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INSTRUCTIONS

TRANSFORMER DIFFERENTIAL RELAY WITH PERCENTAGE AND HARMONIC RESTRAINT

TYPES:

BDD15B, FORMS 11 AND UP
BDD16B, FORMS 11 AND UP

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CONTENTS

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DESCRIPTION

Type BDD relays are differential relays designed specifically for transformer protection. The relays are provided with the features of percentage and harmonic restraint, and use a sensitive polarized unit as the operating element. Percentage restraint permits accurate discrimination between internal and external faults at high fault currents, while harmonic restraint enables the relay, by the difference in waveform, to distinguish between the differential current caused by an internal fault, and that of transformer magnetizing inrush.

Each Type BDD relay is a single-phase unit. The BDD15B relay is designed to be used for the protection of two-winding transformers, and has two through-current restraint circuits and one differential current circuit.

The BDD16B relay is designed for use with three-winding transformers, and has three through-current restraint circuits and one differential current circuit. It may also be used for four circuit transformer protection (Figure 9) when only three circuits require through-current restraint, while the fourth circuit, being the weakest, needs no through-current restraint.

Each BDD relay includes an instantaneous unit in addition to the main differential unit, and is mounted in an M1 size case. The internal connection diagrams for the BDD15B and BDD16B relays are shown in Figures 10 and 11. Typical external connections are shown in Figures 7, 8 and 9.

APPLICATION

The current transformer ratios and relay taps should be selected to obtain the maximum sensitivity without risking thermal overload, or the possibility of misoperation of the relay or current transformers. Therefore, current transformer ratios in the various windings of the power transformer should be selected with the following points in mind:

The lower the relay tap and the lower the CT ratio selected, the higher the sensitivity. However, the lowest CT ratio and the lowest relay tap may not be compatible with some of the following restrictions. Where a choice of increasing either the CT ratio or the relay tap is available, increase the CT ratio in preference to the relay tap.

Since the relay burden is likely to be small compared to the lead burden, increasing the CT ratio tends to improve the relative performance of the CTs as a result of reducing the maximum secondary fault current and increasing the accuracy of the CTs.

The CT secondary current should not exceed the continuous thermal rating of the CT secondary winding.

The relay current corresponding to maximum KVA (on a forced-cooled basis) should not exceed twice tap value, the thermal rating of the relay.

The CT ratios should be high enough that the secondary currents will not damage the relay under maximum internal fault conditions (refer to **RATINGS**).

The relay current corresponding to rated KVA of the power transformer (on a self-cooled basis) should not exceed the relay tap value selected (magnetizing inrush might operate the instantaneous overcurrent unit). If the transformer under consideration does not have a self-cooled rating, the transformer manufacturer should be consulted for the "equivalent self-cooled rating;" that is, the rating of a self-cooled transformer that would have the same magnetizing inrush characteristics as the transformer being considered.

The current transformer tap chosen must be able to supply the relay with eight times rated relay tap current with an error of less than 20 percent of total current. If the current transformers produce an error of greater than 20 percent at less than eight times tap value, the harmonic content of the secondary current may be sufficient to cause false restraint on internal faults.

The CT ratios should be selected to provide balanced secondary current on external faults. Since it is rarely possible to match the secondary currents exactly by selection of current transformer ratios, ratio-matching taps are provided on the relay. Currents may usually be matched within five percent using these taps. When the protected transformer is equipped with load ratio control, it is obvious that a close match cannot be obtained at all points of the ratio-changing range. In this case the secondary currents are matched at the middle of the range, and the percentage-differential characteristic of the relay is relied upon to prevent relay operation on the unbalanced current which flows when the load-ratio control is at the end of the range.

In some applications, the power transformer will be connected to the high voltage or low voltage system through two breakers, as shown in Figure 9; for example, a ring bus arrangement. In this case, the CT ratios must be selected so that the secondary windings will not be thermally overloaded on load current flowing around the ring in addition to the transformer load current. It is recommended that CTs on each of the two low voltage (or high voltage) breakers be connected to a separate restraining winding to assure restraint on heavy through-fault current flowing around the ring bus.

Two parallel transformer banks should not be protected with one set of differential protection, since the sensitivity of the protection will be reduced. In addition, if the banks can be switched separately, there is a possibility of flash operation on magnetizing inrush to one transformer bank causing a "sympathetic inrush" into the bank already energized. In this case, the harmonics tend to flow between the banks, with the possibility that there will be insufficient harmonics in the relay current to restrain the relay.

Typical elementary diagrams for the Type BDD15B and BDD16B relays are illustrated in Figures 7, 8 and 9.

RATINGS

MODELS BDD15B AND BDD16B

Continuous rating:

The through-current transformer and differential current transformer will stand twice tap value for any combination of taps; or they will stand twice tap value if all but one of the restraint windings carry zero current, and the full restraint current, equal to twice tap value, flows through the differential current transformer.

Short time rating (thermal):

The short time (thermal) rating is 220 amperes for one second measured in the primary of any transformer of the Type BDD relay. Higher currents may be applied for shorter lengths of time in accordance with the following equation:

$$I^2t = 48,400$$

where: I = current in amperes
t = time in seconds

Short time (electrical):

For both the Type BDD15B and BDD16B relays, the sum of the multiples of tap current fed to the relay from the several sets of current transformers should not exceed 150. These multiples should be calculated on the basis of RMS symmetrical fault current. Note that in Figure 9, external fault current flows through circuit breakers 51-1 and 51-2 without being limited by the transformer impedance.

AUXILIARY RELAY CONTROL CIRCUIT

The Type BDD15B and BDD16B relays are available for use with either 24-48 volts, 48-125 volts, 110-125 volts, 125-250 volts or 220-250 volts. A tap block is provided so that the relays may be used on either voltage of the dual rating.

CONTACTS

The BDD15B relay is provided with two sets of open contacts and the BDD16B is provided with one set of open contacts. The current-closing rating of the contacts is 30 amperes for voltages not exceeding 250 volts. If more than one circuit breaker per set of contacts is to be tripped, or if the tripping current exceeds 30 amperes, an auxiliary relay must be used with the BDD relay. After tripping occurs, the tripping circuit of these relays should be opened by an auxiliary switch on the circuit breaker, or by other automatic means. A hand-reset relay is recommended, and normally used.

CHARACTERISTICS

PICKUP AND OPERATING TIME

The operating characteristic is shown in Figures 4 and 4A. The curve for various percentage slopes shows the percent slope versus the through-current flowing in the transformer. The percentage slope is a figure given to a particular percent slope tap setting, and indicates approximate slope characteristic. Pickup at zero restraint is approximately 30 percent of tap value (see Table I). Figure 4A is the same curve, except it is expanded from five to zero amperes.

Curves of the operating time of the main unit and of the instantaneous unit are shown plotted against differential current in Figure 5. The main unit time given is the total time, and includes main unit operating time and auxiliary unit operating time.

OVERCURRENT UNIT PICKUP

The overcurrent unit is adjusted to pick up when the differential current transformer ampere-turns are eight times the ampere-turns produced by rated tap current flowing in that tap. For example, when only one CT supplies current, and the tap plug for the CT is in the five ampere tap, 40 amperes are required for pickup. This pickup value is based on the AC component of current transformer output only, since the differential current transformer in the relay produces only a half cycle of any DC (offset) component present.

If ratio matching taps are chosen so that rated CT current is not greater than the tap rating on a self-cooled basis, the overcurrent unit will not pick up on magnetizing inrush. If CT currents are greater than tap rating, there is danger that the unit may pick up, especially on small transformer banks. If this happens, then the CT ratio or relay tap setting should be increased, rather than increasing the pickup of the overcurrent unit. If the overcurrent unit setting must be raised, the requirements on CT error will be more stringent, in accordance with the following equation:

$$E = 20 - (2.5)(P-8)$$

where: E = CT error current in percent at pickup of the overcurrent unit
P = pickup of overcurrent unit in multiples of tap setting.

PERCENTAGE DIFFERENTIAL CHARACTERISTICS

The percentage differential characteristics are provided by through-current restraint circuits. In addition to the operating coil of the polarized unit, which is energized by the differential current of the line current transformers, the relay is equipped with a restraining coil, that is indirectly energized by the transformer secondary currents themselves. For the relay to operate, the current transformer secondary currents must be unbalanced by a certain minimum percentage determined by the relay slope setting (as shown in Figures 4 and 4A). This characteristic is necessary to prevent false operation on through-fault currents. High currents saturate the cores of the current transformers and cause their ratios to change, with the result that the secondary currents become unbalanced. Percentage restraint is also needed to prevent operation by the unbalanced currents caused by imperfect matching of the secondary currents.

HARMONIC RESTRAINT CHARACTERISTICS

At the time a power transformer is energized, current is supplied to the primary which establishes the required flux in the core. This current is called magnetizing inrush, and flows only through the current transformers in the primary winding. This causes an unbalanced current to flow in the differential relay, which would cause false operation if means were not provided to prevent it.

Power system fault currents are of a nearly pure sine wave form, plus a DC transient component. The sine wave form results from sinusoidal voltage generation, and nearly constant circuit impedance. The DC component depends on the time in the voltage cycle at which the fault occurs, and upon the circuit impedance magnitude and angle.

Transformer magnetizing inrush currents vary according to the extremely variable exciting impedance resulting from core saturation. They are often of high magnitude, occasionally having an RMS value with 100 percent offset approaching 16 times full load current for worst conditions of power transformer residual flux, and point of circuit closure on the voltage wave. They have a very distorted wave form, made up of sharply peaked half-cycle loops of current on one side of the zero axis, and practically no current during the opposite half cycles. The two current waves are illustrated in Figure 3.

Any currents of distorted, non-sinusoidal wave form may be considered as being composed of a direct current component, plus a number of sine wave components of different frequencies; one of the fundamental system frequency, and the others, "harmonics," having frequencies which are two, three, four, five (etc.), times the fundamental frequency. The relative magnitudes and phase positions of the harmonics, with reference to the fundamental, determine the wave form. When analyzed in this manner, the typical fault current wave is found to contain only a very small percentage of harmonics, while the typical magnetizing inrush current wave contains a considerable amount.

The high percentages of harmonic currents in the magnetizing inrush current wave afford an excellent means of distinguishing it electrically from the fault current wave. In Type BDD relays, the harmonic components are passed through the restraining coil of the relay, while the fundamental component is passed through the operating coil. The direct current component, present in both the magnetizing inrush and offset fault current waves, is largely blocked by the auxiliary differential current transformer inside the relay, and produces only slight momentary restraining effect. Relay operation occurs on differential current waves in which the ratio of harmonics to fundamental is lower than the given predetermined value for which the relay is set (e.g., an internal fault current wave), and is restrained on differential current waves in which the ratio exceeds this value (e.g., a magnetizing inrush current wave).

BURDENS

Note that burdens and minimum pickup values are substantially independent of the percent slope settings, and are all approximately 100 percent power factor. The figures given are the burdens imposed on each current transformer at 5.0 amperes.

TABLE I

RELAY	TAP SETTING AMPS	ZERO RESTRAINT PICKUP**** AMPS	OPERATING CIRCUIT** 60 HERTZ RELAYS***		RESTRAINT CIRCUIT 60 HERTZ RELAYS***	
			BURDEN VA	IMPEDANCE OHMS	BURDEN VA	IMPEDANCE OHMS
12BDD15B 12BDD16B	2.9	0.87	3.2	0.128	1.3	0.052
	3.2	0.96	2.7	0.108	1.2	0.048
	3.5	1.05	2.4	0.096	1.1	0.044
	3.8	1.14	2.0	0.080	1.0	0.040
	4.2	1.26	1.9	0.076	0.9	0.036
	4.6	1.38	1.6	0.064	0.8	0.032
	5.0	1.50	1.5	0.060	0.7	0.028
	8.7	2.61	0.7	0.028	0.5	0.020

**Burden of operating coil is zero under normal conditions

***Burden of 50 hertz relay is the same or slightly lower

****It should be recognized that pickup current flows not only through the differential current transformer, but also through one of the primary windings of the through-current transformer, producing some restraint. However, compared to the operating energy, this quantity of restraint is so small that it may be assumed to be zero.

CONSTRUCTION

Figures 1 and 1A show the internal arrangement of the components of the BDD16B relay. Reference the internal connection diagrams, Figure 10 and 11, to identify the parts more completely.

CURRENT TRANSFORMERS

In the Type BDD15B relay, the through-current transformer has two primary windings, one for each line current transformer circuit. Winding number 1 terminates at stud 6, and winding number 2 terminates at stud 4.

In the Type BDD16B relay, there are three separate through-current transformers, each with only one primary winding and each terminating at a separate stud, windings number 1, number 2 and number 3, corresponding to studs 6, 4 and 3, respectively.

In either relay, there is a differential current transformer with one primary lead brought out to stud 5.

The primary circuit of each of these transformers is completed through a special tap block arrangement. Two or three horizontal rows of tap positions are provided (depending on whether the relay is a Type BDD15B or BDD16B), one row for each through-current transformer winding. A tap on the differential current transformer is connected to a corresponding tap of the through-current restraint windings by inserting tap plugs in the tap blocks.

When the BDD16B relay is used on four-circuit applications, as shown in Figure 9, the fourth circuit CT is connected to stud 7, and the jumper normally connected between terminals 6 and 7, at the rear of the relay cradle, should be disconnected at the terminal 6 end. It should be reconnected to the upper row in the tap block (above the row marked winding number 1), which connects it directly to the differential current transformer in the BDD relay. The terminal on the movable lead should be placed under the tap screw that gives the best match for the current in the movable end.

The taps permit matching of unequal line current transformer secondary currents. The tap connections are so arranged that when matching secondary currents, and a tap plug is moved from one position to another in a horizontal row, the corresponding taps on both the differential current transformer winding, and one of the through-current transformer windings are simultaneously selected, so that the percent through-current restraint remains constant.

THROUGH-CURRENT RESTRAINT CIRCUIT

A full wave bridge rectifier receives the output of the secondary of each through-current restraint transformer. In the BDD16B relay, the DC outputs of all three units are connected in parallel. The total output is fed to a tapped resistor (R3) through the percent slope tap plate at the front of the relay. A 15, 25 or 40 percent slope adjustment may be selected by means of three taps. Resistor taps are adjustable and preset for given slopes. The right tap corresponds to the 40 percent slope setting. The output is rectified and applied to the restraint coil of the polarized unit.

DIFFERENTIAL CURRENT CIRCUIT

The differential current transformer secondary output directly supplies the instantaneous unit, the operating coils of the polarized unit through a series tuned circuit, and the harmonic restraint circuit through a parallel resonant trap. The operating and restraint currents are each passed through a full wave bridge rectifier before passing through the polarized unit coils.

The series resonant circuit is made up of a five microfarad capacitor (C1) and a reactor (L1) which are tuned to pass currents of the fundamental system frequency, and to offer high impedance to currents of other frequencies. Resistor R1 is connected in parallel on the DC side of the operate rectifier, and can be adjusted to give the desired amount of operate current. The output of the rectifier is applied to the operating coil of the polarized unit.

The parallel resonant trap is made up of a 15 microfarad capacitor (C2) and a reactor (L2) which are tuned to block fundamental frequency currents while allowing currents of harmonic frequencies to pass with relatively little impedance. Resistor R2 is connected in parallel on the AC side of the harmonic restraint rectifier, and can be adjusted to give the desired amount of harmonic restraint. The output of the rectifier is paralleled with the through-current restraint currents and applied to the restraint coil of the polarized unit.

It is evident that if the differential current applied to the Type BDD relay has sinusoidal wave form and system frequency, it will flow mostly in the operating coil circuit, and will cause the relay to operate. If on the other hand, the differential current contains more than a certain percentage of harmonics, the relay will be restrained from operating by the harmonic currents flowing in the restraint coil.

A Thyrite® resistor connected across the secondary of the differential current transformer limits any momentary high voltage peaks which may occur, thus protecting the rectifiers and capacitors from damage, without materially affecting the characteristics of the relay.

OVERCURRENT UNIT

The instantaneous unit is a hinged armature relay with a self-contained target indicator. On extremely heavy internal fault currents, this unit will pick up and complete the trip circuit. The instantaneous target will be exposed to indicate that tripping was through the instantaneous unit.

Because of saturation of the CTs and relay transformers at high fault currents, it is possible that less operating current will be provided from the differential current transformer than the percentage slope tap would imply, and more harmonic restraint will be provided than the actual harmonic content of the fault current would supply. As a result, the main unit may be falsely restrained under conditions of a high internal fault current. However, tripping is assured by the overcurrent unit operation. Pickup is set above the level of differential current produced by maximum magnetizing inrush current. Figure 5 shows the relative levels of pickup and speed of operation of the main unit and overcurrent unit.

MAIN OPERATING UNIT

The main operating unit of Type BDD relays is a sensitive polarized unit with components as shown within the large circuit of the internal connection diagrams, Figures 10 and 11. The unit has one operating and one restraining coil, and its contacts are identified as DHR (differential harmonic restraint) on the diagrams of the external connections diagrams, Figures 7, 8 and 9. The relay is a high-speed, low energy device, and its contacts are provided with an auxiliary unit whose contacts are brought out to studs for connection in an external circuit.

The polarized unit is mounted on an eight-prong base, which fits a standard octal radio socket, and is protected by a removable dust cover. It is mounted behind the nameplate of the BDD relay, and should require no further adjustment after the relay is shipped from the factory.

The auxiliary unit carries an indicating target, and is located on the left-hand side (front view) of the relay. The coil of this unit is not connected in the main circuit as a seal-in coil, but is connected to the DC control bus through an open contact of the polarized relay, and through a series resistor. A tap block is provided on the nameplate for selecting either of two DC control voltages.

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The coil of the auxiliary unit is controlled by both the open and closed contacts of the polarized unit. The polarized unit has approximately 0.005 inch contact gap, which under transient overvoltage conditions on the DC control bus of the order of 1200 volts, could break down momentarily. This will not cause false operation in the event that such a condition occurs, because the auxiliary relay is normally short-circuited by the closed contact of the polarized unit, and the series resistance is high enough to cause the arc to go out at normal voltage.

CASE

The relay case is suitable for either surface or semi-flush panel mounting. Hardware is provided with the relay for either mounting method. The cover attaches to the case and carries the target reset mechanism for the trip indicator and instantaneous unit. Each cover screw has provision for a sealing wire.

The case has studs or screw connections at the bottom for external connections. The electrical connections between the relay units and the case studs are made through spring backed contact fingers mounted in stationary molded inner and outer blocks, between which nests a removable connection plug, which completes the circuit. The outer blocks attached to the case have studs for the external connections, and the inner blocks have terminals for the internal connections.

The relay mechanism is mounted in a steel framework called a cradle and is a complete unit with all leads being terminated at the inner block. The cradle is held securely in the case with a latch at the top and the bottom and by a guide pin at the back of the case. The case and cradle design prevents inserting the relay into the case upside down. The connection plug, besides making electrical connections, also locks the latch in place. The cover, which is fastened to the case by thumbscrews, holds the connection plug in place.

To draw out the relay unit from the case, first carefully remove the cover, then the connection plugs. Shorting bars are built into the relay case to short the current transformer circuits (see Figure 6). Release the latches. The relay unit may now be removed from the case by pulling on the cradle. To replace the relay unit, follow the reverse order. Use care when placing the cover back on to the relay case to avoid damaging the reset mechanism.

A separate testing plug can be inserted in place of the connecting plug to test the relay in place on the panel, either from its own source of current, or from other sources. Or, the unit can be drawn out and replaced by another relay which has been tested in a laboratory.

RECEIVING, HANDLING AND STORAGE

These relays, when not included as part of a control panel, are shipped in cartons designed to protect them against damage. Immediately upon receipt of a relay, examine it for any damage sustained in transit. If damage due to rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Sales Office.

Exercise care when handling or unpacking the relay to avoid disturbing adjustments or damaging the relay.

If the relays are not to be installed immediately, they should be stored in their original cartons in a place that is free from moisture, dust and metallic particles. Foreign matter collected on the outside of the case may find its way to the inside of the case when the cover is removed, creating the possiblity of relay misoperation.

ACCEPTANCE TESTS

Immediately upon receipt of the relay, an inspection and acceptance test should be made to insure that no damage has been sustained in shipment, and that the relay calibrations have not been disturbed.

VISUAL INSPECTION

Check the nameplate stamping to insure that the model number, rating and calibration range of the relay agree with the requisition. Remove the relay from its case and check that there are no broken or cracked molded parts or other signs of physical damage, and that all screws are tight.

MECHANICAL INSPECTION

Check the operation of the auxiliary and instantaneous overcurrent units manually to see that they operate smoothly without noticeable friction or binding in the rotating structure of the units.

ELECTRICAL TESTS:

The following electrical tests are recommended upon receipt of the relay:

- o Check minimum pickup of main operating unit
- o Check minimum pickup of the instantaneous overcurrent unit
- o A single check point test on the harmonic restraint characteristic
- o A single check point test on the slope characteristic curve for the approximate slope to be used.

TEST FACILITIES

The following test equipment will facilitate tests:

- o Two load boxes for regulating test currents
- o Three ammeters (two AC and one DC) for measuring test currents
- o A test rectifier for checking the relay's response to the second harmonic
- o One indicating lamp
- o Two single-pole double-throw switch selector switches, with center-off position
- o A double-pole single-throw line switch.

Check the pickup of the main unit using the connections shown in Figure 12. During this test, the selector switches (S2 and S4) are open, and current passes through the differential circuit only. For example, on a relay set with 25 percent slope and a 2.9 ampere ratio matching tap, the main unit should pick up at 30 percent of tap rating, plus or minus ten percent; or the pickup should be between 0.78 and 0.96 ampere. To check that the main unit has picked up, a source of DC power at rated voltage should be connected as shown in Figure 12. The indicating lamp will provide a signal showing that the main unit has operated.

For an additional pickup test, set the pickup at 1.5 amperes with current flowing in terminals 5 and 6, and place the tap plugs in the five ampere and 25 percent slope tap position. Since the BDD relay uses a polarized unit with a very low energy level, the minimum pickup setting may vary as much as plus or minus ten percent. If the pickup is between 1.35 and 1.65 amperes, no adjustment should be made. Repeated pickup operations in succession erase the magnetic memory of previous tests, which may have affected the first tests. A severe through-fault will produce an effect which will increase the current required to pick up the relay. The pickup of the BDD relay has wider permissible variations than most protective relays, but due to the relay design and application, relay accuracy is entirely adequate under all conditions, even during transformer magnetizing inrush or severe fault conditions.

With the selector switch, S2, in the A position, check the harmonic current restraint as described in **INSTALLATION PROCEDURE**.

The instantaneous overcurrent unit should be checked by passing a high current through the 5-6 terminals. Pickup should be about eight times tap rating. Check through-current restraint as described in **INSTALLATION PROCEDURE**.

After the other tests are complete, check relay dropout with the selector switches(es) open. The purpose of this test is to insure that the polarized operating element will reset properly after a heavy internal fault current, which can leave excessive residual flux in its magnetic structure. Apply a current of 30 amperes to terminals 5 and 6 with tap plugs for all windings in the 2.9 ampere tap position, and the percent slope tap plug in the 25 percent slope position. This will cause the auxiliary relay to pick up sharply. The current should then be reduced, rapidly at first, and then slowly until the auxiliary relay drops out. Dropout current should be 0.1 ampere or more. If dropout current is other than as specified, the polarized unit is defective, and should be replaced.

INSTALLATION PROCEDURE

TESTS

Before placing the relay in service, check the relay calibration that will be used to insure it is correct. The following test procedure is outlined for this purpose.

CAUTION: The relay calibration is accomplished by adjusting resistors R1, R2 and R3. Changes made in any one of these resistors will affect the other two resistors' settings. In the event one setting is changed, the pickup, harmonic restraint and through-current restraint adjustment procedures should be repeated until no further deviation from proper calibration is noted. The best results are obtained when the through-current restraint adjustment is made after the other two settings are correct.

PICKUP

The test circuit for pickup is as shown in Figure 14, with S2 open. Pickup should be 1.5 amperes with current flowing in terminals 5 and 6, and the tap plugs in the five ampere and 25 percent slope tap positions. The pickup operation should be repeated several times until two successive readings agree within 0.01 ampere, with total pickup current being interrupted between successive checks.

The pickup of the polarized unit varies slightly depending upon the history of its magnetic circuit. The repeated pickup operation restores the condition of the magnetic circuit to some reference level, thus eliminating any initial variation in magnetic history.

The condition of the magnetic circuit is influenced by the manner in which pickup current is removed after a test. For this reason, pickup readings will be slightly lower if the current in the differential circuit is reduced gradually, than if the current is abruptly reduced or interrupted. Energy is stored in the series tuned circuit when the current is applied. This energy is dissipated in the harmonic restraint circuit, the path of least impedance, when the current is abruptly reduced or removed. The restraint coil of the polarized unit, having approximately three times as many turns as the operating coil, receives a greater saturating effect than the operating coil. The net effect is as though a restraint saturating current were applied to the relay.

Since the BDD relays use a polarized unit with very low energy level, the minimum pickup may vary as much as plus or minus ten percent. If the pickup is found to be anywhere within this range, 1.35-1.65 amperes, the setting should not be disturbed.

With DC control voltage applied to the proper studs of the relay, the pickup of the auxiliary unit can be used as an indication of operation of the polarized relay unit. This voltage may be applied as shown in Figure 14, and the indicating lamp will indicate that the main unit has operated.

If the pickup is found to be out of adjustment, adjust the position of the band on resistor R1, which is connected in parallel with the operating coil of the polarized unit. Resistor R1 is located at the top of the relay, and is the left-hand adjustable resistor (see Figure 2).

HARMONIC CURRENT RESTRAINT

The harmonic restraint is adjusted by means of a test rectifier, used in conjunction with suitable ammeters and load boxes. The test is shown in Figure 14, with S2 closed to position A. Tests should be made on the 5.0 ampere and 25 percent slope taps.

The analysis of a single-phase, half wave rectified current shows the presence of fixed percentages of DC, fundamental and second harmonic components, as well as negligible percentages of all higher even harmonics. This closely approximates a typical transformer inrush current, as seen at the relay terminals, inasmuch as its principal components are DC, fundamental and second harmonic. Although the percent second harmonic is fixed, the overall percentage may be varied by providing a path for a controlled amount of by-passed current of fundamental frequency. The by-passed current is added in phase with the fundamental component of half wave rectified current, thus providing a means of varying the ratio of the second harmonic to fundamental current.

The following expression shows the relationship between the percent second harmonic, the DC component, and the by-pass current:

$$\% \text{ Second harmonic} = \frac{0.212 \times I_{DC}}{0.45 \times I_1 + 0.5 \times I_{DC}} \times 100$$

Figure 15 is derived from the above expression and shows the percent second harmonc corresponding to various values of bypass current (I_1) for a constant DC set at 4.0 amperes.

Unless otherwise specified by the requisition, the relay is calibrated at the factory using the lower DC control voltage tap. Since the percent second harmonic required to restrain the relay will be approximately one percent higher if the calibration is checked using the higher tap, harmonic restraint must be tested on the lower tap in order for the field test to agree with the factory calibration.

The relay is calibrated with a composite RMS current of two times tap value. When properly set, the relay will restrain with greater than 20 percent second harmonic, but will operate with the second harmonic equal to 20 percent or lower. With the DC ammeter (I_2) set at 4.0 amperes, the auxiliary relay should just begin to close its contacts with gradually increasing bypass current (I_1) at a value of 4.5 to 5.5 amperes. This corresponds to 19 to 21 percent second harmonic (see Figure 15), providing a two percent tolerance at the set point to compensate for normal fluctuations in pickup. It should be noted that the current magnitude in the rectifier branch (I_2) is slightly influenced by the application of bypass current (I_1), and should be checked to insure that it is maintained at its proper value.

In the event a suitable DC ammeter is not available, the proper half wave rectified current may be set using an AC ammeter in position I_2 by shorting out the rectifier and setting the unrectified current at 9.0 amperes. If the rectifier is then unshorted, the half wave rectified current will automatically establish itself at the proper value.

If harmonic restraint is found to be out of adjustment, it may be corrected by adjusting resistor R2, which is connected in parallel on the AC side of the rectifier, with the restraint coil of the polarized relay. This resistor is located at the top of the relay, and is the right-hand adjustable resistor (see Figure 2).

THROUGH-CURRENT RESTRAINT.

The through-current restraint, which gives the relay the percentage differential or percent slope characteristics shown in Figure 5, may be checked and adjusted using the circuit illustrated in Figure 14, with S2 closed to position B. Ammeter I_1 reads the differential current, and I_3 reads the smaller of the two through-currents. When testing BDD16B relays, the setting should be checked with switch S4 first in one position, and then the other, thus checking all the restraint coils. The relay should just pick up for the values of I_1 and I_3 currents indicated in Table II, with the current tap plugs in the 5.0 ampere position, and the percent slope tap plug in the 40 percent position. Repeat with the percent slope tap plug in the 25 and 15 percent positions. If any one of these set points is not as prescribed, adjust the particular band on resistor R3 (located near the top of the case behind the nameplete) associated with it, as indicated in Table II. Note that the current magnitude in the through-current branch (I_3) is slightly influenced by the application of the differential current (I_1) and should be checked to insure that it is maintained at its proper value.

Any change in R3 to obtain the desired slope will have a small effect upon minimum pickup and harmonic restraint. However once the slope setting has been set, any adjustment of minimum pickup will change the slope characteristics. The slope set points must then be rechecked to insure that they are in accordance with Table II.

NOTE: These currents should only be permitted to flow for a few seconds at a time with cooling periods between tests; otherwise, the coils will be overheated.

TABLE II

PERCENT SLOPE TAP	BAND ON RESISTOR R3	AMPERES		TRUE SLOPE
		I_3	I_1	$(I_1/I_3 \times 100)$
40	Right	30	12.0 - 13.2	40.0 - 44.0
25	Middle	30	7.5 - 8.3	25.0 - 27.5
15	Left	30	4.8 - 5.0	15.0 - 16.5

NOTE: The percent slope tolerance is ten percent of nominal, all in the plus direction. This is to insure that the slope characteristic never falls below tap value.

INSTANTANEOUS OVERCURRENT UNIT

This unit is located at the upper right-hand side of the relay. Its setting may be checked by passing a high current of rated frequency through terminals 5 and 6. The unit should pick up at eight times the tap rating as described in **CHARACTERISTICS**. If the setting is incorrect, adjust by loosening the locknut at the top of the unit, and turn the cap screw until the proper pickup is obtained. When making this adjustment, the current should not be allowed to flow for more than approximately one second at a time.

DROPOUT OF MAIN UNIT

After the other tests are complete, check the dropout of the main unit as described in the **ACCEPTANCE TESTS** section.

LOCATION

The location should be clean and dry, free from dust and vibration, and well lighted to facilitate inspection and testing.

MOUNTING

The relay should be mounted on a vertical surface. The outline and panel drilling drawings are shown in Figure 18.

CONNECTIONS

The internal connection diagrams are shown in Figures 10 and 11. Typical wiring diagrams for different applications are shown in Figures 7, 8 and 9. Any through-current transformer winding may be used for any power transformer winding, provided the taps are properly chosen.

When the relay is mounted on an insulating panel, one of the steel supporting studs should be permanently grounded by a conductor of not less than #12 B&S gage copper wire, or its equivalent.

CAUTION

EVERY CIRCUIT IN THE DRAWOUT CASE HAS AN AUXILIARY BRUSH, THE SHORTEST BRUSH IN THE CASE WHICH THE CONNECTING PLUG FIRST ENGAGES. IT IS ESPECIALLY IMPORTANT ON CURRENT CIRCUITS, AND OTHER CIRCUITS WITH SHORTING BARS, THAT THE AUXILIARY BRUSH BE BENT HIGH ENOUGH TO ENGAGE THE CONNECTING PLUG OR TEST PLUG BEFORE THE MAIN BRUSHES DO. THIS WILL PREVENT THE CURRENT TRANSFORMER SECONDARY CIRCUITS FROM BEING OPENED WHEN ONE BRUSH TOUCHES THE SHORTING BAR BEFORE THE CIRCUIT IS COMPLETED FROM THE CONNECTING PLUG TO THE OTHER MAIN BRUSH.

ADJUSTMENTS

TAP PLUG POSITIONING - Ratio Matching Adjustment

To obtain a minimum unbalance current in the differential circuit, Type BDD relays are provided with means to compensate for unavoidable differences in current transformer ratios. Taps on the relay transformer primary windings are rated 8.7, 5.0, 4.6, 3.8, 3.5, 3.2 and 2.9 amperes for each line current transformer. The tap plugs should be placed in the location which most nearly matches the expected CT currents for the same KVA assumed in each of the power transformer windings. The selection of taps should be guided by the method outlined under **CALCULATION OF SETTINGS**. The connection plug must be removed from the relay before changing tap positions in order to prevent open-circuiting a CT secondary. A CHECK SHOULD BE MADE AFTER CHANGING TAPS TO INSURE THAT ONLY ONE PLUG IS LEFT IN ANY HORIZONTAL ROW OF TAP HOLES. INACCURATE CALIBRATION AND OVERHEATING MAY RESULT IF MORE THAN ONE PLUG IS CONNECTED TO ANY ONE WINDING.

UNBALANCE CURRENT MEASUREMENT

Unbalance current measurement is useful in checking the best tap setting when matching current transformer ratios in the field. It is also useful in detecting errors of faults in the current transformer winding, or small faults within the power transformer itself, when the fault current is too low to operate the relay.

Type BDD relays have a special arrangement for measuring the unbalance current flowing in the differential circuit without disturbing the relay connections. Provisions are made for temporarily connecting a five volt, high resistance AC voltmeter (1,000 or more ohms per volt) across the secondary of the differential current transformer. This is accomplished by connecting the meter across terminals 8 and 9 (see Figure 10 or Figure 11). The voltmeter will read zero when a perfect match is obtained by the ratio matching taps, indicating no unbalance. If the voltmeter reads 1.5 volts or less, the unbalance current entering or leaving a given tap equals approximately 0.03 times the voltmeter reading times the tap rating. For higher voltmeter readings, the approximate unbalance current may be calculated by substituting the voltage reading and tap rating into the following equation:

I (Unbalance) = (0.16 [voltmeter reading - 0.2]) x Tap

The unbalance percentage equals 100 times the unbalance current, divided by the measured tap current. For a three winding bank, this unbalance must be checked with load on at least two pairs of windings in order to insure that the connections are correct.

The curves in Figure 16 show the approximate voltages across terminals 8 and 9 required to operate the relay for various percent slope tap settings and through-currents, expressed as percentages of tap. To insure a margin of safety against false operation, the unbalance voltage should not exceed 75 percent of that voltage required to operate the relay for any given through-current and percent slope tap setting. This extent of unbalance may result from the relatively high error currents of low ratio bushing CTs at low multiples of tap current. These curves represent the BDD relay characteristic. A voltage measurement across studs 8 and 9 of 75 percent or less of the value given on the curve does not necessarily indicate that the relay will operate at higher through-current values. This is especially true when very high through-faults may cause CT saturation.

Small rectifier-type AC voltmeters are suitable for measurement of unbalance. The voltmeter should not be permanently connected, since the shunt current it draws reduces the relay sensitivity.

PERCENT SLOPE SETTING

Taps for 15, 25 and 40 percent slope settings are provided in both BDD15B and BDD16B relays. It is common practice to use the 25 percent setting unless special connections make it advisable to use one of the others. See the PERCENT SLOPE SETTING heading in the **CALCULATION OF SETTINGS** section of this instruction book for further details.

CALCULATION OF SETTINGS

METHOD

The calculations required for determining the proper relay and current transformer taps are outlined below. Connections for a sample calculation for the transformer are shown in Figure 17.

CURRENT TRANSFORMER CONNECTIONS

Power Transformer Connections	Current Transformer Connections
o Delta-wye	o Wye-delta
o Wye-delta	o Delta-wye
o Delta-delta	o Wye-wye
o Wye-wye	o Delta-delta
o Delta-zigzag	o Delta-delta

o with zero degrees phase shift between primary and secondary

DETERMINATION OF CT TURNS AND TYPE BDD RELAY TAP SETTINGS

1. Determine the maximum line currents (MAX I_P) on the basis that each power transformer winding may carry the maximum forced-cooled rated KVA of the transformer:

$$\text{MAX } I_P = \frac{\text{Maximum Transformer KVA}}{\sqrt{3}\ (\text{line KV})}$$

2. Determine the full load rated line currents (100% I_P) on the basis that each power transformer winding may carry the full self-cooled rated KVA of the transformer, or the "equivalent" self-ratings:

$$100\%\ I_P = \frac{100\%\ \text{Transformer KVA}}{\sqrt{3}\ (\text{line KV})}$$

   Actually this calculation does not mean that all windings will necessarily carry these maximum load currents continuously. This is only a convenient way of calculating the currents in the other windings in proportion to their voltage ratings. This is the requirement for selecting the relay tap setting so that the relay will not operate for any external fault.

3. Select CT ratios so that the secondary current corresponding to MAX I_P does not exceed the CT secondary thermal rating (five amperes). In the case of a transformer connected to a ring bus, for example, the CT ratio should be selected so that the CT thermal rating will not be exceeded by the maximum load current in either breaker. Also select CT ratios so that the relay currents can be properly matched by means of the relay taps (highest current not more than three times the lowest current).

   For wye-connected CTs:

$$\text{Tap Current} = \frac{100\%\ I_P}{N}$$

   For delta-connected CTs:

$$\text{Tap Current} = \frac{100\%\ I_P\sqrt{3}}{N}$$

   where: N = number of CT secondary turns.

4. Check the matching of relay currents to relay taps to keep the mismatch error as low as possible.

   Calculate the percent mismatch as follows: On two-winding transformers, determine the ratio of the two relay currents and the tap values selected. The difference between these ratios, divided by the smaller ratio, is the percent mismatch. The mismatch should not normally exceed five percent.

For three-winding transformers, the percent of mismatch error should be checked for all combinations of currents or taps.

If taps cannot be selected to keep this error percentage within allowable limits, choose a different CT ratio on one or more lines to obtain a better match between relay and currents and relay taps.

5. Check that the sum of relay currents that will be applied to the relay for a fault at the terminals of the power transformer is less than 220 amperes RMS for one second. If the period during which a fault current flows in the relay can definitely be limited to a shorter time, a higher current can be accommodated in accordance with the equation:

$$(\text{Amperes})^2 \times \text{seconds} = 48{,}400$$

Also check that the sum of the multiples of tap current on an internal or external fault does not exceed 150.

CURRENT TRANSFORMER RATIO ERROR

The current transformer ratio error must be less than 20 percent at eight times relay rated tap current. This is based on the instantaneous unit being set at its normal setting, which is eight times tap rating. If the instantaneous unit pickup is raised above this value, the 20 percent figure must be reduced as described in **CHARACTERISTICS**.

As far as CT performance is concerned, the calculations listed below are for the worst fault condition, which is an internal ground fault between the CT and the transformer winding, with none of the fault current supplied through the neutral of the protected transformer.

1. Determine the burden on each CT, using the following expressions:

For wye-connected CTs

$$Z = B + \frac{Ne + 2.50f}{1000} + 2.27R \text{ ohms}$$

For delta-connected CTs

$$Z = 2B + \frac{Ne + 2.50f}{1000} + 2.27R \text{ ohms}$$

where:
B = BDD relay total burden (See Table III)
N = number of turns in bushing CT
e = bushing CT resistance per turn, milliohms
f = bushing CT resistance per lead, milliohms
R = one-way lead resistance (at maximum expected temperature)

NOTE: The multipliers used on the f and R terms include factors to cover two leads instead of one, increase of resistance due to temperature rise, and resistance of longest CT leads.

TABLE III

TOTAL BURDEN FOR 60 HERTZ RELAYS

BDD TAP (AMPS)	8 TIMES TAP (AMPS)	BURDEN (B) (OHMS)	MINIMUM PICKUP (AMPS)
2.9	23.2	0.180	0.87
3.2	25.6	0.156	0.96
3.5	28.0	0.140	1.04
3.8	30.4	0.120	1.14
4.2	33.6	0.112	1.26
4.6	36.8	0.096	1.38
5.0	40.0	0.088	1.50
8.7	69.6	0.048	2.61

2. Determine CT secondary current for eight times tap setting

$$I_S = 8 \times \text{BDD relay tap setting}$$

NOTE: For the type of fault assumed, all the fault current is supplied by one CT, so that CT current and relay current are the same, regardless of whether the CTs are connected in wye or delta.

3. Determine secondary CT voltage required at eight times tap setting

$$E_{sec} = I_S Z$$

4. From the excitation curve of the particular tap of current transformer being used, determine excitation current, I_E, corresponding to the secondary voltage, E_{sec}.

5. Determine the percent error in each CT

$$\text{Percent error} = \frac{I_E}{I_S} \times 100$$

This should not exceed 20 percent of any set of CTs. If it does, choose a higher tap on that set of CTs, and repeat the calculations on selection of relay taps, mismatch error and percent ratio error.

PERCENT SLOPE SETTING

A proper percent slope is determined by the sum of:

- The maximum range of manual taps and the load-ratio control, or automatic tap changing means in percent.

- The maximum percent of mismatch of the relay taps.

The percentage slope tap selected should be greater than the ratio of maximum total error current to the smallest of the through-currents. In general, if the total error current does not exceed 20 percent, the 25 percent tap is used. If it exceeds 20 percent, but not 35 percent, the 40 percent tap is used.

If the movable lead is used (as in Figure 9, for example), the percent slope tap chosen should be twice as high, since the movable lead provides no restraint.

DETERMINATION OF CT TURNS AND BDD RELAY TAP SETTINGS - Refer to the example in Figure 17.

Transformer and Line	A	B	C
MAX Ip = 3750/ $\sqrt{3}$ (line kV)	19.7	49.5	157
100% Ip = 3000/ $\sqrt{3}$ (line kV)	15.7	39.6	125
Assume CT turns	20	20	60
MAX I_{sec} (less than 5 amps)	0.98	2.47	2.62
100% I_{sec}	0.79	1.98	2.08
CT connections	Delta	Wye	Delta
Relay Current for 100% I_{sec}	1.37	1.98	3.60

Select a relay tap for one of the line currents and calculate what the currents in other lines would be if they were increased by the same ratio. If any current is greater than the square root of three times any other line, the 8.7 tap should be chosen for it, and new, "ideal," relay taps calculated for the other lines.

	A	B	C
Ideal relay taps (set C = 8.7)	3.31	4.78	8.7
Try Relay Taps:	3.2	4.6	8.7

Check mismatch error:

Ratio of taps on lines B-A: $\frac{4.6}{3.2} = 1.43$

Ratio of secondary line's currents: $\frac{1.98}{1.37} = 1.44$

Mismatch: $\frac{1.44 - 1.43}{1.43} = 0.7\%$

Ratio of taps on lines C-B: $\frac{8.7}{4.6} = 1.89$

Ratio of secondary line's currents: $\frac{3.60}{1.98} = 1.82$

Mismatch: $\frac{1.89 - 1.82}{1.82} = 3.8\%$

Ratio of taps on lines C-A: $\frac{8.7}{3.2} = 2.72$

Ratio of secondary line's currents: $\frac{3.60}{1.37} = 2.63$

Mismatch: $\frac{2.72 - 2.63}{2.63} = 3.4\%$

All are less than five percent; therefore, mismatch error is not excessive.

Check that the sum of the maximum relay currents is less than 220 amperes for one second and that the short-time rating of the relay is not exceeded.

PERCENT RATIO ERROR

Burdens on CTs (assume one-way resistance is 0.25 ohms)

$$\text{Line A:} \quad Z = 2(0.156) + \frac{(20 \times 4) + (2.50 \times 50)}{1000} + 2.27(0.25)$$

$$= 0.312 + 0.205 + 0.568 = 1.085$$

$$\text{Line B:} \quad Z = 0.096 + \frac{(20 \times 2.5) + (2.50 \times 35)}{1000} + 0.568$$

$$= 0.096 + 0.138 + 0.568 = 0.80$$

$$\text{Line C:} \quad Z = 2(0.048) + \frac{(60 \times 2.3) + (2.5 \times 12.4)}{1000} + 0.568$$

$$= 0.096 + 0.169 + 0.568 = 0.833$$

	A	B	C
Impedance, ohms	0.085	0.8	0.833
Eight times tap, amperes	25.6	36.8	69.6
E_S CT voltage required (I_Z)	27.8	29.4	50.8
I_E required, from excitation curve	1.00	50	0.5
Percent Ratio Error	3.4%	136%	0.8%

Exciting curve on line B is too high, try higher tap on CT to improve CT performance.

REPEAT: CT TURNS AND RELAY TAP SETTING

	A	B	C
100% I	15.7	39.6	125
Try CT turns: (necessary to change C also for proper match)	20	40	80
100% I_{sec}	0.79	0.99	1.56
Relay current	1.37	0.99	2.70
Ideal relay taps (set C = 8.7)	4.40	3.19	8.7
Use taps:	4.6	3.2	8.7

Mismatch error is less than five percent.

REPEAT: PERCENT RATIO ERROR

Burdens on CTs:

Line A: Z = 0.192 + 0.205 + 0.568 = 0.965

Line B: Z = 0.156 + 0.188 + 0.568 = 0.912

Line C: Z = 0.096 + 0.215 + 0.568 = 0.879

	A	B	C
Impedance, ohms	0.965	0.912	0.879
Eight times tap, amperes	36.8	25.6	69.6
E_{sec}' CT voltage required (I_Z)	35.6	23.4	61
I_E required, from excitation curve	1.1	0.25	0.17
Percent of ratio error	3.1%	1.0%	0.3%

Percent error is less than 20 percent, so CT and relay taps are satisfactory.

PERCENT SLOPE SETTING

Assume load ratio control, maximum range	10.0
Relay tap mismatch, from above (lines A-B)	4.6%
	14.6%

Use 25% tap

OPERATING PRINCIPLES

TARGETS

Targets are provided for both the auxiliary relay and the instantaneous overcurrent unit. In the event of an internal fault, one or both of these units will operate, depending upon the fault magnitude. This will produce a target indication on the unit that operates. The auxiliary relay does not function as a seal-in since it does not carry breaker tripping current. After a fault is cleared, the target should be reset by the reset slide, located at the lower left hand corner of the relay.

DISABLING TYPE BDD RELAYS

When bypassing a breaker during maintenance, the BDD relay must be disabled to prevent false tripping. If disabling is done by a remote switch rather than by removal of the relay connection plug, the following precautions must be taken:

Short circuit studs 8 and 9 of the relay, or open the trip circuit at stud 1. The trip circuit should be opened at stud 1 because the series resistors in the auxiliary relay circuit cannot withstand continuously rated control voltage, in the event that the polarized relay operates.

If the CT secondaries are short-circuited as part of the disabling procedure, the trip circuit should be opened at stud 1, and studs 8 and 9 should be short-circuited before the CT secondaries are short-circuited. Do not rely on short-circuiting the CT secondaries only, because any difference in shorting time may cause false tripping.

MAINTENANCE

CONTACT CLEANING

A flexible burnishing tool should be used for cleaning fine silver contacts. This is a flexible strip of metal with an etched-roughened surface, which in effect resembles a superfine file. The polishing action of this file is so delicate that no scratches are left on the contacts, yet it cleans off any corrosion thoroughly and rapidly. The flexibility of the tool insures the cleaning of the actual points of contact.

Fine silver contacts should not be cleaned with knives, files, or abrasive paper or cloth. Knives or files may leave scratches which increase arcing and deterioration of the contacts. Abrasive paper or cloth may leave minute particles of insulating abrasive material in the contacts and thus prevent closing.

The burnishing tool described above can be obtained from the factory.

PERIODIC CHECKS AND ROUTINE MAINTENANCE

An operation test and inspection of the relay and its connections should be made at least once every six months. Tests may be performed as described in **INSTALLATION TESTS**, or they made be made on the service taps as described in this section.

When inserting or withdrawing a U-shaped test plug through-jumper to complete the trip circuit through the test plug, similar through-jumpers should also be used on studs 8 and 9 to maintain the connections from the relay to the case. If not, false tripping upon insertion or removal of the test plug may occur.

PICKUP

Check pickup as described in **INSTALLATION TESTS**, except pickup current will be different, depending upon the winding 1 service tap. Pickup value may be determined as follows:

$$I_1 = 0.30 \times \text{winding 1 tap}$$

When checking pickup on a particular service tap, the expected plus or minus ten percent variation still applies, with the following acceptable as found values

$$I_1 = 0.90 \times 0.30 \times \text{winding 1 tap to}$$

$$1.10 \times 0.30 \times \text{winding 1 tap}$$

EXAMPLE:

winding 1 tap = 3.5 amperes
$I_1 = 0.90 \times 0.30 \times 3.5$ to $1.10 \times 0.30 \times 3.5$
$I_1 = 0.94$ to 1.16 amperes

HARMONIC CURRENT RESTRAINT

The procedure for checking harmonic restraint is as described in **INSTALLATION TESTS**, except the test current values must be modified as follows:

I_2 (DC) = 0.80 x winding 1 tap
I_1 = 0.90 x winding 1 tap to 1.10 x winding 1 tap

In the event a suitable DC meter is not available, I_2 (AC) = 2.25 x I_2 (DC) (theoretically, this conversion factor would be 2.22 if the rectifier back resistance were infinite).

EXAMPLE

winding 1 tap = 3.5 amperes
I_2 (DC) = 0.80 x 3.5 = 2.8 amperes
$I_1 = 0.90 \times 3.5$ to 1.10×3.5
I_1 = 3.15 to 3.85 amperes

If a DC meter is not available:

$$I_2 \text{ (AC)} = 2.25 \times 2.8 = 6.30 \text{ amperes}$$

THROUGH-CURRENT RESTRAINT

In order to check the service tap slope setting, the test current values indicated in Table II must be modified to take differences in tap setting into account. Furthermore, the test circuit shown in Figure 14 must be set up so that the lead from ammeter I_3 to the test plug is connected to the stud corresponding to the winding with the lowest tap setting. The common lead is connected to the stud corresponding to the winding with the highest tap setting.

For any combination of taps, the percent slope is given by the following equation:

$$\text{Percent slope} = \left[\frac{T1}{T2}\left(\frac{I_1}{I_3} + 1\right) - 1\right] \times 100$$

where:
- $T1$ = smallest tap setting
- $T2$ = highest tap setting
- I_1 = differential current
- I_3 = smaller of two through-currents

Table IV is derived from the above expression and is based on a multiple of tap current six times the lowest tap setting for all combinations of taps, except those which involved the 8.7 ampere tap. For the latter case, a four times tap setting is used, since the total test current for a six times tap setting may be as high as 75.2 amperes, which is not only prohibitively high for many installations, but also may subject the relay to excessive heating.

In some cases, it may not be possible to calibrate the slope setting to within tolerance for all tap combinations being used. In this case, only the tap combination that produces the lowest percent slope should be calibrated using Table IV. This will ensure that none of the tap combinations will have a percent slope characteristic that is below the set point.

For a given tabular value of I_3, corresponding to a given combination of winding and percent slope taps, the values of I_1 (minimum) and I_1 (maximum) correspond to the minimum and maximum percent slope tolerance limits given in Table II. However, for a four times tap setting, both the upper and lower percent slope tolerance limits have been raised by a value equivalent to the difference between the true slope and the nominal slope at four times tap value indicated by the percent slope characteristic curves, shown in Figure 4 and 4A.

EXAMPLE:

Winding 1 tap = 3.5 amperes
Winding 2 tap = 5.0 amperes
Slope tap = 40 percent

Since winding 1 has the lower tap setting, the lead from ammeter I_3 to the test plug should be connected to stud 6, and the common lead should be connected to stud 4.

From Table IV:

I_3 = 21.0 amperes
$I_{1(min)}$ = 21.0 amperes
$I_{1(max)}$ = 22.2 amperes

TABLE IV

TAPS T2		2.9			3.2			3.5			3.8			4.2			4.6			5.0			8.7		
T1	Slopes / Currents	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40
2.9	I_3	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	11.6	11.6	11.6
	I_1(min)	2.6	4.3	7.0	4.6	6.6	9.5	6.7	8.8	12.0	8.8	11.1	14.5	11.6	14.1	17.9	14.3	17.1	21.2	17.1	20.1	24.6	28.7	32.2	37.4
	I_1(max)	2.9	4.8	7.7	5.0	7.1	10.3	7.1	9.4	12.8	9.2	11.7	15.4	12.0	14.8	18.9	14.8	17.8	22.4	17.6	20.9	25.8	29.3	33.1	38.9
3.2	I_3				19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	12.8	12.8	12.8
	I_1(min)				2.9	4.8	7.7	4.9	7.0	10.2	7.0	9.3	12.7	9.8	12.3	16.1	12.5	15.3	19.4	15.3	18.3	22.8	27.5	31.0	36.2
	I_1(max)				3.2	5.3	8.5	5.3	7.6	11.0	7.4	9.9	13.6	10.2	13.0	17.1	13.0	16.0	20.6	15.8	19.1	24.0	28.1	31.9	37.7
3.5	I_3							21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	14.0	14.0	14.0
	I_1(min)							3.1	5.2	8.4	5.2	7.5	10.9	8.0	10.5	14.3	10.7	13.5	17.6	13.5	16.5	21.0	26.3	29.8	35.0
	I_1(max)							3.5	5.8	9.3	5.6	8.1	11.8	8.4	11.2	15.3	11.2	14.2	18.8	14.0	17.3	22.2	26.9	30.7	36.5
3.8	I_3										22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	15.2	15.2	15.2
	I_1(min)										3.4	5.7	9.1	6.2	8.7	12.5	8.9	11.7	15.8	11.7	14.7	19.2	25.1	28.6	33.8
	I_1(max)										3.8	6.3	10.0	6.6	9.4	13.5	9.4	12.4	17.0	12.2	15.5	20.4	25.7	29.5	35.3
4.2	I_3													25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	16.8	16.8	16.8
	I_1(min)													3.8	6.3	10.1	6.5	9.3	13.4	9.3	12.3	16.8	23.5	27.0	32.2
	I_1(max)													4.2	7.0	11.1	7.0	10.0	14.6	9.8	13.1	18.0	24.1	27.9	33.7
4.6	I_3																27.6	27.6	27.6	27.6	27.6	27.6	18.4	18.4	18.4
	I_1(min)																4.1	6.9	11.0	6.9	9.9	14.4	21.9	25.4	30.6
	I_1(max)																4.6	7.6	12.2	7.4	10.7	15.6	22.5	26.3	32.1
5.0	I_3																			30.0	30.0	30.0	20.0	20.0	20.0
	I_1(min)																			4.5	7.5	12.0	20.3	23.8	29.0
	I_1(max)																			5.0	8.3	13.2	20.9	24.7	30.5
8.7	I_3																						34.8	34.8	34.8
	I_1(min)																						5.5	9.0	14.2
	I_1(max)																						6.1	9.9	15.7

RENEWAL PARTS

Sufficient quantities of renewal parts should be kept in stock for the prompt replacement of any that are worn, broken or damaged.

When ordering renewal parts, address the nearest Sales Office of the General Electric Company. Specify the name of the part wanted, quantity required, and complete nameplate data, including the serial number, of the relay.

Since the last edition, the equation has been changed in the THROUGH-CURRENT RESTRAINT section on p.27.

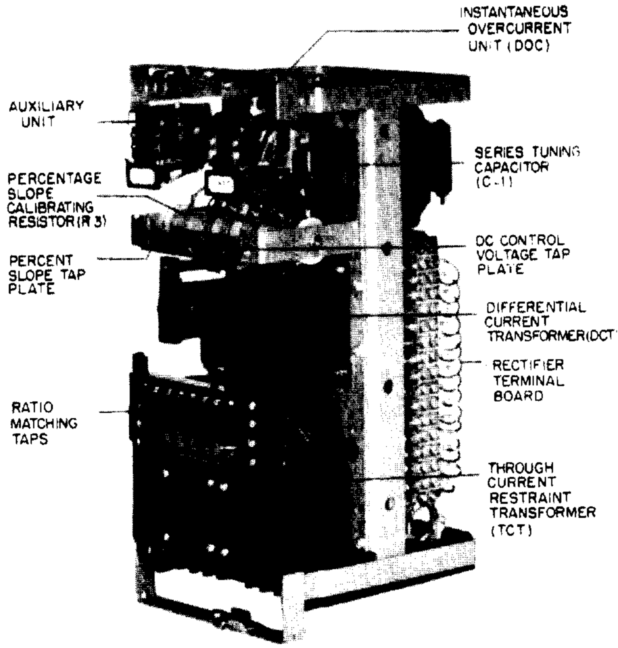


Figure 1 (8031389) Type BDD Relay, Out of Case, Front Right View

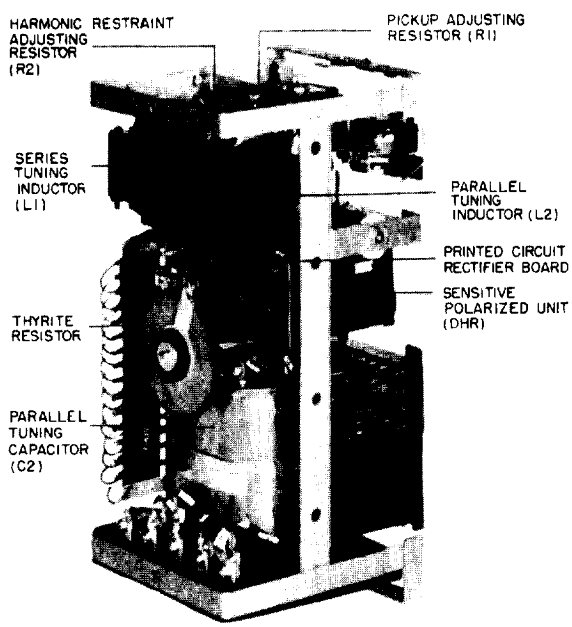
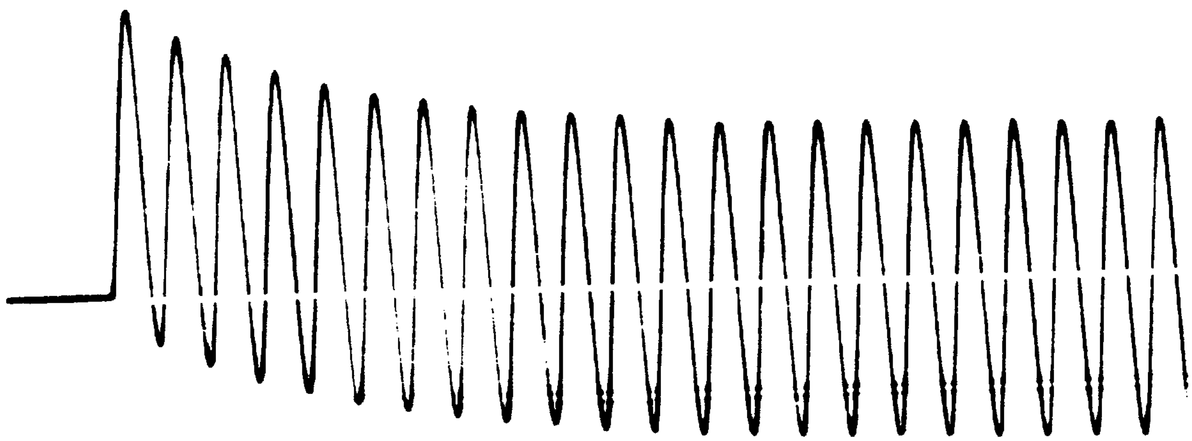
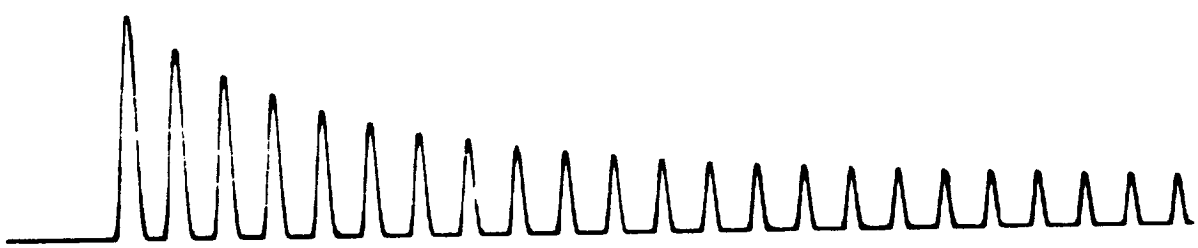


Figure 2 (8031391) Type BDD Relay, Out of Case, Rear Left View



TYPICAL OFFSET FAULT CURRENT WAVE



TYPICAL TRANSFORMER
MAGNETIZING INRUSH CURRENT WAVE

Figure 3 (6209195-0) Fault Current and Magnetizing
Inrush Current Waveforms

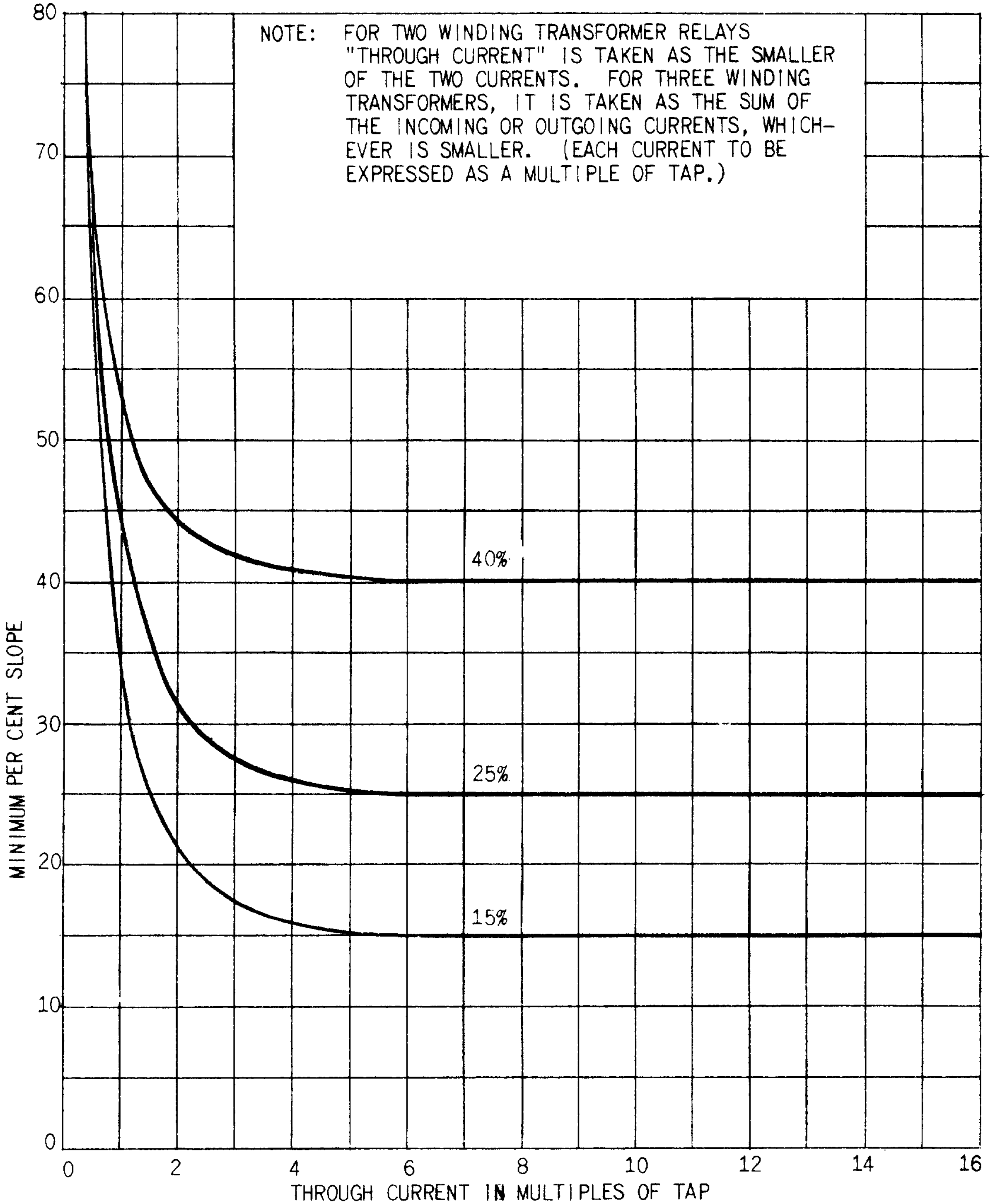


Figure 4 (0378A0588-3) Operating Characteristics of the Type BDD Relay

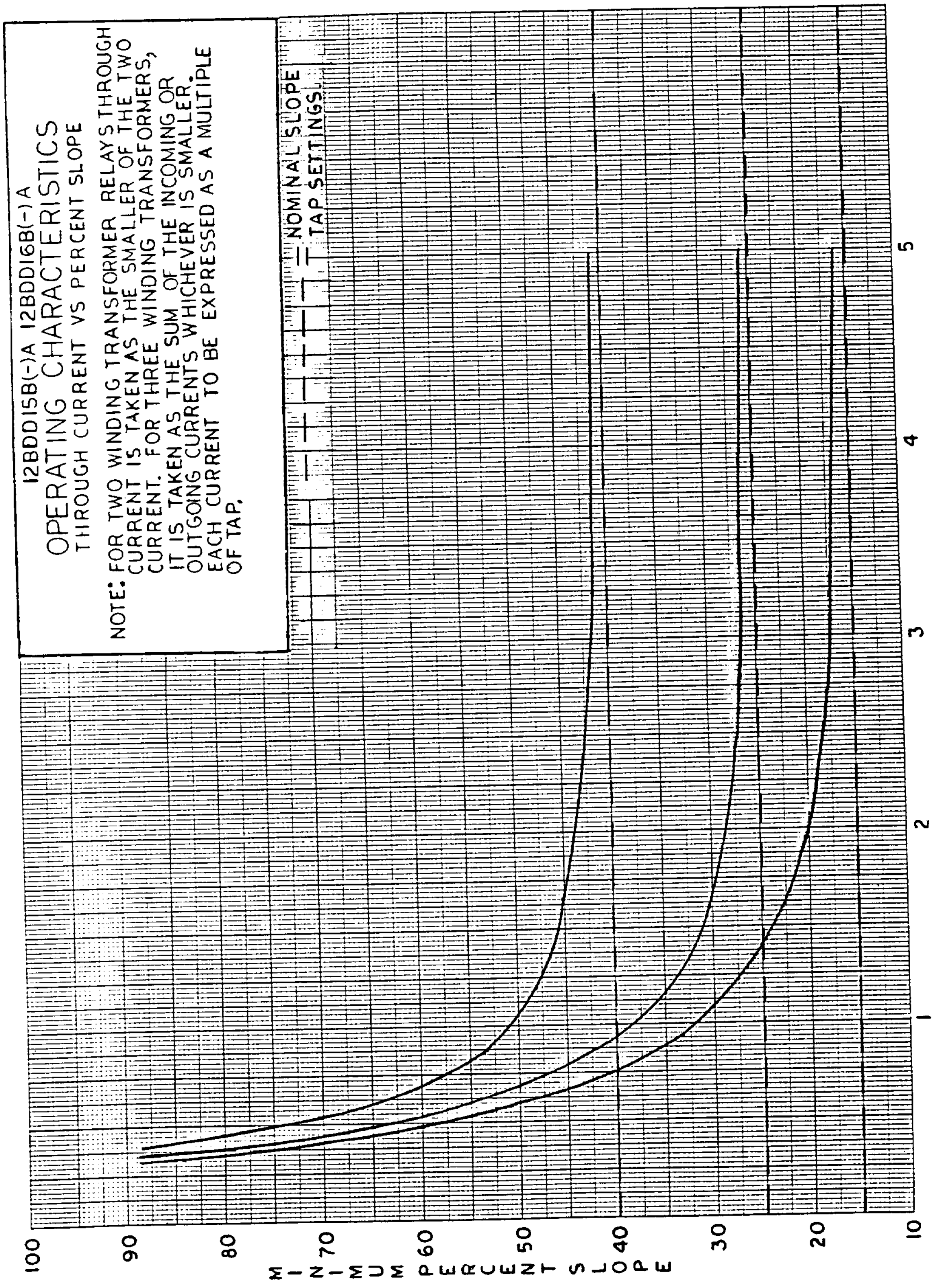


Figure 4A (0257A8579 Sh. 1 [1]) Operating Characteristics
Expanded Curve of Figure 4

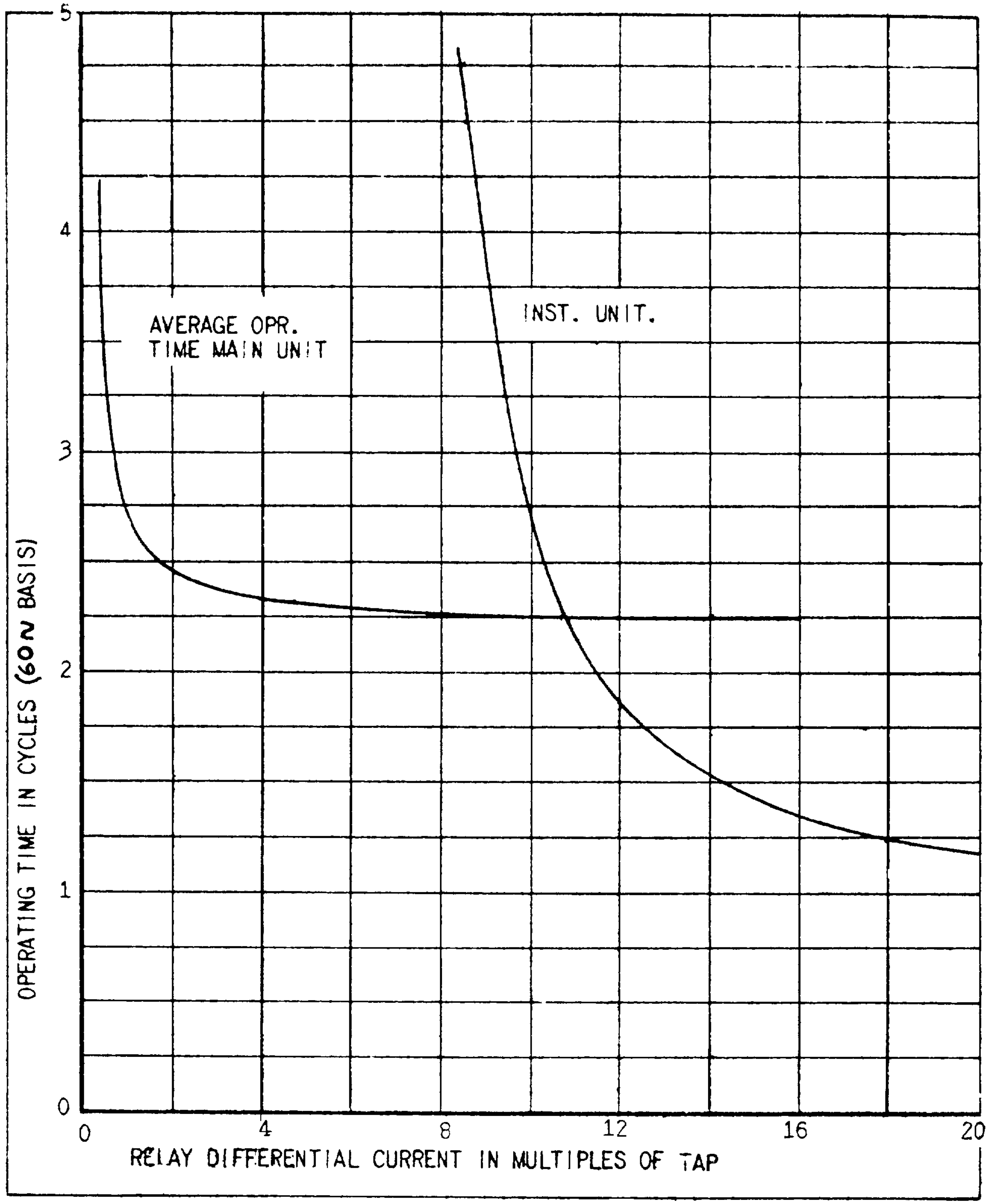
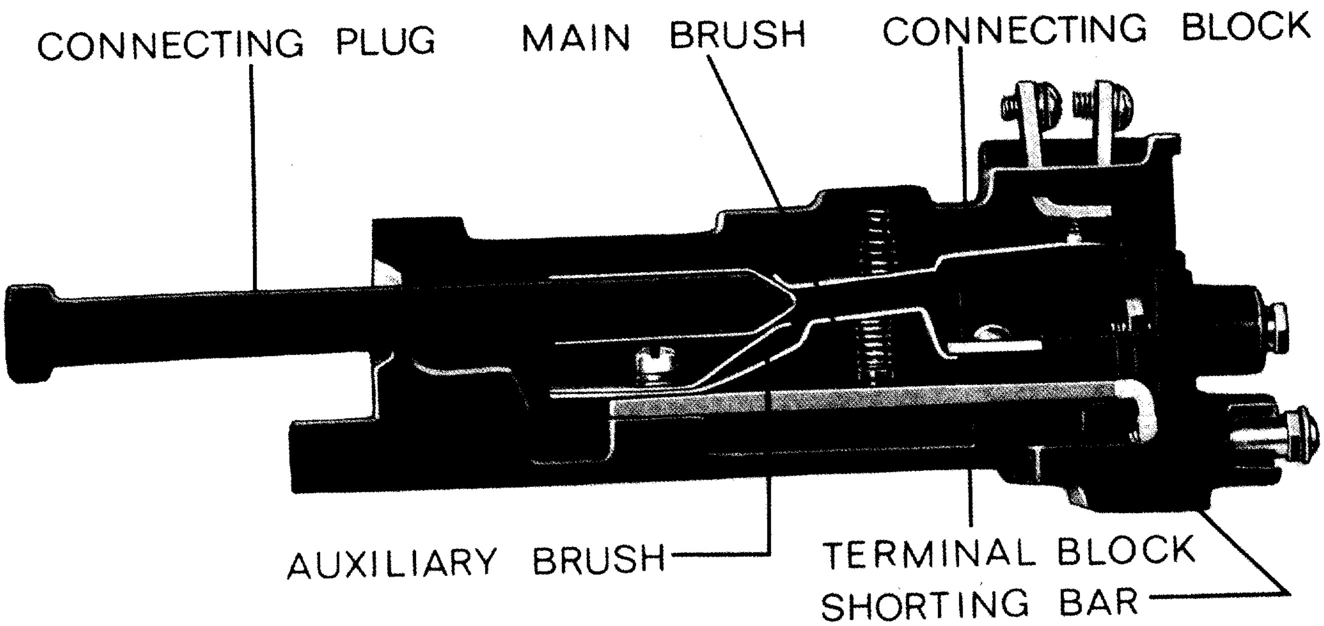


Figure 5 (0378A0587-2) Typical Time-Current Curves for Type BDD Relays



NOTE: AFTER ENGAGING AUXILIARY BRUSH CONNECTING PLUG TRAVELS 1/4 INCH BEFORE ENGAGING THE MAIN BRUSH ON THE TERMINAL BLOCK

Figure 6 (8025039) Cross Section of Drawout Case Showing the Position of the Auxiliary Brush

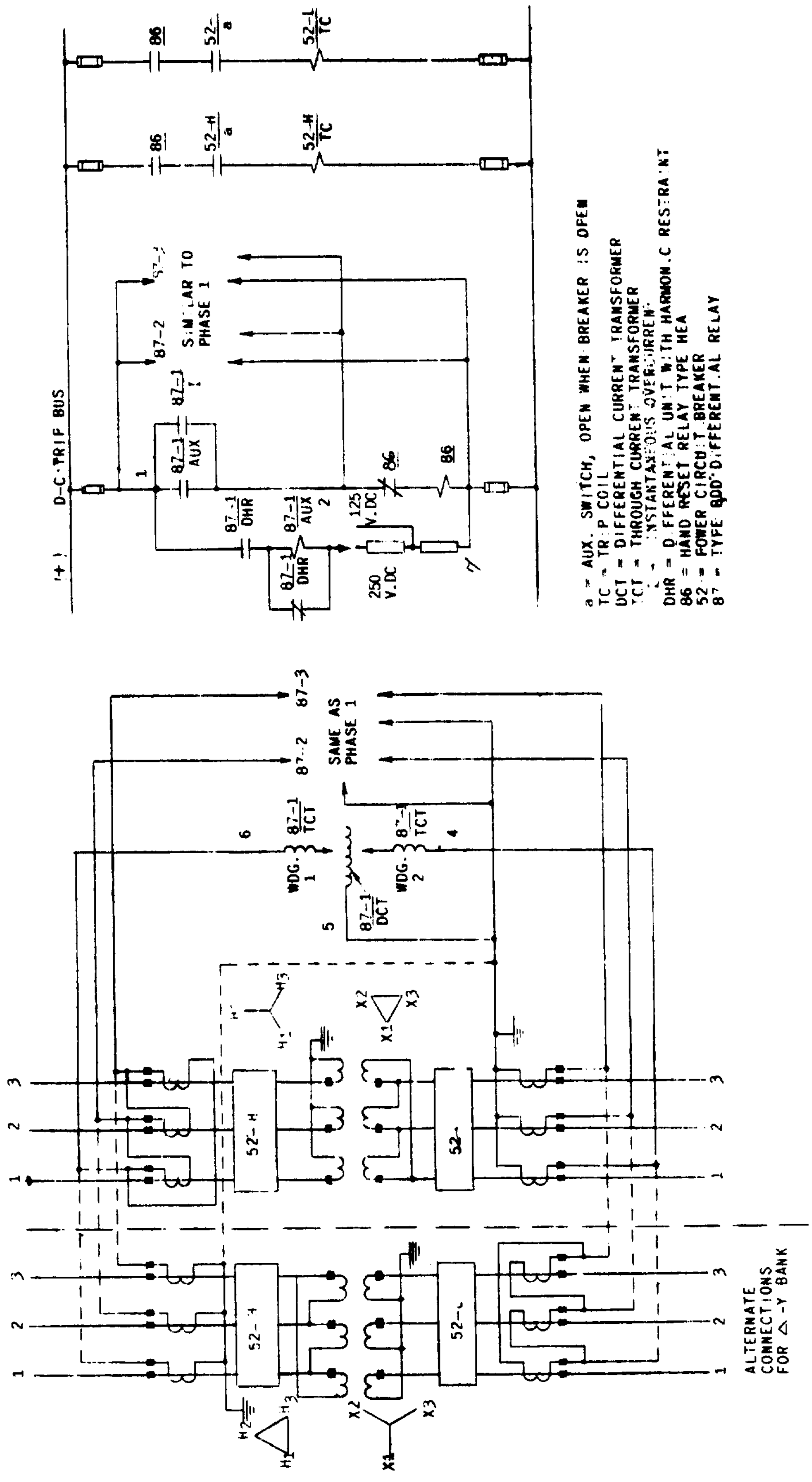


Figure 7 (0264B0498-1) Elementary Diagram for BDD15B11A and Up Relays for Two-Winding Transformer Protection

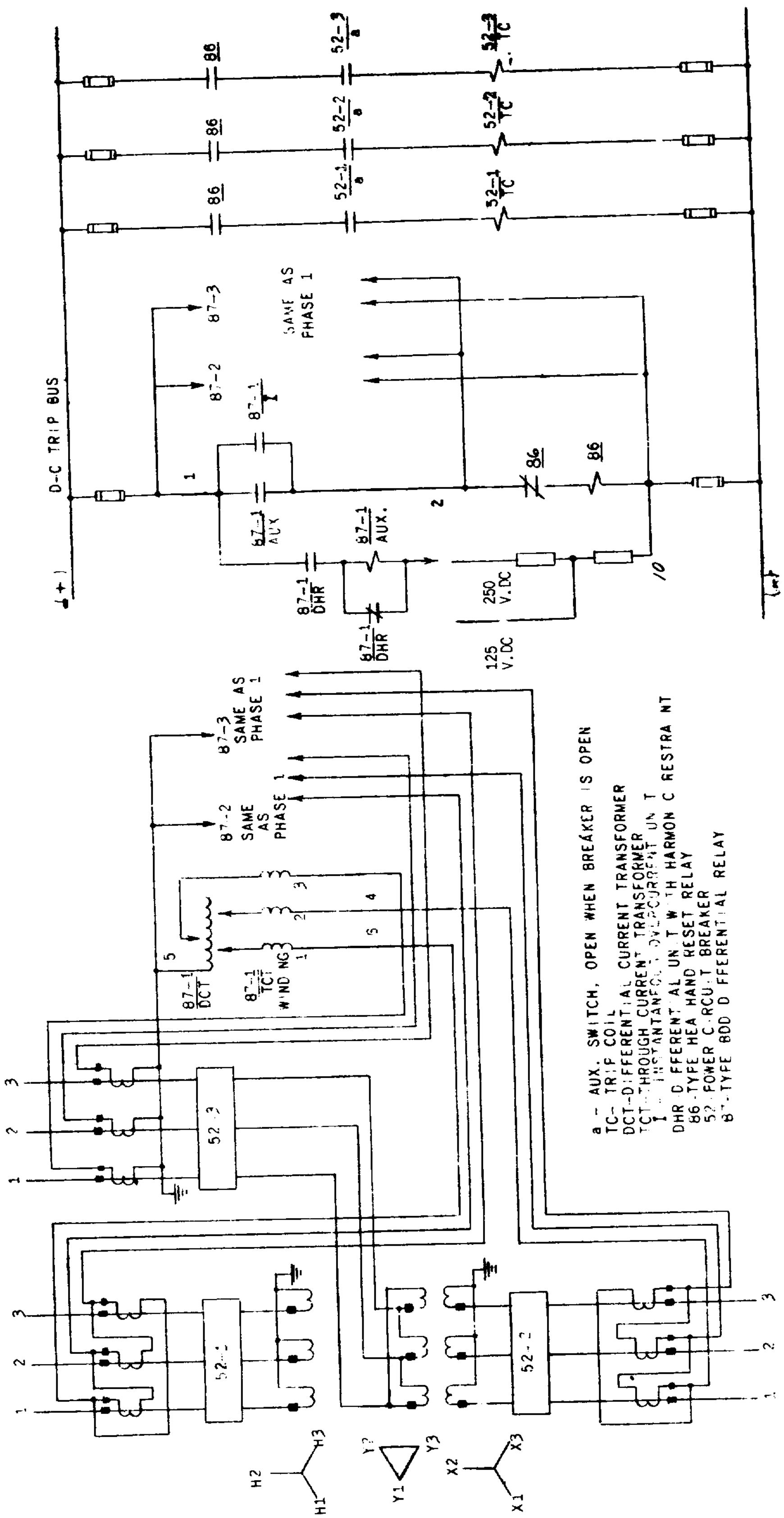


Figure 8 (0264B0497-1) Elementary Diagram for BDD16B11A and Up Relays for Three-Winding Transformer Protection

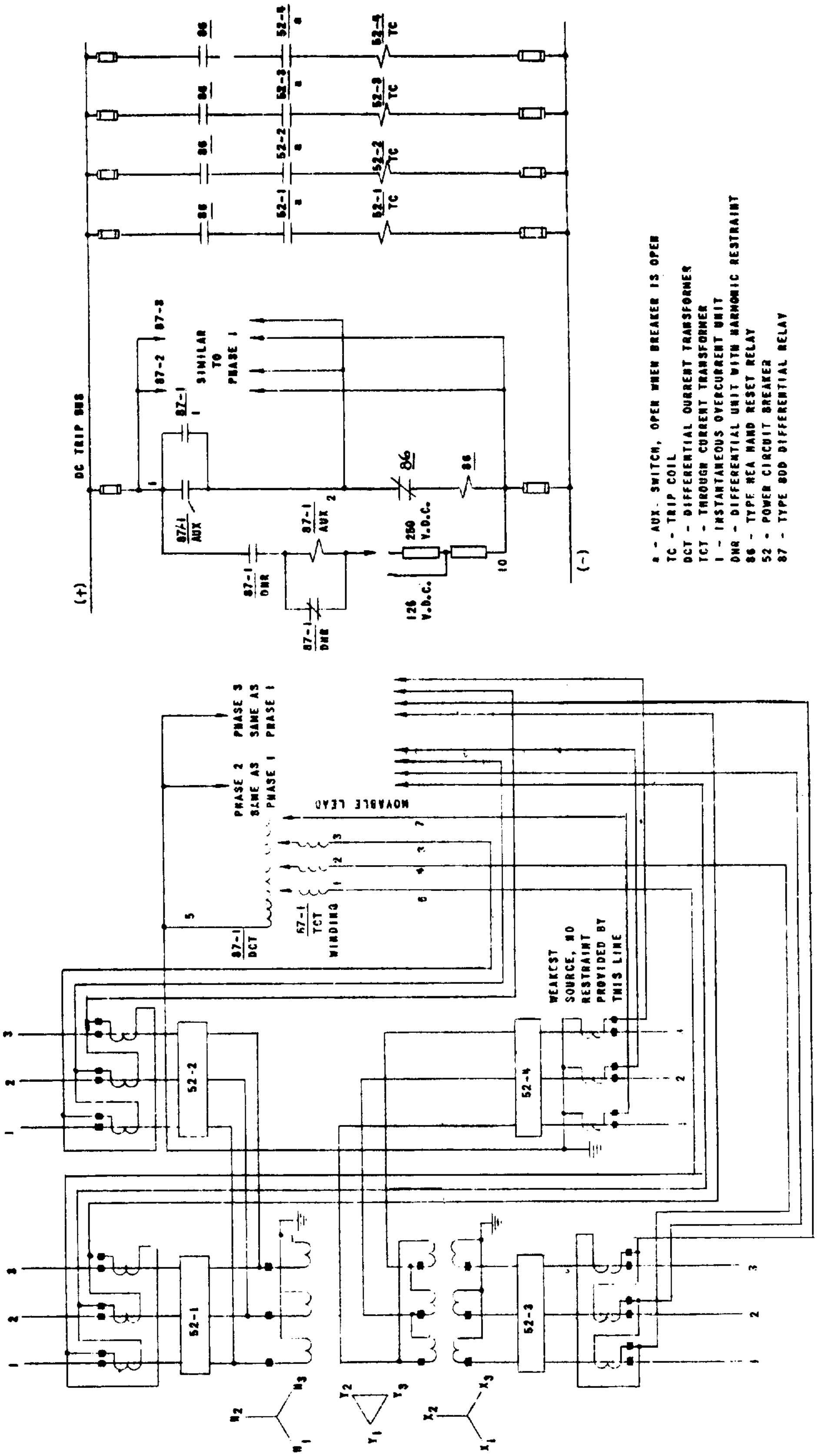


Figure 9 (0264B0499-1) Elementary Diagram for BDD16B11A and Up Relays for Four-Winding Transformer Protection, Using Three Restraints

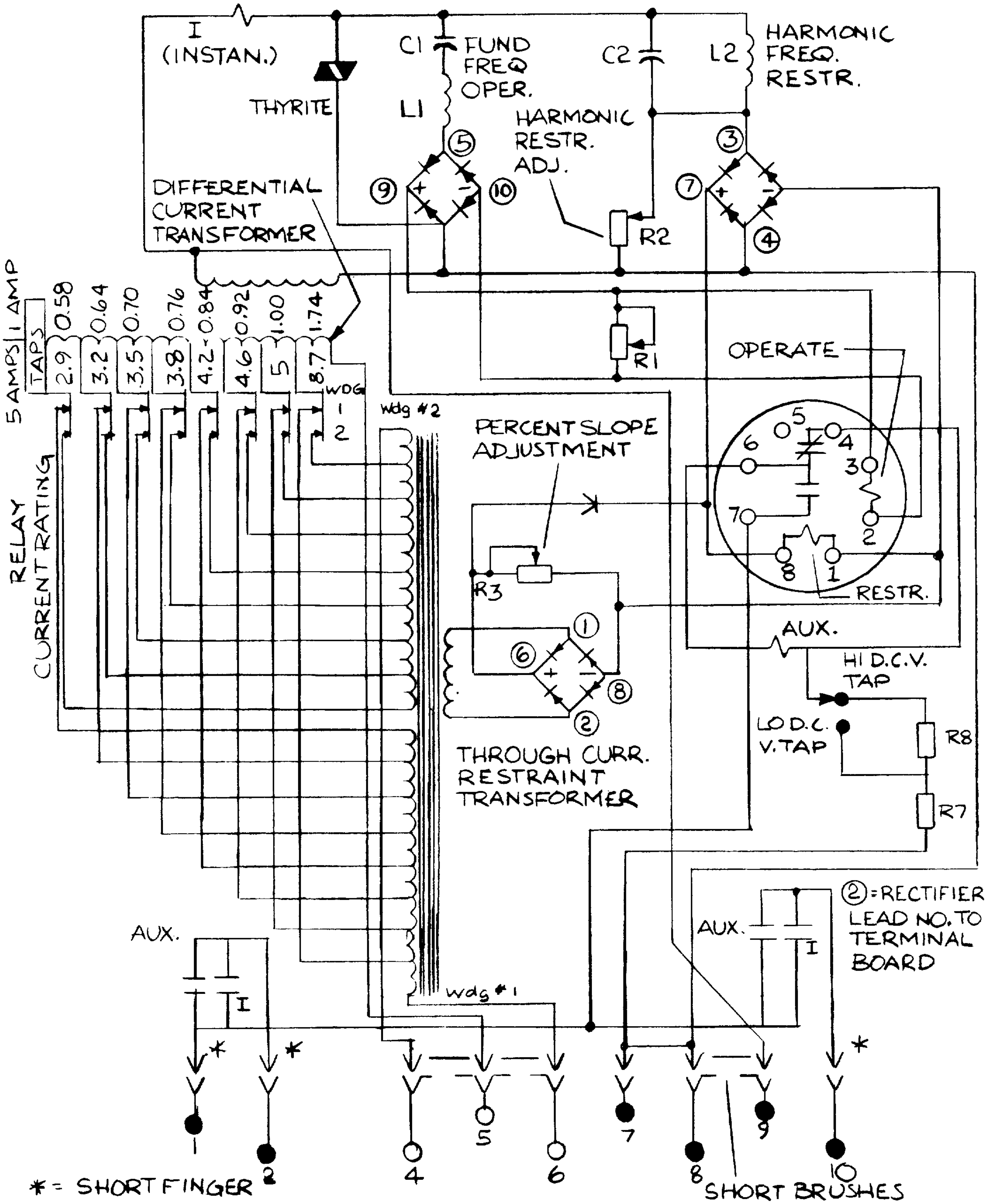


Figure 10 (0165A7513 [5]) Internal Connections Diagram for Type BDD15B11A and Up Relays

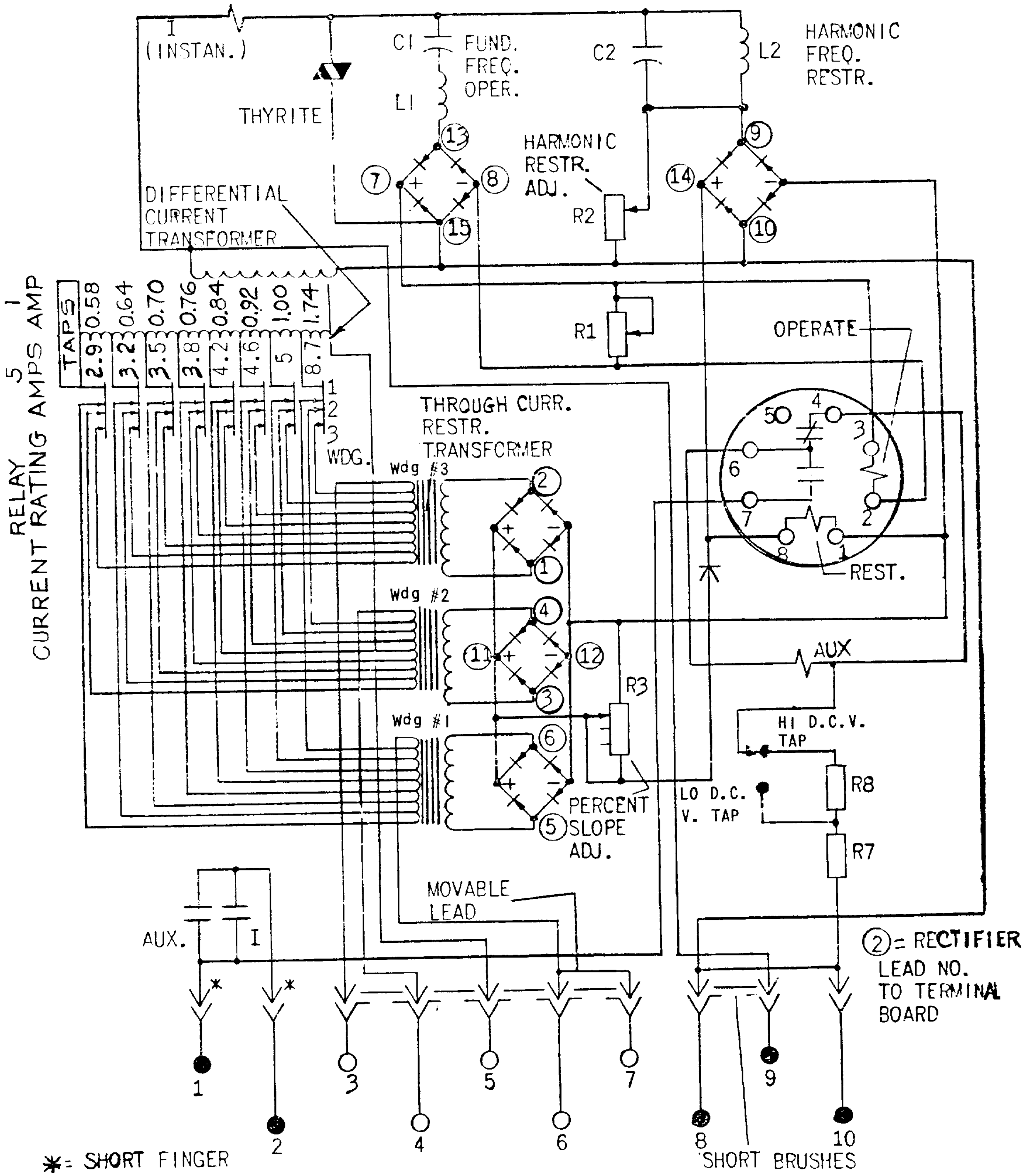
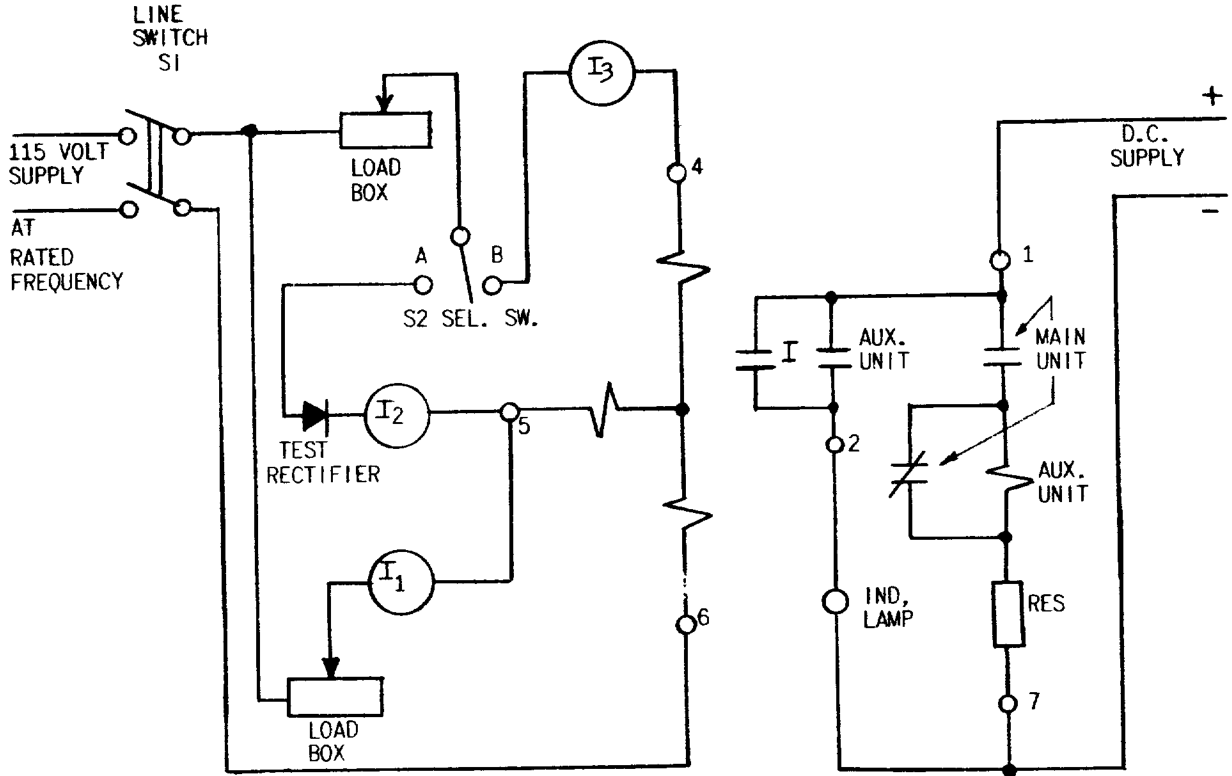
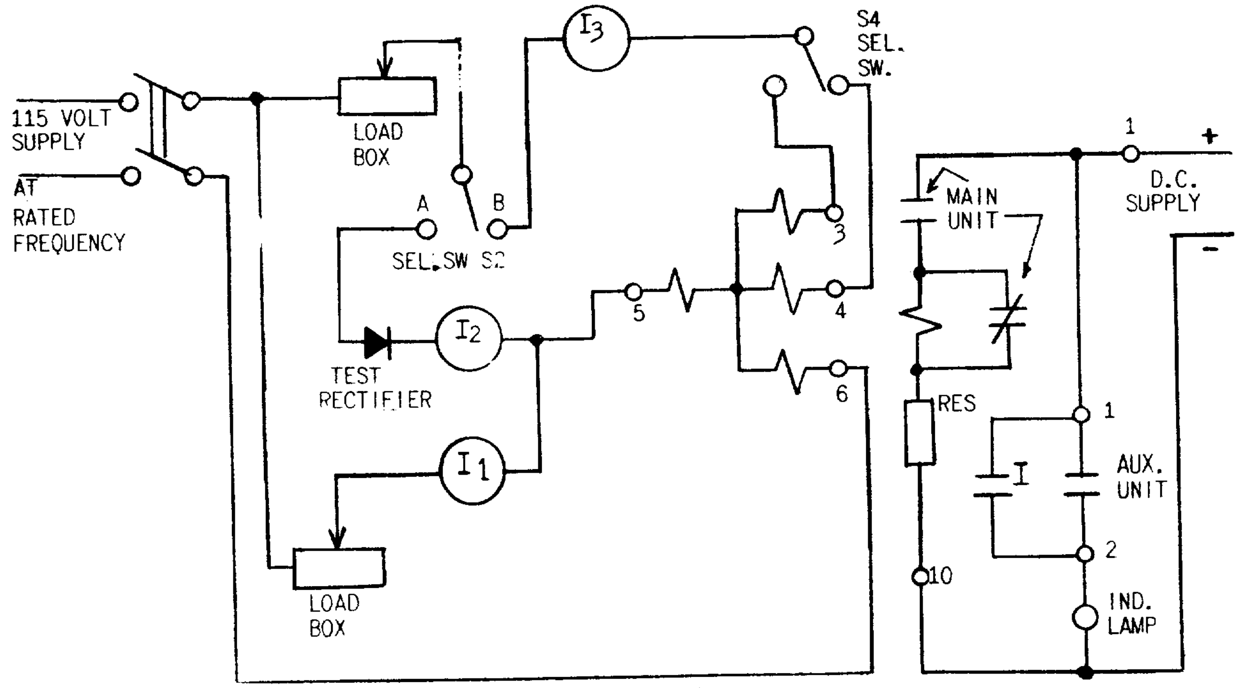


Figure 11 (0165A7514-2) Internal Connections Diagram for
Type BDD16B11A and Up Relays



TEST CONN. FOR BDD15B RELAY



TEST CONN. FOR BDD16B RELAY

LEGEND
I = INSTANTANEOUS OVERCURRENT UNIT

Figure 12 (0116B6801-1) Test Connections

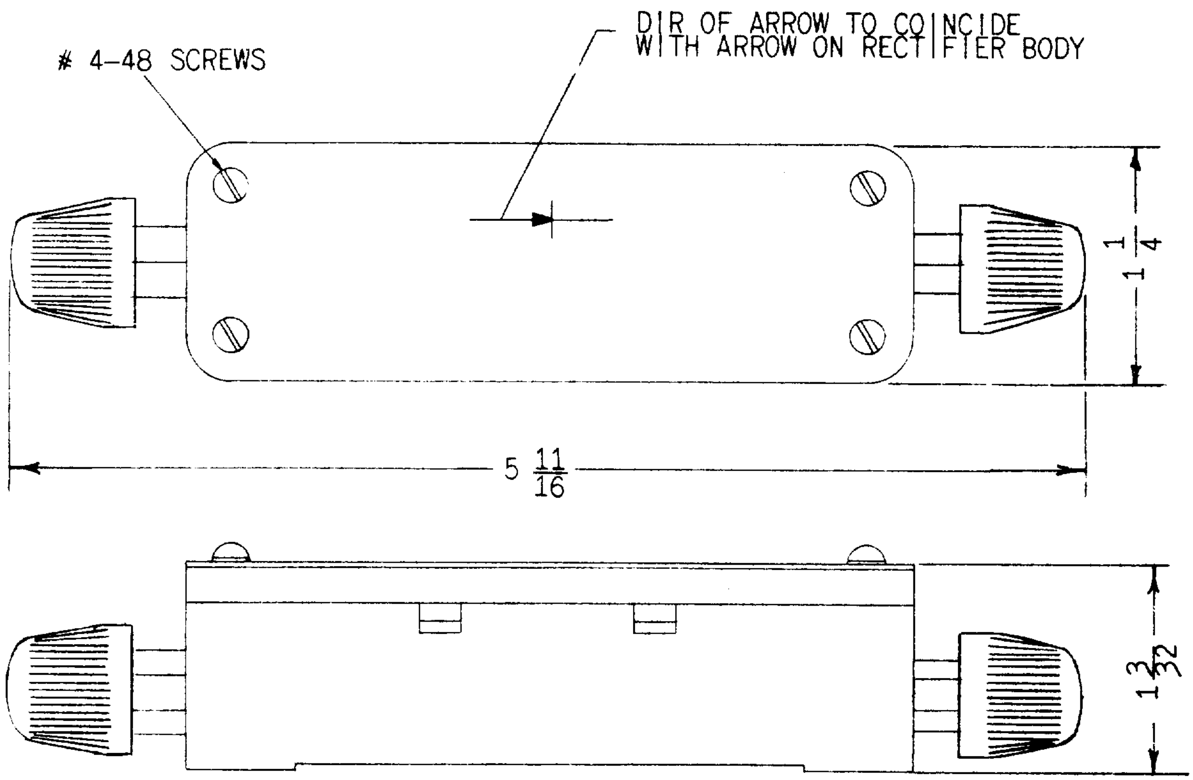
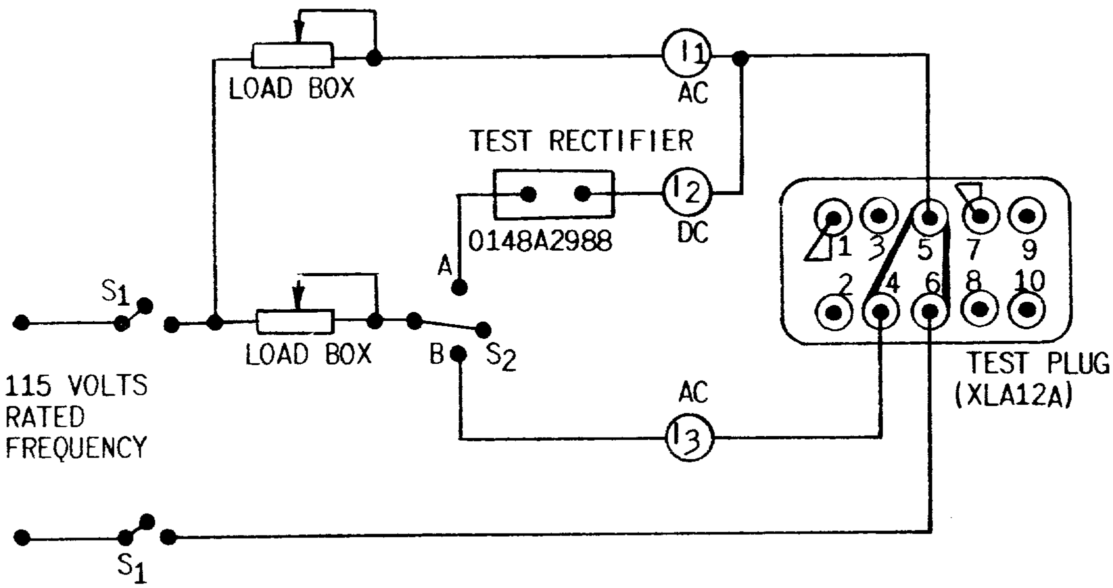
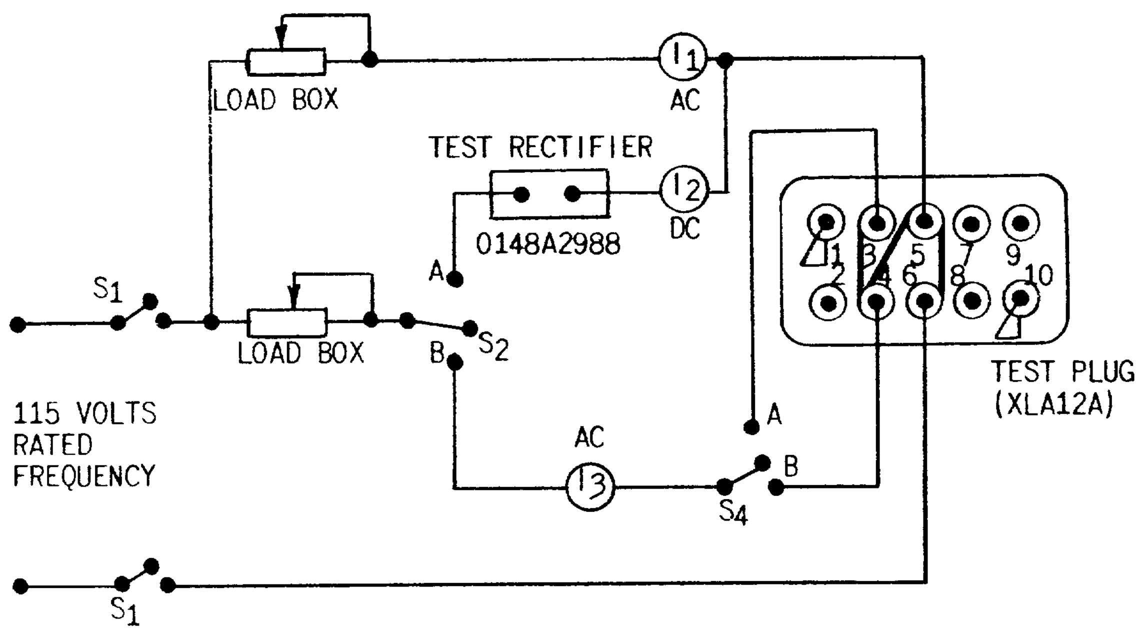


Figure 13 (0148A2994-1) Outline of Test Rectifier



A. TEST CIRCUIT FOR BDD15B RELAYS



B. TEST CIRCUIT FOR BDD16B RELAYS

Figure 14 (0418A0771 Sh. 2 [1]) Test Circuit for Type BDD Relays

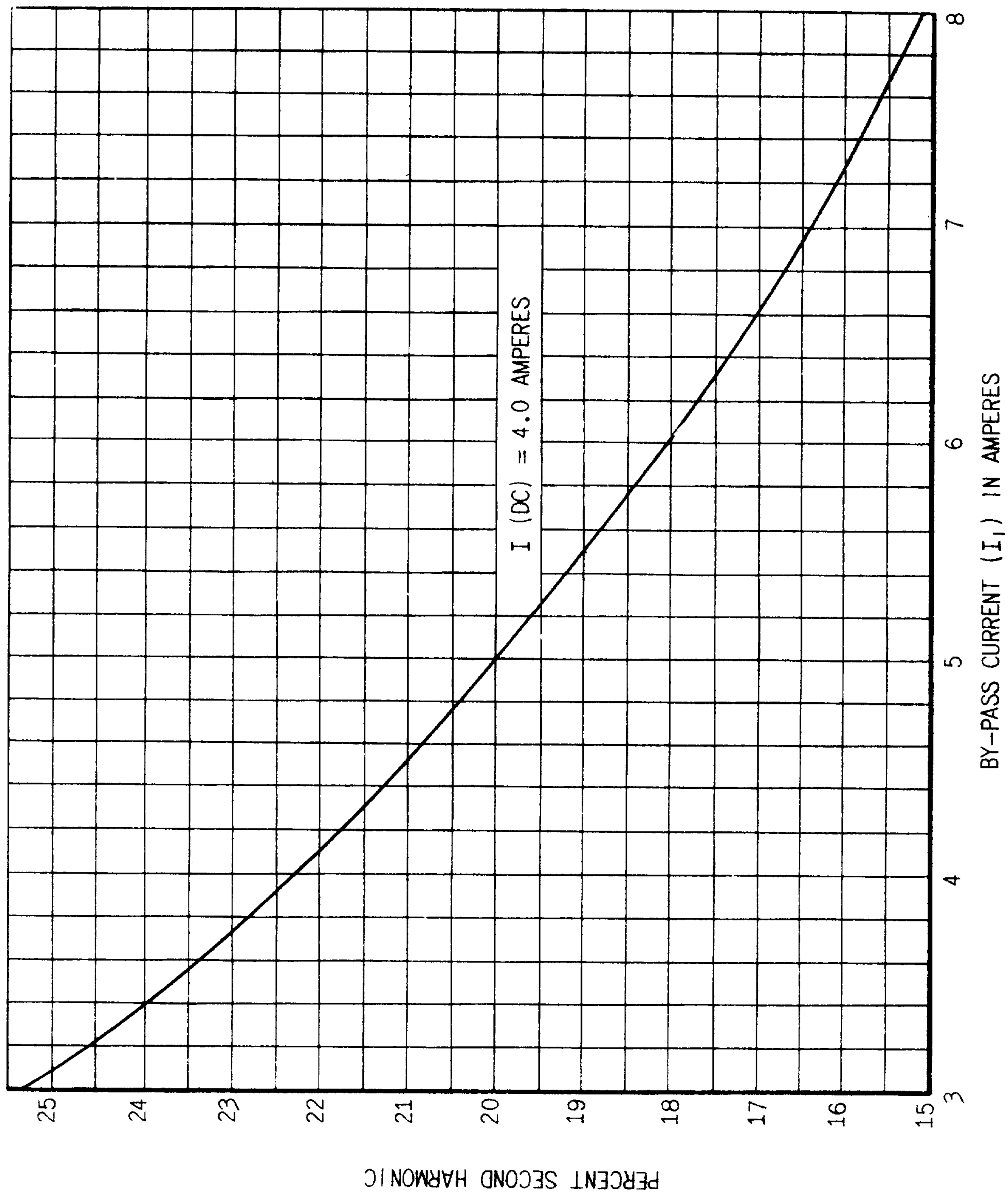


Figure 15 (0418A0786-0) Relationship Between Second Harmonic and Bypass Current with I_{DC} set at Four Amperes

Figure 16 (0178A8111-0) Differential Voltage Operating Characteristics of Type BDD Relays

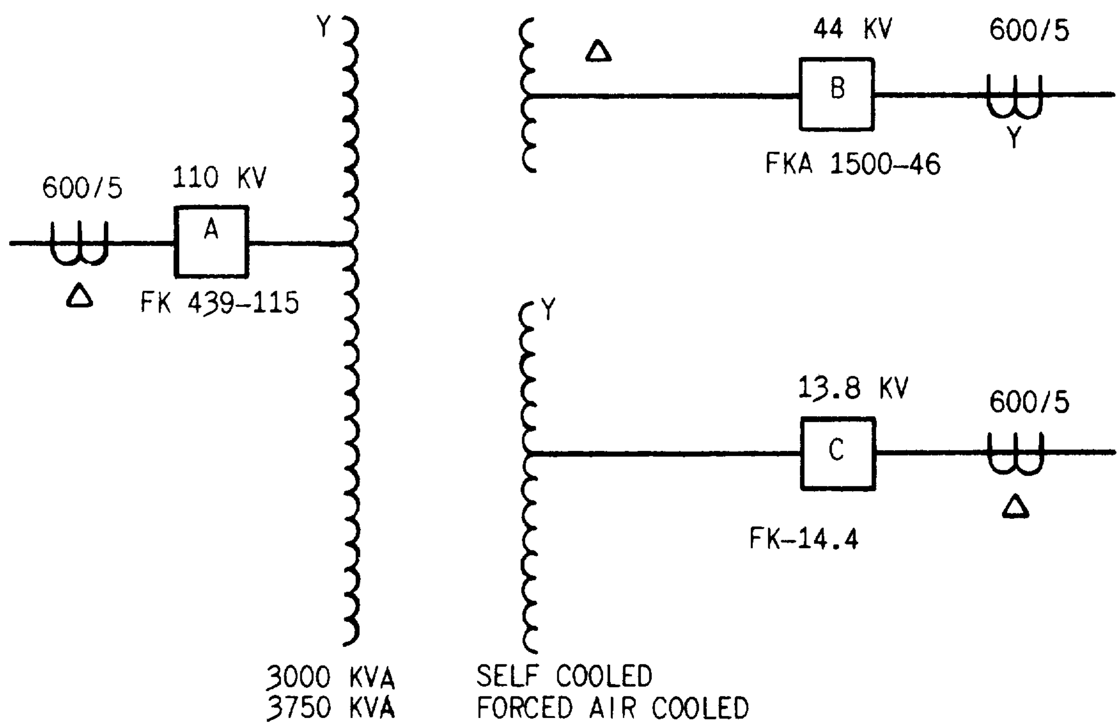


Figure 17 (0165A7601-1) Transformer Connections Used in Sample Calculations

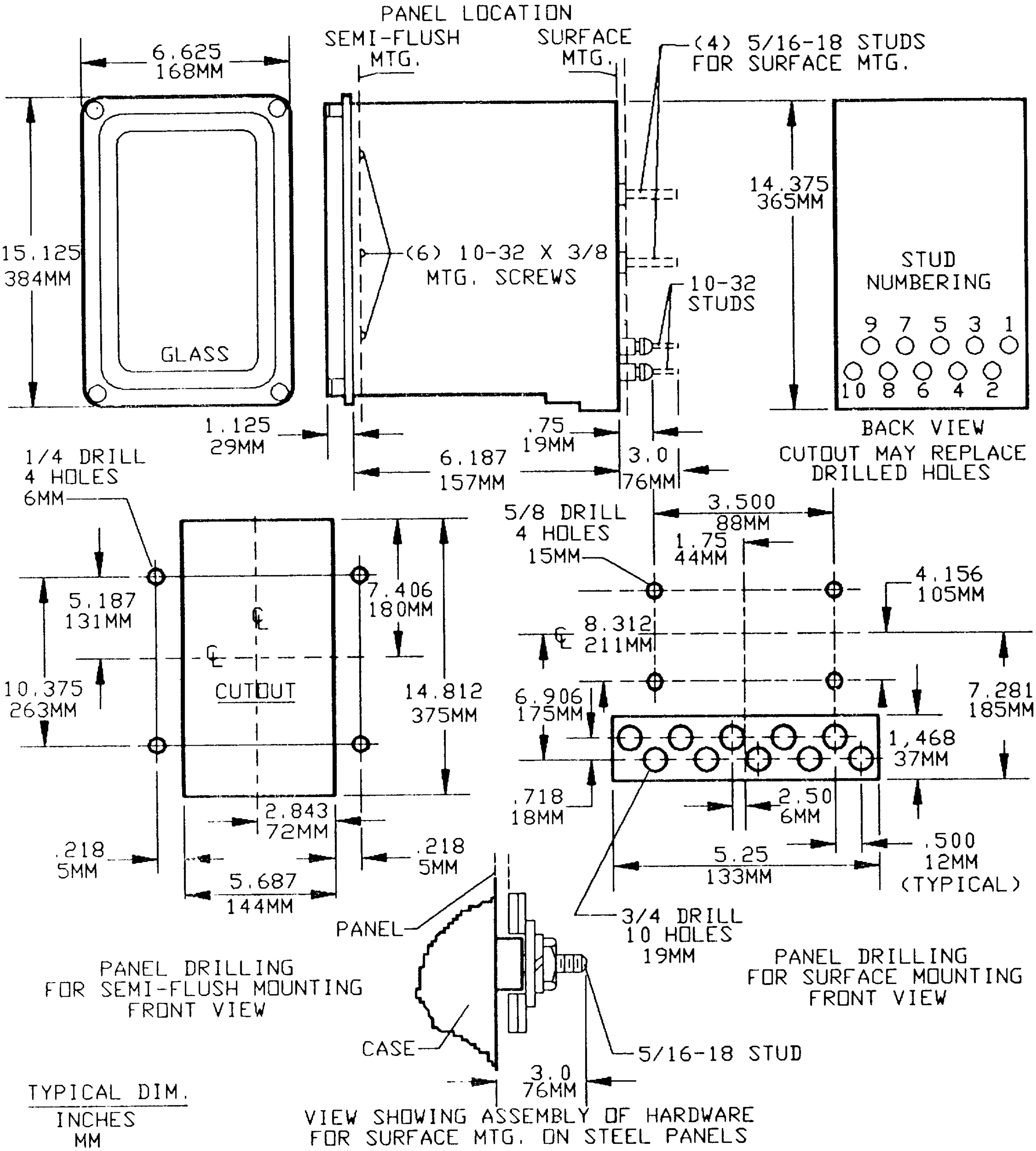


Figure 18 (6209273 [5]) Outline and Panel Drilling Dimensions for Type BDD Relays

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