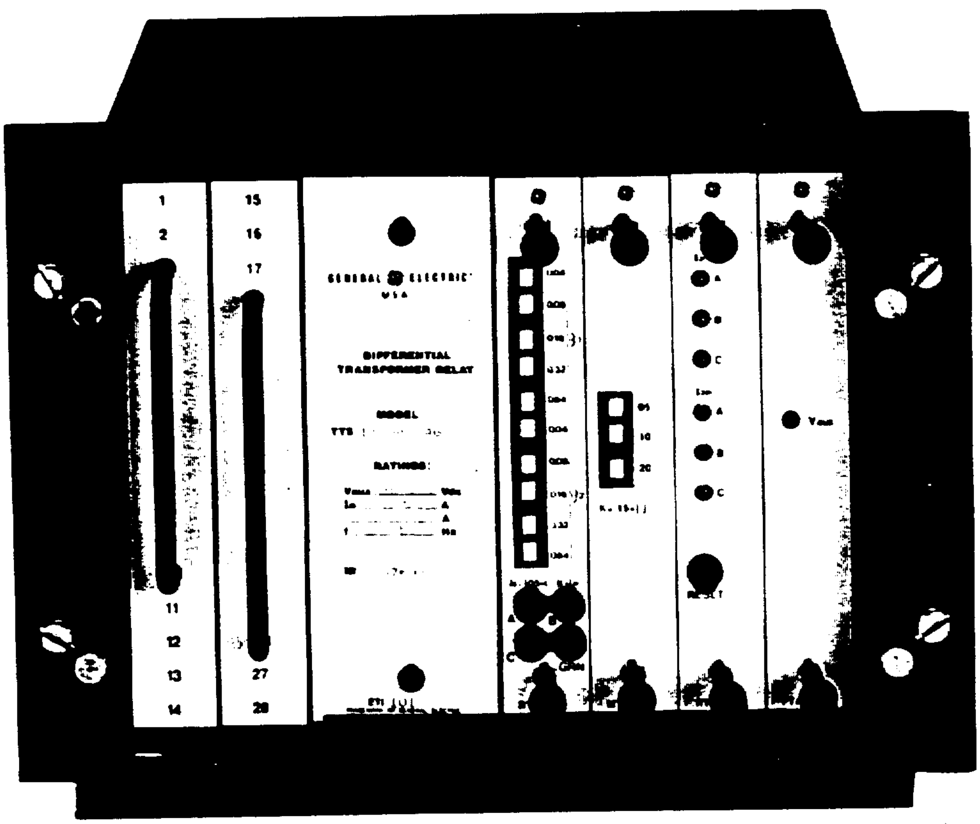
INSTRUCTIONS

GEK - 98824 B
Supersedes GEK - 98824 A

TRANSFORMER DIFFERENTIAL PROTECTION

TTS 1000



GENERAL ELECTRIC

U. S. A.

CONTENTS

DESCRIPTION

TTS1000 relays are three phase differential relays, provided with adjustable percentage (slope) and harmonic restraint, and they offer the possibility of phase matching in the case where the CT's are not dedicated.

The first characteristic allow a great accuracy to recognize internal and external faults in the transformer due to large currents.

The harmonic restraint avoids the relay's operation when the magnetizing inrush current is produced during its connection or disconnection (or in other circumstances which cause sudden variations in the flux created in the transformer). The relay differentiates the magnetizing inrush current from the current caused by the existence of an internal fault.

They are modular version solid state and they are provided in half or one standard 19" rack cases, provided with one or several functions, and making up complete protection systems.

MODEL LIST

Test block		Rated current			Nº of windings			Frecuency Hertz		Aux. voltage Vdc/Vac	
Yes	No	5A	1A	Both	2	3	4	50	60	48-125	110-250
1	0	0	1	2	0	1	2	1	2	G	H

T T S 1 ___ ___ ___ B ___ 2 1 ___ 0 0

CURRENT RANGE

Rated current of input transformers 5A and 1A.

The percentage restraint (slope) value may be adjusted by means of microswitches from 15% to 50% in 5% steps.

The harmonics restraint value is adjusted to 20%.

The instantaneous unit is adjusted to 8 times the value of the tap.

The series models are provided with two tripping output relays common to all measuring units with two N.O. contacts each one. Other models are provided with more than two tripping relay (up to four), and a maximum of six signalling relays (one N.O. contact) for the instantaneous and differential unit operation signalling per phase (REFER TO GE APPLICATION ENGINEERING SERVICES).

THE EXTERNAL CONNECTIONS DRAWINGS, MODULE AND PCB LOCATION, FRONT VIEWS AND OTHER INFORMATION CONTAINED IN THIS INSTRUCTION BOOK CORRESPONDS TO THE STANDARD RELAYS (SERIES MODELS). BECAUSE IT WILL BE IMPOSSIBLE TO INCLUDE IN THIS BOOK THE SAME INFORMATION FOR OTHER TTS RELAYS DUE THE WIDE NUMBER OF MODELS, IT IS NECESSARY TO REQUIRE THAT FROM THE ABOVE GE APPLICATION ENGINEERING SERVICES DEPARTMENT. HOWEVER THE TECHNICAL INFORMATION, OPERATING PRINCIPLES, ACCEPTANCE TESTS, INSTALLATION, RELAY CALIBRATION, INTERNAL/EXTERNAL MATCHING OF POWER TRANSFORMER CONNECTION AND OTHERS ARE SUFFICIENT FOR THEIR PURPOSES

APPLICATION

The ratios between the current transformers and the relay taps must be selected so that the maximum sensitivity is achieved and to avoid relay missoperation or thermal overload either on the relay or on the current transformers. Therefore, the CT ratios of the various windings of the protected transformer should be selected bearing in mind the following considerations:

1. The smaller the relay tap and the CT ratio are, the higher sensitivity is achieved. However, this cannot be compatible with any of the conditions expressed below. When the choice between increasing the CT ratio or the relay tap is possible, it is always more advisable to increase the CT ratio, instead of increasing the relay tap, since in the event of any fault, the current in the secondary will be lower, as the CT accuracy is improved.

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

3. The relay current corresponding to the maximum power of the protected transformer (KVA on a forced cooled basis) should not exceed twice the selected relay tap value, which is the rated value of the relay in steady state.

4. The CT ratio should be high enough so that the secondary currents cannot cause any damage to the relay, given the case of maximum current of an internal fault. (See technical specifications of the TTS relays current circuits.)

5. The relay current corresponding to the rated KVA of the power transformer (on self cooled basis) should not exceed the selected tap value. Otherwise, it could operate the instantaneous unit with the magnetizing inrush current. Should not the mentioned transformer have its rated values specified on self-cooled basis, it is advisable to refer to the manufacturers for information on the equivalent characteristics on this option; That is the rating of a self-cooled transformer with magnetizing inrush characteristics as the transformer under consideration.

6. The TTS relay instantaneous unit is adjusted to trip for a differential current of 8 times the tap current in order to guarantee:

6.1 Instantaneous tripping ($t < 10$ ms) since that unit is not affected by the wave distortion produced by harmonics in very great currents and that however, in function of the harmonics content (%) could inhibit the differential unit tripping due to the harmonic restraint characteristic.

6.2 The 8 times tap value is selected in accordance to the magnetizing inrush current in the primary winding of transformer to assure non tripping operation in this cases. However due that sometimes, and in accordance to time, KV level and core characteristics may appear magnetizing inrush currents of a higher values than this, it is possible that instantaneous unit comes operative and gives a trip.
If this situation takes place, it could be avoided by selecting a higher tap and bearing in mind to keep the same relation "tap/current" for the secondary tap selection as shown in example of page 10.

7. 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 by means of which the currents may usually be matched within 5 percent. 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 percentage restraint 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.

8. In some applications, the power transformer will be connected to the high voltage or low voltage system through two breakers as for example in a ring bus arrangement. In this case the CT turn 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 CT's on each of the two low voltage (or high voltage) breakers be connected to a separate restraining winding to assure the restraint on heavy through fault current flowing around the ring bus.

9. It is not desirable to protect two parallel transformer banks 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 false operation on magnetizing inrush to one transformer bank causing a "sympathetic inrush" into the bank already energized. In is 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.

CALCULATION OF SETTINGS

METHOD

This section describes all the calculation required to establish the CT taps and the taps of the relay itself. A clear example applicable to the transformer shown in fig. 16 is described later on.

CT CONNECTIONS (dedicated transformers.)

	Power transformer connection group (Fig. 23)	CT secondary connection	Connection to be done in TTS relay (RTT board jumpers in Fig. 8)
1.	delta-wye	wye-wye	wye-delta
2.	wye-delta	wye-wye	delta-wye
3.	delta-delta	wye-wye	wye-wye
4.	wye-wye	wye-wye	delta-delta
5.	delta-zigzag with zero degrees phase shift between primary and secondary.	wye-wye	delta-delta

As shown the above table, it is not necessary to make the CT secondary wiring in delta connection, since it can be done in the TTS relay, and thus in consequence permitting to install other protection equipments that needs the wye connection in the same secondary.

DETERMINATION OF CT RATIO AND TTS RELAY TAP SETTING

1. Establish the maximum line currents (I_p max.) so that each power transformer winding would be able to carry the maximum power corresponding to forced cooled rated KVA:

$$I_{p\ max} = \frac{\text{(Maximum transformer kVA)}}{\sqrt{3} \times \text{(Line kV)}}$$

2. Establish the full line currents (100%) so that each transformer winding would be able to carry the full self cooled rated KVA of the transformer, or its "equivalent" self rating, only.

$$100\%\ I_{p\ max} = \frac{100\% \text{ transformer kVA}}{\sqrt{3} \times \text{(Line kV)}}$$

These calculations do not imply that all the windings are necessarily going to provided these currents continuously. It is just an appropriate way of calculating the currents in the other windings according to its rated voltages. This is required for selecting the relay's tap so that it does not operated for external faults.

3. Select the ratios for the CT's so that for the maximum Ip, the CT secondary current does not exceed the CT secondary thermal rating. The relay's taps must also be taken into account, so that secondary currents may be correctly matched.

Due that TTS relay is provided with internal phase angle matching, the changes imposed by the power transformer connection group, may be done easily in the relay (through jumpers in RTT board).

In this manner, CT secondary connection could be only wye connection, keeping in mind to multiply current by $\sqrt{3}$ in those cases were delta connection should be introduced to relay due the power transformer windings connection. Then select appropriate relay tap.

4. Check the currents matching flowing through the relay with the selected taps, in order to maintain the error as low as possible.

The matching error is determined as follows:

In two-winding transformers, determine the ratio between the two currents flowing through the relay and the two selected taps. The matching error is the difference between both ratios divided by the smallest ratio. Normally, this error should not exceed 5%.

In three winding transformers, the matching error should be checked for all the currents and taps combinations.

In the case where the taps can not be selected in order to maintain this error within the allowed limits, it will be necessary to select different CT ratios, in one or several lines, in order to obtain better match between the relay's currents and the taps, it should be considered that TTS relay has several taps from 2.5A to 8.7A in 0.2 steps.

5. During maximum external fault situations, check that in the primary and secondary, the currents applied to the relay for a fault in the power transformer terminals don't exceed 100 I_n during 1 second.

Also check that the sum of the currents applied to the relay for an internal fault don't exceed 220 A during 1 second.

RATIO ERROR IN THE CT

The ratio error in the CT must be less than 20% for a current 8 times relay rated tap current. This is due to the fact that the overcurrent unit is adjusted to the normal value 8 times the relay's tap. Should the instantaneous unit be adjusted to a greater value, the 20% error will have to be decreased according to what is established in section TECHNICAL SPECIFICATIONS.

The calculations shown below correspond to the worst fault condition concerning the CT, that is, when an internal ground fault occurs between the CT and the power transformer winding, with no current flowing through the transformer's neutral.

1. Determine each CT burden using the following expressions:

a).- For Wye-connected CT's:

$$Z = B + \frac{N.e + 2.5\ f}{1000} + 2.27\ R \ \text{Ohms}$$

b).- For Delta-connected CT's:

$$Z = 2B + \frac{N.e + 2.5\ f}{1000} + 2.27\ R \ \text{Ohms}$$

Where:

B: Relay's total burden (see table 1)
N: CT turn relation
e: CT resistance per turn in milliohms
f: CT resistance per lead in milliohms
R: Resistance in one of the wires (at 75°C) going from the CT to the relay.

Multipliers used on the f and R terms include elements to cover the existence of two wires instead of one, resistance increase due to temperature rise and resistance of the CT longest leads.

2. Determine the CT secondary current for 8 times the tap value:

I_s = 8 x relay's tap

NOTE: For the given fault, all the fault currents are provided by only one CT. Therefore, the CT and the relay's currents are the same no matter if the CT's are delta or wye-connected.

3. Determine the CT secondary voltage, required at 8 times the tap setting:

$$E_s = I_s \times Z$$

4. From the CT excitation curve that is being used, determine the excitation current (I_e) corresponding to this E_s voltage.

5. Determine the percent error in each CT with the expression:

$$\% \text{ ERROR} = \frac{I_e}{I_s} \times 100$$

This value should not exceed 20% for any CT. If it does, a higher ratio will have to be selected for the CT, and repeat the relay's tap selection, matching error and percentage error calculations.

PERCENT SLOPE SETTING

The proper percent slope is determined by the sum of:

a) The maximum range of tap changer or load ratio control in percent.

b) The maximum percent of mismatch of the relay taps in percent.

The selected percentage slope must be greater than the ratio of maximum total error current to the smaller of the through currents. In general, if the total error does not exceed 20%, the 25% tap can be used. Should it exceed 20% but not 35%, the 40% tap is the correct one. A fine adjustment can be carried out with this relay since restraint increases in 5% steps.

SETTINGS CALCULATION EXAMPLE (Refer to Fig. 16)

1.-Line	A	B	C
2.-max. $I_p = 5000/[\sqrt{3} \times \text{(line voltage)}]$	21.9	43.8	87.6
3.-100% $I_p = 4000/[\sqrt{3} \times \text{(line voltage)}]$	17.5	35	70
4.-Select CT turn relation	20	20	40
5.-max secondary I. (smaller than 5A)	1.10	2.19	2.19
6.-100% $I_{secondary}$	0.87	1.75	1.75
7.-CT connections	wye	wye	wye
8.-Relay connections*	delta	delta	wye
9.-Relay currents for 100% $I_{secondary}$	1.50	3.03	1.75

* Refer to point 3 of DETERMINATION OF CT RATIO AND TTS RELAY SETTINGS

Select one relay tap for one of the currents by calculating the currents in the rest of the lines, increasing them in the same ratio or select the closest taps to the relay full load line currents.

10.-Relay's taps calculation:

Depending on the application criteria, the tap values closer to the obtained currents may be selected, or, should any other condition exist, a tap for a line will be selected (the greater or lower), maintaining the same ratio of that tap regarding its current in the selection of the taps for the other lines. In this case the minimum available tap is 2,5A. and will be chosen for line A, maintaining same tap/current ratio for the other lines.

Line A selected tap: <u>2.5 A</u>

Line B:
2.5/1.5 = 1.666
3.03 x 1.666 = 5.05 A
B nearest tap = <u>5.1 A</u>

Line C:
2.5/1,5 = 1.666
1.75 x 1.666 = 2.91 A
C nearest tap = <u>2.9 A</u>

11.- Matching error

$$\text{Lines A-B: } \frac{5.1/2.5 - 3.03/1.5}{5/2.9} = 0.99\%$$

$$\text{Lines B-C: } \frac{5.1/2.9 - 3.03/1.75}{3.03/1.75} = 1.57\%$$

$$\text{Lines C-A: } \frac{2.9/2.5 - 1.75/1.50}{2.9/2.5} = 0.57\%$$

If an error greater than 5% is obtained, the unbalance will be always covered by the percentage restraint (slope) adjustment (15% - 50%), but it is not recommended exceed 20% errors (including the maximum transformer tap changer % range).
Moreover , the TTS has several currents taps for primary and secondary from 2.5 to 8.7 A (0.5 - 1.74 A for I_n = 1 A) in 0.2 A steps (0.04 A for I_n = 1 A).
In that manner there always be equal or very close taps to the obtained current value, getting errors too lower than 5%.

12.- Check that the maximum currents going through the relay are less than 220 A, in 1 second, (relay phase current primary or secondary, due to the maximum expected fault current at transformer terminals), so that it does not overrun the relay short time rating.

Note 1: CT used in this example is a multi-ratio ANSI C100 class current transformer. In other cases the CT ratio may be fixed (not multi-ratio) or be dedicated CT's.

Note 2:. The phase compensation (wye - delta changes) may be done externally (in the CT secondary wiring), or it is possible to make it in the differential TTS relay. For example the installation of other equipments in the same secondary requires wye type connection and it is not possible to make "delta" connections. In these cases it is highly useful the TTS relay phase compensation that allows the delta or wye changes through available jumpers in the RTT board.

CT RATIO ERROR

1. CT's burdens: (the resistance of a wire is supposed to be 0,25 ohms).

A) Line A:

$$Z = 0.0244 + \frac{(20 \times 4.1 + 2.5 \times 25)}{1000} + 2.27 \times 0.25$$

$$Z = 0.736$$

B) Line B:

$$Z = 0.0244 + \frac{(20 \times 4.1 + 2.5 \times 25)}{1000} + 2.27 \times 0.25$$

$$Z = 0{,}736$$

C) Line C:

$$Z = 0.0244 + \frac{(40 \times 2.6 + 2.5 \times 25)}{1000} + 2.27 \times 0.25$$

$$Z = 0.758$$

2.	Impedance	0.736	0.736	0.758
3.	Amperes at 8 times the tap value	20	40.8	23.2
4.	E_s required by the CT (I x Z)	14.72	30.02	17.58
5.	I_e required from the excitation curve	0.85A	> 100A	0.25A
6.	Ratio error in percent	4.25%	> 100%	1.07%

The exciting current on line B is excessive, therefore, a higher ratio should be chosen for line B T.C.s.

1st ITERATION

	CT TURNS AND RELAY TAP SETTING	A	B	C
1.	100% I_p	17.5	35	70
2.	Choice of turns (C turns must be changed too, in order to match)	20	40	60
3.	100% $I_{secondary}$	0.87	0.87	1.16
4.	Current in the relay	1.5	1.5	1.16
5.	Ideal taps: (C=2.5)	3.23	3.23	2.5
6.	Approximate taps:	3.3	3.3	2.5

7. Check that matching errors are below 5%.

TABLE 1

TAPS TTS*	8 x TAP AMPERES	IMPEDANCE mOhms	OPERATION. VALUE minimum (A)
2.5	20	24.4	0.75
2.7	21.6	24.4	0.81
2.9	23.2	24.4	0.87
3.1	24.8	24.4	0.93
...	...	...	...
4.5	36	24.5	1.35
4.7	37.6	24.5	1.41
4.9	39.2	24.5	1.47
5.1	40.8	24.5	1.53
...	...	...	...
8.5	68	24.8	2.55
8.7	69.6	24.8	2.61

* TTS relay is provided with other current taps besides those indicated in table 1 (from a minimum of 2.5A up to 8.7A in 0.2A steps).

REPETITION: CT ERROR

1. CT burdens

Line A	Z = 0.736
Line B	Z = 0.758
Line C	Z = 0.792

2. Impedance	0.736	0.758	0.792
3. Amps. at 8 times	26.4	26.4	20
4. E_s	19.43	19.43	15.84
5. I_e required (from excitation curves)	1.3	0.25	0.1
6. Ratio error in percent	4.92	0.94%	0.5%

Percent error is less than 20%, therefore the CT taps and relay taps are satisfactory.

PERCENT SLOPE SETTING

1.	Maximum load ratio control range	10%
2.	Maximum tap mismatch (line C-A)	2%
	TOTAL	12%

Use a 25% percent slope setting

TECHNICAL SPECIFICATIONS

RATED CURRENT AND TAP RANGE

I_n = 5A {from 2.5 to 8.7A in 0.2A steps}
I_n = 1A {from 0.5 to 1.74A in 0.04A steps}

PICK UP AND OPERATING TIME

Figure 2 and 2A. shows the operating characteristics for different values of the percent slope setting, related to the "through current" expressed in multiples of the tap value.

Figure 3 shows the operating time of the main and the instantaneous units according to the differential current expressed in multiples of the tap value.

Figure 3A. shows the operation differential voltage for different values of percent slope setting, related to the "through current" expressed in percent of the tap value.

The response value with a null restraint current, is 30% of the tap value.

INSTANTANEOUS UNIT RESPONSE CURRENT

The instantaneous unit is set to be activated when the differential current is 8 times the tap value.

Example: When only one of the CT provides current and the relay is in the 5A tap, the instantaneous will operate for 40 A.

When the ratio matching taps are chosen so that the current supplied by the CT on a self-cooled basis does not exceed the relay tap value, the instantaneous element will not pick up for the magnetizing inrush current. Being the current supplied by the CT higher than the relay tap value, there is an operation risk in this unit, specially in small transformer banks. In this case, it is recommended to increase the CT ratio or relay tap setting rather than increasing the pick up of the overcurrent unit. When the latter is necessary, the CT error must be more strict, according to:

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

E : CT error in % at pickup of the overcurrent unit.
P : Pickup of overcurrent unit in multiples of tap setting.

PERCENTAGE CHARACTERISTIC

The percentage characteristic prevents from false trips in cases of external faults which produce high currents through CT, with saturations on their cores that cause unbalance on the supplied currents. The percentage restraint prevents as well, from incorrect trips due to the lack of perfect matching of secondary currents.

The percentage restraint adjustment (slope) goes from 15% to 50% in 5% steps.

HARMONICS RESTRAINT CHARACTERISTIC

As the transformer is connected, some current feed the primary, in order to create the magnetic flux required in the core.

This current is known as "magnetizing inrush" and it only flows through the primary circuit, causing a current unbalance that will go through the differential relay and may activate it, if means to prevent it were not provided.

Given the case of currents produced in power system faults, the waveform is a pure sine type, plus dc transient component. The sine waveform results from a sinusoidal voltage generation applied to a virtually constant impedance circuit. The dc component depends on the moment the fault occurs (voltage cycle), according to the circuit impedance angle and magnitude.

The magnetizing inrush current varies according the extremely variable exciting impedance resulting from the core saturation. Very often, this is a great magnitude, and occasionally has RMS values 100% offset approaching 16 times the value of the full load current, given the worst conditions as far as the residual flux in the power transformer and the position where the breaker closes within the voltage wave are concerned. The magnetizing inrush currents presents a very distorted waveform with a sharply peaked half-cycle loops of current on one side of zero axis, and virtually currentless on the opposite half-cycle. Both mentioned current waveforms are shown in figure 4.

Any non-sine waveform current can be considered as compound from a dc, plus certain number of sine components of different frequencies, one of which from the fundamental frequency and the others from multiple frequencies, known as "harmonics" (2, 3, 4,.. times the fundamental frequency). The relative magnitudes and the harmonics phase angles in relation to the fundamental, establish the shape of the wave.

By this analysis of the typical wave shape of a fault current, it is possible to find out the existence of harmonics in a short percentage, whereas as explained in the beginning, the magnetizing inrush current contains harmonics in a much larger amount.

The TTS relay is set to produce an harmonic restraint of a 25%, including the 2^{nd}, 3^{rd} and higher ones.

BURDENS

The burdens and the minimum pickup values shown on the following table are substantially independent from the percentage adjustment and have a power factor close to 1. The given values are imposed on each CT at 5 A.

TABLE 2

Tap *	Zero restraint pickup(A)	Burden VA	Impedance (mOhms)
2.5	0.75	0.15	24.4
3.5	1.05	0.30	24.4
4.5	1.35	0.50	24.5
6.5	1.95	1.05	24.7
7.5	2.25	1.40	24.8
8.7	2.61	1.90	24.8

* TTS relay has another current taps besides those indicated in table 2 (from a minimum of 2.5A to 8.7A in 0.2A steps).

DC POWER SUPPLY

Rated dc/ac voltage	Operation range
48-125 Vdc/Vac	38-150 Vdc/Vac
110-250 Vdc/Vac	88-300 Vdc/Vac

TRIPPING CONTACTS

-Make capacity: 30 A
-Break capacity: 180 VA (resistive) at 125/250 Vdc
60 VA (inductive) at 125/250 Vdc
-Continuous capacity: 3A

SIGNALLING CONTACTS

-Make capacity: 5A during 30 seconds.
-Continuous capacity: 3A
-Break capacity: 5 W (inductive) at 125/250 Vdc
-Make and continuous capacity: 20 W Maximum of 250 Vdc or 5A

ACCURACY

-Operation value: 5%
-Operation time : 5%
-E class error rate according B.S.142 for currents and operation times: E-5 class

RATED FREQUENCY AND EFFECTIVE RANGE

-Rated frequency: 50 or 60 Hz
-Effective range: 47-51 Hz or 57-61 Hz

TEMPERATURE RANGE

-Effective:	-5°C at + 40°C
-Operation:	-20°C at + 55°C
-Storage:	-40°C at + 60°C

AMBIENT HUMIDITY

Up to 95% provided there is no condensation.

ISOLATION

From any terminal to ground: 2000 Vac during 1 minute at industrial frequency.
Between independent circuits: 2000 Vac during 1 minute at industrial frequency.
Between each side of an open contact: 1000 Vac during 1 minute at industrial frequency.

TYPE TESTS

-Impulse level

Impulse with a buildup time of 1.2 és ±30% and a fall time of 50 és ±20%.
Test according IEC 255-4 standards.
Test voltage: 5 kV.

-High frequency disturbances test.

Oscillatory surge dampened decreasing by 50% of the peak value after 3 or 6 cycles.
Frequency 1 MHz ± 10%
Repetitive frequency 400 times per second.
Test according IEC 255-4 standards.
Peak voltage in longitudinal mode 2.5 kV
Peak voltage in transversal mode 1 kV

OPERATING PRINCIPLES

The differential protection principle is the most selective principle to be applied to any the elements of a network. It springs from the protective relay connection, according to the simple one line scheme shown in figure 1.

For equal currents flowing in the direction shown in Fig.1(a), to both sides of the protected element (given the case of external faults) no current flows through the relay.

For different currents the difference I_1-I_2, and even the direction inverted, will flow through the relay as Fig. 1(b) shows. In these cases, any overcurrent relay with the right characteristics could be used on the mentioned connection. This will transform it into a differential relay with the current difference I_1-I_2 flowing through.

However there is almost impossible to obtain a fully balance circuit in case of external faults, due to different CT's infeed when strong faults occur. Also it is necessary to differentiate the magnetizing inrush from the short-circuit currents.
The above proves the need to provide the TTS differential relay with special features.

In order to absorb unbalances, the principle scheme based percentage differential relay shown in figure 1 (c) is introduced.

The differential current required for the operation of this relay is a varying quantity due to the effect of the restraint currents. Therefore, in the event of external faults with great currents flow, the relay requires a greater differential current for its operation, the lowest current is normally called "through current" since it is the part of the total current which flows through the circuit from one extreme to the other. Figure 1 (c) shows in a simple manner the TTS relays operation principles.

From block diagram of Fig. 21., the TTS differential relay keeps the following equation:

$$G_d(I_1\text{-}I_2)_f - G_f(I_1+I_2)_{f+h} - G_a(I_1\text{-}I_2)_h > K_o$$

For a two windings three phase transformer, the relay is provided with two current transformers per phase, one for each side (primary and secondary) of the power transformers. These are used to measure the "through current" and the differential current. It is also provided with a bandpass filter and a band-reject filter which selects the harmonics of the current wave, differentiating current produced in terminal faults and the magnetizing inrush current in the transformer energizing.

The bandpass filter presents a very high impedance to the harmonics, nevertheless allowing the passing of a fundamental component which, once it is regulated by potentiometer G_d (V_d in Fig. 21), it constitutes the operation voltage (1st term of basic equation).

On the other hand, the band-reject filter blocks the fundamental wave and allows the harmonics which, once they have been regulated by potentiometer G_a (V_a in Fig. 21), constitute the harmonic-restraint voltage (3rd term of equation).

The dc component present in the case of external faults and in the magnetizing inrush current is blocked by the input transformers and it only produces a weak momentary restraint effect.

The typical magnetizing inrush current waveform of a transformer, usually presents the following composition:

HARMONIC	FUNDAMENTAL PERCENT
2nd	63.0%
3rd	26.8%
4th	5.1%
5th	3.7%
6th	2.4%

As a result of this, the harmonic-restraint principle used in these relays, allows to distinguish by means of the waveform, between faults and transformer connection. Therefore, they do not need any relay desensitizer device in the transformer connection. The second term of equation represents the percentage component that inhibits the small matching errors introduced by the CT's, and its different performances when severe faults occurs. Its voltage signal is applied to the summing amplifier once has been regulated by the potentiometer G_f (V_f in Fig. 21).

The different sign input signals in the adder will produce a tripping output if the summation gives a positive value higher than a prefixed value.

CONSTRUCTION

CASE

The TTS relays are assembled in a steel plate case. The general dimensions are shown in figures 18 and 19.

The front cover is made of plastic and is adjusted to the relay case by pressing on a rubber joint located all around the relay which produces an airtight seal which keeps it free from dust.

The modules are assembled vertically. They are provided with bases on the back which act as mechanical stand and as an electrical connection element, holding the module firmly in its correct position. They are provided with two plastic guides for each module, one in the upper side and another in the lower side, so that a perfect alignment is achieved.

LEADS AND INTERNAL CONNECTIONS

The external bonding is carried out in the terminal blocks assembled in the back of the case. Each block of terminals contains 7 terminals with a 4mm bolt screwed in a contact plate.

The connections to the printed circuit boards are carried out through 32 point connectors except for the output one which is a 15 point connector. The bases of the printed circuits are assembled on a back plate located 4 cm from the back plate of the case. The block for the connections and test (optional) is assembled at the front of the relay.

All the current inputs are positioned on 4 terminal blocks located in the rear plate of the case which are able to carry the line transformer secondaries currents. In these circuits, the internal wiring is substantially wider than in other wires (except for the tripping relays wires). The length has been reduced to the minimum in order to minimize the current transformers resistive load. The connections are achieved by means of terminals pressure-tight sealed. The current wires are separately braided in order to prevent the effect of the magnetic field coupling due to input currents on weak signal circuits.

IDENTIFICATION

The complete model of the relay is indicated in the nameplate.

On the edges of the upper and lower sides of the front of the case, two adhesive marked stripes indicate the position that every module must occupy in the case.

The blocks of terminals are identified with a letter located in the rear plate, just over the upper edge of each block (looking from the back).

In every terminal blocks, the blinding screws (1 to 7) are marked in the upper side with numbers.

PRINTED CIRCUITS BOARDS

Each board consists of a printed circuit board with the front plate held by two squares. Two pullers that serve the purpose of drawing out and inserting the module are located on that plate. The electric connections are carried out through a male connector which fits into a female connector in the case. There is an exception for the output boards located in one same module. In this case, that module is provided with two connectors.

Each PCB has its corresponding model number, consisting of a 3 letter code followed by a three figure number and located on the lower part of each front plate.

LOCATION OF CONTROLS AND EXTERNAL TARGETS

Figures 7, 13, 14 and 15 represent the front plates of the taps and rectifiers module, the measuring module, the outputs module and the source module. In those figures, the different controls and targets are represented.

INTERNAL CONTROLS AND TEST POINTS

Figures 8 to 12 indicate their location in the relay. The relays are factory calibrated so that no further calibration is necessary to be done by the customer. Anyhow, if for any reason should it be necessary to calibrate the relay, the identification of the adjustment internal controls and jumpers is shown below:

Model TTS 1100B121GOO

It includes:

* Tests block.
* One inputs board with the taps adjustments and the phase compensation (figures 8 to 11).
* One measuring board (figure 12).
* One output board. They include targets (figure 15) and the signalling and trip relays as well as their arrangement.
* Power source. It is provided with a power dc source failure alarm signalling contact.

RECEIVING, HANDLING AND STORAGE

The systems are furnished in a special packing unit that properly protects it during transportation, provided it is done under normal conditions. Immediately after receiving the equipment, the customer should check if there is any evidence of the system having suffered damage during transportation. If injury or damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the factory.

Reasonable care should be exercised in unpacking the relay in order not lose the accessories provided in the box.

If the equipment is not going to be installed immediately, it is convenient to store it in its original packing, in a place free from moisture and dust. It is important to check that the inscription on the nameplate matches the data handed over with the order.

ACCEPTANCE TESTS

It is recommended, once the equipment is received that a visual inspection and the tests given below be performed to make sure that the relay has not suffered any damage in transportation and the factory calibration has not been altered. Should the check or the tests performed prove necessary to carry out some adjustment of the relay, please see section RELAY CALIBRATION.

These tests may be carried out as installation or acceptance tests depending on the criteria of the user. Since most users have different procedures for installation and acceptance test, this section indicates all the tests that can be carried out to relays.

A. VISUAL INSPECTION

Check that the model or models indicated in the plates match the data given in the order. Unpack the equipment and check there are no broken parts and no signs that the system has suffered any damage during transportation.

B. ELECTRIC TESTS

B.1. TWO WINDINGS RELAY

B.1.1. GENERAL CONSIDERATIONS ON THE POWER SUPPLY NETWORK

All the devices that operate with ac current are affected by frequency. Given that a non-sine waveform is the result of a fundamental frequency wave plus a series of harmonics of this fundamental wave, it is drawn out that devices operating with ac current (relays) are affected by the applied waveform.

In order to properly check the relays that operate with ac current, it is most important to use a current and/or voltage sinusoidal waveform. The purity of a sinusoidal waveform (absence of harmonics) can not be expressed in a specific way for a specific relay. However, any relay provided with tuned circuits, R-L and R-C circuits or non linear elements, will be affected by non-sine waveforms.

Those relays with dc voltage infeed should be tested with dc rather than rectified ac because if its waveform contains ripple, it is possible that the relay does not operate correctly due to possible voltage drops in the power source.

Zenner diodes for example, may stop conducting because of power supply voltage drops. As a general rule, the voltage applied should not have a ripple above 5%.

These relays respond to the current's waveform in different way from most ac ammeters. If the infeed network applied contains harmonics of large amplitude, the responses from the ammeter and the relay will differ.

The relays has been factory-calibrated applying a 50 Hz or 60 Hz network with minimum contents of harmonics. The relays should be tested in an infeed network whose waveform contains no harmonics.

The ammeters used for pickup current and relay operation time tests must be calibrated and their accuracy must be better than that of the relay. The infeed network used in the tests must remain stable, specially at those levels near the test pickup current as well as during the time in which the relay operates according to the curve tested.

It is important to point out that the accuracy with which the test is performed depends on the network and on the instruments used. Functional tests performed with unsuitable power supply network and instruments are useful to check that the relay operates properly and therefore its operating characteristics are verified in an approximate manner., Its operational characteristics would be outside tolerance.

B.1.2. GENERAL CONSIDERATIONS AND PREVIOUS ADJUSTMENTS

Once a trip output is produced check that phase and unit LED (differential or instantaneous) under test lights up.

Push reset button for a new test.

Also when a trip output take place, check that associated tripping or signalling contacts close. Current must be interrupted completely after each test.

When specify operation values for some test, those without parenthesis are for relay rated $I_n = 5$ A Values inside parenthesis are for relays rated $I_n = 1$ A

Select in all windings the 4.9A tap (0,98 for $I_n = 1$A) in front of RTT board.

Connect the phase angle matching jumpers (inside the RTT board) as shown Fig. 9B. Adjust percent slope at 25% (from of MTD module).

B.1.3. DIFFERENTIAL UNIT

a) Operation value.

The circuit for checking the operation value is shown in figure 17 with S2 open. Increase I_1 gradually and check that and output is produced for I_1 between 1.44 (0.29) and 1.50 (0.30) A. Should the operation value range between 1.35 (0.27) A and 1.65 (0.33) A, the adjustment should not be changed.

b) Restraint taps check

Connect the relay as shown in figure 17. Set the selector S2 to position B. Increase I_3 up to 29.4 (5.88) A and gradually increasing I_1 until relay operation has produced. This operation should occur when I_1 reaches a value between 7.35 (1.47) and 8.1 (1.62) A.
With the selected percentage, check that the relay operates with the values indicated in table 4.

TABLE 4

Slope value	I_3(A)	I_1(A)	Actual slope
50	29.4 (5.88)	14.7 -16.2 (2.94 - 3.24)	50 - 55
40	29.4 (5.88)	11.76 -13 (2.36 - 2.6)	40 - 44
25	29.4 (5.88)	7.35 -8.1 (1.47 -1.62)	25 - 27.6
15	29.4 (5.88)	4.41 -4.88 (0.882-0.976)	15 - 16.6

NOTES.-

1) These currents must flow only for a few seconds, with cooling periods between one test and the next, or else the input transformers would be overheated.

2) The tolerance of the percentage slope is (10%) in excess, so that the slope never falls below the tap value.

c) Harmonics Restraint.

The circuit is shown in figure 17 being S2 closed in position A.

The analysis of a rectified single phase current (half wave), shows the presence of some fixed dc percentages, the fundamental frequency and a second harmonic together with very low percent quantities of the rest of the higher harmonics. That is, it seems very close to the typical waveform of a transformer magnetizing inrush current.

Even though the percentage of the pure harmonic is fixed, the total percentage may be changed by changing the amount of fundamental component current added in phase to the rectified current.

The following expression shows the relation between the 2[nd] harmonic percentage, the Ic rectified component and the I_1 by-pass current.

$$\% = \frac{0.212\ I_c}{0.45\ I_1 + 0.5\ I_c} \cdot 100$$

Figure 20 is obtained from this expression and it shows the 2[nd] harmonic percentage, corresponding to several values of the I_1 by-pass current for a dc current of 4.0 A.

The relay is calibrated with a current made up of an RMS value twice the value of the tap. When correctly adjusted, it will restrain for a 2nd harmonic percentage greater than 20%, but it will operate for an equal or lower percentage.

With (I_2) dc ammeter set to 4 (0.8) A, the tripping relay must close its contacts with a gradual increase of the (I_1) derived current of 4.5 - 5.5 (0.9 - 1.1) A. This corresponds to a 2nd harmonic percentage of 19 - 20% (figure 20). The 2% tolerance makes up for the normal oscillations in the rectifier zone (I_2) is slightly affected by the application of by-pass current (I_1) and it must be checked in order to ensure that a correct value is maintained.

Should it not be possible to use an dc ammeter, the rectified current may be applied by using an ac ammeter in position I_2, shorting the rectifier and adjusting the non rectified current to the 9.0 (1.8) A value. If the jumper is removed from the rectifier, the rectified current will have the correct value.

B.1.4. OVERCURRENT UNIT

With selector S2 open (see figure 17), it is possible to check its calibration by making a large rated I_1 current flow through it. The unit must operate for 8 times the tap value [37(7.4) and 42(8.4) A].

During the verification, the current must not flow for longer than one second, each time.

Every time a trip is produced, it is necessary to verify that the led corresponding to the phase lights up and its contact closes, since differential unit will operate for I_1 lower than the instantaneous unit value, and tripping contact will not indicate which unit has operate. Once the trip is produced, push the reset button for a new test.

B.2. THREE WINDINGS RELAY.

All the tests described in point B.1, (two windings relay), must be carried out.
Also must be done the following ones:

B.2.1. WIRED.

Modify the test wired in the following way:

PHASE A : Move the wire in A5 to C1.
Move the wire in B5 to D1.

PHASE B : Move the wire in A6 to C2.
Move the wire in B6 to D2.

PHASE C : Move the wire in A7 to C3.
Move the wire in B7 to D3.

B.2.2. UNBALANCE VOLTAGE TEST.

- Close S1 switch maintaining S2 opened. Set the one and three windings taps to 4.9 (0.98) A, set I_1 to 4.9 (0.98) A and check the voltage between the test points located in the front of module RTT as follows:

BETWEEN :		VOLTAGE Vac:
PHASE A	A GRN	279 - 309 mVac
PHASE B	B GRN	279 - 309 mVac
PHASE C	C GRN	279 - 309 mVac

- Open S1 switch and close S2 switch.
- Apply a current I_1 = 4.9 (0.98) A and check the voltage between the test points located in the front of module RTT as follows:

BETWEEN :		TENSION Vac:
PHASE A	A GRN	< 10 mVac
PHASE B	B GRN	< 10 mVac
PHASE C	C GRN	< 10 mVac

INSTALLATION

A. INTRODUCTION

The place where the relay will be installed must be clean, dry free from dust and vibrations and must also be well lit to ease the task of inspection and testing.

The relay must be mounted on a vertical surface. Figures 18 and 19 shows the outline and panel drilling drawings.

The internal connection scheme is shown in figure 5. If the inspection or test performed show the need for a new relay adjustment, please see section RELAY CALIBRATION.

B. GROUND CONNECTION FOR SURGE OVERVOLTAGE SUPPRESSION

Tap C7 of the relay must be connected to ground so that the surge suppression circuits provided within the relay operates properly. This connection must be as short as possible to assure maximum protection level (preferably 25 cm or less).

C. MATCHING TAPS

In the measuring unit, in order to obtain a minimum unbalance current produced by the non-matched currents supplied by the CT's, the TTS relay is provided with taps (see front of inputs board, fig.13) from:

0.5 up to 1.74 A in 0.04A steps for I_n = 1A
2.5 up to 8.7A in 0.2A steps for I_n = 5A

The taps must be selected so that they match as much as possible the currents the CT's are supplying, **based on the same KVA for all the power transformer windings**. See CALCULATIONS SECTION.

D. DIFFERENTIAL CURRENT MEASURING

The unbalance current measuring is useful to verify on the field that the best possible matching taps selection has been performed. On the other hand, it makes it possible to detect faults or errors right inside of the power transformer, when the fault current is not enough to make the relay operate.

For unbalance current measuring, it will be measure the developed voltage in differential circuit V_d. For that matter TTS relay has a front female leads located on RTT board corresponding to the first and second power transformer windings. Leads are designated as A for phase A, B for phase B, and C for phase C.

For the unbalance voltage characteristics necessary to operate the relay as a function of percentage between their lead and that designated as GRN (also located at the front of RTT board).

Figure 3A shows voltage characteristics necessary to operate the relay as a function of percentage slope and "through current" in multiples of tap. To assure against false operations the unbalance voltage does not exceed the seventy five percent of that specified by the characteristic to obtain relay output.

An unbalance of this type could be present due to the considerable mismatch on the bushing type CT for lower currents.

The measure of a voltage lower than the seventy five percent given by the characteristic does not means that the relay will really operate for a higher currents. This is true specially for that cases of a high load currents that will cause saturation on CT.

E. PERCENTAGE SLOPE SELECTION

The TTS relay has a percentage slope range from 15 up to 50% in 5% steps. It is normally use a 25% setting if special conditions does not recommend another value.

F. PHASE ANGLE MATCHING

When using non dedicated CT's for differential protection only, this matching is indispensable. The relay can be factory adjusted, when the power transformer connection group is specified on the purchase order. Figure 22 shows the INPUT BOARD links on RTT board for checking this matter.

For dedicated transformers, that is, when the phase matching has been carried out in the CT's please see figure 23.

RELAY CALIBRATION

The following instructions cover the calibration procedure for a specific TTS relay 50/60 Hz. rated frequency.

To realize the following calibration it is needed that relay has been adjusted as specify ACCEPTANCE TESTS. All the adjustment potentiometers are located in the measuring board MTD (see Fig.12).

If during the tests it is found that the relay is out of tolerance (first of all make sure that the power source and the instruments used comply with the requirements specified in section ACCEPTANCE TESTS), calibration can be made in the following way:

a) Pickup Verification and Adjustment

1. Connect the relay as indicated in figure 17 with S2 open.

2. Apply only I_1, so that the trip is produced with a current within 1.44 (0.29) and 1.50 (0.30) Amperes. Should it has value between 1.35 (0.27) and 1.65 (0.33) Amperes, calibration still be without any change.

PHASE_A:

Should it trip before the correct value, it can be adjusted by a counterclockwise turning of potentiometer P104; should it trip with a higher value, it must be turned to the opposite direction.

PHASE_B:

Should it trip before that value, it can adjusted by a clockwise turning of potentiometer P204; should it trip before, it must be turned to the opposite direction.

PHASE_C:

Should it trip before, it can adjusted by a counterclockwise turning of potentiometer P304; should it trip with a higher value, it must be turned to the opposite direction.

See position of the potentiometers in figure 12.

b) Harmonics Restraint Verification

1. Prepare connections for the harmonics restraint check. For that purpose, according to figure 17, switch S2 will be set to position A.

2. Adjust to a dc I_2 current of 4 (0.8) A and gradually increase I_1. The relay must operate for a I_1 between 4.5 (0.9) and 5.5 (1.1) Amperes.

3. Should the relay be out of tolerance, the procedure will be as follows:

PHASE_A:

First, adjust I_2 to 4 amps, then apply I_1 gradually:

Should it trip before the correct value, it can be adjusted by a counterclockwise turning of potentiometer P103; should it trip a higher value, it must be turned to the opposite direction.

PHASE_B:

Introduce I_2, I_1 currents as in phase A:

Should it trip before that value, it can adjusted by a counterclockwise turning of potentiometer P203; should it trip after, it must be turned to the opposite direction.

PHASE_C:

Introduce I_2, I_1 currents as in phase A:

Should it trip before that value, it can be adjusted by a counterclockwise turning of potentiometer P303; should it trip after, it must be turned to the opposite direction.

c) Percentage Characteristic Verification

Prepare connections for the percentage characteristic verification.

For that purpose, according to figure 17, switch S2 will be set to position B.

Adjust I_3 to 29.4 (5.88) A and gradually increase I_1 until relay has operated.

This operation would be produced with I_1 between 7.35 (1.47) and 8.1 (1.62) Amperes.

Should the relay be out of tolerance, the procedure will be as follows:

PHASE_A:

Should it trip before the indicated value, it can be adjusted by a counterclockwise turning of potentiometer P102; should it trip after, it must be turned to the opposite direction.

PHASE_B:

Should it trip before the indicated value it can adjusted by a counterclockwise turning of potentiometer P202; should it trip after, it must be turned to the opposite direction.

PHASE-C:

Should it trip before margin, it can be adjusted by a counterclockwise turning of potentiometer P302; should it trip after, it must be turned to the opposite direction.

d) Overcurrent Unit Verification

According to figure 17, switch S2 will be open.

Gradually increase I_1 until relay has operated.

This operation will be produced with I_1 between 37 (7.4) and 42 (8.4) Amperes, which will be in accordance to 8 times the adjusted tap.

Should the relay be out of tolerance, the procedure will be as follows:

PHASE_A:

Should it trip before the indicated value, it can be adjusted by a counterclockwise turning of potentiometer P101; should it trip after, it must be turned to the opposite direction.

PHASE_B:

Should it trip before that value, it can adjusted by a counterclockwise turning of potentiometer P201; should it trip after, it must be turned to the opposite direction.

PHASE-C:

Should it trip before that value, it can be adjusted by a counterclockwise turning of potentiometer P301; should it trip after, it must be turned to the opposite direction.

PERIODIC TESTS AND MAINTENANCE

In view of the fundamental role the protective relays play in the operation of any installation, it is recommended to follow a program of periodical tests. Since the interval between periodic tests varies for different types of relays, types of installation, as well as with the experience each user may have on periodic tests, it is recommended to check the points described in section INSTALLATION at interval of 1 to 2 years.

FIGURE LIST

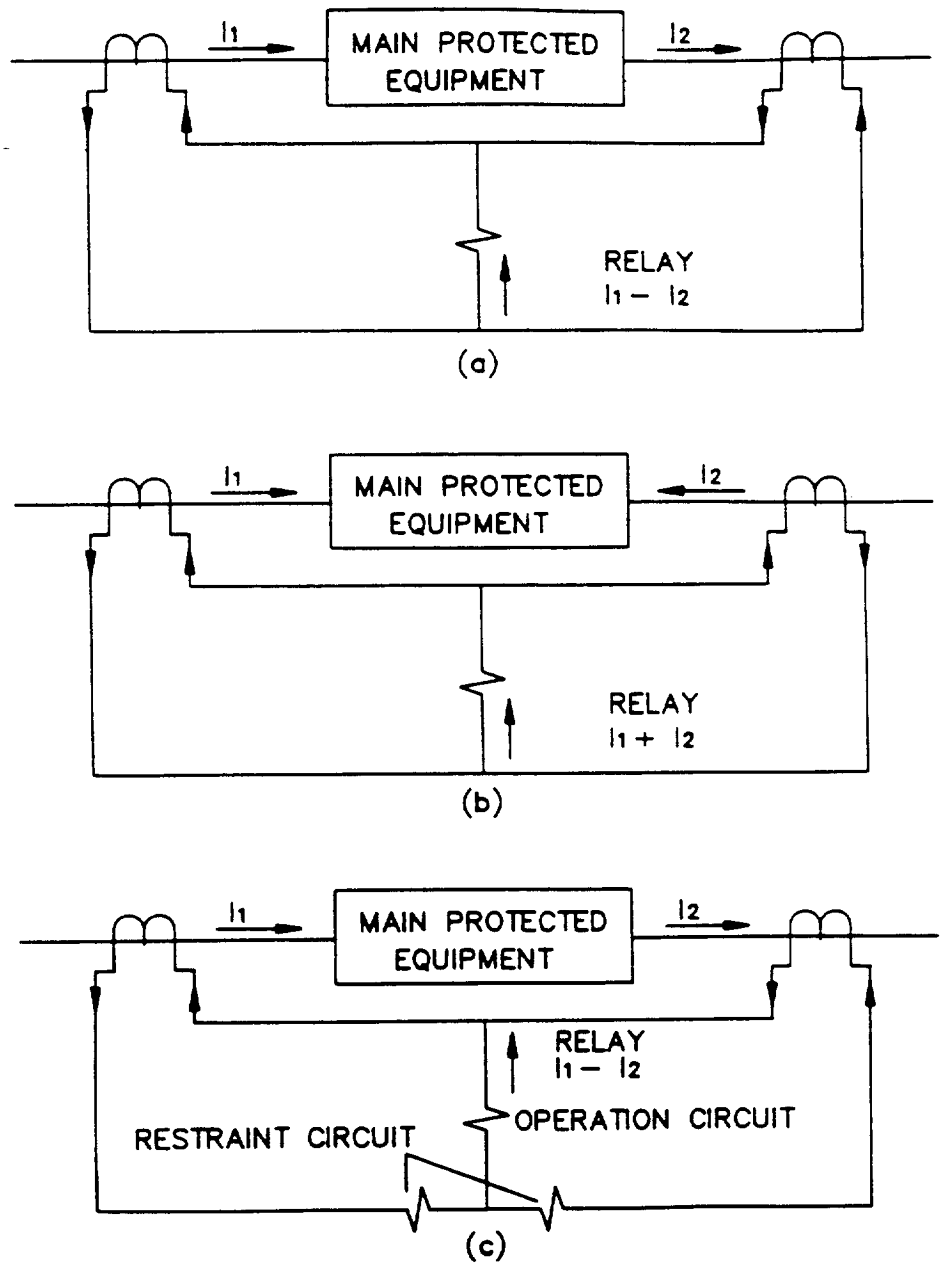


Figure 1 Operating principles.

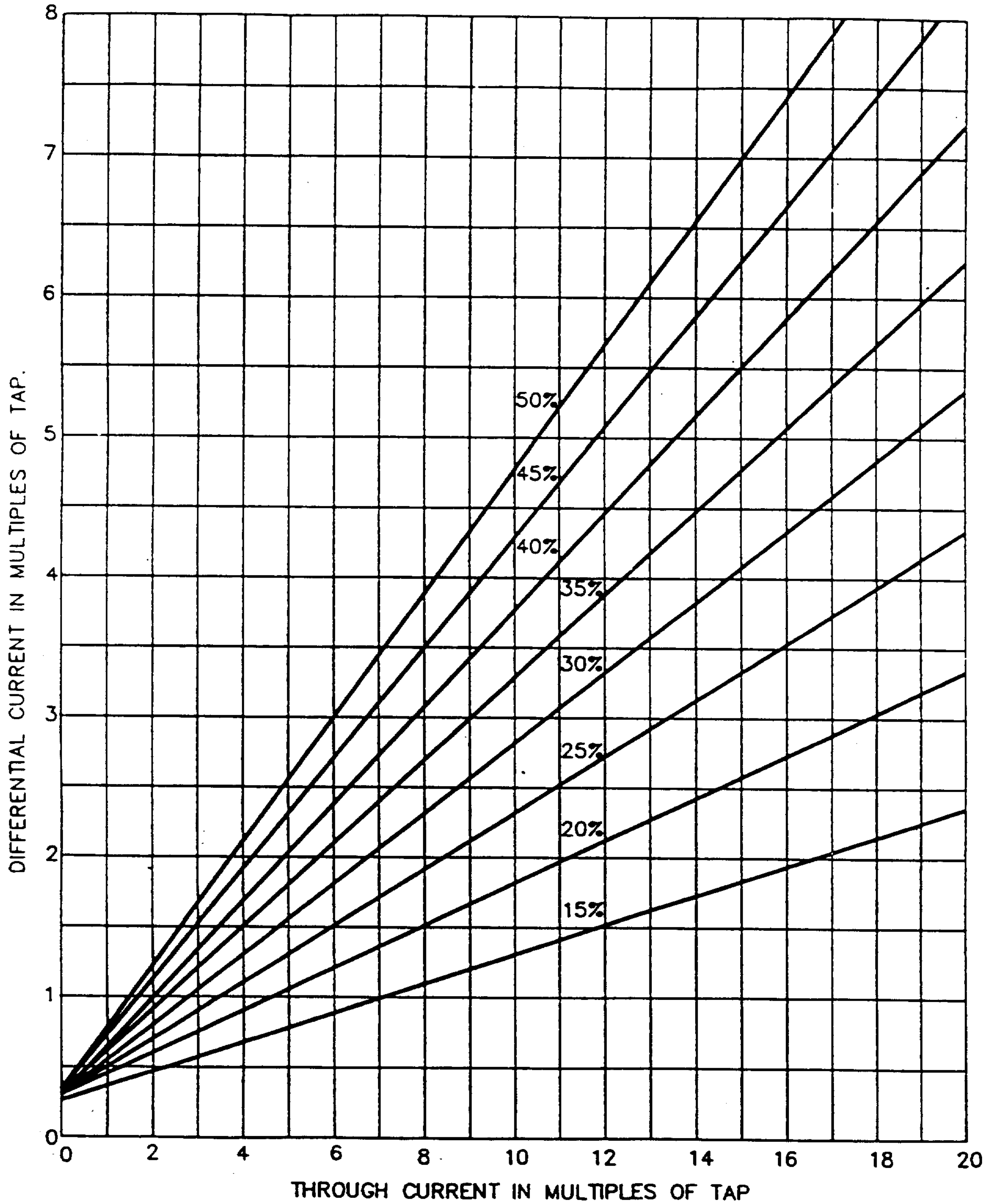


Figure 2 Operating characteristic (1 - 20 x I_n)

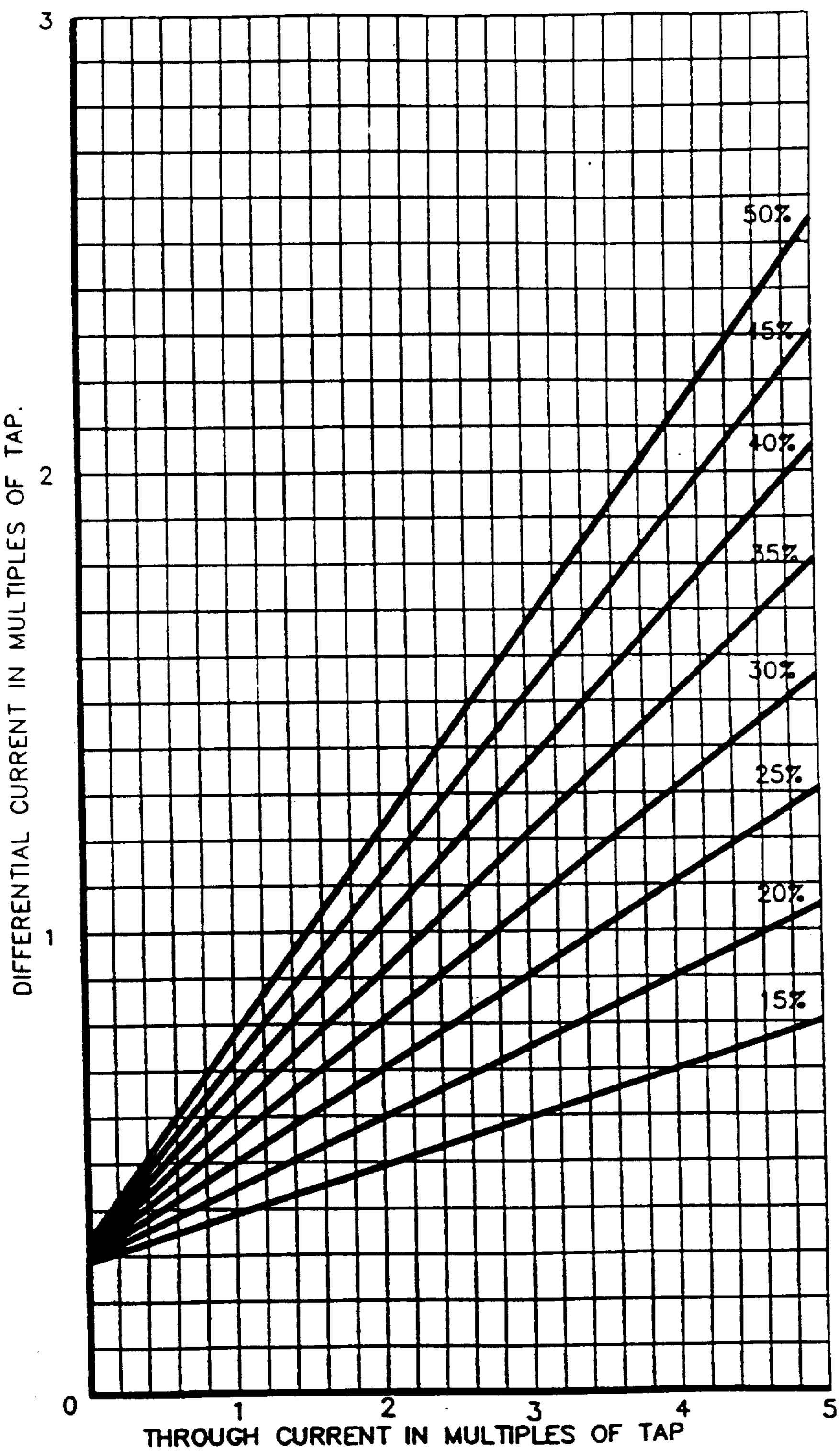


Figure 2A Operating characteristic (1 - 5 x I_n)

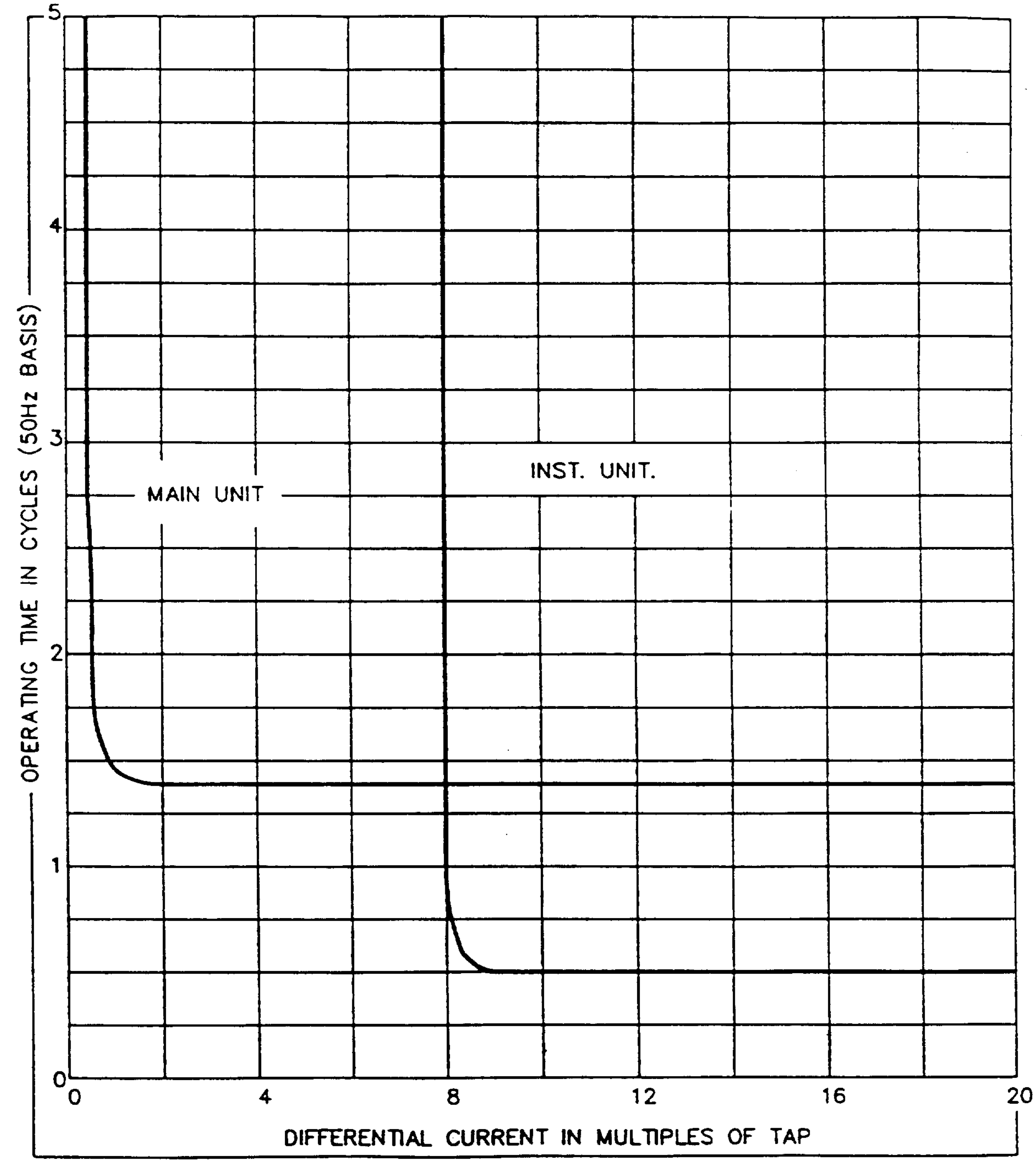


Figure 3 Operating speed characteristic.

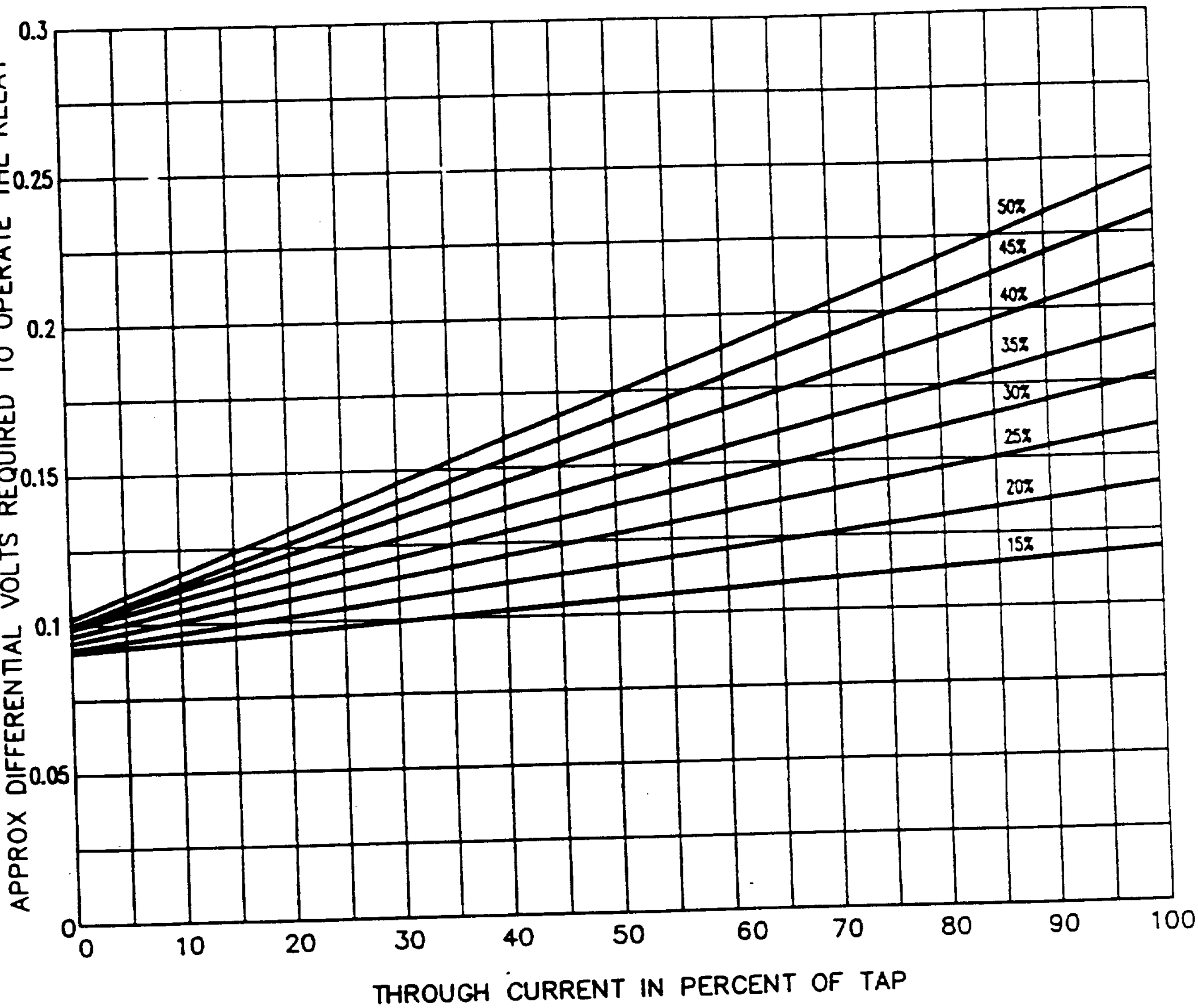
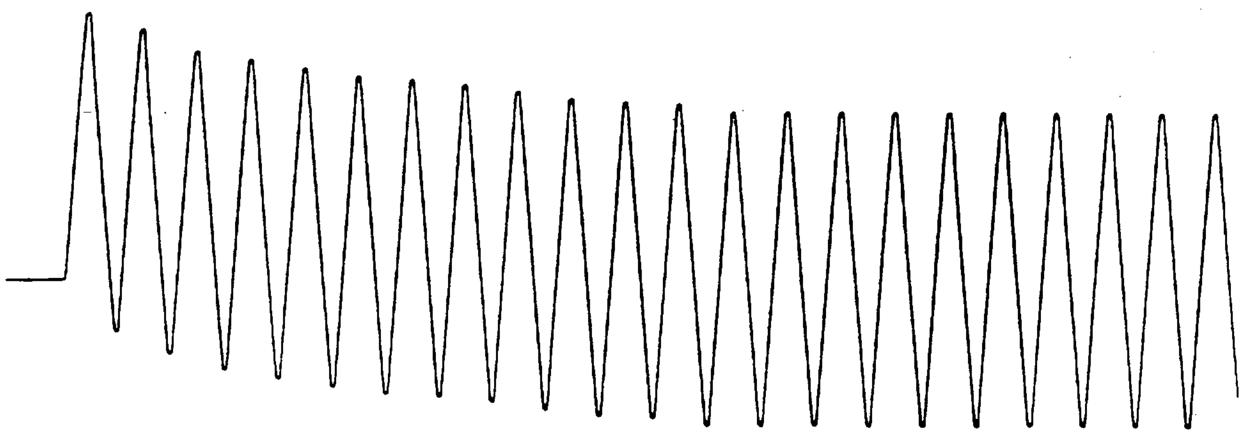
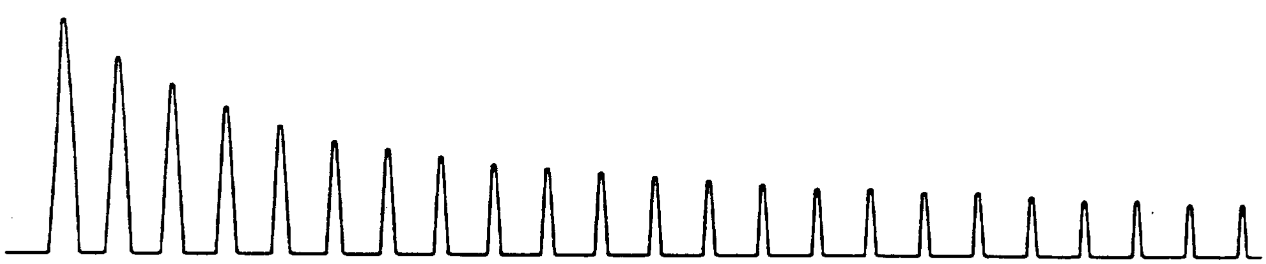


Figure 3A Differential voltage operating characteristic.



TYPICAL OFFSET FAULT CURRENT WAVE
(AC COMPONENT + DC COMPONENT)



TYPICAL TRANSFORMER MAGNETIZING
INRUSH CURRENT WAVE

Figure 4 Wave forms.

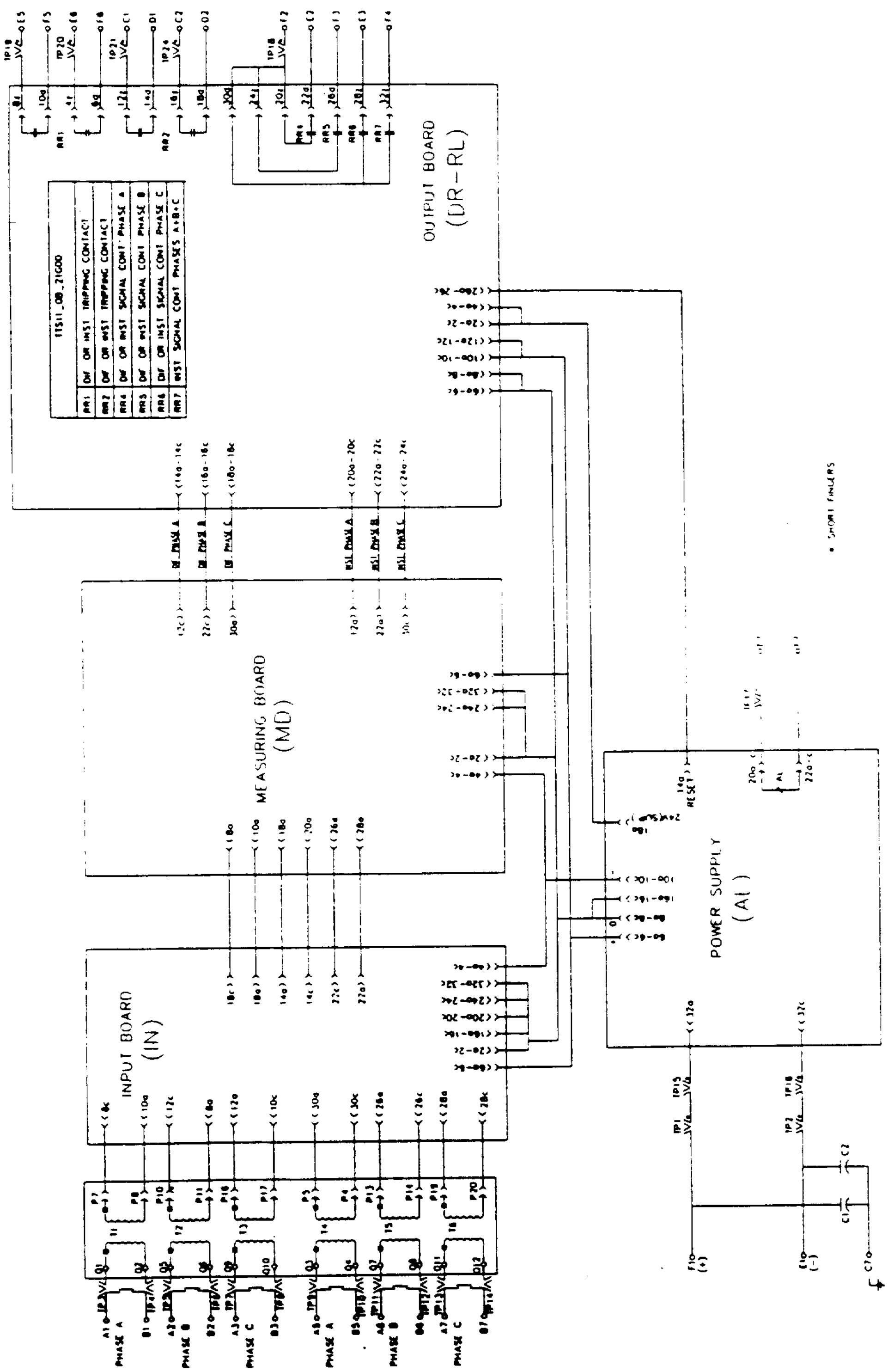


Figure 5 Internal connections.

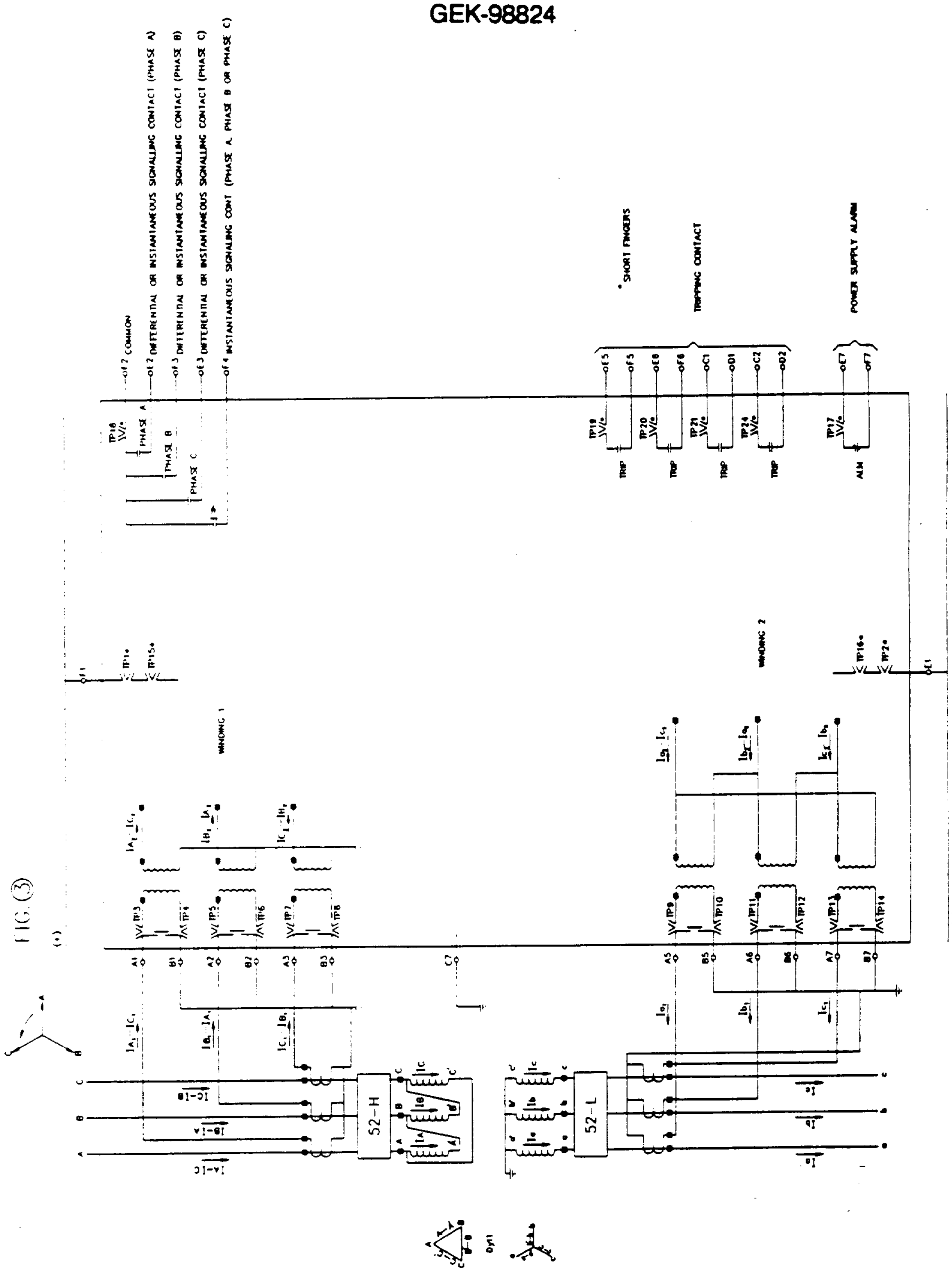


Figure 6A External connections for two windings D y 11 transformer.

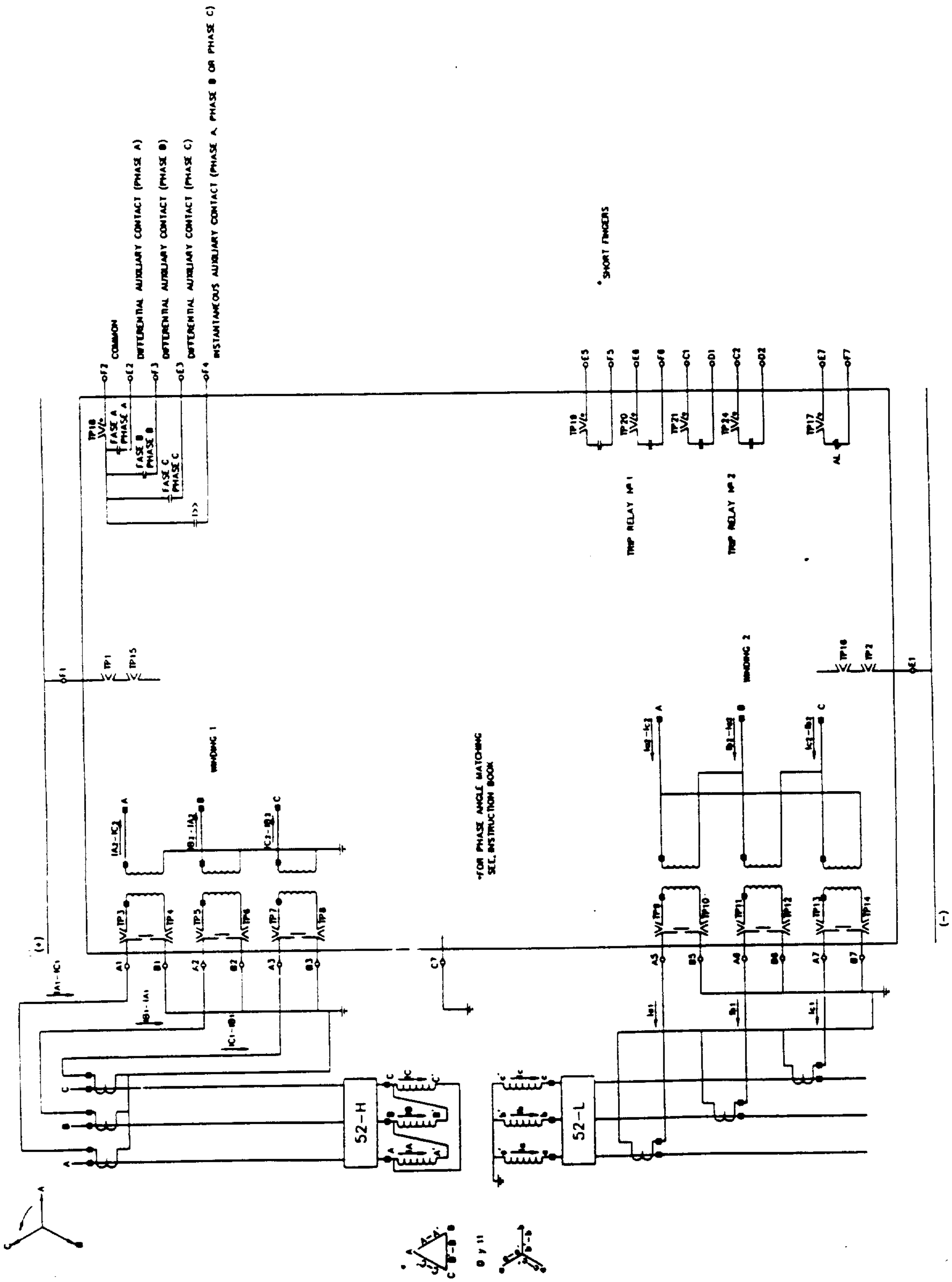


Figure 6B External connections for two windings D y 11 transformer with lock-out devices.

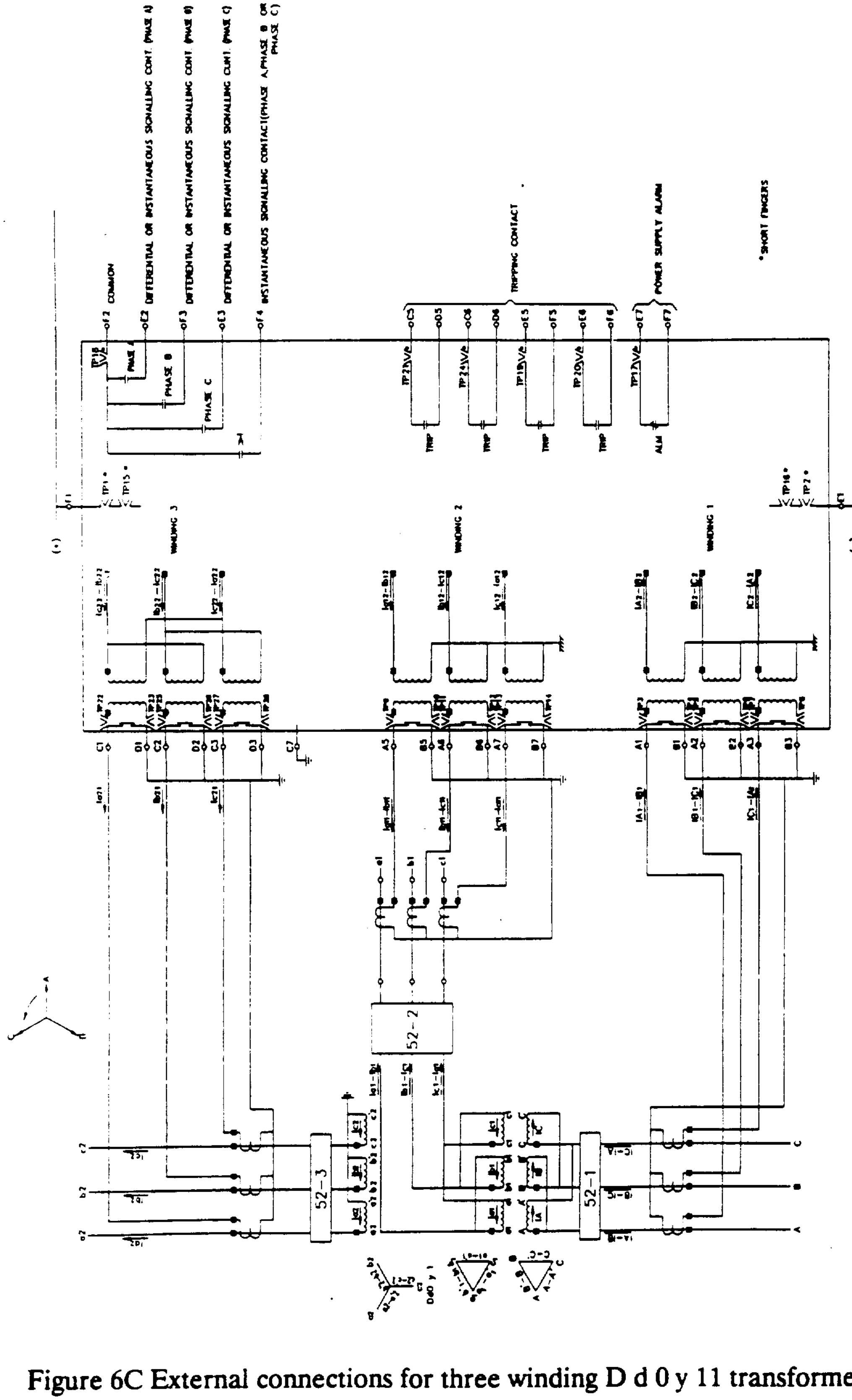
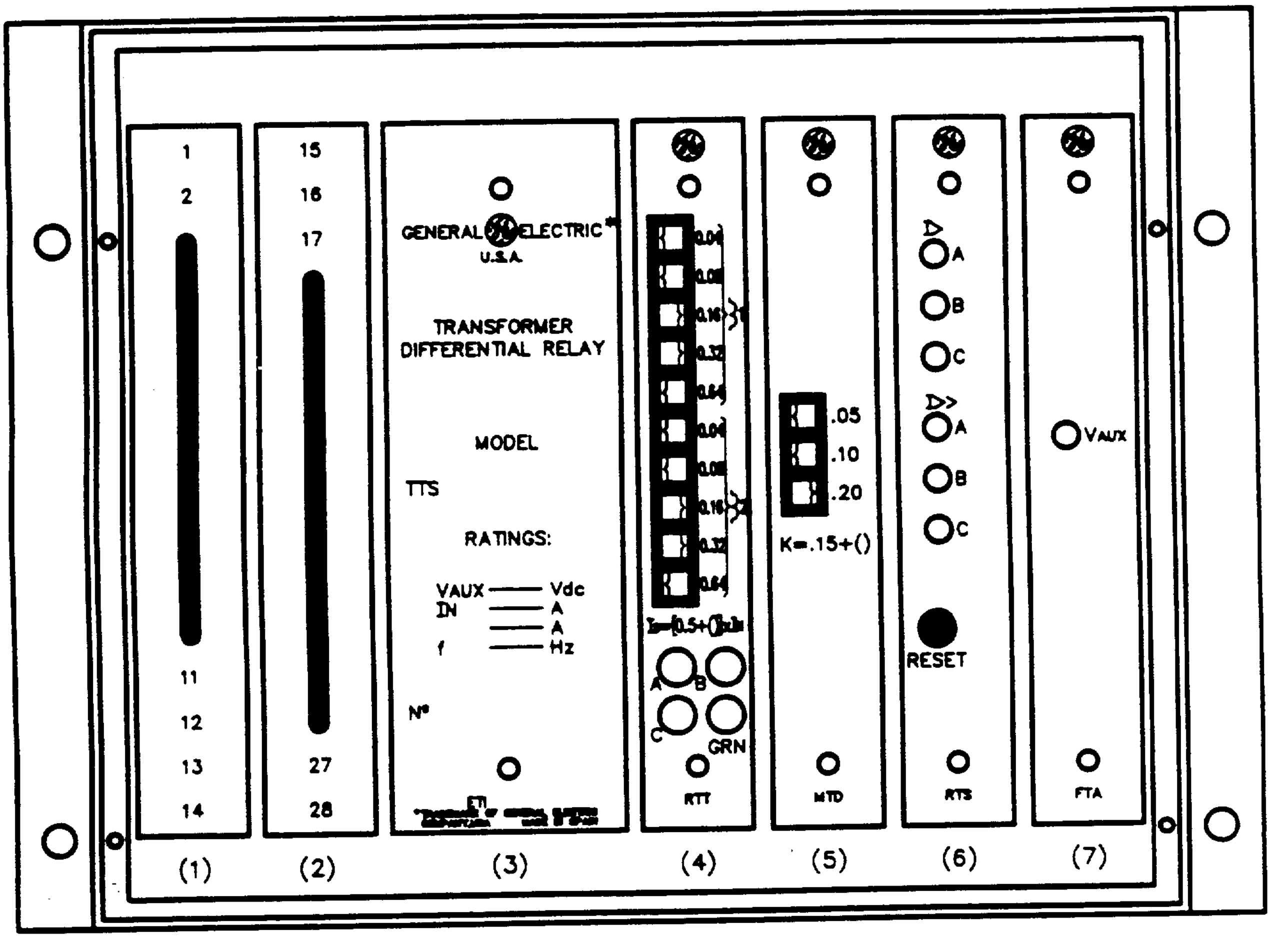


Figure 6C External connections for three winding D d 0 y 11 transformer.



1 AND 2: TEST BLOCK AND CONNECTION PLUG
3: MAGNETIC MODULE
4: INPUT BOARD
5: MEASURING BOARD
6: OUTPUTS BOARD
7: POWER SUPPLY

Figure 7 Front view (2 windings).

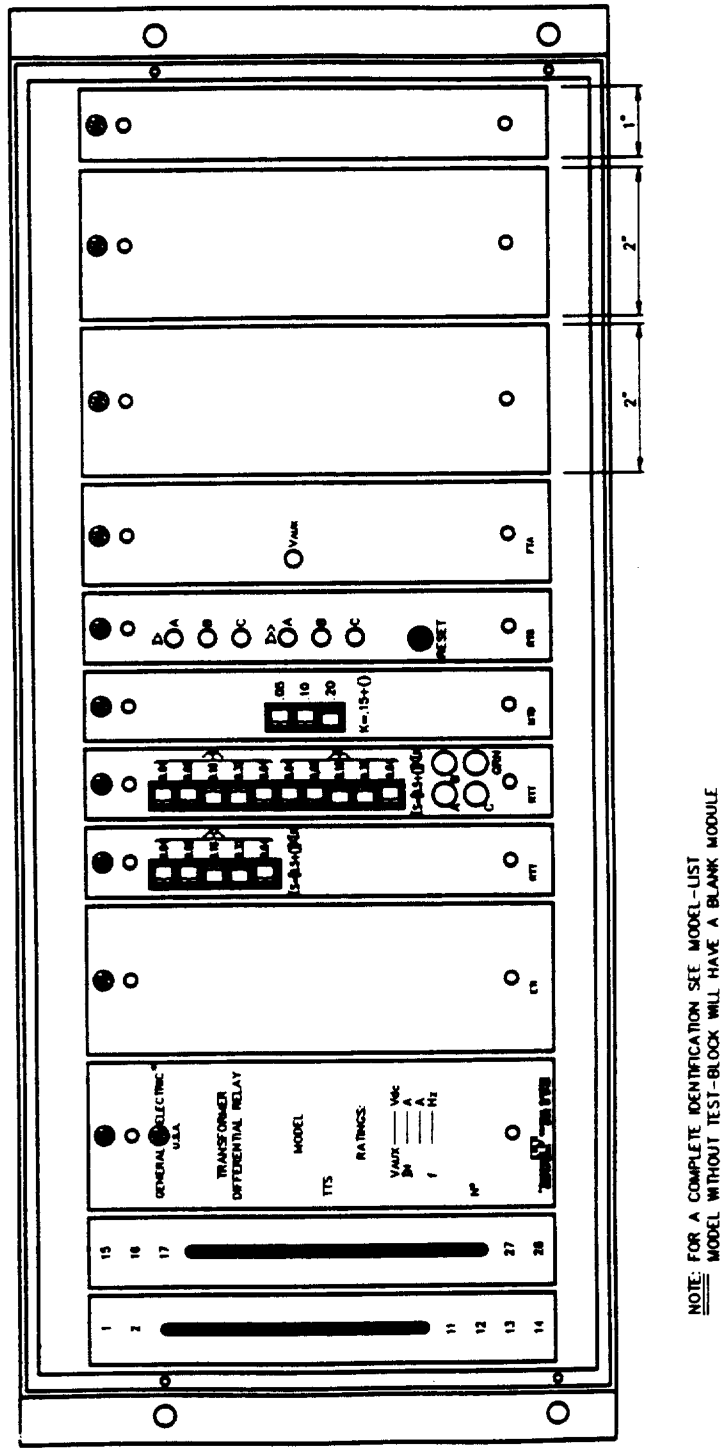


Figure 7A Front view (3 windings).

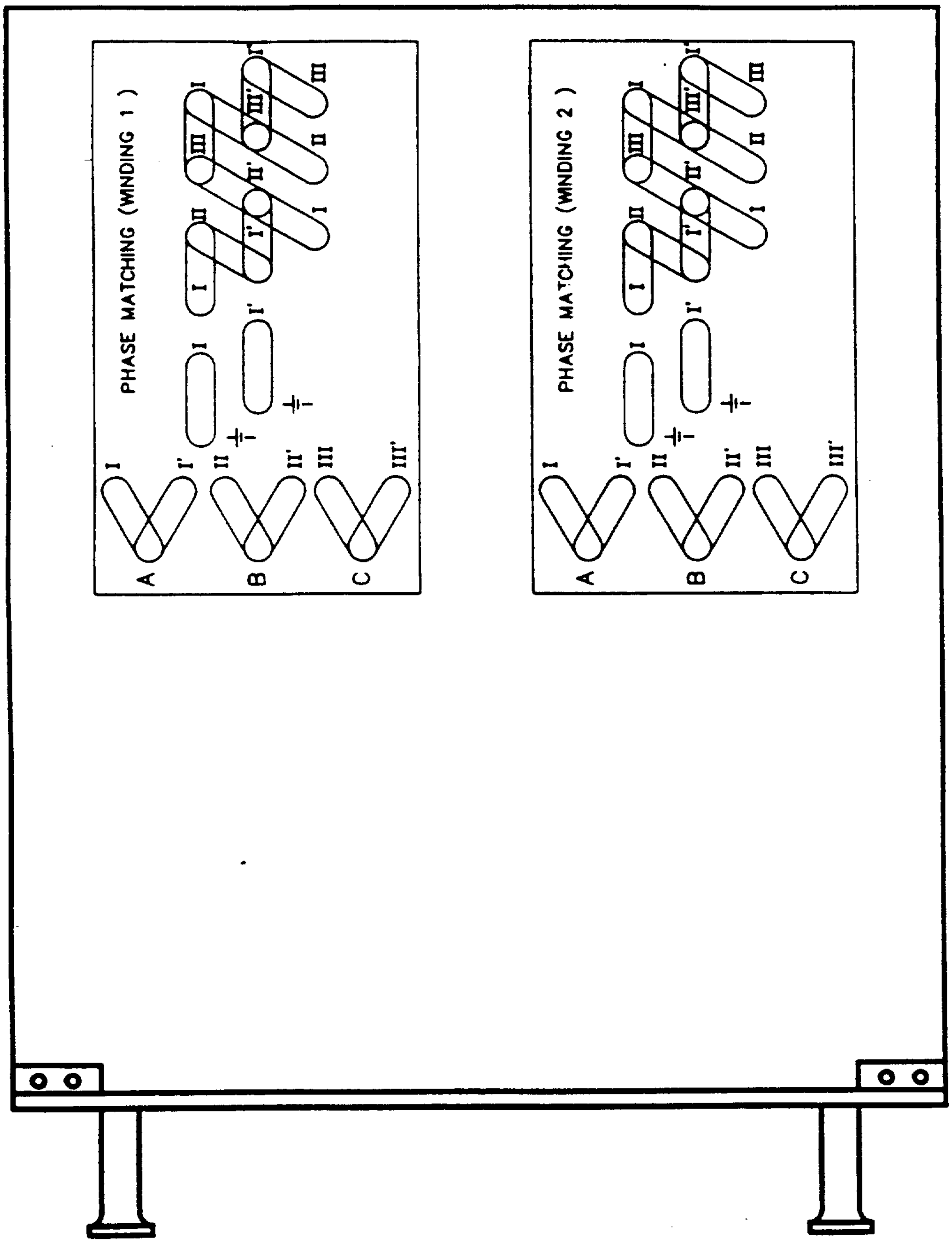
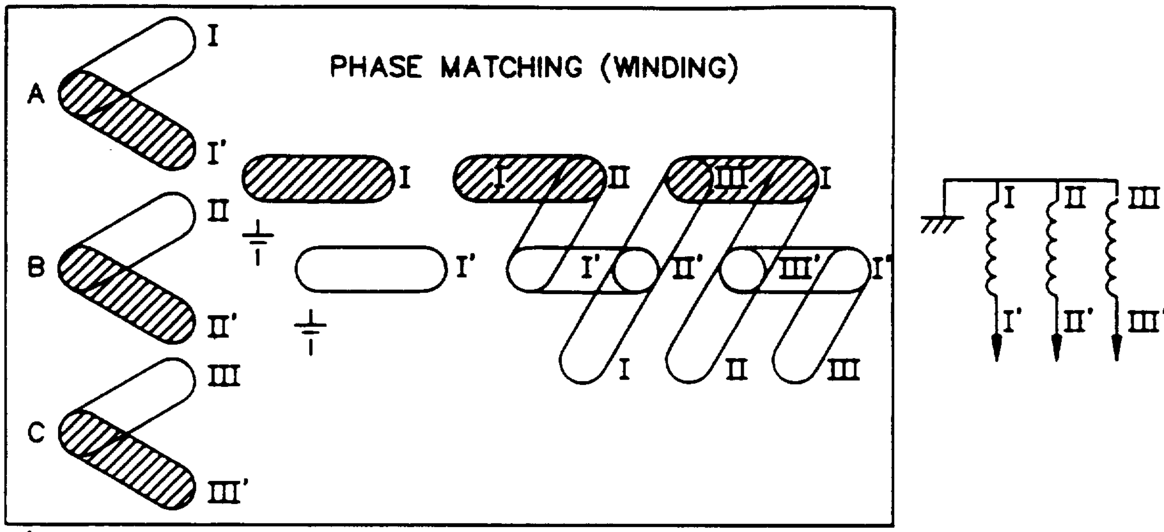
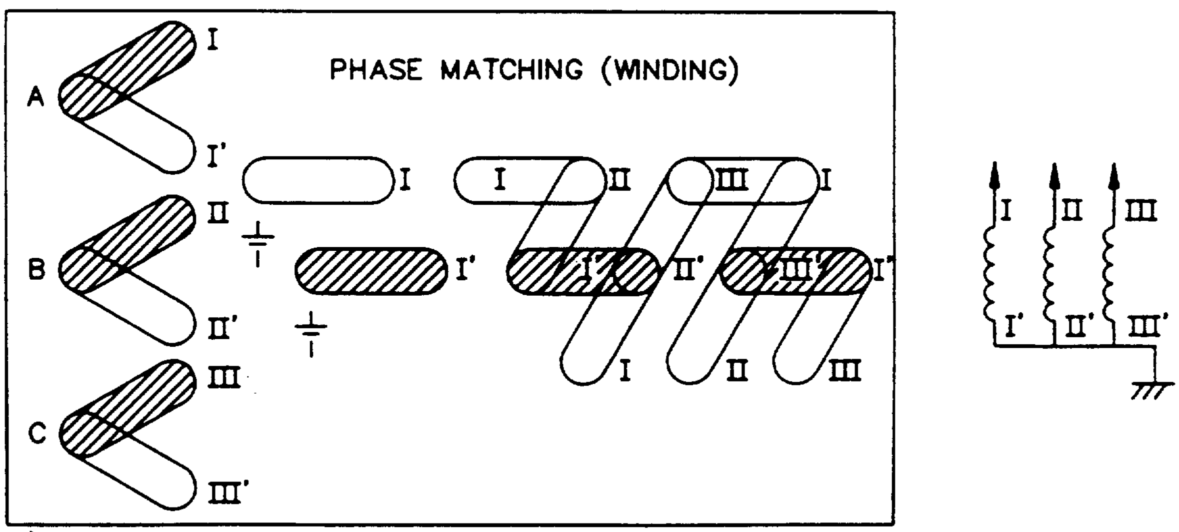


Figure 8 Input current transformers.



a)

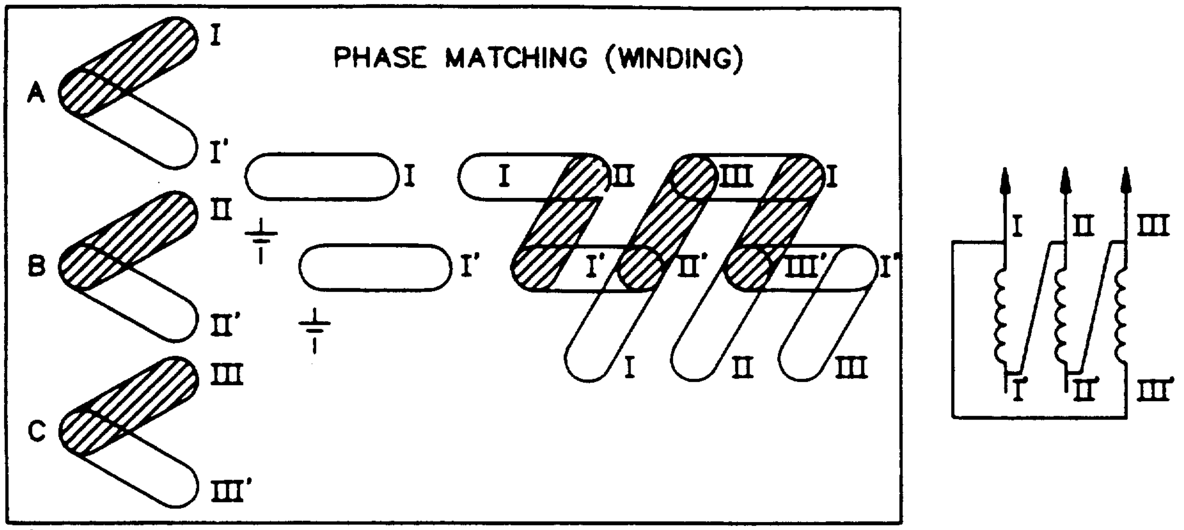


b)

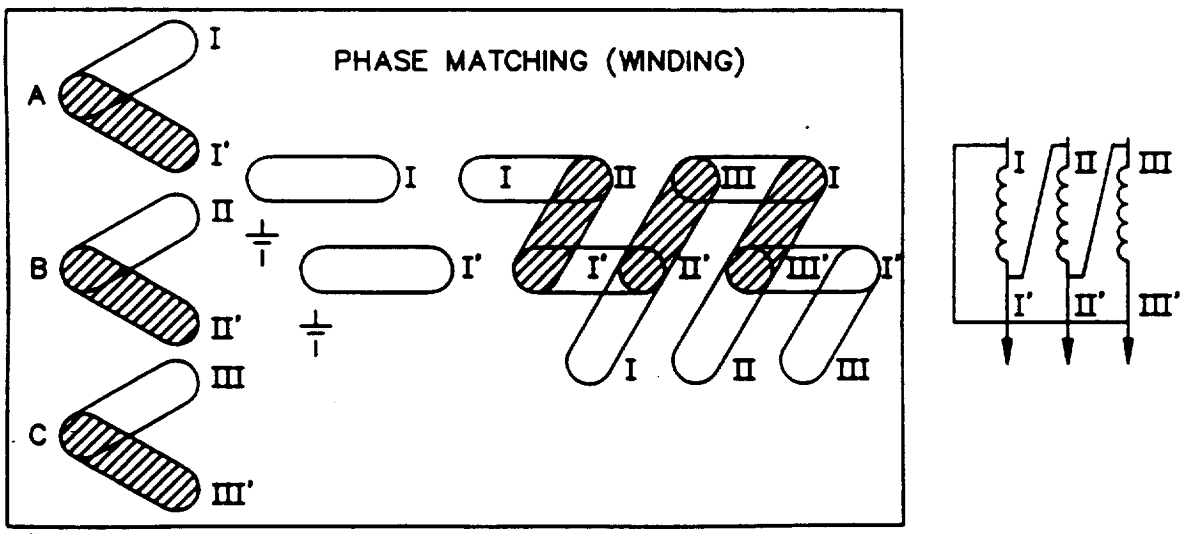
NOTE: INPUT CURRENT TRANSFORMERS CONNECTION:

- PRIMARY WINDINGS HAVE EXTERNAL LEADS AND COULD BE WIRED AS DESIRED
- SECONDARY WINDINGS LEADS MUST BE CONNECTED INTERNALLY IN THE INPUT BOARD BY MEANS OF AVAILABLE LINKS.

Figure 9 Input current transformers connections.



a)



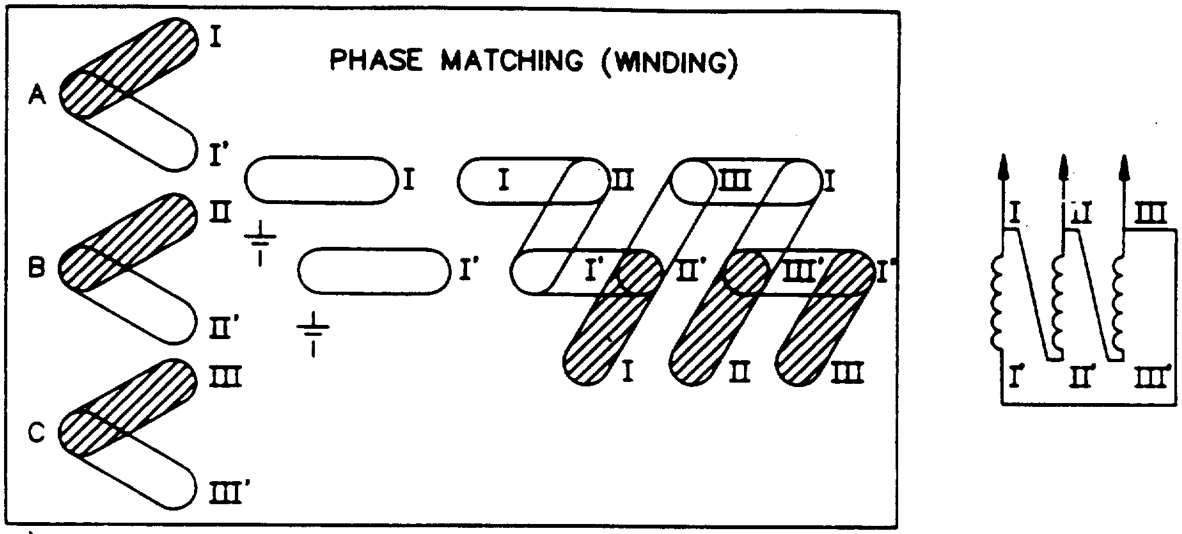
b)

NOTE: INPUT CURRENT TRANSFORMERS CONNECTION:

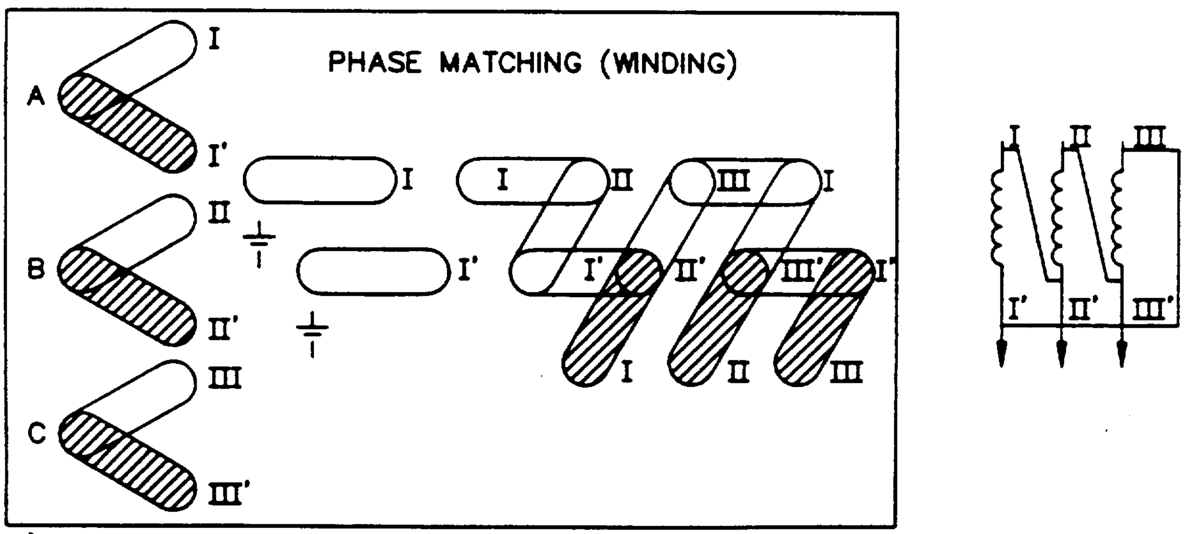
-PRIMARY WINDINGS HAVE EXTERNAL LEADS AND COULD BE WIRED AS DESIRED

-SECONDARY WINDINGS LEADS MUST BE CONNECTED INTERNALLY IN THE INPUT BOARD BY MEANS OF AVAILABLE LINKS.

Figure 10 Input current transformers connections.



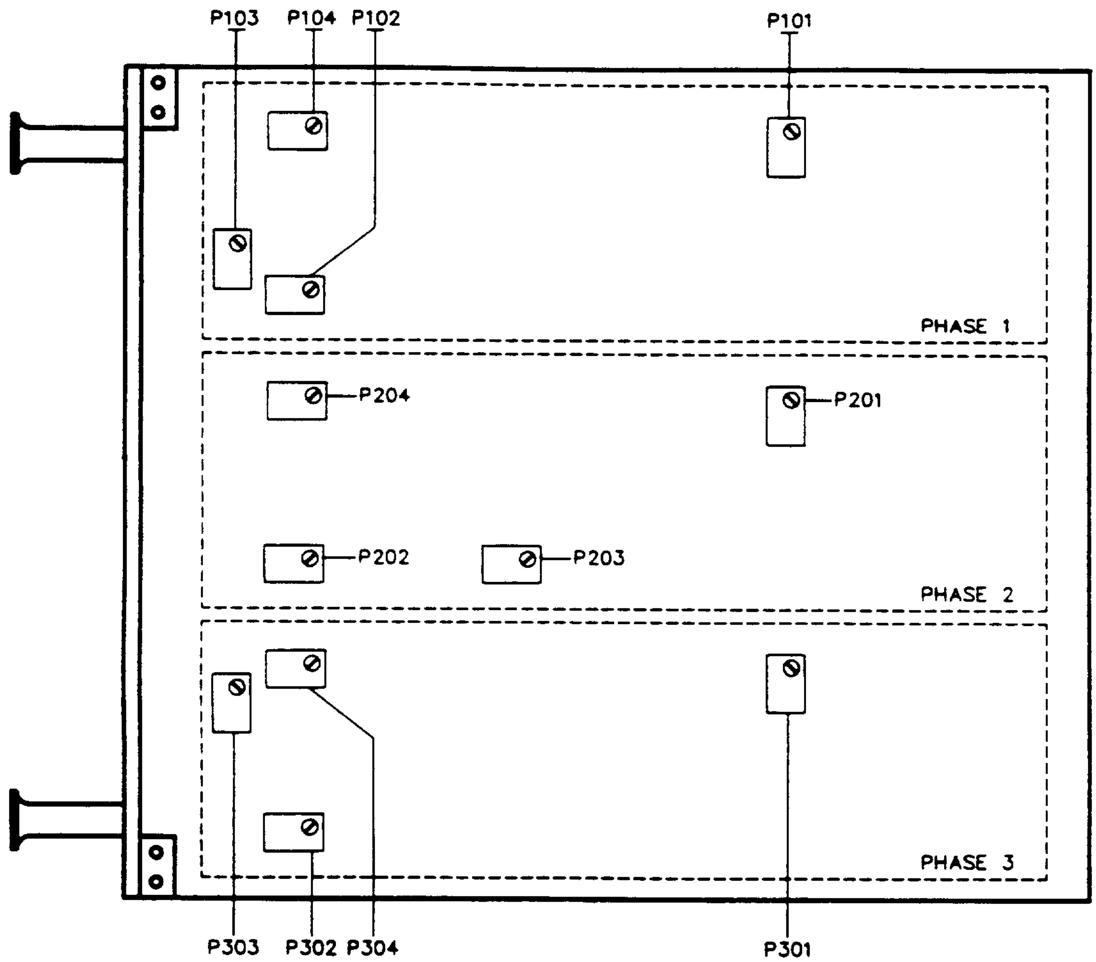
a)



b)

NOTE: INPUT CURRENT TRANSFORMERS CONNECTION:
- PRIMARY WINDINGS HAVE EXTERNAL LEADS AND COULD BE WIRED AS DESIRED
- SECONDARY WINDINGS LEADS MUST BE CONNECTED INTERNALLY IN THE INPUT BOARD BY MEANS OF AVAILABLE LINKS.

Figure 11 Input current transformers connections.



PHASE A	PHASE B	PHASE C	ADJUSTMENT TYPE
P101	P201	P301	INSTANTANEOUS ADJUSTMENT
P102	P202	P302	PERCENTAGE RESTRAINT ADJUSTMENT
P103	P203	P303	HARMONICS RESTRAINT ADJUSTMENT
P104	P204	P304	MINIMUM OPERATING LEVEL ADJUSTMENT

Figure 12 Internal settings measuring unit.

① FIRST WINDING TAP ADJUSTMENT

② SECOND WINDING TAP ADJUSTMENT

EXAMPLE (ASIDE FIGURE)

1st WINDING: $I_S = [0.5+(0.16+0.32)] \times I_N = 0.98 \times I_N$

2nd WINDING: IDEM 1st WINDING

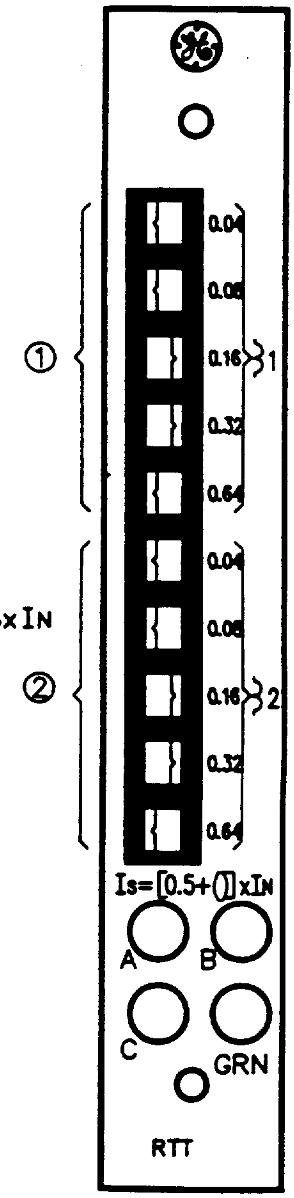


Figure 13 Tap location.

RESTRAINT ADJUSTMENT

IN THE EXAMPLE, THE RESTRAINT HAS BEEN ADJUSTED UP TO:

K=0.15+0.1=0.25 (25%)

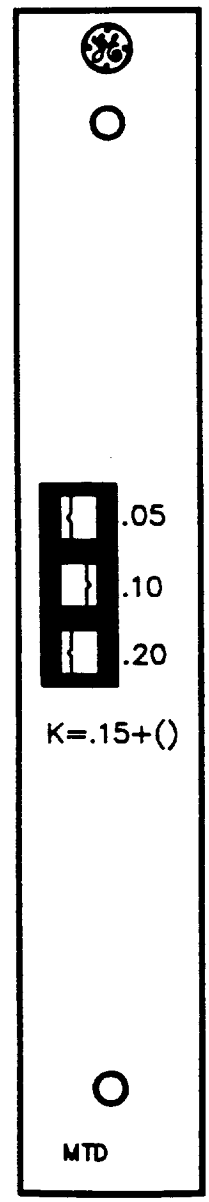


Figure 14 Restraint location.

1.–PHASE A INTERNAL FAULT SIGNALING

2.–PHASE B INTERNAL FAULT SIGNALING

3.–PHASE C INTERNAL FAULT SIGNALING

4.–PHASE A INSTANTANEOUS SIGNALING

5.–PHASE B INSTANTANEOUS SIGNALING

6.–PHASE C INSTANTANEOUS SIGNALING

7.–SIGNALING RESET

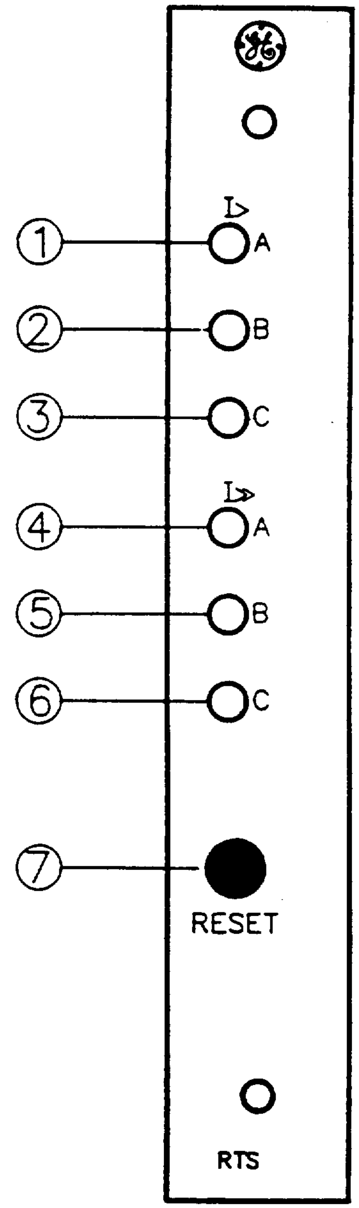
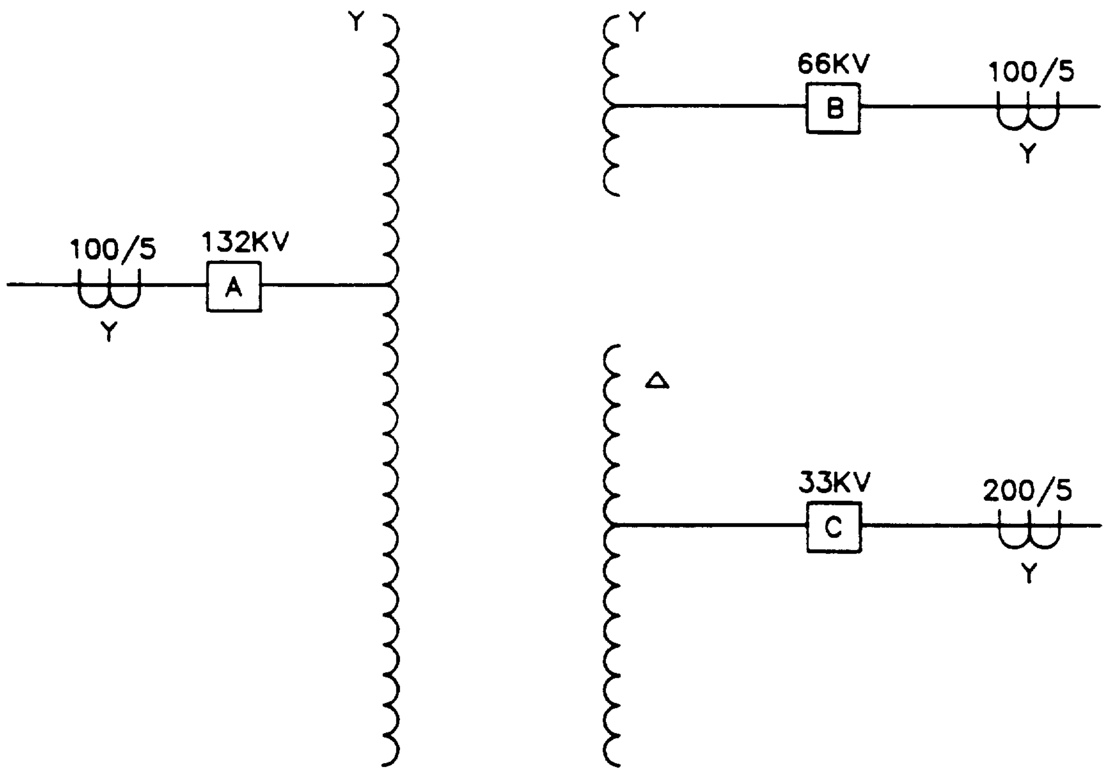


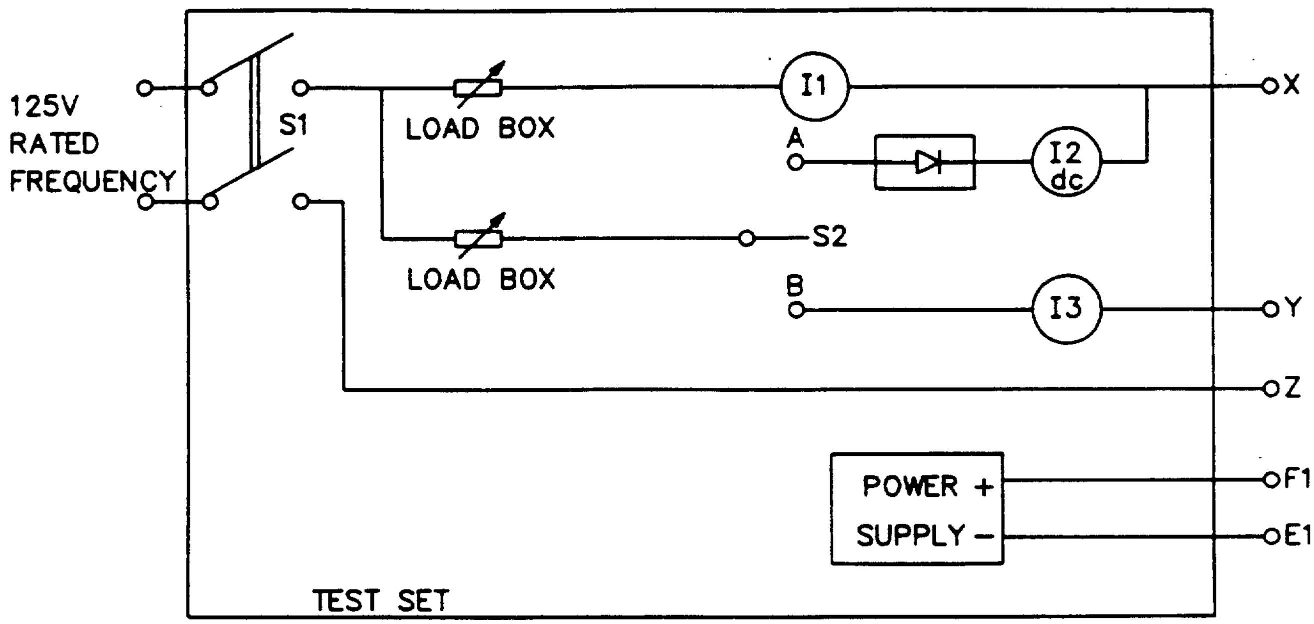
Figure 15 Led's and reset button board.



4000KVA (5000KVA ONAF RATED POWER)

ALL C.T. CONNECTIONS REPRESENTED ARE WYE TYPE. SINCE 1ST AND 2ND WINDINGS MUST BE △ CONNECTIONS AT THE RELAY INPUT (PHASE MATCHING), THE REQUIRED CHANGE CONNECTION COULD BE DONE IN THE RELAY ITSELF BY MEANS OF AVAILABLE JUMPERS.

Figure 16 Transformer used in sample calculations.



PHASE	CONNECTIONS		S2 POSITIONING AS PER SELECTED CHARACTERISTIC TEST			
	TEST SET	RELAY TERMINALS	PICK UP	HARMONICS RESTRAINT	PERCENTAGE CHARACTERISTIC	OVERCURRENT UNIT
A	X	B1–B5	POSITION: OPEN	POSITION: A	POSITION: B	POSITION: OPEN
	Y	A1				
	Z	A5				
B	X	B2–B6				
	Y	A2				
	Z	A6				
C	X	B3–B7				
	Y	A3				
	Z	A7				

Figure 17 Test connections

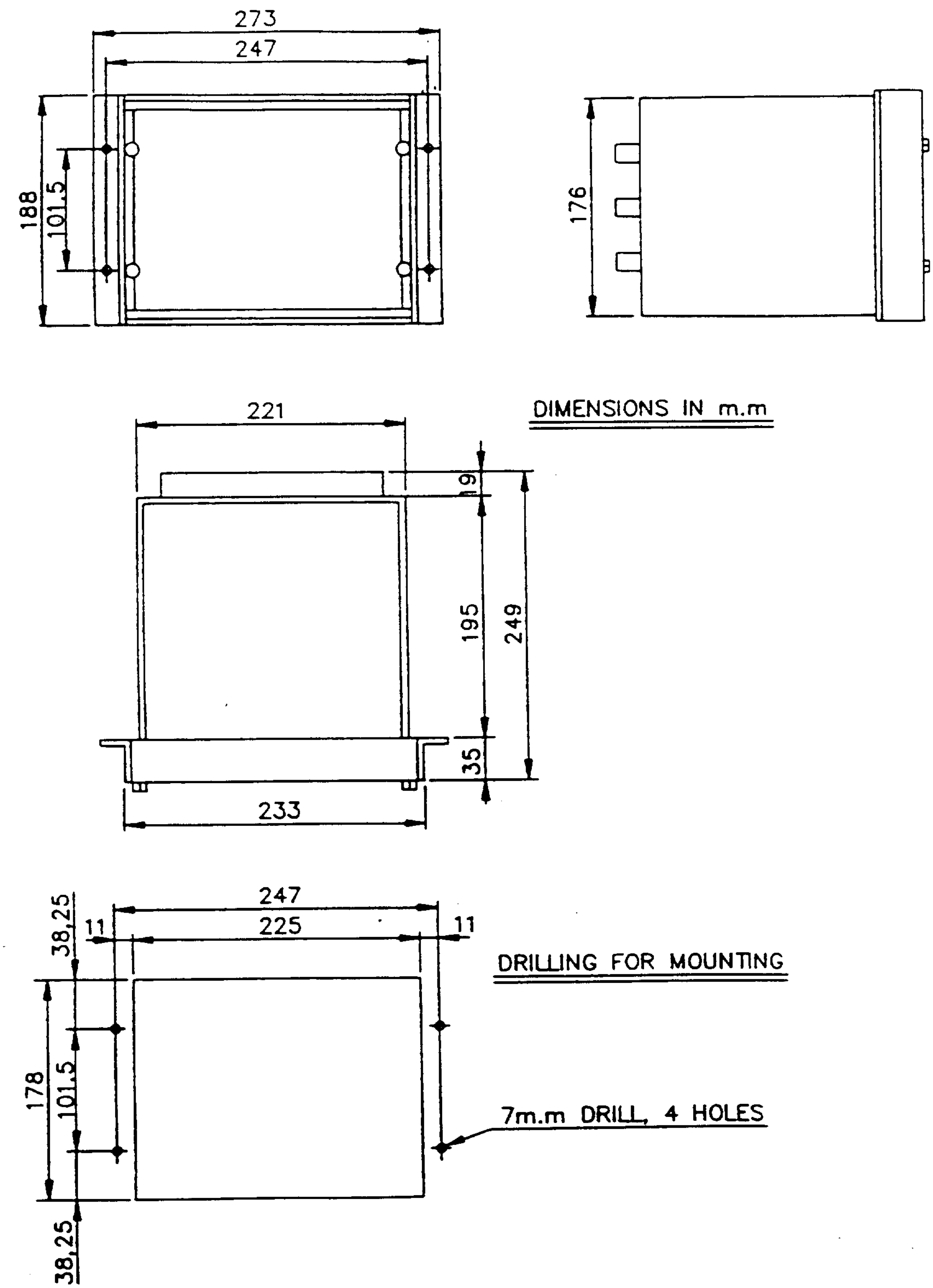


Figure 18 Case dimension and panel drilling (1/2 rack).

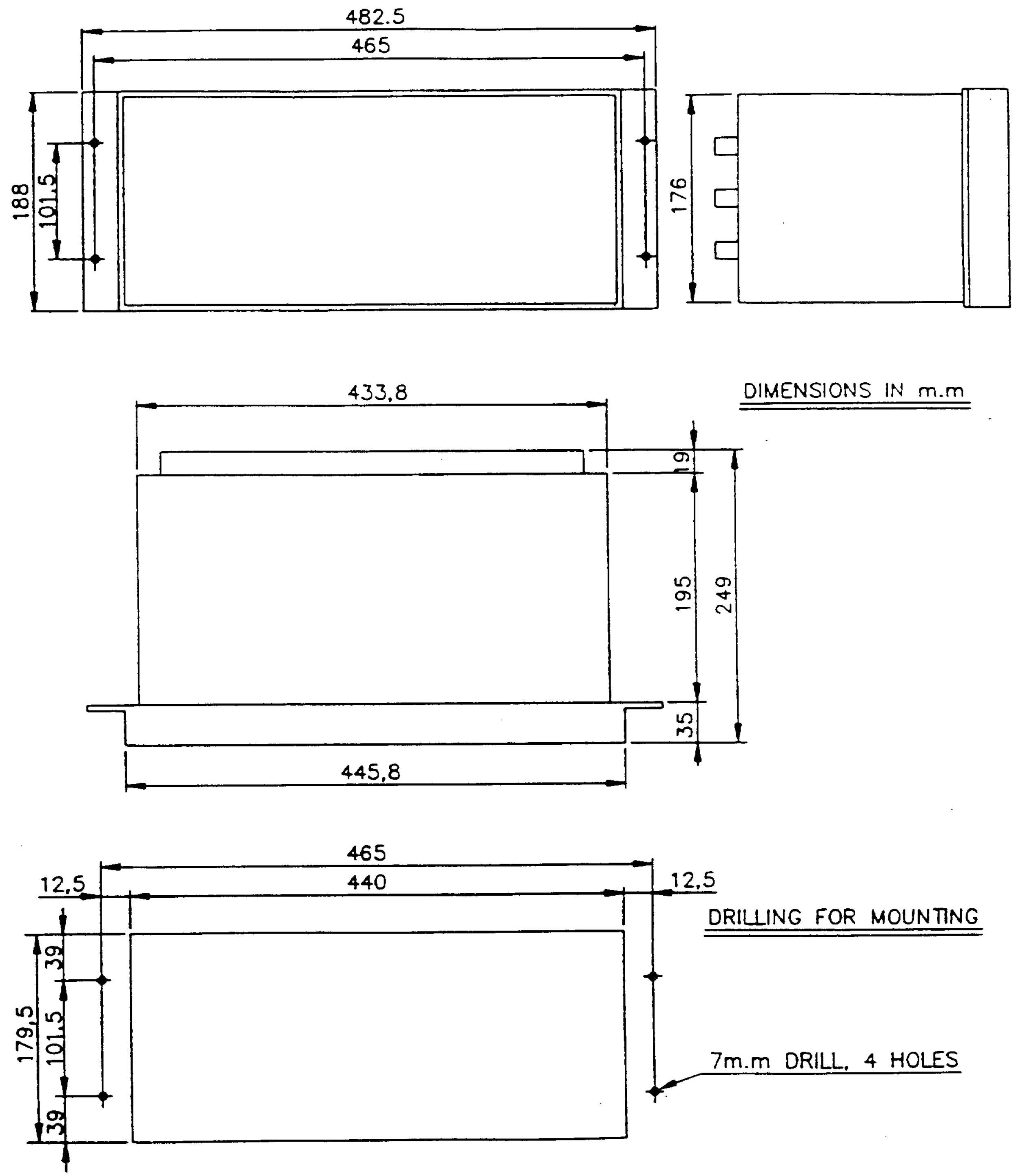


Figure 19 Case dimensions and panel drilling (1 standard rack).

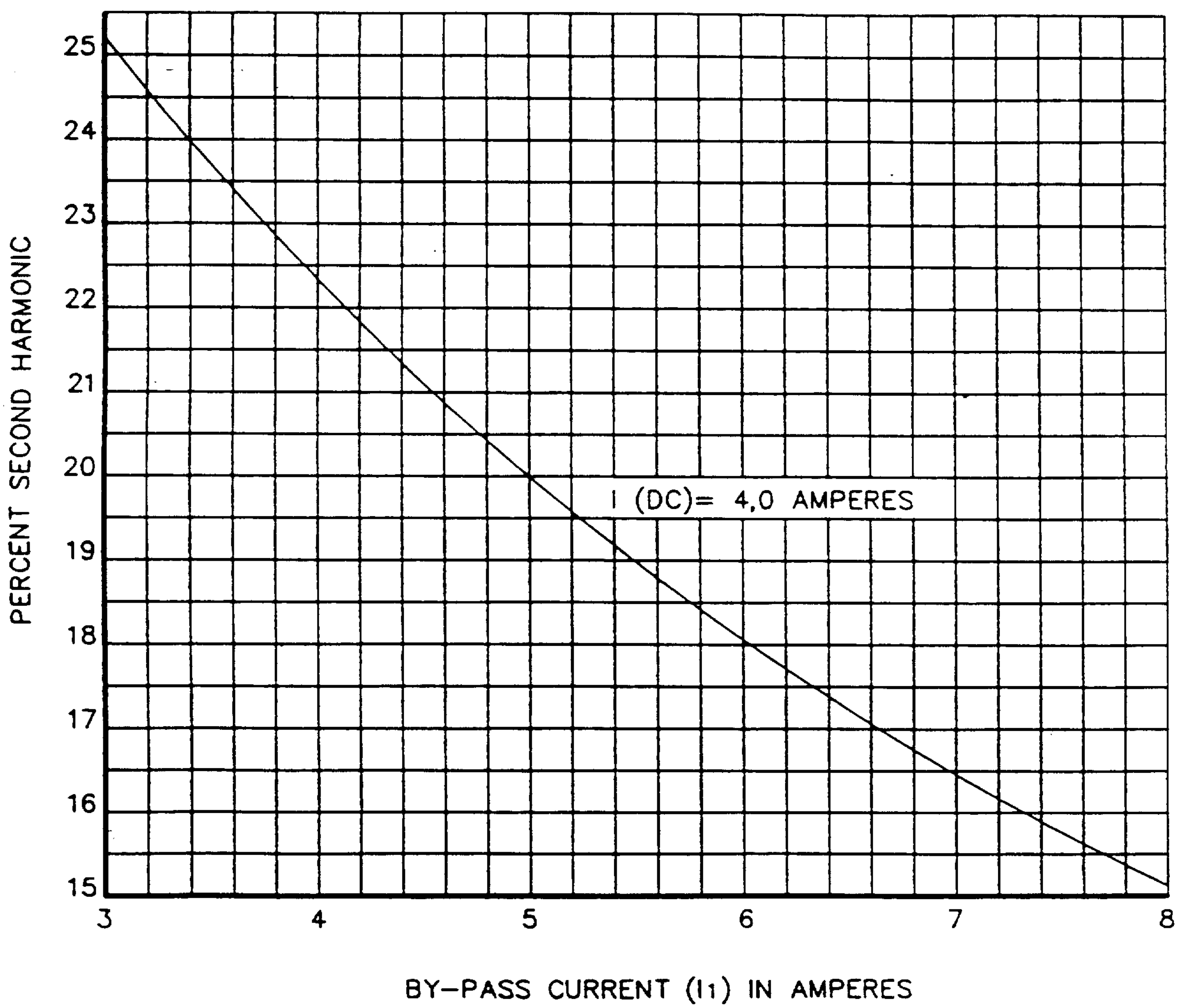


Figure 20 Relationship between percent second harmonic and by-pass current with I(dc) set at 4.0 Amperes.

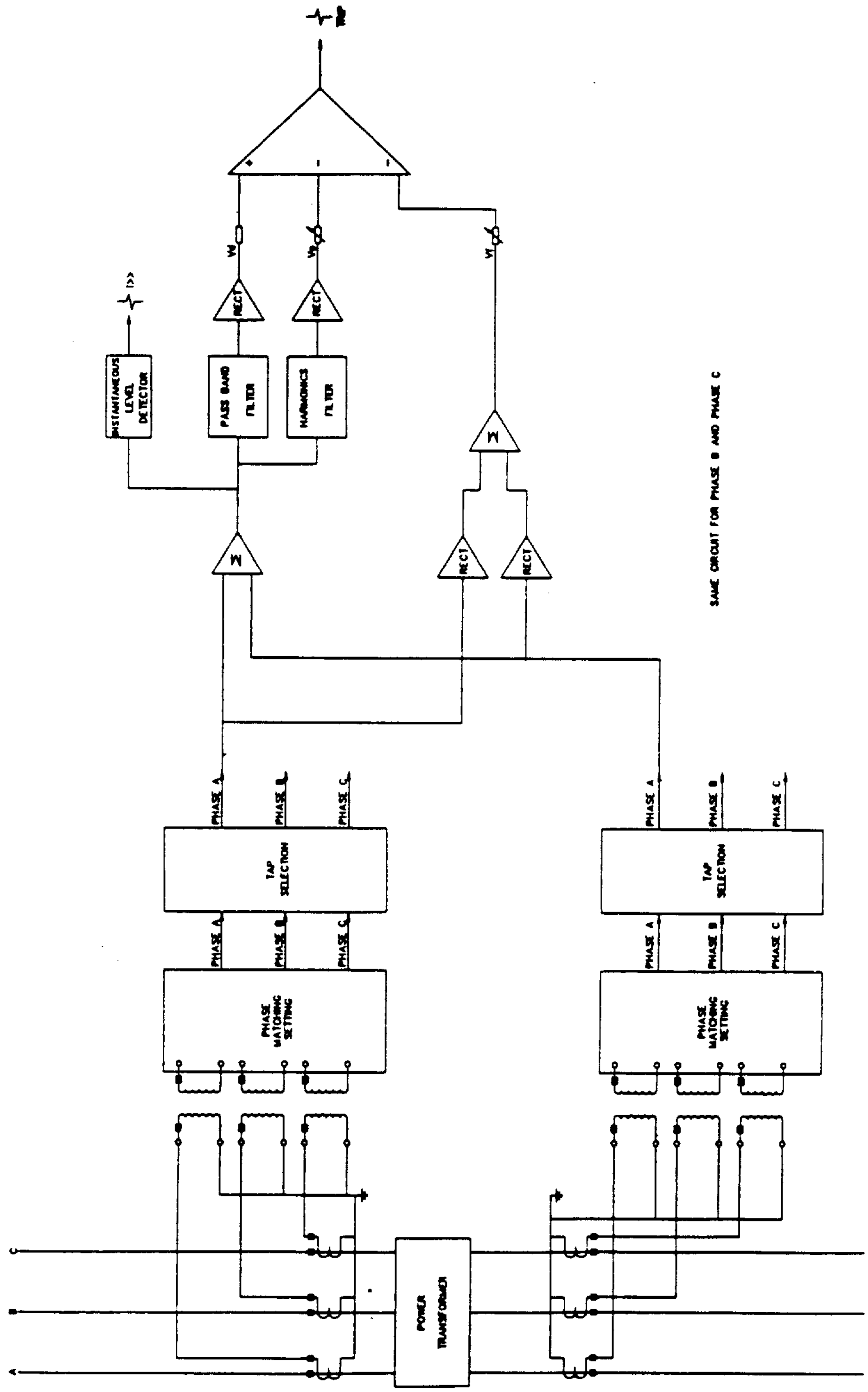


Figure 21 Block diagram.

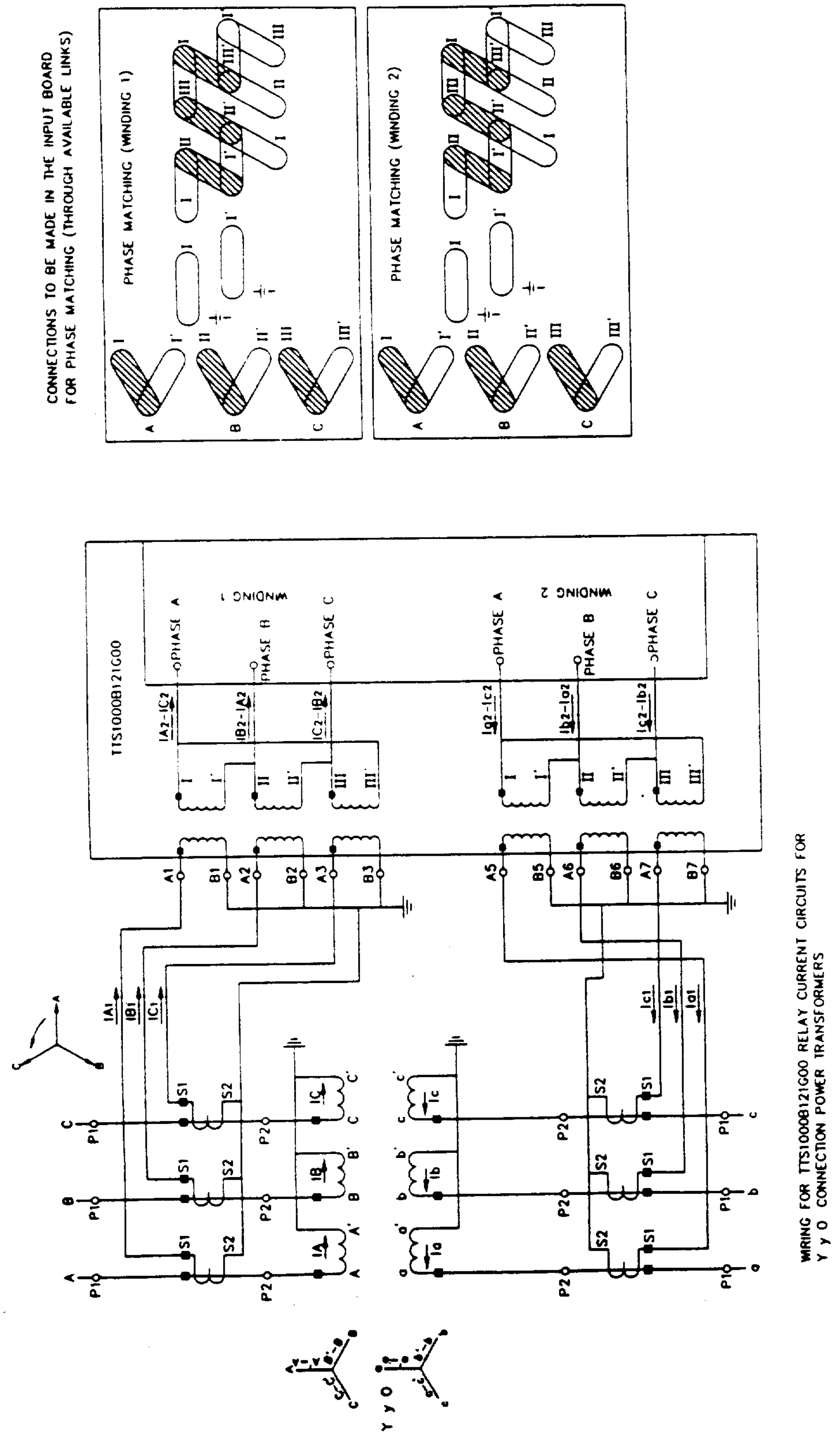


Figure 22 (Sheet 1) Internal match of power transformer connection.

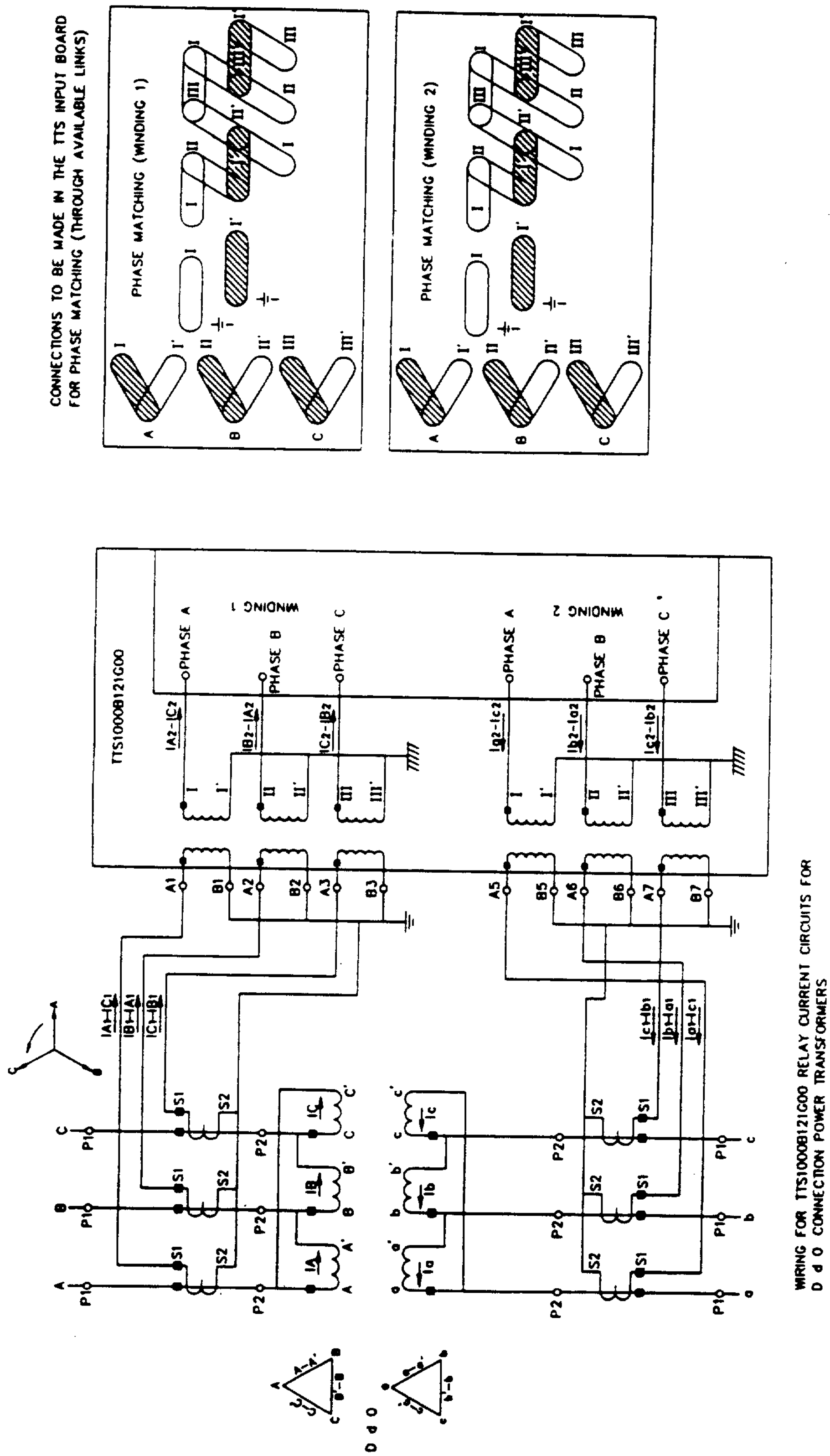


Figure 22 (Sheet 2) Internal match of power transformer connection.

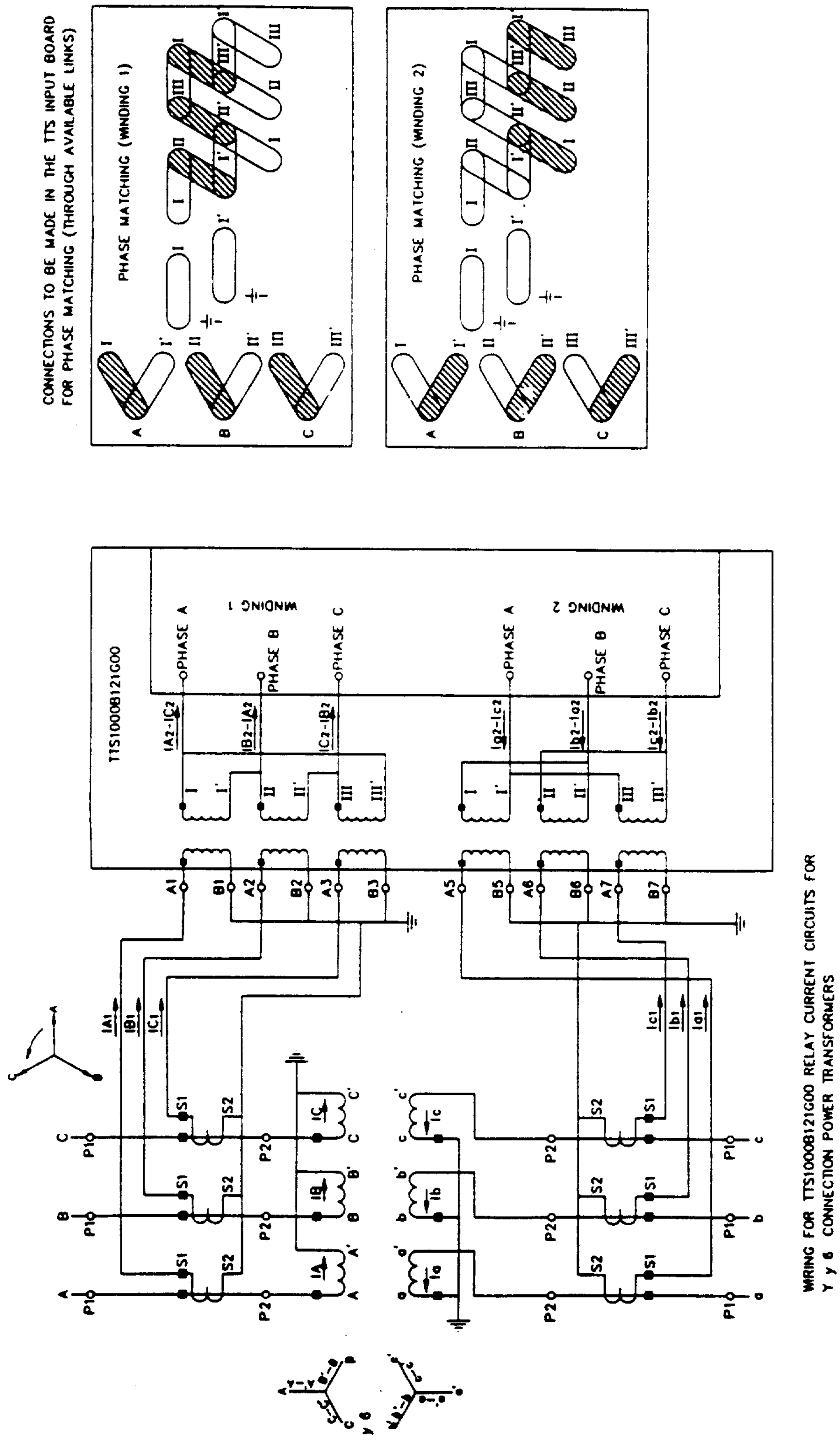


Figure 22 (Sheet 3) Internal match of power transformer connection.

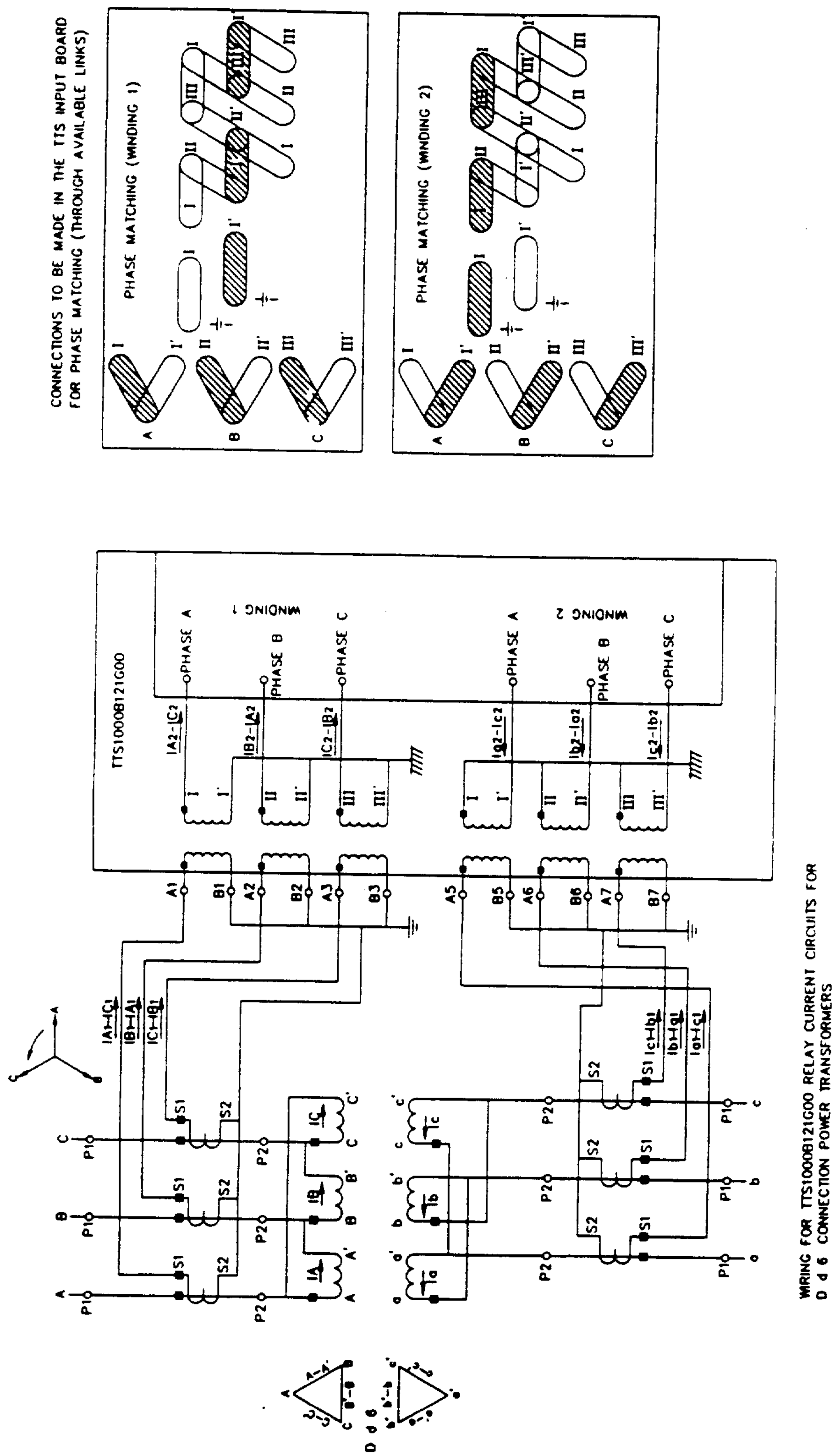


Figure 22 (Sheet 4) Internal match of power transformer connection.

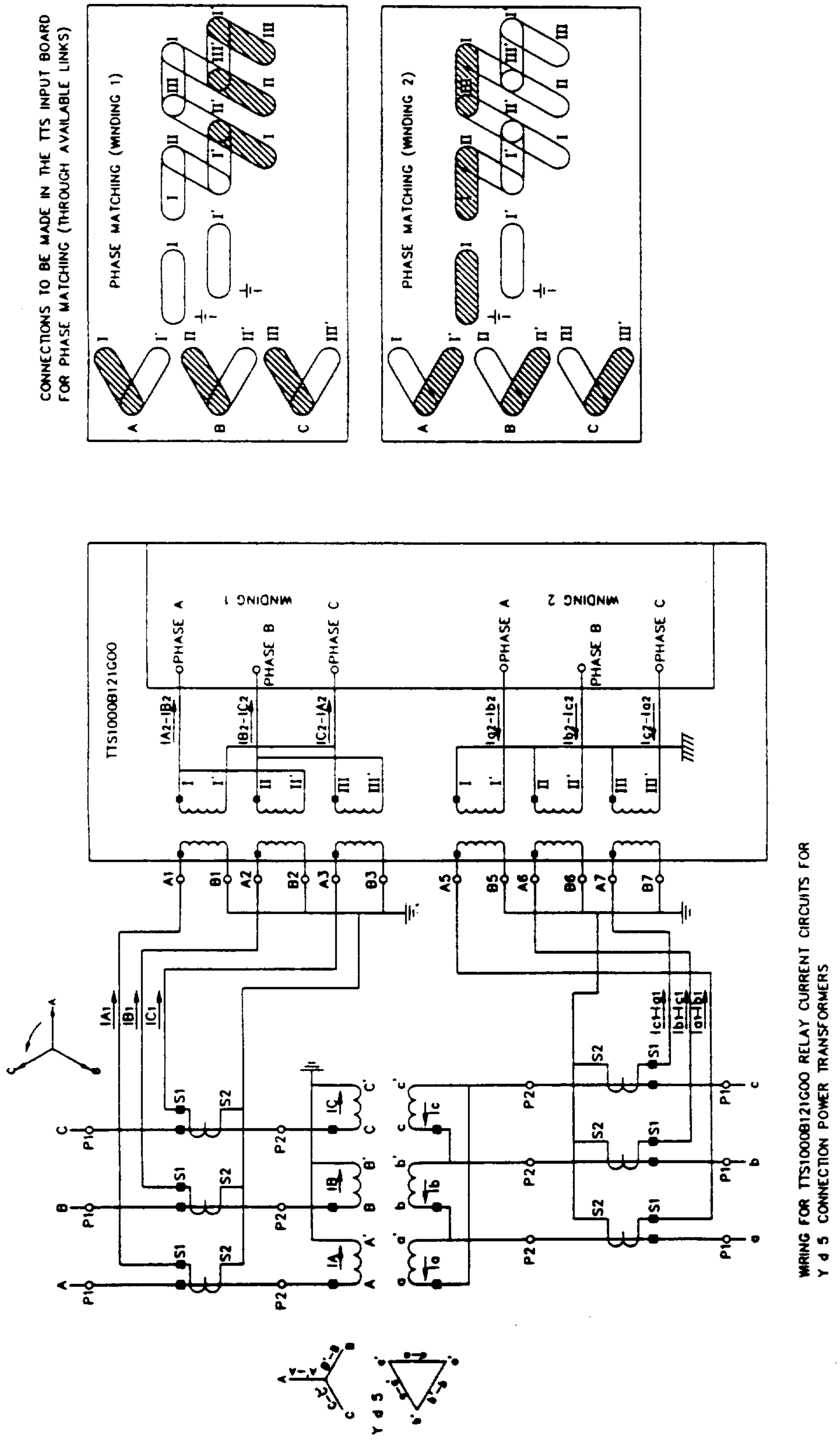


Figure 22 (Sheet 5) Internal match of power transformer connection.

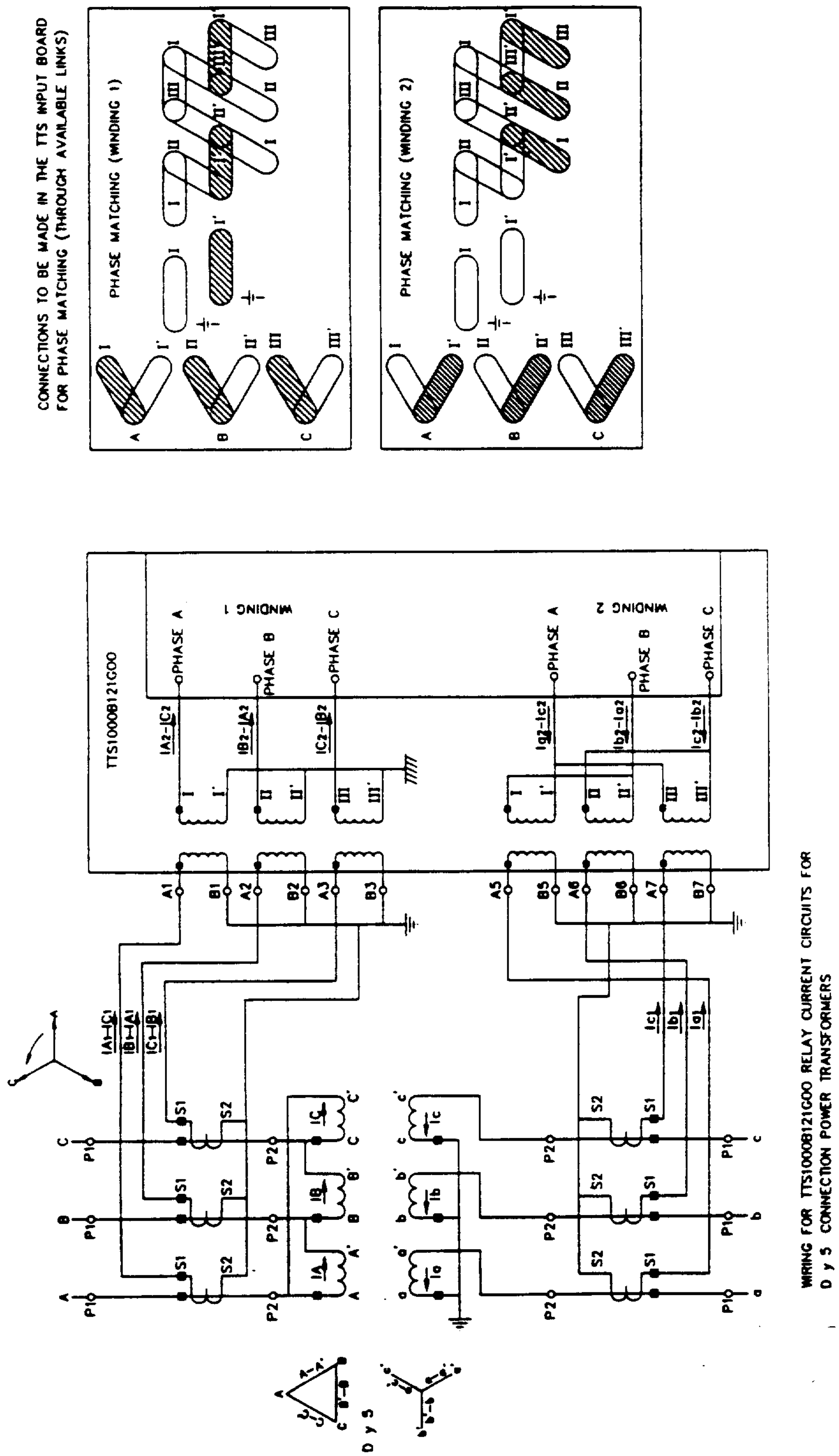


Figure 22 (Sheet 6) Internal match of power transformer connection.

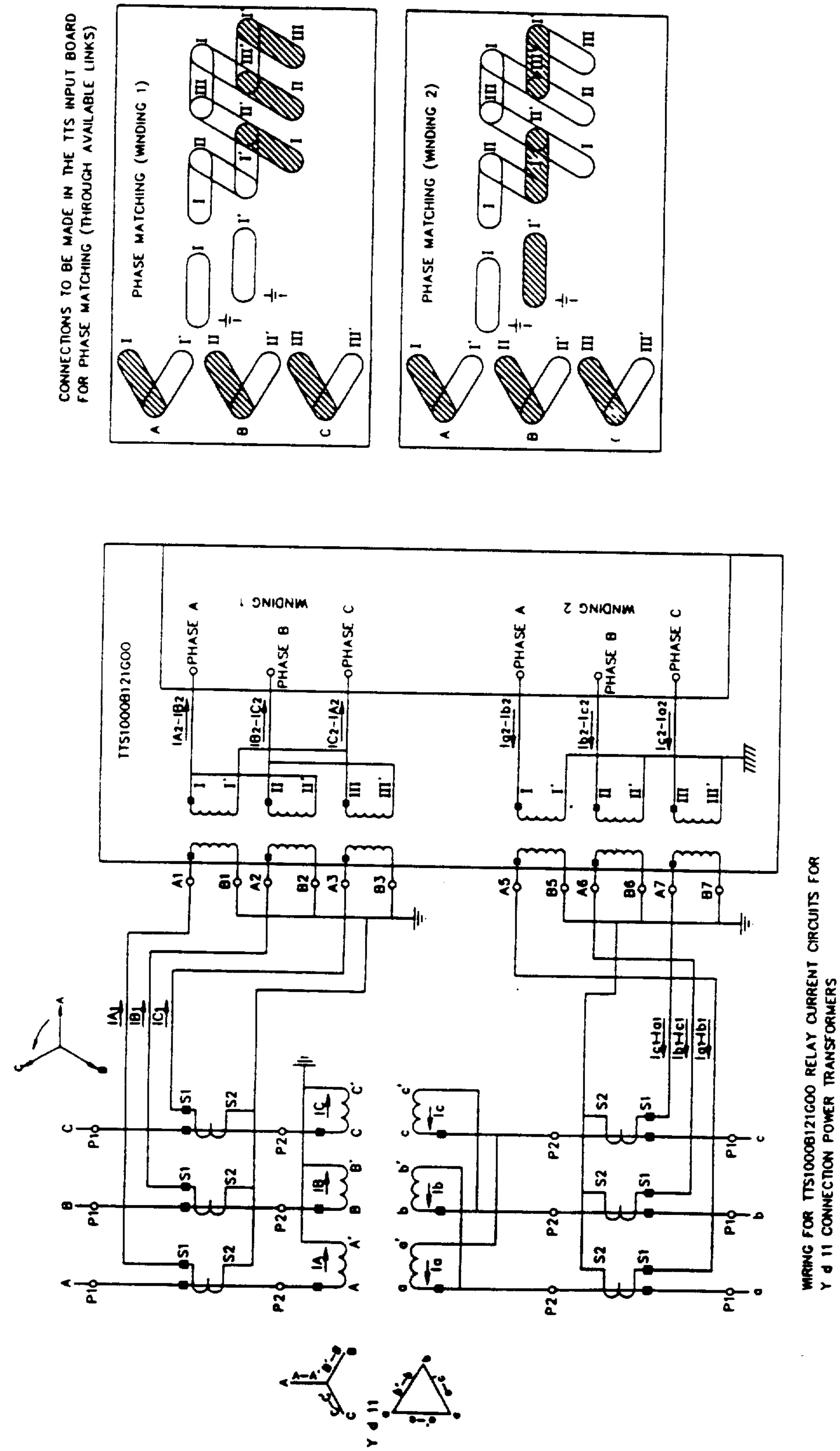


Figure 22 (Sheet 7) Internal match of power transformer connection.

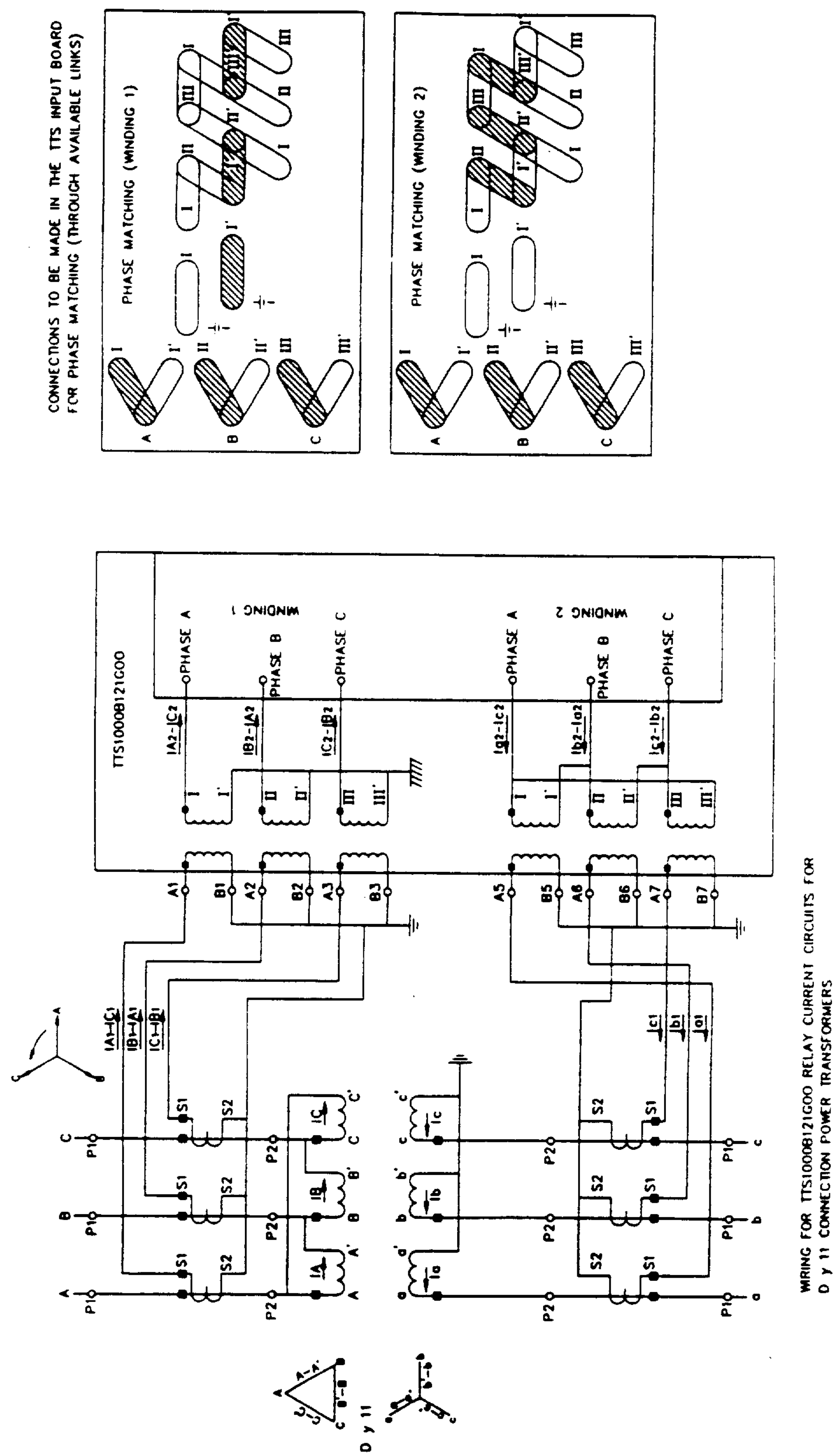


Figure 22 (Sheet 8) Internal match of power transformer connection.

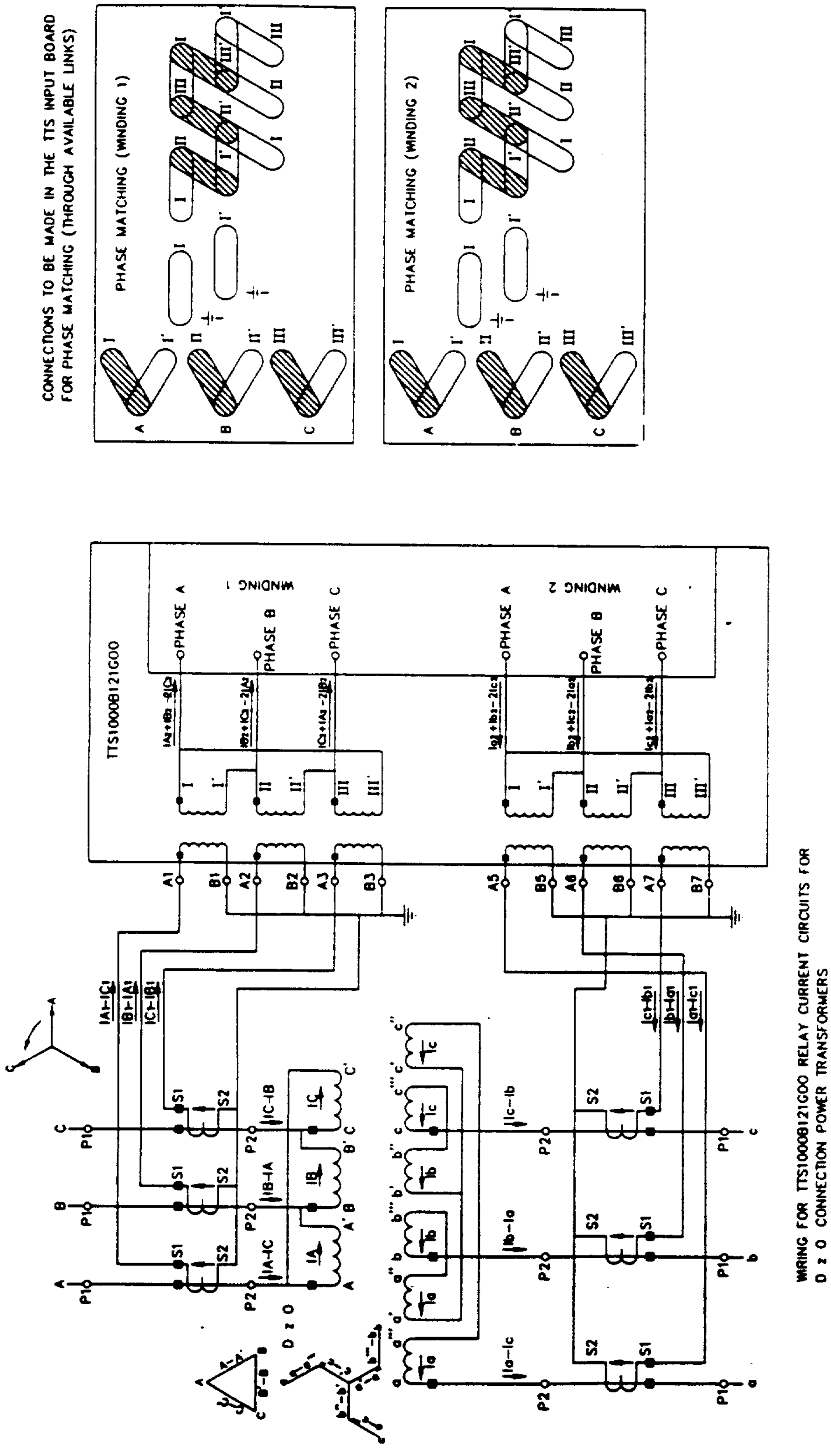


Figure 22 (Sheet 9) Internal match of power transformer connection.

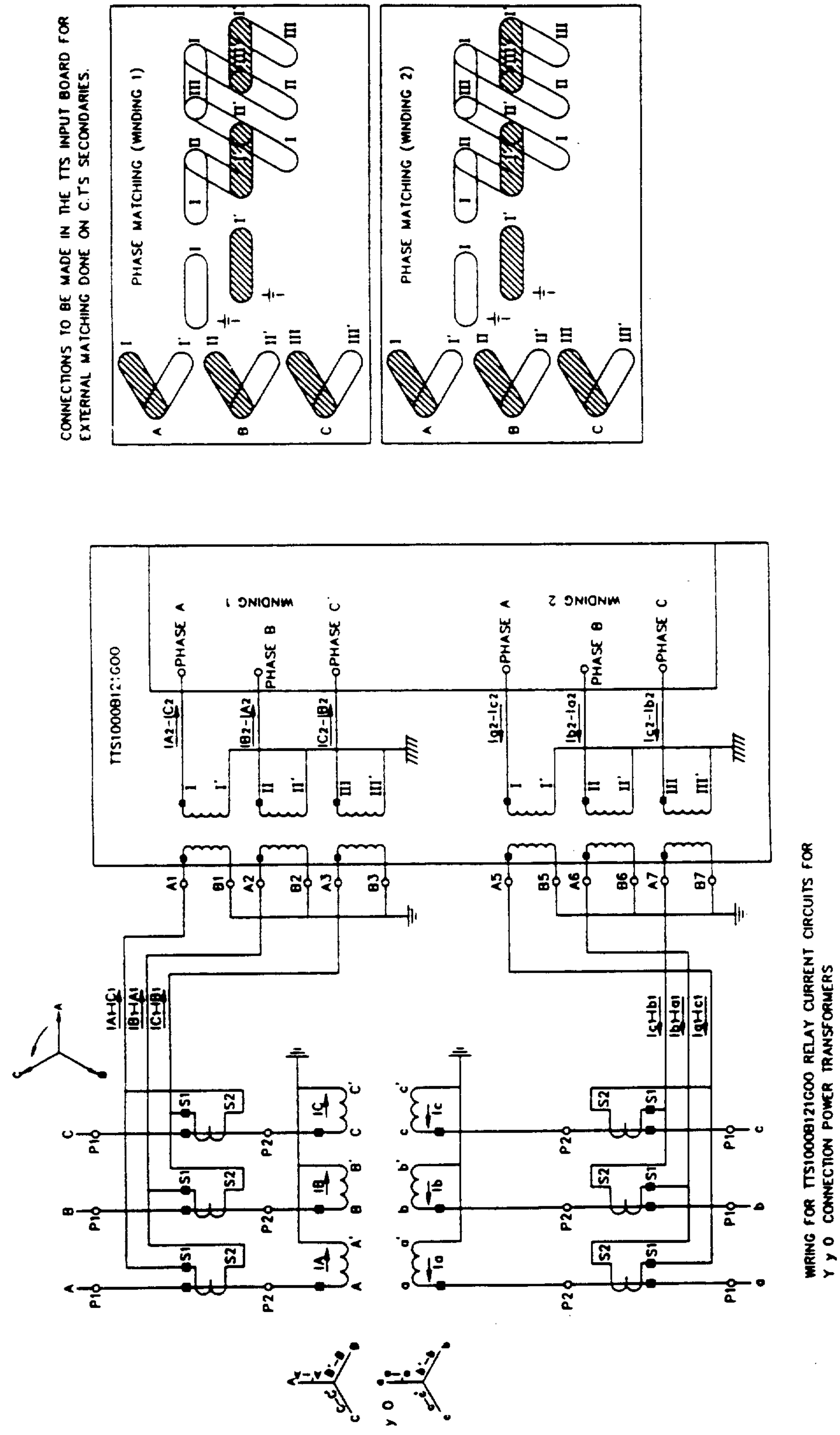


Figure 23 (Sheet 1) External connection of power transformer connection.

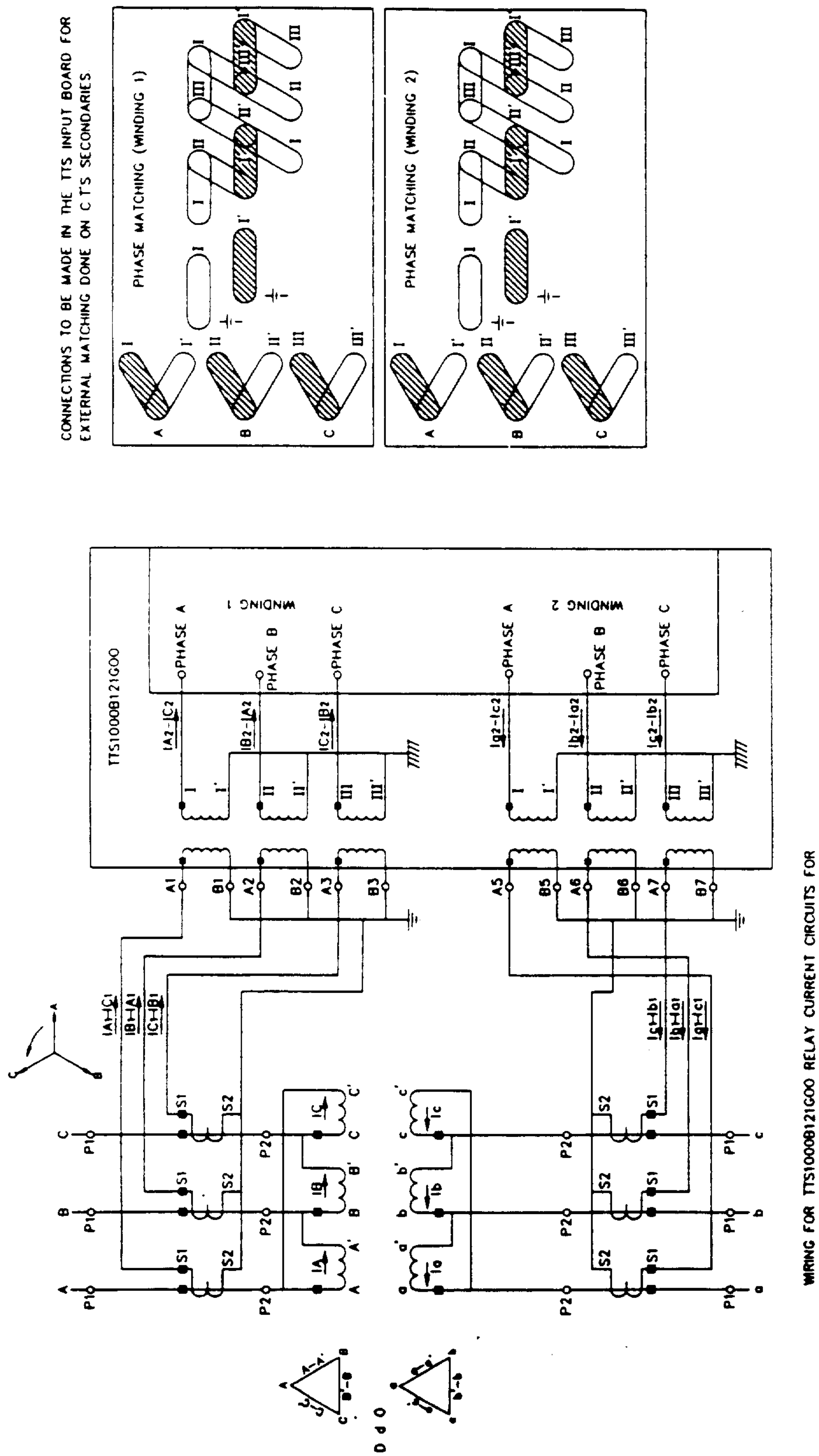


Figure 23 (Sheet 2) External connection of power transformer connection.

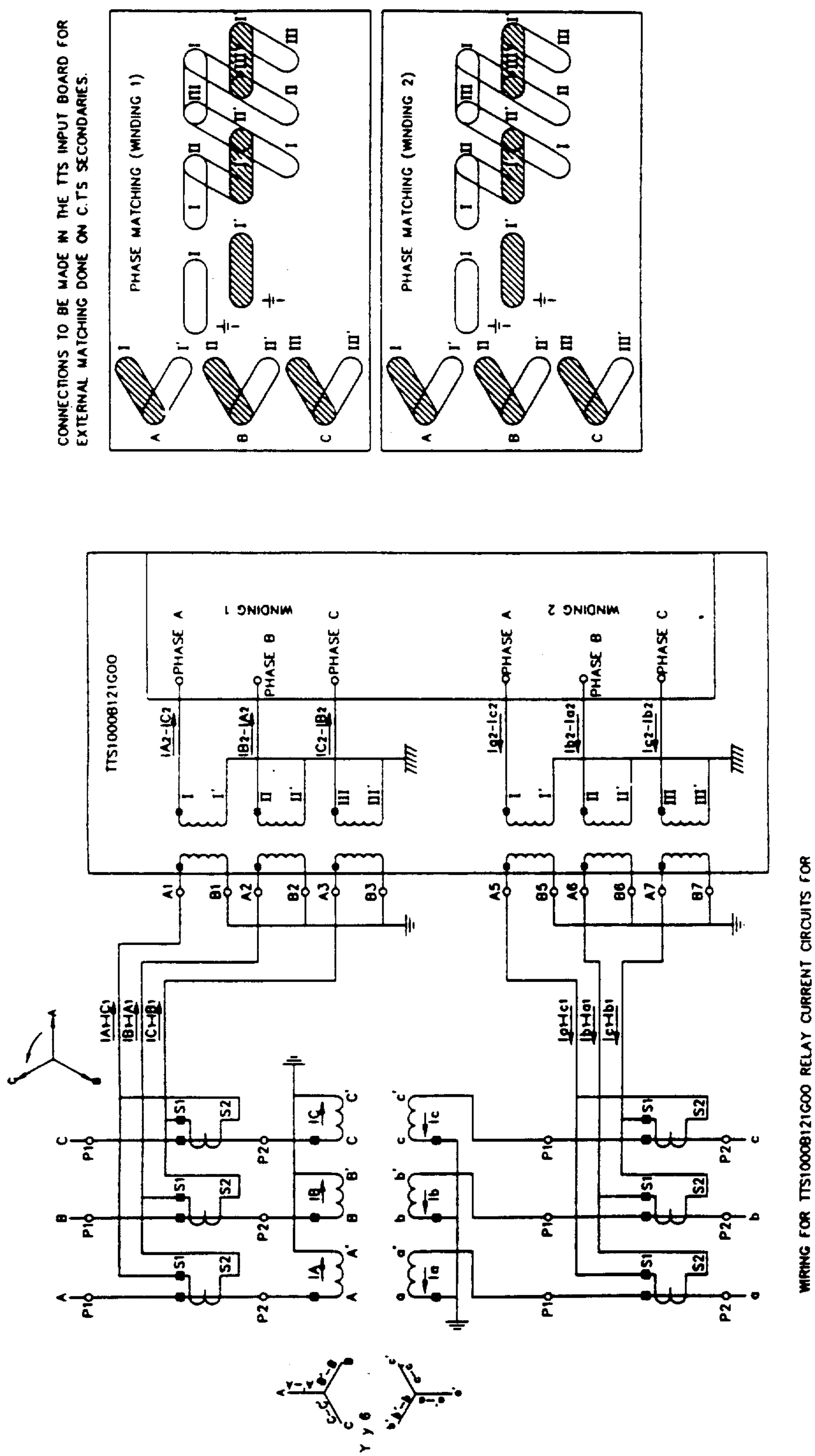


Figure 23 (Sheet 3) External connection of power transformer connection.

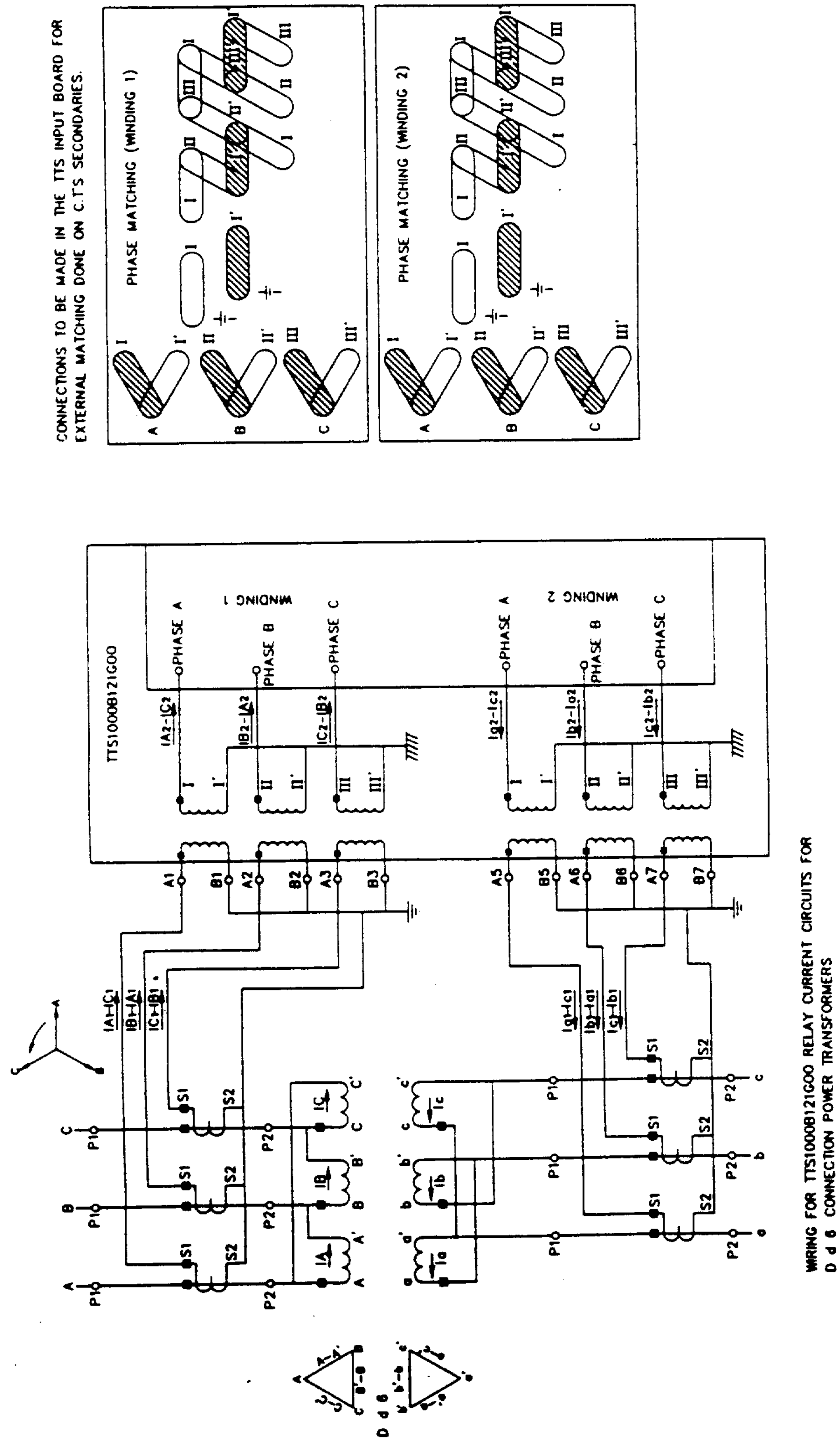


Figure 23 (Sheet 4) External connection of power transformer connection.

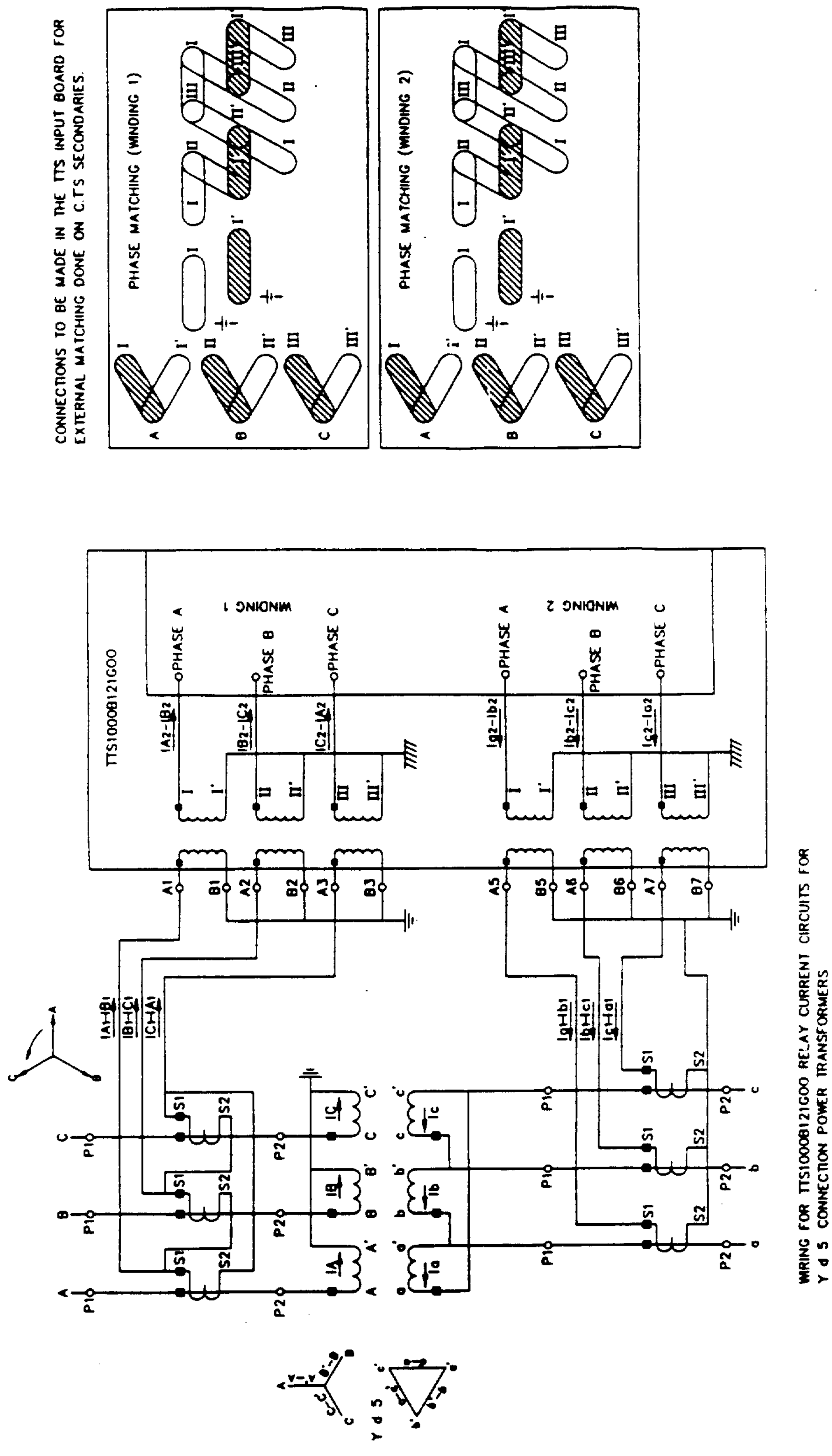


Figure 23 (Sheet 5) External connection of power transformer connection.

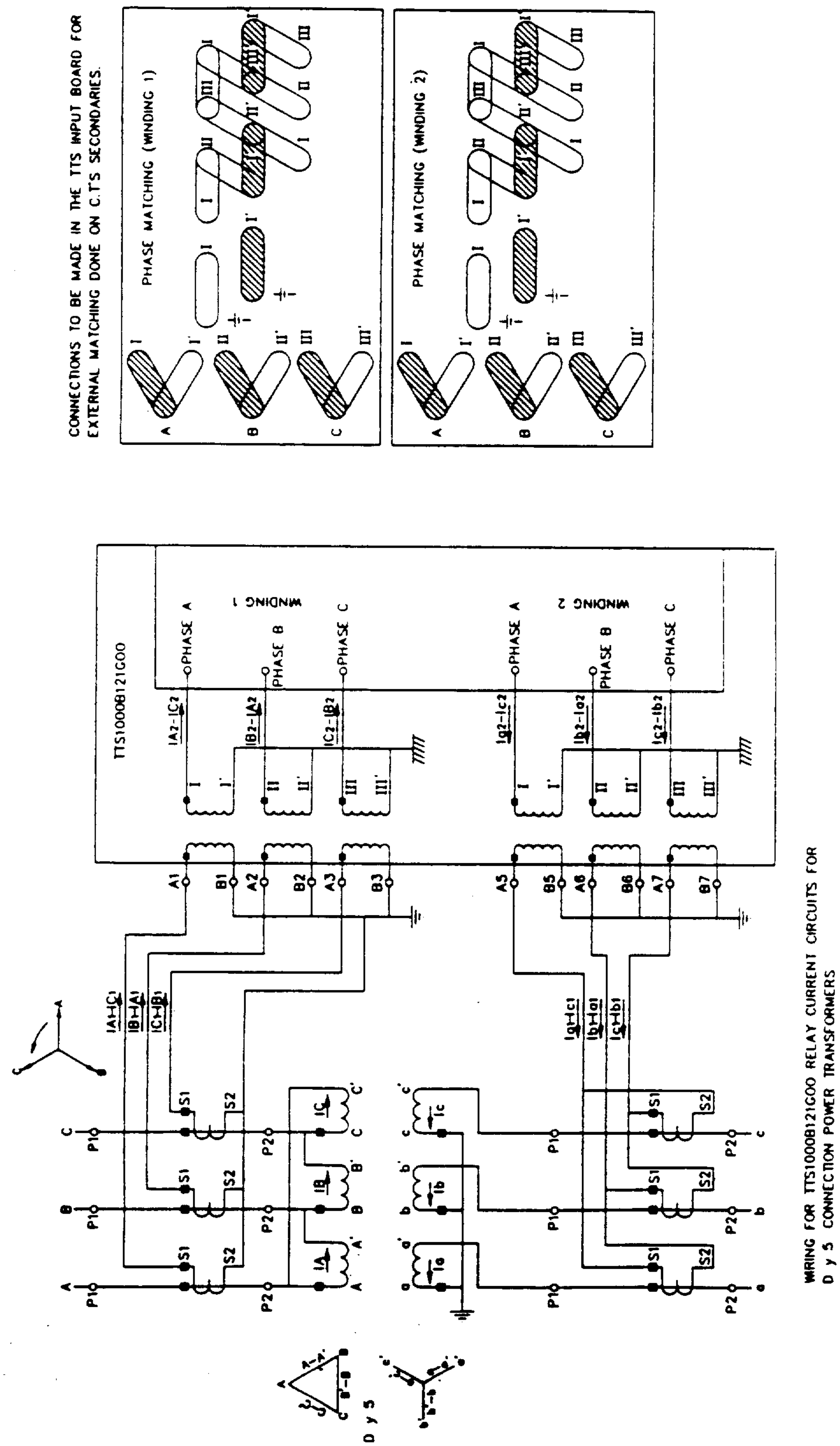


Figure 23 (Sheet 6) External connection of power transformer connection.

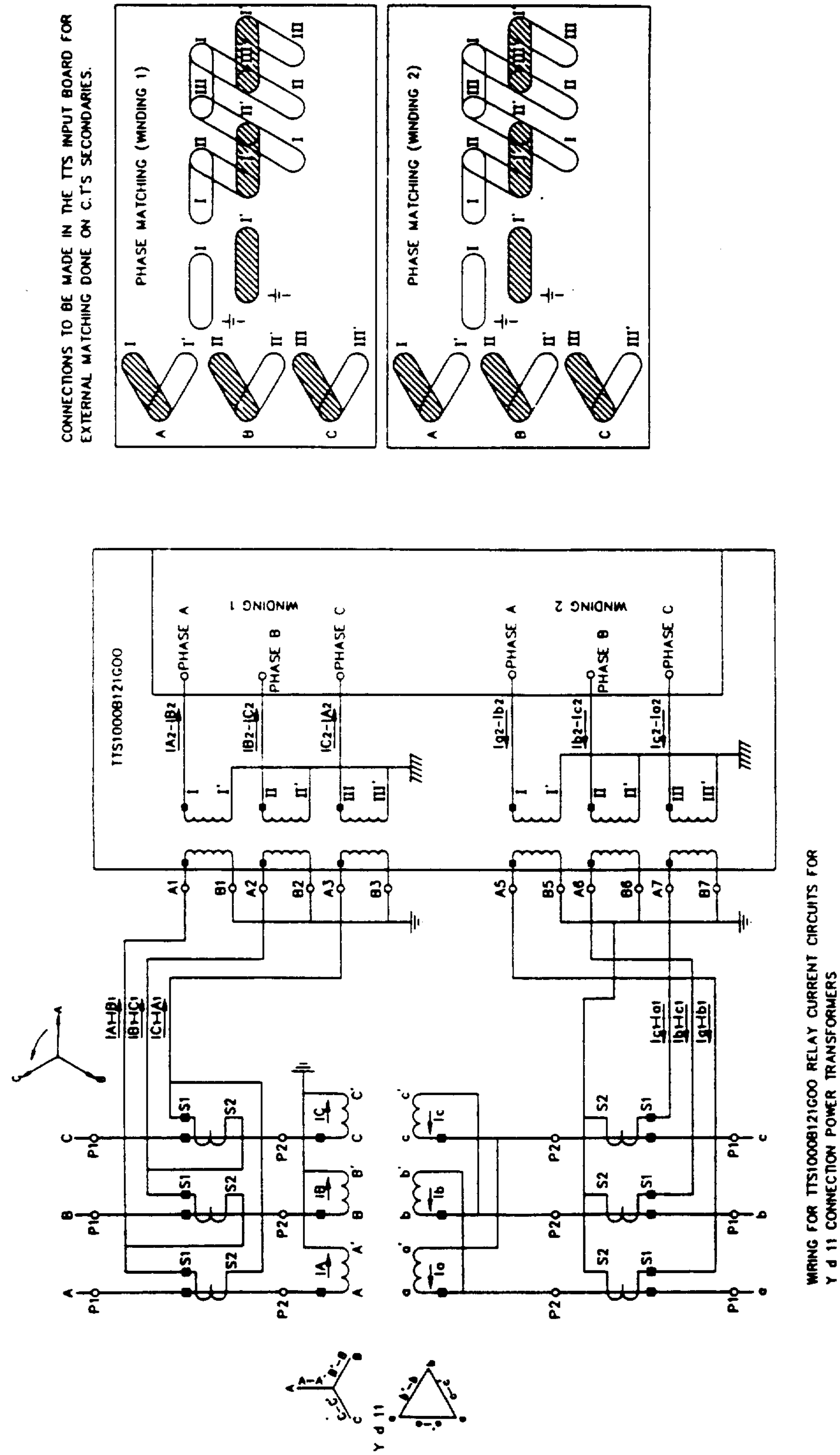


Figure 23 (Sheet 7) External connection of power transformer connection.

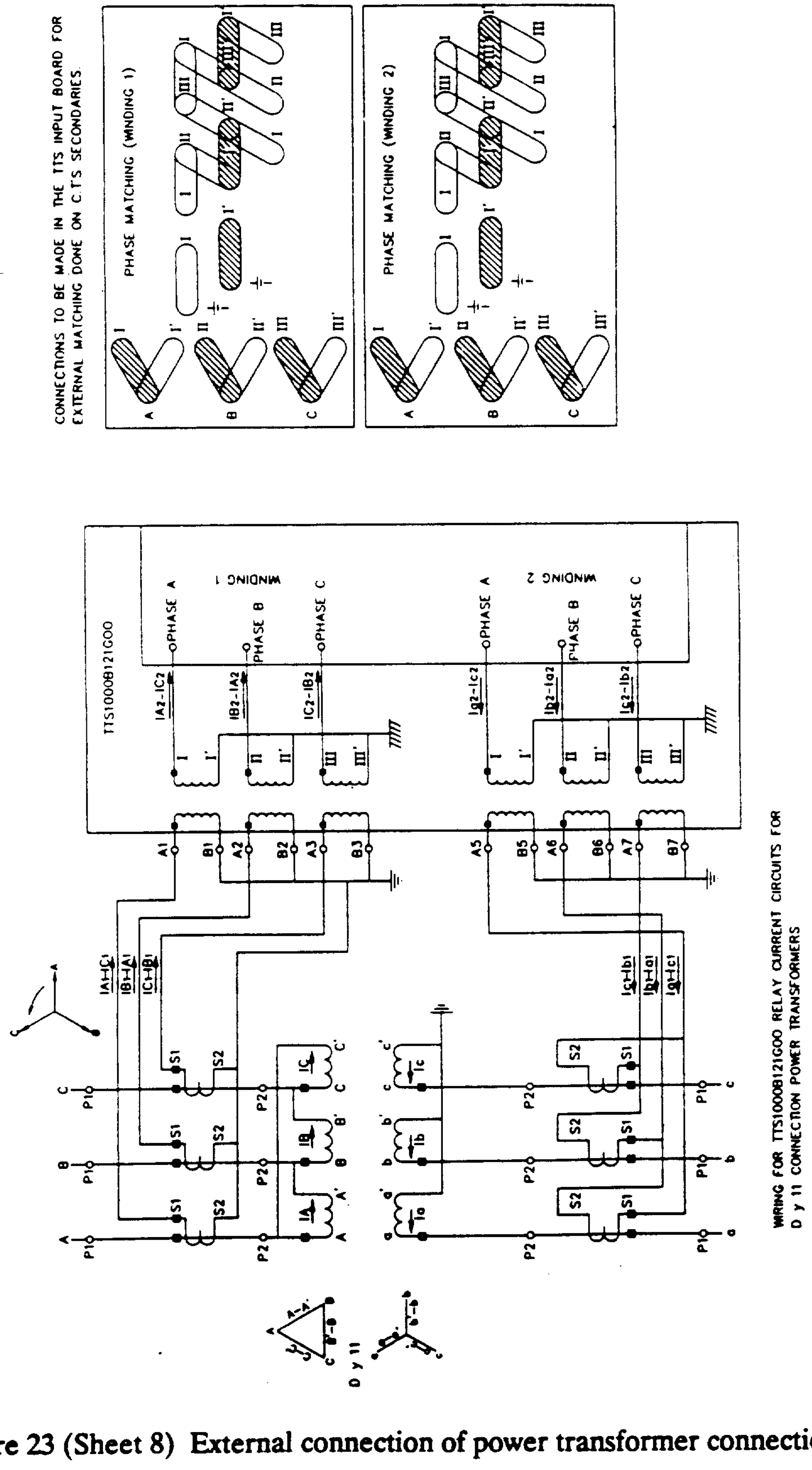


Figure 23 (Sheet 8) External connection of power transformer connection.

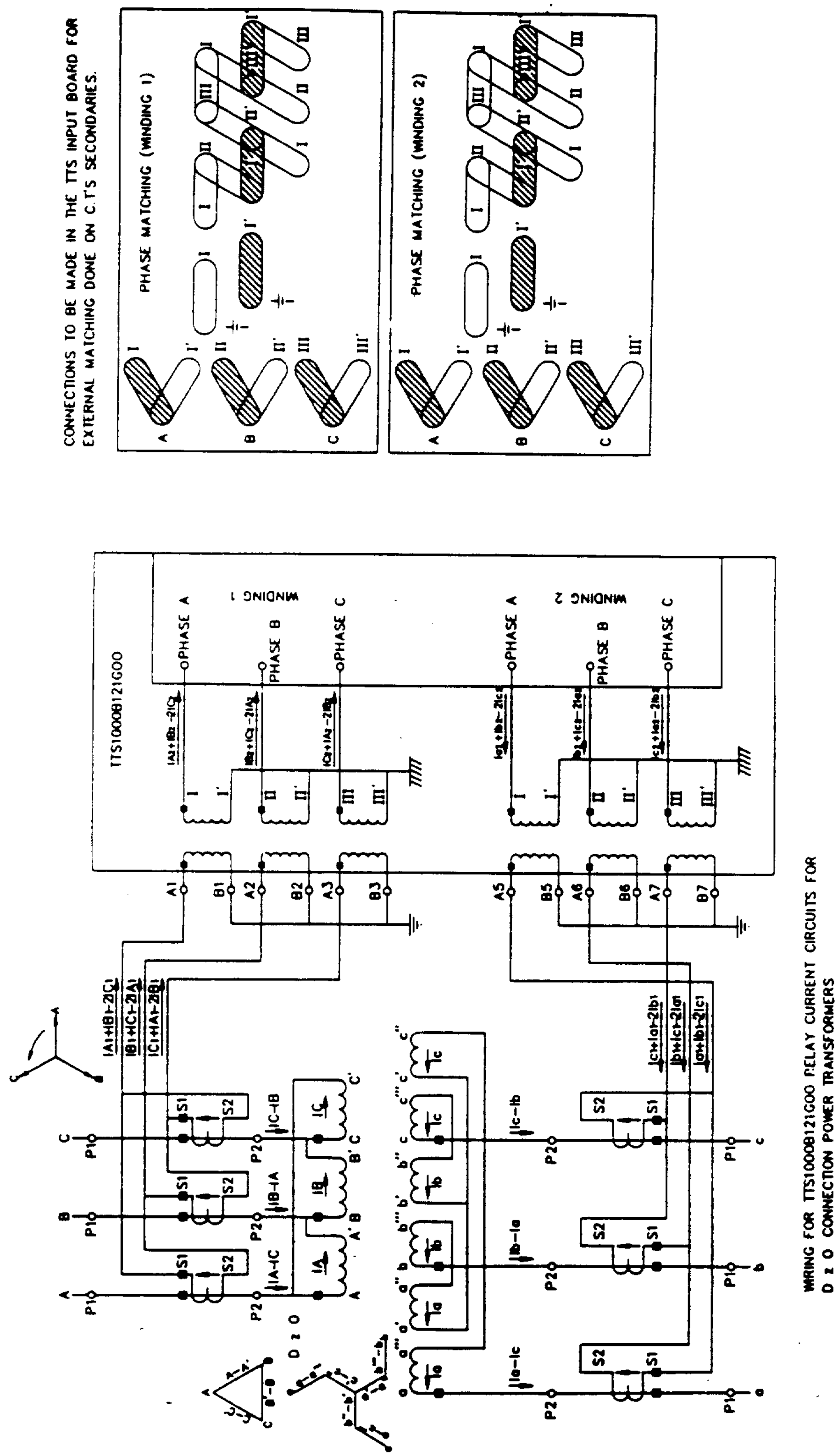


Figure 23 (Sheet 9) External connection of power transformer connection.

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