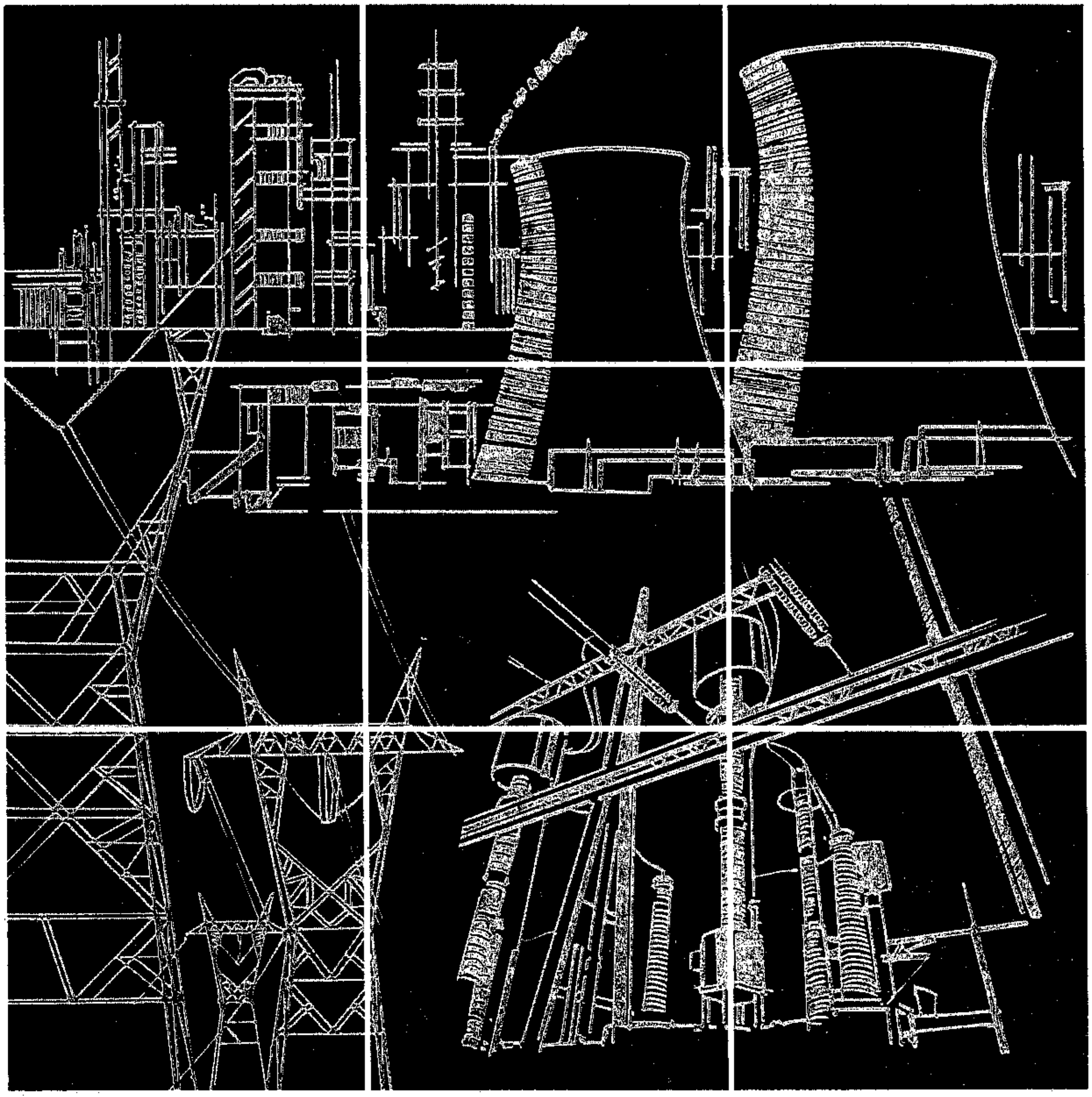
# Service Manual

# Type MBCH

# Transformer Protection



GEC ALSTHOM

T&D

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## Handling of Electronic Equipment

A person's normal movements can easily generate electrostatic potentials of several thousand volts. Discharge of these voltages into semiconductor devices when handling electronic circuits can cause serious damage to components. The damage often may not be immediately apparent, but the reliability of the circuit will have been reduced.

The electronic circuits of **GEC ALSTHOM Protection & Control** relays are completely safe from electrostatic discharge when housed in the case. Do not expose them to the risk of damage by withdrawing modules unnecessarily.

Each module incorporates the highest practicable protection for its semiconductor devices. However, if it becomes necessary to withdraw a module, the following precautions should be taken to preserve the high reliability and long life for which the equipment has been designed and manufactured.

1. Before removing a module, ensure that your are at the same electrostatic potential as the equipment by touching the case.
2. Handle the module by its front plate, frame or edges of the printed circuit board.
3. Do not pass the module to any other person without first ensuring that you are both at the same electrostatic potential. Shaking hands will achieve equal potential.
4. Place the module on an antistatic surface, or on a conducting surface which is at the same potential as yourself.
5. Store or transport the module in a conductive bag. One is supplied with the loose relay.

If you are making measurements on the internal electronic circuitry of equipment in service, it is recommended that you are grounded to the case with a conductive wrist strap. Wrist straps should have a resistance ot ground between 500k and 10 Mohms.

If a wrist strap is not available, you should maintain regular contact with the case to prevent the build-up of static. Instrumentation which may be used for making measurements should be grounded to the case whenever possible.

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# Contents: Transformer Protection Relay Type MBCH

## 1. 0 Overview

Transformer differential relays make the comparison, in phase and magnitude, of the current entering one winding of the power transformer with the current leaving the transformer via the other winding(s). Any difference in current resulting from this comparison passes through the operating winding of the differential relay. When the current difference reaches a predetermined level, relay operation occurs, initiating the tripping of the associated circuit-breakers.

This comparison is complicated by six factors.

1. the ratios of the current transformers which connect the protection to the primary system might not match each other.

2. there might be a phase shift between the power transformer primary and secondary windings.

3. the current transformers can saturate under through fault conditions, giving an effective ratio error.

4. when a power transformer is energized, inrush current flows for a short time into the energized winding with no corresponding flow in the other windings.

5. the power transformer might have a tap changer on one of its windings.

6. over-fluxing of the transformer can give rise to exciting current flowing in only one winding.

These problems are addressed by :

- providing the protection with percentage restraint.
- correctly interconnecting the CTs on the power transformer input and output windings.
- incorporating auxiliary current transformers into schemes if they are needed.
- providing some means of detecting the transformer inrush and over-fluxed conditions.

This service manual covers most aspects of the application of the type MBCH relay to power transformers and explains how the points mentioned above are dealt with.

## 2. 0 Features and Benefits

- Independent single phase relays suitable for single or three phase transformer protection schemes.
- Fast operating times, typically 10 ms to 25 ms.
- Dual slope percentage restraint characteristic with an adjustable setting of 10% to 50% relay rated current.
- High stability during through faults even under conditions of CT saturation with wide tolerance to CT mis-match.
- Immunity to transformer magnetizing inrush currents and over-excitation (over-fluxing).
- From two to six restraint inputs.
- Transformer phase group and line CT ratio correction by means of separate tapped auxiliary transformers where required.
- Two isolated form C tripping contacts plus one isolated normally open latching alarm contact per phase. The individual phases can be interconnected to provide six isolated form C tripping contacts for three phase schemes.
- Light emitting diode (L.E.D.) target per phase.

## 3.0 Description

### 3.1 Mechanical

#### 3.1.1 Relay

Each phase of the type MBCH relay is housed in a metal case 4 inches wide, 6 inches high and 9 inches deep. This case is part of the MIDOS (Modular Integrated Draw Out System) housing system and is suitable for rack or panel mounting. When used with panels, mounting can be flush or semi-projection.

For a three phase power transformer, three relays will provide basic protection against phase and ground faults. The front of the case carries a plexiglass cover which is secured by two captive screws: this cover carries a push button for resetting the light emitting diode target. Settings cannot be changed without removing this cover.

When the cover is removed,

- access is gained to 4 DIP setting switches.
- the relay cradle can be removed.

**Note** - The current transformer inputs are automatically short circuited when the cradle is removed from the case.

**THE DC POWER SUPPLY SHOULD BE DISCONNECTED BEFORE THE CRADLE IS REMOVED FROM THE CASE.**

There are no user adjustments inside the case. The only reasons for removing the cradle are to inspect for damage when the relay is delivered or to trouble shoot.

At the rear of the case is a 28 way terminal block which interfaces directly with the input and output connections inside the case. Connections should be made using the 90° angle lugs supplied with the relay. These lugs can be crimped to 14 gauge wire. The advantages of using these lugs are:

- the recessed nature of the terminals is a safety feature which prevents accidental shorting of connections
- this type of termination is required to make possible the number of connections needed in the space available. The relay connection diagram should be consulted for the function of each terminal.

### 3.1.2 Auxiliary Transformers

The auxiliary transformer are supplied in single-phase units or as a three phase group. The design is of the air- insulated type, each phase unit using a pair of high-grade silicon steel C cores, thus minimizing the magnetizing current and hence ratio error.

## 3.2 Models Available

| Relay Type | Number of Restraint Circuits | Application |
|---|---|---|
| MBCH 12/02 | 2 | Two winding power transformer |
| MBCH 13/03 | 3 | Generally 3 winding power transformers, where percentagerestraint is needed for each of the 3 groups of CTs. |
| MBCH 16/06 | up to 6 | Installations requiring 4, 5 or 6 restraint inputs |

**Auxiliary Current Transformers**

| **Description** | **Ratio** | **Reference Number** |
|---|---|---|
| Single Phase | 1/1A | GJ0104- 010 |
| Single Phase | 5/5A | GJ0104- 020 |
| Single Phase | 5/1A | GJ0104- 030 |
| Three Phase | 1/1A | GJ0104- 050 |
| Three Phase | 5/5A | GJ0104- 060 |
| Three Phase | 5/1A | GJ0104- 070 |

**Figure 10** shows the physical arrangement and dimensions of these transformers.

## 3.3 Relay Settings

### 3.3.1 Current sensitivity

The only adjustment on the relay is its basic sensitivity. This is set by means of DIP switches which are located on the relay front plate.

The range of adjustment is from 10% of relay rated current to 50% of relay rated current in steps of 10%. This setting, Is, defines the current at which the relay will just operate when current flows through the differential input and one restraint input.

### 3.3.2 Percentage Restraint

There is no control for adjusting the amount of percentage restraint present. However, although this is nominally fixed at 20%, the absolute restraint varies with relay current setting. This is covered in detail in section 5, Application. The definition of percentage restraint used for this relay is the slope of the characteristic. If a setting of 20% rated current is selected (1A), then when the mean retsraint has increased to 5A, the relay operating current has incresed from 1A to 1A + 20% of mean restraint = 1A + 1A = 2A.

**Figure 1** shows the overall operating characteristic of the relay.

## 3.4 Principle of Operation

### 3.4.1 Basic Circuit

The basic circuit for circulating current percentage restrained differential protection is shown in **figure 2**. The operate (differential) winding receives, from the CT secondary windings, the vector sum of the currents entering and leaving the system. The restraint windings are arranged so that their combined output is the scaler sum of these currents.

The operate signal is compared with a reference which is dependent upon the size of the restraint signal. When the operate signal predominates, the circuit gives an output which will trip the associated circuit breakers.

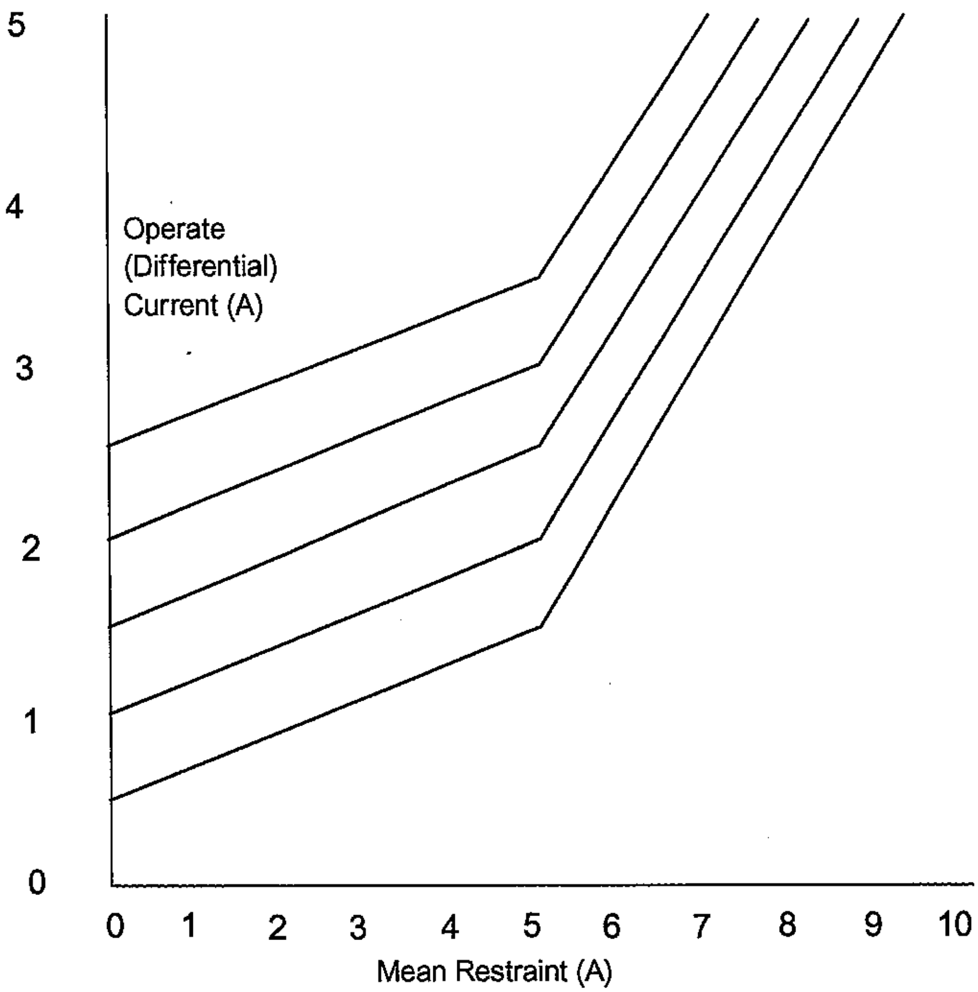



Figure 1. Percentage restraint characteristic for a 5 A relay

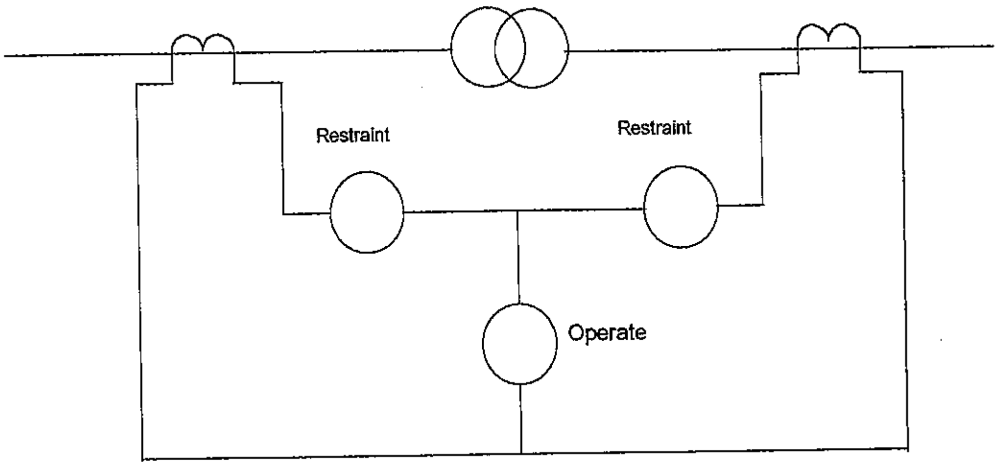



Figure 2. Percentage restrained circulating current protection

### 3.4.2 Variable percentage restraint

Even under normal operating conditions, unbalance current (spill current), can be present in the relay circuit. There are three reasons for this:

1. steady state magnetizing current of the power transformer
2. mis-match of line CTs
3. use of an on-load tap changer

During through faults, the level of spill current will rise with the fault current, due to saturation of the line CTs. In order to avoid unwanted operation due to this current and yet maintain high sensitivity for internal faults, when the difference current is small, the variable percentage restraint characteristic shown in **figure 1** is used.

The setting, Is, is defined as the minimum current, fed into the differential input and one restraint input, that will just cause operation. This is adjustable between 10% and 50% of rated current.

The initial restraint slope is 20% for a mean restraint current from zero to rated current. This ensures sensitivity to faults but allows some line CT ratio mismatch and the use of a load tap changer. This is covered in section 5.

Above rated current, extra errors may be gradually introduced as a result of dc CT saturation. The restraint slope, is therefore, increased to approximately 80%, to compensate for this.

### 3.4.3 Magnetizing inrush restraint

Particularly high inrush currents may occur on transformer energization, depending on the point on wave of switching and on the magnetic remanence in the power transformer core. Since the inrush current flows only in the energized winding, differential current flows in the relay circuit.

To avoid tripping of the power transformer during inrush, it has been customary to incorporate second harmonic restraint, to block relay operation. However, saturation of the line CTs during internal faults also produces second harmonic currents in the line CT secondary windings. This can substantially increase the relay operating time. In order to overcome this problem, the type MBCH relay uses a different technique to distinguish between internal fault current and inrush current. The waveform of magnetizing inrush current is characterized by a period during each cycle when only the normal steady state exciting current flows, as shown in **figure 3**.

This exciting current is typically less than 1% of the power transformer rated current. By measuring the duration of this virtually zero current period, the relay is able to determine whether the differential current is due to magnetizing inrush current or to genuine fault current.

Operation is therefor inhibited only during the inrush condition. This measurement technique ensures that operating times are short even during periods of line CT saturation.

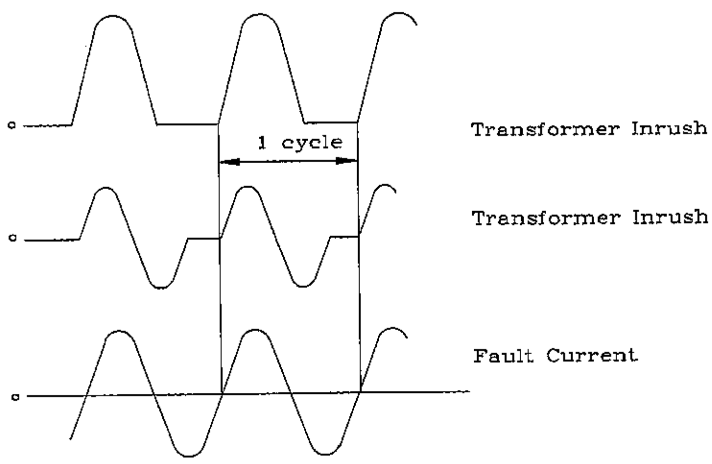
The minimum duration of the virtual zero current period during inrush, is one quarter of a cycle. Figures 4 and 5 illustrate the principle of operation of the relay. Two delay on pick-up timers are used. Timer 2 has a delay of one cycle and timer 1 has a delay of a quarter of a cycle. This timer measures the duration of any period of virtually zero current during a cycle.

With no differential current, there is no output from the level detector. An inverter on the input of timer 1 causes it to time out for this condition and provide an output. This output is inverted by the inverter on the input of timer 2. This ensures that this timer is reset and thus no trip signal is present.

When inrush current is present, however, **(figure 4)** the differential current will give an output from the comparator which will reset timer 1. Timer 2 will start to time out, but before the cycle of inrush current is complete, the quarter cycle period of virtual zero current will occur, which will cause timer 1 to operate, resetting timer 2, before it can give an output signal.

When fault current flows, **(figure 5)** the output from the level detector will cause the inverter on the input to timer 1 to reset this timer. Timer 2 now starts to time out and issues a trip output after one cycle.

**Figure 3 - Typical current waveforms**



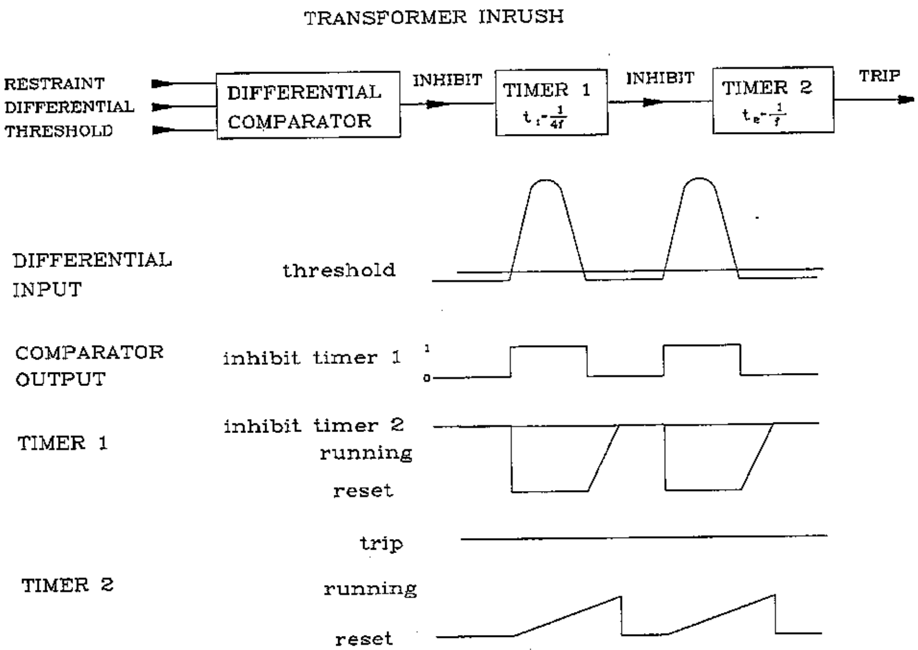




**Figure 4 - Operation under inrush conditions**

When a load is suddenly disconnected from a power transformer, the voltage at its input terminals can rise by as much as 20% of rated value. This causes an appreciable increase in transformer steady state exciting current as the voltage will may then exceed the knee point voltage of the power transformer. This increase may cause a differential current to flow which is higher than the differential protection setting, since this current is seen by the input line current transformers only. The waveshape of this current is shown in **figure 6**.

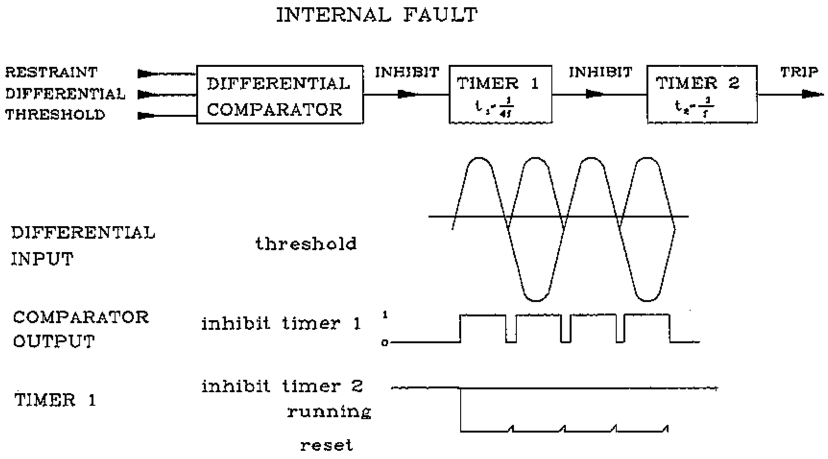



**Figure 5 - Operation under internal fault conditions**

By detecting the periods when the current remains below relay setting, in a similar manner to that used to identify magnetizing inrush current, the relay is able to detect and remain insensitive to substantial over-excitation current. Where extremely large and potentially damaging over-exciting currents are possible it is recommended that an over-fluxing relay, responsive to volts per hertz, is used. Such relays are designed to operate after a time delay of several seconds.

### 3.4.4 High set feature

An instantaneous high-set feature is also incorporated to provide very fast clearance of heavy internal faults. This instantaneous feature has an auto-ranging setting, low at normal load currents, but automatically rising to a high value under heavy through fault conditions. Furthermore, immunity to magnetizing current inrush is guaranteed by requiring a portion of both positive and negative half cycles to exceed the high-set threshold before tripping can occur.

The composite time-current characteristic of the relay is shown in **figure** 7.

**Figure 6**

EXCITING CURRENT WITH TRANSFORMER OVERFLUXED

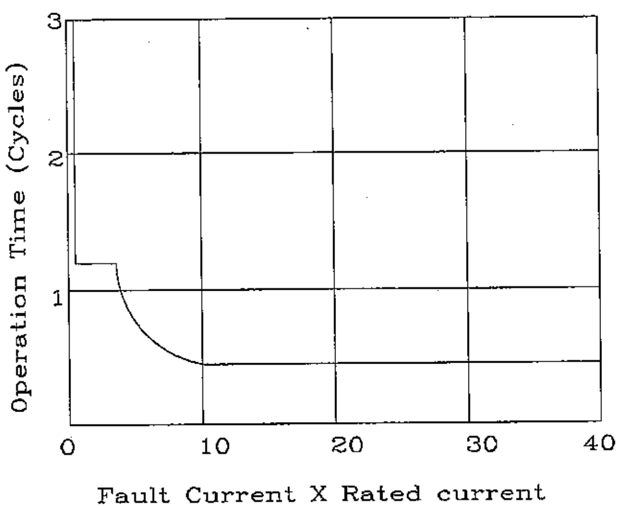



**Figure 7 - The composite/time current characteristic**

# 4.0 Technical Data

## 4.1 Relays

**NOTE**: All values assume a relay rating of 5A

**Ratings**

AC Rated Current (In) — 5A (1A rating is also available)

Frequency — 60Hz (50 Hz is also available)

Auxiliary dc supply (Vx)

| Voltage Rating (Vdc) | Operating Range (Vdc) |
|---|---|
| 30 - 34 | 24 - 41 |
| 48 - 54 | 37.5 - 65 |
| 110 - 125 | 87.5 - 150 |
| 220 - 250 | 175 - 300 |

**Ripple on the dc supply** — The relay will operate with specified accuracy, provided that the peaks and troughs of the ripple fall within the operating range for a particular rating.

**Minimum basic setting**

Restraint feature — 10%, 20%, 30%, 40%, 50% of 5A

High-set feature — 20 A up to a mean restraint current of 45 A, increasing to 40 A at a mean through current of 70A.

**Accuracy** — ± 10%

**Operating characteristic** — Dual slope, 20% up to 5 A mean through current, 80% above this.
(slope is defined in section 3.3.2)

**Operating time** — Typically 10 ms to 25 ms.

**Number of current inputs** — MBCH 12 - 2 restraint inputs
MBCH 13 - 3 restraint inputs
MBCH 16 - 6 restraint inputs

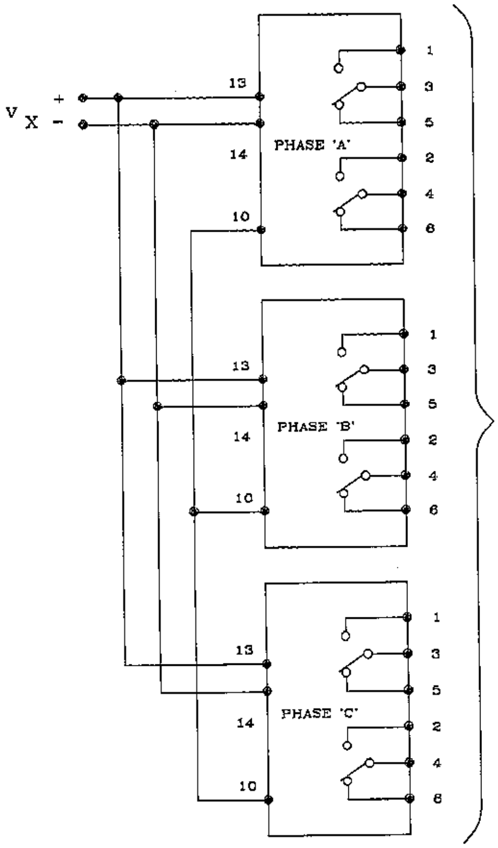



**Figure 8**
**DC Connections to the Relay**

**AC thermal rating**

Continuous

| | |
|---|---|
| MBCH 12 | 10 A |
| MBCH 13 & 16 | 20 A |

Short time, all versions — 400 A for 1s

**DC burden**

| DC voltage rating (V) | Burden (Watts) Outputs not operated | Outputs operated |
|---|---|---|
| 30-34 | 3 | 4 |
| 48-54 | 3 | 4 |
| 110-125 | 4 | 7 |
| 220-250 | 8 | 12 |

**AC burden**

| | |
|---|---|
| With through current only | 0.3 VA |
| With differential current only | 3.2 VA |

**Contact arrangement**

Two form C self-reset tripping contacts per relay. (For 3 phase schemes relays can be interconnected as shown in **figure 8** to provide instantaneous operation of all three sets of form C tripping contacts.)
One normally open latching alarm contact per relay.

**Contact rating**

Make and carry 7500 VA for 0.2 with maxima of 30A and 300V ac or dc.
Carry continuously 5A ac or dc.

Break 1250 VA ac or 50W dc resistive, 25W, L/R = 0.04s. Subject to maxima of 5A and 300V.

**Target**

Light emitting diode (red), one per phase, hand reset by front mounted push button.

**Line current transformer requirements -**
IEEE/ANSI class C400 CTs are suitable, provided that the sum of the lead burden and CT secondary winding resistance does not exceed 2.3 ohms. For other applications,

| **Knee Point Voltage Vk** | **Through fault** | |
|---|---|---|
| | Max X/R | Max If (xIn) |
| Vk > 24 In {Rct + 2Rl + Rt} | 40 | 15 |
| Vk > 48 In {Rct + 2Rl + Rt} | 40 | 40 |
| | 120 | 15 |

Where:

In = Rated line CT secondary current (1A or 5A).
Rct = Resistance of line CT secondary winding.
Rl = Resistance of a single lead from line CT to relay.
Rt = Effective resistance of auxiliary CT where used.
X/R = Maximum value of primary system reactance/resistance ratio.
If = Maximum value of through fault current.

**General Points**

1. The knee point voltage must be higher than 12V for 5 A CTs and 60V for 1 A CTs.

2. The formulae given above hold for both delta and wye connected current transformers.

3. The ratio $\frac{Vk}{Rct + 2Rl + Rt}$ for each current transformer must

   be less than 3 times this ratio for the CT on any other power transformer winding.

4. The maximum value of Rct + 2Rl + Rt for any current transformer is 3.2 ohms for 5 A CTs and 16 ohms for 1 A CTs.

5. For X/R ratios of the primary system less than 120 with a maximum through fault level of 15 times rated current, the knee point voltage requirement is reduced according to **figure 9**.

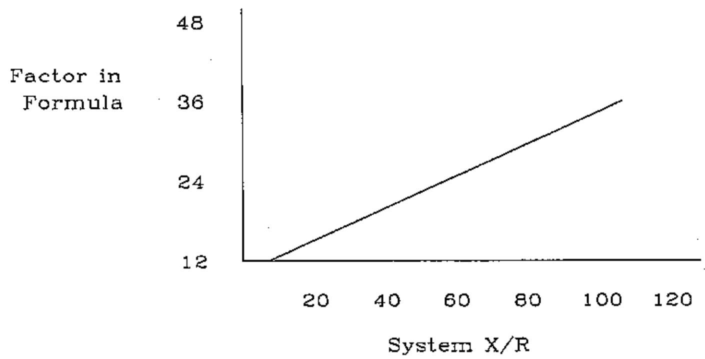



**Figure 9 Variation of the Factor in the Kneepoint Voltage Formula with System X/R**

**Insulation Voltage Withstand**

| | |
|---|---|
| Specification IEC 255-5<br>BS 142 Section 1.3 | ▪ 2kV rms for 1 minute between all terminals connected together and the case grounding terminal<br>▪ 2kV rms for 1 minute between independent circuits including contact circuits.<br>▪ 1kV rms for 1 minute across normally open output contacts. |
| High voltage impulse<br>5 kV peak 1.2/50 sec,<br>0.5 J. IEC 255-4 | ▪ Between all case terminals of each independent circuit connected together and the case ground terminal.<br>▪ Between independent circuits including contact circuits.<br>▪ Between terminals of the same circuit except output contacts. |
| High frequency disturbance<br>IEC 255-6 Class III<br>per second. | 1MHz bursts decaying to 50% of peak value after 3 to 6 cycles. Repetition rate 400<br>▪ 2.5 Kv between all case terminals of each independent circuit connected together and the case ground terminal.<br>▪ 2.5 Kv between independent circuits including contact circuits.<br>▪ 1kV between terminals of the same circuit except output contacts. |

**The relay also fully complies with the appropriate ANSI/IEEE standards for power system protection relays. (C37.90)**

**Environmental Withstand**

| | |
|---|---|
| Temperature<br>IEC 68-2-1 and | Storage and transit -25°C to +70°C<br>Operating range -25°C to +55°C. |
| IEC 68-2-2<br>Humidity IEC 68-2-3 | 56 days (at 93% RH and +40°C). |
| Enclosure protection<br>IEC 529 | IP50 (dust protected) |
| Vibration<br>BS 142 Section 2.2 | Class S2, 0.5g between 10 Hz and 300 Hz. |

## 4.2 Auxiliary Current Transformers

| | |
|---|---|
| Rated frequency | 50/60Hz |
| Thermal withstand | ▪ 4 x In (rated current) continuously<br>▪ 30 x In (rated current) for 10s<br>▪ 100 x In (rated current) for 1s with 400A max. |
| Effective resistance Rt | ▪ 2.0 ohms for 0.58 -1.73:1<br>▪ 0.2 ohms for 2.89 -8.66:5<br>▪ 0.15 ohms for 2.89 -8.66:1 |
| Insulation test voltage | 2.5 kV, 50 Hz |
| Maximum terminal block wire size: | 14 AWG |
| Dimensions: | Outline drawings for single and triple group are shown in **figure 10** |

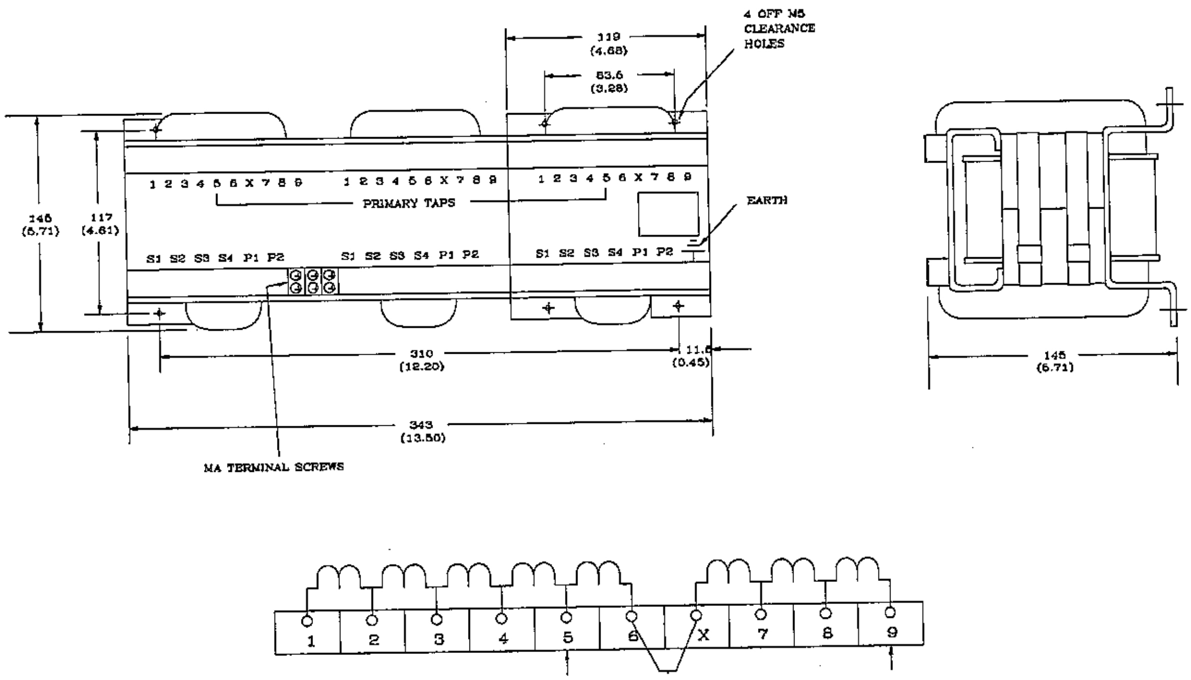



**Figure 10 Details of auxiliary CTs**

**Insulation Voltage Withstand**

| | |
|---|---|
| Specification IEC 255-5<br>BS 142 Section 1.3 | ▪ 2kV rms for 1 minute between all terminals connected together and ground.<br>▪ 2kV rms for 1 minute between independent circuits |
| High voltage impulse<br>IEC 255 - 5 | ▪ 5kV peak, 1.2/50 sec, 0.5J.<br>▪ 2.5 kV between all case terminals of each independent circuit connected together and ground<br>▪ 2.5 kV between independent circuits<br>▪ 1kV between terminals of the same circuit |
| High frequency disturbance<br>IEC 255-6 Class III | 1MHz bursts decaying to 50% of peak value after 3 to 6 cycles. Repetition rate 400 per second.<br><br>The relay also fully complies with the appropriate ANSI/IEEE standards for power system protection relays. (C37.90) |

**Environmental Withstand**

| | |
|---|---|
| Temperature<br>IEC 68-2-1 and<br>IEC 68-2-2 | Storage and transit -25°C to +70°C<br><br>Operating range -25°C to +55°C. |
| Humidity IEC 68-2-3 | 56 days (at 93% RH and +40°C). |
| Enclosure protection<br>IEC 529 | IP50 (dust protected) |
| Vibration<br>BS 142 Section 2.2 | Class S2, 0.5g between 10 Hz and 300 Hz. |
| Nominal secondary current rating, | In 5A or 1A |
| Nominal current ratios selectable in steps of 4% rated current | 0.58 to 1.73 :1<br>2.89 to 8.66 :1<br>2.89 to 8.66 :5 |

**Please note: These are nominal ranges only. The transformer taps allow wider ratio matching**

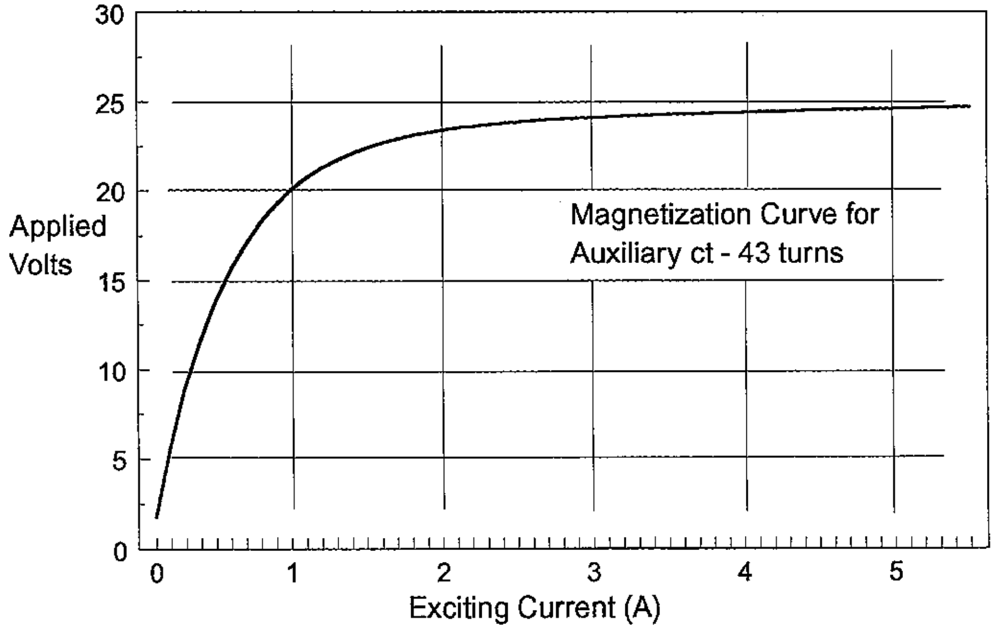
| Primary Tap Terminals | Number of Turns and Current Ratings | | |
|---|---|---|---|
| | 1A\1A | 5A/1A | 5A/5A |
| 1 - 2 | 5 | 1 | 1 |
| 2 - 3 | 5 | 1 | 1 |
| 3 - 4 | 5 | 1 | 1 |
| 4 - 5 | 5 | 1 | 1 |
| 5 - 6 | 125 | 25 | 25 |
| X - 7 | 25 | 5 | 5 |
| 7 - 8 | 25 | 5 | 5 |
| 8 - 9 | 25 | 5 | 5 |
| Secondary Tap Terminals | | | |
| S1 - S2 | 125 | 125 | 25 |
| S3 - S4 | 90 | 90 | 18 |

**TABLE 1**

**Notes:**

1. The primary winding is energized from line CTs by terminals P1 and P2.
2. The relay should be connected to terminals S1 and S2, or S1 and S4 with terminals S2 and S3 jumpered.
3. For wye connected output windings use S1-S2 or S1-S4 (with S2-S3 linked). Where winding S1-S2 is used, S3-S4 is available for forming a delta tertiary winding.
4. For delta connected output windings, use S1-S2 or S1-S4 (with S2-S3 linked)

The reason for this is to provide the relay with an adequate voltage to maintain its quoted operating speed.




The graph shown above is the magnetizing characteristic for the 43 turns on the auxiliary CT. The curve for any number of secondary turns can be derived from this by taking the voltage axis in proportion to the turns needed. For example, the voltage would be multiplied by 18/43 to obtain the curve for the 18 turn winding.

## 5.0 Application

### 5.1 General

The relay should be set at the most sensitive value possible, taking into account on load tap changers and mis-match in the line CT ratios, however it is recommended that unless the power transformer has a very low exciting current, a minimum setting of 20% rated current is used. The connection of the relay to the primary system depends on the system configuration. A relay type MBCH 12, having two restraint windings can be applied to a simple two winding power transformer as shown in **figure 11** or a three winding transformer, provided that the paralleled current transformers are on windings that are loads only. This is shown in **figure 12**.

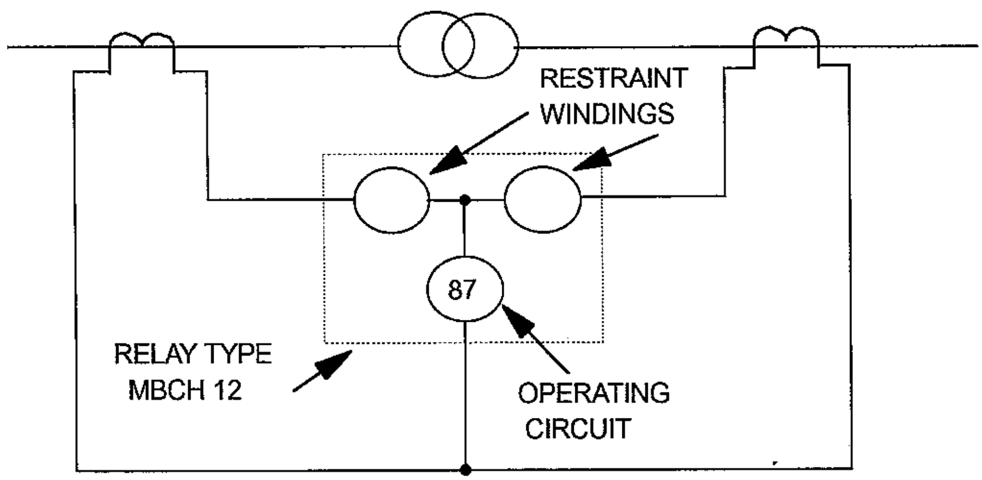



**Figure 11 Basic Application of a Relay Type MBCH 12**

The type MBCH 13 is applied with three-winding transformers or where a two winding transformer has bus-mounted CTs as shown in **figure 13**. An arrangement showing a three winding transformer with bus-mounted current transformers on all windings is shown in **figure 14**. Where four or five restraint windings are needed the MBCH 16 is designed to be used but with the extra restraint inputs unconnected. If an application initially needs two restraint circuits but extension to three is possible, then a type MBCH 13 can be used with the extra restraint circuit left unconnected.

### 5.2 Percentage restraint

In order to apply percentage restraint differential transformer protection to the best advantage, the concept of percentage restraint must be fully understood. The restraint characteristic of these relays generally has a slope which changes at some point above full load current.

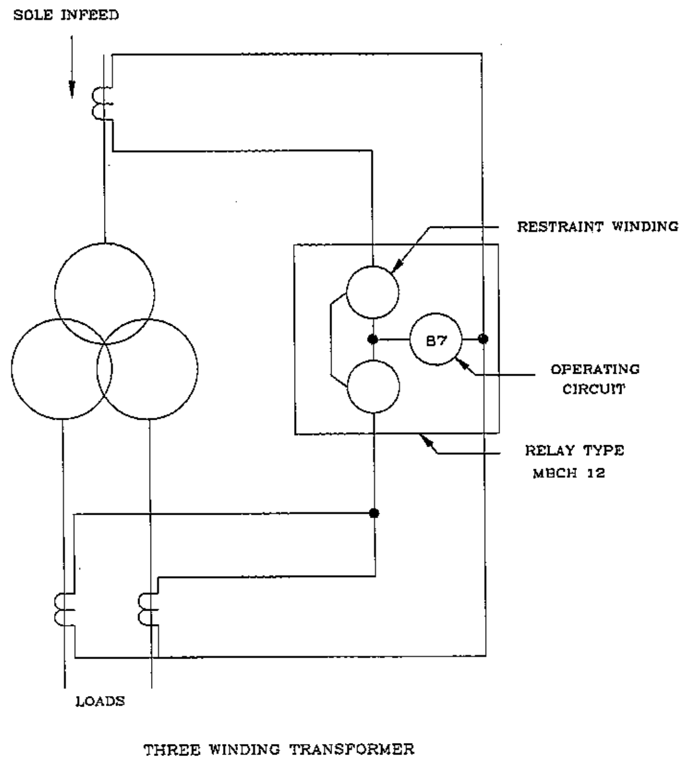



**Figure 12 - Application of a Relay Type MBCH 12 on a Power Transformer Having Two Loaded Windings**

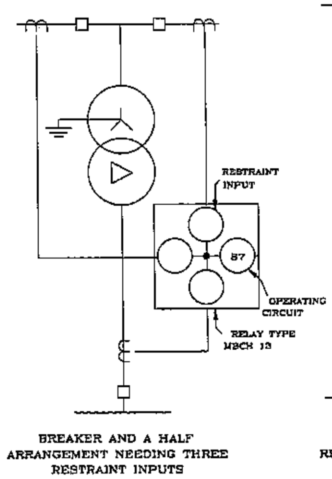



**Figure 13**

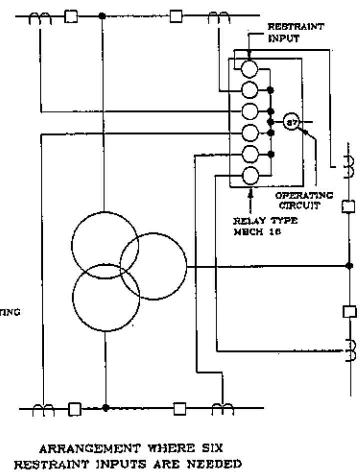



**Figure 14**

The purpose of this is to use a lower value restraint to cater for current unbalance due to line current transformer mismatch or tap changers and a higher slope to counter the effects of the saturation of line current transformers during through faults. The lower restraint below full load current gives the relay increased sensitivity to internal faults. Unfortunately, the way that percentage restraint is specified, varies from one manufacturer to another. The differences are explained in detail in appendix 2. **Figure 15** is a simple diagram of the operating and restraint inputs of one phase of such a relay.

In figure 15, Ix is the current contribution from one line CT, Iy is the contribution from the other line CT and Id is the differential current. Ix - Iy = Id. Currents Ix and Iy flow in the restraint inputs and current Id flows in the differential (operate) input of the relay. Is is the setting current of the relay when Iy or Ix = 0 (and Ix or Iy = Is) and is that current at which the relay just operates under this condition.

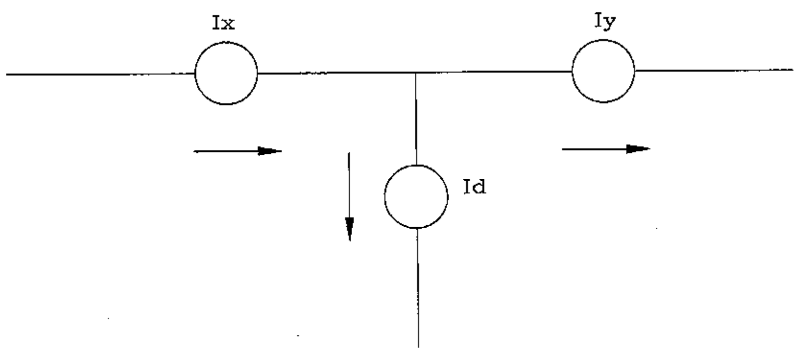



**Figure 15**

**Figure 16** shows the restraint characteristic for the type MBCH relay for each tap setting and up to 10 times rated current. The minimum percentage restraint present at each current setting is shown in Appendix 2)

| **Tap Setting** | | **Minimum Percentage Restraint** |
|---|---|---|
| **% x 5 A** | **Amps** | |
| 10 | 0.5 | 30 |
| 20 | 1 | 40 |
| 30 | 1.5 | 50 |
| 40 | 2 | 60 |
| 50 | 2.5 | 70 |

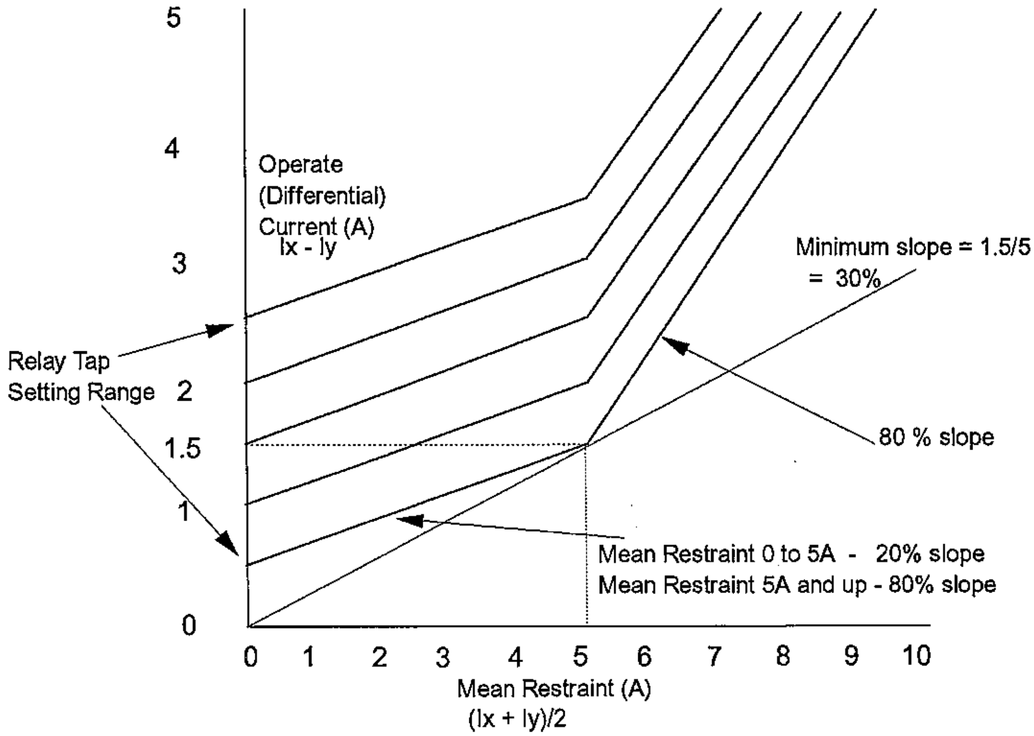



**Figure 16 - Percentage Restraint Characteristic**

## 5.3 Application examples

### 5.3.1 General

The ratio of CT chosen for a power transformer winding should take into account the full load current of the power transformer and the maximum through fault current. Thermal problems on internal faults are of secondary importance as the main protection is fast enough to avoid overheating. However, thought should be given to the thermal rating of the back-up protection for terminal faults when the main protection might be out-of-service.

The CT primary rating for a particular winding should be determined by dividing the power transformer power rating by the phase to phase voltage multiplied by $\sqrt{3}$ . The nearest practical CT ratio should then be chosen for each power transformer winding.

For delta co nnected ct windings, the ct ratio chosen should allow a current as near as possible to relay rated current to flow in the relay when the power transformer is operating at full load. This means that the actual CT ratio as determined above should be reduced by a factor of $\sqrt{3}$ .

Where the transformer to be protected has a delta-delta winding configuration, the line CTs can all be connected in wye or delta (taking account of thermal ratings) but wye-wye power transformers must have line CTs delta connected. This is because external ground faults can cause zero phase sequence current to flow in only one power transformer winding and this would cause mis-operation of the differential protection if the zero sequence current were not blocked by the delta connection of the CTs.

**Power Transformer Tap Changer**

Where there is a tap changer on the power transformer, the unbalance of the relay currents should be checked at each extreme of the tap changer range and should not exceed the values given in appendix 2. Where CT connection recommendations or mismatch of current ratios cannot be avoided, auxiliary CTs can be used as detailed in the following sections.

### 5.3.2 Matched Line Current Transformers, two winding application

**Figure 17** shows a 30 MVA 66 kV to 11 kV delta wye power transformer.

The full load currents are:

66 kV side $\frac{30 \times 1000}{\sqrt{3} \times 66} = 262$ A

11 kV side $\frac{30 \times 1000}{\sqrt{3} \times 11} = 1575$ A

The CT ratios needed are

262 : 5 and 1575 : $\frac{5}{\sqrt{3}}$ (or 2728 : 5)

because the CTs on the delta side of the transformer will be connected in wye and the CTs on the wye side of the transformer will be connected in delta.

If the ratios chosen are 300:5 and 3000:5, then

the relay currents will be $\frac{262}{300} \times 5 = 4.37$ A

and $\frac{1575}{3000} \times 5 \times \sqrt{3} = 4.55$ A

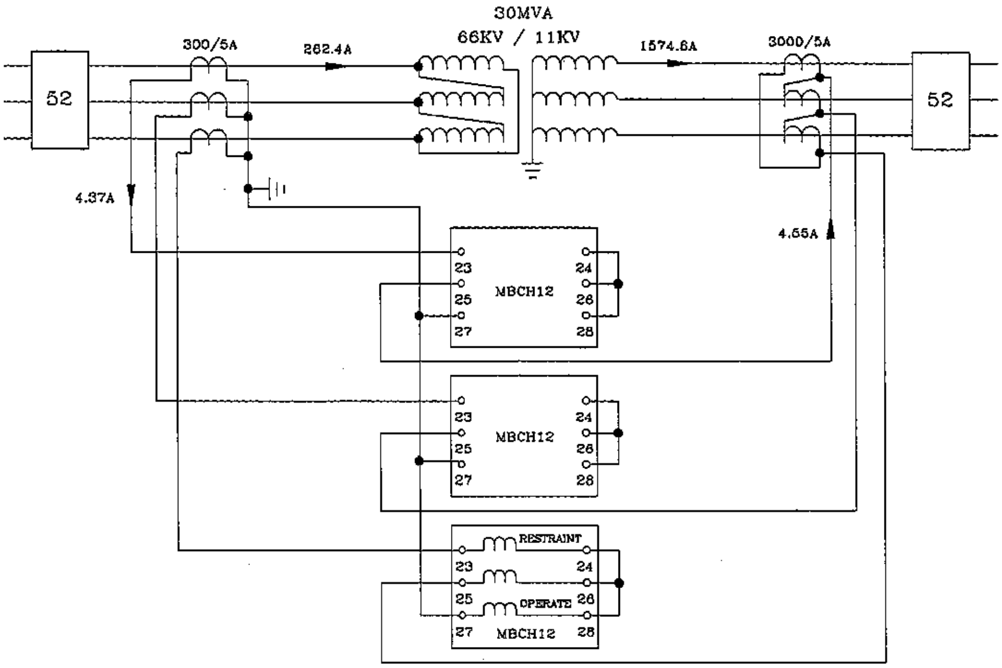



**Figure 17**

The relay currents are 4.37 A and 4.55 A giving an unbalance of 0.18 A. A relay setting of 20% can be used since the relay operating current for mean restraint of 4.46 A is equal to 1.9 A. The differential current of 0.18 A is well below 1.9 A, therefore the unbalance will not be a problem.

### 5.3.3 Unmatched Line Current Transformers, two winding application .

#### 5.3.3.1 Notes on the use of auxiliary current transformers

**Physical Location**
The auxiliary transformers, should located close to the associated differential relay. This minimizes the resistance between the auxiliary CT and the relay, ensuring high speed relay operation.

**Output Connections**
The relay connections of the auxiliary current transformers are S1-S2, and S1-S4. It should be noted that the S3-S4 winding should not be used on its own as the output winding to the relay. The reason is that this winding does not produce sufficient output voltage to maintain the quoted relay operating time. For wye-connected output windings, section S1-S2 may be used with (or without) section S3-S4 connected in series. For delta-connected output windings, where any one phase winding would be required to energize two poles of the relay in series, it is recommended that windings (S1-S2) and (S3-S4) should be connected in series per phase. With the link between terminals (6) and (X) connected as necessary, the incoming input connections to P1 and P2 can be linked across to the appropriate input winding terminals according to the number of turns required.

Connections to the auxiliary transformer are repeated below :

| **Primary Tap Terminals** | **Number of Turns and Current Ratings** | | |
|---|---|---|---|
| | **1A\1A** | **5A/1A** | **5A/5A** |
| 1 - 2 | 5 | 1 | 1 |
| 2 - 3 | 5 | 1 | 1 |
| 3 - 4 | 5 | 1 | 1 |
| 4 - 5 | 5 | 1 | 1 |
| 5 - 6 | 125 | 25 | 25 |
| X - 7 | 25 | 5 | 5 |
| 7 - 8 | 25 | 5 | 5 |
| 8 - 9 | 25 | 5 | 5 |
| Secondary Tap Terminals | Number of turns connected to the relay | | |
| S1 - S2 | 125 | 125 | 25 |
| S3 - S4 | 90 | 90 | 18 |

**5.3.3.2 Delta - wye transformer.**

If, in the example given in section 5.3.2, the CTs used on the 11 kV side had been 1500 : 5, then auxiliary CTs would be needed. This is shown in **figure 18**.

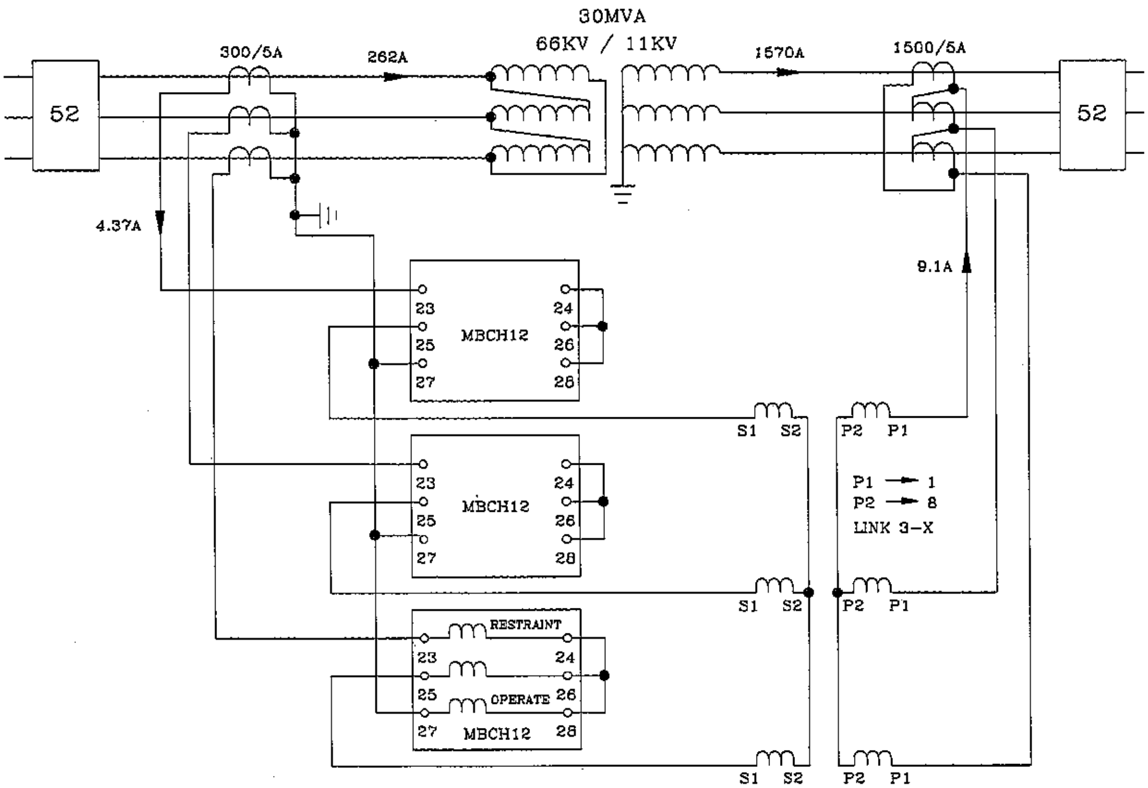



**Figure 18**

Assuming that the line CTs are delta connected, the line CT secondary currents for the 1500 : 5 CTs are:

$$\underline{\text{Primary}} \qquad \underline{\text{Secondary}}$$

$$1575\,(5) = 15000\,\frac{(\text{I relay})}{\sqrt{3}}$$

$$\text{I relay} = \frac{1575\,(5)\,(\sqrt{3})}{1500} = 9.09\text{ A}$$

The matching current for the relay is 4.37 A, so connecting the auxiliary CTs wye-wye and using the 25 turn secondary winding for the relay connection, the primary turns are as follows, where:
Relay current = 4.37 A. Turns between terminals S1 and S2 = 25.
Ampere turns = 109.25 Current transformer current = 9.1 A.

$$(\text{Primary turns})\,(9.1) = (25)\,(4.37)$$

$$\text{Primary turns} = \frac{109.25}{9.1} = 12\text{ turns}$$

If the primary taps used are P1 to tap 1 and P2 to tap 8 with the link on terminals 3 and x, the number of active turns will be 1 + 1 + 5 + 5 = 12

### 5.3.3.3 Three Winding Transformer

This is an example of a three-winding transformer where load current flows in all three windings, as illustrated in **figure 19**. For the purpose of applying differential protection to such a transformer, the choice of line current transformer ratios ought to be based on the relationship of the winding voltages rather than on the rated MVA of the individual windings.
Since in many cases the line CT ratios will have already been chosen in terms of the MVA ratings of the windings then auxiliary CTs will be necessary in order to balance the these currents for the application of differential protection.

It will be found that more accurate matching taps may be chosen on the auxiliary CTs if the most lightly rated main transformer winding be considered first. In the case being considered this will be the 13.5kV winding supplying only 100MVA.

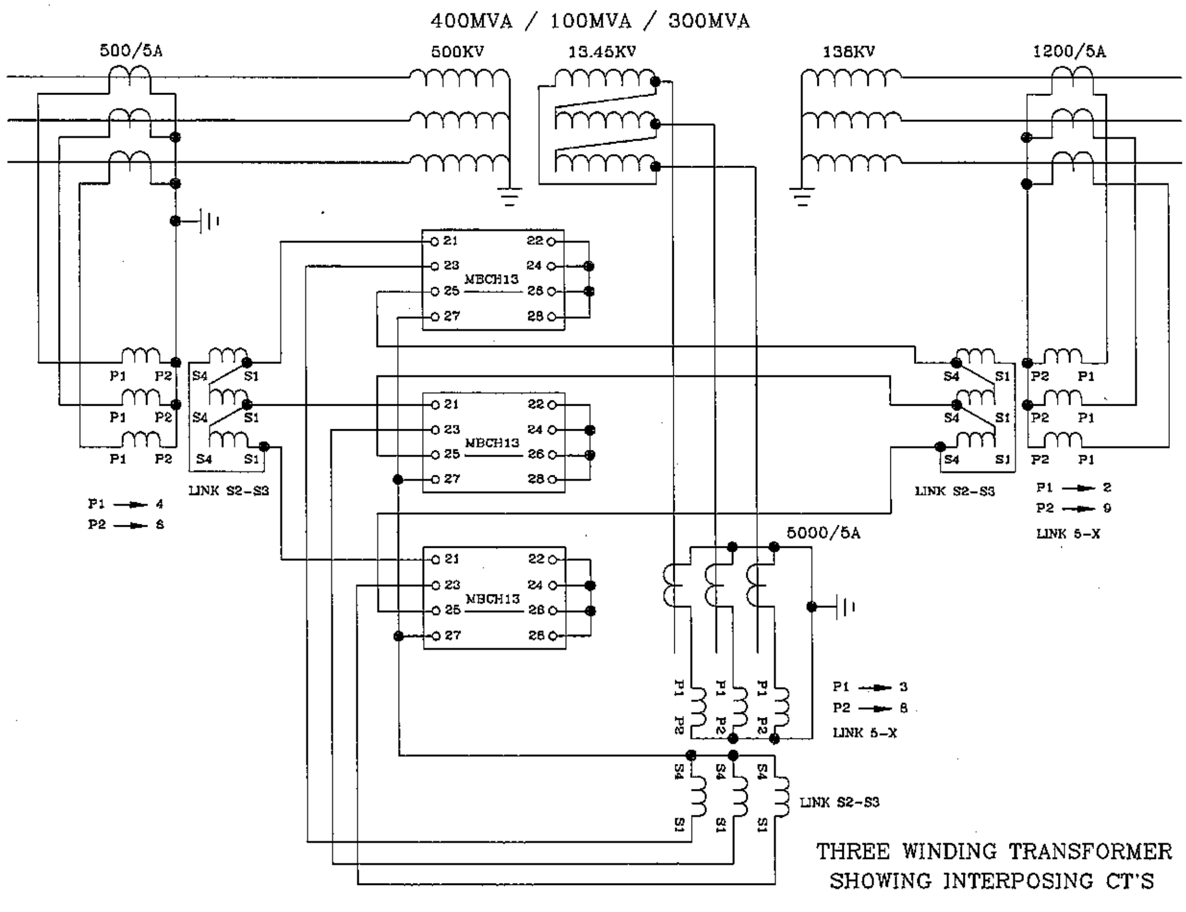



**Figure 19**

**13.5kV winding**

Rated current $= \frac{100\ MVA}{\sqrt{3} \times 13.5kV} = 4276.7A$

Line Current transformer ratio = 5000/5A

Therefore Line ct output current $= \frac{4276.7}{5000} \times 5.0A = 4.28A$

During external fault conditions, however, the line CT output current must be related to the primary input MVA and thus becomes :

Rated Current $= \frac{400MVA}{\sqrt{3} \times 13.5kV} = 17106.67\ A$

Line Current transformer ratio = 5000/5A

Therefore,
Line CT output current $= 17106.67 \times \frac{5}{5000} = 17.106\ A$

The auxiliary transformer associated with the 13.5kV CTs will be wye-wye connected and is shown in **figure 20**. Although, from an output point of view, the S1-S2 winding would suffice, it would in this case be preferable to include winding S3-S4 giving a total of 43 turns per secondary phase. This is because the higher the number of output winding turns, the more turns will be required on the input side, or primary, for a given current ratio, thus the smaller will be the tap percentage error.

Input turns required to produce 5A in output winding $\frac{5 \times 43}{17.106} = 12.5$; say 12 turns

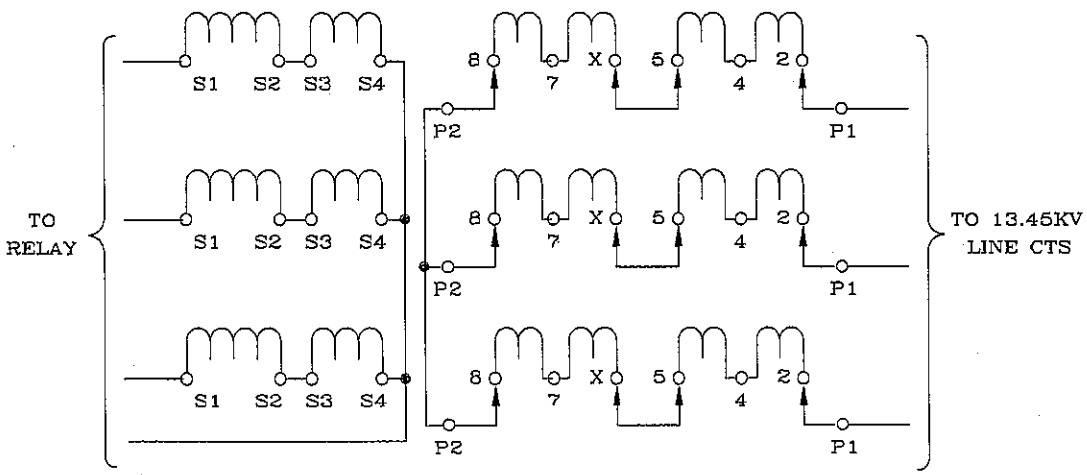



**Figure 20 - Auxiliary current transformer associated with 13.5kV CTs**

In order to obtain 12 turns on the auxiliary transformer input winding, use terminals 3 and 8 with link 6-X removed and terminal numbers 5 and X connected. Output winding current will now be:

$$Is = \frac{12 \times 17.106}{43} = 4.744A$$

Regard 4.7A as rated current to which the currents from the 500kV and 138kV auxiliary CTs must be matched.

**500kV winding**

$$\text{Rated Current} = \frac{400MVA}{\sqrt{3} \times 500kV} = 462A$$

Secondary Current of line CTs 500/5A $= 462 \times \frac{5.0A}{500} = 4.62A$

Aux CT, delta connected, needs to match 4.744 A.

Relay current = 4.744 A. Turns between terminals S1 and S2 = 43.
Current transformer current = 4.62 A.

| **Primary** | **Secondary** |
|---|---|
| (Primary turns) (4.62) | $= (43)\,\frac{(4.744)}{\sqrt{3}}$ |

$$\text{Primary turns} = \frac{43}{4.62} \times \frac{4.744}{\sqrt{3}} = 25 \text{ turns approx.}$$

Therefore, required ratio of auxiliary CTs $= \frac{4.6}{4.8/\sqrt{3}}$ i.e. 4.6/2.7A

Auxiliary CT terminals 4 and 6 give 26 turns. This is shown in **figure 21**.

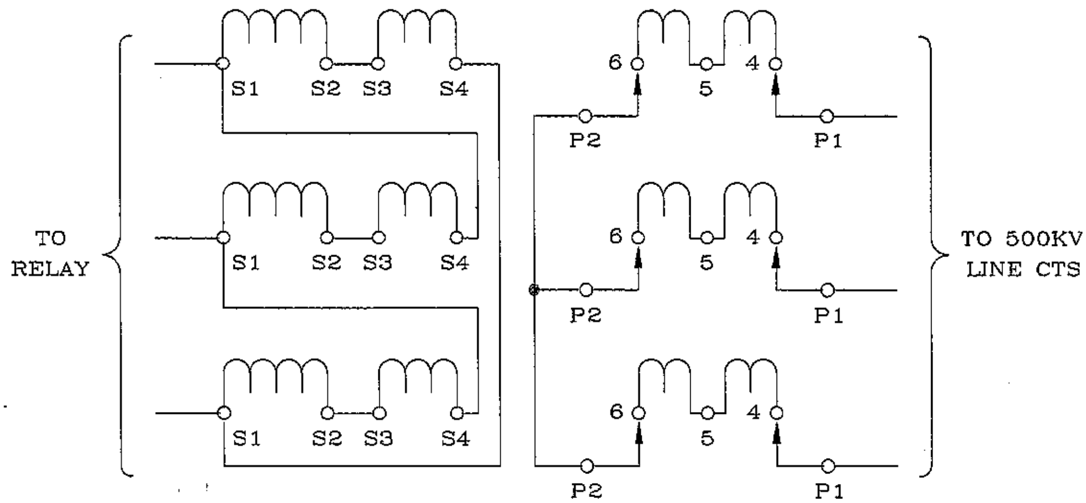



**Figure 21 - Auxiliary current transformer associated with 500kV CTs**

**138kV winding**

Rated current based 400MVA $= \dfrac{400MVA}{\sqrt{3} \times 138kV} = 1673.5A$

Secondary current of line CTs 1250/5A $= \dfrac{1673.5}{1250} \times 5A = 6.7A$

The ratio of the auxiliary CTs will therefore be $= \dfrac{6.7}{4.8/\sqrt{3}} = 6.7/2.77$

Auxiliary current transformer turns $= \dfrac{2.77 \times 43}{6.7} = 17.8$ say 18 turns

Auxiliary CT input taps to give 18 turns are: 2 and 5, 9 and X

This is shown in **figure 22**.

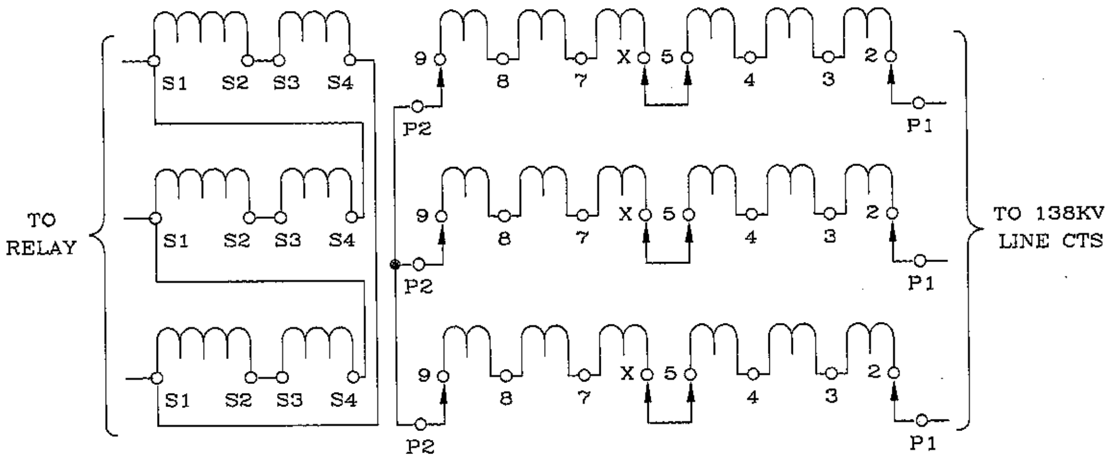



**Figure 22 - Auxiliary current transformer associated with 138kV CTs**

### 5.3.3.4 Transformer with a breaker and a half arrangement.

Where a transformer is fed from a breaker-and-a-half bus arrangement (**figure 23**) and thus controlled by two circuit breakers, the rating of such a transformer will normally be somewhat lower than that of other feeders emanating from the bus arrangement.

Because the current transformers within the bus will have a higher current rating than those associated with the transformer, their use as differential protection CTs for the transformer will result in a higher effective fault setting of the differential protection system.

A better location therefore, for the differential protection CTs, is in the direct feed to the transformer, at point P in **figure 23**. Where suitable CTs are available at point P, the application and selection of suitable auxiliary CTs is as described previously.

In those cases where the only CTs available for the transformer differential protection, are located at the circuit breakers on the high current bus, the protection arrangement will be as shown in figure 23 and described below.

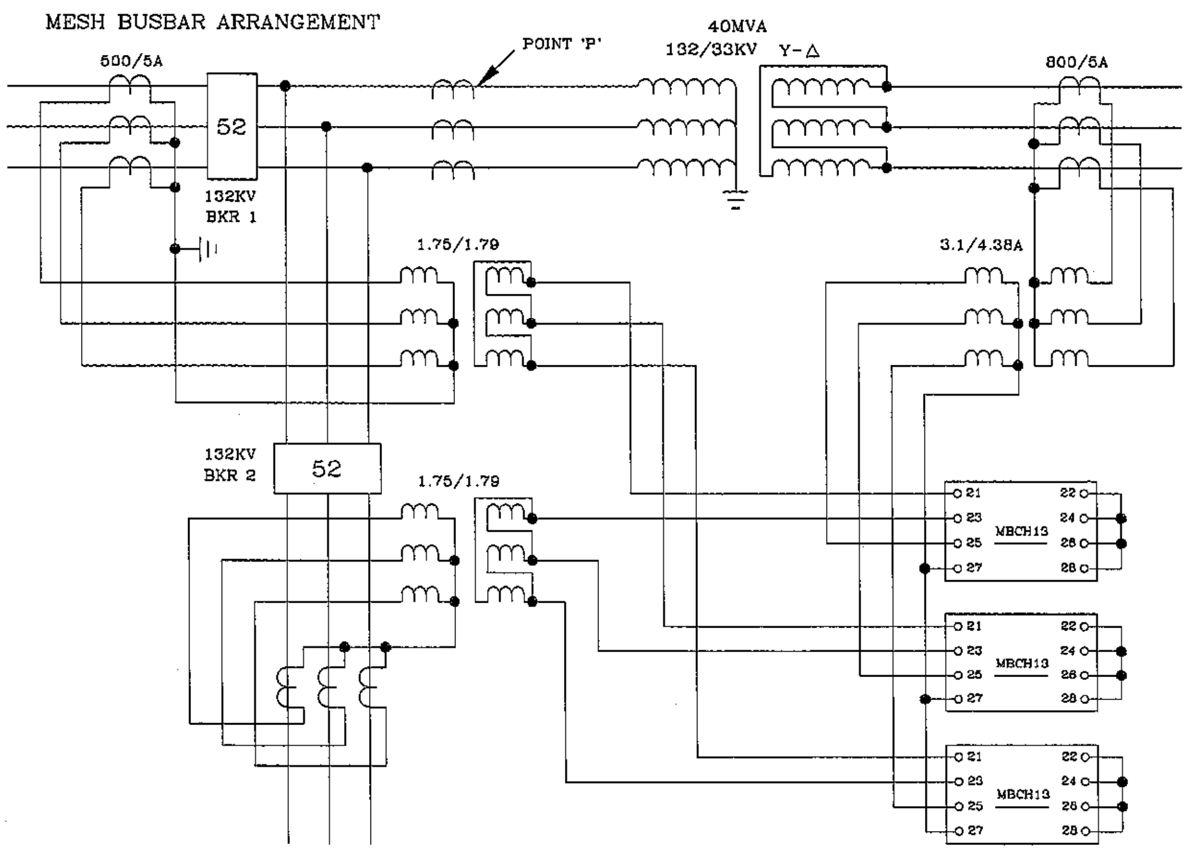



**Figure 23**

The transformer is 40MVA, 132/33kV, wye-delta connected

**132kV (Breaker-and-a-half side)**

Line current transformer ratio: 500/5A

Transformer rated current (at 132kV) $= \dfrac{40\text{MVA}}{\sqrt{3} \times 132\text{ kV}} = 175\text{ A}$

Current in current transformer secondary winding : $\dfrac{175}{500} \times 5 = 1.75\text{ A}$

Preferred current ratio of auxiliary CT : $1.75 : 5/\sqrt{3}$ . This would give a relay current of 5A at full load.

It is recommended that the full auxiliary winding is used with delta connections so the maximum ratio available is : 44 : 43 turns. Thus maximum relay current is:

$$\frac{1.75 \times 44}{25 + 18} \times \sqrt{3} = 3.1\text{ A}$$

**33kV Side**

| | | | |
|---|---|---|---|
| 33kV auxiliary CT: | wye-wye connection | | |
| Output winding turns: | 43 turns winding | | |
| 33kV line current: | $\dfrac{40MVA}{\sqrt{3} \times 33kV}$ | = | 700 A |
| 33kV CT secondary current: | 700/800 x 5 | = | 4.4 A |
| Ratio of 33kV auxiliary CT: | 4.4/3.1 | | |
| Input winding turns: | $\dfrac{43 \times 3.1}{4.4}$ | = | 30 turns |

The connections to the auxiliary CT are shown in **figure 24**

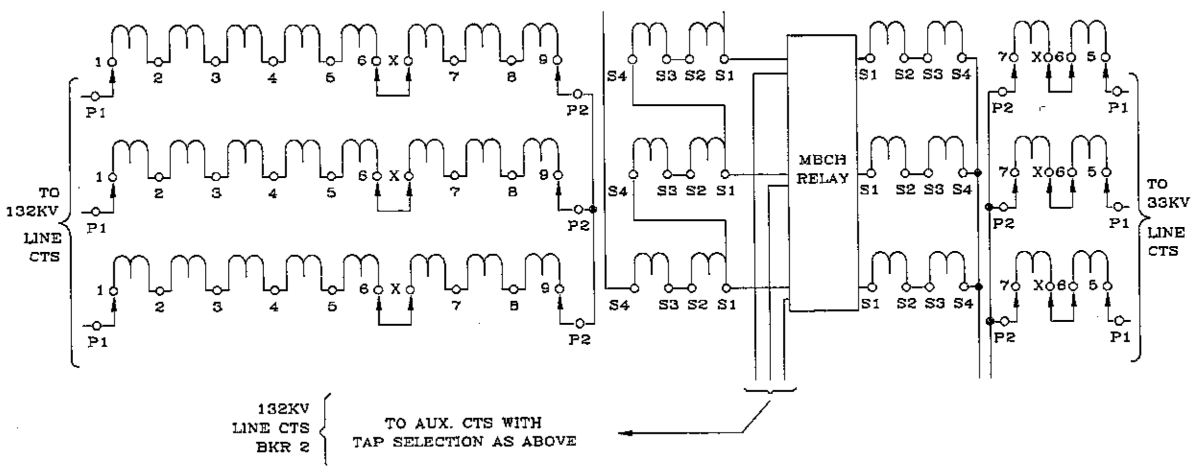



**Figure 24 - Auxiliary CTs associated with breaker-and-a-half application**

It will be noted that when the rated current of the transformer flows, the corresponding current flowing in the relay circuit will be 3.2A. Thus the effective protection setting will be:

$$\frac{5.0}{3.2} = 1.6 \times \text{ selected relay setting}$$

It will be clear that the above increase in setting is due to the nominal primary rating of the line current transformers being appreciably greater than the rating of the transformer being protected. This condition is unavoidable.

**5.3.3.5 Wye - delta transformer; grounding transformer on the delta side.**

The transformer is 75MVA and 132/33kV.

Where a three phase grounding transformer is associated with a delta-connected low voltage winding as in **figure 25**, a zero sequence path is thereby provided within the protected zone. This would permit the passage of zero sequence currents, through the differential relay, under conditions of an external ground fault.

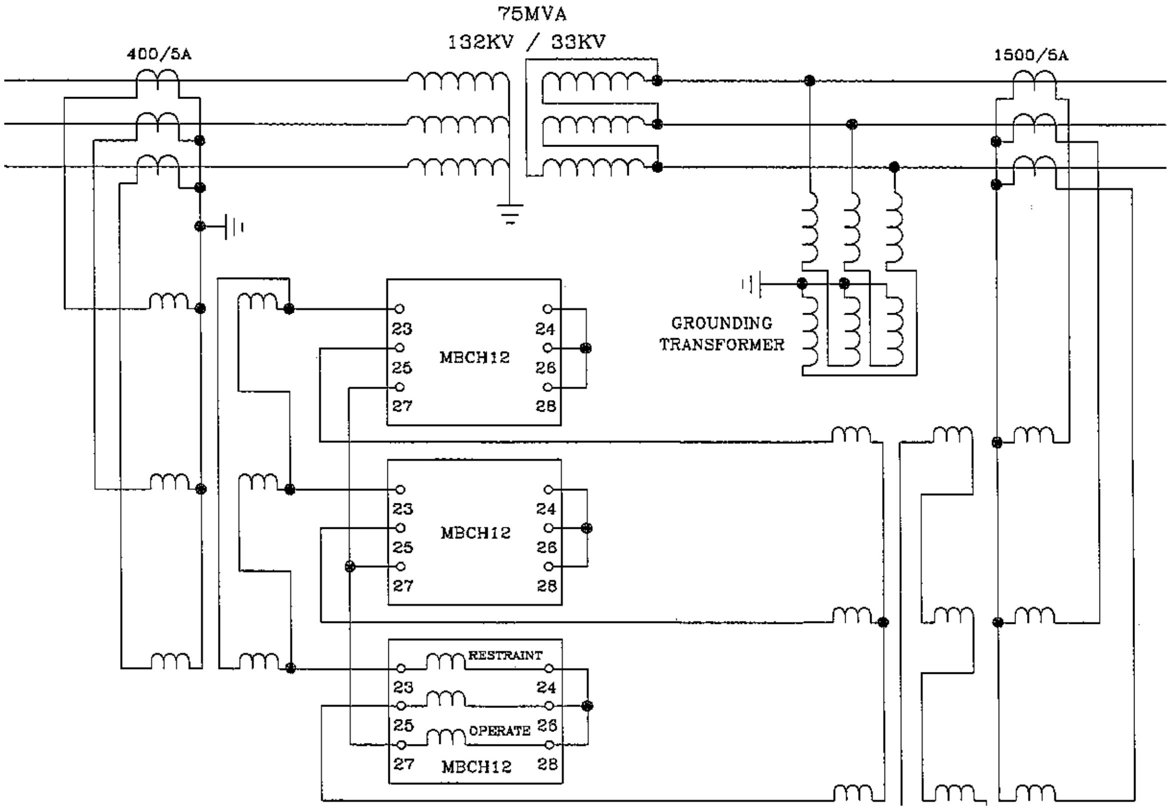



**Figure 25**

It is therefore necessary to block such currents by inserting a wye-delta-wye auxiliary current transformer. This same auxiliary CT may be used for ratio correction required due to any mismatch between the high voltage and low voltage line current transformers.

**132kV Side**

| | | | |
|---|---|---|---|
| Normal current at 132kV: | $\dfrac{75MVA}{\sqrt{3} \times 132kV}$ | = | 330 A |
| Current transformer ratio: | 400/5A | | |
| Secondary current: | $\dfrac{330}{400} \times 5$ | = | 4.1 A |
| Auxiliary transformer required: | wye-delta | | |
| | ratio = | | $\dfrac{4.1}{5/\sqrt{3}\text{ A.}}$ A per phase |
| Relay output winding turns: | (S1-S4) 25 + 18 | = | 43 turns |
| Input winding turns: | $\dfrac{43 \times 5}{4.1 \times \sqrt{3}}$ | = | 30.28 say 30 turns |

This is shown in **figure 26**.

**33kV Side**

| | | | |
|---|---|---|---|
| Normal current: | $\dfrac{75\text{ MVA}}{\sqrt{3} \times 33kV}$ | = | 1312A |
| Current transformer ratio: | 1500/5A | | |
| Secondary current: | $\dfrac{1312 \times 5}{1500}$ | = | 4.37A |
| Auxiliary CT primary turns: | $\dfrac{5}{4.3} \times 25$ | = | 29 turns |

**NOTE:** Wye-delta-wye P1 - P2 (29 turns) S3 - S4 (18 turns) S1 - S2 (25 turns)

This is shown in **figure 27**

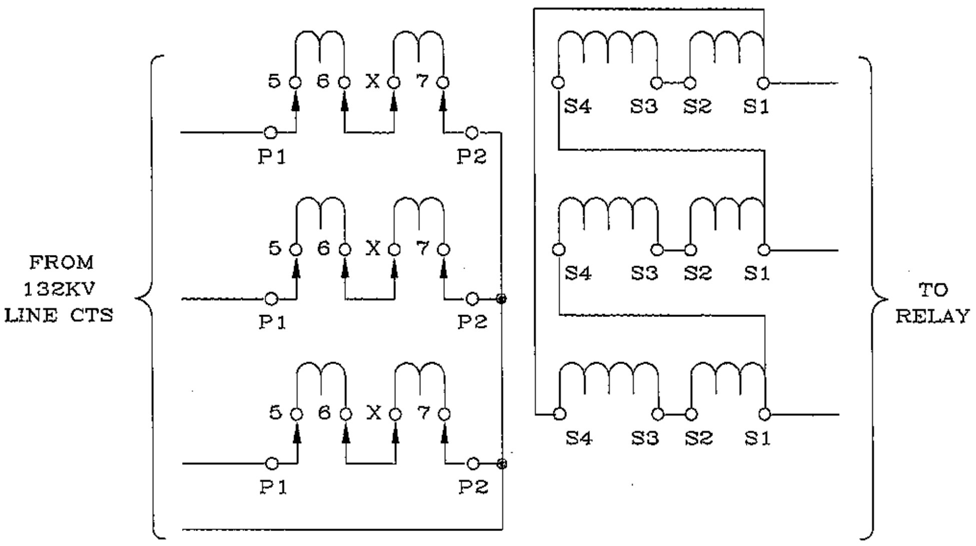



**Figure 26**

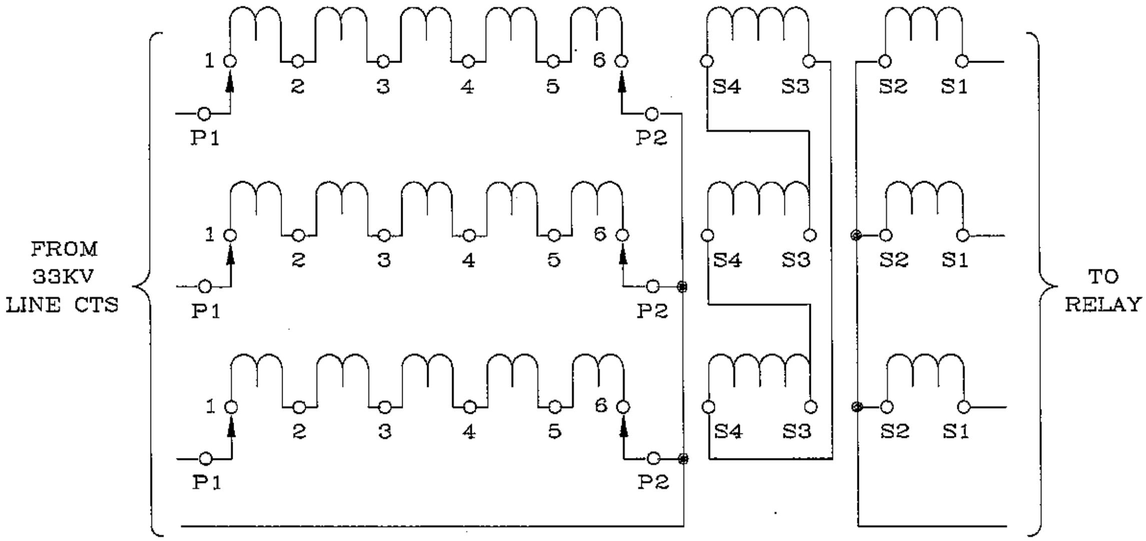



**Figure 27**

## 6.0 Installation

If relays are not installed immediately upon receipt they should be stored in their original cartons. The storage temperature range is -25°C to +70°C.

An outline diagram is normally supplied showing panel cutouts and hole centers. For individually mounted relays these dimensions will also be found in publication R-6017.

Publication R-7012 is a Parts Catalog and Assembly Instructions. This document will be useful when individual relays are to be assembled as a composite rack or panel mounted assembly.

Publication R-6001 is a leaflet on the modular integrated drawout system of protective relays (MIDOS).

Publication R-6014 is a list of recommended suppliers for the insulated right angle crimp connectors .

## 7.0 Commissioning Instructions

### 7.1 Commissioning Preliminaries

#### 7.1.1 Electrostatic Discharges

The relay uses components which could be affected by electrostatic discharges. When handling the withdrawn module, care should be taken to avoid contact with components and connections. If the relay is stored out of its case, it should be placed in an anti-static bag.

#### 7.1.2 Inspection

Remove the plexiglass front cover by undoing the two knurled plastic nuts. The cradle can now be withdrawn by the handles provided. Carefully examine the cradle assembly and case to see that no damage has occurred during transit. Check that the relay serial number on the module, case and cover are identical and that the model number and rating information are correct.

#### 7.1.3 Wiring

Check that the external wiring is correct to the relevant relay diagram and scheme diagram. The relay diagram number appears inside the case. Note that the shorting switches shown on the relay diagram are fitted internally across case terminals and that they close when the module is withdrawn.

If a test block is provided, type MMLG, the connections should be checked to the scheme diagram, particularly that the supply connections are to the live side of the test block (colored orange) and with terminals allocated with odd numbers (1, 3, 5, 7 etc.). The auxiliary supply voltage to the scheme should be routed via test block terminals 13 and 14.

### 7.1.4 Grounding

Ensure that the case ground connection above the rear terminal block is used to connect the relay to a local ground bar.

### 7.1.5 Insulation

The relay and its associated wiring, may be insulation tested between:

(a) all electrically isolated circuits

(b) all circuits and ground

An electronic or brushless insulation tester should be used, having a dc voltage not exceeding 1000V. Accessible terminals of the same circuit should first be strapped together. Circuit ground links, removed for the tests, subsequently must be replaced.

### 7.1.6 DANGER: Avoid open circuit CT secondary

**DO NOT OPEN CIRCUIT THE SECONDARY CIRCUIT OF A CURRENT TRANSFORMER SINCE THE HIGH VOLTAGE PRODUCED MAY BE LETHAL AND COULD DAMAGE INSULATION.**

When the type MMLG test block facilities are installed, it is important that the sockets in the type MMLBO1 test plug that correspond to the CT secondary windings are LINKED BEFORE THE TEST PLUG IS INSERTED INTO THE TEST BLOCK. Similarly, a MMLB02 single finger test plug must be terminated with an ammeter BEFORE IT IS INSERTED to monitor CT secondary currents.

**7.2 Commissioning tests:** (The instructions are written for relays with a current rating of 5 A.)

### 7.2.1 Test equipment required

- Overcurrent test set. (With timing facilities or separate timer).
- DC Power Supply (to suit relay dc supply rating Vx).
- 2 multimeters
- Double pole switch
- Single pole switch
- MMLB01 test plug (If MMLG Test Block is supplied.)
- MMLB02 single finger test plug
- 8 amp. variable auto-transformer
- 2 variable resistors 0 - 100 ohms, suitably rated
- Diode rated 7 amps for magnetizing inrush test.

**NOTE:** The following test instructions are based on injecting current directly into the relay terminals, however if an MMLG test block is used in the scheme, it is more convenient to inject current into the MMLG test block. Refer to the relevant scheme diagram for connections.

### 7.2.2 Auxiliary dc supply

Check the relay rated auxiliary voltage Vx on the front plate and connect a suitable smoothed dc supply or station battery supply to relay terminals 13 (+ve) and 14 (-ve).

### 7.2.3 Relay settings

1. Connect the overcurrent test set to the relay as shown in **figure 28** below. Adjust the relay front panel switches to give a relay setting IS = 0.1 x In (10% setting, In = relay rated current).

2. Slowly increase the current until the relay operates, indicated by a light emitting diode (LED) on the front plate. Check that the operate (differential) current is within the range of 0.45 to 0.55A for a relay with a 10% relay setting.

3. Check that the relay trip contacts (terminals 1,3 and 2,4) are closed with the current above the setting, and that these contacts open as the current is removed.

4. Check that the relay alarm contacts (terminals 9,11) are closed with the current above the setting and remain closed as the current is removed.

5. Press the reset button on the relay front plate and check that the LED indicator resets and that the alarm contacts open.

6. Repeat the test with the relay adjusted to settings of 0.2 x In, 0.3 x In, 0.4 x In and 0.5 x In in turn. The range of pickup current for each setting is given in table 2.

| Relay Setting % | A | Current for Operation A |
|---|---|---|
| 10 | 0.5 | 0.45 to .055 |
| 20 | 1 | 0.9 to 1.1 |
| 30 | 1.5 | 1.35 to 1.65 |
| 40 | 2 | 1.8 to 2.2 |
| 50 | 2.5 | 2.25 to 2.75 |

**Table 2**

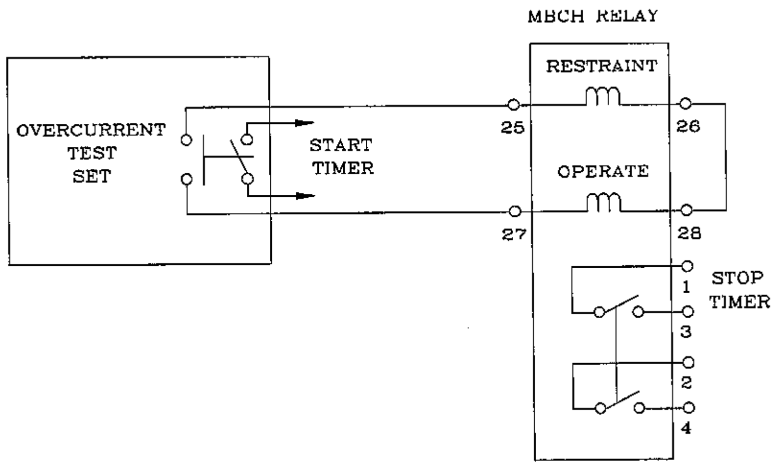



**Figure 28**

**NOTES**:

1. The settings can also be checked using a variable auto-transformer, resistor and ammeter, as an alternative to an overcurrent test set.

2. During commissioning do not disconnect the dc. auxiliary supply without first removing the ac. operating current, otherwise the trip contacts on terminals 1,3 and 2,4 may remain operated. If this does occur the contacts can be reset by removing the ac operating current and then switching on the dc auxiliary supply at rated voltage.

3. The dc supply should be switched off before inserting or removing modules.

### 7.2.4 Operating time

1. Connect the test circuit as shown in **figure 28**.
2. Set the relay to Is = 0.2 x In (20% of rated current)
3. Inject 3.5 x In (17.5 A for a 5 A relay) and record the relay operating time by starting a timer when the current is applied and stopping it when the relay output contact on terminals 1 and 3 closes.
4. The time should be within the range 22 ms ± 3 ms.
5. To check operation of the instantaneous circuit (high set), inject 22.5A x In (4.5 A for a 1 A relay) and record the mean relay operating time. This should be less than 22 msec.

### 7.2.5 Restraint check Using Variable Resistors

Connect the test circuit as shown in **figure 29** below; ensure that both variable resistors are non-inductive.

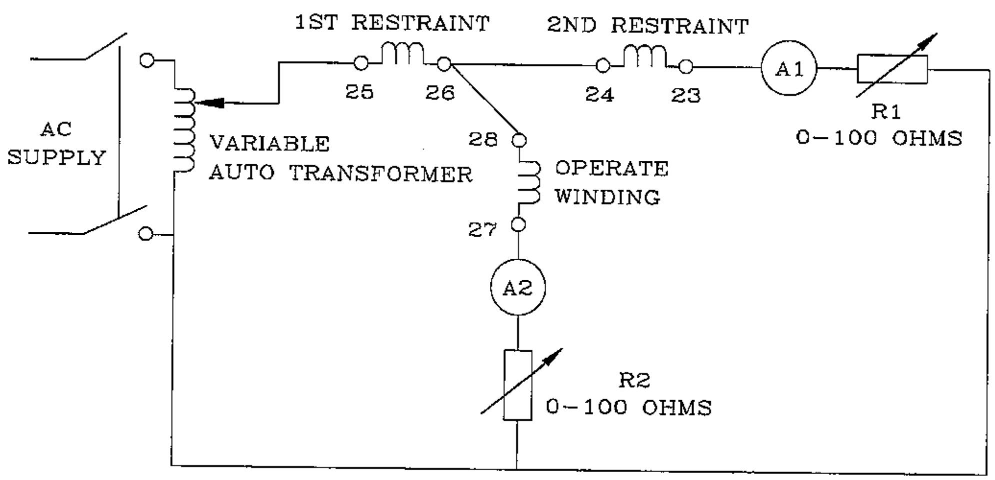



**Figure 29 Connections for Checking the Restraint Curve**

1. With the relay set to Is = 0.2 x In (20% setting), adjust resistor R1 to about 8 ohms and resistor R2 to about 20 ohms. Switch on the supply and increase the applied voltage until ammeter A1 indicates 3 amps MBCH 12, 13, 16; (or 5 amps MBCH 02, 03, 06).
2. Slowly increase the differential current by decreasing resistor R2 until the relay operates as indicated by the front plate LED. Record the values of current A1 and A2.
3. Calculate the mean restraint using the formula: Mean restraint $= A1 + \frac{A2}{2}$ amps.
4. From **figure 15**, Id = A2 and Iy = A1 thus Ix = Iy + Id = A1 + A2
5. Therefore, mean restraint $= \frac{Ix + Iy}{2} = A1 + \frac{A2}{2}$
6. Use the restraint curve shown in **figure 31** to determine the theoretical differential current and check that the measured current A2 is within 20% of this theoretical value.

**NOTES:**

1. MBCH 03, 13 Only - Repeat the above test with the third restraint coil (terminal 21).
2. MBCH 06, 16 Only - Repeat the above test with the third to sixth restraint coils (terminals 21, 19, 17 and 15 respectively).
3. Reconnect the 2nd restraint coil as shown in the connection diagram and adjust the current shown on ammeter A1 to be 8.5 amps.
   (Note that this current may exceed the continuous rating of the variable auto transformer and should therefore be switched on for short durations only).
4. Increase the differential current until the relay operates and check that this value is within 20% of the theoretical value by calculating the mean restraint as described above.

**7.2.6** Repeat tests **7.2.5** for the relays associated with the other phases

### 7.2.7 Checking the Restraint Curve Using an Overcurrent Test Set

The relay should be connected to an overcurrent test set as shown in **figure 30**.

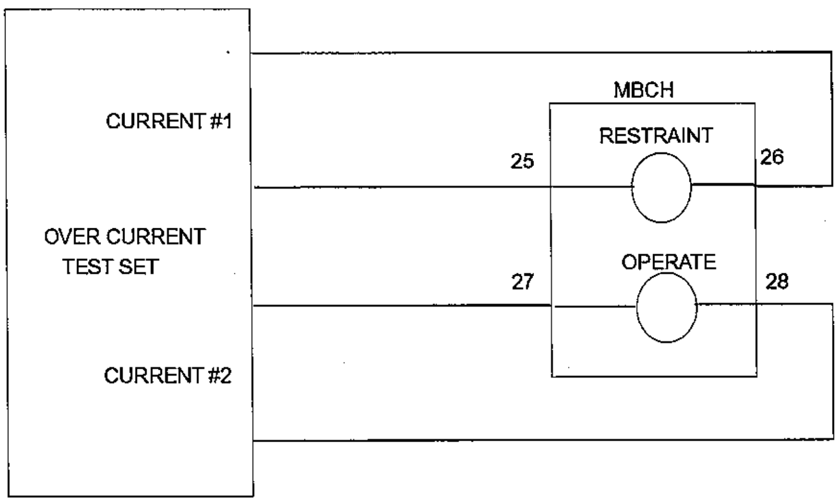



**Figure 30 - Test Connections For Testing the Restraint Curve Using Two independent Currents**

By injecting current separately into the operate and restraint input of the relay, its behavior can be checked according to the restraint characteristic shown in **figure 31**.

Inject 5A into the restraint winding. The mean restraint will be (5 + 0)/2 = 2.5 A. From **figure 31**, it can be seen that for a relay set on 20% rated current (1A) the theoretical operating current would be 1.4A. The range over which operation can be expected is from 1.4 A to 1.60 A.

The operation at other settings and currents can be checked in a similar way, applying a -0 + 10% tolerance below a mean restraint of 5A and a 20% tolerance when the mean retsraint is above 5A.

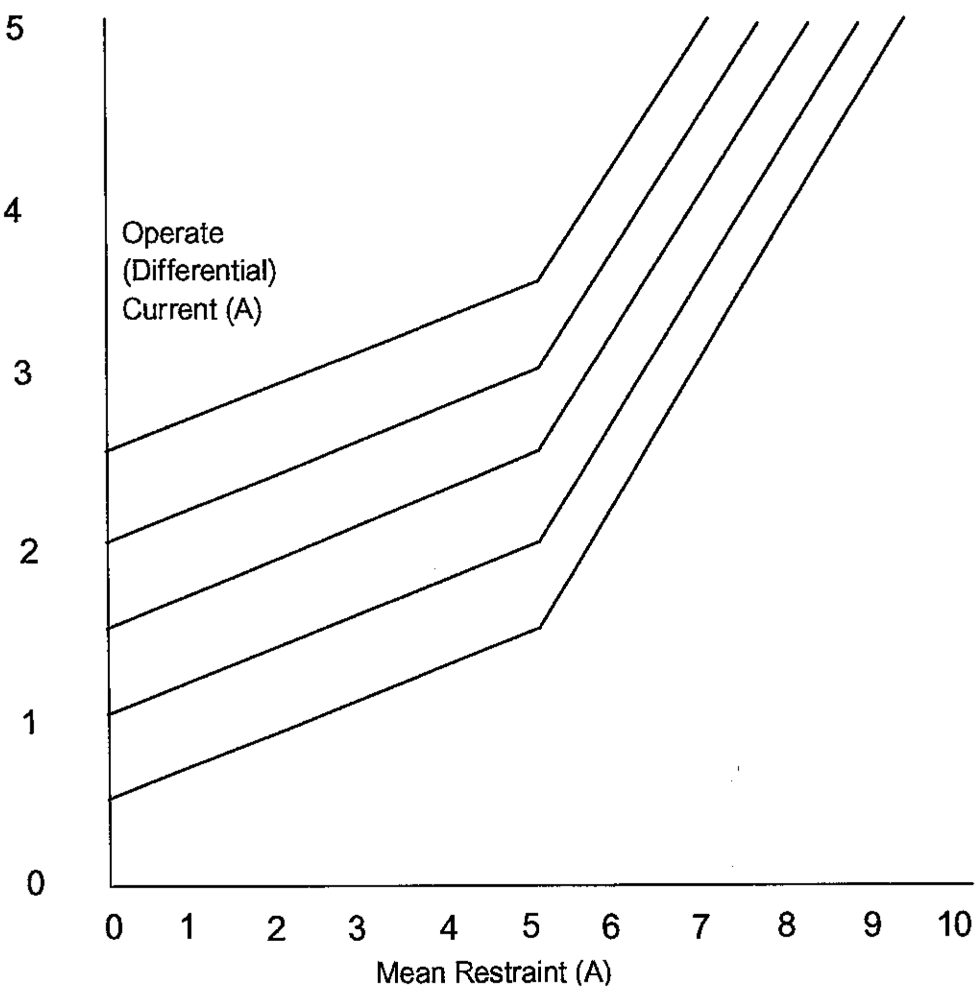



**Figure 31 - Theoretical Percentage Restraint Characteristic**

### 7.2.8 Circuit breaker tripping

**NOTE: THE FOLLOWING INTERCONNECTION MAY ONLY BE DONE ON MODELS MBCH 12, 13 OR 16. INTERCONNECTING THESE TERMINALS ON MODELS MBCH 02, 03 OR 06 MAY CAUSE INADVERTENT TRIPPING.**

By interconnecting terminal # 10 of all three.phase relays, six self -resetting form C contacts can be provided for three phase tripping of six circuit breakers. (As shown in **figure 8**).

If this is required, check that terminals number 10 are connected together and check that the relay trip contacts (terminals 1,3 and 2,4) on all three phase relays close as the current injected into a single phase relay exceeds the relay setting.

### 7.2.9 On load tests

The object of the on-load tests is to check that the relay is connected correctly to the system. If the relay is protecting a transformer with no tap changer then the differential current could be less than 1% of the load current. However, if the transformer has a tap changer and the CTs are not matched to the transformer, then the normal differential current with the tap changer away from the nominal position could be as much as 20% of the load current.

Check that the load current in each restraint coil is close to the value which is expected for the particular application. For the MBCH 16 relay particularly, it may be preferable to energize different transformer windings in turn to ensure that all connections are satisfactory. Check that the differential current under any of these conditions is within 1 - 20% of the load current, the actual of differential current depending upon the particular application as stated above.

Check also that the currents measured in the same restraint and differential coils of each phase relay are similar.

### 7.2.10 Magnetizing inrush test

The relay may be tested with a simulated waveform representing magnetizing inrush, by connecting a diode in series with the relay to produce a half wave rectified waveform.

With reference to **figure 32**, close switches S1 and S2 and set the current to 5 amps. Check that the relay operates.

Open switch S2, close switch S1 and check that the relay does not operate.

Note: The diode must be rated at greater than 7A.

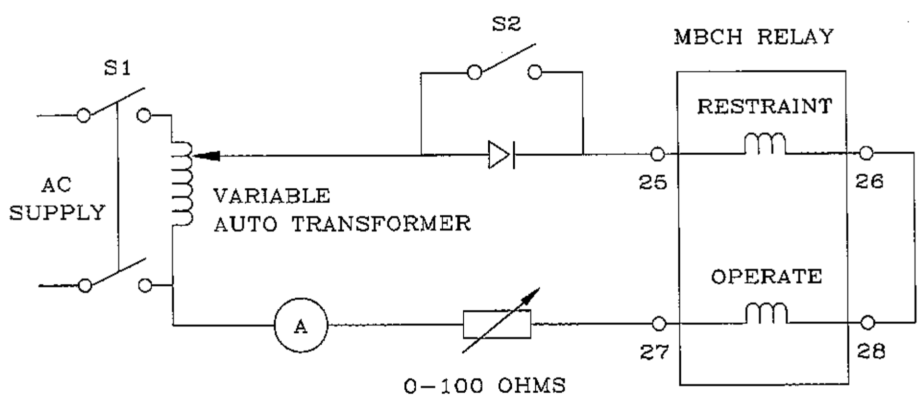



**Figure 32 - Connections to the relay to simulate magnetizing inrush current waveform.**

## 8. 0 Maintenance

Periodic maintenance is not required, however, periodic inspection and test is recommended.

The general condition of the relay should be monitored by periodic visual inspection and general operational tests should be performed.

## 9. 0 Problem analysis

### 9.1 Introduction

Problem analysis is carried out by following the flowchart instructions contained in Appendix 1.

The flowcharts refer to the notes contained below, and to printed circuit boards pcb.1, pcb.2 and pcb.3 which are identified as follows:

- pcb.1. is ZJ 0077 part numbers 001 to 008
- pcb.2. is ZG 0931 part numbers 001 to 003
- pcb.1. is ZG 0878 part number 006

The analysis does not go to component level, but identifies faulty printed circuit boards or transformer assemblies.

If replacement assemblies are required, it is recommended that the relay be returned to the factory or to a GEC ALSTHOM service agent.

Before beginning the problem analysis, the module should be inspected to identify any loose internal wires or broken connections.

### 9.2 Equipment required

1. dc voltmeter and dc power supply to supply Vx (see Note 1, sect. 9.3, for current drain).
2. dc voltmeter capable of measuring up to 20V.
3. dc ammeter capable of measuring up to 150mA.
4. ac current source capable of supply up to 5A at frequency 60 Hz with at least a 3 VA rating.
5. ac ammeter capable of measuring up to 5A at 60 Hz
6. continuity detector to monitor the state of the tripping contacts.
7. oscilloscope (optional)

### 9.3 Notes for problem analysis flowcharts

1. Approximate current drains from the auxiliary dc supply are shown in the table below and apply to all MBCH models i.e. MBCH 12 MBCH 13 and MBCH 16.

| **D.C. Voltage Nominal Value** | **Approximate D.C. Current Drain ( mA) at Nominal Voltage** | | |
|---|---|---|---|
| | **Trip LED off** | **Trip LED on** | **Trip LED on and tripping contacts closed** |
| 30/34 | 76 | 86 | 103 |
| 48/54 | 36 | 48 | 62 |
| 110/125 | 28 | 40 | 49 |
| 220/250 | 26 | 37 | 41 |

2. Internal dc rails should be measured with respect to TP7 on the main pcb (ZJ0077). TP8 should be 9.2V + 0.5V and TP9 should be -9.2 + 0.5V.

3. TP4 on the main pcb (ZJ0077) should be monitored with respect to TP9. With no ac current flowing into the relay terminals, TP4 and TP9 should be at approximately the same potential. When the ac current specified in the flowchart is injected, the potential at TP4 should rise to approximately 16V.

4. Connect a dc voltmeter across R2 on the main pcb (ZJ0077). A reading of approximately 2V per multiple of 5 amps injected should be obtained.

   If an oscilloscope is available, the voltage across R2 may be monitored. A full wave rectified sine wave should be displayed, of peak value approximately 3.2V per multiple of 5 amps injected.

5. The two self reset form C tripping contact sets are wired to terminal numbers 1, 3 and 5 (first set, with 1 and 3 normally open) and 2, 4 and 6 (second set, with 2 and 4 normally open).

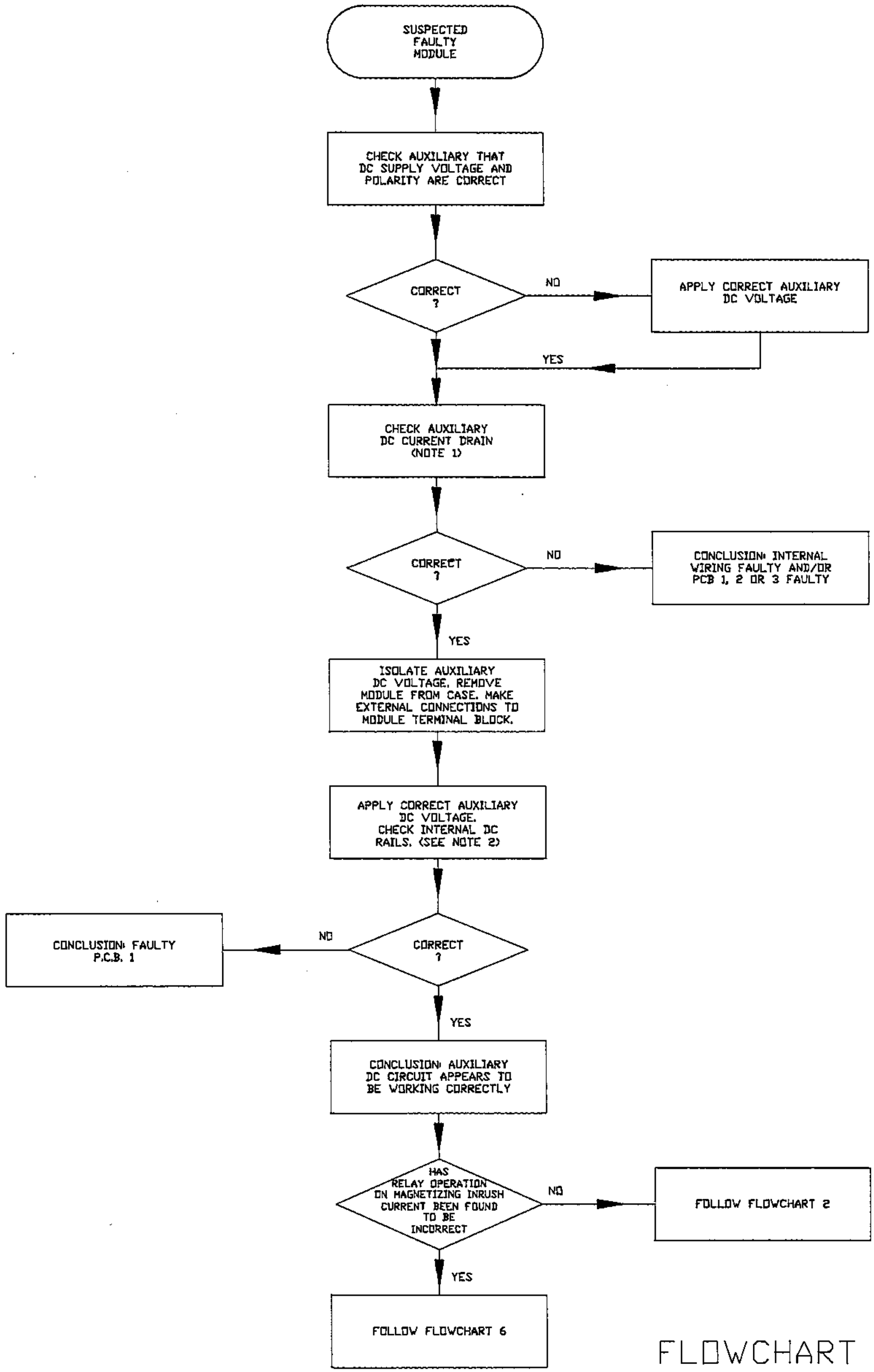
6. Connect a dc voltmeter across R1 on the main pcb (ZJ0077). A reading of approximately 1.1V per multiple of 5 amps injected should be obtained.

   If an oscilloscope is available, the voltage across R1 may be monitored. A full wave rectified sine wave should be displayed, of peak value approximately 1.7V per multiple of 5 amps injected.

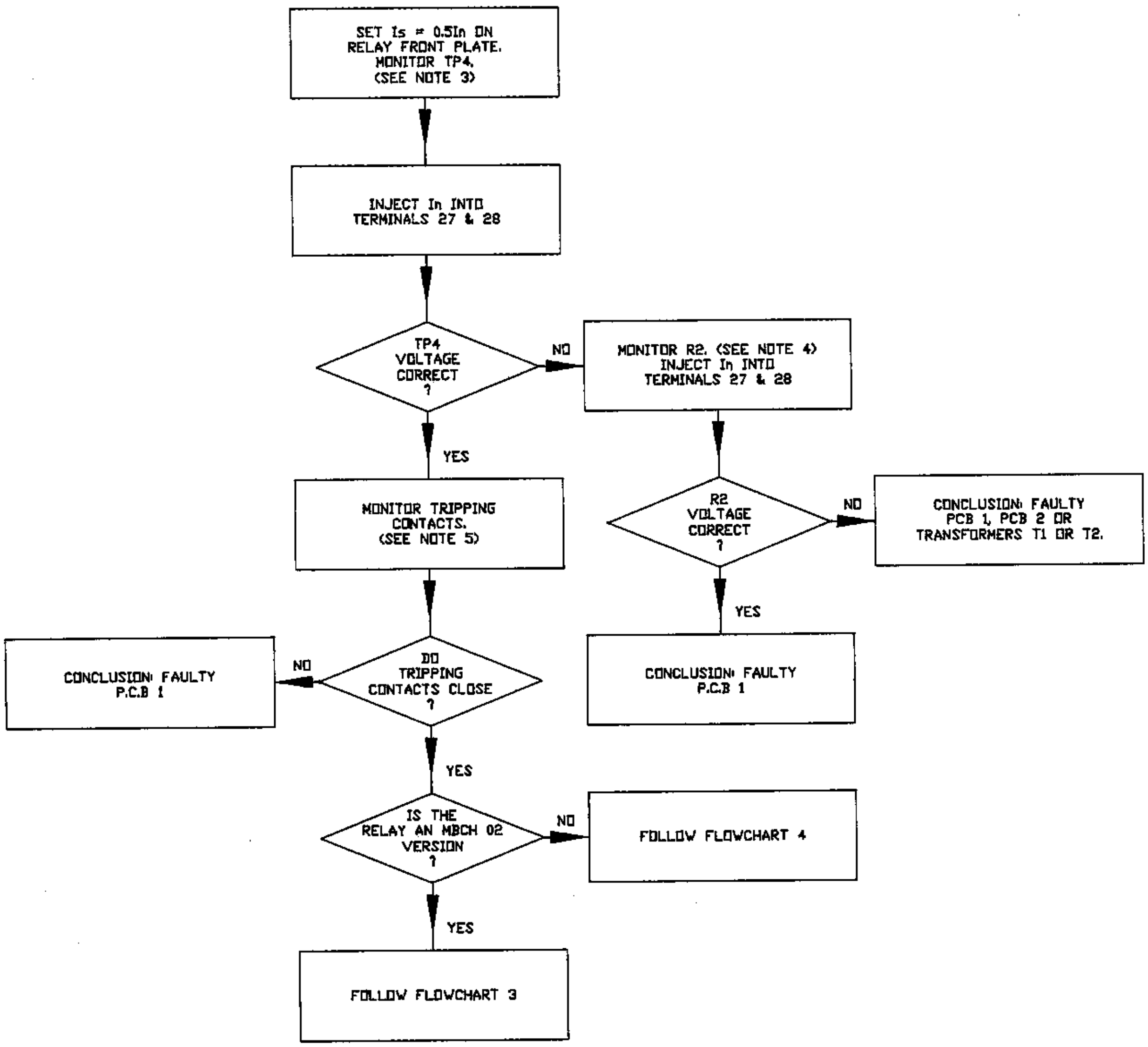
7. Connect a dc voltmeter between TP2 and TP7 on the main pcb (ZJ0077). A reading of approximately 3.6V should be obtained when a current of 0.5In is injected into terminals 27 and 28.

   If an oscilloscope is available, the voltage between TP2 and TP7 may be monitored. A full wave rectified sine wave should be displayed, of peak value approximately 5.5V. Some distortion of the sine wave may be evident.

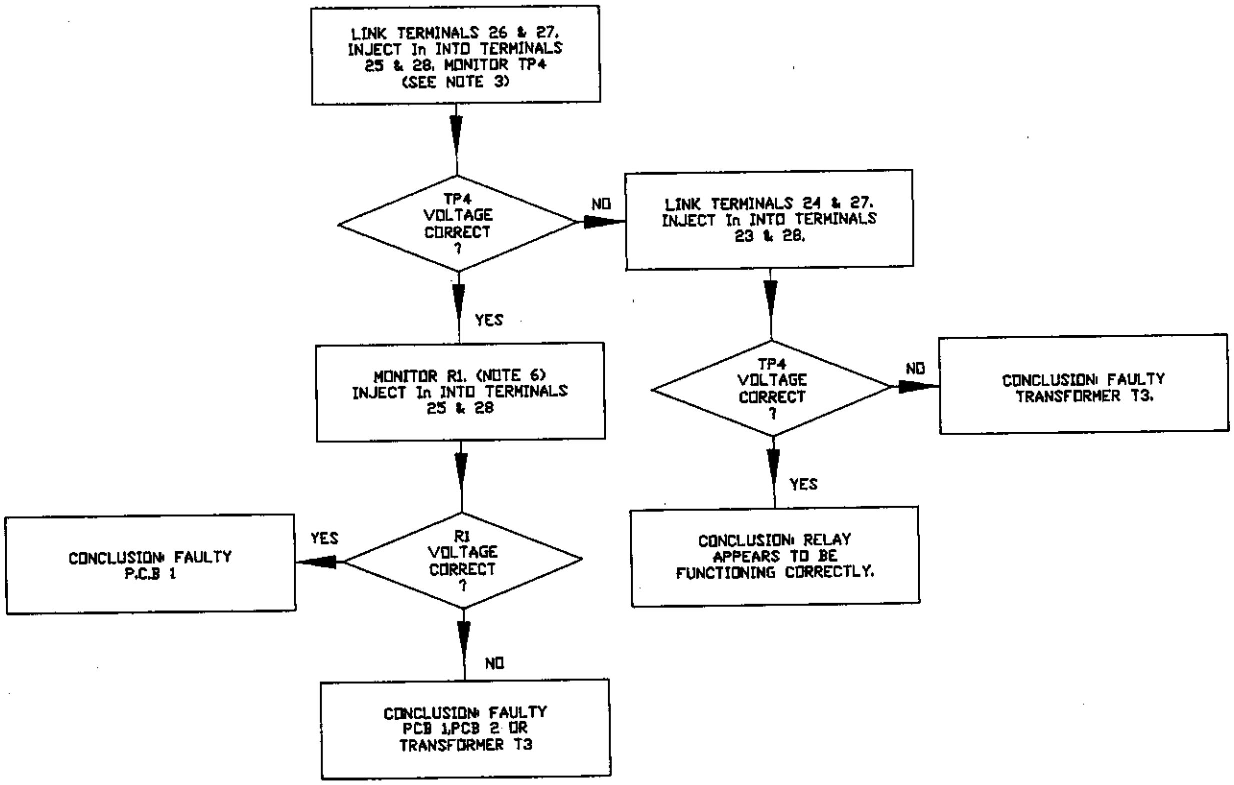
# Appendix 1


SUSPECTED FAULTY MODULE
CHECK AUXILIARY THAT DC SUPPLY VOLTAGE AND POLARITY ARE CORRECT
CORRECT ?
NO
APPLY CORRECT AUXILIARY DC VOLTAGE
YES
CHECK AUXILIARY DC CURRENT DRAIN (NOTE 1)
CORRECT ?
NO
CONCLUSION: INTERNAL WIRING FAULTY AND/OR PCB 1, 2 OR 3 FAULTY
YES
ISOLATE AUXILIARY DC VOLTAGE. REMOVE MODULE FROM CASE. MAKE EXTERNAL CONNECTIONS TO MODULE TERMINAL BLOCK.
APPLY CORRECT AUXILIARY DC VOLTAGE. CHECK INTERNAL DC RAILS. (SEE NOTE 2)
CORRECT ?
NO
CONCLUSION: FAULTY P.C.B. 1
YES
CONCLUSION: AUXILIARY DC CIRCUIT APPEARS TO BE WORKING CORRECTLY
HAS RELAY OPERATION ON MAGNETIZING INRUSH CURRENT BEEN FOUND TO BE INCORRECT
NO
FOLLOW FLOWCHART 2
YES
FOLLOW FLOWCHART 6

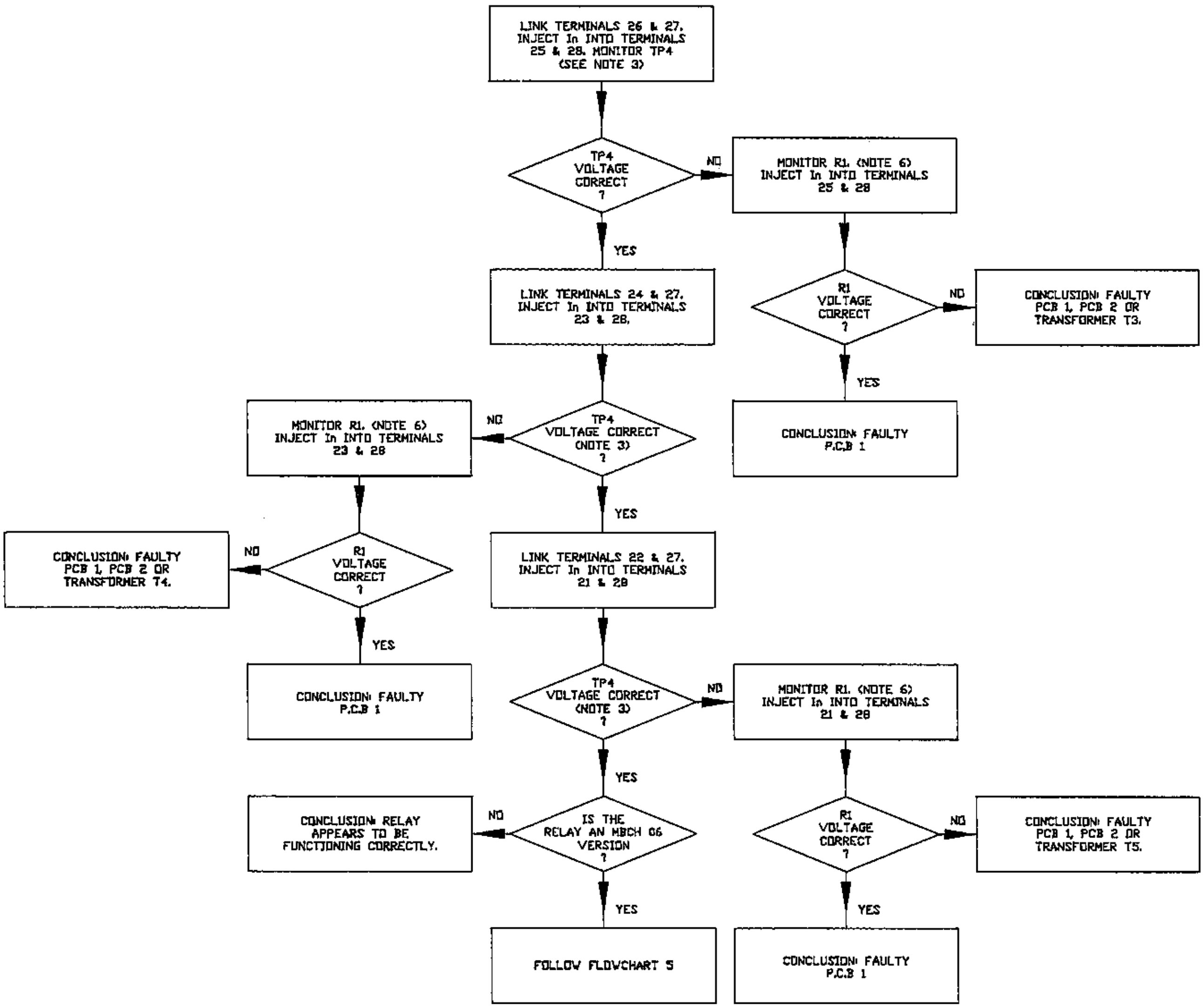
FLOWCHART 1


SET Is = 0.5In ON RELAY FRONT PLATE. MONITOR TP4. (SEE NOTE 3)
INJECT In INTO TERMINALS 27 & 28
TP4 VOLTAGE CORRECT ?
NO
MONITOR R2. (SEE NOTE 4) INJECT In INTO TERMINALS 27 & 28
YES
MONITOR TRIPPING CONTACTS. (SEE NOTE 5)
R2 VOLTAGE CORRECT ?
NO
CONCLUSION: FAULTY PCB 1, PCB 2 OR TRANSFORMERS T1 OR T2.
YES
CONCLUSION: FAULTY P.C.B 1
NO
DO TRIPPING CONTACTS CLOSE ?
CONCLUSION: FAULTY P.C.B 1
YES
IS THE RELAY AN MBCH 02 VERSION ?
NO
FOLLOW FLOWCHART 4
YES
FOLLOW FLOWCHART 3

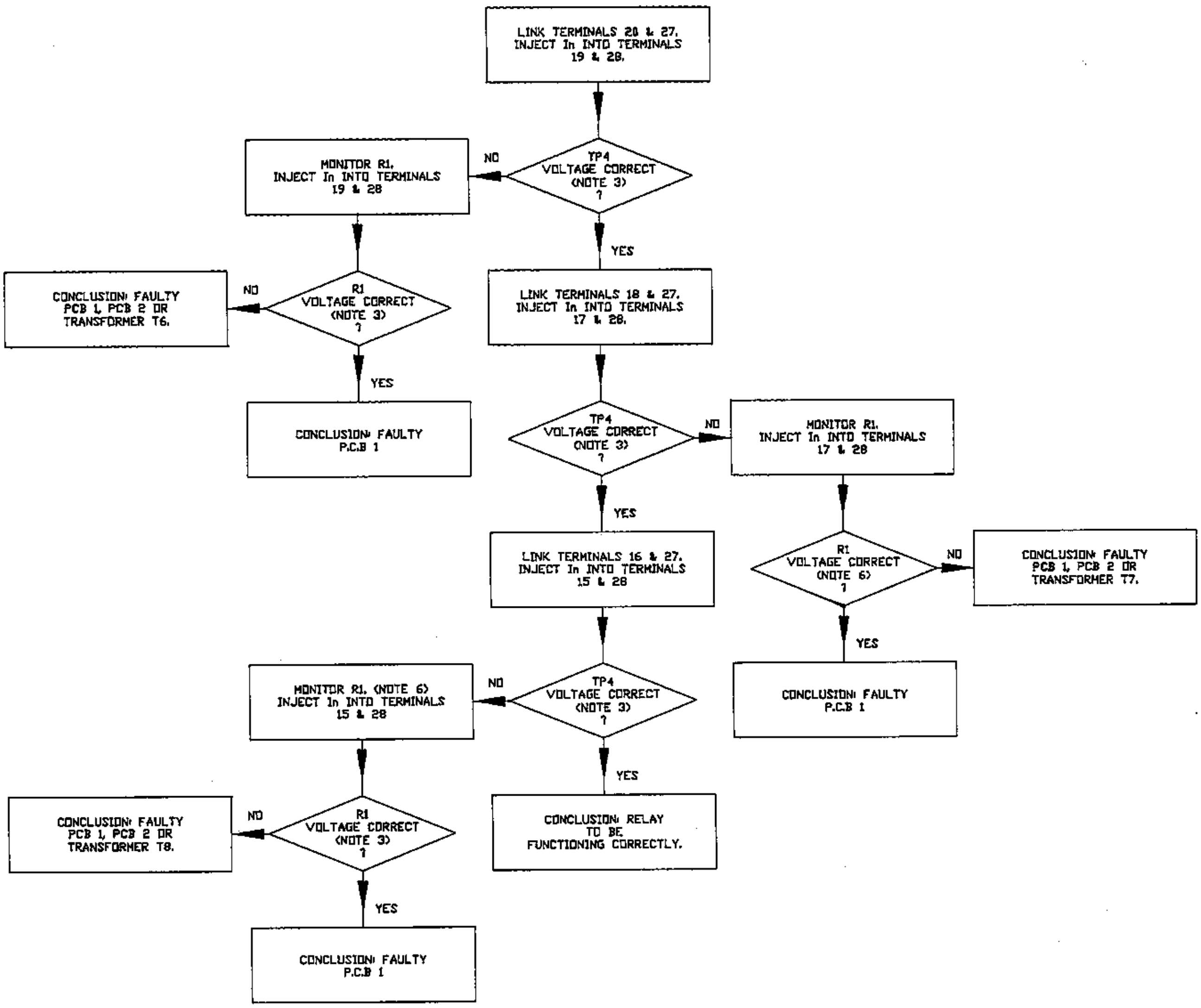
FLOWCHART 2


LINK TERMINALS 26 & 27. INJECT In INTO TERMINALS 25 & 28. MONITOR TP4 (SEE NOTE 3)
TP4 VOLTAGE CORRECT ?
NO
LINK TERMINALS 24 & 27. INJECT In INTO TERMINALS 23 & 28.
YES
MONITOR R1. (NOTE 6) INJECT In INTO TERMINALS 25 & 28
TP4 VOLTAGE CORRECT ?
NO
CONCLUSION: FAULTY TRANSFORMER T3.
YES
CONCLUSION: RELAY APPEARS TO BE FUNCTIONING CORRECTLY.
YES
CONCLUSION: FAULTY P.C.B 1
R1 VOLTAGE CORRECT ?
NO
CONCLUSION: FAULTY PCB 1,PCB 2 OR TRANSFORMER T3

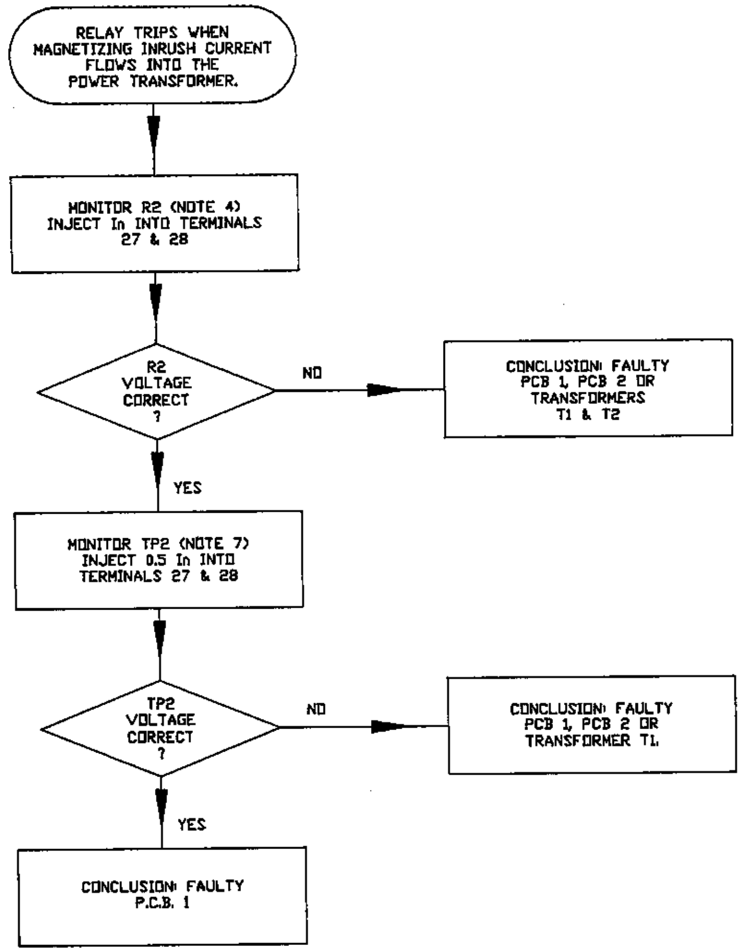
FLOWCHART 3


LINK TERMINALS 26 & 27. INJECT In INTO TERMINALS 25 & 28. MONITOR TP4 (SEE NOTE 3)
TP4 VOLTAGE CORRECT ?
NO
MONITOR R1. (NOTE 6) INJECT In INTO TERMINALS 25 & 28
YES
LINK TERMINALS 24 & 27. INJECT In INTO TERMINALS 23 & 28.
R1 VOLTAGE CORRECT ?
NO
CONCLUSION: FAULTY PCB 1, PCB 2 OR TRANSFORMER T3.
YES
CONCLUSION: FAULTY P.C.B 1
MONITOR R1. (NOTE 6) INJECT In INTO TERMINALS 23 & 28
NO
TP4 VOLTAGE CORRECT (NOTE 3) ?
YES
CONCLUSION: FAULTY PCB 1, PCB 2 OR TRANSFORMER T4.
NO
R1 VOLTAGE CORRECT ?
LINK TERMINALS 22 & 27. INJECT In INTO TERMINALS 21 & 28
YES
CONCLUSION: FAULTY P.C.B 1
TP4 VOLTAGE CORRECT (NOTE 3) ?
NO
MONITOR R1. (NOTE 6) INJECT In INTO TERMINALS 21 & 28
YES
CONCLUSION: RELAY APPEARS TO BE FUNCTIONING CORRECTLY.
NO
IS THE RELAY AN MBCH 06 VERSION ?
R1 VOLTAGE CORRECT ?
NO
CONCLUSION: FAULTY PCB 1, PCB 2 OR TRANSFORMER T5.
YES
YES
FOLLOW FLOWCHART 5
CONCLUSION: FAULTY P.C.B 1

FLOWCHART 4


LINK TERMINALS 20 & 27.
INJECT In INTO TERMINALS
19 & 28.
TP4
VOLTAGE CORRECT
(NOTE 3)
?
NO
MONITOR R1.
INJECT In INTO TERMINALS
19 & 28
R1
VOLTAGE CORRECT
(NOTE 3)
?
NO
CONCLUSION: FAULTY
PCB 1, PCB 2 OR
TRANSFORMER T6.
YES
CONCLUSION: FAULTY
P.C.B 1
YES
LINK TERMINALS 18 & 27.
INJECT In INTO TERMINALS
17 & 28.
TP4
VOLTAGE CORRECT
(NOTE 3)
?
NO
MONITOR R1.
INJECT In INTO TERMINALS
17 & 28
R1
VOLTAGE CORRECT
(NOTE 6)
?
NO
CONCLUSION: FAULTY
PCB 1, PCB 2 OR
TRANSFORMER T7.
YES
CONCLUSION: FAULTY
P.C.B 1
YES
LINK TERMINALS 16 & 27.
INJECT In INTO TERMINALS
15 & 28
TP4
VOLTAGE CORRECT
(NOTE 3)
?
NO
MONITOR R1. (NOTE 6)
INJECT In INTO TERMINALS
15 & 28
R1
VOLTAGE CORRECT
(NOTE 3)
?
NO
CONCLUSION: FAULTY
PCB 1, PCB 2 OR
TRANSFORMER T8.
YES
CONCLUSION: FAULTY
P.C.B 1
YES
CONCLUSION: RELAY
TO BE
FUNCTIONING CORRECTLY.

# FLOWCHART 5


RELAY TRIPS WHEN MAGNETIZING INRUSH CURRENT FLOWS INTO THE POWER TRANSFORMER.
MONITOR R2 (NOTE 4) INJECT In INTO TERMINALS 27 & 28
R2 VOLTAGE CORRECT ?
NO
CONCLUSION: FAULTY PCB 1, PCB 2 OR TRANSFORMERS T1 & T2
YES
MONITOR TP2 (NOTE 7) INJECT 0.5 In INTO TERMINALS 27 & 28
TP2 VOLTAGE CORRECT ?
NO
CONCLUSION: FAULTY PCB 1, PCB 2 OR TRANSFORMER T1.
YES
CONCLUSION: FAULTY P.C.B. 1

# FLOWCHART 6

# Appendix 2

**Appendix 2**

There are four main ways of specifying the amount of restraint present and these are described below.

1) **Restraint Slope Concept**

In the first concept considered, the slope of the restraint characteristic is specified as shown in **figure 33**. The percentage restraint is quoted as 20%. When the mean through current has increased to a value where (Ix + Iy)/2 = 5 amps. (rated current) the relay setting has increased by 20% of this mean through current, from Is to Is + 20% x 5A. (i.e. Is to Is + 1A)

It should be noted here that proportionately, minimum restraint is present when the mean through current is 5A., because a line drawn through the origin to touch the characteristic has minimum slope when it passes through the elbow of the characteristic. The actual percentage restraint therefore varies with tap setting value. Table 2 compares this method of specifying percentage restraint with the three other main ones and table 3 shows how they can be usefully interpreted.

2) **Mean Restraint Concept**

This method of specifying restraint gives the percentage restraint as the ratio

$$\frac{Id}{1/2(Ix + Iy)}$$

where the relay just operates with differential current Id.

3) **Larger Through Current Concept**

This method simply takes the ratio Id/Ix as the percentage restraint value where Id is the current at which the relay just operates and Ix is the larger of the two values of the restraint current.

4) **Smaller Value of Through Current Concept**

This method simply takes the ratio Id/Iy as the percentage restraint where Id is the point at which the relay operates and Iy is the smaller of the two values of restraint current.

**Comparison of the four methods**

The relay type MBCH is quoted as having a 20% restraint characteristic. Table 3 shows how the restraint for this relay varies with tap setting and how it relates to the other three methods of specifying percentage restraint. An example of the calculations involved is given on pages 53 and 54.

| MBCH Relay Differential Current Setting | | Percentage Restraint Given by the Other Three Methods | | |
|---|---|---|---|---|
| % x 5 A | Amperes | 2 | 3 | 4 |
| 10 | 0.5 | 30 | 26 | 35 |
| 20 | 1 | 40 | 33 | 50 |
| 30 | 1.5 | 50 | 40 | 66 |
| 40 | 2 | 60 | 46 | 86 |
| 50 | 2.5 | 70 | 52 | 108 |

**Table 3**

Although the relay MBCH has a restraint characteristic that is nominally fixed at 20% it can be seen that the effective percentage restraint varies as the relay differential tap setting is changed.

The most useful way of specifying percentage restraint should directly indicate the degree of mismatch which is permitted between the two values of through current Ix and Iy for the relay to be stable under load and through fault conditions. The method of quoting mis-match, however, influences the numerical value.

In table 4, mis-match is specified as:

$$\text{mismatch} = \frac{Ix - Iy}{\text{the larger of Ix and Iy}}$$

| MBCH Relay Setting | | Maximum mismatch that can be tolerated | Maximum recommended mismatch |
|---|---|---|---|
| % of 5A | Amperes | % | % |
| 10 | 0.5 | 26 | 16 |
| 20 | 1 | 33 | 23 |
| 30 | 1.5 | 40 | 30 |
| 40 | 2 | 46 | 36 |
| 50 | 2.5 | 52 | 42 |

**Table 4**

Thus it can be seen that where the line CTs are closely matched in ratio (and the $\sqrt{3}$ factor is taken into account for delta connected ct secondaries) a current setting of 0.5 amp. will allow a power transformer ratio change of + 26% by tap changer. If the 20% setting is chosen (1 amp.) then + 33% can be tolerated. This assumes however that the mismatch is always taken as a percentage of the larger current. (A sample calculation is shown later).

However, this would leave no margin at all for current transformer and relay tolerance. At least 10% margin should be allowed. Thus if the current transformers are matched or auxiliary current transformers have been applied, the MBCH relay will tolerate at least +16% variation due to a tap changer when the relay setting is 10% of rated current and at least +23% change with a tap setting of 20% of rated current.

**Calculation of effective percentage restraint**

In **figure 33** it can be seen that the lowest value of restraint slope that can be plotted touches the characteristic where the mean value of restraint current is 5A. Thus for each relay tap the effective restraint can be easily calculated.

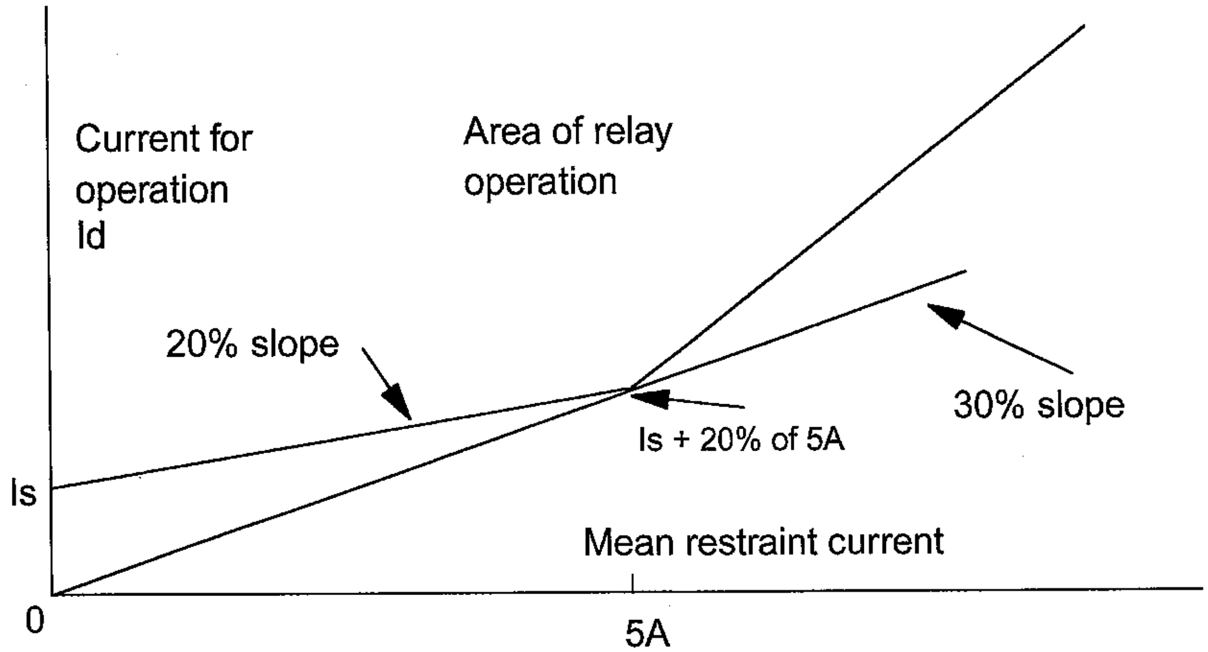



**Figure 33 - Theoretical Restraint Curve for the Relay Type MBCH**

Mean restraint $1/2(Ix + Iy) = 5A$
Differential current $Id = Ix - Iy$
for relay operation $= Is + 20\%$ of 5A
For the 10% tap this is $= 0.5 + 1$
$= 1.5$ amps.

Thus for $Is = 0.5$ (10% setting)
$Ix + Iy = 10$
$Ix - Iy = 1.5$
thus $Ix = 5.75$ amps. and $Iy = 4.25$ amps.

Concept 2 gives the restraint as $\frac{Id}{1/2(Ix + Iy)} = \frac{1.5}{5} = 30\%$

Concept 3 gives the restraint as $\frac{Id}{Ix} = \frac{1.5}{5.75} = 26\%$

Concept 4 gives the restraint as $\frac{Id}{Iy} = \frac{1.5}{4.25} = 35\%$

**Calculation of maximum permitted current transformer mis-match**

Assume that under full load conditions there is a mismatch of $Ix - Iy$ of current transformer secondary currents.

This can be defined as $\frac{Ix - Iy}{Ix}$ %

With a 10% setting, the MBCH relay operates at 1.5 amps when the mean restraint is 5A. (This point corresponds to the lowest possible value of restraint).

Thus $\frac{Ix + Iy}{2} = 5$ amps

$Ix - Iy = 1.5$ amps

$2Ix = 11.5$ amps

$Ix = 5.75$ amps

$Iy = 4.25$ amps

Thus percentage mis-match is $\frac{5.75 - 4.25}{5.75} = 26\%$

# Appendix 3

**Appendix 3**

Magnetizing Inrush Test Simulation for Type MBCH relays.

**Test Equipment Required:**

- 2 multimeters
- 1 ammeter
- 10 amp variable auto transformer
- Isolating transformer (2kVA or greater for 5A rated relay)
- Variable resistor of suitable power rating
- Battery (50V dc minimum)
- 1 form C switch (SW1)
- 1 switch (SW2)
- Diode D1 10A rated .

The test equipment should be connected as in **figure 34**.

**Note**: The ac supply should be capable of providing a voltage of at least 10% greater than the dc supply voltage.

**D.C. Auxiliary Supply**

Check the relay rated auxiliary voltage Vx on the relay frontplate and connect a suitable smoothed dc supply or station battery to relay terminals 13(+ve) and 14(-ve).

**Procedure**

a) Adjust the relay front panel switches to give a relay setting

IS = 0.1 x In.

Set the ammeter to read dc current. Move SW1 to position 1 and close SW2. Adjust RV1 to obtain a current of 5.0A dc + 10%.

b) Move SW1 to position 2. Set the ammeter to read ac current. Energize the isolating transformer and using the variable auto transformer set the reading on the ac voltmeter to be the same as or greater than that on the dc voltmeter.

c) Set SW1 to position 1 and open SW2. Check that the reading on the ac voltmeter does not alter. If VAC changes, saturation of the ac supply has occurred and its VA rating should be increased.

d) If the ac voltage reading remains unchanged then slowly reduce the ac voltage until the relay operates.

e) To reset the relay, remove both the ac and dc supplies.

**Calculation of Relay Critical Gap**

The relay waveform applied to the relay is as shown below in **figure 35**.

Using the test results recorded the relay critical gap can be calculated as follows:

$$\alpha = \sin^{-1} \frac{Vdc}{\sqrt{2}\, Vac}$$

$$\beta = \pi - 2\alpha$$

$$\text{or time of } \beta = \frac{\beta}{\pi} \times \frac{1}{2x frequency}$$

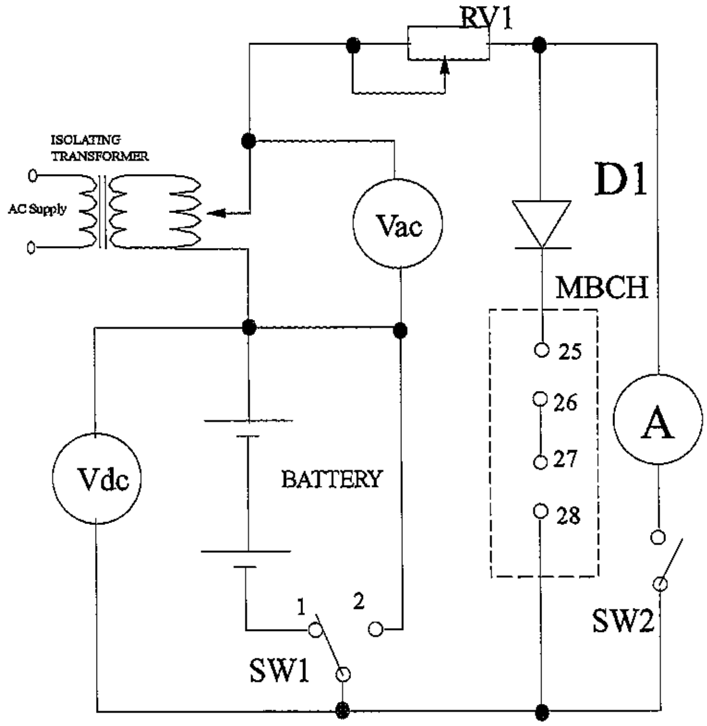



**Figure 34 - Circuit For Inrush Current Immunity Testing**

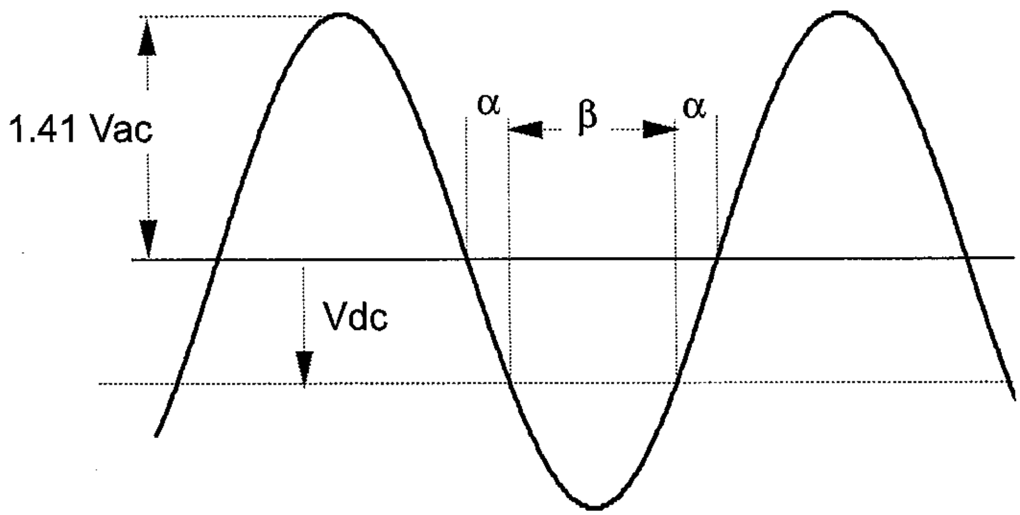
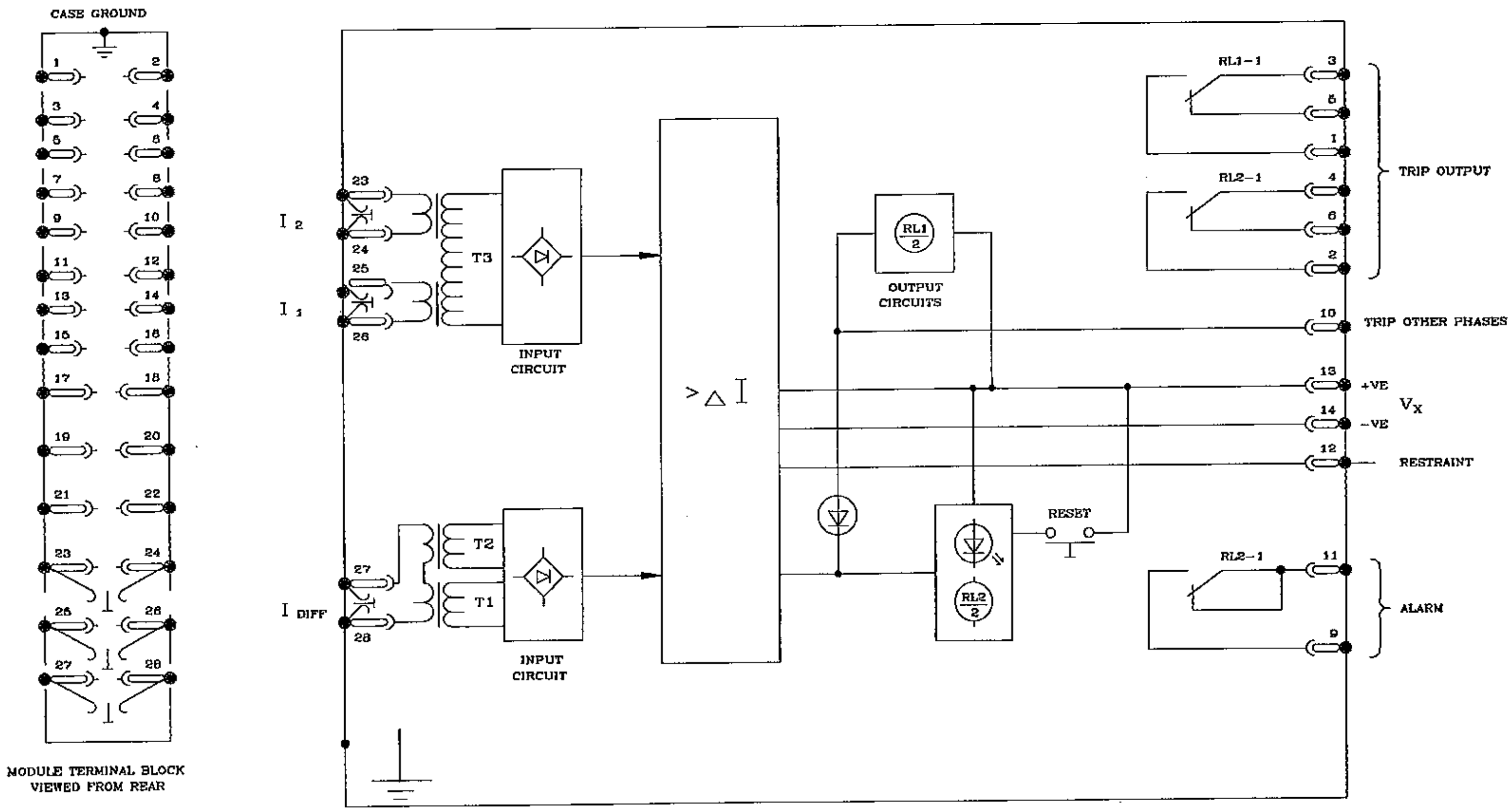



**Figure 35 - Waveform Generated By Figure 34**

# PERCENTAGE RESTRAINED TRANSFORMER PROTECTION RELAY TYPE MBCH TEST RECORD

| | | | |
|---|---|---|---|
| STATION | | TRANSFORMER | |
| MODEL # MBCH | | | |
| SERIAL # | Phase A | Phase B | Phase C |
| | | | |
| DC VOLTAGE Vx | RATED CURRENT = 5A | | |
| | | | |
| Measured DC Volts | | | |
| | Phase A | Phase B | Phase C |
| Relay Settings (tap) | | | |
| 10% 0.5 A | | | |
| 20% 1.0 A | | | |
| 30% 1.5 A | | | |
| 40% 2.0 A | | | |
| 50% 2.5 A | | | |
| Operating time<br>at 17.5 A | | | |
| at 23 A | | | |
| Restraint Check Is = 1.0 A | | | |
| Differential Current = 3 A | | | |
| Differential Current = 8.5 A | | | |
| Three Phase Tripping | | | |
| On Load Check<br>Differential Current | | | |
| Inrush Test | | | |
| | | | |
| Commissioning<br>Engineer | | Date | |
| | | | |
| Witness | | | |




NOTES:

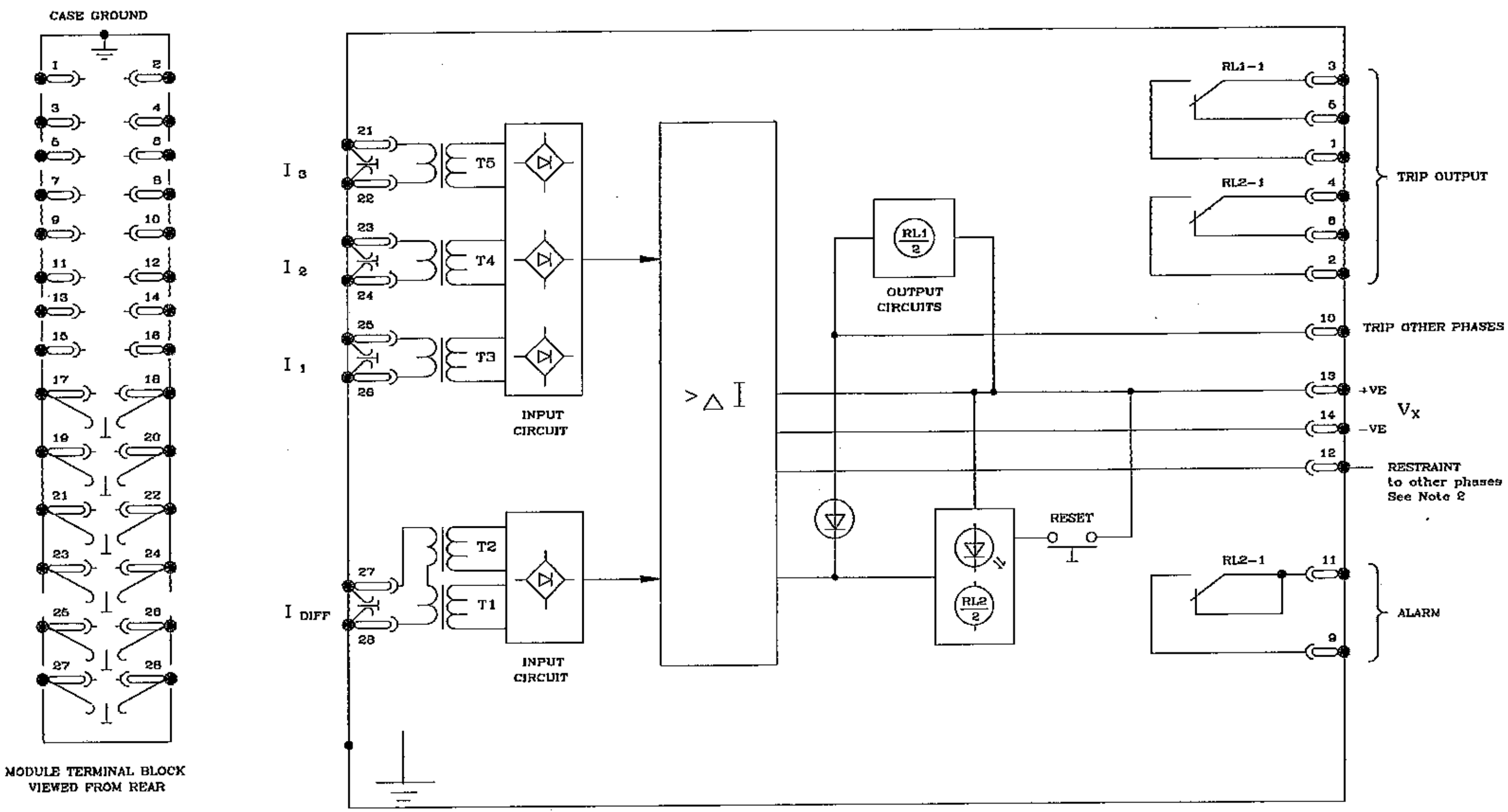
1. (a) C.T. SHORTING LINKS MAKE BEFORE (b) & (c) DISCONNECT

   (b) SHORT TERMINALS BREAK BEFORE (c).

   (c) LONG TERMINALS

2. INTERCONNECT TERMINAL 12 ON EACH PHASE RELAY

CONNECTION DIAGRAM
FOR MBCH 12




NOTES:

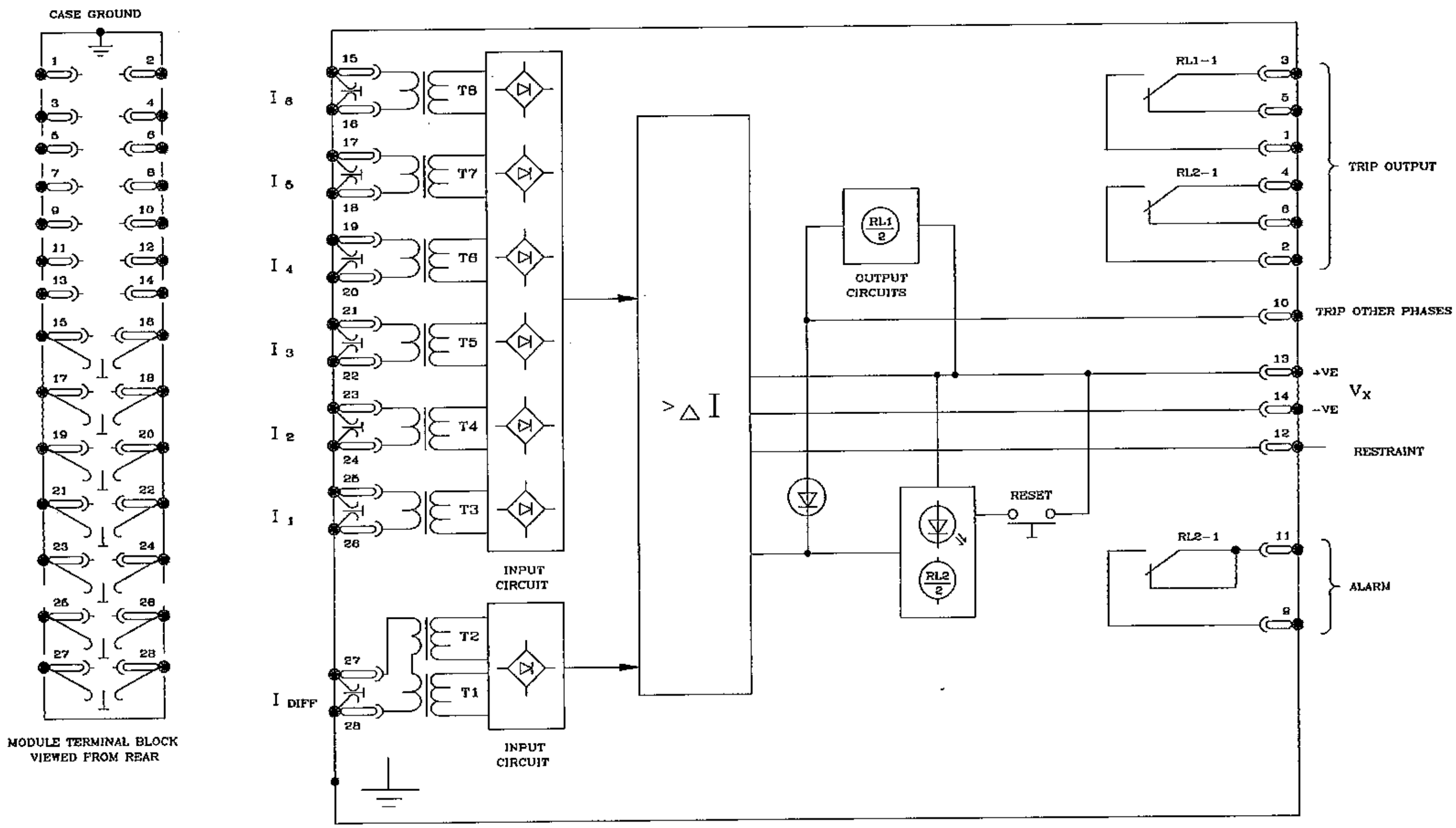
1. (a) C.T. SHORTING LINKS MAKE BEFORE (b) & (c) DISCONNECT

(b) SHORT TERMINALS BREAK BEFORE (c).

(c) LONG TERMINALS

2. INTERCONNECT TERMINAL 12 ON EACH PHASE RELAY

CONNECTION DIAGRAM
FOR MBCH 13




NOTES:

1. (a) C.T. SHORTING LINKS MAKE BEFORE (b) & (c) DISCONNECT

(b) SHORT TERMINALS BREAK BEFORE (c).

(c) LONG TERMINALS

2. INTERCONNECT TERMINAL 12 ON EACH PHASE RELAY

CONNECTION DIAGRAM
FOR MBCH 16

GEC ALSTHOM

T&D

GEC ALSTHOM & CONTROL DIVISION
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**Publication MBCH Service Mnl; US 6070 E; 8/93**