Interpoising Current Transformers

For use in conjunction with Type MBCH Transformer Differential Protection

ALSTOM

Interposing Current Transformers

General

Transformer differential relays compare the phase and magnitude of the current entering one winding of the transformer with that leaving via the other winding(s). Any difference in phase or magnitude between the measured quantities will cause current to flow through the operate winding of the relay. If this current exceeds the relay setting, tripping of the transformer circuit breakers will be initiated.

To enable a comparison to be made, the differential scheme should be arranged so that the relay will see rated current when the full load current flows in the protected circuit. In order to achieve this, the line current transformers must be matched to the normal full load current of the transformer. Where this is not the case it is necessary to use an auxiliary interposing current transformer to provide amplitude correction.

The connection of the line CTs should compensate for any phase shift arising across the transformer. Alternatively the necessary phase correction may also be provided by the use of an interposing CT.

The interposing current transformers listed in Table 1 are available for current ratio and phase angle matching of the line CTs used with transformer differential relay type MBCH (Publication Nos. R6070 and R6017).

The general winding arrangement is as shown in Figure 1, whilst Table 2 gives details of the number of turns on each of the transformers whose current ranges are noted in Table 1.

Description		Reference No.
Single-phase transformer	0.577 – 1.732/1A	GJ0104 010
Single-phase transformer	2.886 – 8.66/5A	GJ0104 020
Single-phase transformer	2.886 – 8.66/1A	GJ0104 030
Three-phase transformer group	0.577 – 1.732/1A	GJ0104 050
Three-phase transformer group	2.886 – 8.66/5A	GJ0104 060
Three-phase transformer group	2.886 – 8.66/1A	GJ0104 070

Table 1

Primary Winding Taps	Number of Turns		
	Transformer Rating		
	0.577 – 1.732/1A	2.886 – 8.66/1A	2.886 – 8.66/5A
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
S1 – S2	125	125	25
S3 – S4	90	90	18

Table 2

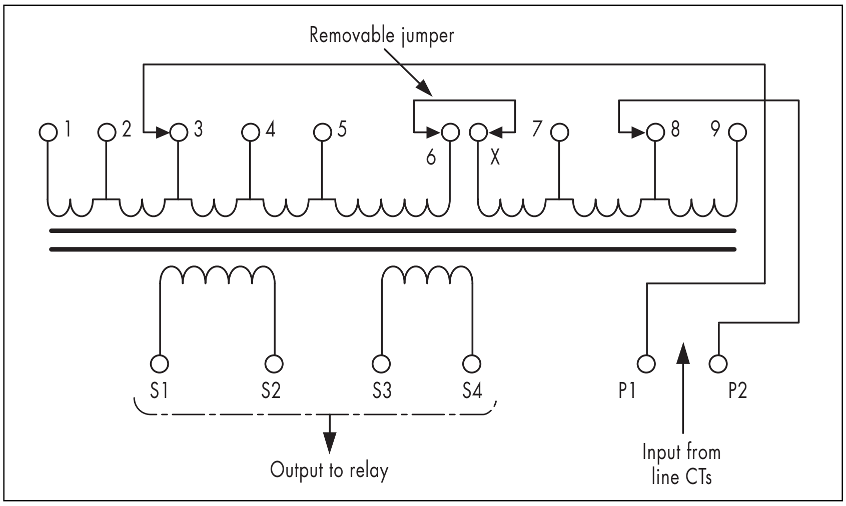

Figure 1: Disposition of windings on interposing transformer

Main and interposing current transformers

WARNING: do not open the secondary circuit of a live CT since the high voltage produced may be lethal to personnel and could damage insulation.

Before the power circuit is energised, two precautions are essential regarding the interposing current transformer:

- the primary and the secondary windings of the CT must have connections made to at least one section of each winding
- neither set of connections must include any break.

The above are very important, as dangerously high voltages could be present on leads and winding taps if the warning is not observed.

When the chosen connections have been made to the various taps on the windings of the interposing CT to give the desired ratio, (see Figure 1) it is important to realise that any part of any winding section that was not used in making these connections, should **not** be linked or connected to anything else, otherwise the accuracy and effectiveness of the CT will be greatly impaired.

Main transformer tap change range

The required interposing CT ratios should be calculated using the power transformer transformation ratio which corresponds to the mid-tap point on the tap change range. The examples used in this publication assume that the mid-tap point coincides with the nominal transformation ratio.

Design

The interposing transformers may be supplied as single or triple unit assemblies. The design is of the air-insulated type, each phase unit consisting of a pair of high-grade silicon steel 'C' cores, thus minimising the magnetising current and thereby limiting the current error. Figure 16 shows the physical arrangement and dimensions of these transformers.

Physical location

The interposing transformers, where used, should be located in the same panel as the associated differential relay. The electrical proximity maximises the transformer output voltage applied to the relay under internal fault conditions and thereby ensures high speed relay operation with minimum transformer dimensions.

Transformer output

The maximum output voltages available from the interposing CT windings S1–S2, and S1–S4 (see Figure 1) are indicated by the magnetisation characteristics shown in Figure 15.

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 by itself to maintain the quoted relay operating time. For star-connected output windings, section S1–S2 may be used either alone or with section S3–S4 connected in series.

For delta-connected output windings, where any one phase winding would be required to energise two poles of the relay in series, windings (S1–S2) and (S3–S4) must be connected in series.

With the link between terminals (6) and (X) connected as necessary, the incoming input connections to P1 and P2 may be linked across to the appropriate input winding terminals according to the number of turns required as indicated in Table 2.

The following examples illustrate the procedure.

EXAMPLE 1

Single phase transformers

In a single phase transformer the rated primary and secondary currents are 195A and 780A respectively as shown in Figure 2. The outputs from the respective current transformers are thus 4.875A and 3.9A.

In order to match these two current values, so that no relay differential current flows under healthy conditions, an interposing CT will be required to adjust the main line CT output of 3.9A to a value of 4.875A. This is illustrated in Figure 2.

Using taps S1 – S2 on the secondary winding gives 25 turns. Thus the number of turns (Tp) required on the primary input winding will be given by:

$$Tp = \frac{25 \times 4.875}{3.9} = 31.25$$

The current imbalance due to the use of 31 turns is limited to:

$$\text{Error} = \frac{31.25 - 31}{31.25} \times 100\% = 0.8\%$$

The tap positions required to give 31 turns on the primary winding are shown in Table No. 2 to be nos. 4–7.

It may be noted that an interposing transformer could also have been used in conjunction with the 200/5A CTs. This would have increased the output current from 4.875A to 5.0, and the interposing CT already considered above would have required a ratio of 3.9/5A instead of 3.9A/4.875A.

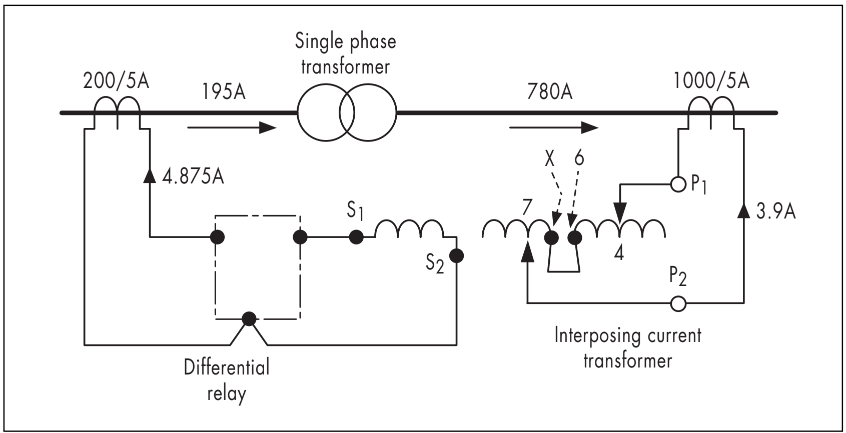

Figure 2

In omitting to provide a second interposing CT the effective setting would be increased by the ratio:

$$\frac{5}{4.875} \times 100\% = 1.025\%$$

This would give a setting of:

1.025 x 20% = 20.5%
on the 20% tap

This slight increase in effective protection setting would normally be acceptable and thus a second interposing CT may be considered unnecessary.

EXAMPLE 2

Three phase transformer (see Figures 3 and 11)

30MVA 11/66kV, Delta-star

11kV Winding:

Normal current at 11kV

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

As the 11kV winding is delta-connected the associated current transformers should be star-connected, and during rated load conditions will give the following current per pilot phase:

$$\frac{1575}{1600} \times 1.0A = 0.984A$$

This current is sufficiently close to the relay rated value (1A) that no correction is required.

66kV Winding:

Rated current at 66kV

$$= \frac{30\ MVA}{\sqrt{3} \times 66kV} = 262.5A$$

Normally, delta connected current transformers would be associated with the star-winding of the main transformer. However, since the latter in this case are star connected, the necessary phase and amplitude correction may be carried out using a star-delta connected interposing transformer, as shown in Figures 3 and 11.

The output current of the 300/1A HV current transformers will be:

$$\frac{262.5}{300} \times 1.0A = 0.875A$$

Thus the required ratio of the interposing CT will be 0.875/

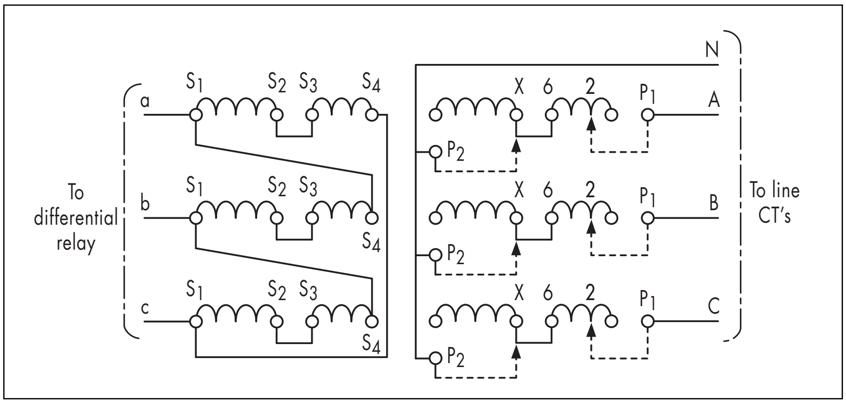

Figure 3: Interposing transformer connections for example No. 2

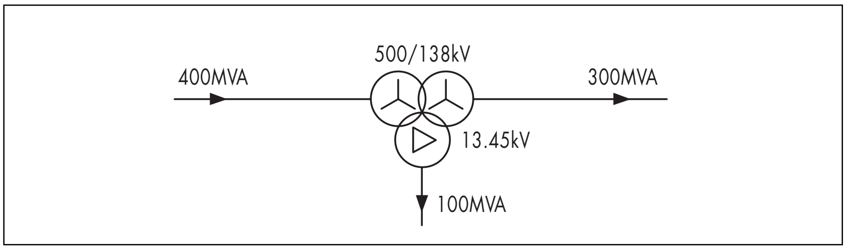

Figure 4

0.984A. Using output windings (S_1 – S_2) and (S_3 –S_4) connected in series gives 125 + 90 = 215T.

Hence input winding turns should be:

$$\frac{215 \times 0.984}{\sqrt{3} \times 0.875} = 139.6 \text{ say } 140 \text{ turns}$$

The input taps giving 140 turns are Nos. 2 – 6 as shown in Figure 3.

EXAMPLE 3
(see Figures 4, 5, 6, 7 and 12)

Three winding transformer

Taking the case of a three-winding transformer where load current flows in all three windings (as illustrated in Figure 4) to apply differential protection to such a transformer, the choice of line current transformer ratios ought to be based on the MVA rating of the primary input winding, rather than on the MVA ratings 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, interposing CTs will be necessary in order to match the secondary currents.

It will be found that more accurate matching taps may be chosen on the interposing CTs if the most lightly rated main transformer winding be considered first. In the case being considered this will be the 13.45kV winding supplying only 100MVA.

13.45kV side:

Rated current =

$$\frac{100\ MVA}{\sqrt{3} \times 13.45kV} = 4{,}293A$$

Line current transformer ratio: 5000/5A

$\therefore$ Line CT output current

$$= \frac{4293}{5000} \times 5.0A = 4.293A$$

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

Rated Current
(for external fault consideration)

$$= \frac{400\ MVA}{\sqrt{3} \times 13.45kV}$$

= 17,170A

The interposing transformer associated with the 13.45kV CTs will be star-star connected. From an output point of view the S1–S2 winding would suffice, however it is 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:

$$\frac{5 \times 43}{17.17} = 12.52 \text{ say 12 turns}$$

In order to obtain 12 turns on the interposing transformer input winding, use terminals 3 and 8 with link 6–X removed and terminal nos 5 and X connected. See Figure 5.

Output winding current will now be:

$$I_s = \frac{12 \times 17.17}{43} = 4.792\text{A}$$

Regard 4.8A as rated current to which must be matched the currents from the 500kV and 138kV interposing CTs respectively.

500kV side:

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

Secondary current of line CTs 500/5A:

$$\frac{462}{500} \times 5.0\text{A} = 4.62\text{A}$$

∴ Required ratio of interposing CT:

$$\frac{4.62}{4.8/\sqrt{3}} \text{ ie. } 4.62/2.77\text{A}$$

Interposer input winding turns

$$\frac{2.77 \times 43}{4.62} = 25.78 \text{ say 26 turns}$$

Error in interposing CT secondary winding current

$$\frac{26 - 25.78}{25.9} \times 100\% = 0.853\%$$

Interposing CT input taps to give 26 turns

nos. 4 and 6 (see Figure 6)

138kV side:

Rated current base 400MVA:

$$\frac{400 \text{ MVA}}{\sqrt{3} \times 138\text{kV}} = 1673\text{A}$$

Secondary current of line CTs 1250/5A:

$$\frac{1673}{1250} \times 5.0\text{A} = 6.69\text{A}$$

The ratio of the interposing CTs associated with the 138kV line CTs will therefore be:

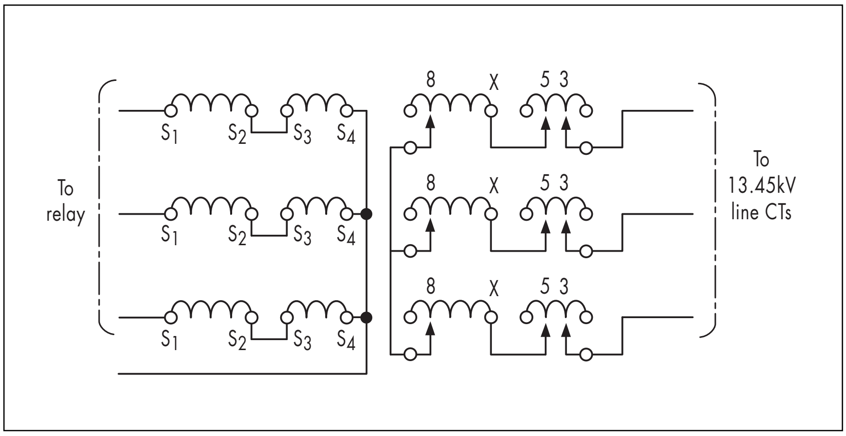

Figure 5: Interposing transformer associated with 13.45kV CTs

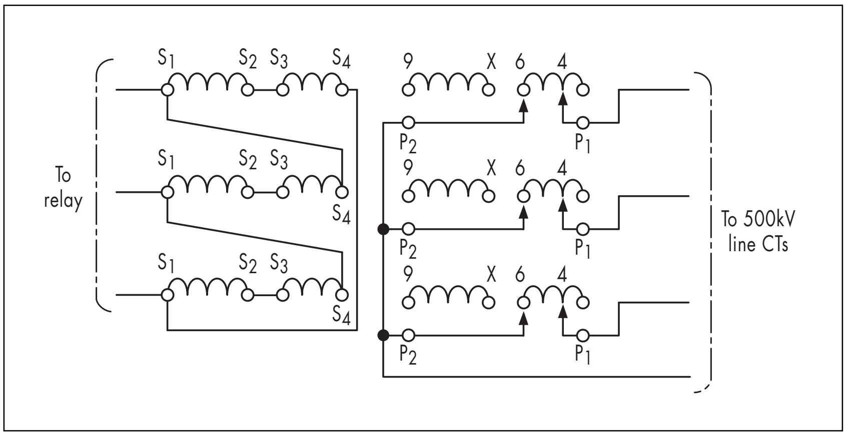

Figure 6: Interposing transformer associated with 500kV CTs

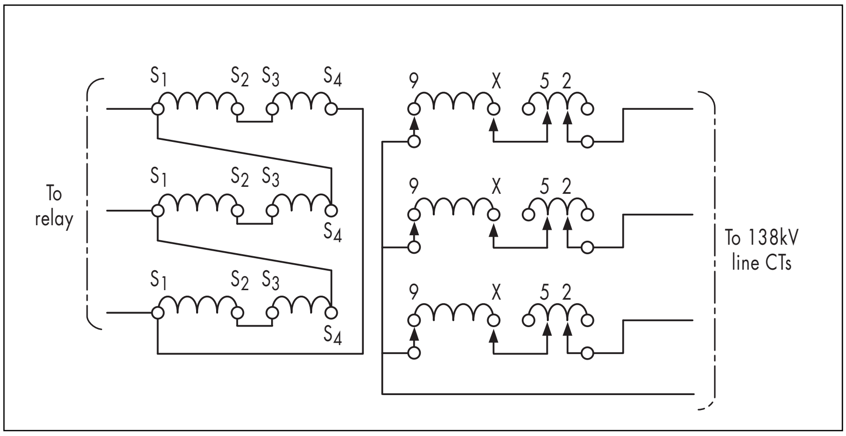

Figure 7: Interposing transformer associated with 138kV CTs

$$\frac{6.69}{4.8/\sqrt{3}} \text{ ie. } 6.69/2.77\text{A}$$

Interposing transformer input turns:

$$\frac{2.77 \times 43}{6.69} = 17.8 \text{ say 18T}$$

Error in interposing secondary winding current:

$$\frac{18 \times 17.8}{17.8} \times 100\% = 1.12\%$$

Interposing CT input taps to give 18 turns

2 and 9 (See Figure 7) with link (5 – X) reconnected

EXAMPLE 4

Transformer fed via mesh busbar arrangement (see Figures 8 and 13)

Where a transformer is fed from a mesh busbar arrangement and controlled by two circuit breakers in

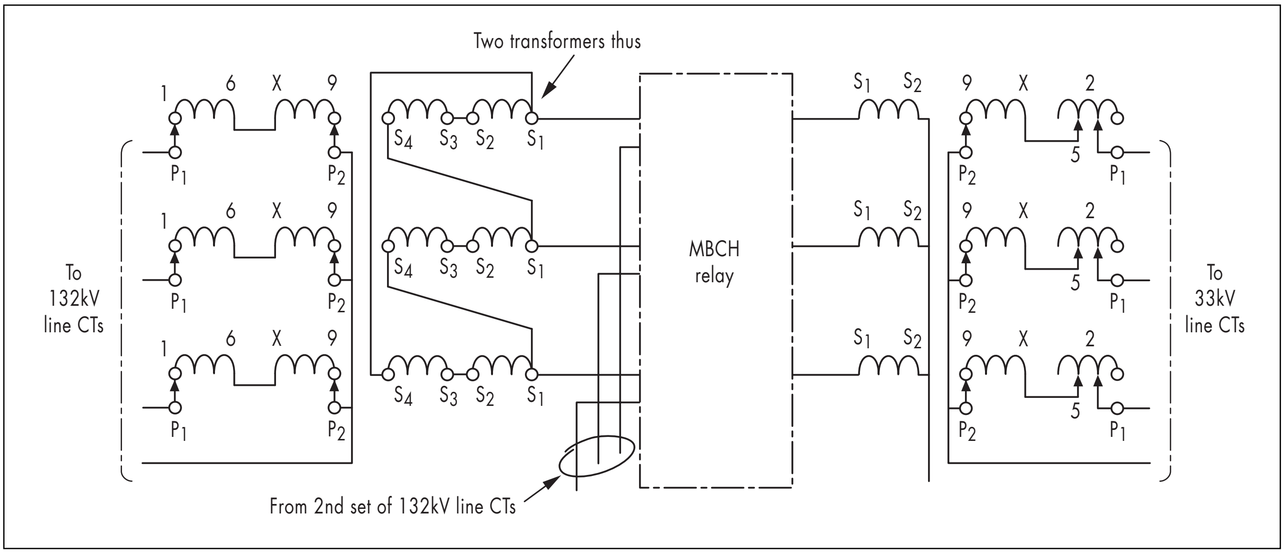

Figure 8: Interposing CTs associated "mesh busbar" transformer

the mesh, the rating of the transformer will normally be somewhat lower than that of other feeders emanating from the mesh.

Because the current transformers within the mesh 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 for the differential protection CTs is in the direct feed to the transformer, at point 'P' in Figure 13. Where suitable CTs are available at point 'P', the application and selection of suitable interposing CTs is exactly as described in Example 2.

In those cases where the only CTs available for the transformer differential protection are located at the circuit breakers within the 'mesh', then the protection arrangement will be as shown in Figure 13.

EXAMPLE

40MVA 132/33kV Star-Delta Transformer

132kV (Mesh side):

Line current transformer ratio : 500/1A

Transformer rated current (at 132kV):

$$\frac{40\ \text{MVA}}{\sqrt{3} \times 132\text{kV}} = 175\text{A}$$

$\therefore$ Current in current transformer secondary winding:

$$\frac{175\text{A}}{500} \times 1.0 = 0.35\text{A}$$

Preferred current ratio of interposing CT:

$$0.35 \Big/ \frac{1.0}{\sqrt{3}} = 0.35/0.577\text{A}$$

NB. Δ output winding
However, the maximum input winding turns are:

220 turns (see Figure 8)

$\therefore$ Increase in current through the transformer:

$$\frac{0.35 \times 220}{(125 + 90)} = 0.358\text{A}$$

Note: It has already been stated (see Page 3) that for delta connected output windings both windings (S1 – S2) and (S3 – S4) must be connected in series.

Pilot current to the relay:

$$\sqrt{3} \times 0.358 = 0.62\text{A}$$

33kV side:

33kV Interposing CT:

star/star connection

Output winding turns:

125 turns winding (S_1 – S_2)

33kV Line current:

$$\frac{40\ \text{MVA}}{\sqrt{3} \times 33\text{kV}} = 700\text{A}$$

33kV CT Secondary current:

$$^{700}/_{800} \times 1 = 0.875\text{A}$$

Ratio of 33kV Interposing CT:

0.875/0.62A

Input winding turns (see Figure 8):

$$\frac{125 \times 0.62}{0.875} = 88.57 \text{ say } 90 \text{ turns}$$

Referring to Figure 13 it will be noted that when the rated current of the transformer flows, the corresponding current flowing in the relay circuit will be 0.62A. Thus the effective protection setting will be:

$$\frac{1.0}{0.62} = 1.6 \times \text{selected relay setting}$$

The above increase in setting is due to the nominal primary rating of the line current transformer being appreciably greater than the rating of the transformer being protected.
This condition is unavoidable.

EXAMPLE 5

Star delta transformer with earthing transformer on delta side
(see Figures 9, 10 and 14).

75MVA – 132/33kV

Where a three phase earthing transformer is associated with a delta-connected LV winding as in Figure 14, a zero sequence path is provided within the protected zone. This permits the passage of zero sequence currents through the differential relay, under external earth fault conditions.

It is necessary to block such currents by inserting a star-delta-star interposing current transformer as shown in Figure 14. This same interposing CT may be used for ratio correction required due to any mismatch between the HV and LV line current transformers.

132kV side:

Normal current at 132kV:

$$\frac{75\ \text{MVA}}{\sqrt{3} \times 132\text{kV}} = 328\text{A}$$

Current transformer ratio: 400/5A

Secondary current:

$$\frac{328}{400} \times 5.0\text{A} = 4.1\text{A}$$

Interposing transformer required: star/delta ratio $4.1/5/\sqrt{3}$ A (per phase)

Figure 9 shows details of the transformer.

Relay output winding turns:

($S_1 – S_4$) 25 + 18 = 43 turns

Input winding turns:

$$\frac{43 \times 5}{4.1 \times \sqrt{3}} = 30.28 \text{ say 30 turns}$$

33kV Side:

Normal current:

$$\frac{75\ \text{MVA}}{\sqrt{3} \times 33\text{kV}} = 1312\text{A}$$

Current transformer ratio: 1500/5A

Secondary current:

$$\frac{1312 \times 5}{1500} = 4.37\text{A}$$

Interposing transformer required:

– star/delta/star

Secondary winding $S_3 – S_4$ is used for the delta connection. The relay is connected to windings $S_1 – S_2$ = 25 turns.

Interposing CT primary turns:

$$\frac{5}{4.37} \times 25 = 28.6 \text{ say 29 turns}$$

Interposing CT connections are shown in Figure 10.

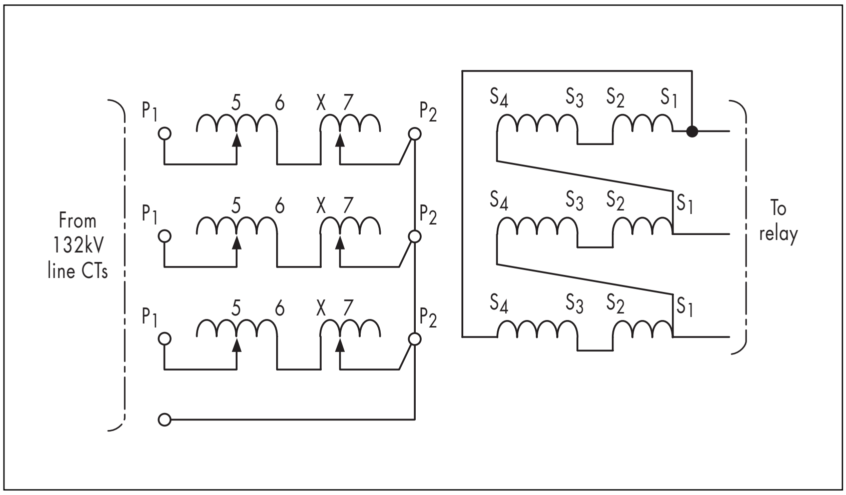

Figure 9: Interposing transformer connections for example No. 5

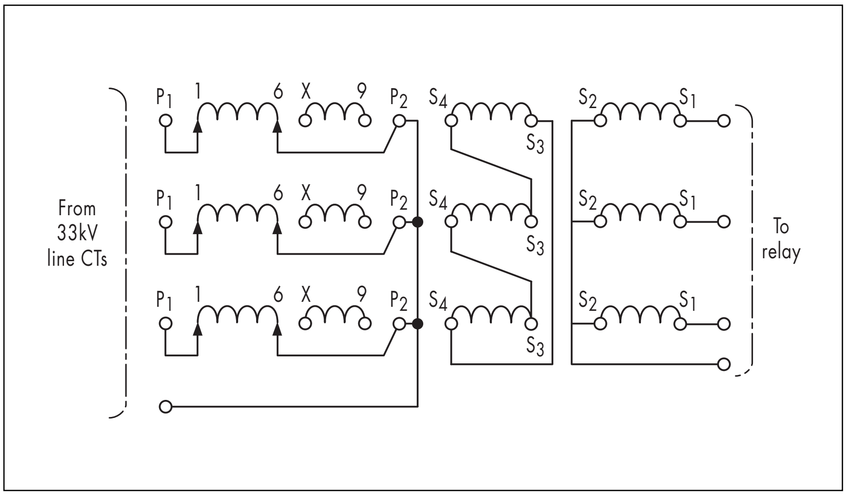

Figure 10: Interposing CTs for example No.5

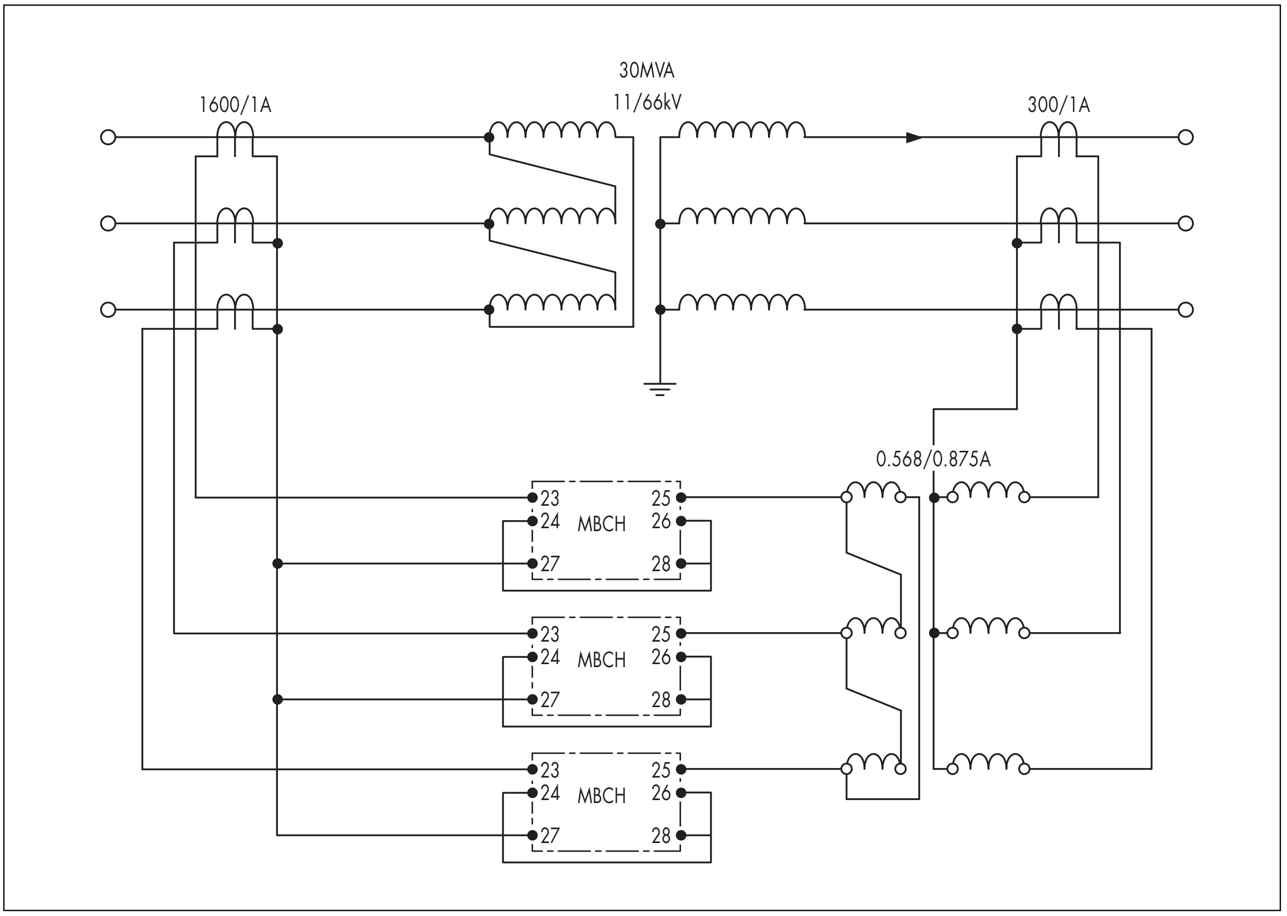

Figure 11: Interposing CTs

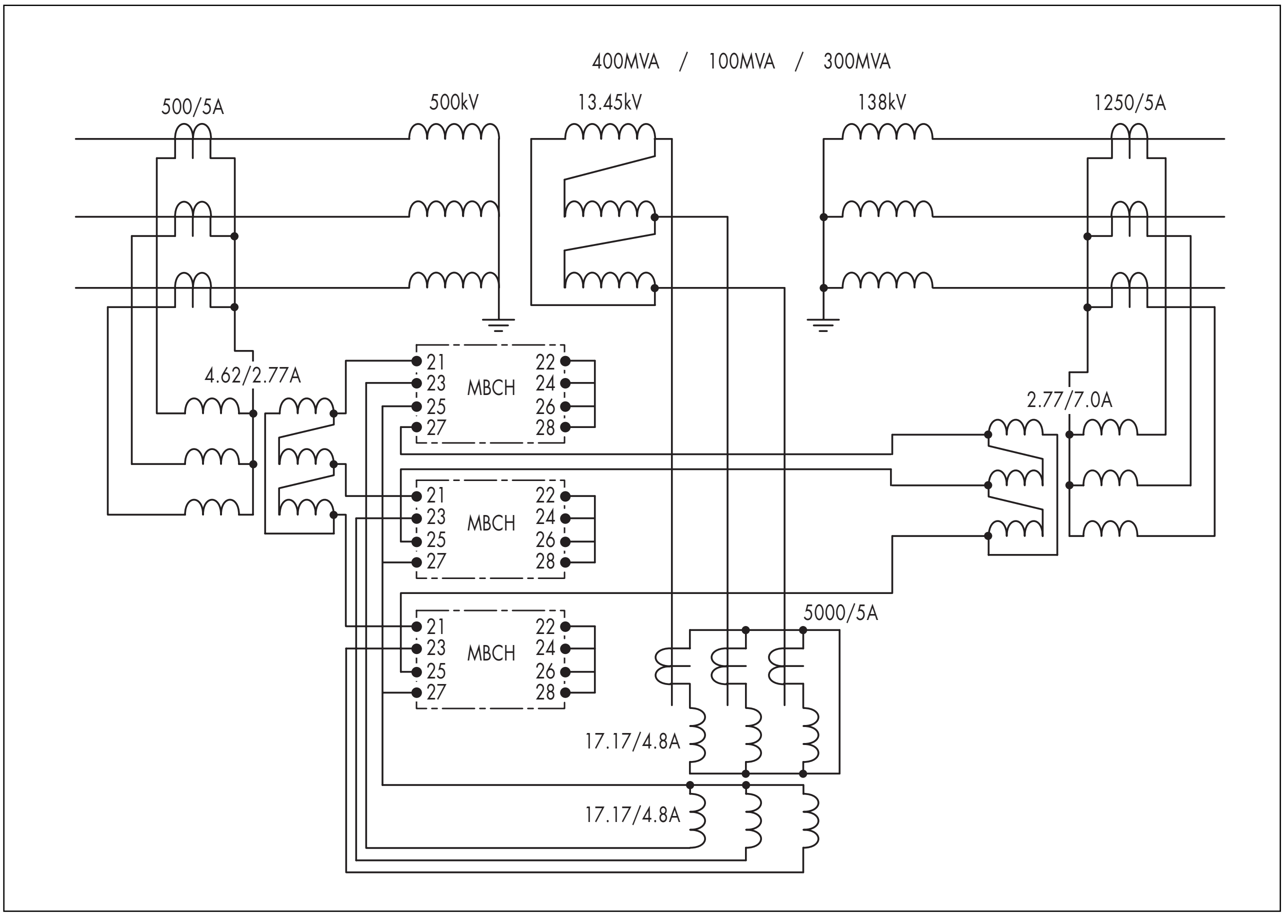

Figure 12: Three winding transformer showing interposing CTs

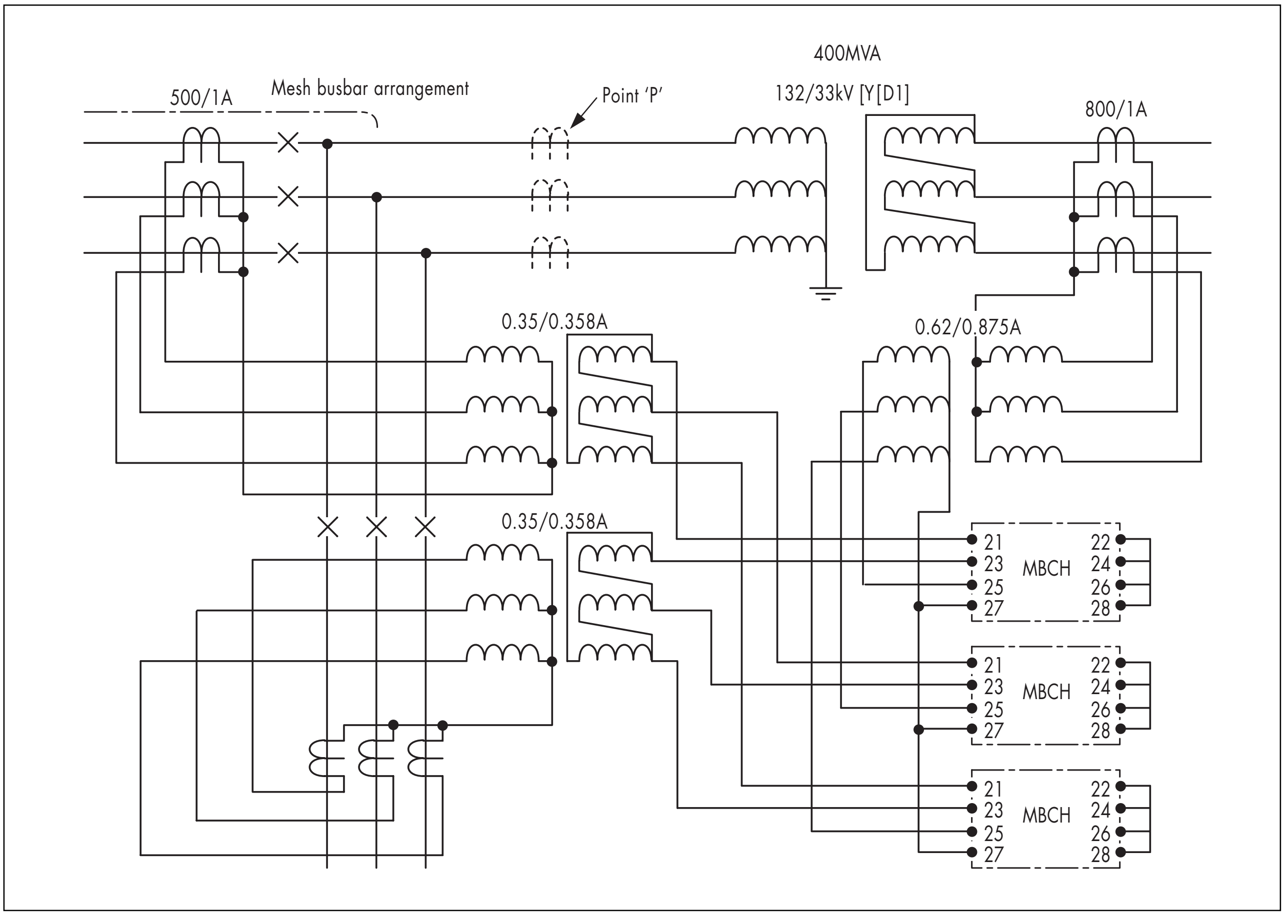

Figure 13: Mesh-bus arrangement showing interposing CTs

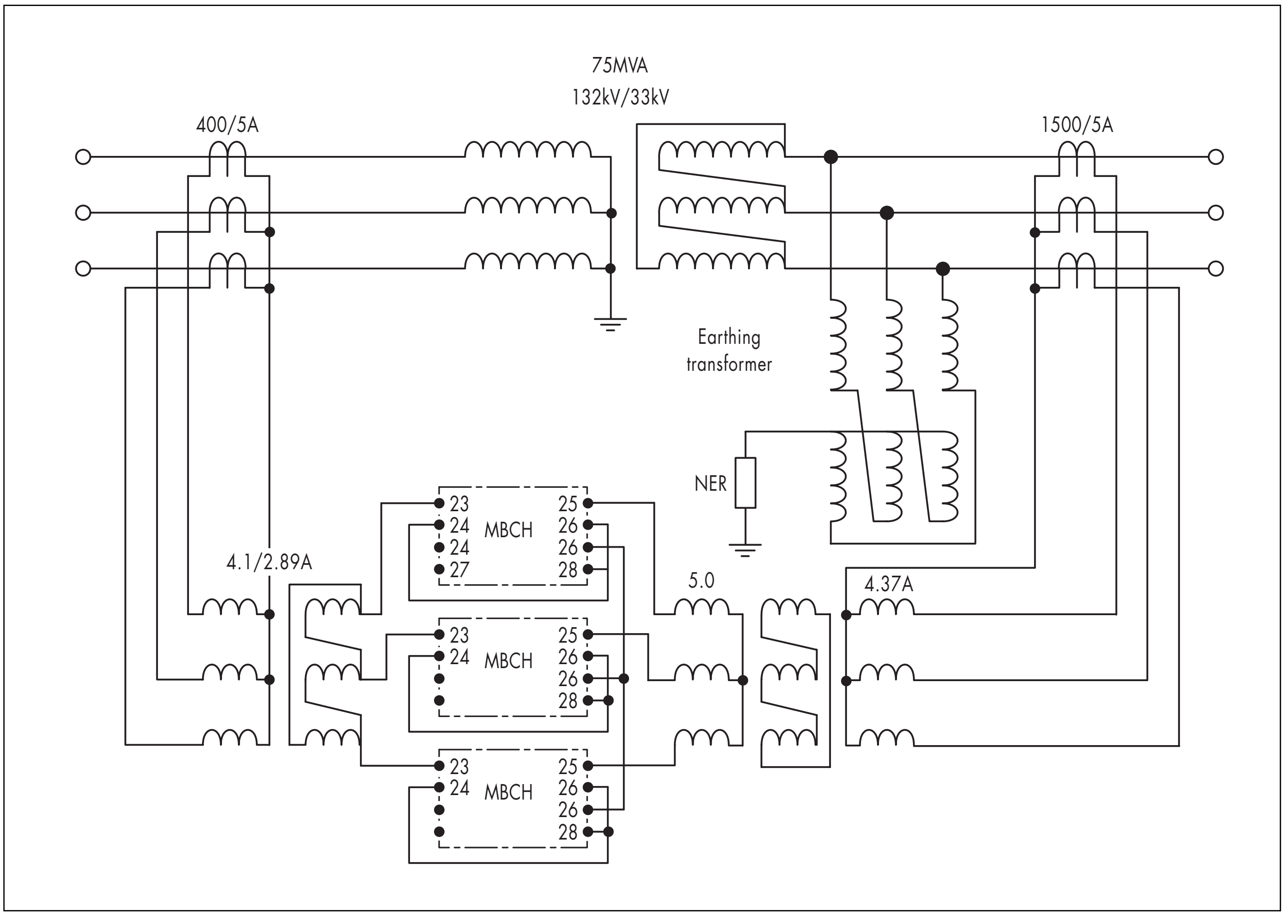

Figure 14: Star/Delta transformer with earthing-transformer on delta-side

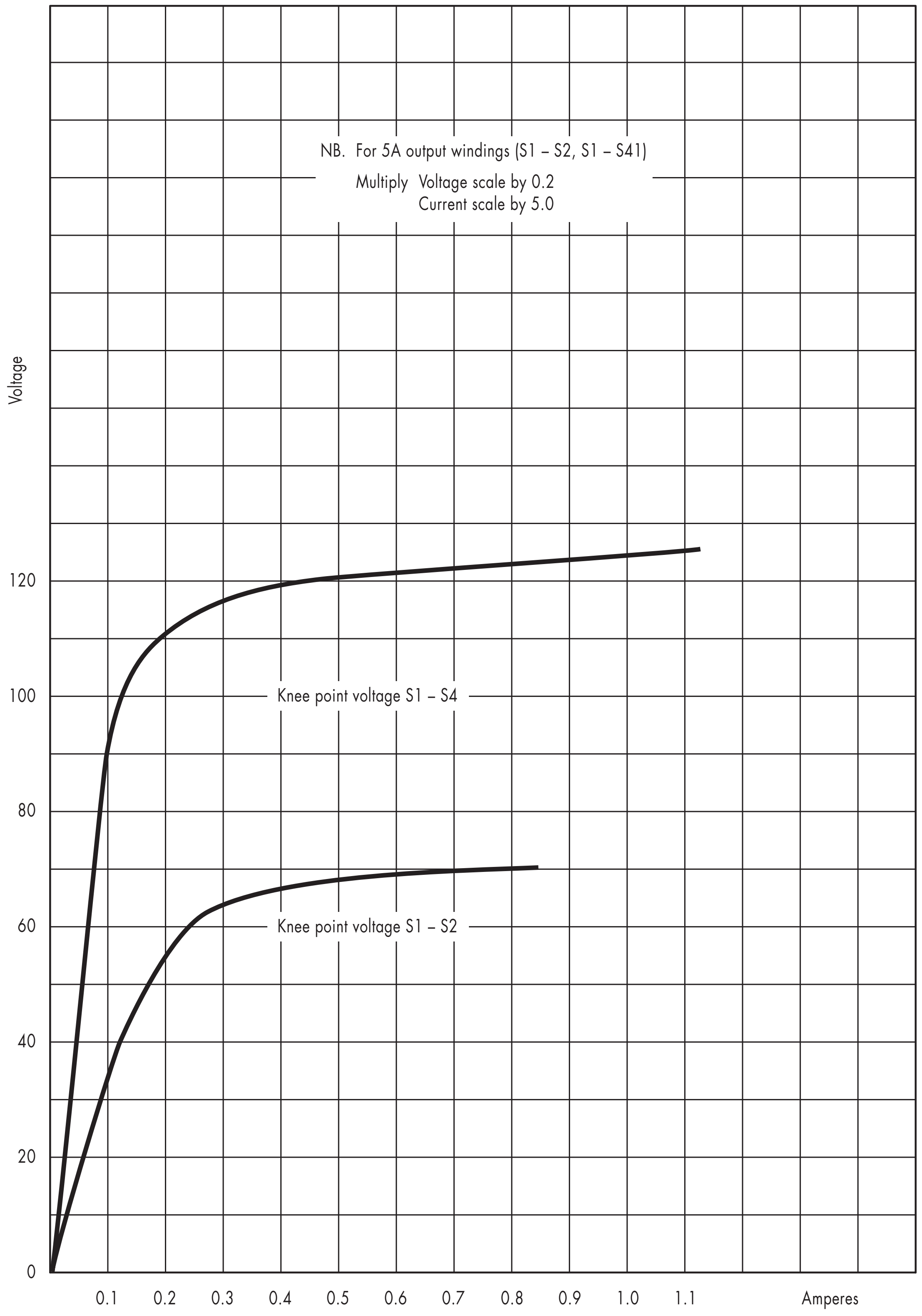

Figure 15: Magnetisation characteristic for 0.58 1.73/1A 2.89 8.66/1A

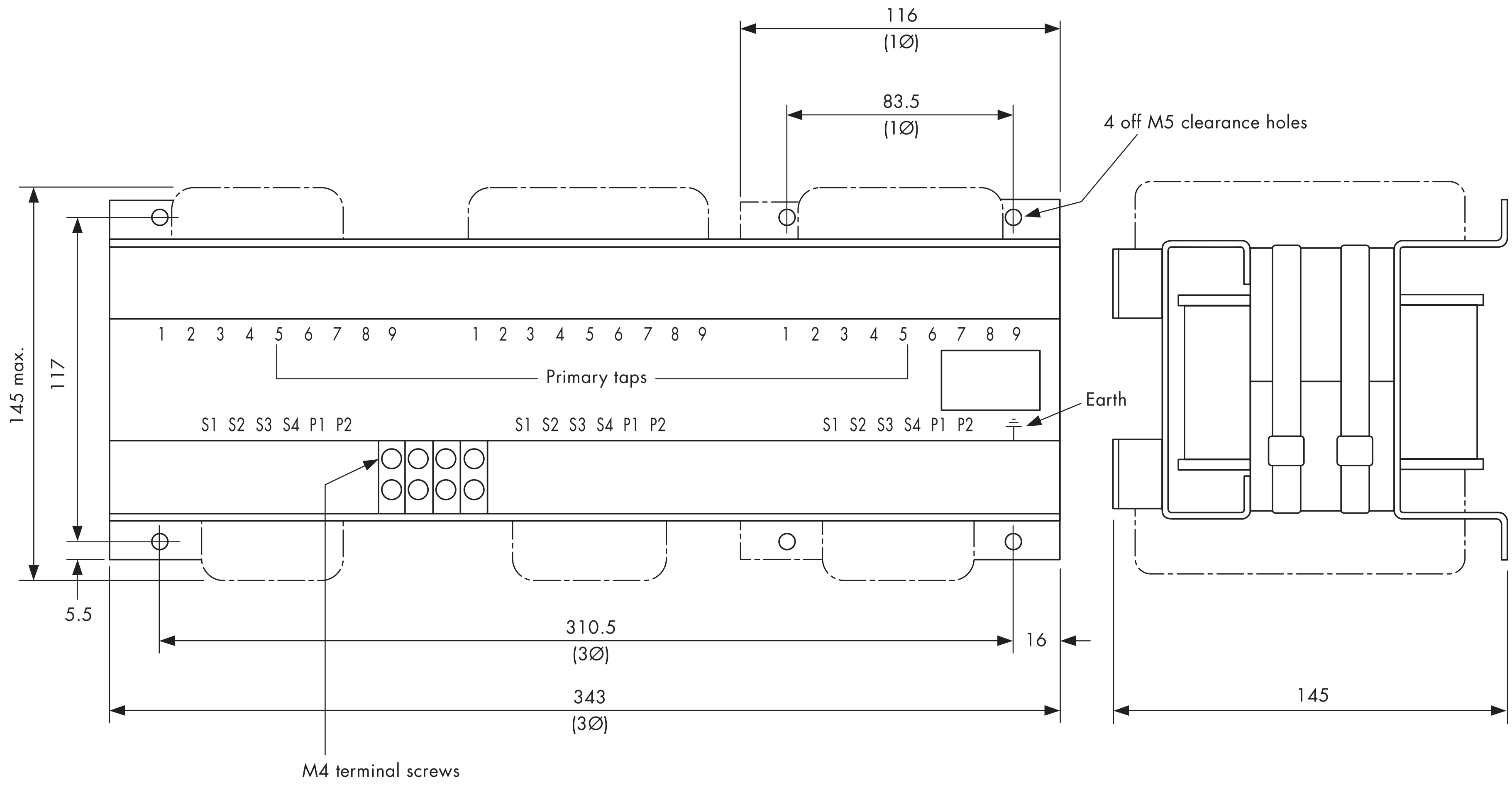

Figure 16: Outline details of single and triple unit auxiliary interposing transformer assembly

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