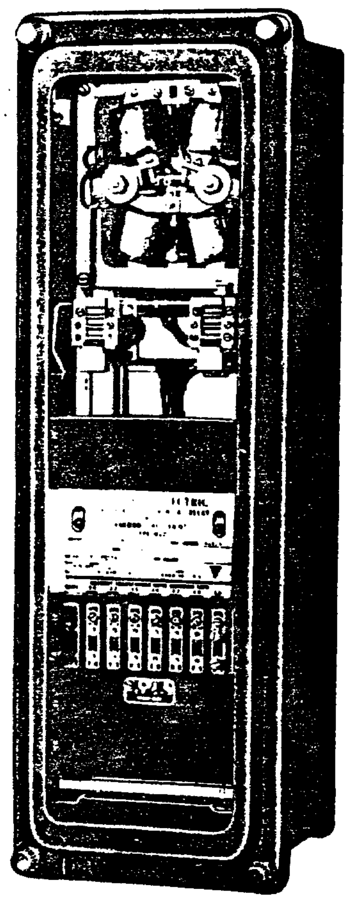
INSTRUCTIONS Switchgear

TRANSFORMER DIFFERENTIAL RELAYS

WITH PERCENTAGE AND HARMONIC RESTRAINT



Types
HDD15A5, HDD16A5,
and Up

GENERAL ELECTRIC

A

NOTES

CONTENTS

These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes, the matter should be referred to the General Electric Company.

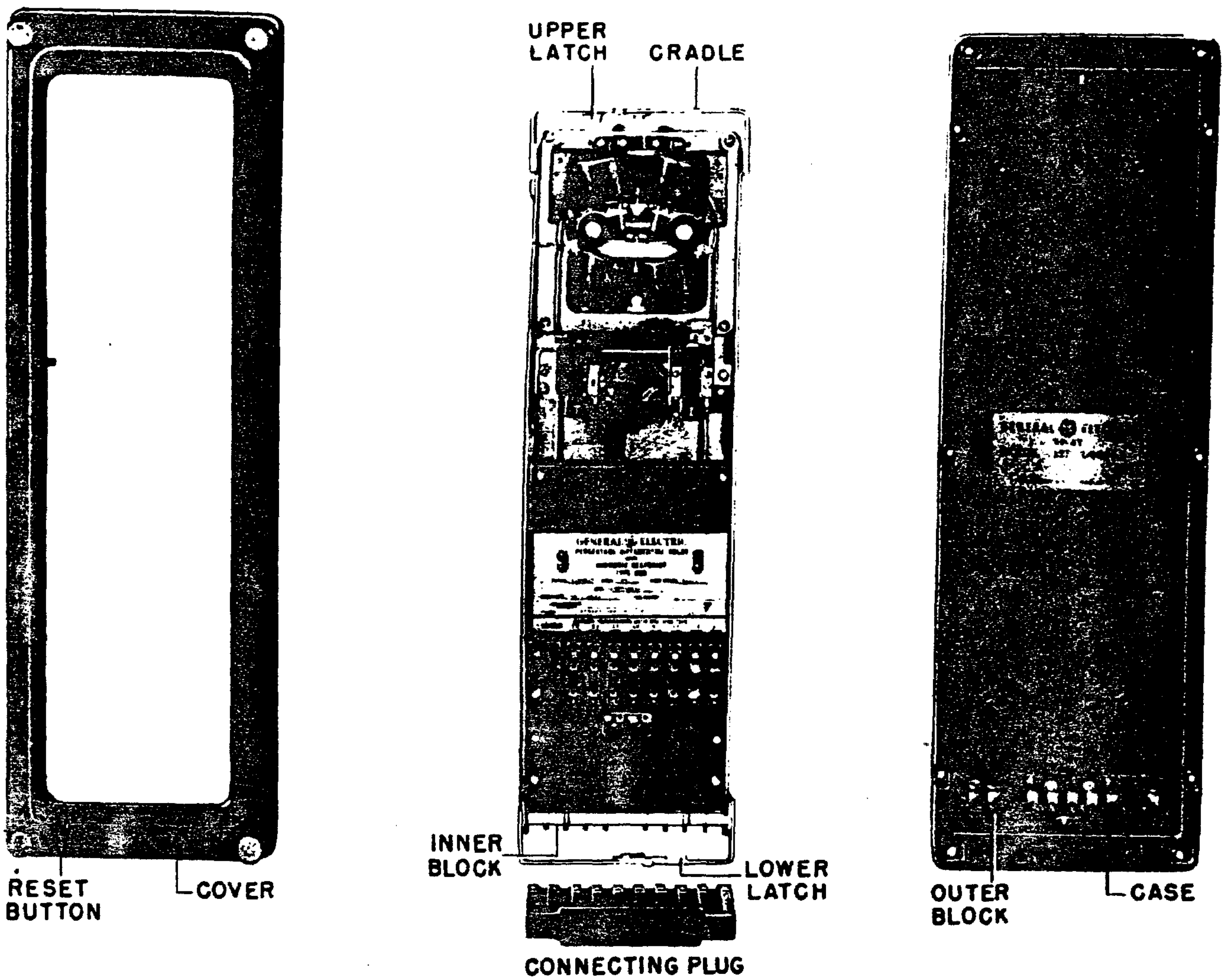


Fig. 1 Type HDD Relay Partially Disassembled

TRANSFORMER DIFFERENTIAL RELAYS WITH PERCENTAGE AND HARMONIC RESTRAINT

TYPES HDD15A5 AND HDD16A5 AND UP

INTRODUCTION

Relays of the HDD type are transformer differential relays provided with the features of percentage and harmonic restraint. Percentage restraint permits accurate determination between internal and external faults at high currents. Harmonic restraint enables the relay to distinguish, by the difference in waveform, between the differential current caused by an internal fault and that caused by transformer magnetizing inrush. The relay operates with high speed on internal fault currents. It is energized by current alone and does not require potential transformers.

APPLICATION

The application of Type HDD relays is very similar to that of other transformer protective relays of the percentage differential type. Use of the Type HDD relay is recommended, however, on 50 and 60 cycle transformer banks rated 2000 kva and above, or 15,000 volts or higher. The sensitive high speed operation of this relay affords greater protection and better service than other types of percentage differential relays. External connection diagrams showing typical circuits for the protection of two-winding and three-winding transformer banks employing the relay Types HDD15A and HDD 16A are shown in Figs. 10 and 11, respectively.

The Type HDD relay may also be used as shown in Fig. 14 as a ground fault detector or as an overcurrent unit when percentage differential relaying cannot be employed. In this application an advantage is realized from the harmonic restraint characteristics since reliable operation is assured during transformer energizing without loss of speed under fault conditions.

CURRENT TRANSFORMERS

Current transformers in the various windings of the power transformer should be selected with high enough ratios that their secondary currents will not damage the relay under maximum through fault conditions (refer to RATINGS). However, the ratios should not be so high as to impair sensitivity to internal faults in the power transformer. It is desirable to select ratios that will provide the same secondary currents for a given kva flowing in each winding of the power transformer.

The transformers chosen must be able to supply the relay with 8 times rated tap current with an error of less than 20 per cent.

RATIO MATCHING TAPS

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 by means of which the currents may usually be matched within 5 per cent. 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 ends of the range.

OPERATING CHARACTERISTICS

PICKUP AND OPERATING TIME

The pick-up characteristic of the HDD relay, as a function of fault current, is shown in Fig. 2. The curve, for various percentage slopes, shows the operating, or differential, current required to close contact versus the through current flowing in the transformer. The percentage slope is an arbitrary figure given to a particular per cent slope tap setting and indicates an approximate slope characteristic.

A range of operating times is shown in Fig. 3 as a function of differential current. The exact time lies between the limits shown, and is dependent upon the point in the voltage cycle at which the fault is initiated.

OVERCURRENT UNIT PICKUP

The overcurrent unit is adjusted to pick up when the differential current transformer ampere-turns are 8 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 this CT is in the 5 ampere tap, 40 amperes are required for pickup. This pickup value is based on the a-c component of current transformer output only since the unit receives a negligible amount of any d-c (offset) component present.

If ratio matching taps are chosen so that rated CT current is not greater than the tap rating, the overcurrent unit will not pickup on magnetizing inrush. If CT currents are greater than tap rating, there is danger that the unit may pick up under certain circumstances. If this condition should arise, it is recommended that the CT ratio be increased rather than increasing the pickup of the overcurrent unit. If the overcurrent setting must be raised, the requirements on CT error will be more stringent in accordance with the following equation:

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

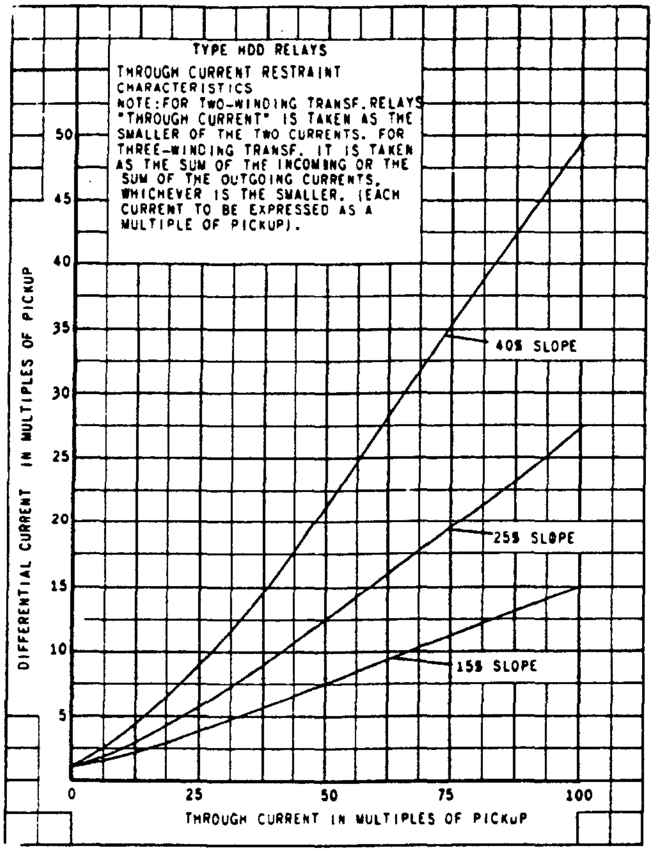


Fig. 2 Pick-up Current Characteristic of Type HDD Relay

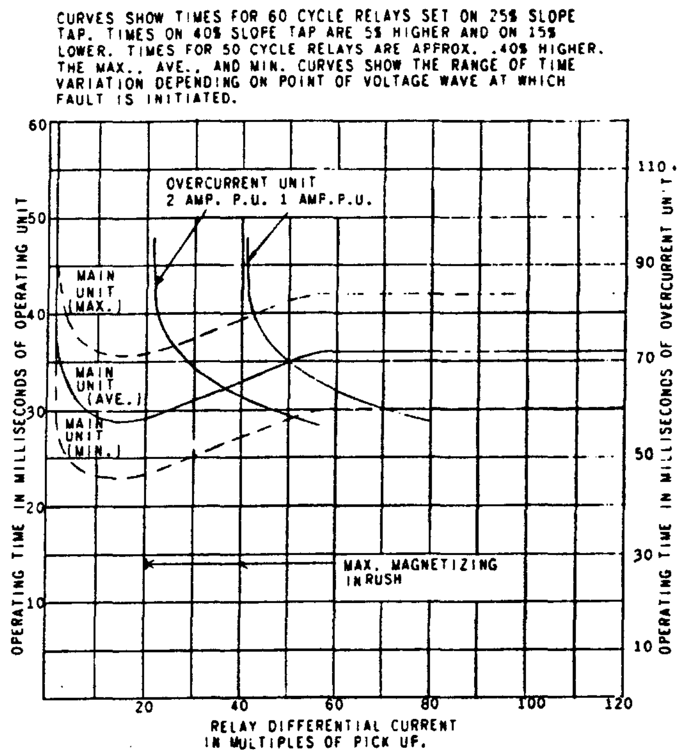


Fig. 3 Operating Time Characteristic of Type HDD Relay

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 coils, which are energized by the differential current of the line current transformers, the relays are equipped with restraining coils which are 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 Fig. 2). This characteristic is necessary to prevent false operation on extremely high 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 unbalance currents caused by imperfect matching of the secondary currents as previously described under RATIO MATCHING TAPS.

HARMONIC RESTRAINT CHARACTERISTICS

At the time a power transformer is energized, current is supplied to the primary which establishes the required flux distribution in the core. This current is called magnetizing inrush, and flows only through the current transformers in the primary winding. This causes an unbalance 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 waveform plus a d-c transient component. The sine waveform results from sinusoidal voltage generation and nearly constant circuit impedance. The d-c 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 per cent offset approaching 16 times full load current for worst conditions of power transformer history and point of circuit closure on the waveform. They have a very distorted waveform 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 Fig. 4.

Fig. 4 (K-6209195)

Fig. 5 (K-6209128)

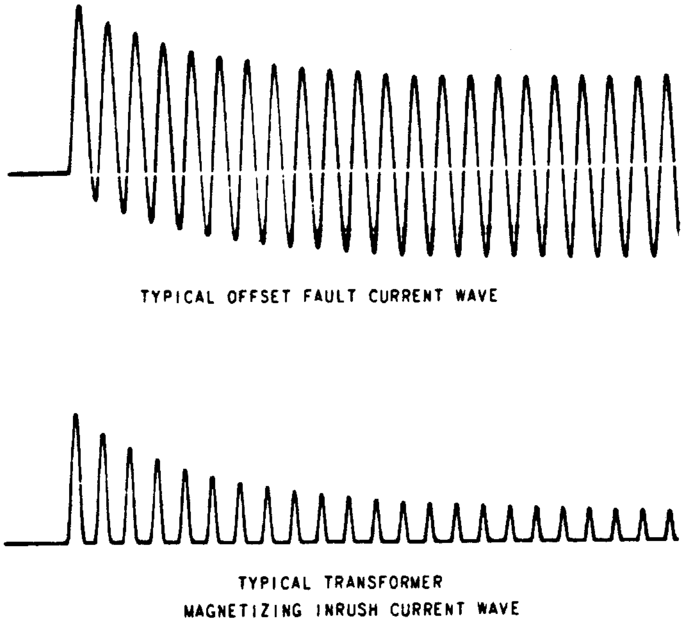


Fig. 4 Fault Current And Magnetizing Inrush Current Waves

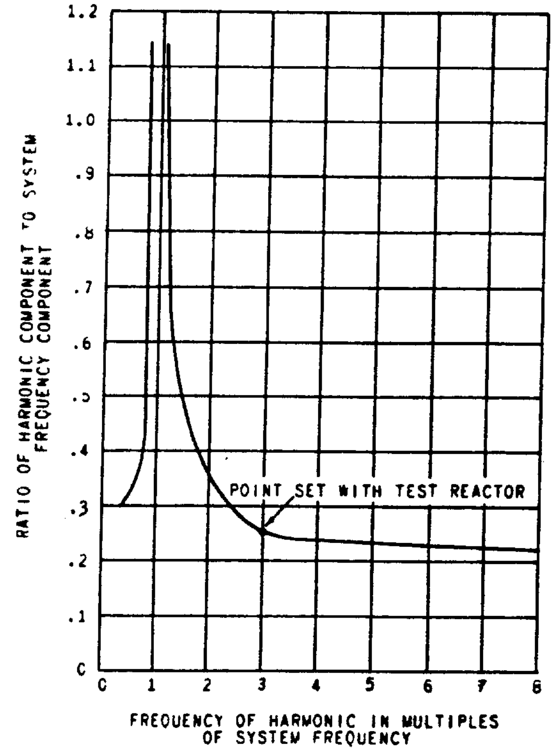


Fig. 5 Harmonic Restraint Characteristic of Type HDD Relays

Any current of distorted, nonsinsoidal waveform 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, called "harmonics", having frequencies which are 2, 3, 4, 5, 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 harmonic analysis of a typical magnetizing inrush current wave is given in Table I.

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 the Type HDD relays, the harmonic components are separated from the fundamental component by suitable electric filters. The harmonic current components are passed through the restraining coils of the relay, while the fundamental component is passed through the operating coils. 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 a slight momentary restraining effect. Relay operation occurs on differential current waves in which the ratio of harmonics to fundamental is lower than a 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).

A harmonic restraint characteristic curve for Type HDD relays is shown in Fig. 5. This shows the proportion of any given harmonic required to restrain the relay when that harmonic only is present with the fundamental in the differential current. When several harmonics are present, as is usually the case, their restraining effects do not add directly as might be expected. Actually, because of the presence of a rectifier, the restraining effects combine in a complex way roughly approximating the result obtained by taking the square root of the sum of the squares of the individual restraining effects.

Comparison of the harmonic percentages shown in Table I for a typical magnetizing inrush current wave with the harmonic percentages required for restraint, as given by the curve in Fig. 5, indicates that there is a sufficient amount of either the second or the third harmonic, acting alone, to restrain the relay. This seemingly excessive margin is necessary to insure proper restraint under certain inrush conditions in applications where delta-connection of either the power transformer or the current transformers is employed. A reduction of the harmonic percentages is caused by the combination of delta currents, and only a reasonable margin is left for restraint.

TABLE I

Harmonic Analysis of a Typical Transformer Magnetizing Inrush Current Wave.

WAVE COMPONENT	RATIO OF AMPLITUDE OF HARMONIC COMPONENT TO AMPLITUDE OF FUNDAMENTAL (PERCENTAGE)
Fundamental	100.0
Direct Current	57.7
2nd Harmonic	63.0
3rd Harmonic	26.8
4th Harmonic	5.1
5th Harmonic	4.1
6th Harmonic	3.7
7th Harmonic	2.4

RATINGS

CURRENT RATING OF RELAY TRANSFORMERS

Models 12HDD15A5, 6 and 12HDD16A5, 6

Continuous - Tap rating in the operating circuit (stud 6) and 2 times tap rating in the through current restraint circuit (studs 3, 4, and 5).

Short time - Measured in the primary of any transformer of the Type HDD relay:

1 second - 140 amperes
1/4 second - 280 amperes

Models 12HDD15A7, 8 and 12HDD16A7, 8

Continuous - Tap rating in the operating circuit (stud 6) and 2 times tap rating in the through current restraint circuit (studs 3, 4, and 5).

Short time - Measured in the primary of any transformer of the Type HDD relay:

1 second - 220 amperes
1/4 second - 440 amperes

RATINGS OF TARGET COILS

TABLE II

FUNCTION	AMPERES, A-C OR D-C	
	2.0 Amp. Tap (0.10 Ohm, d-c)	0.2 Amp Tap (7.0 Ohms, d-c)
Tripping Duty	30	5
Carry Continuously	4	0.8

The 0.2 ampere tap is for use with trip coils that operate on currents ranging from 0.2 up to 2.0 amperes at the minimum control voltage. If this tap is used with trip coils requiring more than 2 amperes, there is a possibility that the 7 ohms will reduce the current to so low a value that the breaker will not be tripped.

BURDENS

TABLE III

NOTE: Burdens are substantially independent of the per cent slope settings and are all approximately 100 per cent power factor. Figures given are burdens imposed on each current transformer at 5.0 amperes.

Relay	Tap Setting Amps	Min. Pickup (25% Slope) Amps.*	OPERATING CIRCUIT †				RESTRAINT CIRCUIT	
			60 Cy. Relays		50 Cy. Relays		50 and 60 Cycle Relays	
			Burden VA	Imped. Ohms	Burden VA	Imped. Ohms	Burden VA	Imped. Ohms
12HDD15A5, 6 12HDD16A5, 6	2.9	0.58	29.0	1.16	36.2	1.44	3.5	0.14
	3.2	0.64	25.2	1.01	31.4	1.26	2.8	0.11
	3.5	0.70	21.9	0.88	27.4	1.10	2.5	0.10
	3.8	0.76	19.3	0.78	24.1	0.96	2.3	0.09
	4.2	0.84	16.7	0.66	20.9	0.84	2.0	0.08
	4.6	0.96	14.1	0.56	17.6	0.70	1.7	0.07
	5.0	1.00	12.2	0.48	15.3	0.62	1.5	0.06
	8.7	1.74	5.1	0.20	6.5	0.26	0.9	0.04
12HDD15A7, 8 12HDD16A7, 8	2.9	1.16	8.0	0.32	10.0	0.40	2.8	0.110
	3.2	1.28	6.9	0.28	8.6	0.34	2.4	0.096
	3.5	1.40	5.8	0.24	7.3	0.29	2.2	0.088
	3.8	1.52	5.1	0.20	6.4	0.26	2.0	0.080
	4.2	1.68	4.4	0.18	5.5	0.22	1.7	0.068
	4.6	1.92	3.8	0.15	4.8	0.19	1.5	0.060
	5.0	2.00	3.3	0.13	4.1	0.16	1.3	0.052
	8.7	3.48	1.3	0.05	1.7	0.07	0.83	0.032

* Pick-up amperes are approximately 1 per cent higher on 40 per cent slope tap; 1 per cent lower on 15 per cent slope tap.

† Burden of operating coil is zero under normal conditions.

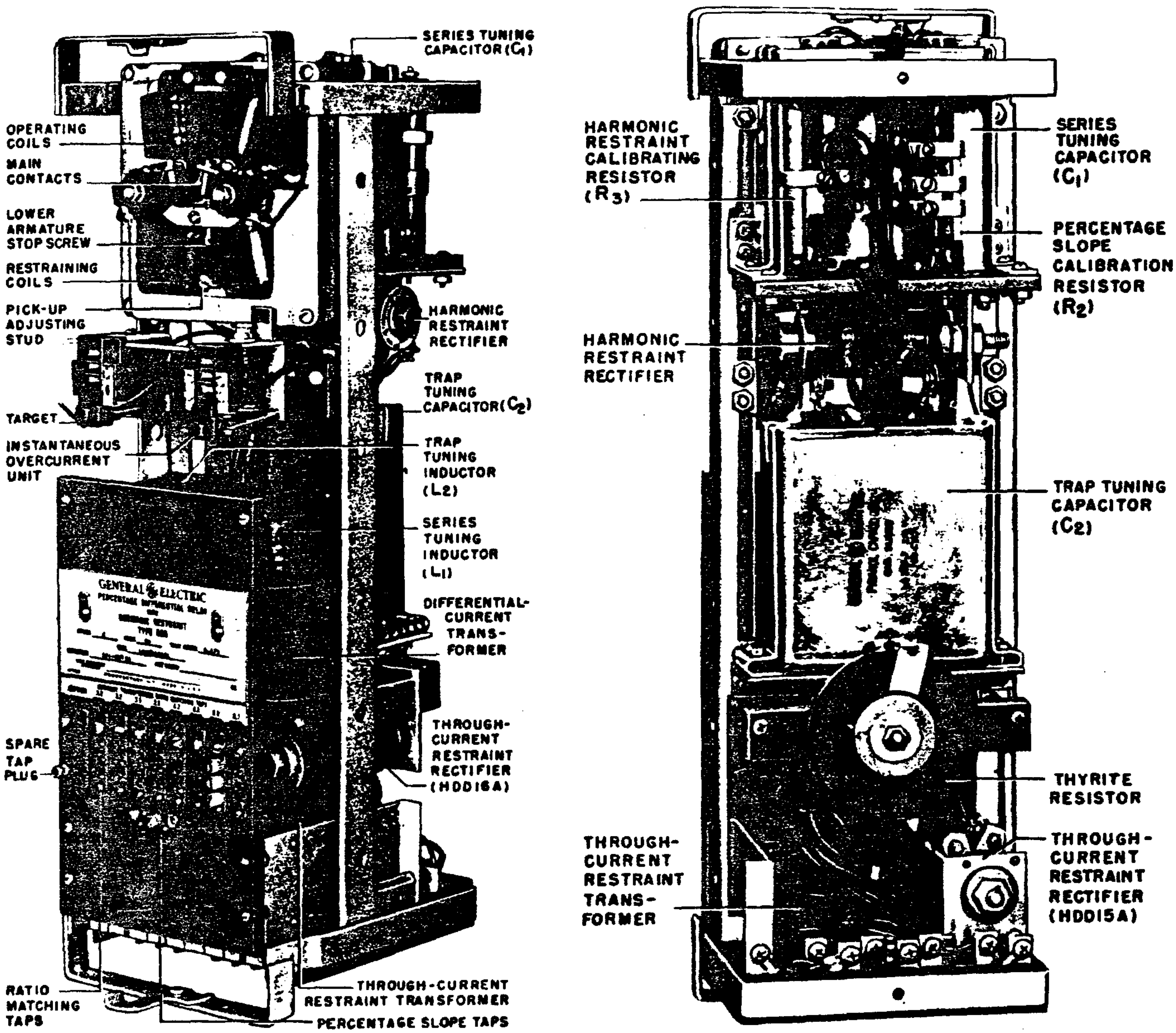


Fig.6 (8006186 & 8011691)

Fig. 6 Type HDD Relay In Cradle Front And Rear Views

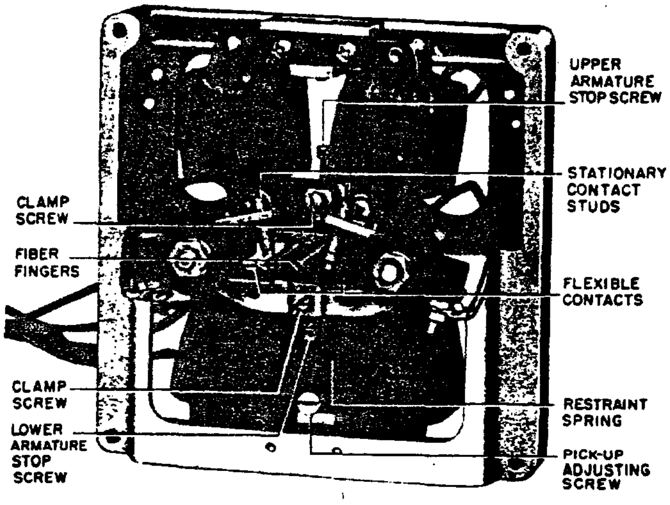


Fig. 7 Front View of Main Operating Unit of Type HDD Relay

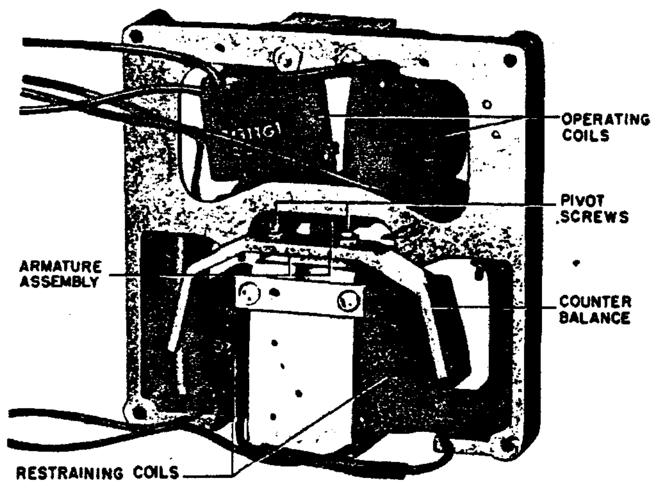


Fig. 8 Rear View of Main Operating Unit of Type HDD Relay

RECEIVING, HANDLING AND STORAGE

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

Reasonable care should be exercised in unpacking the relay in order that none of the parts are injured or the adjustments disturbed.

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 chips. Foreign matter collected on the outside of the case may find its way inside when the cover is removed and cause trouble in the operation of the relay.

DESCRIPTION

Each Type HDD relay is a single-phase unit and has two circuit-closing contacts which have one lead in common. The Type HDD15A relay is designed to be used for the protection of two-winding power transformers and, therefore, has two through current restraint circuits and a differential current circuit. The Type HDD16A is designed for use with three-winding power transformers and correspondingly has three through current restraint circuits in addition to a differential current circuit.

INTERNAL CONSTRUCTION

Figs. 6 and 7 show the internal arrangement of components in the HDD relay. Reference also to the internal connection diagrams, Figs. 12 and 13, will identify the parts more completely.

TRANSFORMERS

A through current restraint transformer winding is provided for each line current transformer circuit. In the Type HDD15A, one transformer with two primary windings is used. Winding No. 1 terminates at stud 5 and winding No. 2 at stud 4. The Type HDD16A employs three transformers, each with only one primary winding, and each terminating at a separate stud, winding No. 1, No. 2, and No. 3 corresponding to studs 5, 4, and 3 in that order. The differential current circuit of the line CT's is connected to the primary of the differential current transformer through stud 6.

The primary circuit of each of these transformers is completed through a special tap block and tap plug. Two or three horizontal rows of tap positions are provided (depending on whether the relay is a Type HDD15A or HDD16A), 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 the tap plug.

THROUGH CURRENT RESTRAINT CIRCUIT COMPONENTS

A full wave bridge copper oxide rectifier receives the output of the secondary of each through current restraint transformer. In the HDD16A, the d-c outputs of all three units are connected in parallel. The total output is fed to a tapped resistor (R_2) through the per cent slope tap plate at the front of the relay. By means of the three taps a 40, 25, or 15 per cent slope adjustment may be selected. Resistor taps are adjustable and preset for the given slopes. The upper tap corresponds to the 40 per cent slope setting. The output is applied to the restraint coils of the operating element.

DIFFERENTIAL-CURRENT CIRCUIT COMPONENTS

Differential current transformer secondary output current supplies the operating coils and the instantaneous overcurrent unit through a series tuned circuit, and also the harmonic restraint circuit through a parallel resonant trap. The operating coils are located on the two poles of the upper laminated iron core. The instantaneous unit is a hinged armature relay with a self contained target indicator. The series resonant circuit is made up of a 3 microfarad pyranol capacitor and an inductor which are tuned to the power system frequency.

A Thyrite resistor parallels the differential current transformer secondary load.

HARMONIC CIRCUIT COMPONENTS

The parallel resonant trap is made up for a 15 microfarad capacitor and an inductor which tunes the circuit to power system frequency. Currents which pass the trap are rectified in a copper oxide full wave bridge rectifier. The input to the rectifier is shunted by the calibrating resistor R_3, which 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 coils. These coils are located on the lower iron core, Fig. 7.

MAIN OPERATING UNIT

The contact operating unit of the Type HDD relay is a modified form of hinged armature relay, (see Fig. 7). In the dropped out position, two fiber fingers attached to the armature hold the contact circuits open by pressing down on the flexible phosphor bronze moving contact mounting strips. When the armature is drawn to the upper magnet assembly, the fiber fingers release the movable contact strips and spring action causes them to close with the stationary contacts to complete the trip circuits.

The armature is pivoted on two steel pivot points (see Fig. 8). These points rest in recesses in the frame which holds the lower magnet assembly. The points are attached to pivot screws in the armature which are used to control the clearance between the armature and the frame. Locknuts are provided on both screws. A specially formed counterbalance located very near the pivot serves to prevent vibration of the armature from mechanical shocks. A low tension spring exerts a restraining force in the dropped-out position near the pivot point. The pickup adjusting screw moves the fixed end of the spring parallel to the armature. This causes a change in spring tension and also a variation in the effective lever arm on which the force acts by changing the angle at which it is applied.

CASE

The case is suitable for surface or semiflush panel mounting and an assortment of hardware is provided for either method. The cover attaches to the case and carries the target reset mechanism for the trip indicator and instantaneous unit (see Fig. 1). Each cover screw has provision for a sealing wire.

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

The relay mechanism is mounted in a steel framework called the cradle and is a complete unit with all leads terminating at the inner block. This cradle is held firmly 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 are so constructed that the relay cannot be inserted in the case upside down. The connecting plug, besides making the electrical connection between the blocks of the cradle and case, also locks the latch in place. The cover, which is fastened to the case by thumbscrews, holds the connecting plug in place.

To draw out the relay unit, the cover is removed and the plug is drawn out. Shorting bars are provided in the case to short the current transformer circuits. The latches are then released and the relay unit can be easily drawn out.

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 relay unit can be drawn out and replaced by another which has been tested in the laboratory.

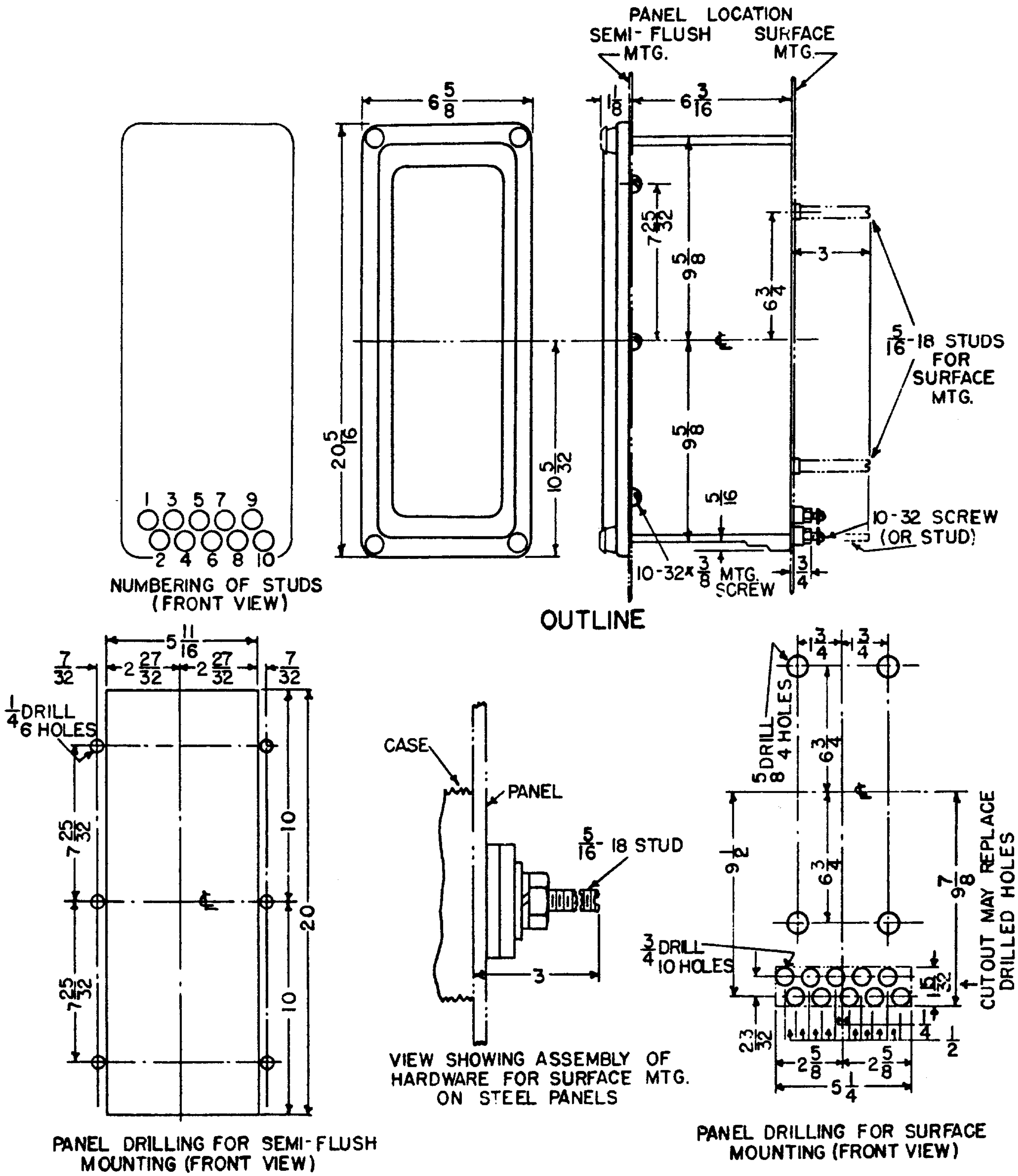
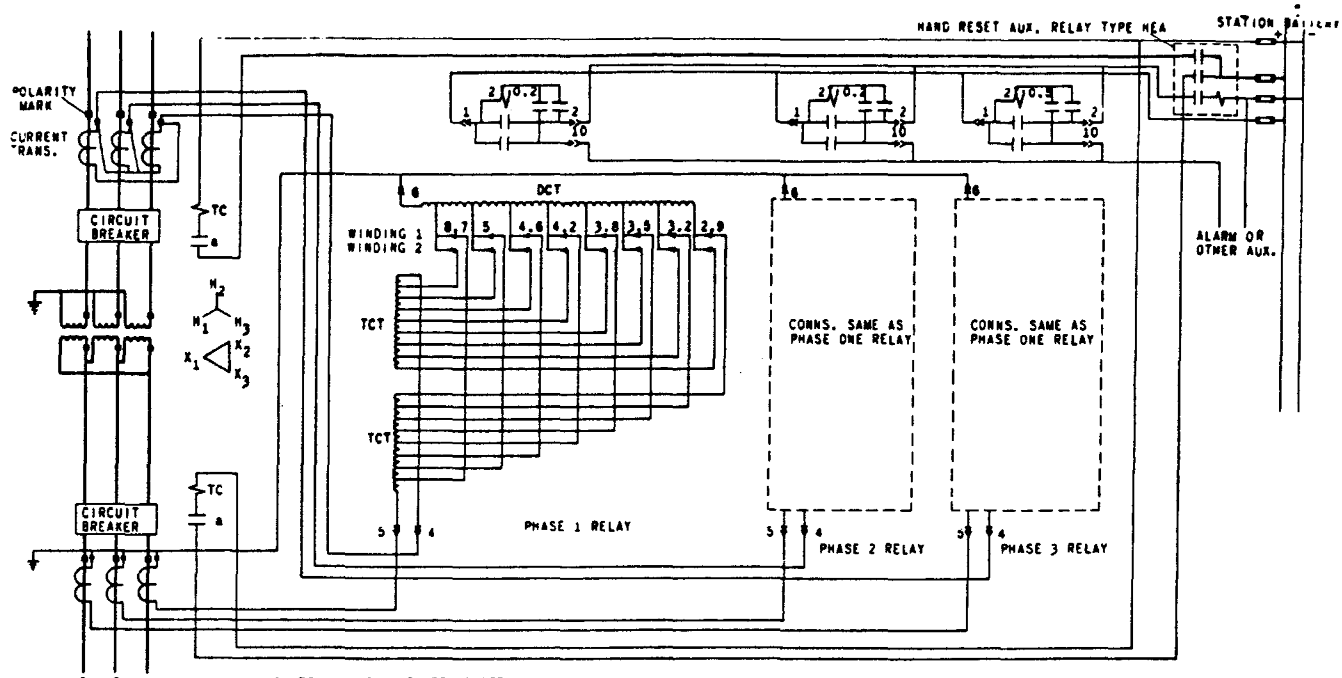


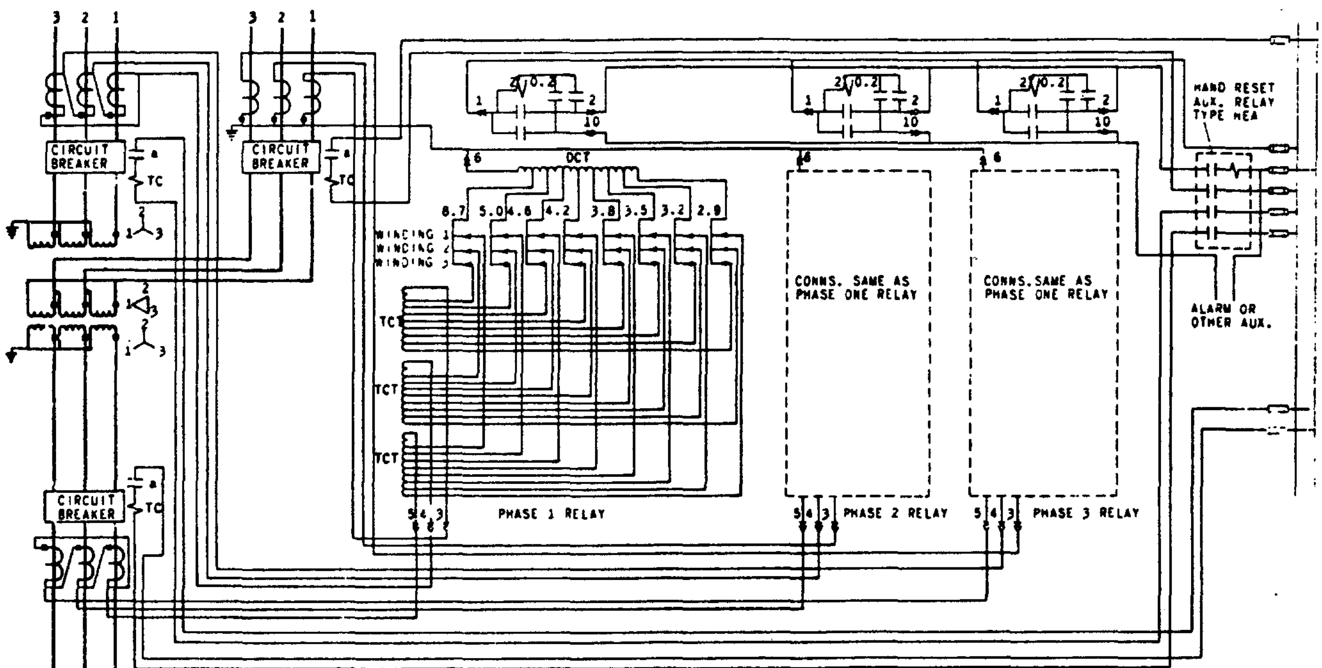
Fig. 9 Outline And Panel Drilling Dimensions of Type HDD Relay



a = AUX. SWITCH - OPEN WHEN CB IS OPEN
TC = TRIP COIL
DCT = DIFFERENTIAL CURRENT TRANSFORMER
TCT = THROUGH CURRENT TRANSFORMER

Fig. 10 (M-6216006)

Fig. 10 External Connections For Type HDD15A Relay



a = AUX. SWITCH - OPEN WHEN CIRCUIT BREAKER IS OPEN.
TC = TRIP COIL.
DCT = DIFFERENTIAL CURRENT TRANSFORMER.
TCT = THROUGH CURRENT TRANSFORMER.

Fig. 11 (M-6216007)

Fig. 11 External Connections For Type HDD16A Relay

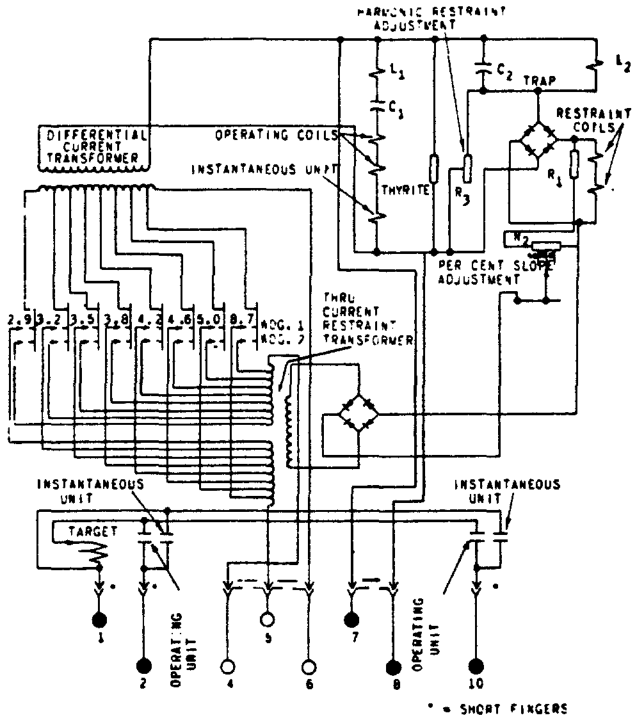


Fig. 12 Internal Connections For Type HDD15A Relay

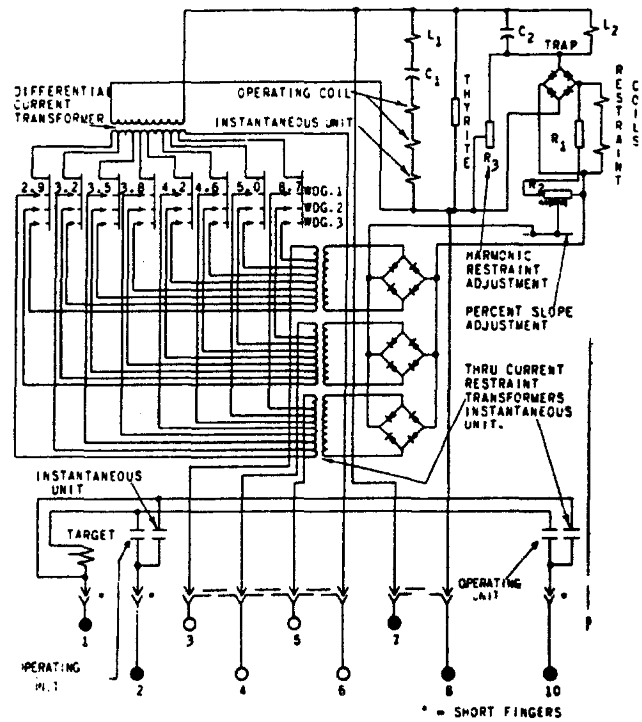


Fig. 13 Internal Connections For Type HDD16A Relay

INSTALLATION

LOCATION

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

MOUNTING

The relay should be mounted on a vertical surface. The outline and panel drilling dimensions are shown in Fig. 9.

CONNECTIONS

Internal connection diagrams are shown in Figs. 12 and 13. Typical wiring diagrams are given in Figs. 10 and 11 for differential applications, and in Fig. 14 for straight overcurrent applications.

When the relay is mounted on an insulating panel, one of the steel supporting studs should be permanently grounded by a conductor not less than No. 12 B & S gage copper wire or its equivalent.

ADJUSTMENTS

The relay has been adjusted at the factory to conform to the proper characteristics and it is advisable not to disturb these adjustments. If for any reason they have been disturbed, refer to the section titled MAINTENANCE for the procedure to be followed in restoring them. Front panel tap adjustments are provided for flexibility of application. Taps should be selected as indicated in the following paragraphs.

TAP PLUG POSITIONING

RATIO MATCHING ADJUSTMENT

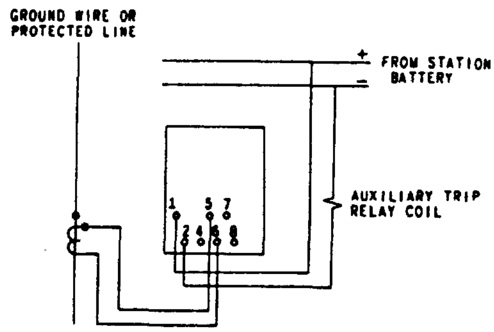
To obtain a minimum unbalance current in the differential circuit, means are provided in the HDD relay to compensate for unavoidable differences in current transformer ratios. Taps on the relay transformer primary windings are rated 8.7, 5.0, 4.6, 4.2, 3.8, 3.5, 3.2, and 2.9 amperes for each line current transformer. The tap plugs should be moved to the locations which most nearly match 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 CALCULATIONS. A spare tap plug is provided at the left of the tap block. This should be inserted in the desired tap before the existing plug is removed from the winding under adjustment. This procedure will avoid opening a current transformer circuit. A check should be made 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 left in a 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 or faults in the current transformer wiring, or small faults within the power transformer itself where the fault current is too low to operate the relay.

The Type HDD relays have a special arrangement for measuring the unbalance current flowing in the differential circuit without disturbing the relay connections. Provision is made for temporarily connecting a 5 volt high-resistance a-c voltmeter (1000 ohms per volt) across the secondary of the differential current transformer. This may be done by connecting the meter across terminals 7 and 8 (see Fig. 12 and 13). When a perfect match of relay currents is obtained by the ratio-matching taps, the voltmeter will read zero, indicating no unbalance current. When the voltmeter does not read zero, the equivalent unbalance current in amperes, referred to a particular tap, is approximately equal to the current rating of the tap multiplied by 0.06 times the voltmeter reading in volts.

Small rectifier-type a-c voltmeters such as the DO-45, DO-46, or DO-55 are suitable for the measurement of unbalance. The voltmeter should not be left permanently connected since the shunt current it draws reduces the relay sensitivity.



% SLOPE SETTING - 15

CURRENT TAP SETTING	2.9	3.2	3.5	3.8	4.2	4.6	5.0	8.7
PICKUP AMPS (1A RELAYS)	0.57	0.63	0.69	0.75	0.83	0.91	0.99	1.72
PICKUP AMPS (2A RELAYS)	1.15	1.27	1.39	1.50	1.66	1.82	1.98	3.45

Fig. 14 External Connections Showing Type HDD Relay Used As Ground Fault Detector or Overcurrent Relay

Fig. 14 (K-6400675)

PERCENTAGE DIFFERENTIAL SETTING

Taps for 15, 25, and 40 per cent slope settings are provided in both the HDD15A and HDD16A relays. It is common practice to use the 25 per cent setting unless special conditions make it advisable to use one of the others.

TARGET COIL TAP SELECTION

At the time of installation, the proper tap setting of the target unit should be chosen. In changing taps it is recommended that the screw from the opposite stationary contact be removed and inserted in the vacant tap before the factory-set tap screw is loosened. This will preserve the factory adjustment of the contact wipe and alignment.

CALCULATIONS

METHOD

The calculations required for proper ratio matching tap selection are outlined below. Corresponding steps in the solution of a sample problem are given in the right-hand column of this page.

I Connections of CT's

Power Transformer Connections	CT Connections
Wye-Delta	Delta-Wye
Delta-Delta	Wye-Wye
Wye-Wye	Delta-Delta
Delta Zig-Zag with zero degrees phase shift between primary and secondary.	Delta-Delta

EXAMPLE

Given a three-winding power transformer connected and rated as shown in Fig. 15. Apply Type HDD relays to protect this transformer.

I Connections of CT's

Power Transformer Connections	CT Connections
Delta-Wye-Wye	Wye-Delta-Delta

The following figure applies to the example in the right-hand column of this page.

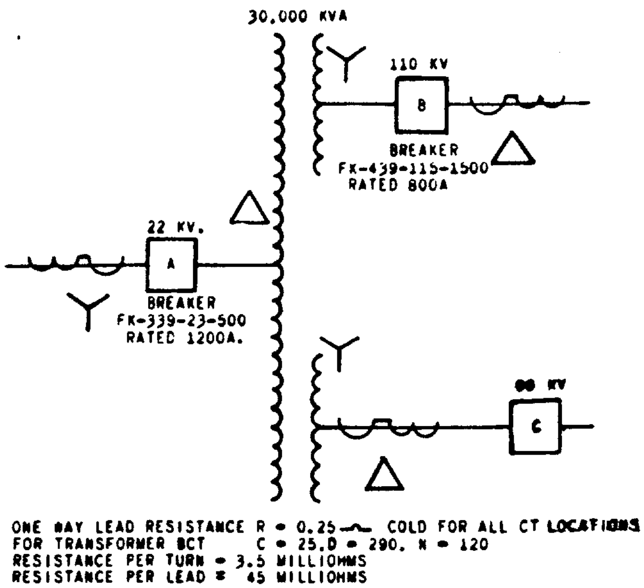


Fig. 15 Typical Differential Relay Transformer Protection

II Determination of CT Turns and Type HDD Relay Tap Setting

1. Find maximum line currents (max. I_p) on the basis that each power transformer winding may have the maximum forced air cooled rated KVA of the transformer imposed upon it.

$$\text{Max. } I_p = \frac{\text{Maximum Transformer KVA}}{(\text{Line KV})\ \sqrt{3}}$$

2. Find the full load rated line currents (100 per cent I_p) on the basis that each power transformer winding may have 100 per cent rated KVA of the transformer imposed upon it.

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

3. Choose the number of CT turns (N) to give a current which is less than or equal to the lowest possible HDD relay tap rating based on 100 per cent I_p. Do this for two windings.

For wye connected CT's -

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

For delta connected CT's -

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

II Determination of CT Turns and Type HDD Relay Tap Setting

For these calculations the three lines will be referred to as marked, A, B, and C.

1. This transformer is not equipped with forced air cooling.

2. $100\%\ I_pA = \dfrac{30{,}000}{22\sqrt{3}} = 787$ amperes

$100\%\ I_pB = \dfrac{30{,}000}{110\sqrt{3}} = 157$ amperes

$100\%\ I_pC = \dfrac{30{,}000}{66\sqrt{3}} = 262$ amperes

3a. CT's of breaker A are wye connected. Try N (CT turns) = 240.

$\text{Tap current} = \dfrac{787}{240} = 3.28$ amperes

Use the 3.5 ampere tap

3b. CT's of breaker B are delta connected.

Try N = 120

$\text{Tap current} = \dfrac{157\sqrt{3}}{120} = 2.27$ amperes

Use the 2.9 ampere tap

4a. Both currents are within the 5 ampere secondary rating of the CT's.

5a. Ratio of HDD taps of 3a and 3b $= \dfrac{3.5}{2.9} = 1.21$

Ratio of CT currents of 3a and 3b =

$\dfrac{3.28}{2.27} = 1.44$

% difference in ratios =

$\dfrac{1.44 - 1.21}{1.44} \times 100 = 16.0\%$

This is greater than 15 per cent and therefore is not acceptable.

3c. Try 100 turns for the BCT on breaker B

$\text{Tap current} = \dfrac{157\sqrt{3}}{100} = 2.72$

Use the 2.9 ampere tap.

4b. This current is within CT rating.

5b. Ratio of HDD taps of 3a. and 3c. =

$\dfrac{3.5}{2.9} = 1.21$

Ratio of CT currents of 3a. and 3c. =

$\dfrac{3.28}{2.72} = 1.20$

% difference in ratios =

$\dfrac{1.21 - 1.20}{1.21} \times 100 = 0.8\%$

This transformer is not equipped with tap changing means, and no additional error due to variation in I_p will be encountered. The CT turns and relay taps are therefore satisfactory up to this point.

4. Check that in each case the CT ratings are not exceeded under maximum load conditions.

$$\text{Rated CT secondary current} > \frac{\text{Max. } I_p}{N}$$

5. Calculate the percentage difference between the ratio of CT currents of the windings and the ratio of the tap ratings chosen for the same windings. Add to this figure the maximum possible percentage variation in I_p if the transformer has tap changing means. If the resultant figure is greater than 15 per cent, it is necessary to choose another value of CT secondary turns and recalculate the current. Use the same process to find the CT turns and ratio matching tap for the third winding (Type HDD16A relays), and check the percentage ratio matching error as before.

3d. CT's of line C are delta connected. Try 120 turns for the BCT on line C

$$\text{Tap current} = \frac{262\sqrt{3}}{120} = 3.78$$

Use the 4.2 ampere tap (in preference to the 3.8 ampere tap for better ratio matching.

4c. This current is within CT rating.

5c. Ratio of HDD taps of 3c. and 3d. = $\frac{2.9}{4.2} = 0.69$

Ratio of CT currents of 3c. and 3d. = $\frac{2.73}{3.78} = 0.72$

% difference in ratios = $\frac{0.72 - 0.69}{0.72} \times 100 = 4.2\%$

5d. Ratio of HDD taps of 3a. and 3d. = $\frac{3.5}{4.2} = 0.83$

Ratio of CT currents of 3a. and 3d. = $\frac{3.28}{3.78} = 0.87$

% difference in ratios = $\frac{0.87 - 0.83}{0.87} \times 100 = 4.6\%$

III Type HDD Relay Minimum Pickup Rating

1. Use the Type HDD relay with one ampere minimum pickup (five ampere tap) when the sum of the transformer secondary currents that will be supplied to a relay for any fault at the terminals of the power transformer is less than 280 amperes RMS for 0.25 seconds.

NOTE: If the period during which a fault current flows in the relay can be definitely limited to a shorter time, a higher current can be accommodated in accordance with the relation: $(\text{amperes})^2 \times (\text{seconds})$ 12,100.

2. Use the model with 2 ampere minimum pickup (5 ampere tap) if currents above 280 and up to 440 amperes are to be encountered for up to 0.25 seconds in cases where the above limitation cannot be met.

III Type HDD Relay Minimum Pick-up Rating

Assume that the sum of the current transformer maximum secondary currents that will be supplied to the Type HDD relays is less than 220 amperes RMS for 0.25 seconds.

Under these conditions, use a Type HDD relay with a minimum pickup of 1 ampere (5 ampere tap)

IV PER CENT SLOPE

Use the 25 per cent slope tap if the load ratio control maximum per cent range plus the per cent mismatch of the HDD taps plus the current transformer per cent ratio error at maximum external fault current does not exceed 20 per cent. If the sum of these exceeds 20 per cent, but not 30 per cent, use the 40 per cent slope tap.

V CT Ratio Error

The CT ratio error must be less than 20 per cent at 8 times the rated tap current. This is based upon a normal pick up setting of the instantaneous unit. If the instantaneous unit is set above normal, the following equations do not apply. Refer to the General Electric Company in this case. Check that the error is within 20 per cent by the following operations.

IV Per Cent Slope

In this example, the percentage difference between HDD tap ratios and current transformer current ratios is less than 15 per cent, and the transformer is not of the tap changing type. The total ratio matching error is therefore less than 15 per cent. Use the 25 per cent slope tap.

V CT Ratio Error

1. For Type HDD relays on line A, CT's are wye connected.

$$VN \geq M\left[B + \frac{Ne + 2.5f}{800} + 2.27R\right]$$

$$1.10\,(240) \geq 28\left[0.98 + \frac{240\,(4.5) + 2.5\,(30)}{800} + 2.27\,(0.25)\right]$$

These calculations are for the worst fault conditions of 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.

Refer to Tables A and B and calculate both sides of the appropriate equation which follows:

SYMBOL	MEANING	TABLE
V	CT voltage per turn	A
N	CT turns (turns ratio)	Previously Calculated
M	8 times tap used	B
B	HDD total burden	B
e	milliohms per turn	A
f	milliohms per lead	A
R	one way lead resistance in ohms from CT to HDD relay	Data from customer

These formulas include factors to convert cold resistance to hot resistance.

($\geq$ means greater than or equal to)

For wye connected CT's -

$$VN \geq M\left[B + \frac{Ne + 2.5f + 2.27R}{800}\right]$$

For delta connected CT's -

$$VN \geq M\left[2B + \frac{Ne + 2.5F + 2.27R}{800}\right]$$

NOTE: The term in brackets is the ohmic burden on the CT. If auxiliary CT's or other burdens are also imposed on this CT, their resistances must be added directly to the burden shown.

If this equation cannot be satisfied it is necessary to increase the CT turns and repeat all calculations to this point.

$264 > 83.6$ volts.

The equation is satisfied; therefore, the CT ratio error is within limits.

2. For Type HDD relays on line B, CT's are delta connected.

$$VN \geq M\left[2B + \frac{Ne + 2.5f}{800} + 2.27R\right]$$

$$3.75\ (100) \geq 23.2\left[2\ (1.30) + \frac{100\ (3.5) + 2.5\ (60)}{800} + 2.27\ (0.25)\right]$$

$375 > 78.8$ volts

3. For Type HDD relays on line C, $N_T = 120$ turns C = 25 D = 290. Drawing the excitation curve by the template method, it is found that with I_e at 5.8 amperes $E_S = 240$. Then $A = \frac{E_S}{N_T} = 2.0$ volts.

The CT's are delta connected.

$$VN \geq M\left[2B + \frac{Ne + 2.5f}{800} + 2.27R\right]$$

$$2\ (120) \geq 36.8\left[2\ (0.63) + \frac{120\ (3.5) + 2.5\ (45)}{800} + 2.27\ (0.25)\right]$$

$240 > 94$ volts

The selection of CT turns and HDD taps is found to be satisfactory for this application.

TABLE B

	8x Tap Current	FOR HDD WITH 1 A. MIN. P.U. ON 5A. TAP BURDEN		FOR HDD WITH 2A. MIN. P.U. ON 5A. TAP BURDEN	
HDD TAPS	M AMPS	B OHMS	MIN. P.U. AMPS	B OHMS	MIN. P.U. AMPS
2.9	23.2	1.30	0.58	0.431	1.16
3.2	25.6	1.12	0.64	0.376	1.28
3.5	28.0	0.98	0.70	0.328	1.40
3.8	30.4	0.87	0.76	0.280	1.52
4.2	34.6	0.74	0.84	0.248	1.68
4.6	36.8	0.63	0.96	0.210	1.92
5.0	40.0	0.54	1.00	0.182	2.00
8.7	69.6	0.24	1.74	0.082	3.48

TABLE A

CIRCUIT BREAKERS			CURRENT TRANSFORMERS***						
TYPE	RATINGS		No. of Turns in Full Winding	Drawing No. ** L-6193387 Group -	Constants for Drawing Characteristic Curves by Template Method		Approx. Internal Res. Milliohms		CT Volts per turn V*
							per turn	per lead	
	KV	AMPS			C	D	e	f	
FKO-227-7.2	7.2	600	120	28	10	140	3.0	10	0.80 †
FLO-15-14.4	14.4	600	120	02	17	200	2.5	20	1.40
FLO-15-14.4	14.4	1200	240	03	17	200	2.5	20	1.40
FK-339-14.4	14.4	1200	240	09	13	170	4.5	25	1.10
FK-339-14.4	14.4	2000	400	04	13	240			1.12
FK-339-14.4	14.4	3000	600	05	10	280	2.5	25	0.875
FK-339-14.4	14.4	4000	800	06	13	320	2.5	25	1.10
FK-339-23	23	600	120	08	13	170	4.5	30	1.10
FK-339-23	23	1200	240	09	13	170	4.5	30	1.10
FK-339-23	23	2000	400	04	13	240	2.5	30	1.10
FK-339-34.5	34.5	600	120	11	15	180	3.5	35	1.25
FK-339-34.5	34.5	1200	240	12	15	180	3.5	35	1.35
FK-339-34.5	34.5	2000	400	13	14	270	2.5	35	1.08
FK-339-34.5	34.5	3000	600	14	10	270	3.0	35	0.81
FK-339-46	46	600	120	17	17	220	2.5	35	1.30
FK-339-46	46	1200	240	18	17	220	2.5	35	1.40
FK-439-69	69	600	120	43	25	290	3.5	45	2.00
FK-439-69	69	1200	240	44	25	290	3.5	45	2.20
FK-439-115	115	800	120	33	40	520	3.5	60	3.75
FK-439-115	115	1200	240	34	40	520	3.5	60	3.30
FK-439-138	138	800	120	35	40	600	3.5	60	3.30
FK-439-161	161	800	240	37	40	670	3.5	70	3.25
FK-439-230	230	800	240	42	43	1040	2.5	80	3.50
FH or ARA	14.4/35.5							2/ft.	1.30

* Voltages not good below 20 turns. Data given are from a 20 turn characteristic curve at 5.8 amperes excitation current.

† Not good below 40 turns

** Excitation curves are on K-63070-- (last two numbers are group numbers of K-6193387

*** For other types of CT's obtain the secondary voltage at the excitation current which results in 20 per cent CT error. This voltage replaces VN in the formulas.

OPERATION

RELAY CURRENT TRANSFORMERS

Currents flow in the fault sensitive relay elements from the secondaries of small auxiliary current transformers mounted inside the relay case. One of these is connected in the differential circuit of the line transformers and is called the "differential current transformer". In the two-winding transformer relay, Type HDD15A, there is a second small auxiliary transformer with two identical primary windings, one of which is connected in each of the line current transformer circuits. This transformer is called the "through current restraint transformer" since it supplies the restraint on through fault currents which gives the relay its percentage differential or slope characteristic. In the three-winding transformer relay, Type HDD16A, there are three independent through current restraint transformers each with a single primary winding.

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

OPERATING AND RESTRAINING CIRCUITS

The secondary winding of the differential-current transformer supplies current to both the operating and the restraining coils of the relay through two parallel circuits. The operating coil circuit is tuned by means of capacitor C_1 and reactor L_1 to pass currents of the fundamental system frequency and to offer high impedance to currents of other frequencies. The restraining coil circuit includes a wave trap consisting of capacitor C_2 and reactor L_2 connected in parallel, and tuned to block fundamental frequency currents while allowing currents of harmonic frequencies to pass with relatively little impedance. The harmonic currents are rectified before passing through the restraint coils, not only to smooth the restraining pull on the armature, but also to permit the application of similarly rectified current from the secondaries of the through current restraint transformers to the same restraint coils. It will be evident that if the differential current applied to the relay is of 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 proportion of harmonics the relay will be restrained from operating by the harmonic currents flowing in the restraint coils.

The proportion of harmonics in the differential current used to restrain the relay is determined by the characteristics of the tuned circuits and by the setting of the adjustable resistor R_3. The general slope of the harmonic restraint characteristic curve (Fig. 5) is fixed by the filter circuits. Its height is set by the resistor. In test, the curve shown is obtained by adjustment of this resistor while supplying the relay with a current drawn through a special testing reactor calibrated to give exactly 25 per cent third harmonic component and negligible percentages of other harmonics. (See section titled MAINTENANCE - HARMONIC CURRENT RESTRAINT.)

The through current restraint is controlled by means of the tapped shunting resistor R_2. This resistor provides a means of selecting any desired per cent of restraint from the through current transformers. Preset taps allow a ready selection of 15, 25, and 40 per cent slope characteristics.

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

OVERCURRENT UNIT

On extremely heavy internal fault currents, the instantaneous overcurrent unit, which is connected in the operating coil circuit of the main unit, will pick up and complete the trip circuit. The instantaneous unit target (I) will be exposed, but since the contacts by-pass the target coil, the trip current will not cause operation of that target (T).

Because of saturation of the CT's 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, under conditions of a high internal fault current supplied from both sides of the power transformer, the main unit may be falsely restrained. Tripping is assured, however, by the overcurrent unit operation. Pickup is set above the level of differential current produced by maximum magnetizing inrush current. Fig. 3 shows the relative levels of pickup and speed of operation of the main unit and the overcurrent unit.

MAINTENANCE

CONTACT CLEANING

For cleaning fine silver contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etched roughened surface, resembling in effect a superfine file. The polishing action is so delicate that no scratches are left, yet corroded material will be removed rapidly and thoroughly. The flexibility of the tool insures the cleaning of the actual points of contact. Sometimes an ordinary file cannot reach the actual points of contact because of some obstruction from some other part of the relay.

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 is included in the standard relay tool kit obtainable from the factory.

PERIODIC TESTS

An operation test and inspection of the relay and its connections should be made at least once every six months.

If adjustments are necessary for any reason, the entire relay may be adjusted in accordance with the following paragraphs.

ARMATURE AIR GAPS

The air gap at the hinge end of the armature should be adjusted to 0.001 inch by means of the two fine-threaded pivot screws (See Fig. 8). The locknuts should be securely tightened after this adjustment is made.

The air gap between the restraint (lower) magnet and the armature should be adjusted to approximately 0.006 inch by means of the lower armature screw (See Fig. 7). Tighten the clamp screw after this adjustment.

The air gap between the armature and the operating (upper) magnet poles, with the armature against its lower stop, should be adjusted to 0.050 inch by loosening the four mounting screws and shifting the magnet up or down slightly. The structure should be securely tightened after this adjustment.

The upper armature stop screw should be adjusted to provide an air gap of 0.010 inch between the armature and the operating magnet when it is in the picked-up position. The clamp screw should be tightened after this adjustment.

CONTACTS

The contacts should be adjusted to close with a contact pressure of 4 to 6 grams measured at the end of the contact brush. This adjustment is made by means of the fine-threaded contact screws, or by slightly bending the flexible contact strip if necessary.

The contact assemblies should then be rotated on their mounting studs until the contacts are opened approximately 0.030 inch when the armature is against the lower stop. When the armature is lifted against the upper stop. There should be a clearance of 0.010 inch or more between the operating arms and the brushes of the closed contacts.

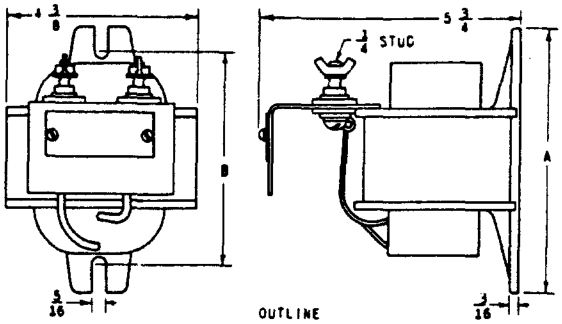
PICKUP

Pickup is adjusted by screwing the shaft which holds the lower end of the armature spring, in or out on its stud. This varies the leverage of the spring, which holds the armature down in its bearings. Pickup should be 1 ampere for relay types 12HDD15A5, 6 or 12HDD16A5, 6, and 2 amperes for relay types 12HDD15A7, 8 or 12HDD16A7, 8 with current flowing into the relay through terminals 5 and 6, and with the tap plugs in the 5 ampere tap and the 25 per cent slope tap.

HARMONIC CURRENT RESTRAINT

The harmonic restraint is adjusted to have the characteristic shown in Fig. 5 by means of a special reactor (see Fig. 16). Tests should be made using the circuit shown in Fig. 17 and the 5 ampere and 25 per cent slope taps. Table IV lists the relay models and corresponding reactor drawing numbers. The reactor has been designed and adjusted at the factory to draw, at 120 volts, a current having 25 per cent third harmonic and negligible percentages of other harmonics. The reactor may be used on a voltage source of rated frequency and within the range of 115-125 volts. The current drawn at 120 volts is approximately 10 amperes RMS for group 4 and 5 reactors, and 20 amperes RMS for group 6 and 7 reactors. This current changes rapidly as the applied voltage varies within the indicated range, but the harmonic content remains comparatively constant. No resistor or other current-limiting device should ever be used in series with the reactor and relay. The reactor should not be used on any other voltage or frequency source since this would change the harmonic percentage and result in an improper harmonic restraint setting of the relay.

When the relay is properly set with reactor current flowing through it, the armature should buzz noisily but not pick up. This test should be made on the steady-state current of the reactor, not its transient switching current. The armature may pick up on the transient switching current since, owing to the special design of the reactor, the transient current may have lower harmonic content than the steady-state current. To avoid this, the relay armature should be held down by hand while the switch is being closed.



GR. NO.	CAT. NO.	NAME PLATE	REACTOR DWG. NO.	GR	COIL SPEC.	RATING V	RATING CYC	A	B	FUSED WITH RELAYS
4	6174403-4	79242	L-6193350	7	K-6174506 G-1	115	60	$6\frac{1}{16}$	$4\frac{3}{4}$	HDC12A11,12 HDD11A13,14 HDD11B9,10
5	6174403-5	79242	L-6193350	8	K-6275001 G-1	115	50	$6\frac{13}{16}$	$5\frac{1}{2}$	HDDC12A13, 14 HDD11A15,16 HDD11B11,12
6	6174403-6	79242	L-6193350	13	K-6275069 G-1	115	60	$7\frac{3}{8}$	$6\frac{1}{8}$	HDC12A15,16 HDD11A17,18 HDD11B13,14
7	6174403-7	79242	L-6193350	14	K-6275069 G-2	115	50	$6\frac{13}{16}$	$7\frac{9}{16}$	HDD11A19,20 HDD11B15,16

Fig. 16 Outline And Index of Test Reactor

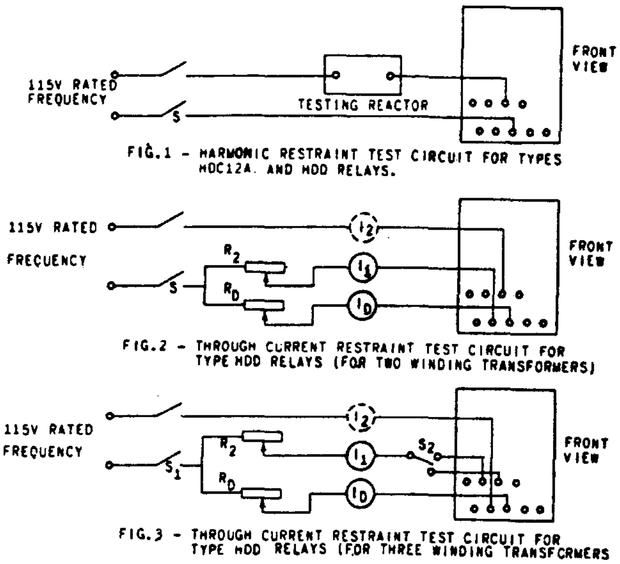


Fig. 17 Test Connections For Type HDD Relay

If the relay is slightly out of adjustment it may be corrected by adjusting the position of the band on resistor R_3. This resistor is located at the top right side of the relay case, behind the relay unit. If the relay is badly out of adjustment, as might be caused by disturbing the mechanical adjustments of the relay armature, the band on R_3 should be placed at about the center of the resistor and, with the test reactor current flowing in the relay, the air gap between the armature and the lower magnet poles should be adjusted by means of the lower armature stop screw. Following this adjustment, it will be necessary to readjust the through-current restraint resistor band settings as described in the next section.

TABLE IV

Model		Reactor
12HDD15A5,	16A5	1674403-4
12HDD15A6,	16A6	5
12HDD15A7,	16A7	6
12HDD15A8,	16A8	7

THROUGH-CURRENT RESTRAINT

The through-current restraint, which gives the relay the percentage differential or per cent slope characteristics shown in Fig. 2, may be checked and adjusted using the circuit illustrated in Fig. 17. Ammeter I_1 reads the smaller of the two through currents, I_2 reads the larger, and I_D reads the differential current. Since the current in I_2 is the sum of the currents in I_1 and I_D, this meter is not necessary for making the test. In testing HDD16A relays the setting should be checked with the switch S_2 first in one position and then the other, thus checking all the restraint coils. With the current tap plugs in the 2.9 ampere position and the per cent slope tap plug in the 40 per cent position, adjust the upper band on resistor R_2 (located at the top left side of the case, behind the relay unit) until the relay just picks up for values of the I_1 and I_D currents indicated in Table V. Repeat with the per cent slope tap plug in the 25 per cent and 15 per cent positions, making adjustments on the middle and lower bands of R_2, respectively.

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

When the settings are made, the 40 per cent slope band should be very near the upper end of the resistor with the 25 and 15 per cent bands well spaced below. In making the adjustment, if it is found that the 40 per cent band comes down so low that the bands are crowded, or up so high that the 40 per cent setting cannot be obtained, then the band should be placed at the top end of the resistor and the air gap between the armature and the lower magnet poles of the relay adjusted by means of the lower armature stop to obtain the 40 per cent slope adjustment. Following this, the 25 per cent and the 15 per cent slope bands may be adjusted, and finally the band on the harmonic restraint resistor R_3 should be reset as described in HARMONIC CURRENT RESTRAINT.

TABLE V

Relay Model	Per Cent Slope Tap	Band on Res. R_2	Amperes	
			I_1	I_D
12HDD15A5, 6 12HDD16A5, 6	40	Upper	25	10.0
	25	Middle	30	7.5
	15	Lower	30	4.5
12HDD15A7, 8 12HDD16A7, 8	40	Upper	50	20.0
	25	Middle	60	15.0
	15	Lower	60	9.0

INSTANTANEOUS OVERCURRENT UNIT

This unit is located in the central right-hand side of the case and is marked I. Its setting may be checked by passing a high current of rated frequency through terminals 5 and 6. The unit should pick up at 8 times the tap rating as described under OPERATING CHARACTERISTICS. If the setting is incorrect, it may be adjusted by loosening the locknut at the top of the unit and turning the cap screw until the proper pickup is obtained. In making this adjustment, the current should not be allowed to flow for more than approximately one half second at a time.

DISABLING OF TYPE HDD RELAY

To make the Type HDD relay inoperative, short the studs connected to the lower rated tap first. As indicated in Figs. 12 and 13, winding No.1 terminates at stud 5, winding No. 2 at stud 4, and winding No. 3 at stud 3. Stud 6 is in common with all windings through the differential circuit. Short circuits should be made from stud 6 to the other studs in the appropriate order. It is not safe to short all sets of studs unless the lower rated is shorted first. The opposite sequence of shorting may cause relay operation. Disabling can be used to make the relay inoperative during breaker maintenance or similar operations.

RENEWAL PARTS

It is recommended that sufficient quantities of renewal parts be carried in stock to enable 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 quantity required, name of part wanted, and give complete nameplate data, including serial number. If possible, give the General Electric Company requisition number on which the relay was furnished.