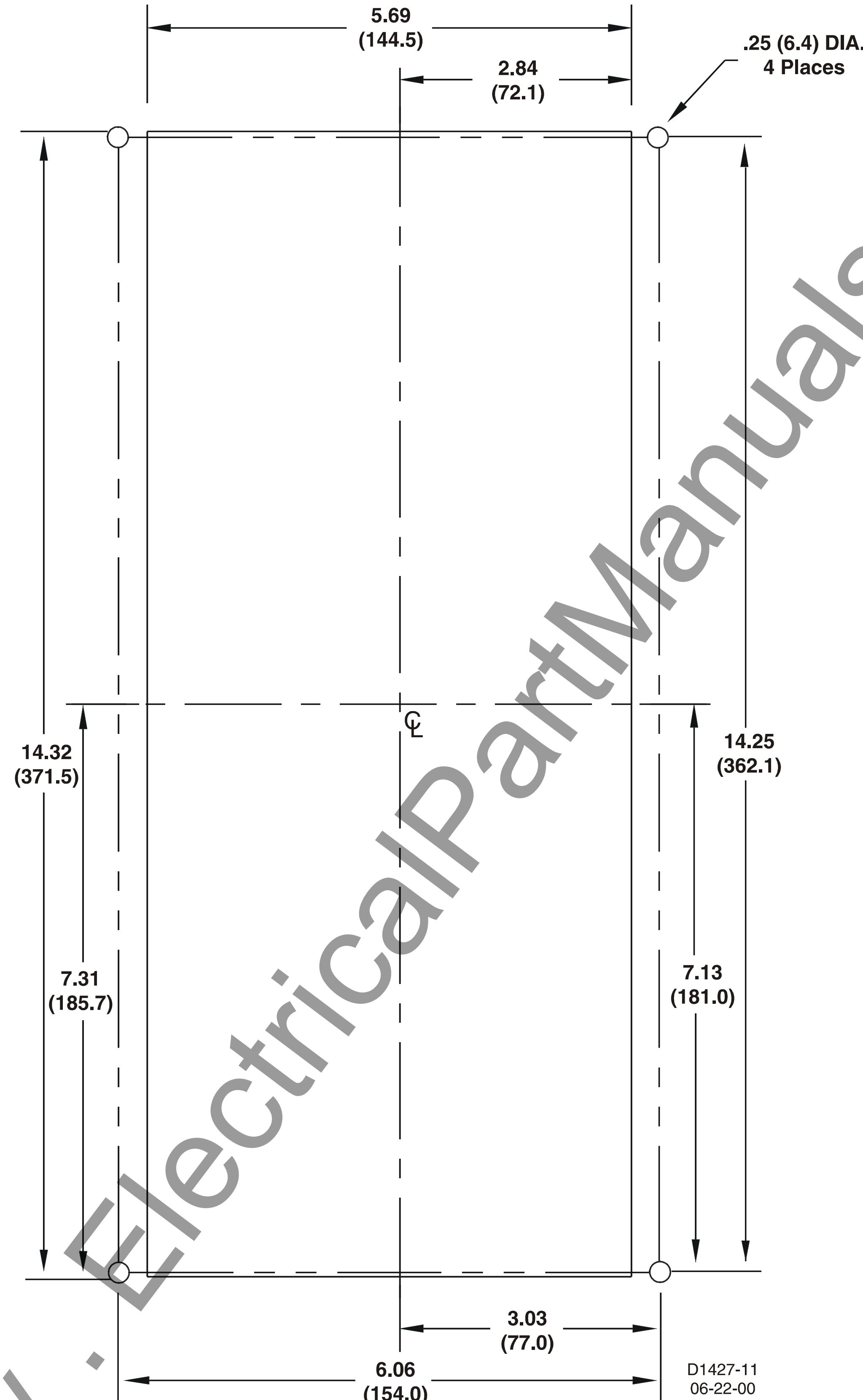

Figure 4-11. M1 Case, Panel Drilling Diagram, Semi-Flush Mounting

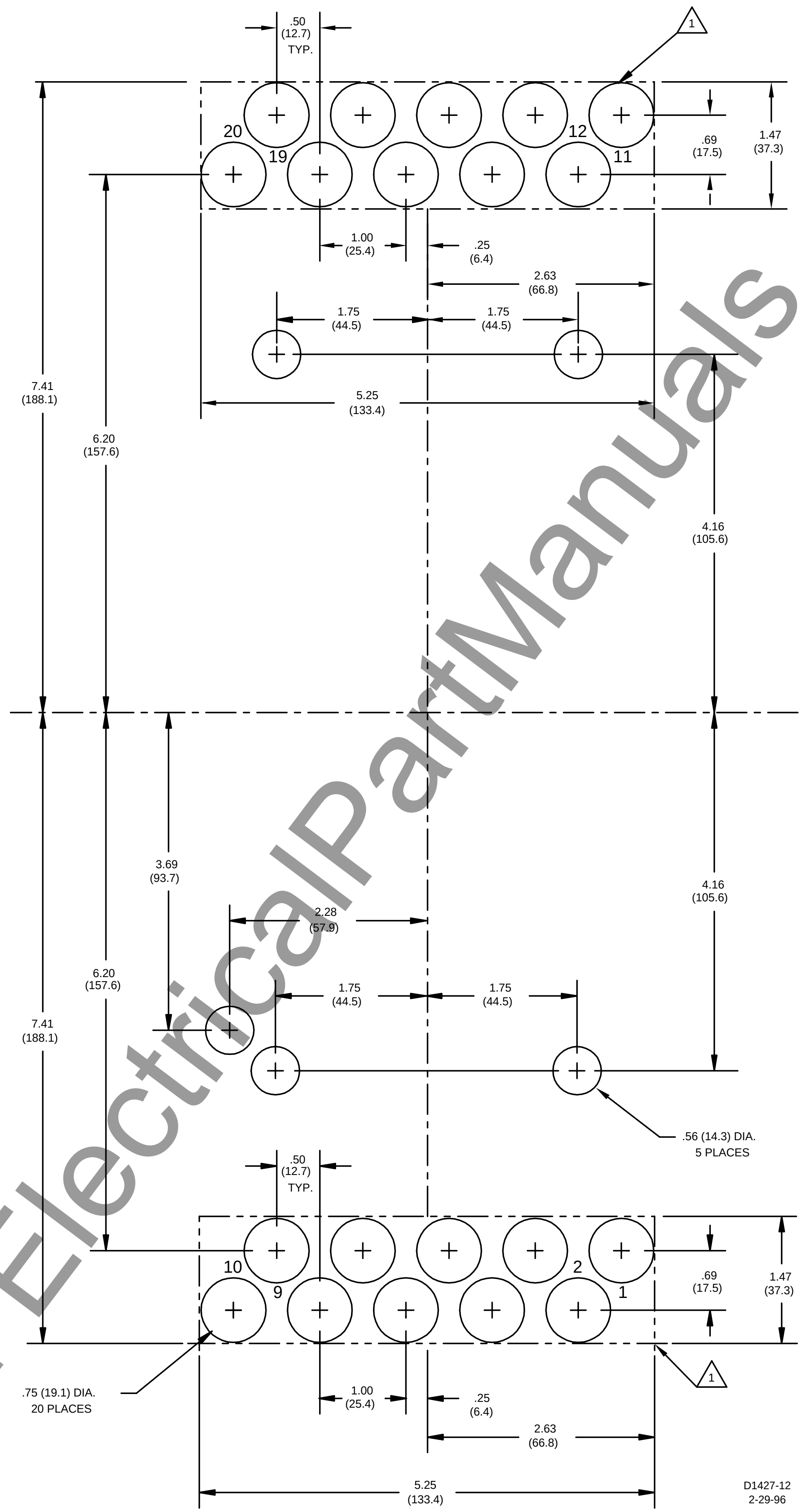

Figure 4-12. M1 Case, Panel Drilling Diagram, Projection Mounting

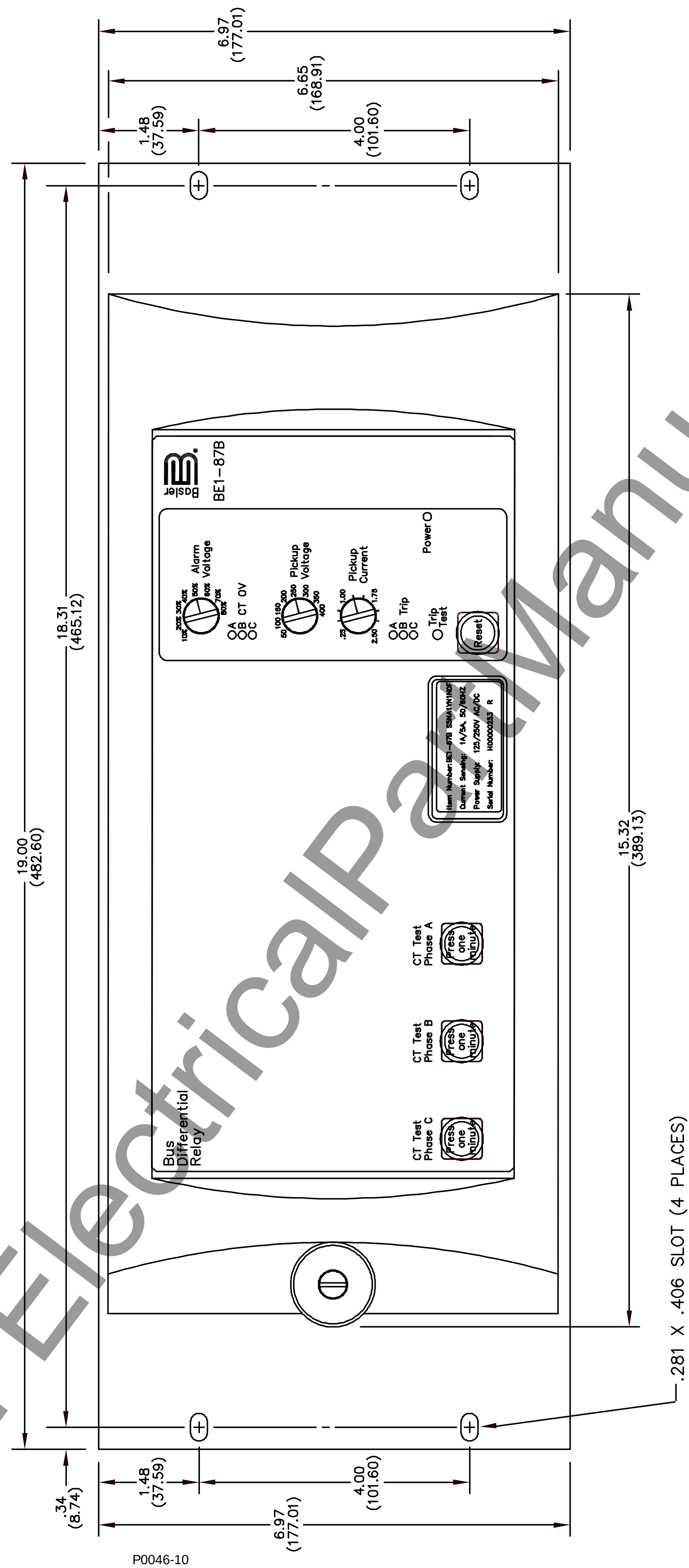

Figure 4-13. 19" Horizontal Rack-Mount, Front View (Shown Vertically)

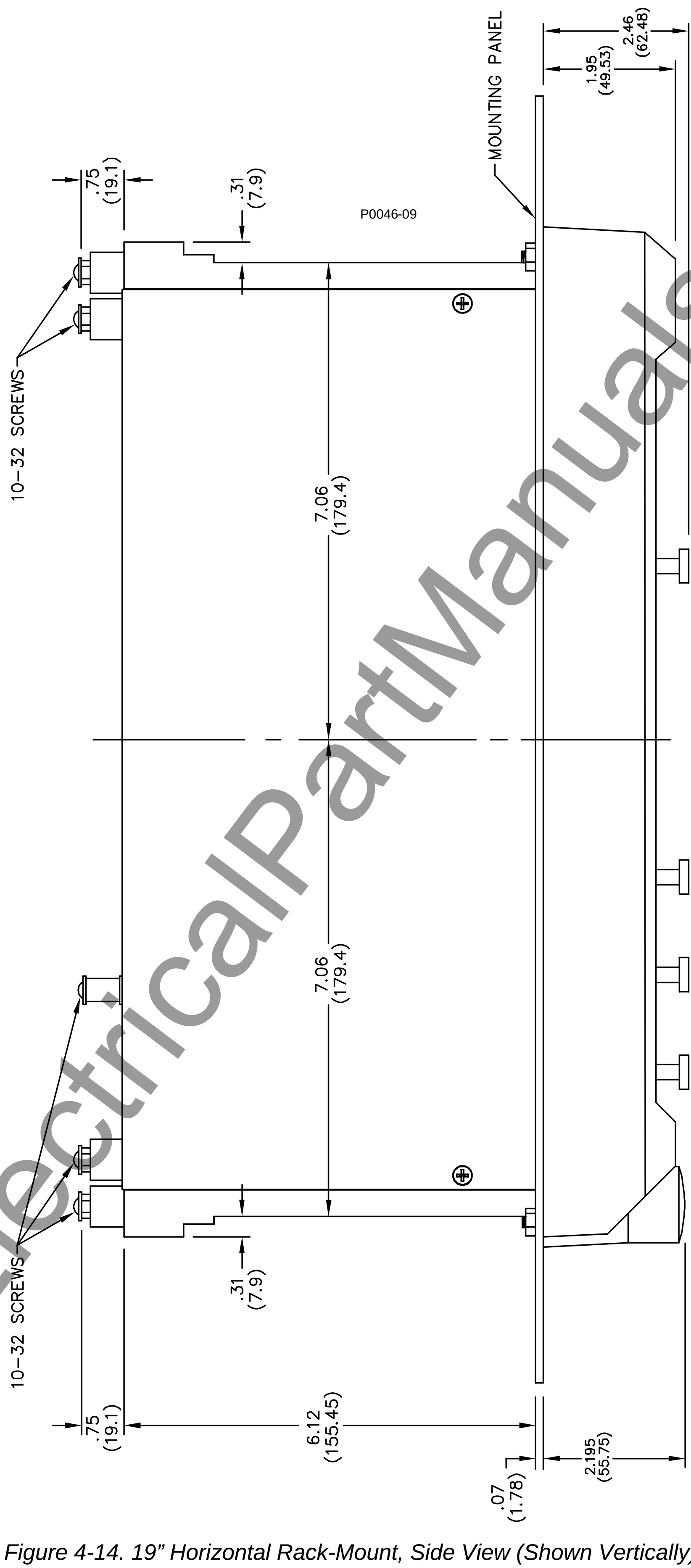

Figure 4-14. 19" Horizontal Rack-Mount, Side View (Shown Vertically)

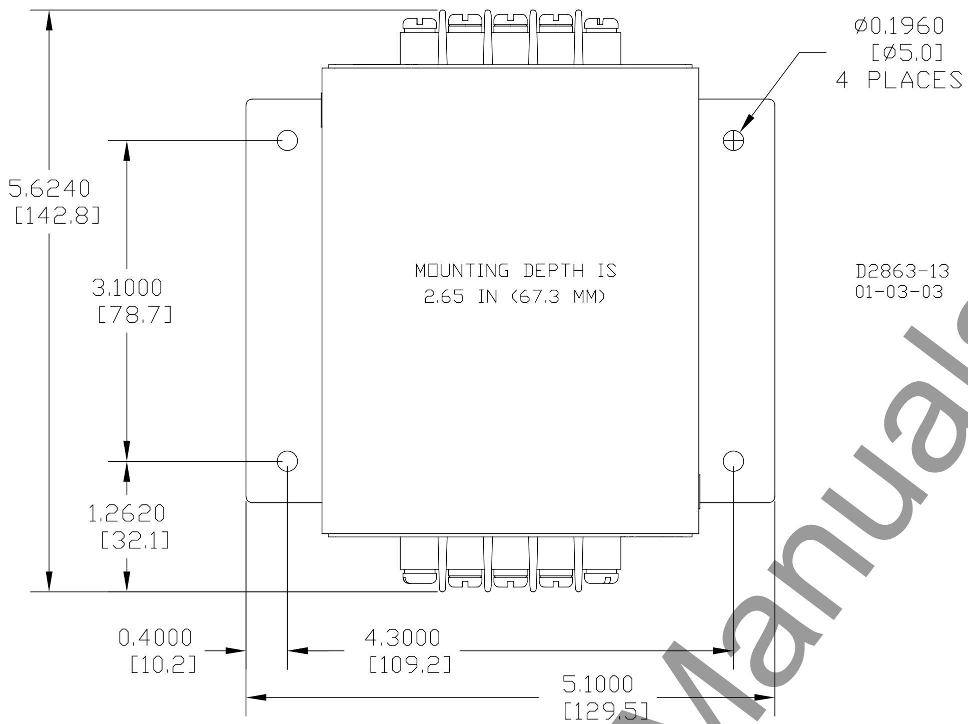

Figure 4-15. Mounting and Drilling Dimensions for CT Diagnostic Test Source Assembly

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.

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 minimum wire size of 14 AWG. Internal connections are shown in Figures 4-16 and 4-17. Be sure to use the correct input power for the power supply specified.

CT Diagnostic Test Source Assembly

Operating parameters for the CT test circuit are defined by the application. The Pickup Voltage setting for the specific bus protection application is required before operating parameters for the CT test circuit can be determined. Refer to Section 2, *Application, CT Test Circuit Calculations* for information about determining which CT test voltage tap to use when making CT Diagnostic Test Source connections.

Connections should be made with minimum wire size of 14 AWG. Internal connections are shown in Figure 4-18.

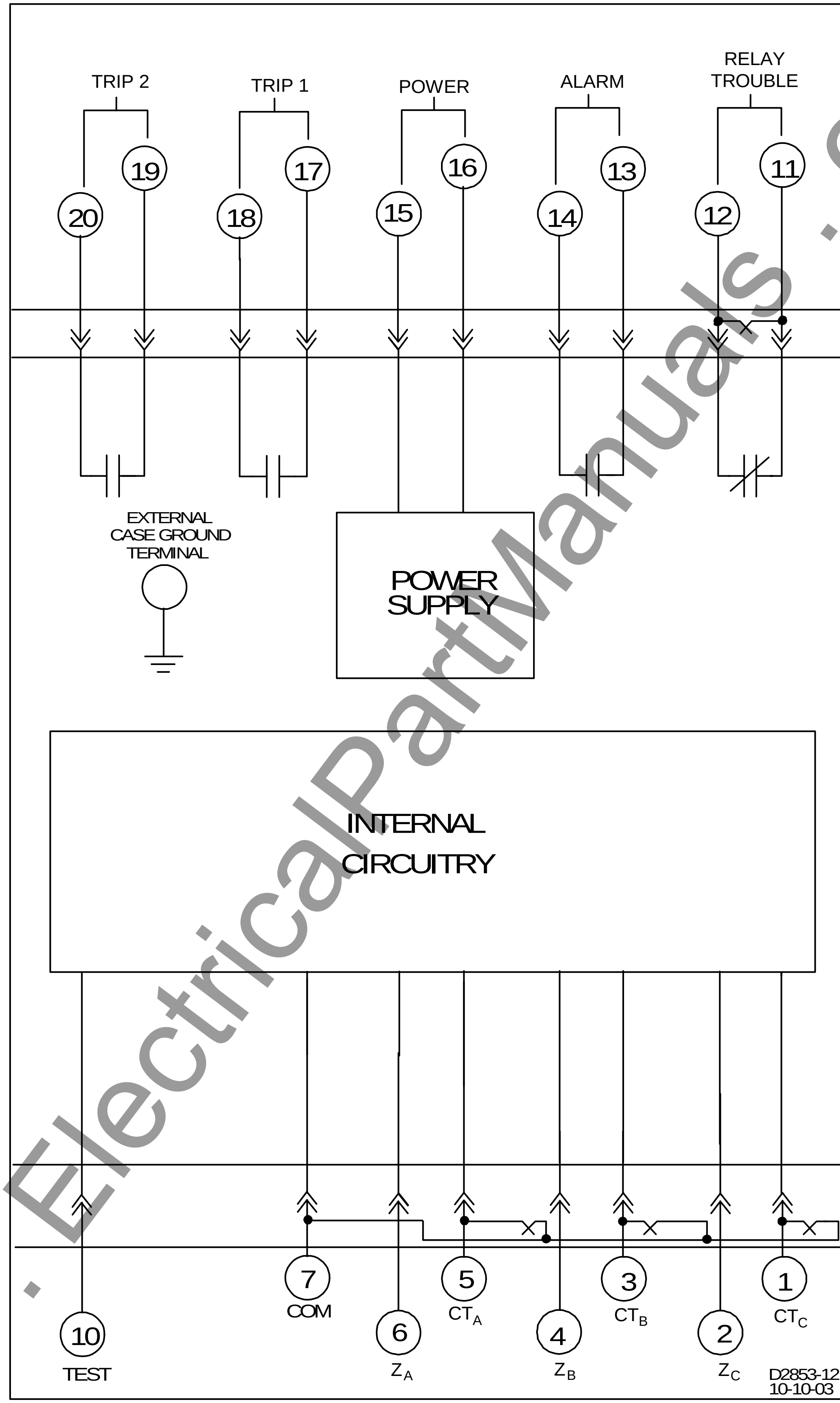

Figure 4-16. BE1-87B, Three-Phase Internal Connection Diagram

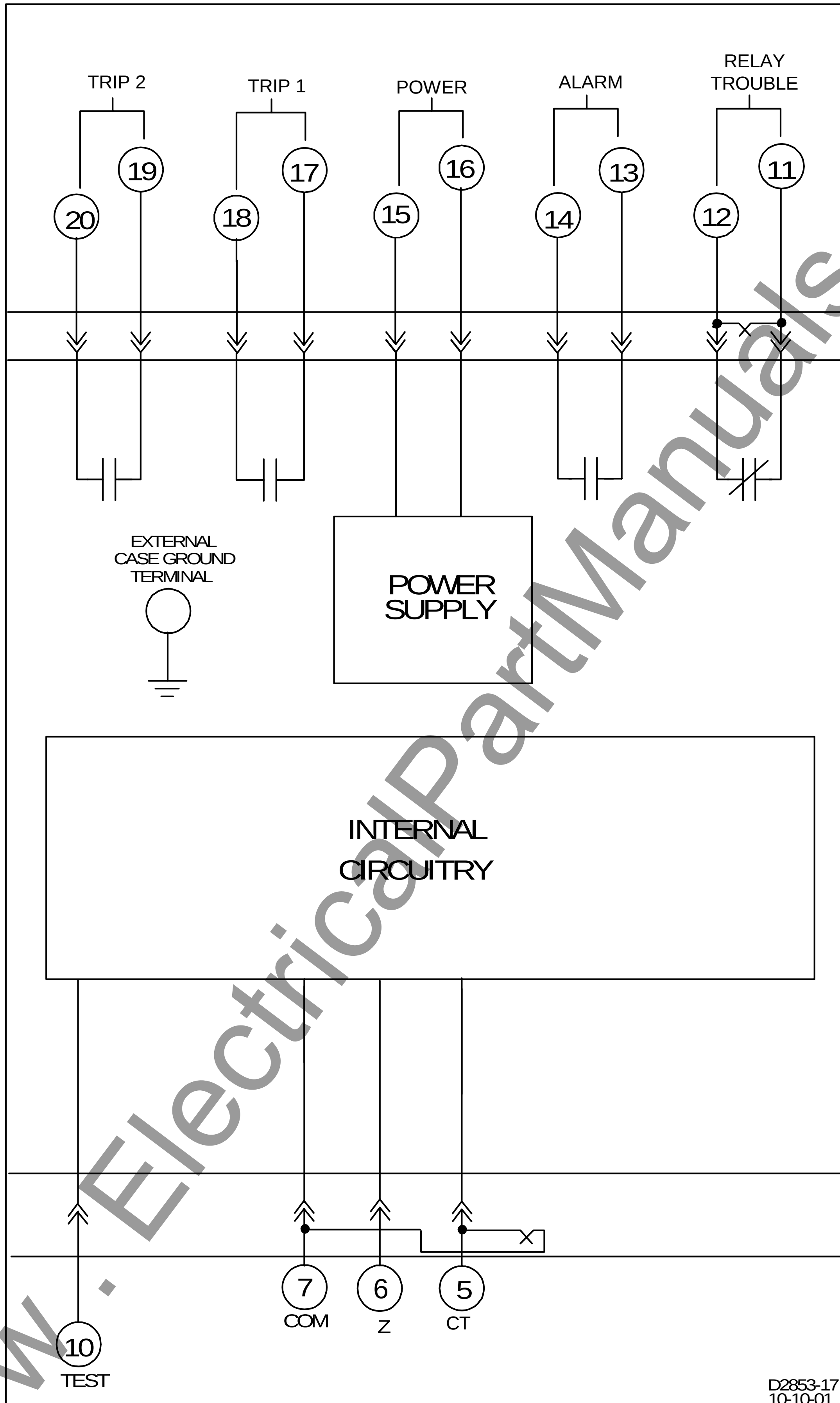

Figure 4-17. BE1-87B, Single-Phase Internal Connection Diagram

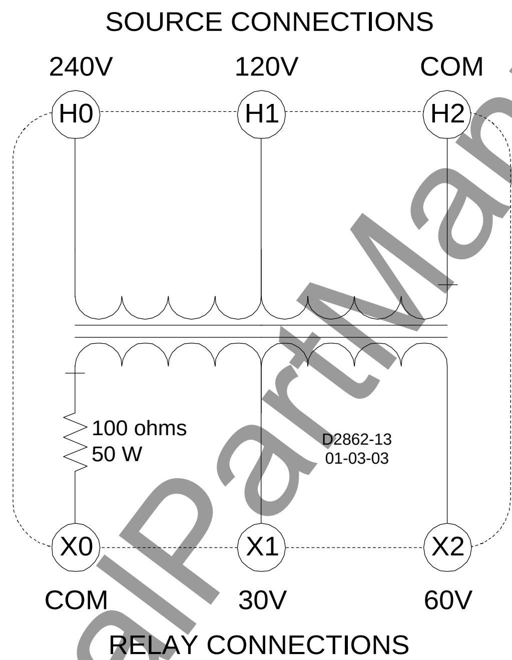

Figure 4-18. CT Diagnostic Test Source Assembly Internal Connection Diagram

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SECTION 5 • TESTING

TABLE OF CONTENTS

Figures

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SECTION 5 • TESTING

CT CIRCUIT TESTING

The CT Diagnostic Test Source, available with the BE1-87B, provides a simple way to test and verify that the CT input circuit is not shorted. The Test Source assembly (Basler P/N 9282300014) consists of a 120/240 volts to 30/60 volts, 50 VA transformer with a 100 ohm, 50 watt resistor is series with the common lead of the secondary (Figure 4-16). All components are contained in a metal enclosure and have screw-terminal connections. The CT Test pushbutton on the relay front panel is used to apply the test voltage. This pushbutton is standard on all BE1-87B relays. The output of the CT Diagnostic Test Source should be connected between relay terminals 7 (COM) and 10 (TEST).

The voltage supplied by the CT Diagnostic Test Source is derived from an isolation transformer to avoid applying multiple grounds to the CT circuit. The input to the Test Source is dual rated to meet the user's nominal secondary station service voltage rating. The output of the Test Source can be connected for 30 volts or 60 volts, depending on the requirement of the application.

Operating Principle – CT Circuit Testing

The CT Diagnostic Test Source provides convenient verification of CT circuit integrity. By applying an external test voltage (30 Vac or 60 Vac) through a 100 ohm, 50 watt resistor to an energized CT circuit, the Test Source causes a low-level current to flow through the effective parallel impedance of the CTs and the relay input impedance. Test voltage is applied by pressing the CT Test button (front panel) for one minute or until the front panel CT OV LED lights. Phases should be tested individually; faulty results may occur if more than one phase is tested simultaneously. In a healthy CT circuit, the resulting voltage drop will light the CT OV LED and close the Alarm output contacts (terminals 13 and 14). If a CT or current circuit cable is shorted when the test voltage is applied, all of the voltage will be dropped across the Test Source resistor and the CT OV LED and Alarm output will not operate.

Section 2, *Application, CT Test Circuit Calculations* provides information about determining the appropriate relay settings and Test Source voltage to use for CT circuit testing.

Security Considerations – CT Circuit Testing

The voltage required to gate the BE1-87B SCRs is two times V DIFF or 300 volts as in the CT test example of Section 2, *Application, CT Test Circuit Calculations.* By maintaining the test voltage at approximately 1.5 times V ALARM or 30 volts as in the example, a transient of 10 per unit would have to occur to gate the SCRs.

If a severe voltage transient occurs while the CT Test button is being pressed, it would have to last several milliseconds to overcome filtering delays. The probability of this combination of events occurring is very low. But, if a severe transient should turn on the SCRs during the test, a current fault detector set above the unhealthy current flow provides a second level of security. Therefore, CT testing offers no threat to the security of the differential scheme.

ACCEPTANCE TESTING

The following procedures should be used for acceptance testing the BE1-87B relay. The only difference between testing a single-phase model and three-phase model is the test connections for phases B and C of the three-phase model. Refer to the connection diagram associated with each test. Also refer to Figures 3-1 through 3-3 for the location and description of the relay controls and indicators. Figure 5-1 shows the side view of the M1 or 19" Rack-Mount and S1 relays with the individual circuit boards identified. Figure 5-2 illustrates the use of the circuit board extender card.

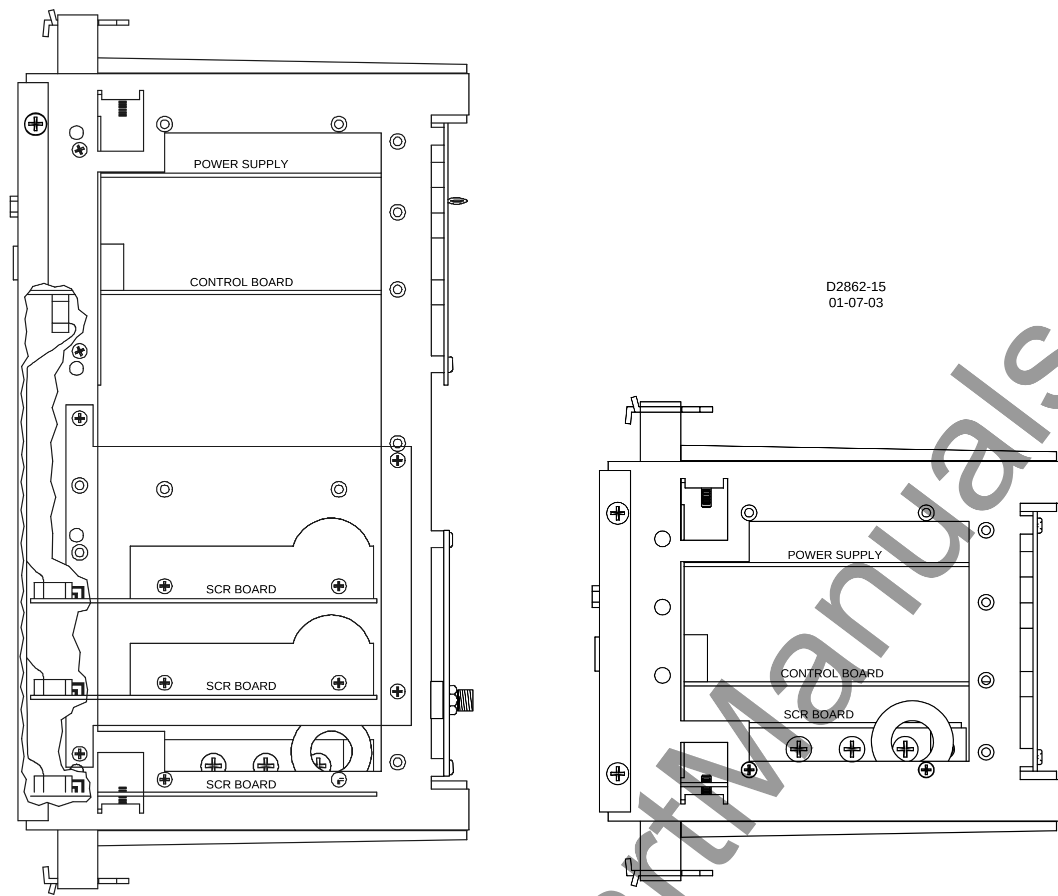

Figure 5-1. Side View of Cradle Assembly (M1 or 19" Rack-Mount and S1 Configuration)

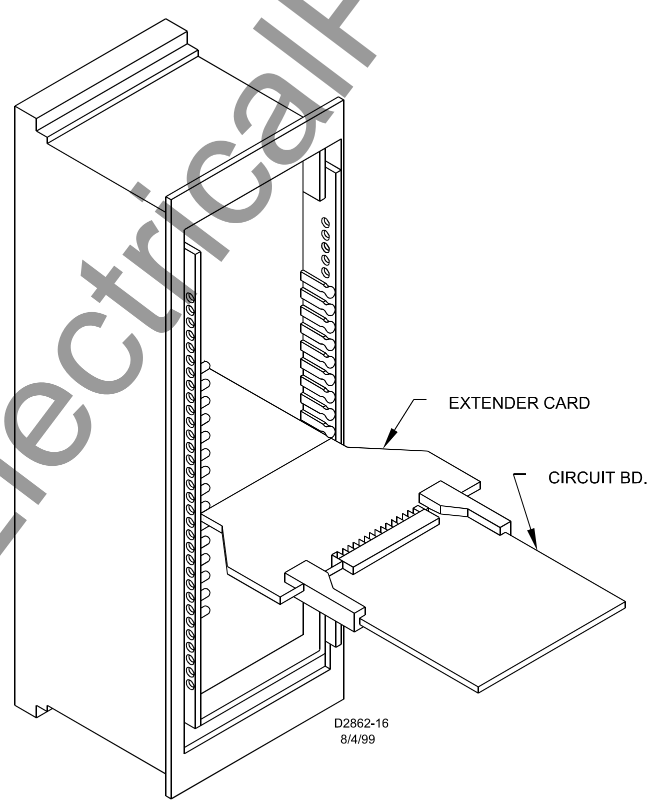

Figure 5-2. Circuit Board Extender Card

Test Equipment

- Variable voltage source, 0 to 200 volts rms, with provision for automatic removal of test voltage upon sensing of contact closure
- Variable current test source, 0 to 3 amperes ac
- Timer
- Digital multimeter
- Circuit board extender card, Basler P/N 9112930101

Power Supply Status

1. Connect a digital multimeter set for continuity checking between relay terminals 11 and 12 (normally closed contact, de-energized power supply) and verify zero ohms resistance (refer to Figure 4-13 or 4-14).
2. With the multimeter still connected between terminals 11 and 12, energize the relay power supply, terminals 15 and 16, with name plate voltage. Verify that the contact between terminals 11 and 12 opens and that the power LED lights.
3. The power supply status is designed to be “fail-safe” in that the contact will “fail closed” if power supply voltage is removed. Remove the power supply voltage and verify that the contact between terminals 11 and 12 closes.

Pickup Voltage Control Test

To eliminate the historical need for progressively higher test voltages (up to 800 volts rms symmetrical) required for testing High Z differential relays, the following test was developed. It will verify the BE1-87B Pickup Voltage Control settings (this procedure is identical for single-phase and three-phase models because the three-phase model uses a common Control Board):

1. Verify that the power supply voltage is disconnected (terminals 15 and 16).
2. Remove the front panel of the relay (four screws on either side of the cradle).
3. Disconnect the ribbon cable that runs between the Control Board and the SCR Board(s), at the Control Board end. Exercise standard precautions for handling printed circuit boards.
4. Remove the Control Board, refer to Figure 5-1, and install the Circuit Board Extender Card, Basler part number 9112930101 (refer to Figure 5-2).
5. Insert the Control Board into the card extender.
6. Connect a digital multimeter set for dc voltage between card extender pins 40 and 43, positive on 40.
7. Verify that the Pickup Voltage Control is set to 50 volts.
8. Apply power supply voltage to terminals 15 and 16.
9. Digital multimeter should read 1 volt dc with the Pickup Voltage Control set for 50 volts.
10. Move the Pickup Voltage Control to the 100-volt position and the digital multimeter should read 2 Vdc.
11. Move the Pickup Voltage Control to the 150, 200, 250, 300, 350, and 400 volt positions while reading the dc voltage. The corresponding dc voltage readings should be 3, 4, 5, 6, 7, and 8 Vdc respectively.
12. Return the Pickup Voltage Control to the 50 volt position (1 Vdc).
13. Remove power supply voltage from terminals 15 and 16.
14. Remove the Control Board from the card extender.
15. Remove the circuit board extender card.
16. Return the Control Board to the original position.
17. Carefully reconnect the ribbon cable. Make sure the board pins are aligned with the ribbon socket.
18. Replace the front panel (4 screws).

Alarm Voltage Test

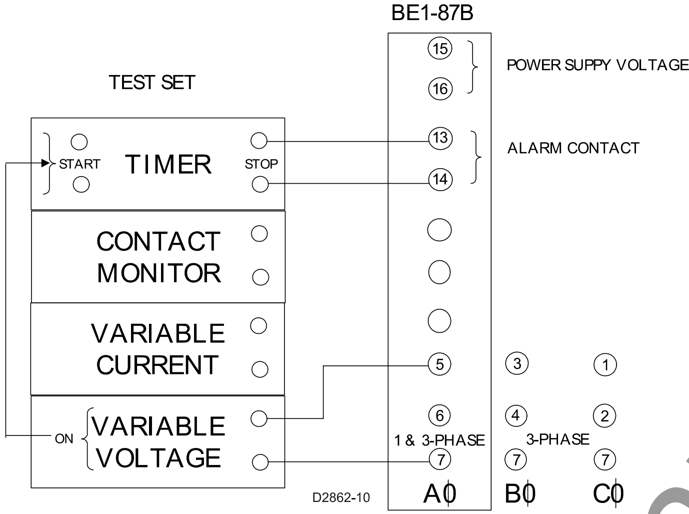

Figure 5-3. Alarm Voltage Test Setup

1. Set the BE1-87B Pickup Voltage Control to 50 volts.
2. Set the Alarm Voltage Control to 10%. The Alarm Voltage pickup setting should be 5 volts rms (0.1 x 50) ±5%. Connect the relay as per the test diagram in Figure 5-3. Energize the relay power supply and verify that the CT OV and Trip LEDs are reset.
3. Preset the Alarm Pickup Voltage to 90% of the pickup setting (4.5 volts rms). Set the timer to start on application of test voltage and stop when the alarm contacts between terminals 13 and 14 close. Apply the voltage to the relay for a minimum of 10 seconds and verify that the normally-open alarm contacts between relay terminals 13 and 14 do not close (timer never stops) and the CT OV LED does not light. Remove the test voltage.
4. Preset the Alarm Pickup Voltage to 110% of the pickup setting (5.5 volts rms). Set the timer to start on application of test voltage and stop when the alarm contact between terminals 13 and 14 closes. The alarm relay has intentional time delay to prevent nuisance alarms during normal operating voltage excursions. Apply the voltage to the relay and verify that the alarm contact between relay terminals 13 and 14 closes in several seconds and the CT OV LED lights. Remove the test voltage and verify that the CT OV LED goes out.
5. With the Pickup Voltage Control set for 50 volts, repeat steps 2, 3, and 4 for the remaining Alarm Voltage Control settings (20%, 30%, 40%, 50%, 60%, 70%, and 80% respectively). Repeat for B and C phase test connections (three-phase model) and verify operation of the appropriate CT OV LED (three-phase model).

Pickup Voltage Test

The pickup voltage test (Figure 5-4) verifies the rms firing point of the SCRs and seals through the primary of T1 effectively shorting out the test source voltage. As a result, the following test should be performed with a voltage source that will automatically turn off when the trip contact between terminals 17 and 18 closes.

> **NOTE**
>
> Select R_{LOAD} that will cause the trip contacts to close (250 mA) or verify that the voltage channel used for this test can supply 250 mA and cause the trip contacts to close.

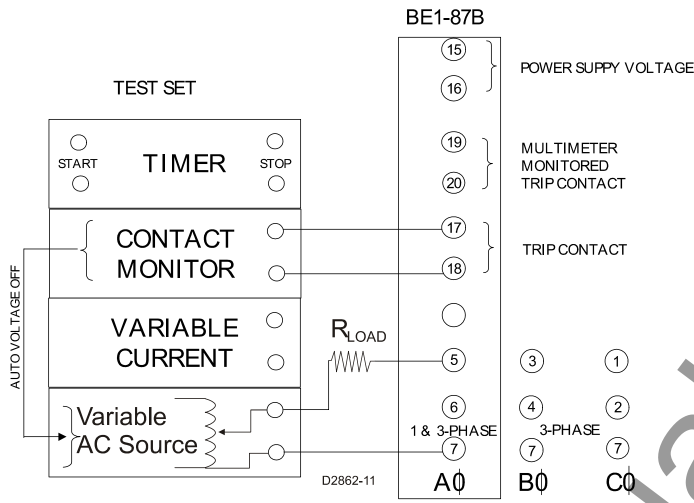

Figure 5-4. Pickup Voltage Test Setup

1. Set the 87B Pickup Voltage Control to 50 volts. Set the Pickup Current Control to 0.25 amperes. The 87B Test Pickup Voltage should be 100 volts rms symmetrical or twice the Pickup Voltage setting (this is the rms test value equivalent to a fully offset waveform). The CT OV LED will light during this test, as the Alarm Pickup Voltage will be exceeded. Connect the relay as per the test diagram in Figure 5-4. Verify that the CT OV and Trip LEDs are reset.
2. Configure the test voltage source to automatically turn off when the trip contact closes. Preset the Test Pickup Voltage to 95 volts rms. Apply the test voltage and note that the relay does not trip. Slowly increase the test voltage until the trip output contacts close and the Trip LED lights (100 volts ±5%). Note that the Trip LED remains lighted after the test voltage has been removed. Press the Reset pushbutton to turn off the Trip LED.
3. Set the Pickup Voltage Control to 100 volts and the Pickup Current Control to the 0.25 amperes. As described above, the Test Pickup Voltage will be twice the selector switch voltage or 200 volts rms symmetrical. The CT OV LED will light during this test, as the Alarm Pickup Voltage will be exceeded. Connect the relay as per the test diagram in Figure 5-4. Verify that the CT OV and Trip LEDs are reset.
4. Configure the test voltage source to automatically turn off when the trip contact closes. Preset the Test Pickup Voltage to 190 volts rms. Apply the test voltage and note that the relay does not trip. Slowly increase the test voltage until the trip output contacts close and the Trip LED lights (200 volts ±4%). Note that the Trip LED remains lighted after the test voltage has been removed. Press the Reset pushbutton to turn OFF the Trip LED. Return the Pickup Voltage selector switch to the 50-volt setting.
5. Repeat the 100 and 200 volt tests for B and C phases test connections (three-phase model) and verify operation of the appropriate Trip LED (three-phase model).
6. The full Pickup Voltage range of the relay was tested previously under *Pickup Voltage Control Test.* The 100 and 200 volt test points used under *Pickup Voltage Test* verify that the voltage sensing circuit and the pickup voltage setting (scaling) circuit are working together and will fire and seal the SCRs through T1. There is no need to apply higher rms test voltages to the relay.

This completes the voltage tests for the BE1-87B. Set the Alarm Voltage and Pickup Voltage Controls to the values calculated for the user's specific application.

Pickup Current Test

1. Connect the test circuit as shown in Figure 5-5.
2. Set the Pickup Current Control to the 0.25 amp position. Apply the current test source. Slowly increase current until the output contacts close and the Trip LED lights.
3. Remove the current test source and verify that the Trip LED remains lighted. Pickup should be 0.25 amps ±5%. Press the Reset button to turn off the Trip LED.

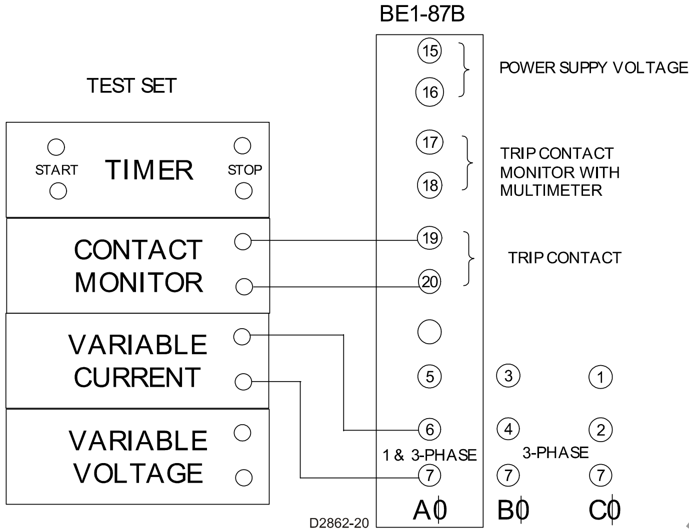

Figure 5-5. Pickup Current Test Setup

Repeat the test for each Pickup Current Control position. Return the Pickup Current Control to the 0.25 ampere position and repeat the test for phase B and phase C test connections (three-phase model). Verify operation of the appropriate Trip LED (three-phase model).

Trip LED, Loss of Power Test

1. Connect the test circuit as shown in Figure 5-4.
2. Set the Pickup Current Control to the 0.25 ampere position. Apply the current test source and increase current until the output contacts close and the Trip LED lights.
3. Remove the current test source and verify that the Trip LED remains lighted.
4. Remove the power supply voltage on terminals 15 and 16, wait several minutes, and reapply the power supply voltage. Verify that the Trip LED is still lit.

Trip Time Test

1. Connect the test circuit as shown in Figure 5-6. The test set timer should be set to start on the application of current and stop on trip contact (17 – 18) closure.

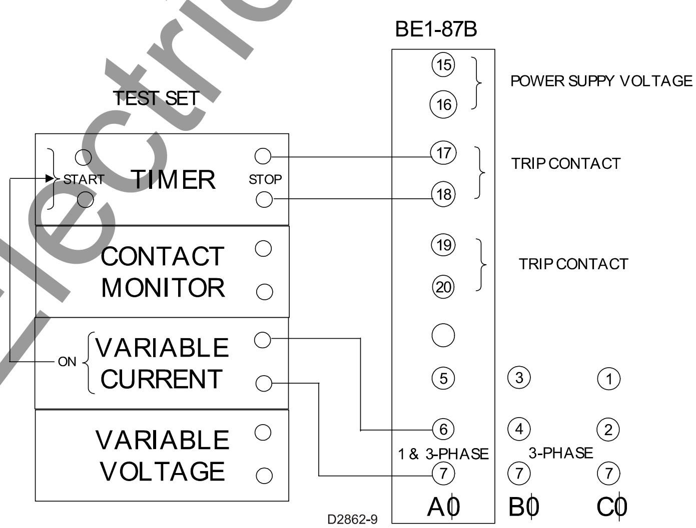

Figure 5-6. Trip Time Test Setup

2. With the Pickup Current Control set for 0.25 amperes, apply 0.75 amperes or 3.0 times the selector switch setting. The trip contacts should close in approximately 4.5 ms (see timing curve Figure 1-2) and the Trip LED should light.
3. Repeat the test several times to verify consistent trip times. Verify the closing time of the second trip contact by moving the timer stop leads shown in Figure 5-4 from terminals 17 – 18 to 19 – 20 and repeat the Trip Time Test.

Trip Time Delay Test

This test is required only when trip time delay will be used.

1. Change the jumper on the Control Board from position 1-2 to 2-3 (see Figure 3-3). Connect the test circuit as shown in Figure 5-6. The test set timer should be set to start on the application of current and stop on trip contact closure.
2. With the Pickup Current Control set for 0.25 amperes, apply 0.75 amperes or 3.0 times the Pickup Current Control setting. The trip contacts should close in approximately 24.4 ms (see timing curve Figure 1-3). Repeat the test several times to verify consistent trip times.

When the timing tests are complete, set the Current Pickup Control to the values calculated for the user's specific application. Verify that the Alarm Voltage and Pickup Voltage Controls have been set to their calculated positions.

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