INSTRUCTIONS

Transformer Differential Relay

CIRCUIT ⊕ SHIELD ®

TYPE 87T	Catalog Series 219	Standard Case
TYPE 87T	Catalog Series 419	Drawout Test Case

TWO WINDING RELAY

TABLE OF CONTENTS

INTRODUCTION

These instructions contain the information required to properly install, operate, and test the ABB Circuit-Shield™ Type 87T single-phase Transformer Differential Relay.

These relays are housed in a case suitable for conventional semi-flush panel mounting.   All connections to the relay are made at terminals located on the rear of the case and clearly numbered.

Relays with catalog numbers starting with 419 are similar in function to relays of the earlier 219 series, but offer totally drawout construction with integral test facilities.   Current transformer shorting is accomplished by a direct-acting spring and blade assembly upon removal of the relay from its case.   Units of the 219 series are of partial drawout construction, with the input transformers remaining in the case upon withdrawal of the lower electronic circuit board.

PRECAUTIONS

The following precautions should be taken when applying these relays:

1. Incorrect wiring may result in damage.   Be sure wiring agrees with the connection diagram before energizing.   Be sure that the dc control voltage is applied in the correct polarity.

2. Apply only the rated dc control voltage marked on the front panel.

3. Do not attempt to change a current tap setting while the relay is in service. This will likely cause the relay to trip due to the mismatch created. (Pulling the tap pin does not open the ct circuit.)

4. High voltage tests are not recommended.   If a control wiring insulation test is required, withdraw the unit from its case before applying the test voltage.

5. Follow test instructions to verify that the relay is in proper working order.

CAUTION: *since troubleshooting entails working with energized equipment, care should be taken to avoid personal shock. Only competant technicians familiar with good safety practices should service these devices.*

PLACING THE RELAY INTO SERVICE

1. RECEIVING, HANDLING, STORAGE

Upon receipt of the relay (when not included as part of a switchboard) examine for shipping damage. If damage or loss is evident, file a claim at once and promptly notify Asea Brown Boveri. Use normal care in handling to avoid mechanical damage. Keep the relay clean and dry.

2. INSTALLATION

Mounting: the outline dimensions and panel drilling are given in Figure 1.

Connections:

Internal connections in Figure 2. Typical connection diagrams for two and three winding transformers are shown in Figures 3 and 4.

Special care should be taken to connect the dc control power in the proper polarity.

These relays have a metal front panel which is connected through printed circuit board runs to a rear terminal marked "G". In all applications this terminal should be wired to ground.

The 87T relay includes an external resistor which is supplied mounted to the case and wired between terminals 9 and 10. This resistor must be connected for proper operation.

Note: Connections are critical in this application. Most problems experienced during commissioning are due to incorrect connections: interchanged phases, or ct polarities, or incorrect make-up of the delta ct connections. Using the transformer nameplate drawing as the reference, a phasing-check should be made to be sure that the ct secondary connections are made up properly properly for the particular transformer winding configuration.   In case of difficulty during commissioning, a plug-in test unit is available on loan from the factory as an aid in analyzing connection problems; however, significant load current must be flowing to use this device.

3. SETTINGS

Procedures for calculating settings for a particular installation are given in the Application section.

CURRENT TAPS:

The ct secondary currents seen by the relay are usually unequal due to the primary to secondary ratio of the transformer being protected and the choice of ratios for the ct's on the primary and secondary sides of the transformer.

The tap settings are selected to equalize the input currents seen by the differential measurement unit of the relay. The tap values and ratios provided are shown in Table 1.

Setting calculations will determine the tap selection required for the high-side and low-side ct inputs. It is important to identify which input terminals of the relay are connected to the high-side ct's and to the low side ct's.   Then when making these settings, to relate the front panel tap to the input current terminals it affects: the left side tap for input terminals 1-2, the right side tap for terminals 5-6, and the center tap (on 3 winding units) for input terminals 3-4.

% DIFFERENTIAL:

The ABB Circuit-Shield Type 87T relay operates when its input currents differ in magnitude (vectorially).   The operating point occurs when the difference, expressed as a percentage of the smaller, exceeds the setting.

The percentage differential or "slope" setting is made with the left-hand front panel dial. This continuously adjustable control allows settings from 15 to 40%, and is illustrated in the graphs of Figures 6 and 7.   In these plots the vertical axis is the operate current relative to the tap value,

$$M_o = (I_1/T_1) - (I_2/T_2)$$

and the horizontal axis is the smaller restraint current relative to tap value,

$$M_R = I_2/T_2$$

The Percent Differential is $D = M_o/M_R$

      where I_1 is the larger restraint current
      into T_1 the tap value,
      and I_2 is the smaller restraint current
      into T_2 the tap value.

      Note: $M_R = R$ when $I_2/T_2 < R$
        where R = (adjustable) Minimum Restraint

MINIMUM RESTRAINT (Minimum Operating Current):

The minimum operating current is set by the right-hand dial on the front panel, which is continuously adjustable. The minimum operating current value is determined by the following relationship between the restraint dial setting, the percent differential setting, and the current tap setting:

$$I_m = (D/(100 + D)) \times R \times T$$

where D = % differential setting
       R = adj min restraint setting
       T = tap setting
       I_m= minimum operating current in amperes

For example, with D = 25%, R=2.3, and T=5A:
$$I_m = (25/125) \times 2.3 \times 5 = 46\% \times 5A = 2.3A$$

The effect of varying the Minimum Restraint adjustment is graphically illustrated in Figure 7 and tabulated in this chart:

Percent Differential Setting	Restraint Dial Setting	Minimum Operate Current
40%	1.05	30% of tap
	1.5	43%
	2.3	65%
25%	1.05	21%
	1.5	30%
	2.3	45%
15%	1.05	14%
	1.5	20%
	2.3	30%

The setting that provides a 30-40% minimum operating current would be typical for most applications.

INSTANTANEOUS:

The instantaneous element operates directly on magnitude of the measured current difference. This internal adjustment is factory set at 10x tap, but may be adjusted from 8 to 20x as may be required by the application. This element must be set by test. Refer to the section on Testing for the calibration procedure.

HARMONIC RESTRAINT:

The harmonic restraint unit blocks relay operation on transformer energization by detection of the second harmonic content of the inrush current. This element is factory set to restrain on 15% second harmonic, which is appropriate for most applications. An internal calibration adjustment provides a range of approximately 10-20%, and may be set by test. Refer to the section on Testing for the calibration procedure.

APPLICATION DATA

The ABB Circuit-Shield™ Type 87T provides high-speed differential protection for power transformers.

The Type 87T is a single-phase relay. A set of three relays is required for the protection of one power transformer. The relay is offered in models for the protection of two winding and three winding transformers.

The relay has a linear percentage differential characteristic in order to accomodate ct ratio mismatch, the operation of on-load tap changers, and ct errors at high fault currents external to the protected zone. Controls are provided on the front panel to adjust the slope (15-40%), and the minimum operate current.

A second-harmonic restraint unit prevents relay operation on transformer magnetizing inrush current. This unit is factory calibrated to restrain on 15% second harmonic content, but may be adjusted if required.

An unrestrained instantaneous unit which operates on the magnitude of the difference current is provided to back up the percentage differential unit. The instantaneous unit is factory set at 10x tap, but may be adjusted (8-20x) in the field.

The relay has ratio correcting taps, therefore, external auxiliary ct's will not usually be required. The high continuous rating of each tap gives the user more flexibility in selecting taps. The low burden of the relay (see table 3) provides improved ct performance.

A procedure for calculating the relay settings for a particular application follows on page 10.
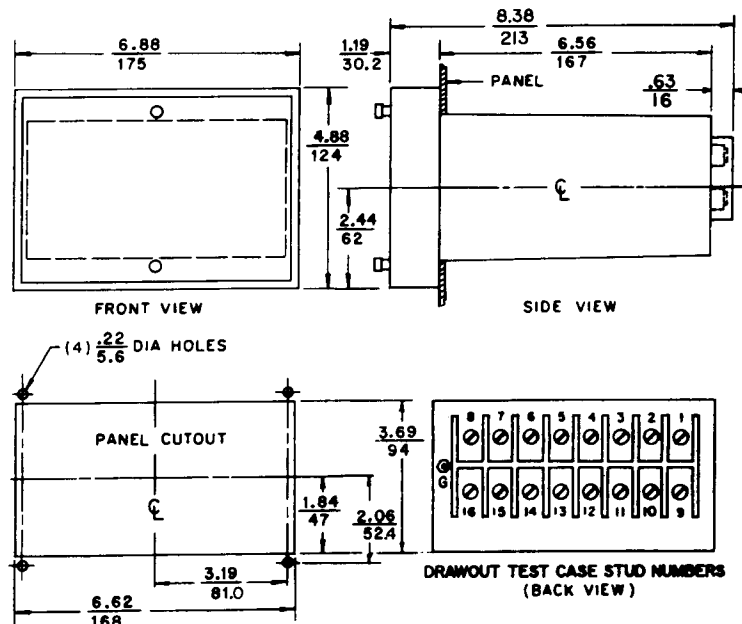

Figure 1: Relay Outline and Panel Drilling

Specifications

Input Circuits:

        Ratio Matching Taps: see Table 1.
        Continuous rating: see Table 2.
        1 Second rating: 200 Amperes, any tap.
        Burden: see Table 3.

Percentage Restraint Element:

        Minimum operate current: adjustable 13-65% of tap setting.
        Slope: adjustable 15-40%.
        Refer to Figures 6 and 7.

Instantaneous Element:

        Internally adjustable 8-20x tap.
        Factory set at 10x tap.

Harmonic Restraint Element:

        Restrain on 2nd harmonic.
        Internally adjustable approximately 10%-20%.
        Factory setting - 15%.

Operating Time: See Figure 5.

Output Contact Rating:

	@ 125vdc	@ 250vdc	
	30A	30A	closing/tripping
	5A	5A	continuous
	0.3A	0.1A	break

Operating Temperature Range: -20 to +70°C

Control Voltage: models available for

    125vdc @ 0.05A max. drain (allowable range 100-140vdc)
    110vdc @ 0.05A max. drain (allowable range 88-125vdc)
    250vdc @ 0.05A max. drain (allowable range 200-280vdc)
    220vdc @ 0.05A max. drain (allowable range 176-250vdc)
    48vdc @ 0.05A max. drain (allowable range 38- 58vdc)
    32vdc and 24vdc: see note 2 below, and page 22.

TABLE 4: CATALOG NUMBERS - COMMON UNITS

Type	Windings	System Freq.	Control Voltage	Catalog Numbers Std Case	Test Case
87T	Two	60Hz.	48vdc	219T2431	419T2431
			110vdc	219T2401	419T2401
			125vdc	219T2441	419T2441
			250vdc	219T2451	419T2451
		50Hz.	48vdc	219F2431	419F2431
			110vdc	219F2401	419F2401
			125vdc	219F2441	419F2441
			220vdc	219F2421	419F2421
87T	Three	60Hz.	48vdc	219T3431	419T3431
			110vdc	219T3401	419T3401
			125vdc	219T3441	419T3441
		50Hz.	48vdc	219F3431	419F3431
			110vdc	219F3401	419F3401
			125vdc	219F3441	419F3441

Notes: 1. Select 419 series units for new applications due to the
          the improved testing features.

        2. Contact factory for availability of units for control
          voltage ratings not listed. For 24 or 32vdc control use
          Type 96 dc/dc inverter and 48vdc rated 87T: see page 22.

TABLE 1   Type 87T   Tap Ratios

	2.9	3.2	3.6	4.0	4.5	5.0	8.7
2.9	1.00	1.10	1.24	1.38	1.55	1.72	3.00
3.2		1.00	1.13	1.25	1.41	1.56	2.72
3.6			1.00	1.11	1.25	1.39	2.42
4.0				1.00	1.13	1.25	2.18
4.5					1.00	1.11	1.93
5.0						1.00	1.74
8.7							1.00

TABLE 2   Continuous Current Ratings

Tap Setting	Continuous Rating
2.9A	10A
3.2A	10A
3.6A	10A
4.0A	10A
4.5A	10A
5.0A	10A
8.7A	17A

TABLE 3   Burden Data

Tap Setting	Ohms	P.F.
2.9A	0.05	1.0
3.2A	0.05	1.0
3.6A	0.04	1.0
4.0A	0.04	1.0
4.5A	0.04	1.0
5.0A	0.04	1.0
8.7A	0.04	1.0

Figure 2:   Internal Connection Diagrams

16D419B   Type 87T
Transformer Differential Relay
Drawout Test Case
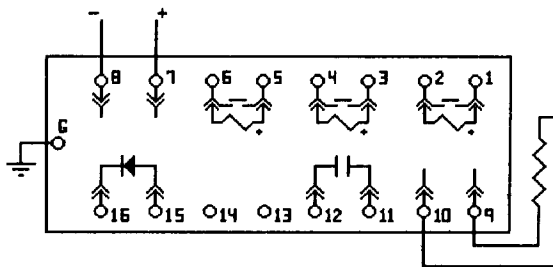
16D219B   Type 87T
Transformer Differential Relay
Standard Case
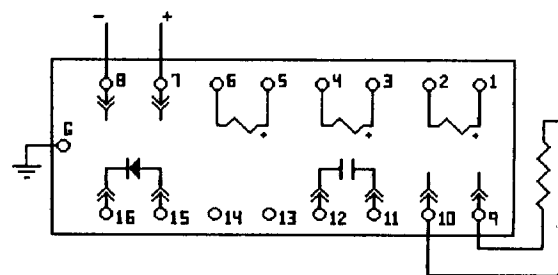
Notes:
1. Omit coil 3-4 for two winding relays.
2. The tap block associated with coil 1-2 is on left hand side, when viewed from the front of the relay.
3. The tap block for coil 5-6 is on the right hand side.
4. If provided, the tap block for coil 3-4 is in the center.
5. The external resistor shown connected between terminals 9 and 10 is supplied mounted on the relay and must be in place for proper operation.
6. The diode shown between terminals 15 and 16 is used for testing only. See test procedures.
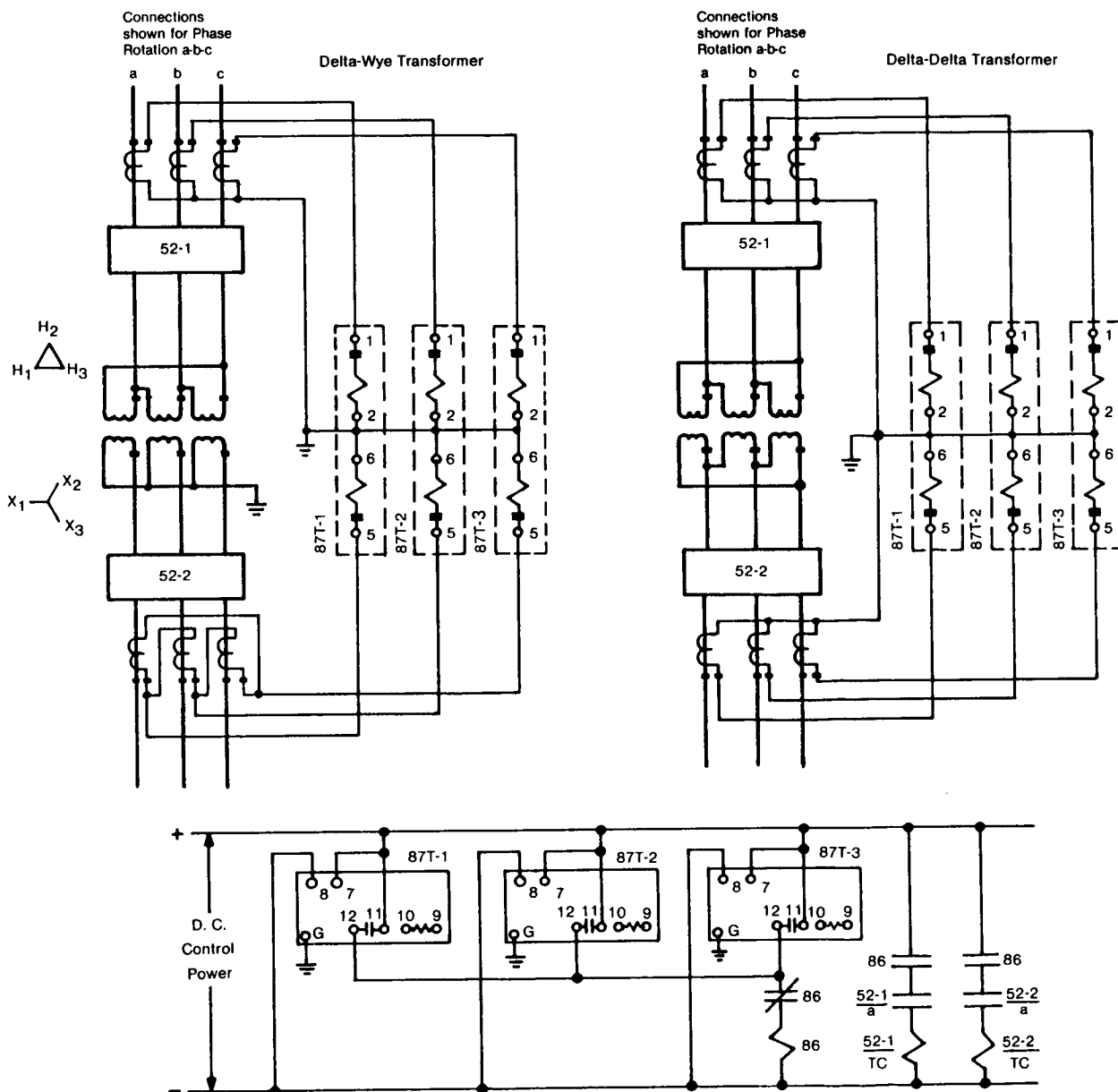
Figure 3: Typical Connections for Differential Protection
Two-Winding Three-Phase Power Transformer

Note: using the transformer nameplate drawing as a reference,
a "phasing-check" should be made to insure that the ct
secondary connections are made up properly for the
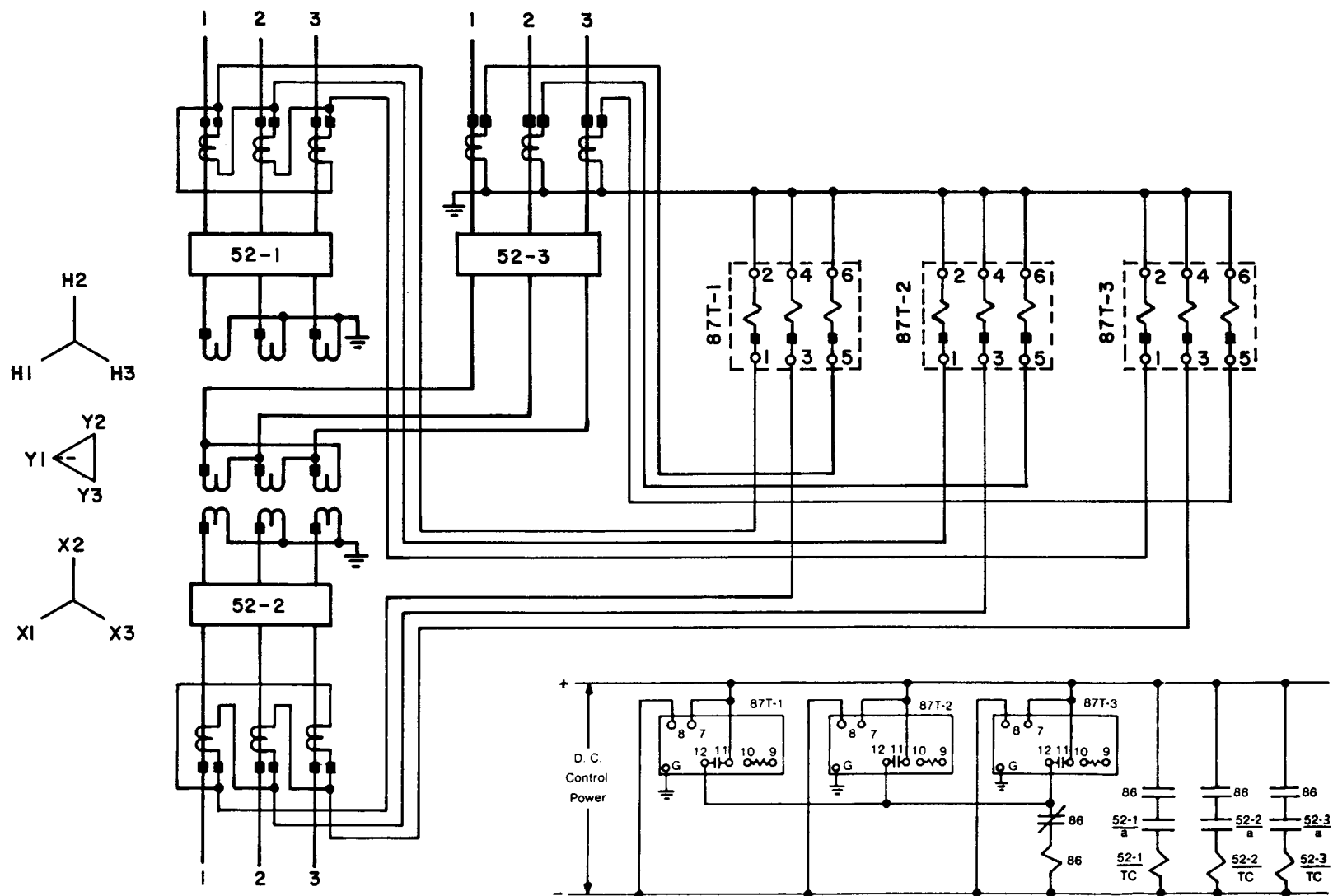particular transformer winding configuration.

Figure 4: Typical Connections for Differential Protection – Three-Winding Three-Phase Transformer

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CALCULATION OF SETTINGS:

A procedure for calculating the relay settings follows. An example is given at the
end of the procedure.

1. Determine the maximum load currents of the transformer, on the high-side I_H and
the low-side I_L.

2. Determine the maximum through-fault currents, I_{HF} and I_{LF}.

3. Choose the ct ratio in accordance with step 1 to give approximately 5A secondary
current at the maximum load current; and, also so that the maximum external fault
current is less than 100 amperes secondary.   If the ct ratios have been specified by
others, check that they meet the requirements above. (Note that for 2 winding
applications, through-fault current is limited by the transformer impedance.)

4. Calculate the load currents on the ct secondary side, I_{HS} and I_{LS}.

5. Calculate the relay currents, I_{HR} and I_{LR}, remembering to multiply by $\sqrt{3}$ for ct
secondaries connected in delta.

6. Calculate the ratio of the relay currents, taking the larger/smaller = A.

7. Referring to Table 1, choose the taps so that the tap ratio (T) is closest to the
relay current ratio (A). Properly assign the larger and smaller value tap selections
to the high-side and low-side relay currents - in the same manner as (A) was cal-
culated in step 7.

If more than one selection of taps is available for the tap ratio desired, it is
usual practice to choose tap values closest to the normal relay currents I_{HR} and I_{LR}.

8. Check that the relay currents are within the continuous rating of the relay -
refer to Table 2.

9. Calculate the mismatch: M = Mismatch = $\left| (T-A)/(\text{smaller of T or A}) \right|$

10. Select the slope (percentage differential) setting. Both the mismatch and the
transformer's load tap changer range must be considered.   S = M + LTC.   For
security, the 25% setting should be used for calculated slopes of 15% and below, and
the 40% setting for calculated slopes of 15-30%.

11. Select the Instantaneous setting. This internal adjustment is factory set at 10x
tap value. The recommended setting is approximately 10 times the power transformers
self-cooled load current rating: (a) Calculate the relay current at the
                                        transformers self-cooled rating.
                                    (b) Divide by the high-side relay tap value.
                                    (c) Multiply by 1.2 for margin.

Set the internal potentiometer R119 using the calibration procedures given in the
section on Testing.

12. CT performance check: The maximum burden presented to a ct is given by the
following equations:
                    R = $2.3R_L$ + R_B + R_A for wye-connected ct's.
                    R = $3.4R_L$ + $3R_B$ + $3R_A$ for delta-connected ct's.
(this includes a correction factor for the increased resistance of the leads due to
self-heating effects)

            where R_L is the one-way lead resistance from ct to the relay.
                   R_B is the relay burden. (See Table 3)
                   R_A is the burden of other devices in series with the relay.

CT performance should be satisfactory if the maximum external fault current flowing
through R does not require a voltage higher than one-half the ANSI Class C accuracy
rating of the ct.   Therefore V_C > 2x RI_{FS} must be satisfied for both the high-side
and low-side ct's. (Note: if a multi-ratio ct is being used, and if the full
secondary winding is not being used, then adjust the "C" rating by the factor N_S/N_T
to account for the lower effective "C" rating. (N_S = secondary turns used; N_T =
total secondary turns.)

13. Minimum operating current: a setting giving 25-40% minimum operating current
would be usual practice. See chart on page 4.

SETTINGS CALCULATION - Example:

The following transformer is assumed for this example: 12/16/20 MVA OA/FA/FA,
115 kv delta, 13.8 kv wye, 8.5% impedance, on-load tap changer range +/-10%.

             High Side (115 kv delta)   Low Side (13.8 kv wye)

1. Maximum load current (at 20MVA):
      I_H = 20000/(115 * $\sqrt{3}$) = 100.4A I_L = 20000/(13.8 * $\sqrt{3}$) = 837A

2. Maximum through fault currents (assuming infinite bus):
      I_{HF} = 12000/(115 * $\sqrt{3}$ * 0.085) I_{LF} = 12000/(13.8 * $\sqrt{3}$ * 0.085)
           = 709A   = 5907A

3. Choose ct ratios:
           = 100:5   = multiratio 1200:5 set on
                                                   1000:5 tap.
   CT secondary currents at maximum through fault:
      I_{HFS} = (709/100) * 5 = 35.5A (ok) I_{LFS} = (5907/1000) * 5 = 29.5A (ok)

4. Load currents on ct secondary side at maximum transformer rating (20MVA):
      I_{HS} = (100.4/100) * 5 = 5.02A I_{LS} = (837/1000) * 5 = 4.19A

5. Relay currents at maximum load current:
      High-side ct secondaries in wye   Low side ct secondaries in delta
      I_{HR} = 5.02A I_{LR} = 4.19 * $\sqrt{3}$ = 7.26A

6. Ratio of relay currents:
           A = larger/smaller = low side/high side = 7.26/5.02 = 1.446

7. Select taps from Table 1:
           Closest ratio is 1.41 using taps 4.5/3.2.
           Assign taps in proper relationship as calculated in step 6:
               Larger value for low side ct's = 4.5A tap.
               Smaller value for high side ct's = 3.2A tap.
           (see notes on Figure 2 page 7 for physical relationship of
           of tap settings to input terminals)

8. Check continuous ratings of taps from Table 2:
               Both taps selected are rated 10A continuous - ok.

9. Calculate the mismatch:
           M = |(T-A)| / (smaller of T or A) = |(1.41 - 1.446)| / 1.41
             = 0.036/1.41 = 0.025 = 2.5%.

10. Select percentage differential setting (slope):
           S = M + LTC = 2.5 +10 = 12.5%.   Use 25% setting.

11. Select the instantaneous setting:
       High-side relay current at self-cooled rating =
           (12000/(115 * $\sqrt{3}$) * 5/100 = 3.01A
       (3.01 * 10)/(high side tap) = 30.1/3.2 = 9.4 (x tap)
       Multiply by 1.2 for margin = 9.4 * 1.2 = 11.3 (x tap).
       Calibrate relay to give instantaneous setting 11 x tap.

12. CT performance check:
       Determine the approximate lead lengths and wire size used for the ct secondary
       connections. Determine the one way lead resistance, and the burden of any
       other devices connected.

       For this example we assume the high-side ct's (100:5) are ANSI class C200 and
       the low-side ct's (1200:5 multiratio) are C400.

   I_{HFS} = 35.5A I_{LFS} = 29.5A

                                            Effective C rating of low side ct =
                                               400 * 1000/1200 = 333

   Maximum allowable burdens are:
      R_{HS} = (200v/2)/35.5A = 2.82 ohms R_{LS} = (333v/2)/29.5A = 5.64 ohms

12. CT performance check (continued):

   Assuming only the relay is connected to the ct's:

   High side ct's in wye   Low side ct's in delta
   2.82 ohms = $2.3R_{LH} + R_B$ 5.64 ohms = $3.4R_{LL} + 3R_B$

   Relay Burdens from Table 3:
   R_{BH} = 0.05 ohms (3.2A tap) R_{BL} = 0.04 ohms (4.5A tap)

   Calculate maximum allowed one-way lead resistance:
   R_{LH} = (2.82 - 0.05)/2.3 R_{LL} = (5.64 - 3 * 0.04)/3.4
        = 1.20 ohms max.   = 1.62 ohms max.

13. Select minimum operating current setting:

   For a minimum operating current of 25% relative to full load current:
   I_{HS} = 5.02A (from step 4)
   High side tap = 3.2A (from step 7)
   (25% x 5.02)/3.2 = 39% of tap.

   From page 4: I_m = (D/(100 + D)) x R X T
                 I_m/T = .39
                 R = .39 * (100 +D)/D   D=25% from step 10
                 R = .39 * (125/25) = 1.95 (Minimum Restraint setting)

Calculations for Three-Winding Transformers:

Tap selections are calculated two at a time, based on the primary rating of the transformer and not on the ratings of the individual secondary windings.

For the following example assume transformer ratings:

Primary	Secondary	Tertiary
161kv, 30/40 Mva OA/FA	69kv, 30/40 Mva	12.4kv, 7.5/10 Mva
wye	wye	delta

ct's: 1200:5 C800   600:5 C200   1200:5 C200
(all are multiratio)
ct connections: delta   delta   wye

impedances: primary to secondary - 9.5%   primary to tertiary - 16%
(based on OA rating)

Sample calculation:	Primary	Secondary	Tertiary
1. Max load currents	143A (@40Mva)	335A (@40Mva)	465A (@10Mva) (1862A @40Mva)
2. Max through fault currents (assuming only source is infinite bus on primary side)	1509A	3523A	11640A
3. Choose ct ratios	400:5	600:5	1000:5
4. CT secondary currents at maximum load	1.79A	2.79A	2.32A (9.31A @ 40Mva)
5. Relay currents at maximum load	3.10A	4.83A	2.32A (9.31A @ 40Mva)

6. Ratio of relay currents
   (Note: for this calculation, the same transformer rating must be used for all
        windings; in this case the 40Mva rating.)

   A_{12} = larger/smaller = secondary/primary = 4.83/3.10 = 1.558.

   A_{13} = larger/smaller = tertiary/primary = 9.31/3.10 = 3.003.

   A_{23} = larger/smaller = tertiary/secondary = 9.31/4.83 = 1.928.
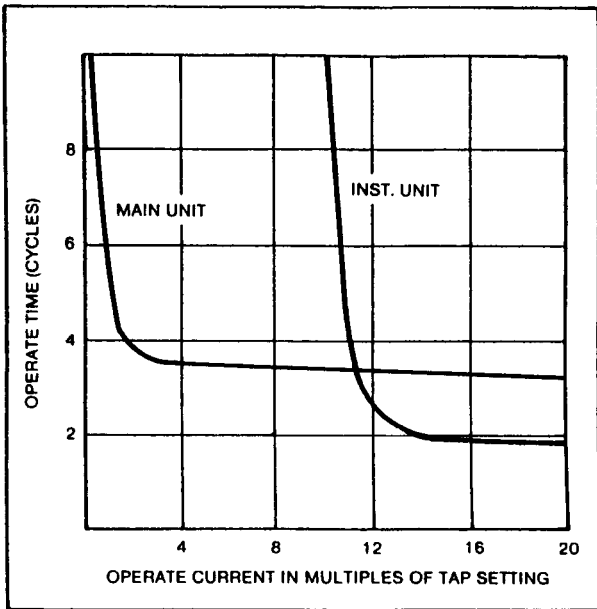
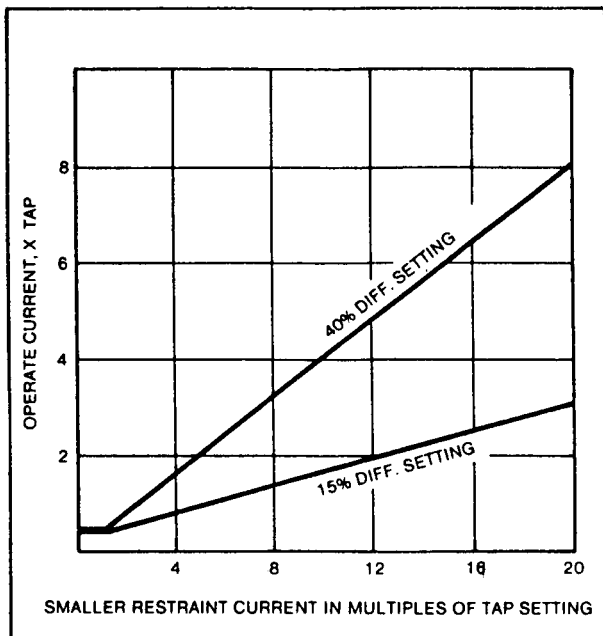Figure 5: Typical Operating Time

Figure 6: Percentage Differential
          Operating Characteristic
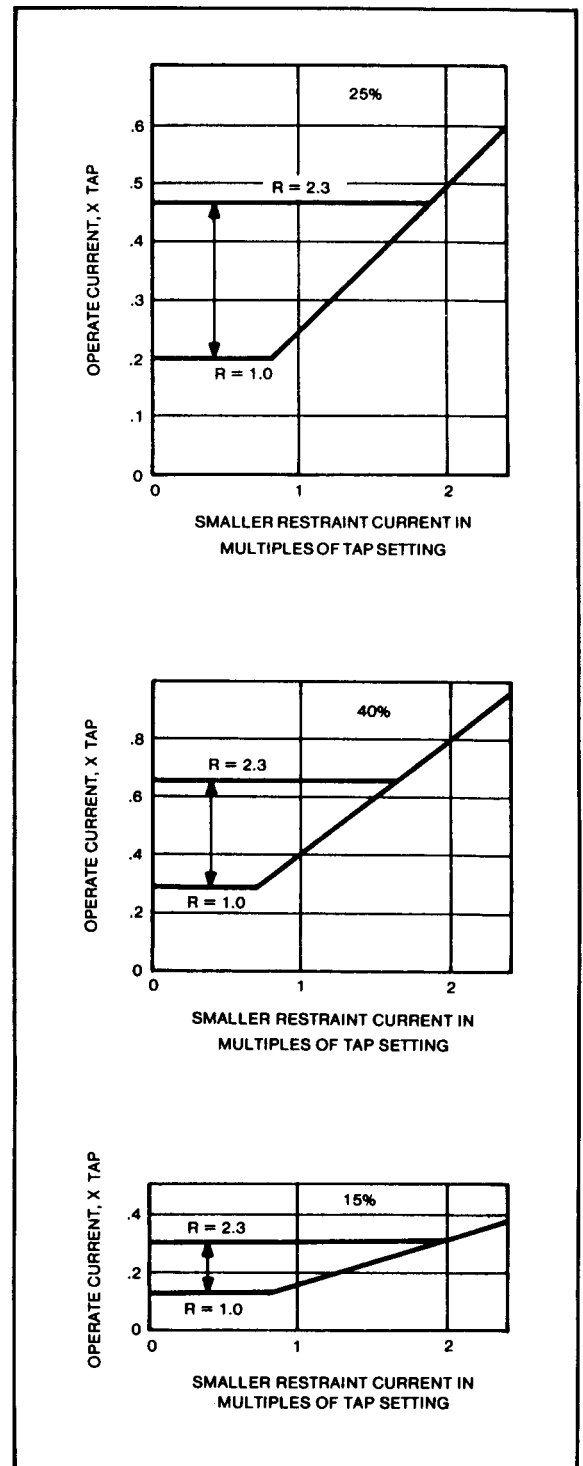
(see Figure 7 for detail at
low restraint currents)

Figure 7: Percentage Differential
Characteristics at Low Currents
for 15%, 25%, and 40% Settings
showing minimum operate current
as a function of R.

Minimum Restraint Dial (R)
adjustable from 1.0 to 2.3.

TESTING

1. MAINTENANCE AND RENEWAL PARTS

No routine maintenance is required on these ABB Circuit-Shield™ solid-state relays. Follow test instructions to verify periodically that the relay is in proper working order. We recommend that an inoperative relay be returned to the factory for repair; however, a schematic diagram is available on request. Renewal parts will be quoted on request to the factory.

219 Series Units:

Drawout circuit boards of the same catalog number are interchangible. A unit is identified by the catalog number stamped on the front panel and by a serial number stamped on the bottom side of the drawout circuit board. The board is removed using the metal pull knobs on the front panel. Removing the board does not open-circuit the ct secondaries; however, a nuisance operation is possible if removed or inserted while in service.

An 18 point extender board, catalog 200X0018 is available for use in calibrating or troubleshooting.

419 Series Units:

Metal handles provide leverage to withdraw the relay assembly from the case.

The assembly is identified by a catalog number stamped on the front panel of the relay and a serial number stamped on the bottom of the circuit board.

Test connections are readily made to the drawout relay unit by means of standard banana plugs. Current connections are made to the vertical posts at the blade assemblies. Control power and output connections are made at the rear vertical circuit board. This rear board is marked for easier identification of the connection points.

IMPORTANT: in order to test the drawout unit a suitable resistor must be temporarily connected between terminals 9 and 10 on the rear vertical circuit board. The value of this resistor depends on the control voltage rating of the relay: 1400 ohms for units rated 125vdc, 200 ohms for 48vdc units. A 25 watt resistor is suitable for testing. If no resistor is readily available, the resistor mounted on the rear of the relay case could be removed and used; however, *be sure to remount the resistor on the case at the conclusion of testing.*

Disassembly: Should separation of the upper and lower circuit boards be necessary, remove the (2) screws holding the handle assemblies in place. Some units may also require the removal of (2) screws from the underside of the unit near the rear vertical circuit board. The lower circuit board may then be withdrawn forward from the printed circuit connector. An 18 point extender board, catalog 200X0018 is available to provide access to the lower circuit board for calibration or trouble-shooting.

Test Plug:
A test plug assembly, catalog 400X0001 is available for use with the 419 series units. This device plugs into the relay case on the switchboard and allows access to all the external circuits wired to the case including the ct secondaries. See Instruction Book IB 7.7.1.7-8 for details on the use of this device.

2. HIGH POTENTIAL TESTS

High potential tests are not recommended. A hi-pot test was performed at the factory before shipping. If a control wiring insulation test is required, withdraw the drawout element from the case before applying the test voltage.

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3. BUILT-IN TEST FUNCTION

A built-in test function is provided for convenience in running a test on the relay and associated trip circuits. The test button is labelled TRIP, and depressing the button will cause an immediate trip.

CAUTION: tests should be made with the main circuit de-energized. If tests must be made on an energized circuit, take all necessary precautions.

4. ACCEPTANCE TESTS

The following procedures can be used to verify and adjust the operating characteristics of the Type 87T relay.

A. Minimum Operating Current and % Differential Tests:

Connect the relay in the test circuit shown in Figure 8. Apply control voltage per the relay's rating as marked on the front panel. Select and make settings from the listing in Table 5.

    <u>Minimum Operating Current:</u> Increase the I_2 current until the 87T operates. ($I_1 = 0$)
                                         Compare with the expected value from Table 5.

    <u>Differential Characteristic:</u> Set the I_2 current for 5.8 amps.
                                    Increase the I_1 current to 5.8 amps.
                                    The 87T output contact should now be open.
                                    Reset the target to black.
                                    Increase the I_1 current until the 87T operates.
                                    The I_1 current should be within the limits shown.

    Remember: since the %Differential and Minimum Restraint dials are continuously adjustable, you may trim their positions if desired to obtain more precisely the required operating values.

    Important note:
        Some commercial test sets that have 2 independent sources are not suitable for the differential test shown above because there is a phase-shift between the sources. If you are using such a set, then an alternative test for the differential element using a single source is as follows:
                a. Connect the relay as shown in Figure 9.
                b. Set %Diff dial to 40%, taps to 3.6A.
                c. Apply 7.2A test current. The relay should not trip.
                d. Move <u>one</u> tap pin to 2.9A position. Apply 7.2A and then rotate the %Diff dial counterclockwise slowly until the relay trips. The dial position should be 21-27%.

Table 5: Suggested Settings for the Acceptance Test

Taps	(D) % Diff	(R) Min Restraint	I_2 Min Operate Lim	Differential Test Set I_2	I_1 limits
2.9A	15%	2.3	0.75 – 1.0A	5.8A	6.4 – 6.9A
2.9A	25%	1.5	0.75 – 1.0A	5.8A	7.0 – 7.5A
2.9A	40%	1.0	0.75 – 1.0A	5.8A	7.8 – 8.4A

The suggested settings selected for Table 5 use the lowest tap value (2.9A) to minimize the currents required for the tests. If you must check the values to be used in your application, the following formulas apply:

    1. Minimum operating current: $I_m = (D/(100+D)) \times R \times T$
        D = % Diff setting, R = Minimum Restraint Setting, T = tap value
        Increase the test current to one input of the relay. The relay should trip within +/-15% of the value calculated. (Trim dial position as rqd.)

    2. Differential characteristic: apply test currents of 2 times the tap value to each of two current inputs. The output contact should be open. Increase one source until the output contact closes. The current at which the contact closes should be within +/-5% of the value calculated from: $I = T \times (2D+2)$ T= tap of "increased" source   D= %Diff setting.

B. Instantaneous Unit Tests:

CAUTION: in the testing and calibration of the instantaneous unit, high currents are
required. Apply test current for only a short time in order to avoid thermal damage.
If the expected operation is not obtained, shut off the current source and review
your connections and procedures. Wait 30 seconds before repeating a test. Selection
of the lowest tap value (2.9A) for the initial testing will reduce the test current
required.

Typical test connections are shown in Figure 10.

If you are using an electronic current source test set it may be necessary to place
two of the independent sources in parallel in order to obtain the necessary current
level. Be sure that both sources are set for the same phase angle and connected with
the same polarity so the currents add together at the relay input terminals.

(Alternate method: for test sets with limited capacity, the required test current
will be reduced to one-half of normal by connecting two relay input windings in
series: test current into terminal 1, out 2, into 5, and out terminal 6.)

To verify the factory setting of 10x tap, it is not necessary to separate the upper
and lower circuit boards; however, if you plan to recalibrate the relay, the adjust-
ment potentiometer R119 is located on the lower circuit board as shown in the circuit
board layout on page 19. Use of the 18 point extender board will allow easier access
to this adjustment.

Locate the connector pins labelled 1 through 5 on the module board - see circuit
board layouts on page 19. To defeat the operation of the main differential unit, a
jumper must be connected temporarily between pins 3 and 5. (Take care to prevent
shorting to any of the other pins.)   Only the instantaneous unit will remain active.

Apply rated dc control voltage to the relay.

Increase the test current until the relay operates and note the value.   The relay is
factory calibrated for an operating point of 10x tap (tolerance +/-15%). If the 2.9A
tap is being used, a trip should be obtained at 25-33A.   If necessary, readjust R119
and repeat the test until the desired operating point is obtained.

At the completion of this test, remove the temporary jumper.

C. Harmonic Restraint Tests:

The Type 87T uses 2nd harmonic restraint to block relay operation on transformer
inrush upon energization. The factory calibration is restraint for 2nd harmonic
content of 15% and above.

To verify the factory setting of 15%, it is not necessary to separate the upper and
lower circuit boards; however, if you plan to recalibrate the relay, the adjustment
potentiometer R217 is located on the module board of the lower circuit board as shown
in the circuit board layouts on page 19. Use of the 18 point extender board will
allow easier access to this adjustment.

The procedure to be used to verify the harmonic restraint function depends on the
type of test set being used: the more modern electronic current-source, or, the older
style voltage-source. Most electronic current-source units can be set up to provide
one output current at the fundamental and another output at the second-harmonic
frequency. When using voltage-source sets, the relay's built-in diode is used to
generate second-harmonic.

   1. Electronic current-source testing:

        a. Connect the relay as shown in Figure 11. Apply rated dc control volts.
        b. Set the taps at 2.9A.   %Diff and Minimum Restraint: any settings.
        c. Apply 4.0 amperes of fundamental current. The relay should close its
           output contact.
        d. Apply 2nd harmonic current and increase its value until the output
           contact drops out.   Percent 2nd for restraint = $I_{2nd}/I_{fund} \times 100$.

           For the 4.0A fundamental, restraint should occur for I_{2nd} = 0.58-0.66A.
           The 2nd harmonic current may be increased and decreased to determine the
           restraint and release points, and R217 may be readjusted as needed to
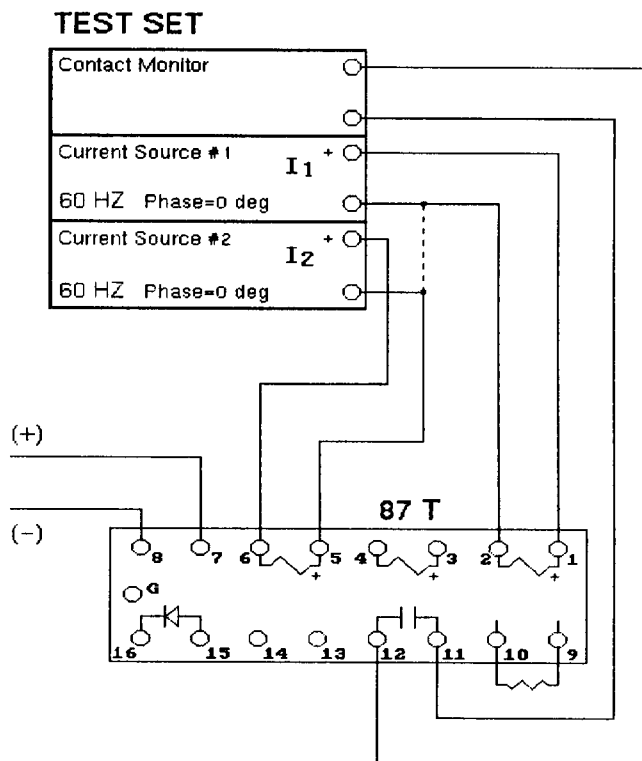   obtain the desired restraint point.

Figure 8:
Typical Test Connections

Minimum Operating Current
and Pct Differential
Characteristic
Tests.

Connection shown dotted
optional depending on
test set.

Note: use 50Hz sources if
relay has 50Hz nameplate
rating.

Apply dc control power
per relay's nameplate
rating. Resistor required
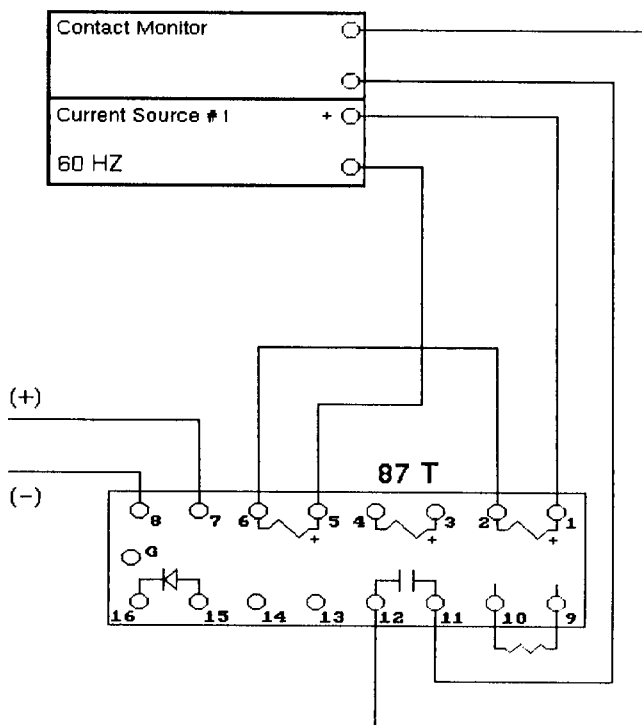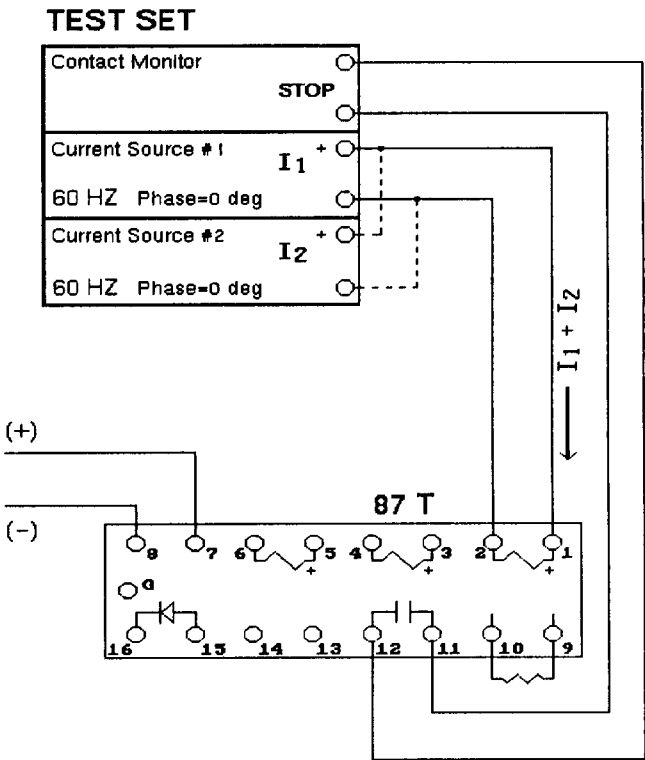between terminals 9 and 10.
See page 14.

Figure 9:
Typical Test Connections

Alternate Method for
Pct Differential
Characteristic
Test

Figure 10:
Typical Test Connections

Instantaneous Unit
Pickup Test

If second source required
in parallel to obtain
needed current levels,
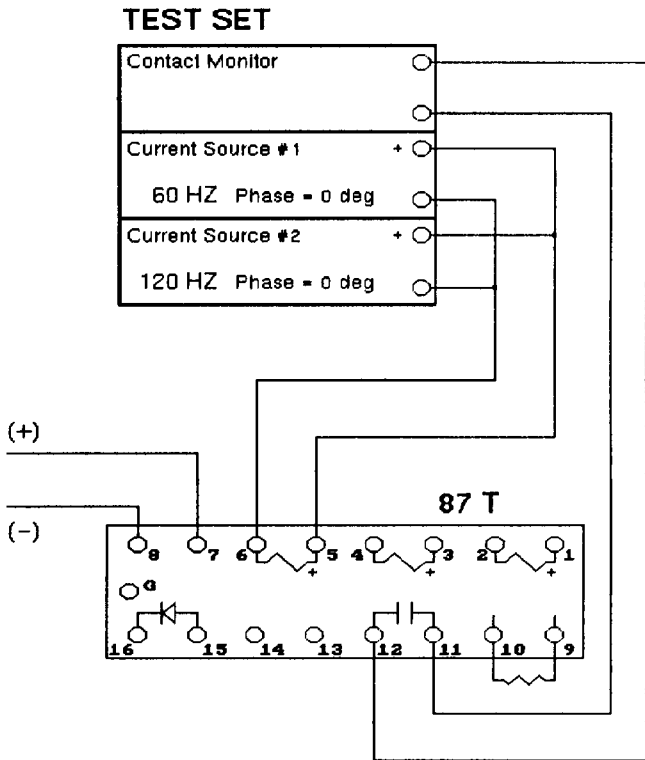connect as shown by
dotted lines.

Note use 50Hz and 100Hz
sources if relay has a
50Hz nameplate rating.

Apply dc control power per
relay's nameplate rating.
Resistor required between
terminals 9 and 10. See
page 14.

Figure 11:
Typical Test Connections

Harmonic Restraint Test
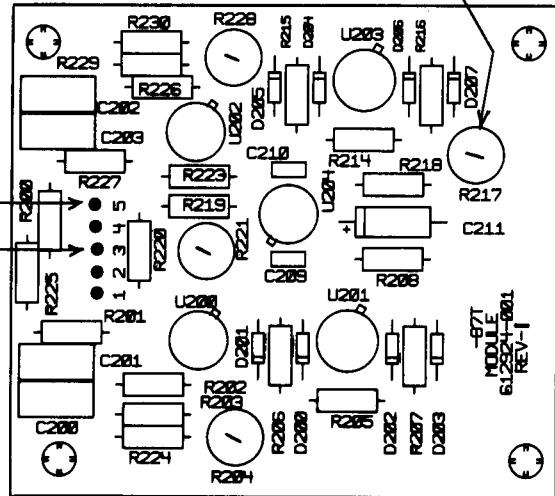using Electronic Current
Source.

R217
Percent-second-harmonic
calibration potentiometer

Turn R217 clockwise to
reduce the percentage of
second harmonic required
to restrain relay operation.

Connect jumper between
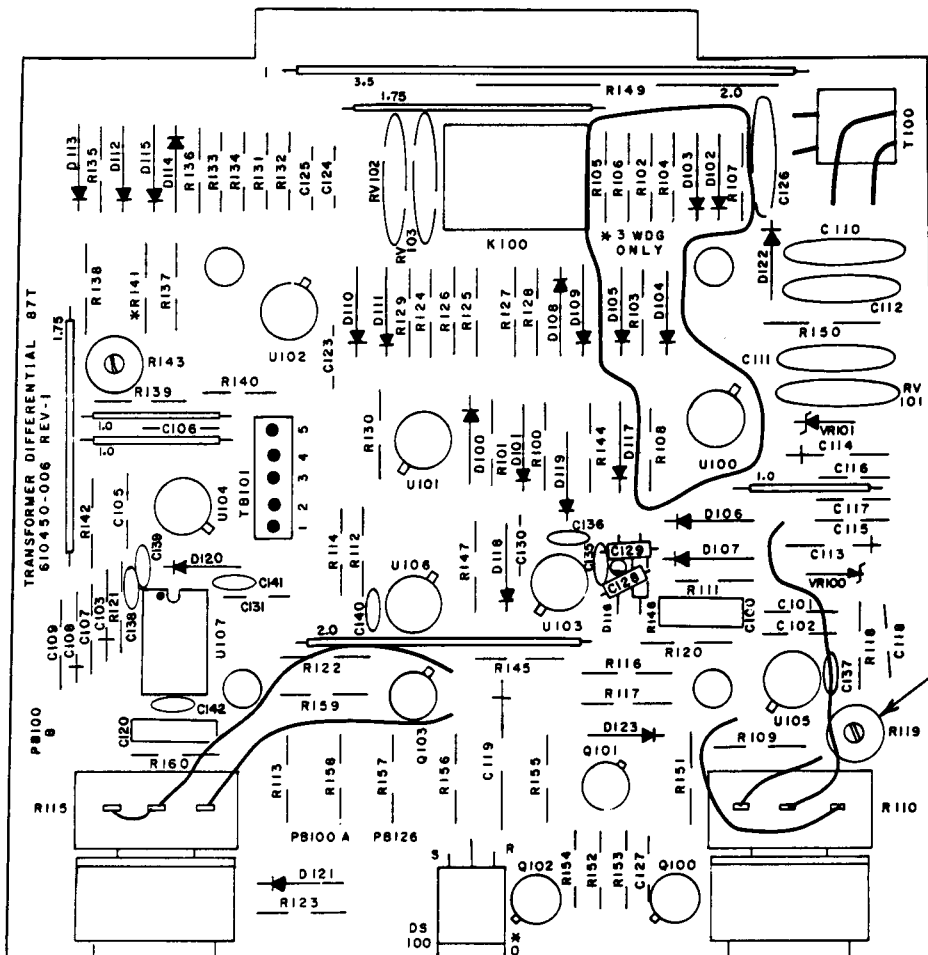pins 3 and 5 for test
of 87T Instantaneous Unit

Typical Layout - Type 87T
Harmonic Restraint
Module Board

Type 87T
Typical Layout
Main Lower
Circuit Board

R119
Instantaneous Unit
Pickup Calibration
Potentiometer

Turn R119 clockwise
to increase pickup.

C. Harmonic Restraint Tests   (continued from page 16)

2. Voltage-source testing:

A typical test circuit is shown in Figure 13a. In this method, the built-in
diode between terminals 15 and 16 is used to generate 2nd harmonic content in
the current waveform.   (Do not use an electronic current source test set with
this method.)

a. Set the %Diff dial to 15% and the MinRestraint dial to 1.0.
   (if these settings have already been calibrated, mark the positions so you
   can return to the calibrated positions at the end of this test.)

b. Place the tap pins in the 2.9A tap.

c. Apply rated dc control voltage to the relay.

d. Set the Branch B current at zero. With the switch closed across the diode,
   increase the current in Branch A to 1.0 ampere. The 87T output contact
   should close since the input current is all fundamental.

e. Open the contact across the diode, thus causing significant 2nd harmonic
   content in the current waveform. Do not readjust the Branch A source.
   The apparent current on the Branch A ammeter will drop, but that is proper.
   The 87T relay should be restrained (output contact open).   Actuate the
   target-reset button to reset the target.

f. Slowly raise the current in Branch B, increasing the fundamental content.
   The 87T will return to the trip condition (output contact closed, target
   displayed) when the percentage of 2nd harmonic falls below the set value.
   This value may be read directly from the curve in Figure 13b. Since the
   Branch A current was originally set to 1.0A, the vertical scale may be
   read as the current in Branch B.

   For the factory calibration of 15% nominal, the Branch B current should
   be between 0.8 and 1.0 ampere for acceptance testing.

   The Branch B current may be raised and lowered to determine the "restrain"
   and "unrestrained" values.

   Example: Assume the relay restrained with a Branch B current of 0.92 amps.
            Reading the curve at 0.92 gives 15% 2nd harmonic on the horizontal
            scale.

   Adjustment: internal potentiometer R217 may be used to adjust the value of
                2nd harmonic that causes restraint. Refer to the circuit
                board layouts on page 19 for the location of R217.

   Note: a change in the restraint point may occur if the polarity of the
         current in winding 1-2 is reversed. This is due to internal amplifier
         offset. The operating point should be within the limits of 0.8-1.0A
         as given above.

D. Additional Tests for 3 Winding Relays:

When a 3 winding relay is being tested, the Differential Characteristic Test should
be repeated so that the third input is also tested. Referring to either Figure 8 or
Figure 9 as appropriate, the wire on terminal 5 should be moved to terminal 3, and
the wire on terminal 6 moved to terminal 4.

E. Note on Target Operation:

The relay's target may drop on loss of dc control power, even though the relay has
not closed its output contact. Upon reapplication of control power, the target
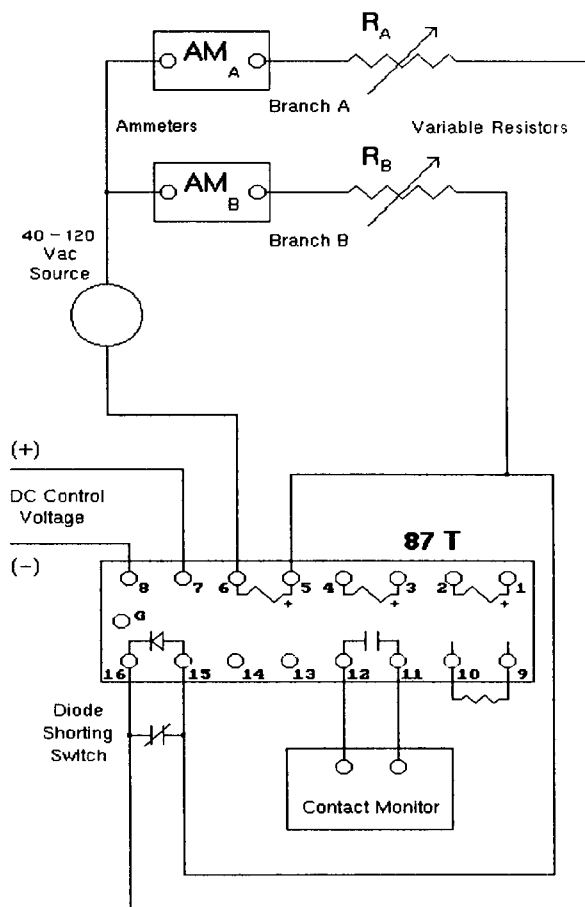should be reset if required.

Figure 12a:

Typical Test Connections

Harmonic Restraint Test
using voltage source and
built-in test diode.

Source is 60Hz for 60Hz units,
50Hz for 50Hz rated units.

Apply dc control voltage
per relay nameplate rating.

Resistor required between
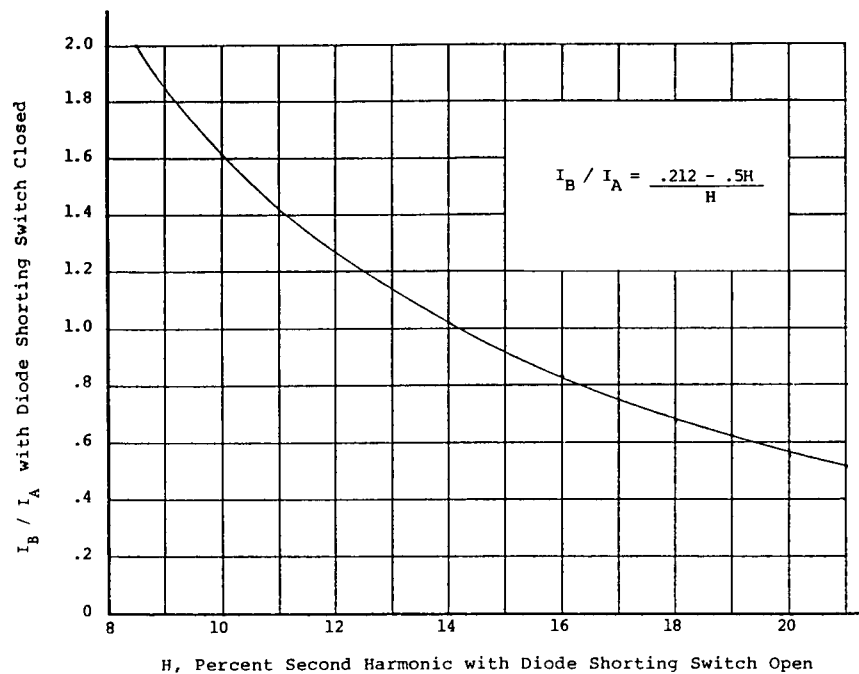terminals 9 and 10. See
page 14.

Formulas:

$$H = \frac{0.212 I_A}{0.5 I_A + I_B}$$

or

$$\frac{I_B}{I_A} = \frac{0.212 - 0.5H}{H}$$

Figure 12b: Percent 2nd Harmonic Content as a Function of I_B/I_A

Note: Set I_A with the Diode Shorting Switch closed. Do not readjust
       the current I_A after opening the switch. Open switch to obtain
       the harmonic content indicated on the graph.

Figure 13: Typical Control Connections with Type 96 DC/DC Inverter

The Type 87T is not available for direct application on systems using
24vdc or 32vdc control voltage. However, the Type 96 Inverter is
available for use in the basic scheme shown above. Use one inverter
for each Type 87T.   Specify the Type 87T with 48vdc control rating.

Type 96 DC/DC Inverter: 24vdc to 48vdc Catalog Number 200P2448
                            32vdc to 48vdc Catalog Number 200P3248

Figure 13b: Outline Dimensions Type 96

Three-Winding Sample Settings Calculation (continued from page 12):

	Primary	Secondary	Tertiary

7. Select tap values
   A_{12} = 1.558 Closest ratios are 1.56 (5.0/3.2) and 1.55 (4.5/2.9), but
   looking at the second requirement:
   A_{13} = 3.003 requires the use of taps 8.7/2.9 = tertiary/primary; therefore,
   to satisfy both A_{12} and A_{13} select tap 2.9 for the primary side.
   This also automatically satisfies A_{23} = 1.928: 8.7/4.5 = 1.93.

Tap values are then   2.9A   4.5A   8.7A

(Note: in some cases it will be necessary to select different ct ratios and
       recalculate to obtain a workable combination of tap settings. In
       difficult cases it may be necessary to use a set of external auxiliary
       ct's to adjust one of the current inputs to a workable value.)

8. Relay currents at   1.79A   2.79A   2.32A
   max load currents
   Continuous rating of
   relay tap (Table 2)   10A ok   10A ok   17A ok

9. Mismatches M_{12} = (1.555-1.55)/1.55 M_{23} = (1.933/1.928)/1.928
                        =   0.3%   = 0.3%
                   M_{13} = (3.003-3.00)/3.00
                        =   0.0%

10. Select percentage differential setting:
    Mismatch is less than 15%, so use a relay setting of 25%.

11. Select the instantaneous setting:
    High-side relay current at self-cooled rating = $(30000/(161 * \sqrt{3}) * 5/400 * \sqrt{3}$
                                                  = 2.32A
    (2.32 * 10)/(primary side tap) = 23.2/2.9 = 8 (x tap).
    Multiply by 1.2 for margin: 8 x 1.2 = 9.6 (x tap)
    (Factory setting of 10 x tap is ok)

12. CT performance check
    CT secondary currents at max fault
                          18.9A   29.4A   58.2A
    Effective C ratings of ct's
                          267   200   167
    Maximum allowable burdens
                          7.0 ohms   3.4 ohms   1.4 ohms
    Maximum one-way lead resistance (assuming relay is the only connected device)
                          2.0 ohms   1.0 ohms   0.59 ohms

13. Minimum operating current
    Select setting to give minimum operating current of 30% relative to full load
    current:
                Primary side relay current at max load = 3.1A
                Primary side relay tap 2.9A
                30% x 3.1A/2.9A = 32% of tap
                R = .32*(100+D)/D = .32*(125)/25 = 1.6 (Min Restraint setting)