s shown in Figure
in Figure 17.3(d).
power and time and
unit of energy is the
tt-hours = kilowatts

energy units on its
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7.2.
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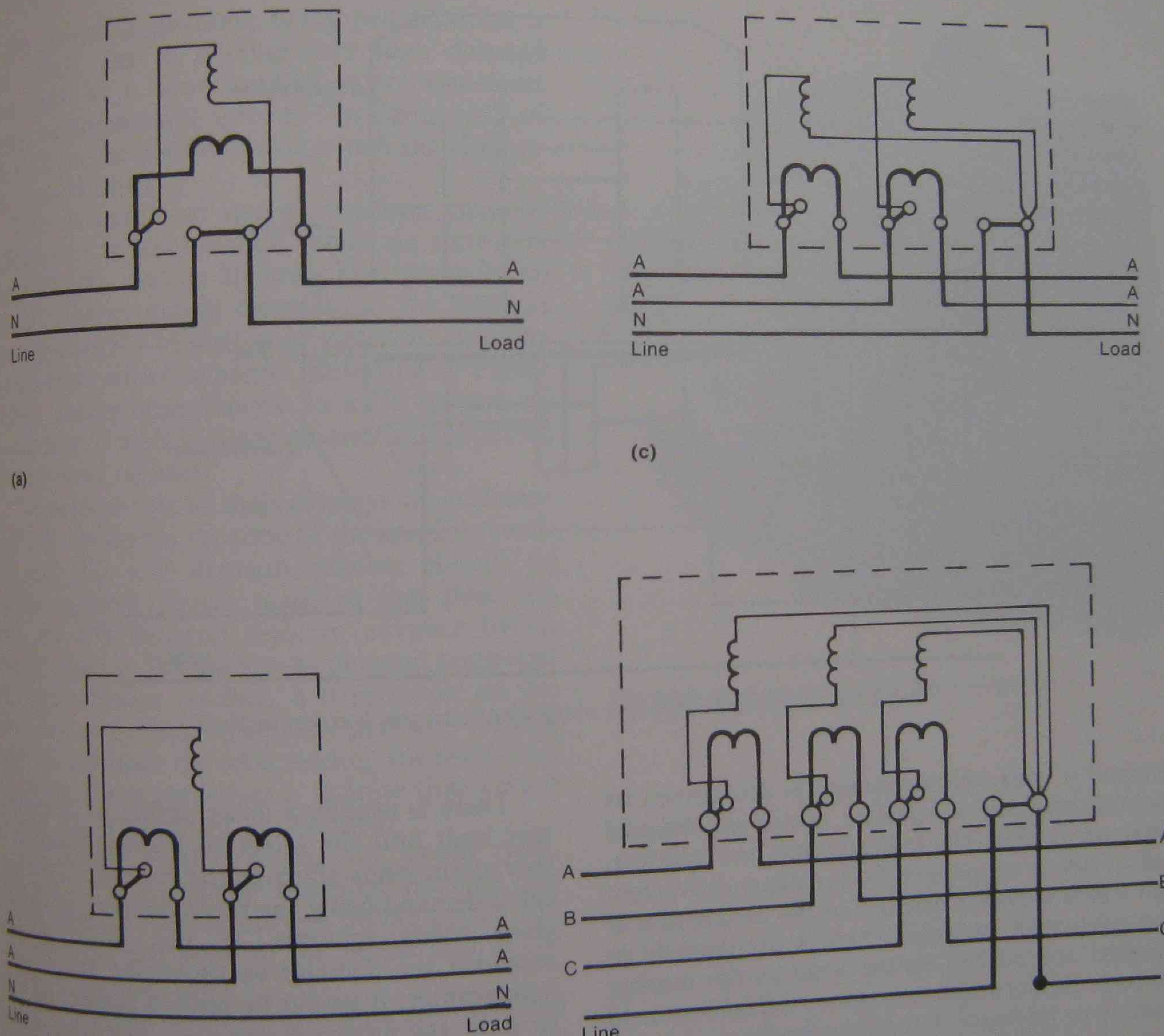


(a) (b) (c) (d)

...three wire (d) Three-phase

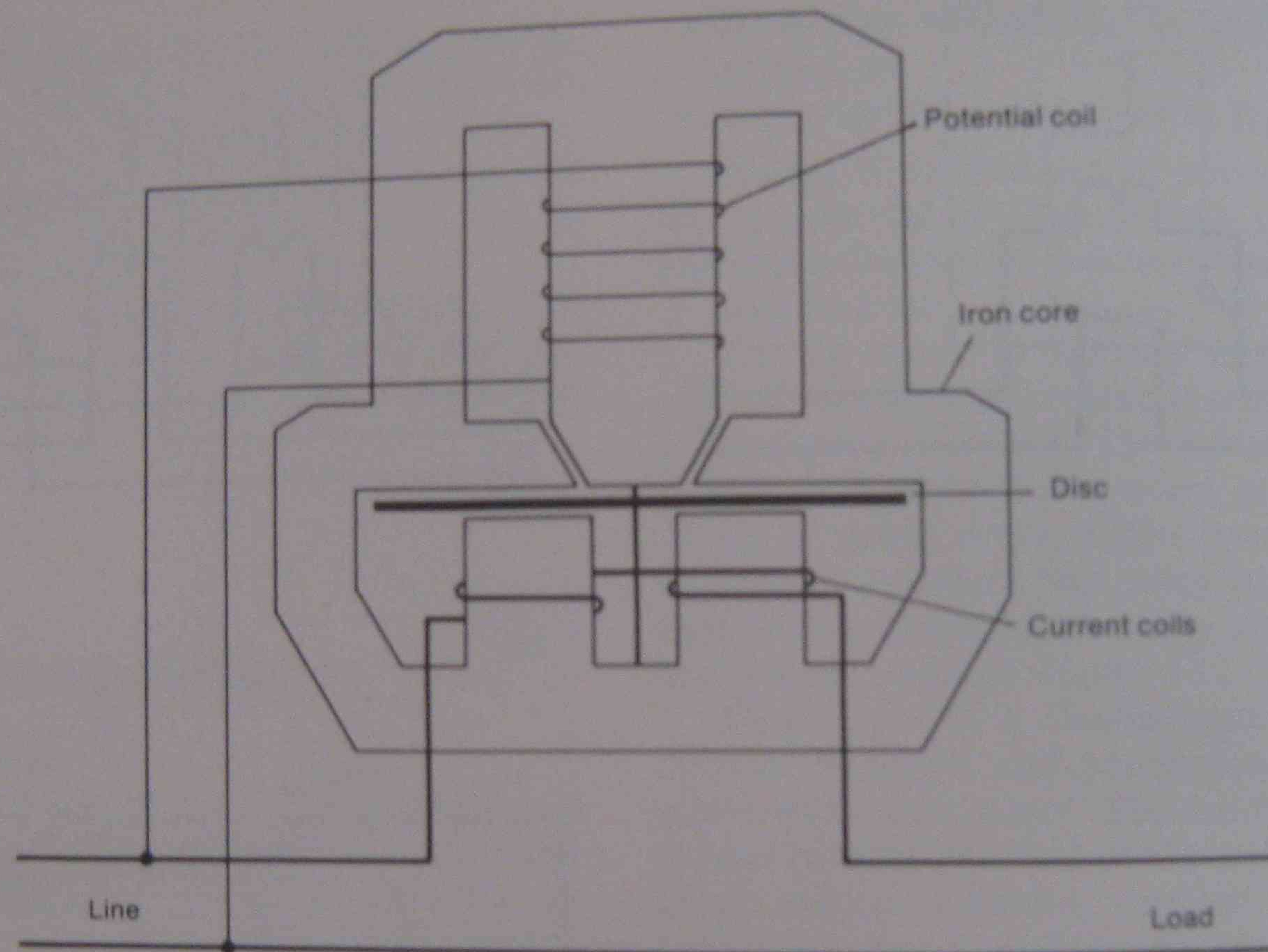


Fig. 17.4 *Single-phase watt-hour meter electromagnet and connections*

demand is used, the assessment is determined by the indication of a separate maximum demand indicator (MDI). The indicator has two pointers, one of which is operated by the meter movement and which indicates demand of the installation at any given time, and one which is friction-held in position and pushed up the scale by the moving pointer. This arrangement causes the friction-held pointer to be finally left in the position of maxi-

There is usually a delay period of thirty minutes built into the meter to prevent transient or short-term loads affecting the indication, the indicated demand being the mean demand of the previous thirty minutes. If this mean demand exceeded the demand as shown by the friction-held pointer, it would be pushed further up scale to show the increased demand. The friction-held position and pushed up the scale by the moving pointer. This arrangement causes the friction-held pointer to be finally left in the position of maximum indication of the moving pointer, thus indicating maximum demand of the installation.

up scale to show the increased demand. The friction-held pointer is usually reset to zero by the meter reader each quarter.

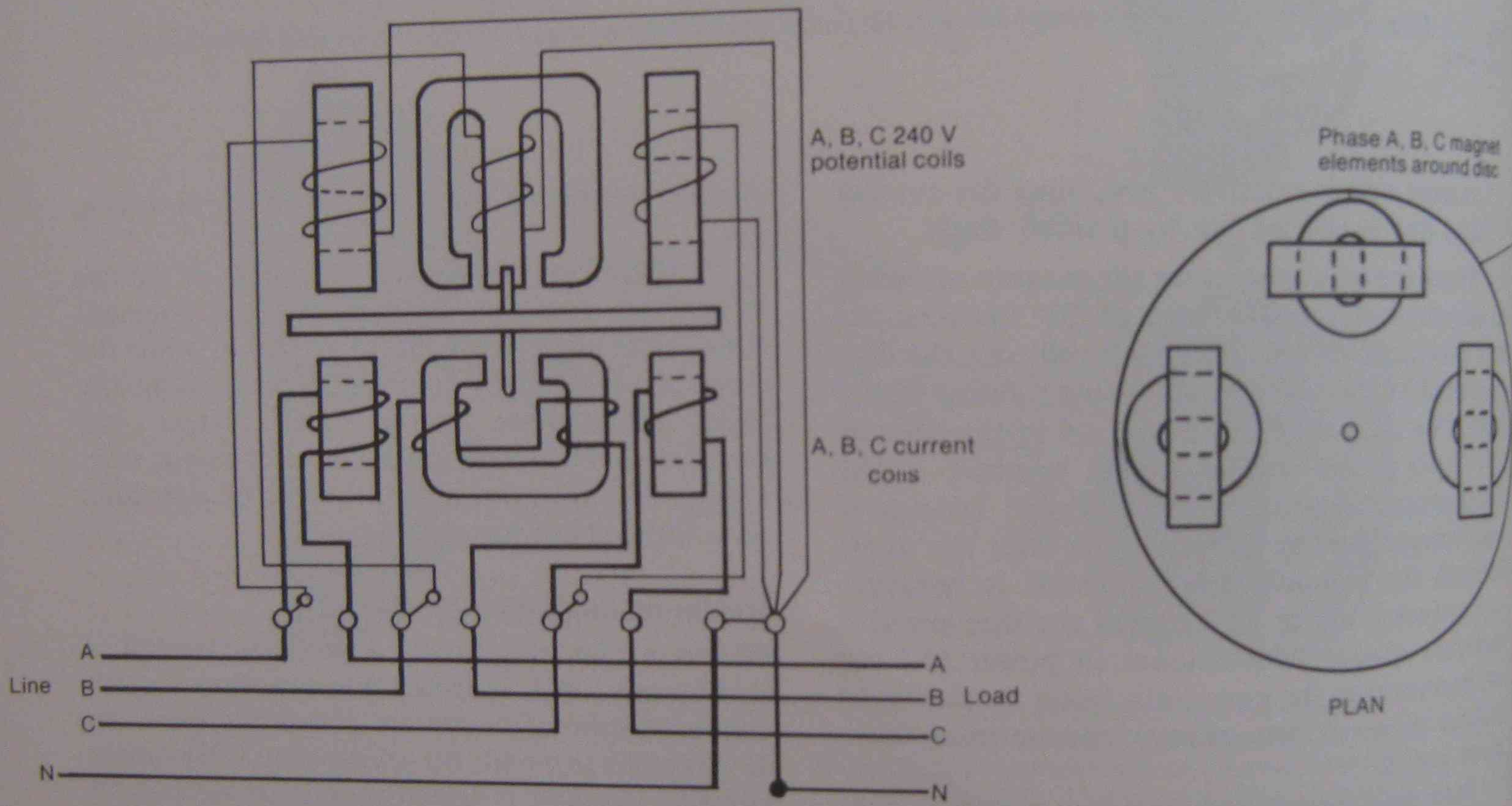


Fig. 17.5 *Three-phase meter principle*

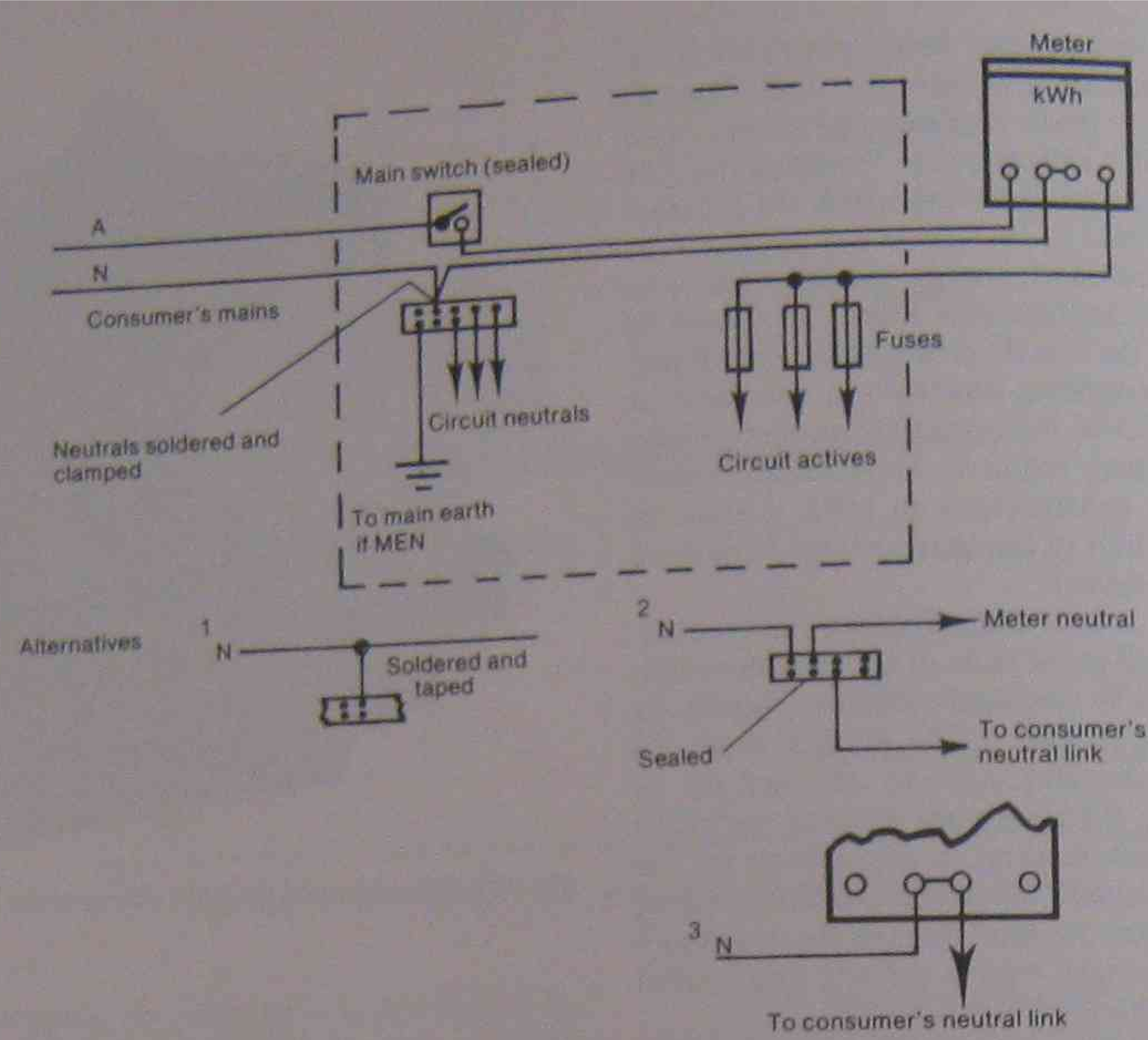


Fig. 17.7 *Single-meter tariff arrangement for general light and power supply*

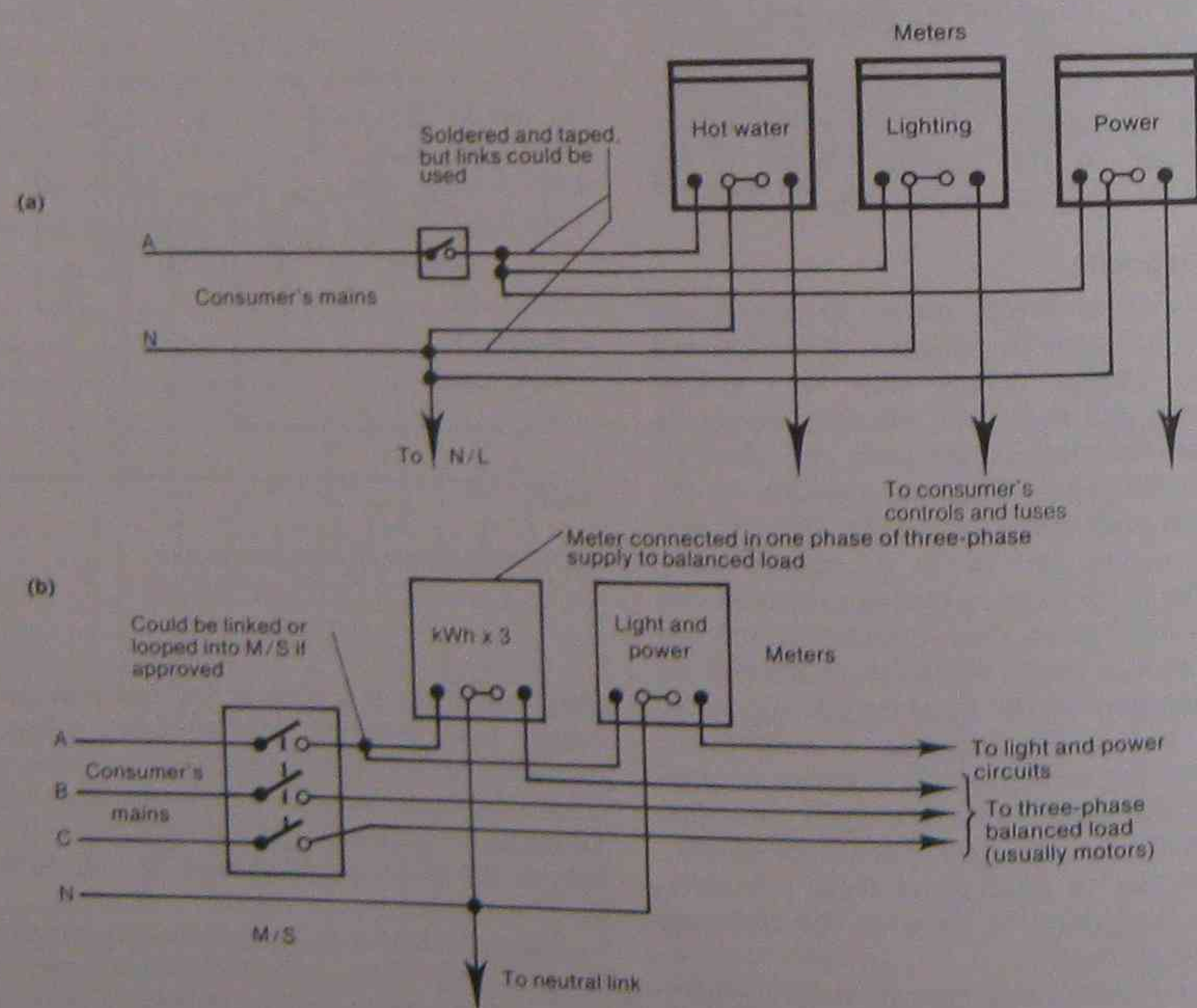


Fig. 17.8 **(a)** *Single-phase three-part tariff* **(b)** *Metering of a three-phase balance load using one single-phase meter*

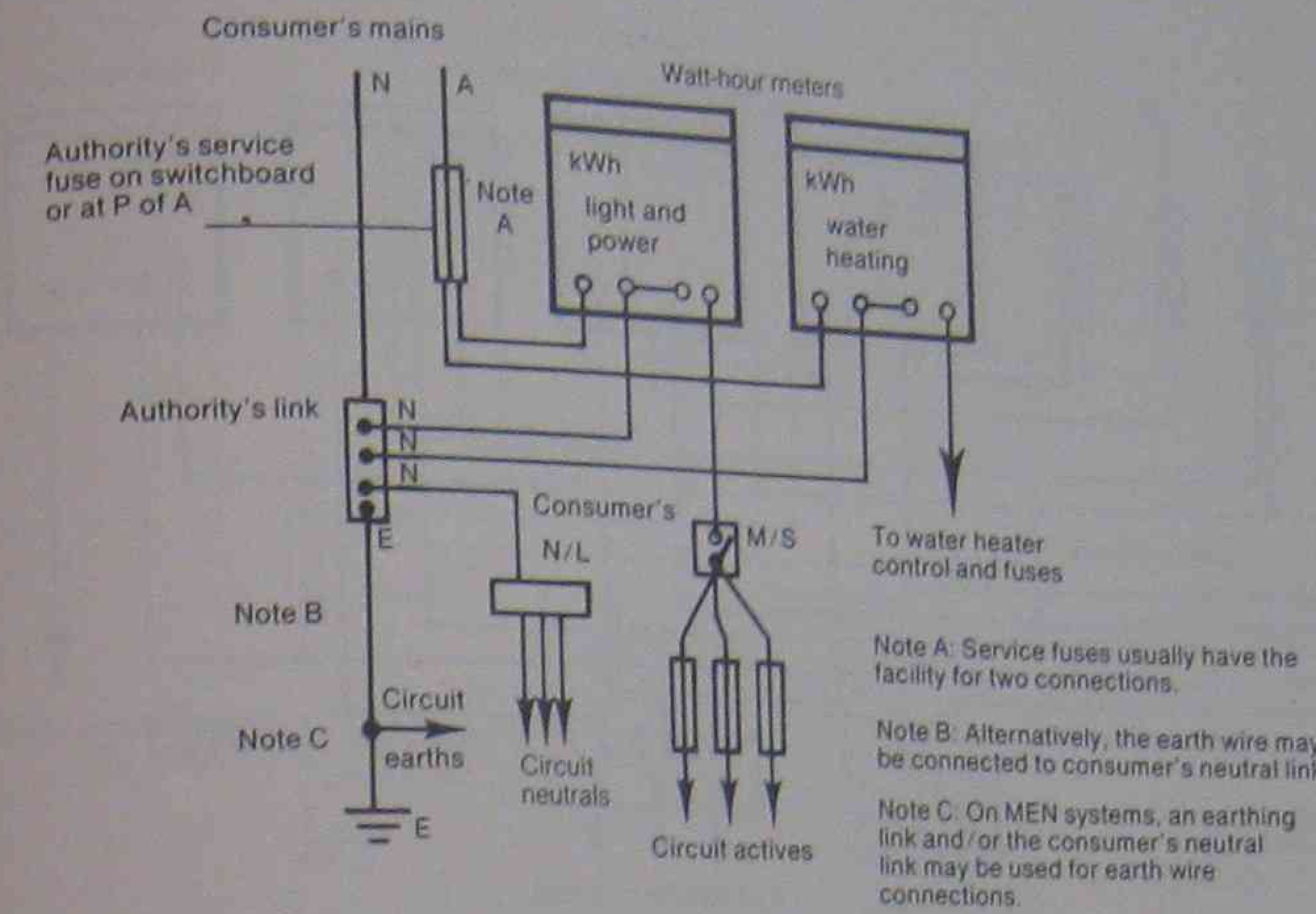


Fig. 17.9 *Simple two-meter (two-part) tariff*

Note the alternative connection arrangements. The methods employed depend upon the supply authority's requirements. Figures 17.8(a) and (b) show soldered joints at common connections. Not many supply authorities use this system, the majority prefer links which provide ready means for testing and for alterations or additions.

Figure 17.8(b) illustrates control and metering to a small three-phase installation on single-rate general tariff with a special rate for the **balanced** three-phase motor load.

When assessing the energy used by the motor load, the reading of the single-phase meter, connected in one phase, is multiplied by three. This is why the meter is often termed a k3 or M3 meter. This method for metering a balanced three-phase load is utilised by some authorities for the type of installation in which there is no possibility of unbalanced conditions, e.g. farm motors in rural areas.

In the previous examples, the main switch is sealed and connected on the line or supply side of the metering. This system is employed by some authorities and should be studied, but a system more widely used is one in which the main switch is connected on the outgoing or **load side** of the meters and thus controls **only** the consumer's equipment. Note that with this system, which is the most common, no control is provided on the incoming supply side. The practical aspect is that with the main control "off" the incoming terminals are still "live", and to isolate them from the supply requires withdrawal of the supply authority's service fuses, which are sealed. Protection for the supply authority's equipment is provided by the service fuses, which are usually installed either on the main switchboard protecting the metering and auxiliary equipment only, or at the point of attachment, in which case the consumer's mains will also be protected. Sometimes they are installed at the street pole, providing protection for service lines in addition to consumer's mains, metering and auxiliary equipment. The system is illustrated in Figure 17.9.

For a mixed single-phase and three-phase loac or a high-demand single-phase load balanced ove three phases, a polyphase meter or three single phase meters are required.

Figure 17.10 illustrates typical connection using single-phase meters.

Use of single-phase meters provides a flexibl system for additions, alterations or disconnec tions with minimum disturbance and reduces th number of meter types held in store, but on th other hand the polyphase meter is space-saving i installation and although not as popular as th single-phase system, it is still widely used. Figur 17.5 shows that in principle it is the equivalent o three single-phase meters whose elements act on common disc. Figure 17.11 shows typical con nections for polyphase metering of a three-phas mixed load and an additional single-phase mete for the special rate.

Some authorities use a **two-phase** meter o three-wire supplies of two phases and neutral (se Fig. 17.12). This should not be confused with single-phase three-wire supply such as the 480 SWER system, metering connections for whic are shown in Figure 17.3(b).

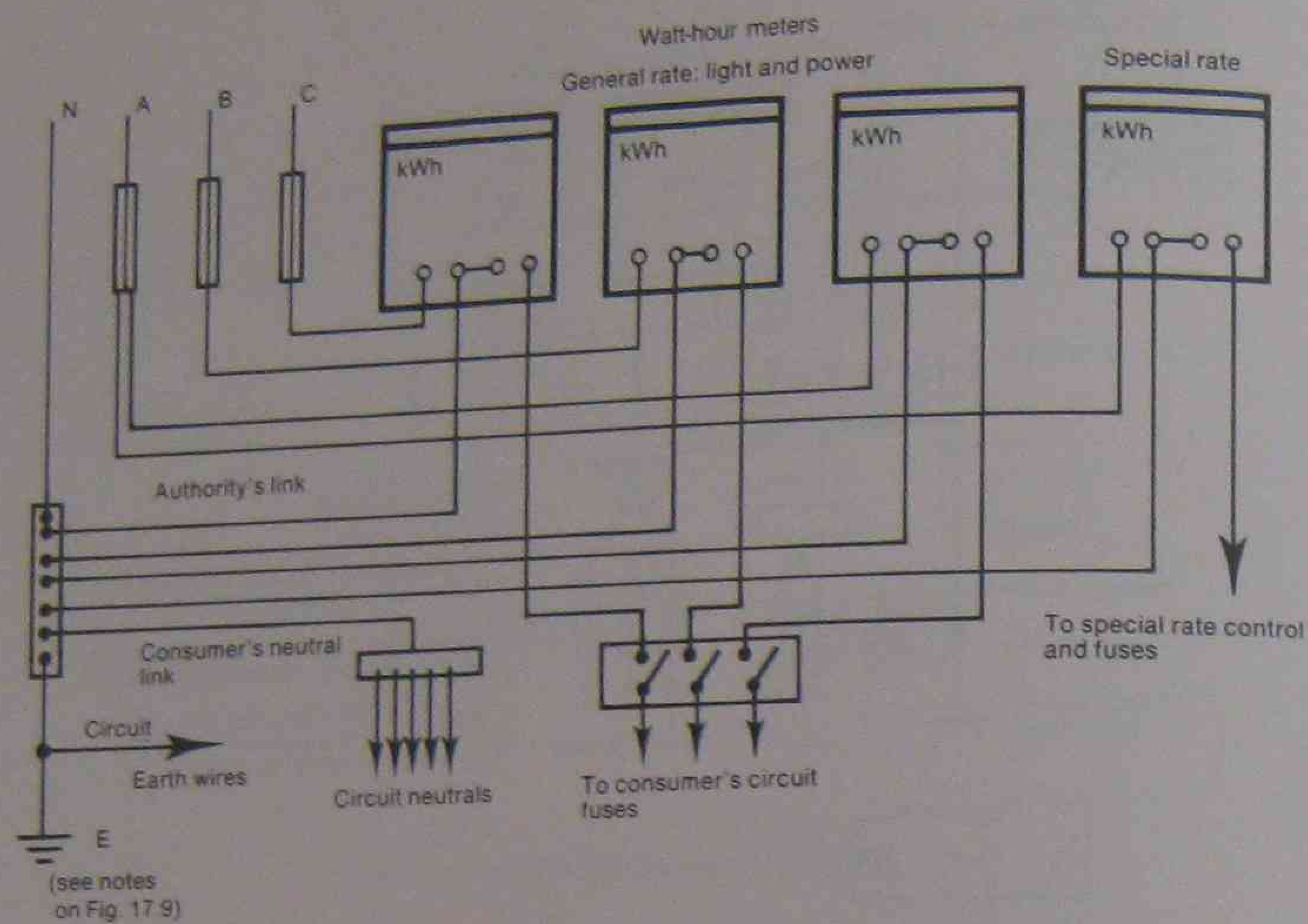


Fig. 17.10 *Mixed three-phase load with four single-phase meters*

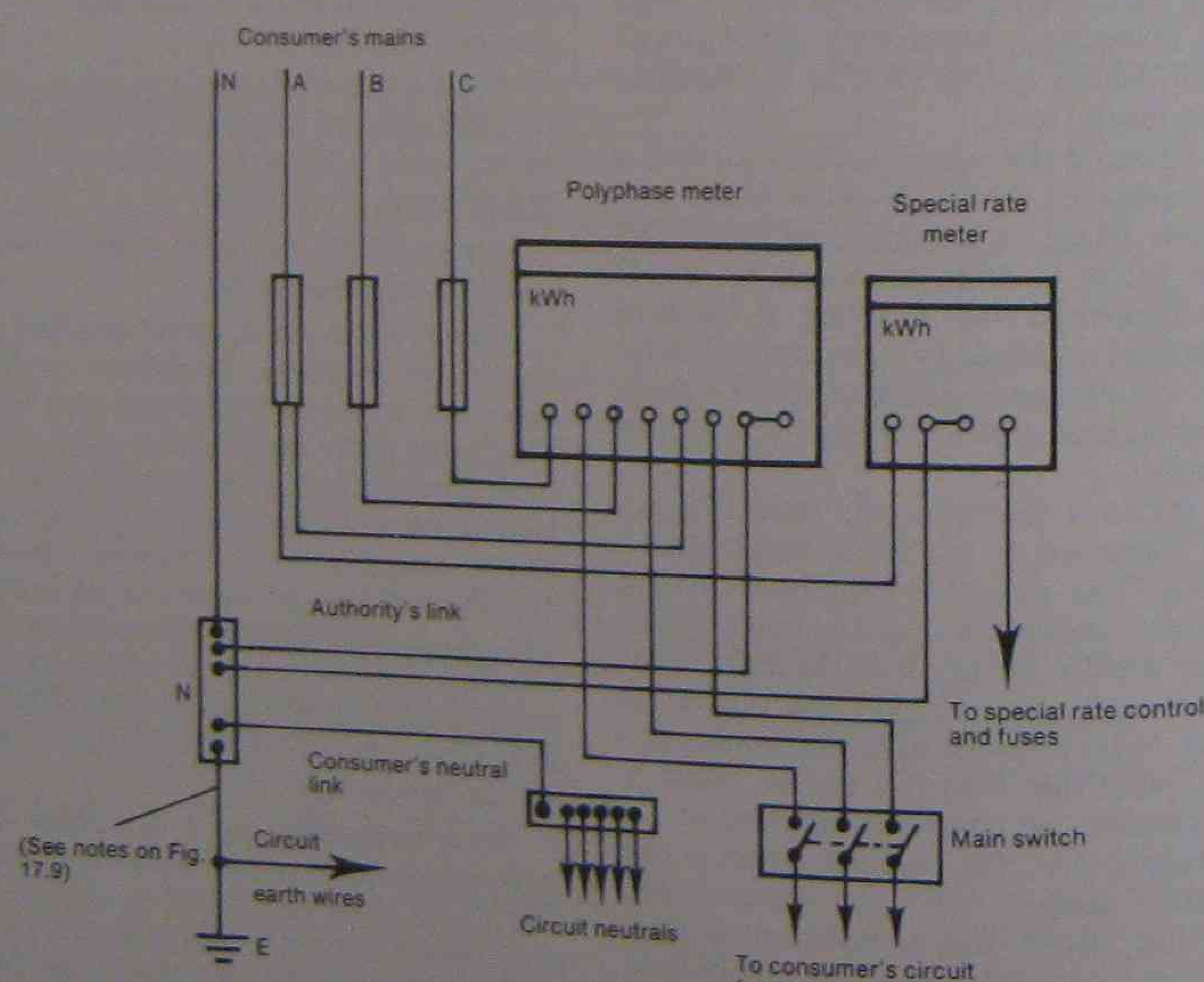


Fig. 17.11 *Three-phase metering with a polyphase meter*

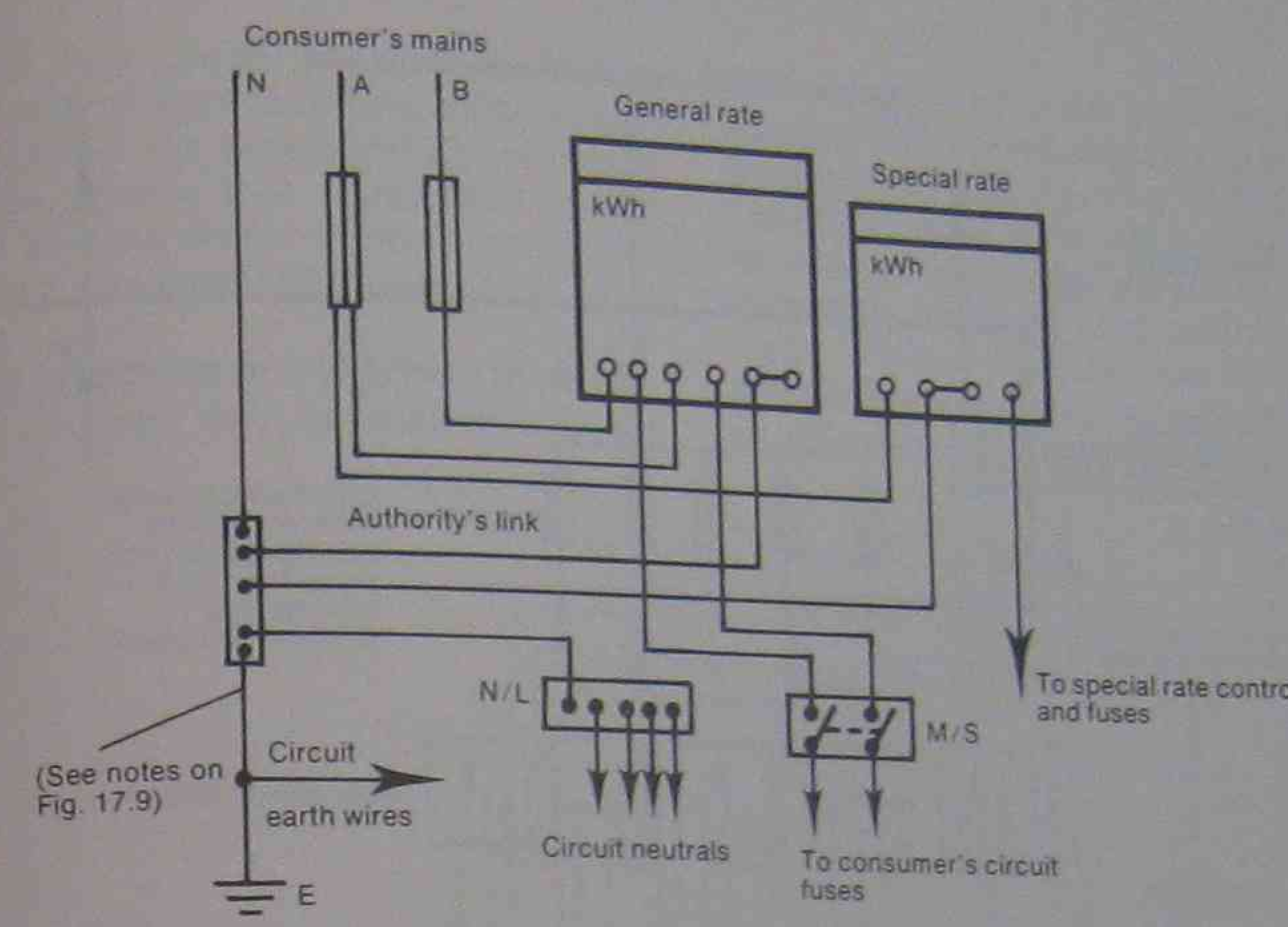


Fig. 17.12 *Two-phase metering with one meter, and a separate single-phase meter for special rate tariff*

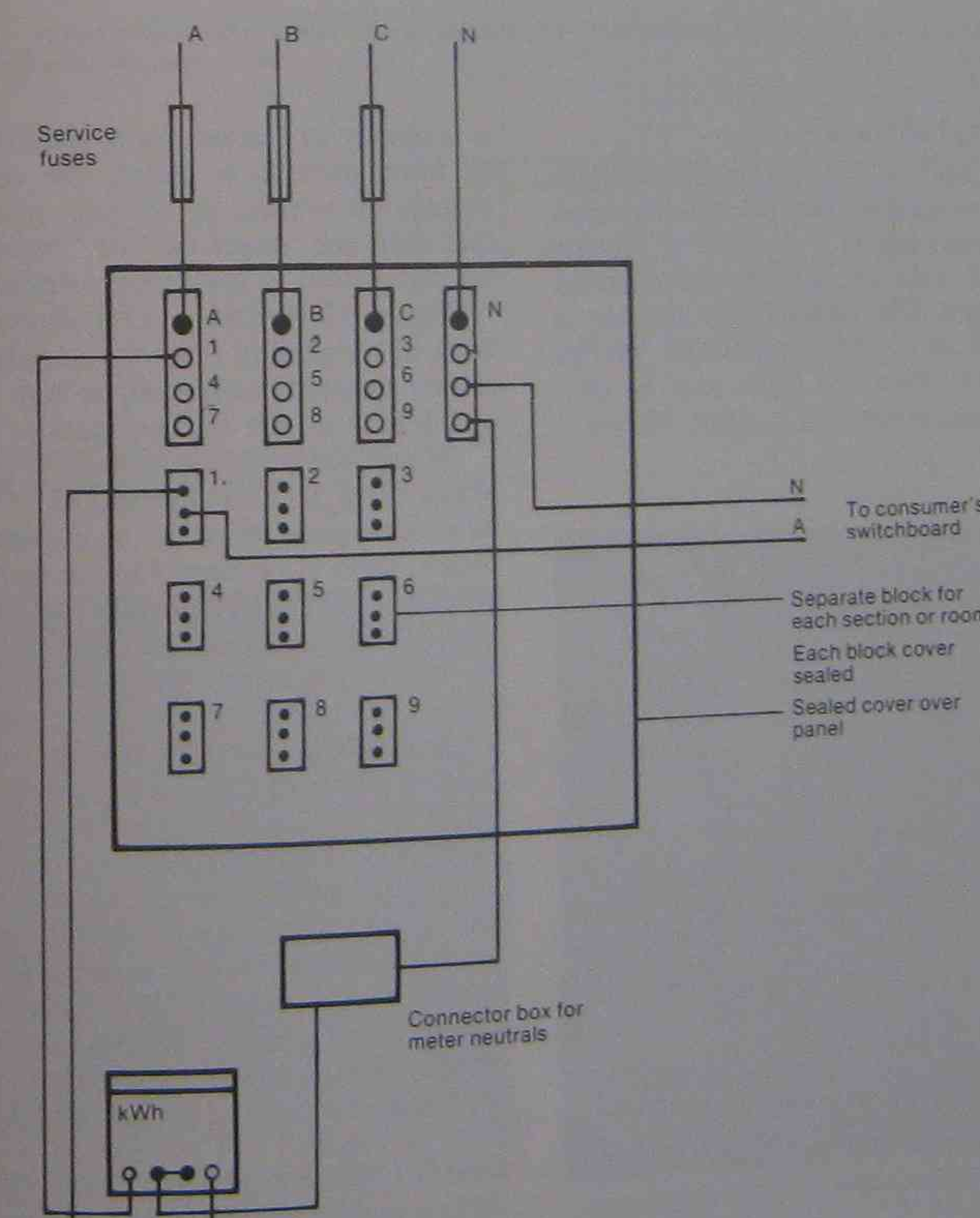


Fig. 17.13 *Paralleling links for multi-occupied buildings*

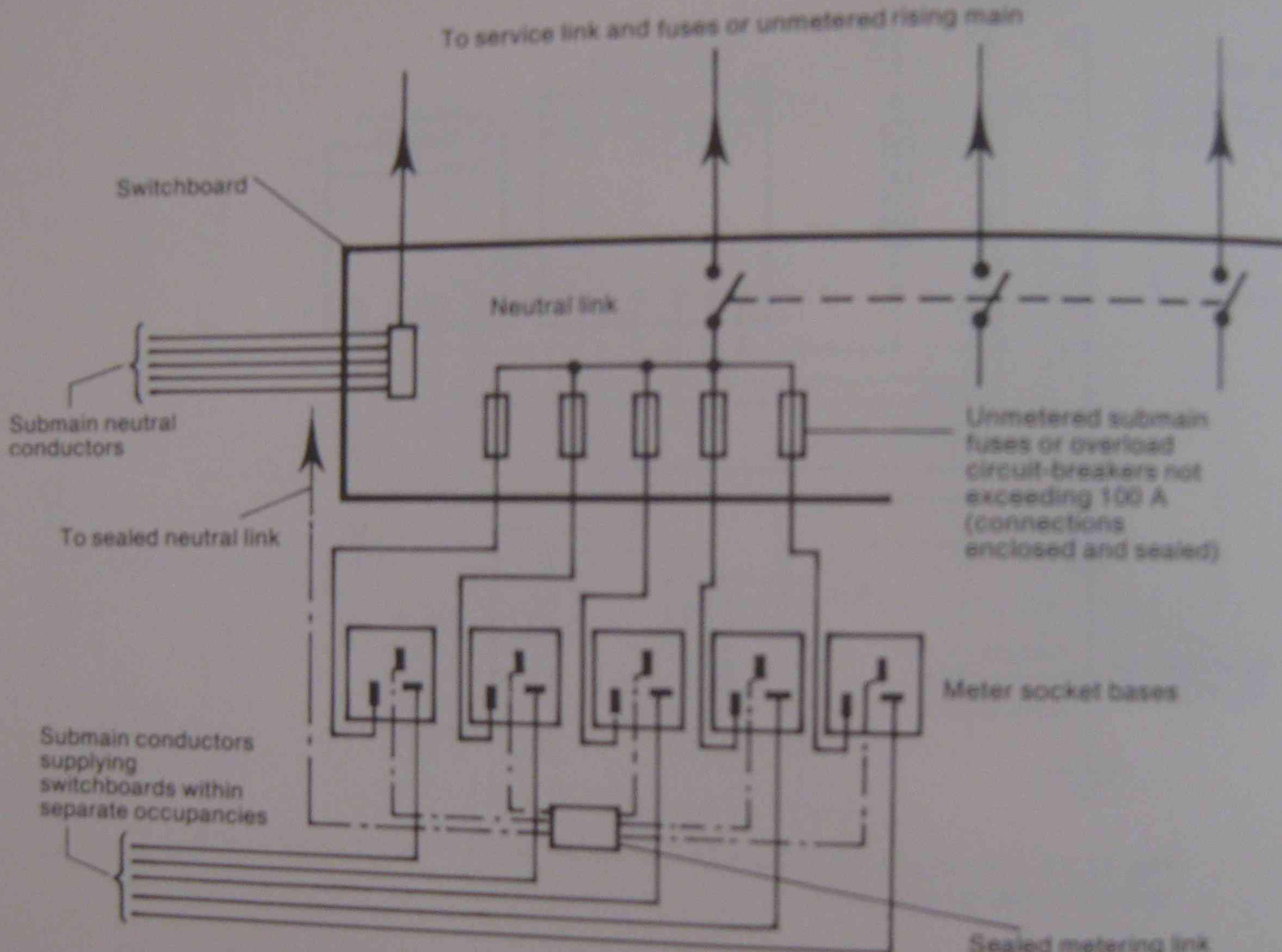


Fig. 17.14 *Schematic diagram showing meters connected on load side of submain protection*

Adapted from diagram supplied by SCC

Multi-occupancy buildings

In installations such as multi-occupied buildings where changes of tenancy and the area occupied by customers takes place ...

is necessary to connect more than one portion of an installation to a meter, the consumer shall arrange the ... of links, so

The meter socket bases, which have to be provided by the customer have terminals suitable for

... the moulded retaining ring and sealable screws are provided and fitted by an officer of the supply authority.

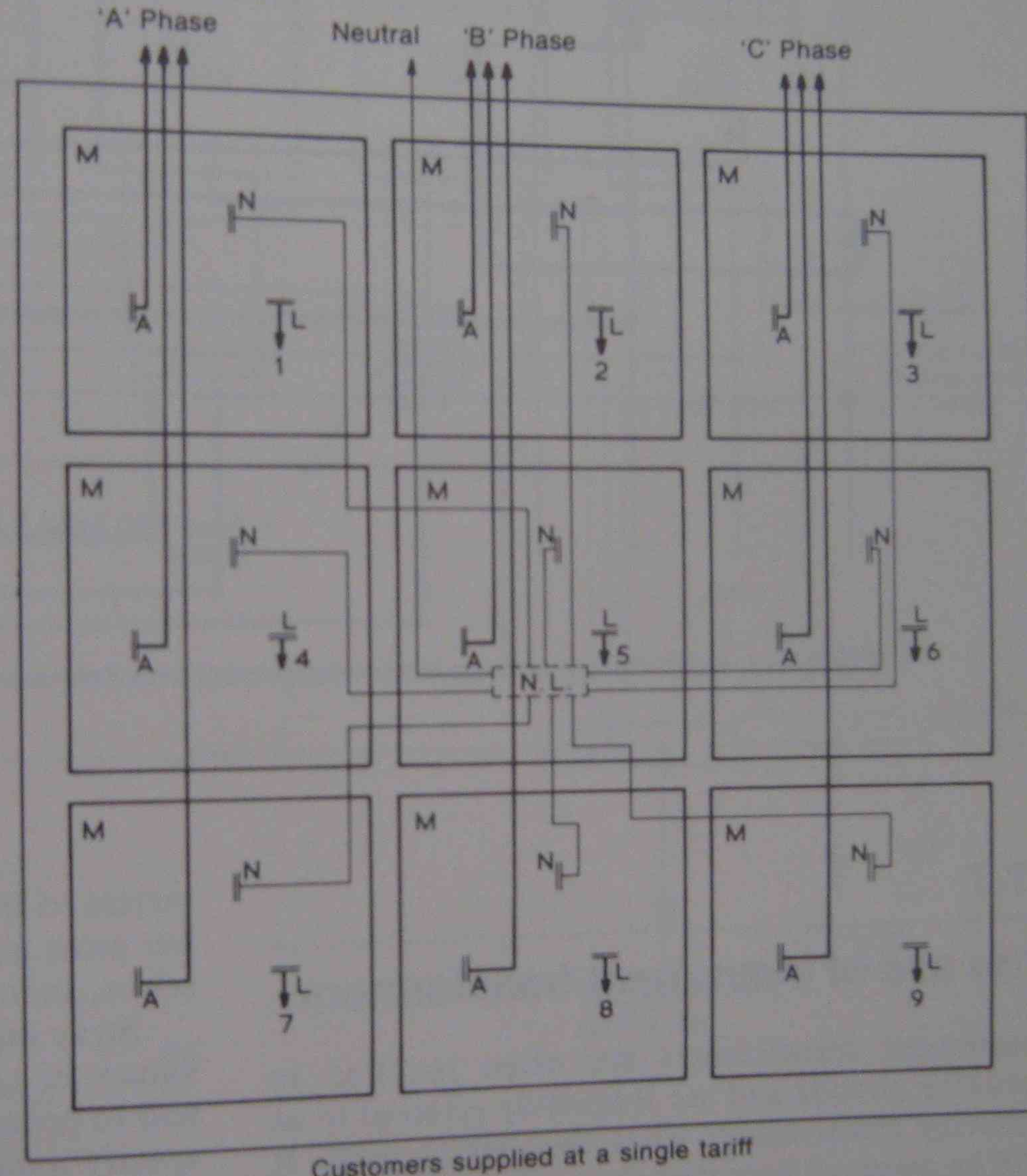


Fig 17.16 *Multiple installation meter panel module — layout and diagram of connections*
SCC

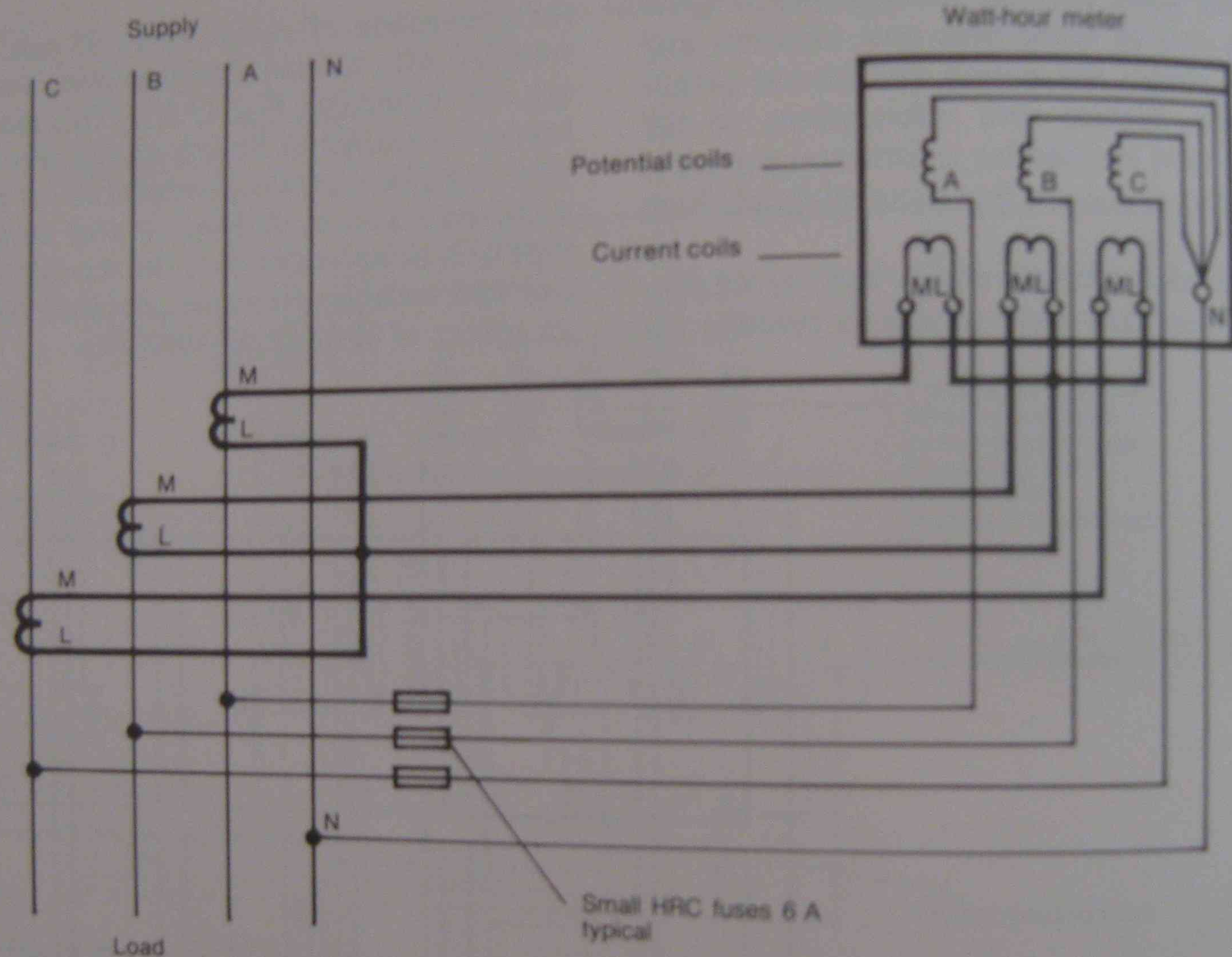


Fig. 17.18 *Metering a polyphase load using current transformers and a polyphase watt-hour meter*

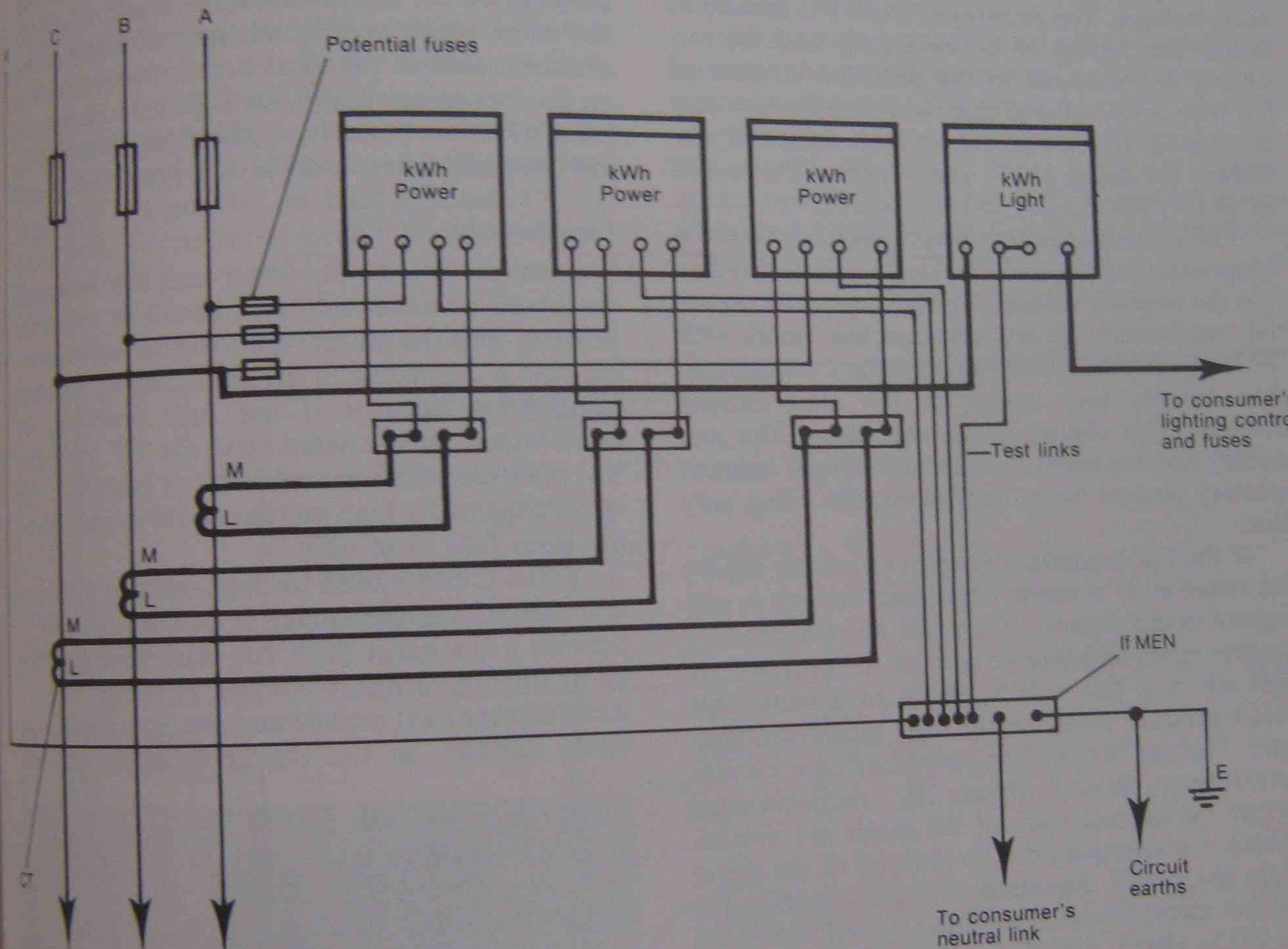
17.7

our meter

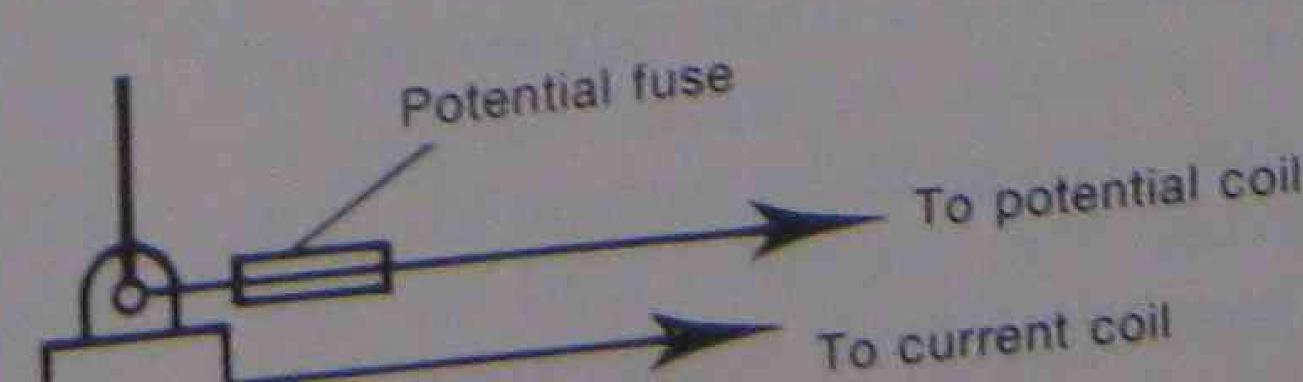
lectrical contractor, is equipment them- tion purposes.

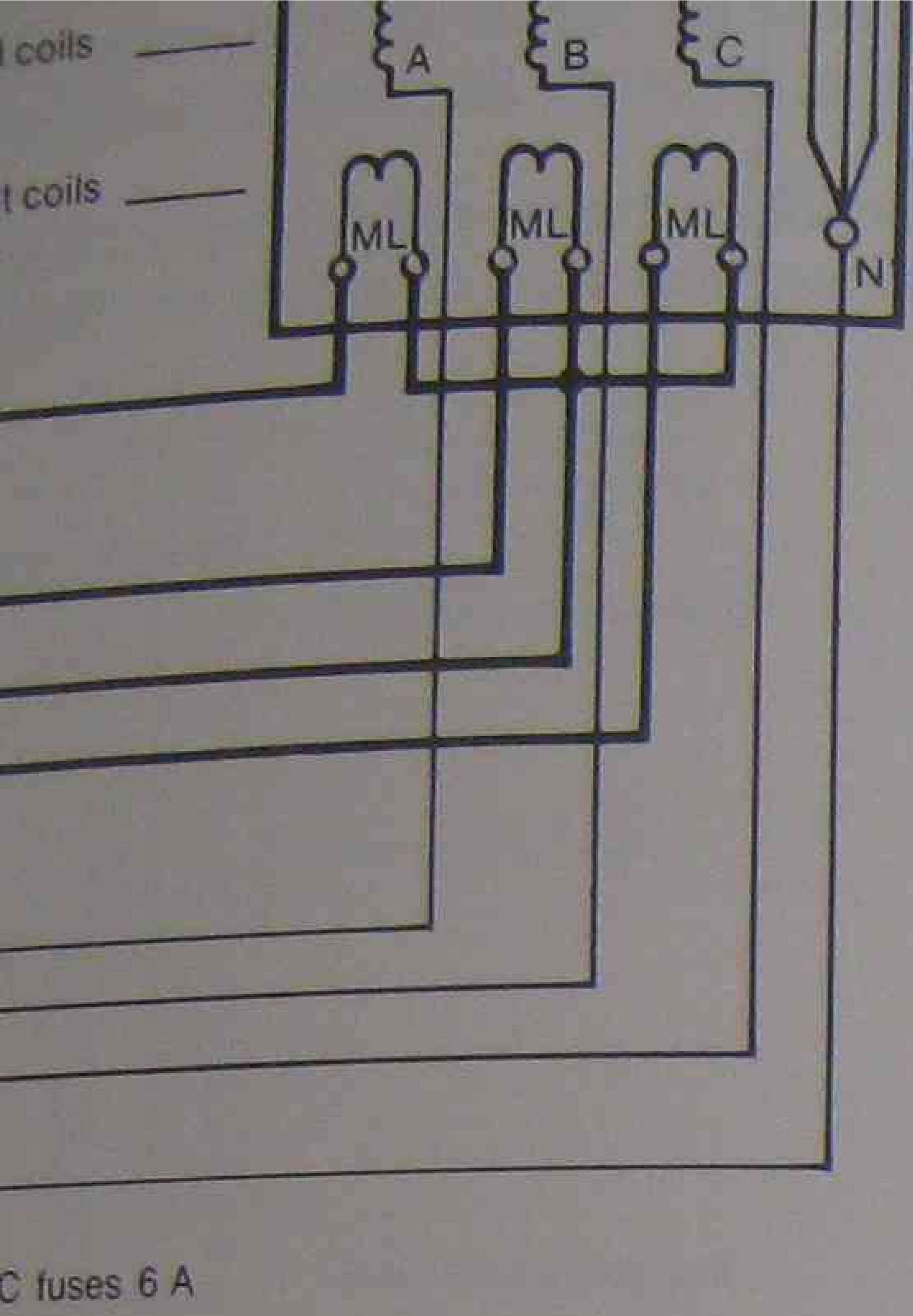
iced by high current affect the metering, service rules usually between meters and h values of current. ds upon the supply elow are quoted as

pacing
pacing 600 mm
pacing 900 mm
1200 mm



(a)





sformers and a polyphase watt-hour meter

ers to be supplied by the electrical contractor, most authorities supply this equipment them-es, mainly for standardisation purposes.

Stray magnetic fields produced by high current ues in conductors could affect the metering, to prevent this occurring, service rules usually cify a minimum clearance between meters and se conductors carrying high values of current. spacing required depends upon the supply hority, but those given below are quoted as cal.

Up to 100 A: no special spacing
100 A–200 A: minimum spacing 600 mm
200 A–500 A: minimum spacing 900 mm
500 A–1000 A: minimum spacing 1200 mm
1000 A–2000 A: minimum spacing 2400 mm

The spacing does not apply to conductors that not radiate an external magnetic field (such as current-carrying conductors of a three-phase le) or where the conductors are enclosed in a l conduit or pipe.

The supply authority will also specify both the e and size of "meter wiring" and the method installation for CTs and connecting cables or bars. One provision common to all authorities hat the meter wiring must not be associated h any other conductors and to prevent inter-ence it must be enclosed, usually within a

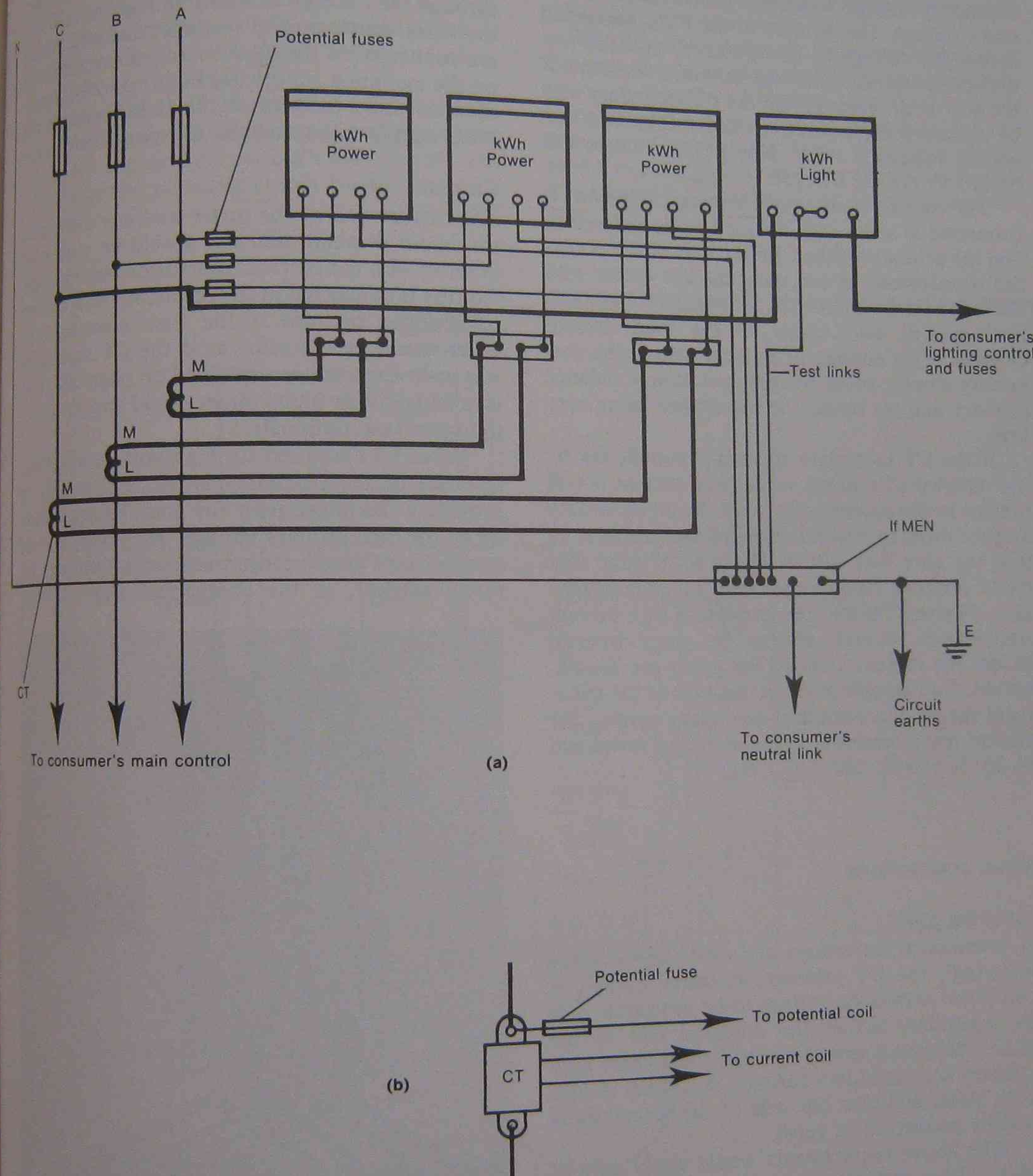


Fig. 17.19 **(a)** *and* **(b)** *Metering a polyphase load using single-phase meters on a two-part tariff*

be measured, and the ...
the potential element of
that the PT secondary may
erse effects. Standard sec-
, hence typical ratios will
10 . . . etc.
rmer primary, however, is
the load to be metered so
, unlike that of the poten-
constant but varies with
the secondary voltage and
es as the load current
f current causes the sec-
vary and almost balance
he impedance being very

is open-circuited, say by
while load current is still
here will be no secondary
those of the primary, so
uild up to a value that
sly high secondary volt-
e secondary of a current
vays be short-circuited
of the meter are discon-
to removal of the meter
d secondary current for
A, and typical ratios will
. . etc.

are used (high-voltage
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ry fault could cause high
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otential transformers are
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nt transformers are used,
e available at the meter
to the potential coil of
ought out and connected
propriate phase active. If
in this meter wiring, the
nly be limited by the

are connected to the nearest convenient positions on the incoming supply. In Figure 17.20 the position of these fuses is at the links between the HRC supply fuses and the CT panel below.

Current coils

The current coil of the meter and any associated maximum demand indicator would be connected in series with the current transformer secondaries. No fuse is connected in the secondary of a current transformer because if the fuse operated, the effect would be the same as if the CT secondary was open-circuited as explained on page 000, that is, a dangerously high voltage could appear across the open fuse terminals.

When CTs are used for high-voltage metering, one side of the secondary is earthed, mainly to provide a discharge path for static charges built up by the high primary voltage. However, current transformers used on low and medium voltage are rarely earthed, as the charge build-up at these

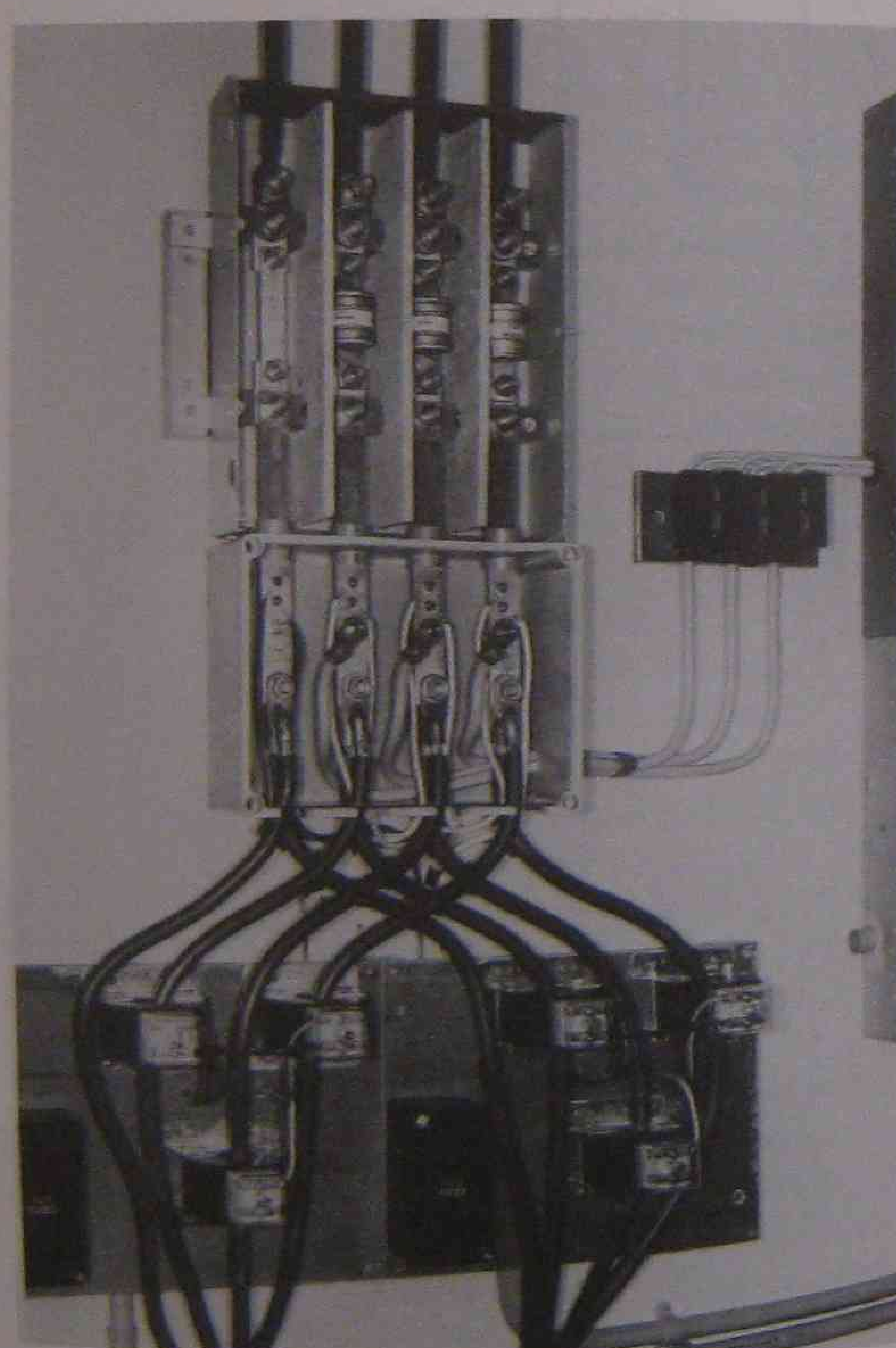


Fig. 17.20 *Current transformers in metering* SCC

meter ... ations (see Fig. 17.19(a)).

Figure 17.18 is diagrammatic to illustrate one type of connection for metering of polyphase load using star connections on both CT and PT circuits. Note the potential circuit fuses.

... diagrams have been included to illustrate the **principles** involved in metering connections. Supply authorities, however, provide actual wiring diagrams for metering both for reference and use within their particular supply areas; two such diagrams are shown in Figures 17.21 and 17.22. Figure 17.21 would be used for

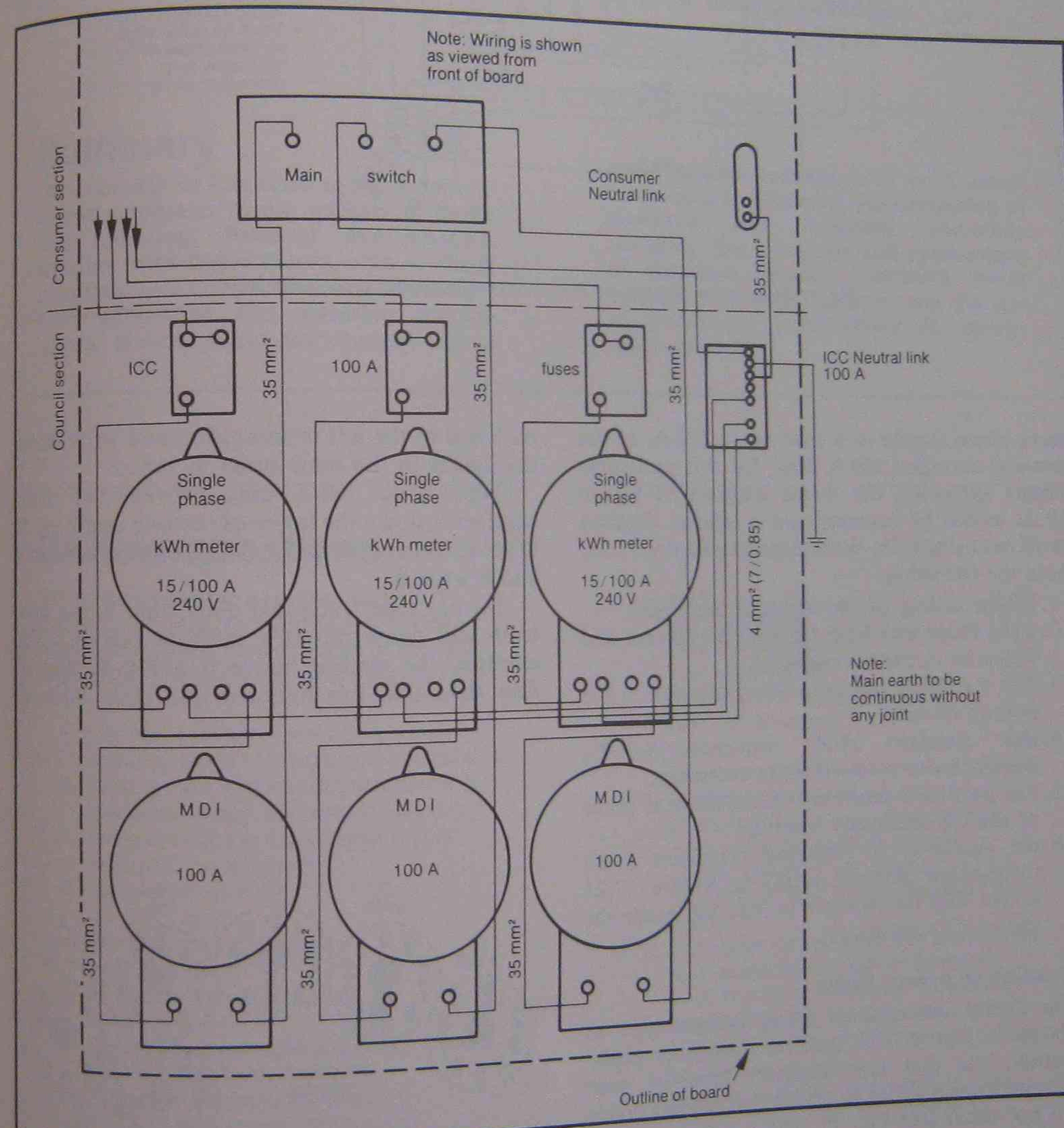


Fig. 17.21 *Metering diagram for three-phase supply with MDI. 100 A maximum* ILLAWARRA COUNTY COUNCIL

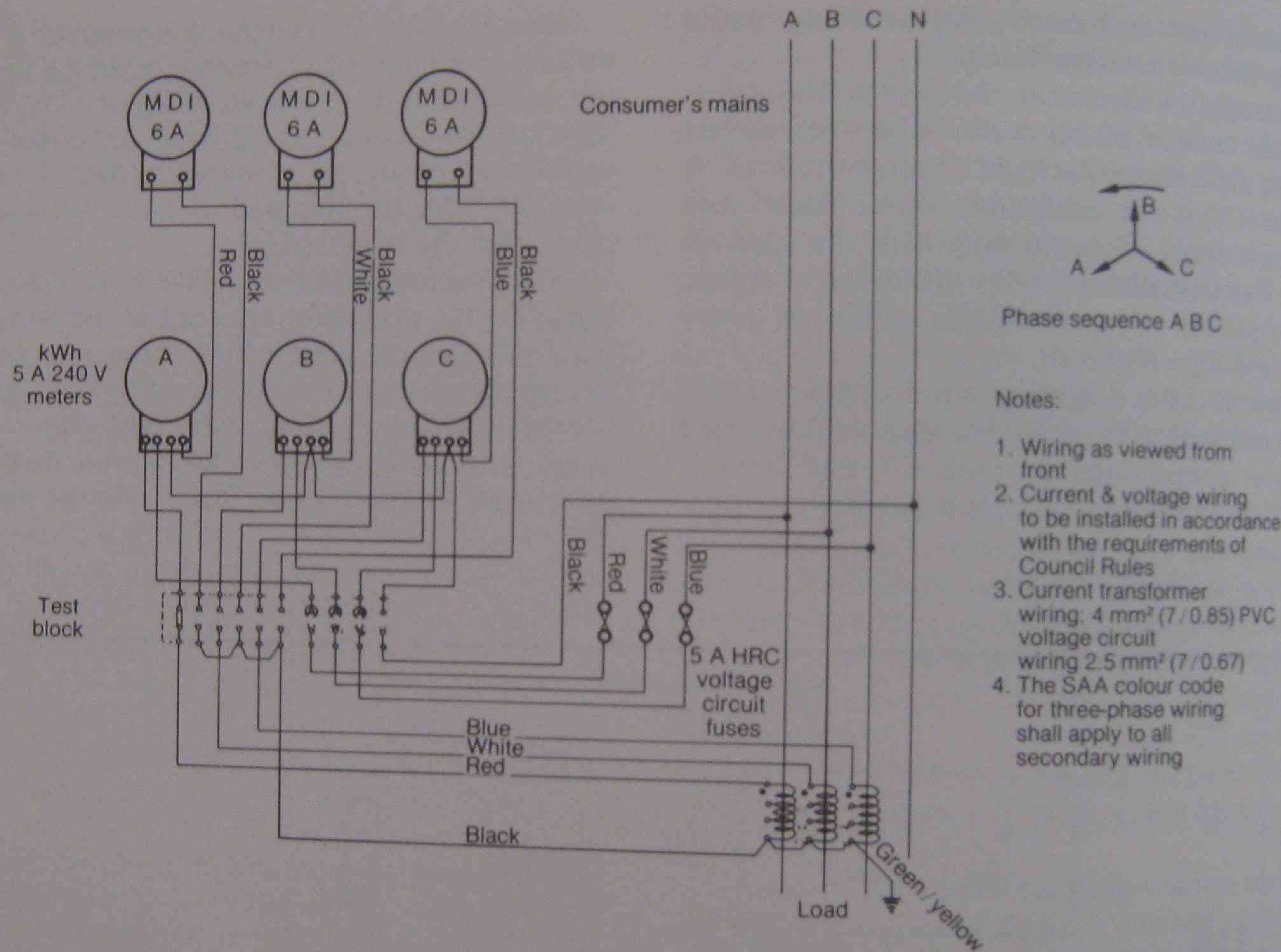


Fig. 17.22 *Metering diagram for three-phase CT metered supply with MDI*

ILLAWARRA COUNTY COUNCIL

three-phase supply to a load up to 100 A. If the demand exceeded 100 A then, for this particular supply authority, the wiring diagram of Figure 17.22 would be necessary on a similar demand tariff but using CT

each dial to the left in succession and write down the figures in the same order as read.

When a dial hand points between two num-

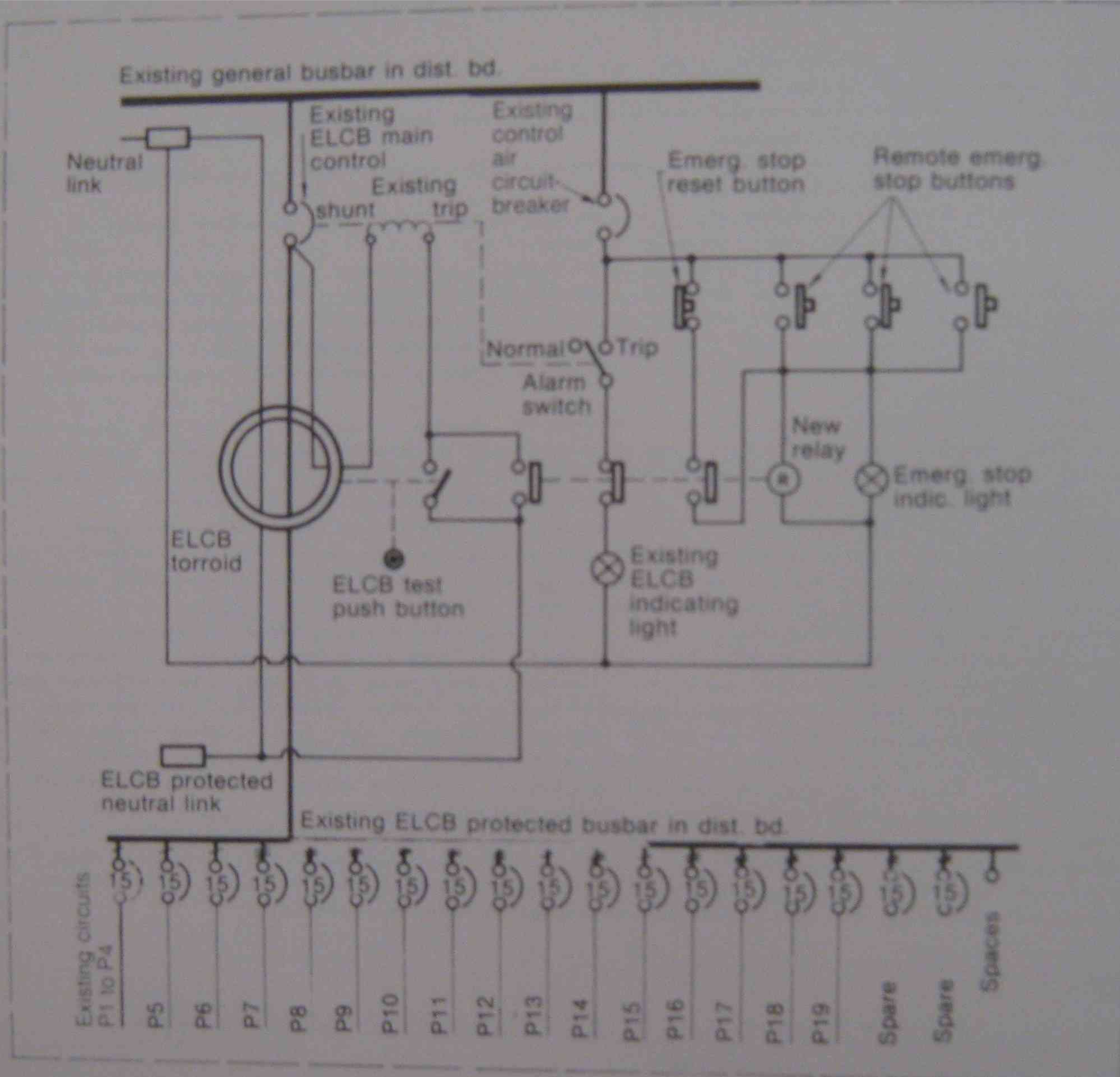


Fig. 21.7 *Single line diagram of additions to a distribution board*

NSW DEPT OF TAFE

Because the voltage ratings of most appliances and lamps are similar, it follows that the parallel connection is the one commonly used for ordinary wiring. There are many examples of parallel

In the older-style airport runway lighting circuit illustrated in Figure 7.4(c), a constant current of 6.6 A in the circuit is maintained by a special variable voltage transformer. If a lamp burns out (open circuits) a special film installed in the base

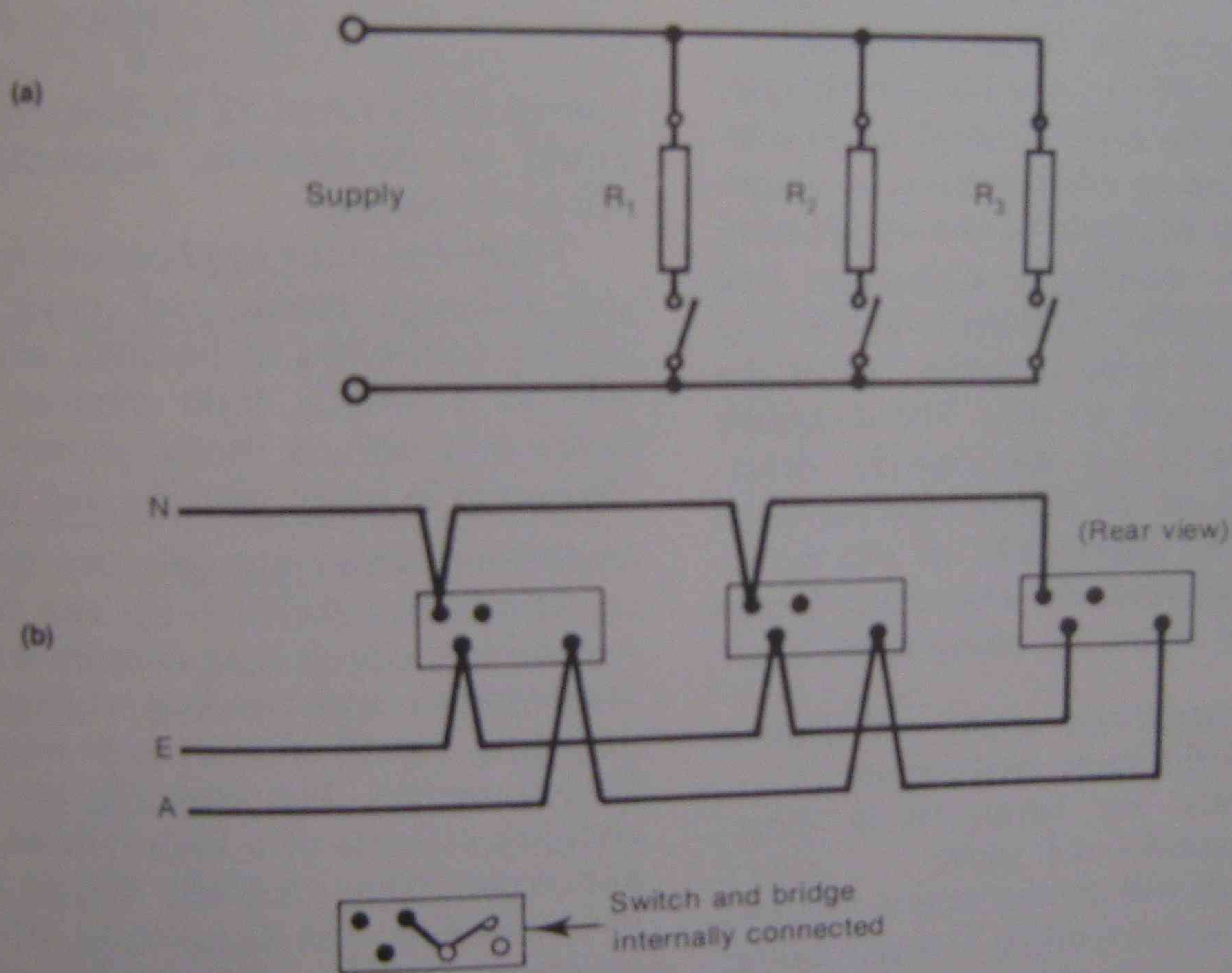


Fig. 7.3 *Parallel connections:* **(a)** *Three resistors in parallel* **(b)** *Three power outlets in parallel*

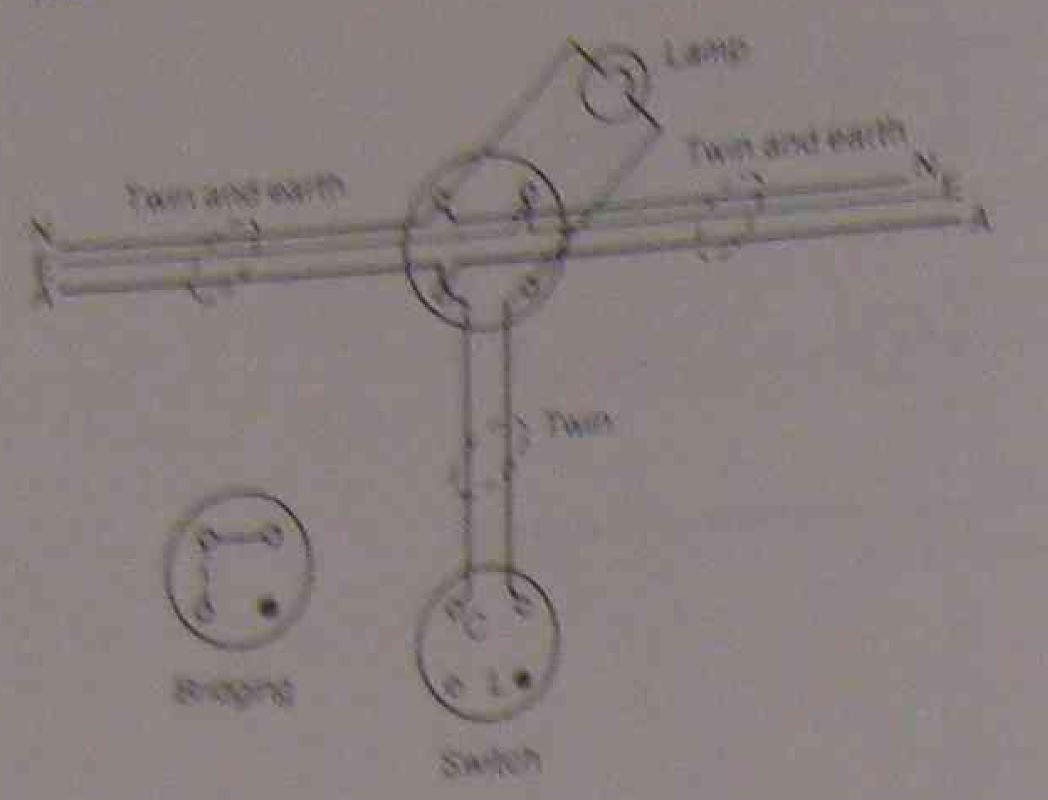


Fig. 7.7 (a) Looping-in at batten holder or ceiling rose — looping terminal in switch not used

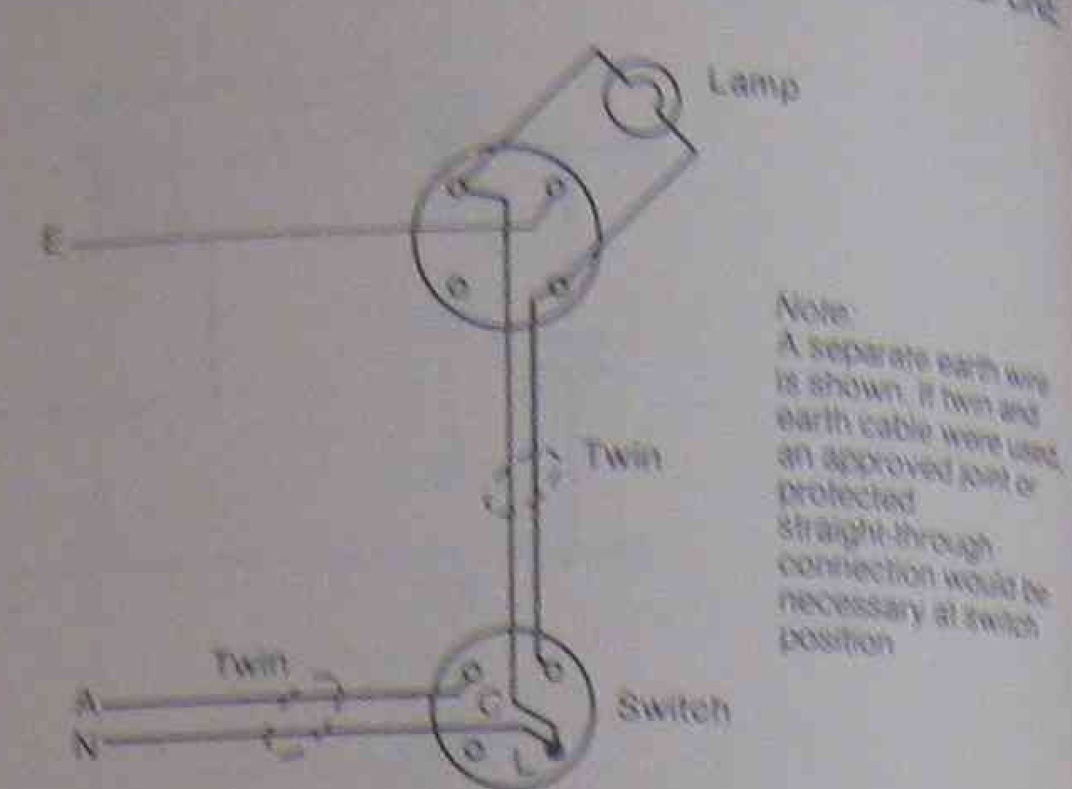


Fig. 7.7 (b) Looping-in at switch — looping terminal at batten holder or ceiling rose not used

Electrical installations in caravans and caravan parks, and *Clause 6.10* of AS 3000.)

For general wiring circuits, the "loop-in" system is the normal wiring method, and most modern wiring accessories such as switches, ceiling roses and batten holders are provided with a spare "looping" terminal for this purpose. The looping-in system makes the joins of conductors accessible at common terminals in these accessories, and obviates the use of multiple junction boxes. Junction boxes are usually less accessible and take longer to install. Junction boxes are still used, however, where convenient or expedient, but looping-in is the normal method and is preferred by most electricians and supply authorities.

In Figure 7.7(a) the looping terminal in a ceiling rose or batten holder is used, while in Figure 7.7(b) the looping is done at the switch.

The system of Figure 7.7(a) is the most common, and is employed both in thermoplastic-sheathed (TPS) cable wiring and with single-insulated PVC cables in PVC or steel conduit, where a "draw-in" job is required. Drawing in of cables is required in concealed wiring or conduit buried in a concrete screed, where elbows and tees are not used (see Fig. 7.8).

Figure 7.9 shows a system of wiring in conduit commonly used prior to the introduction of tough rubber-sheathed (TRS) and TPS wiring in domestic installations and in surface wiring for industrial installations.

Note here that the basic circuit of Figure 7.6(a) applies to all these circuits; it is only the method of wiring that is different, for example in Figures 7.7(a) and 7.7(b) the "looping" is done at **either** the light fitting or the switch, whereas in Figure 7.9 **both** the switch **and** light fitting are used for looping.

In Figure 7.10, all the joins are made in a junction box.

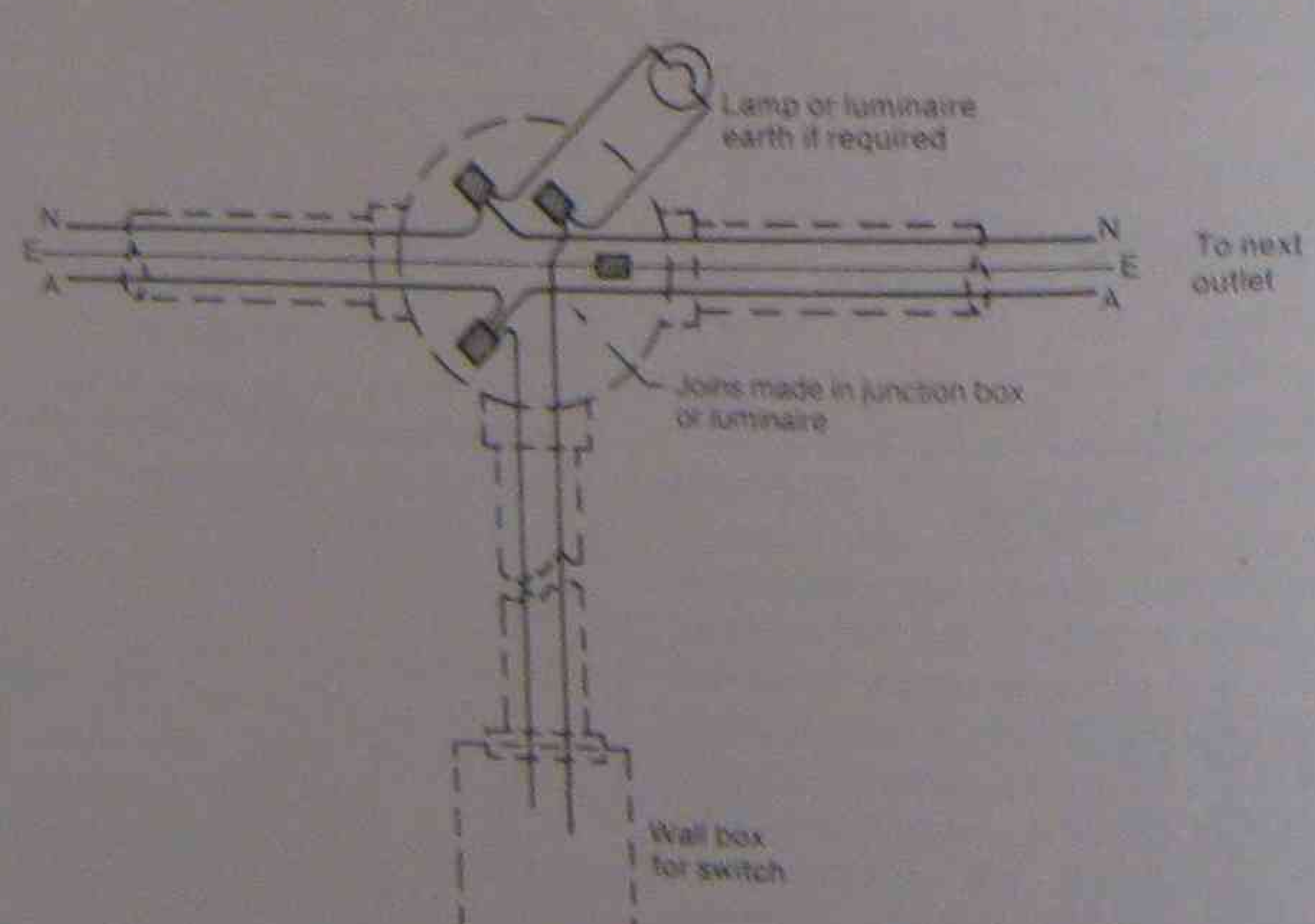


Fig. 7.8 Looping-in at accessible junction box or luminaire in a conduit system buried in concrete

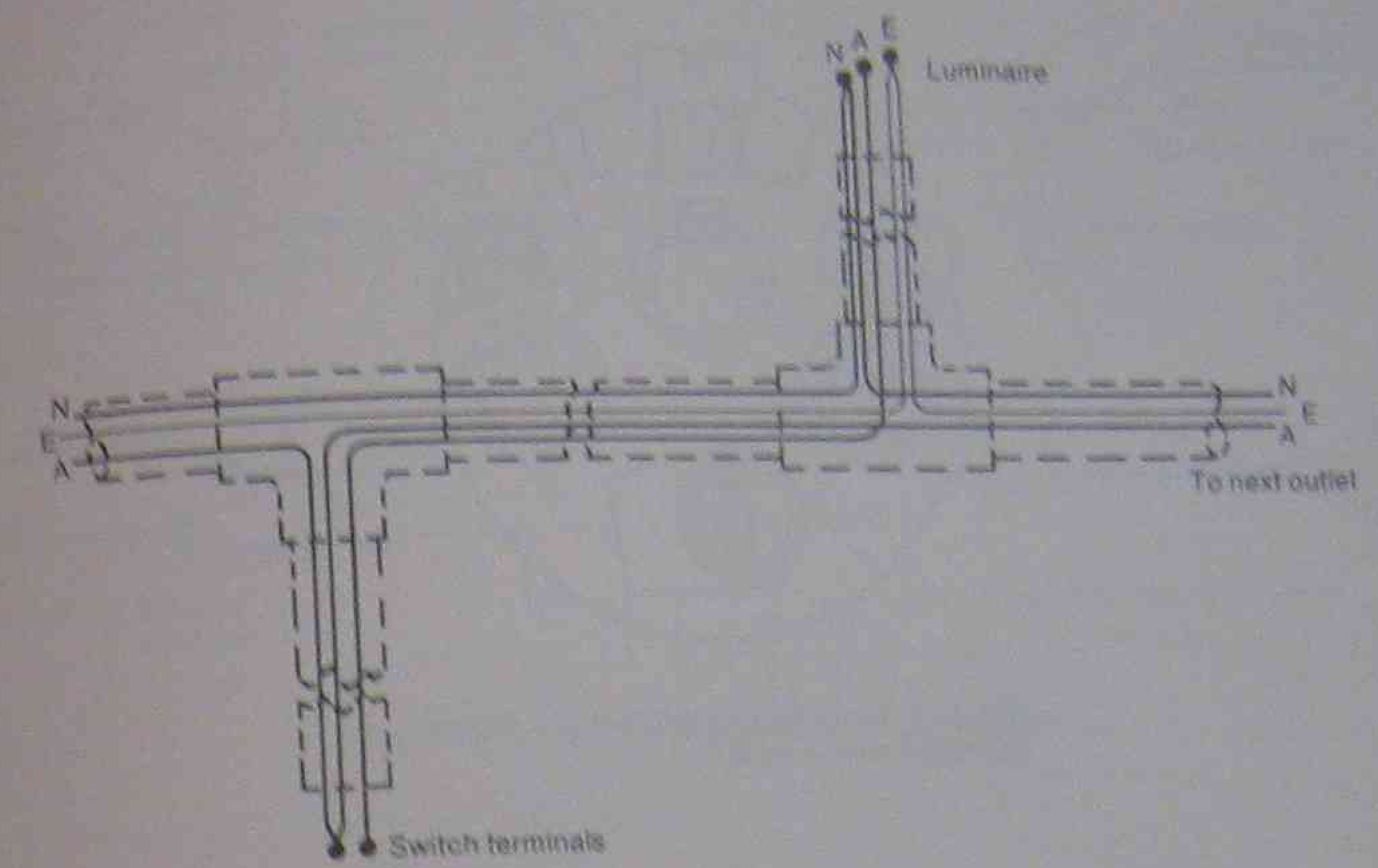


Fig. 7.9 In this surface conduit system, actives are looped at the switch and neutrals and earths at the outlet or luminaire

The looping-in system is usually preferable, but sometimes it is expedient to use a junction box provided in an existing installation or for "cutting-in" to the existing wiring, such as at point X in Figure 7.10. A junction box may also be used to avoid looping at a light fitting that does not provide for looping connections in its base, for example in some types of outside porch lanterns.

2. Control from two positions

Whereas the modern single-pole or one-way switch has two operative terminals plus a spare or looping terminal, the two-way switch used for control from two positions has three operative terminals, and usually a fourth looping terminal. The terminal connections for one type of modern two-way switch is shown in Figure 7.11. They are SPDT switches usually provided with a fourth (looping) terminal and are intended to be used either as a one-way or two-way switch.

Figure 7.12 illustrates (a) the basic switching action of the two-way switch and (b) the basic and most-used circuit for control from alternative positions.

Figure 7.13 illustrates an adaptation of the basic circuit to add the two-way facility to an existing circuit in circumstances where it is either not desirable or it is impracticable to disturb the existing wiring.

For any extra-low-voltage circuit (not exceeding 32 V ac or 115 V dc) such as signalling, indicator, communication, control or extra-low-voltage lighting, the circuit of Figure 7.14 may be used to advantage for an application where a saving in labour or material is desired. This saving is effected by elimination of the conductors interconnecting the switches.

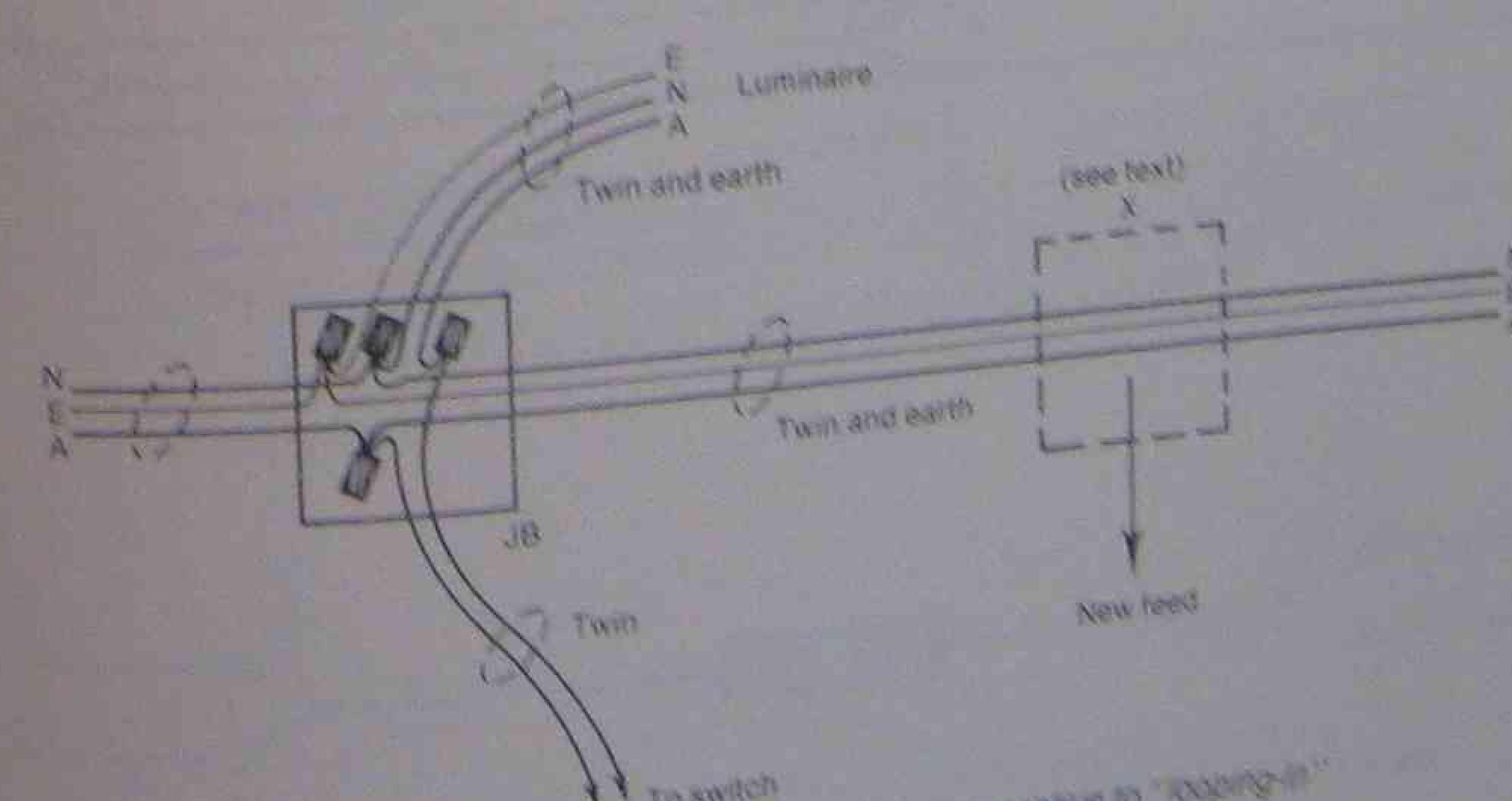


Fig. 7.10 The use of a junction box as an alternative to "looping-in"

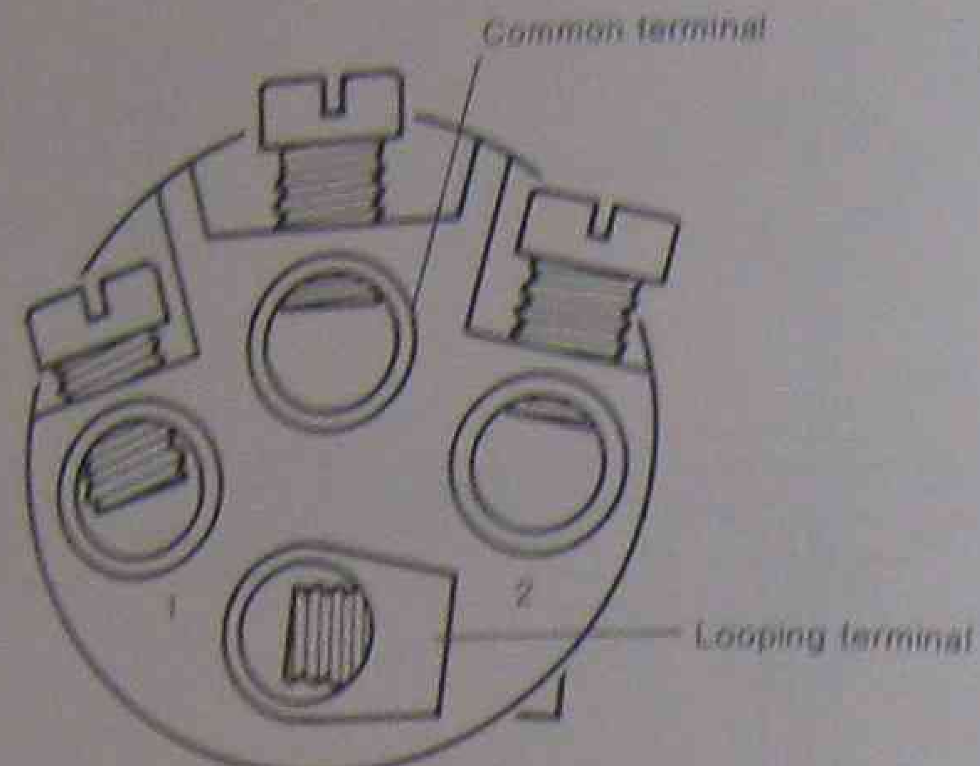


Fig. 7.11 *Terminal arrangement of a modern one way/two-way switch*

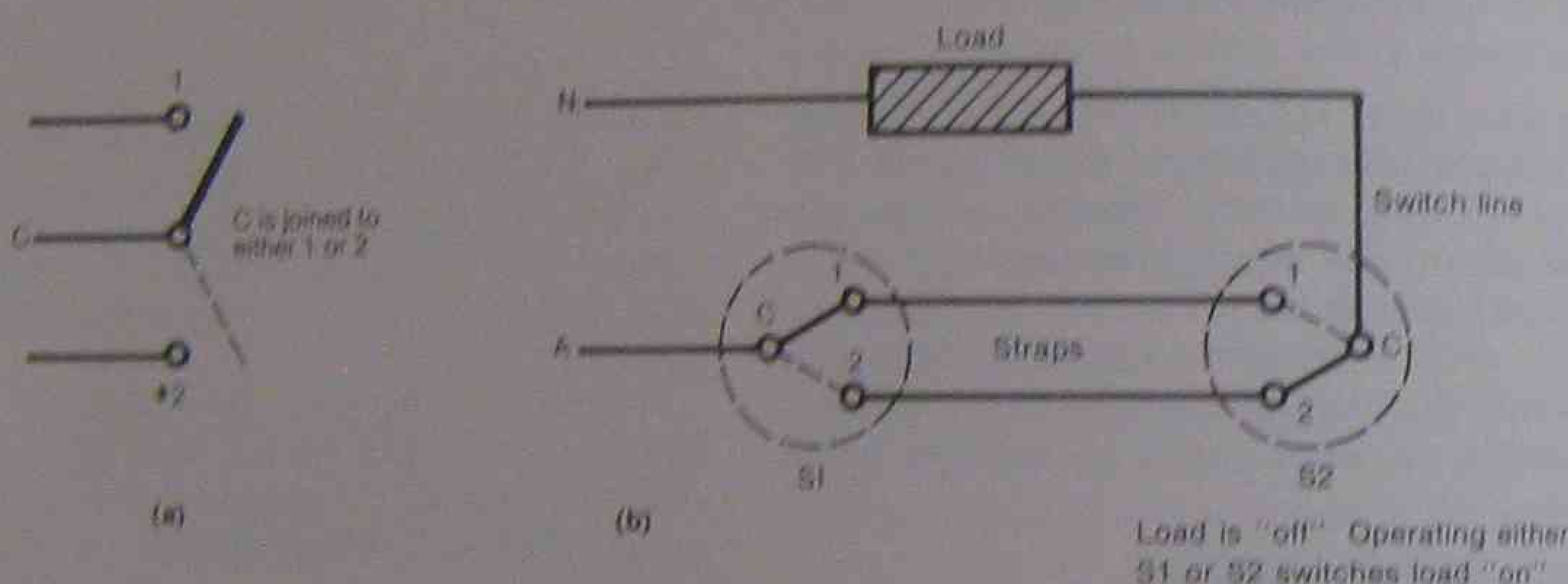


Fig. 7.12 *Two-way switching*

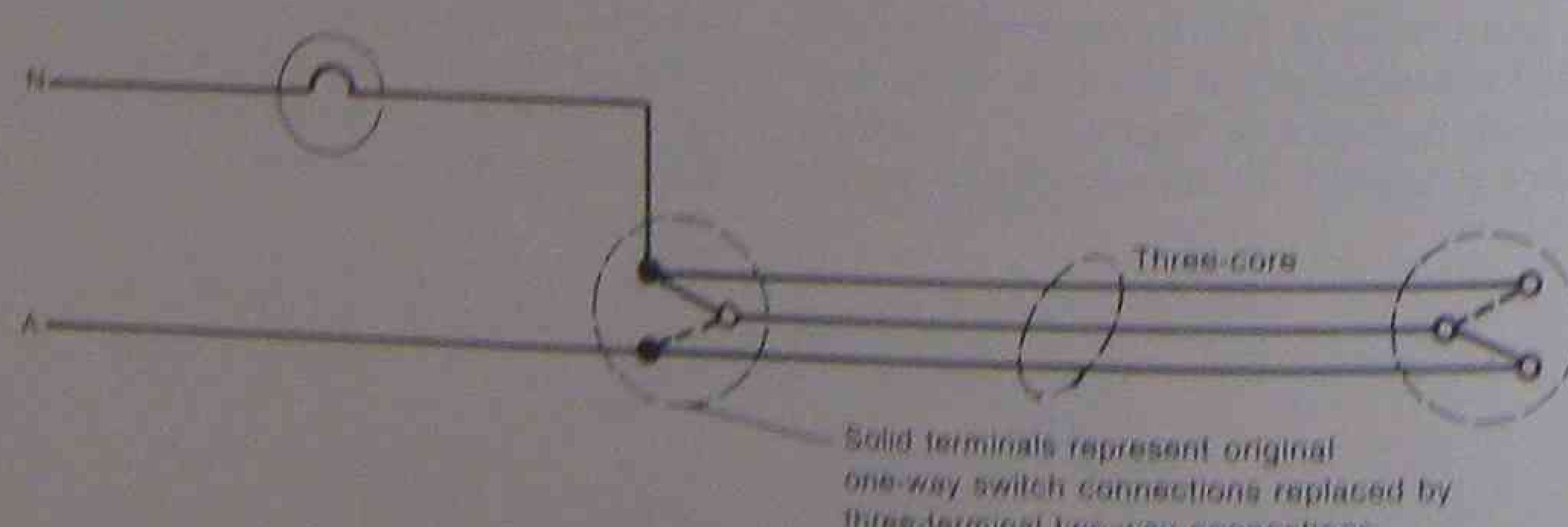


Fig. 7.13 *Changing from one-way to two-way control*

Fig. 7.14 *Two-way switching method, suitable for some extra-low voltage applications*

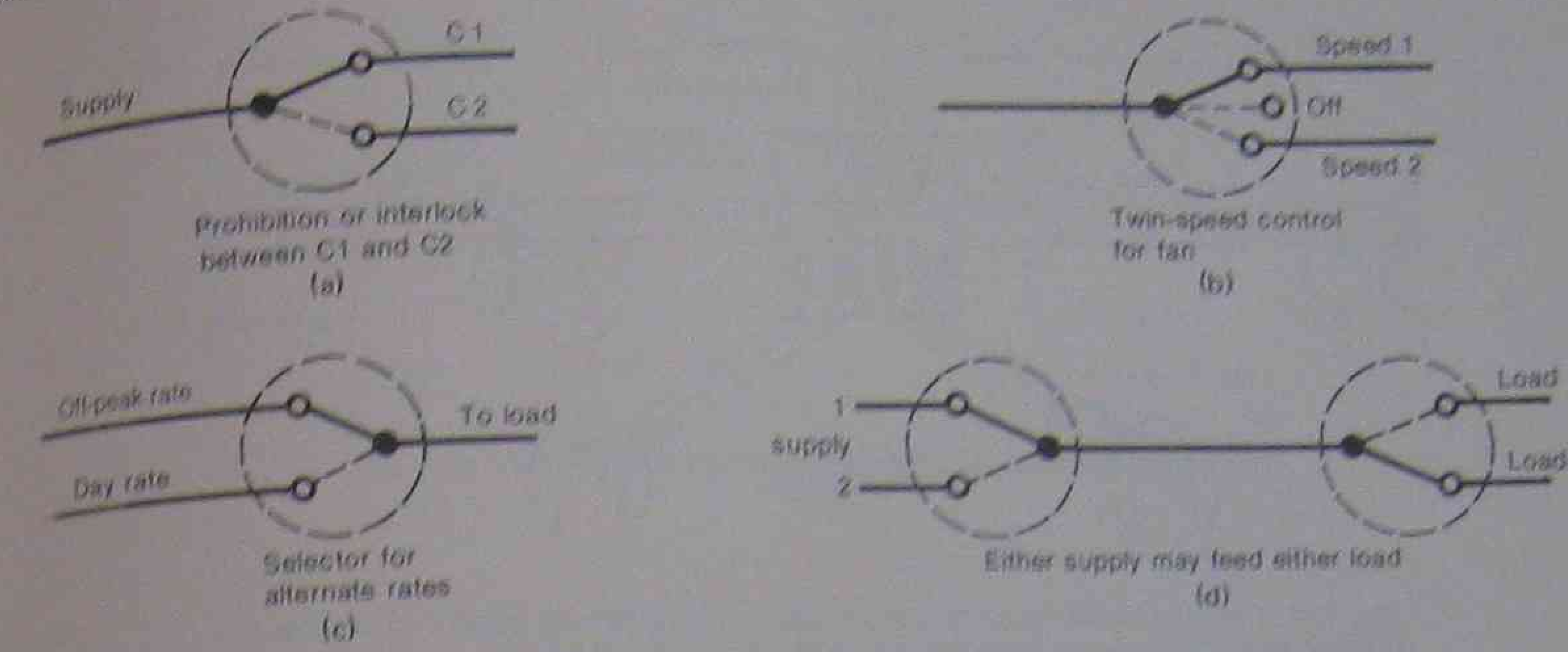


Fig. 7.15 *Some other applications of two-way switches*

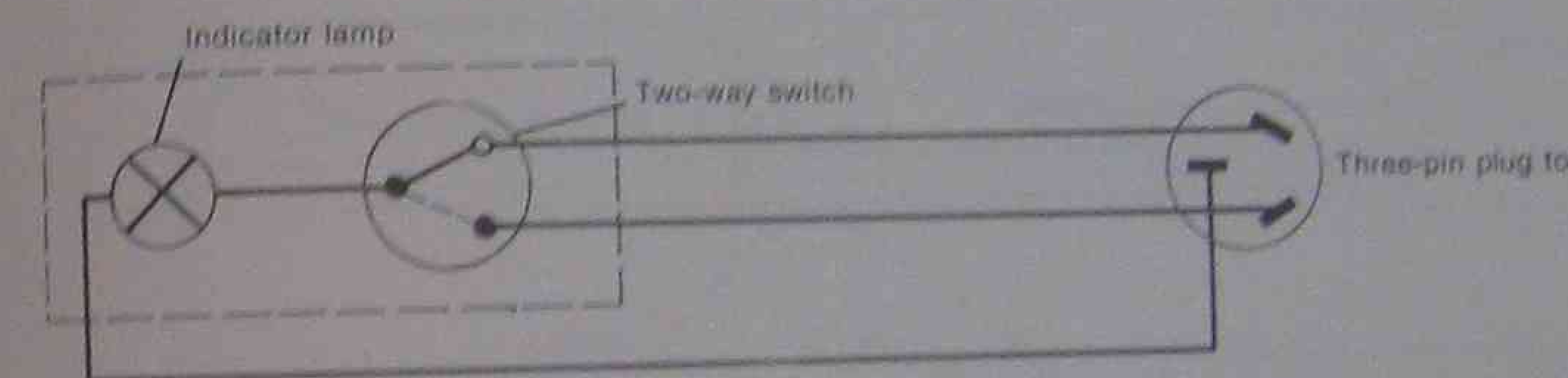


Fig. 7.16 *Simple polarity tester for power outlets*

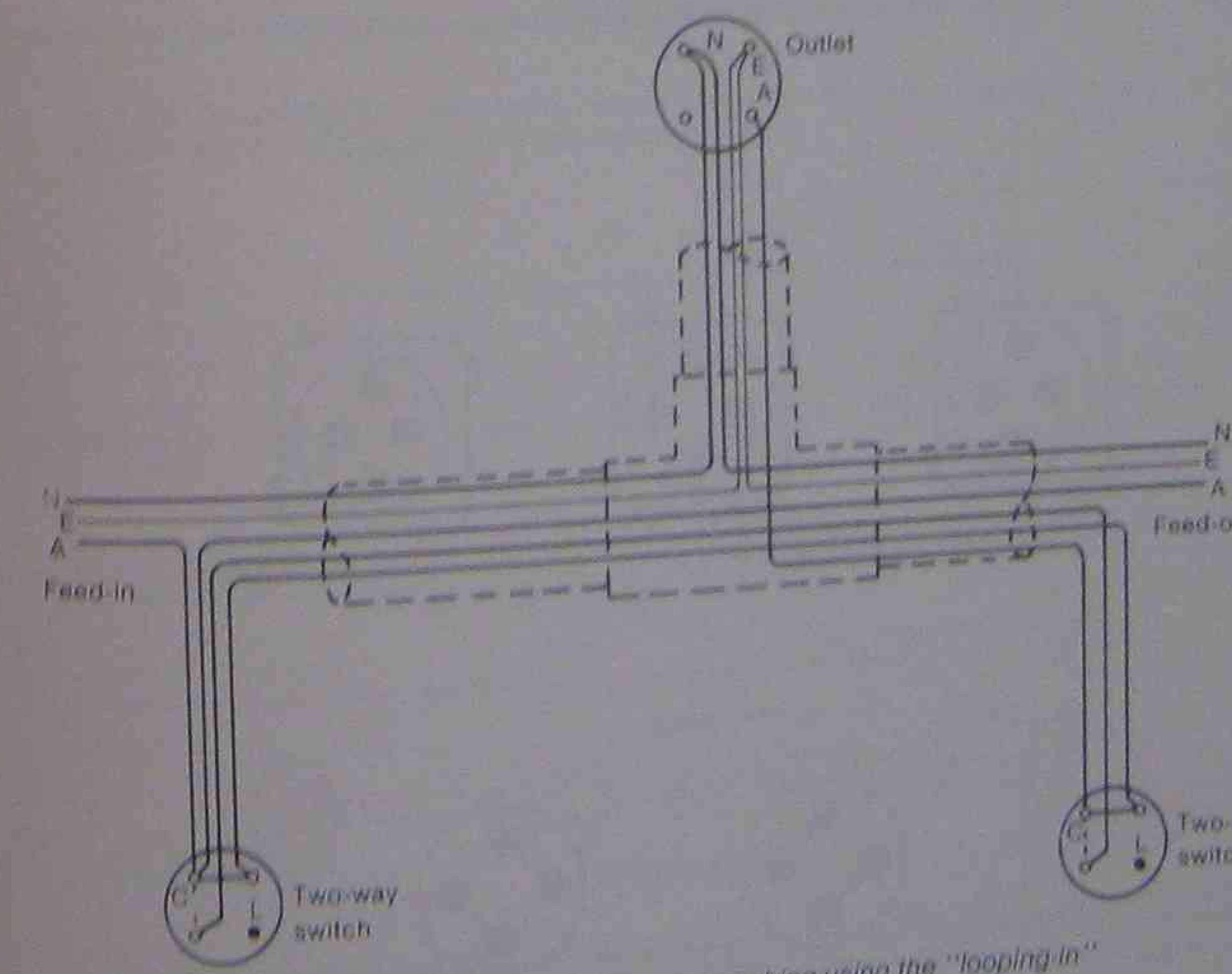


Fig. 7.17 *Connections for two-way switching using the "looping-in" system with surface wiring in conduit*

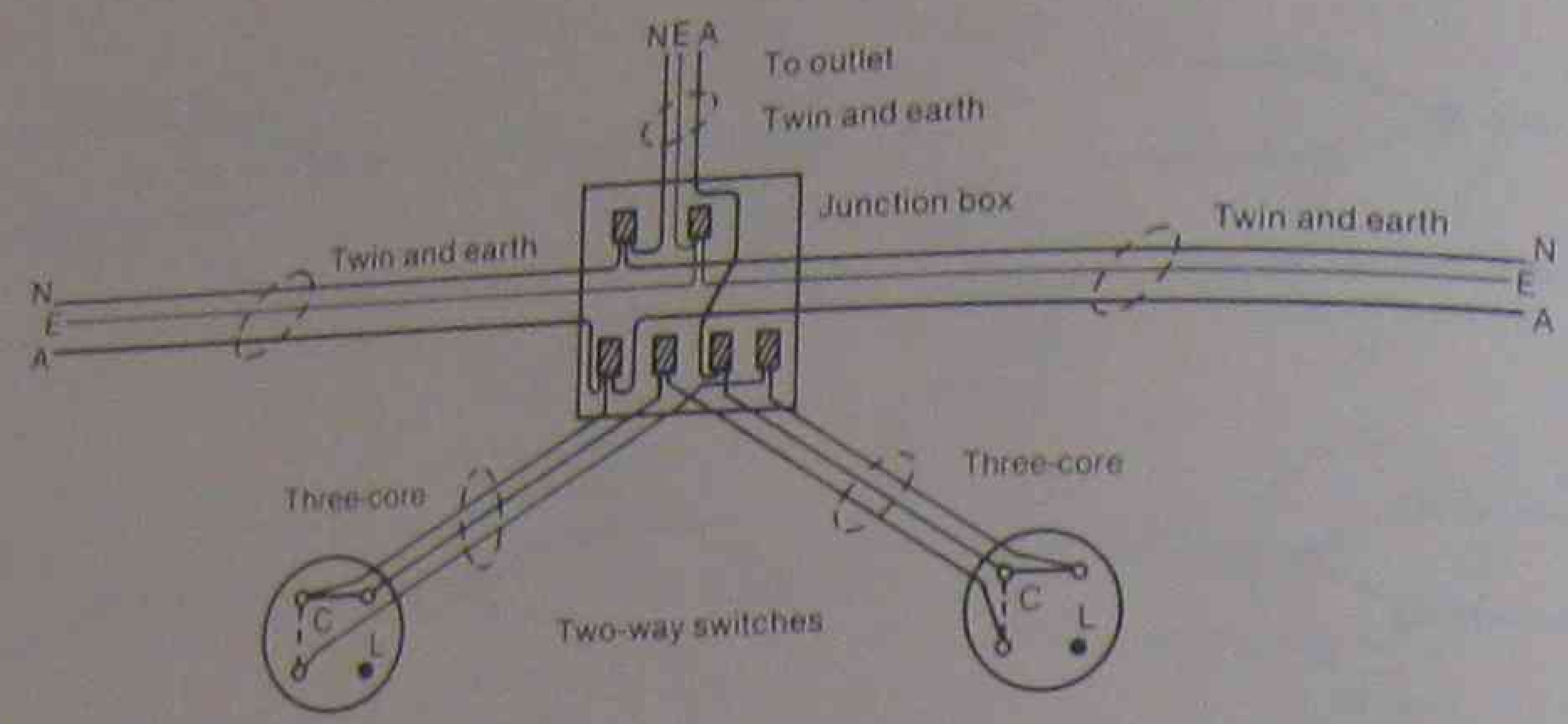


Fig. 7.18 *Two-way switching using twin and earth, and three-core cable and junction box. A two-core and single-core cable may be used in lieu of the three-core*

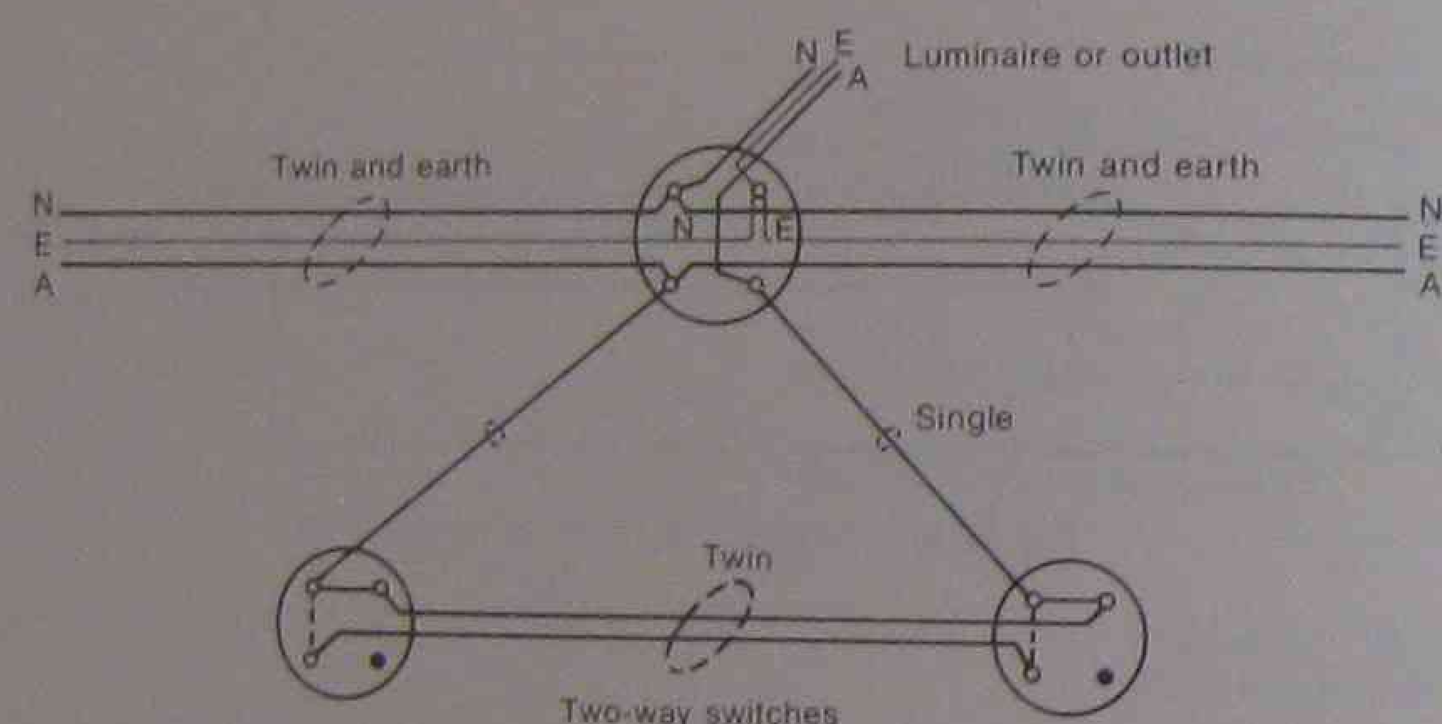


Fig. 7.19 *A method for two-way switching using single-core, two-core and twin and earth cables*

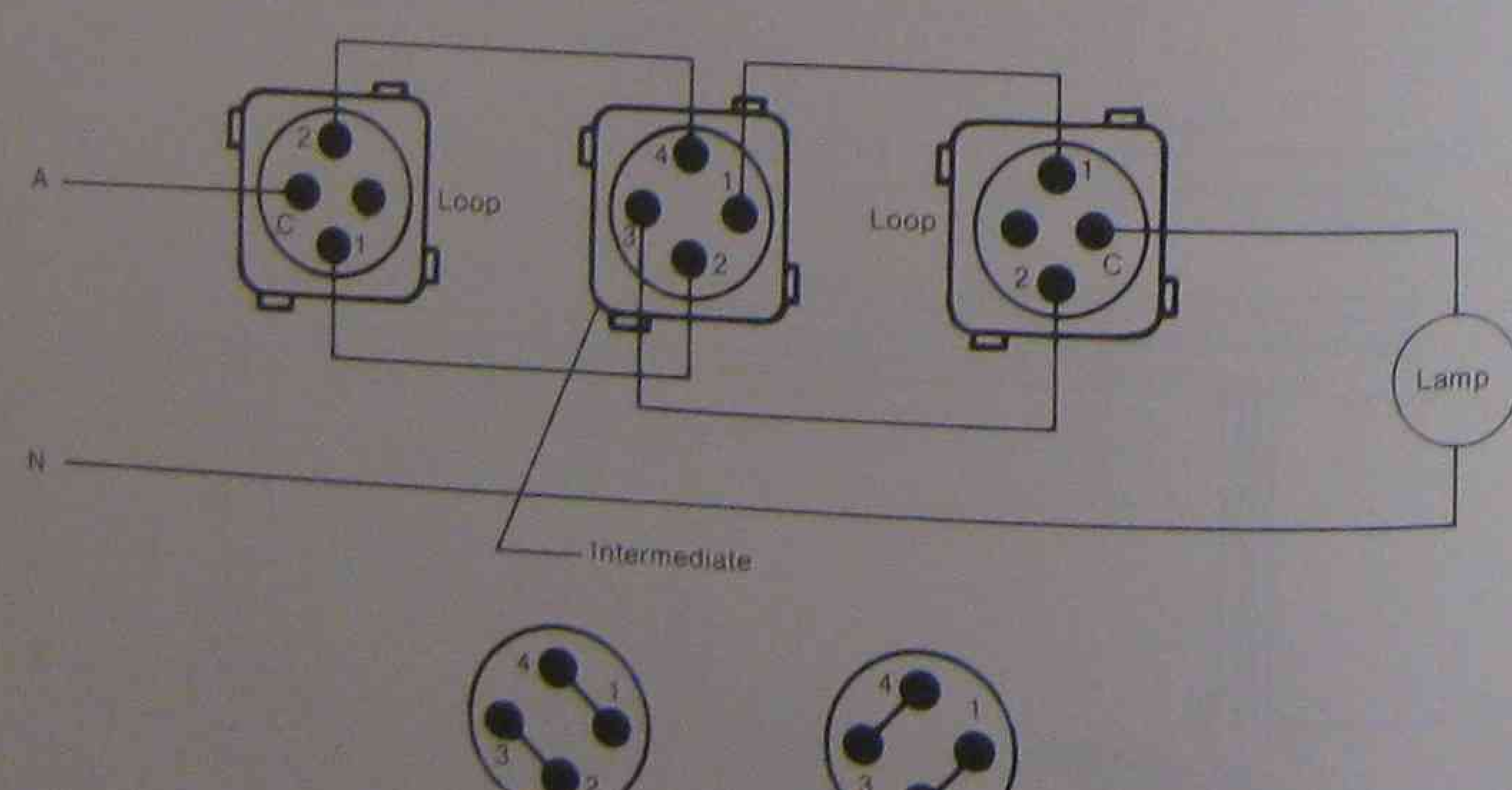


Fig. 7.20 *Rear terminal connections of a modern intermediate switch*

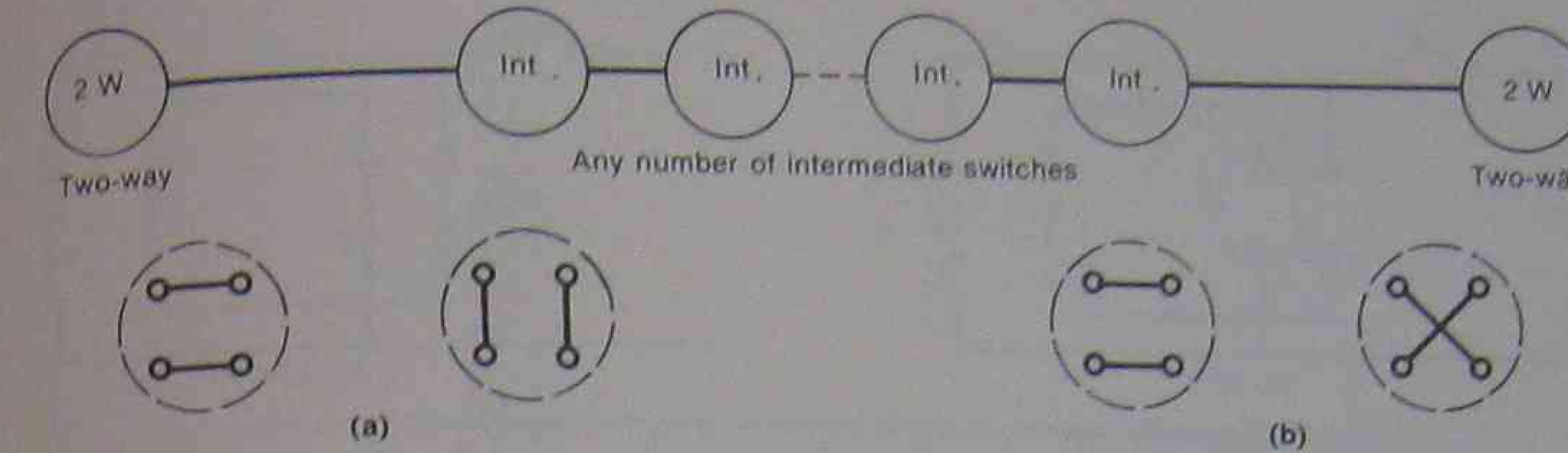


Fig. 7.21 *Two common methods of bridging for intermediate switches*

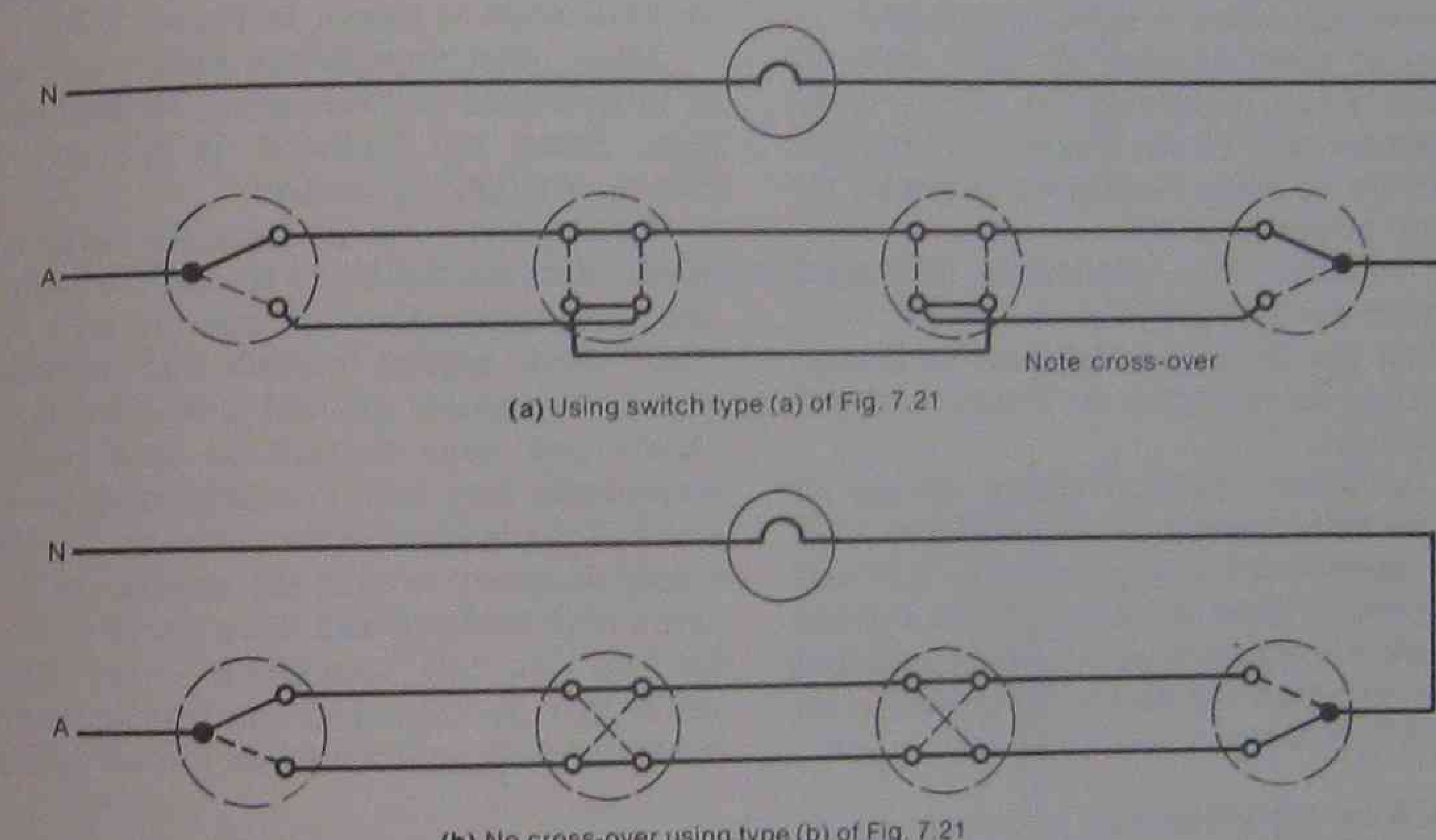


Fig. 7.22 *Connection of "strap" wires between two-way switches to the intermediate switch depends on internal bridging of the intermediate switch*

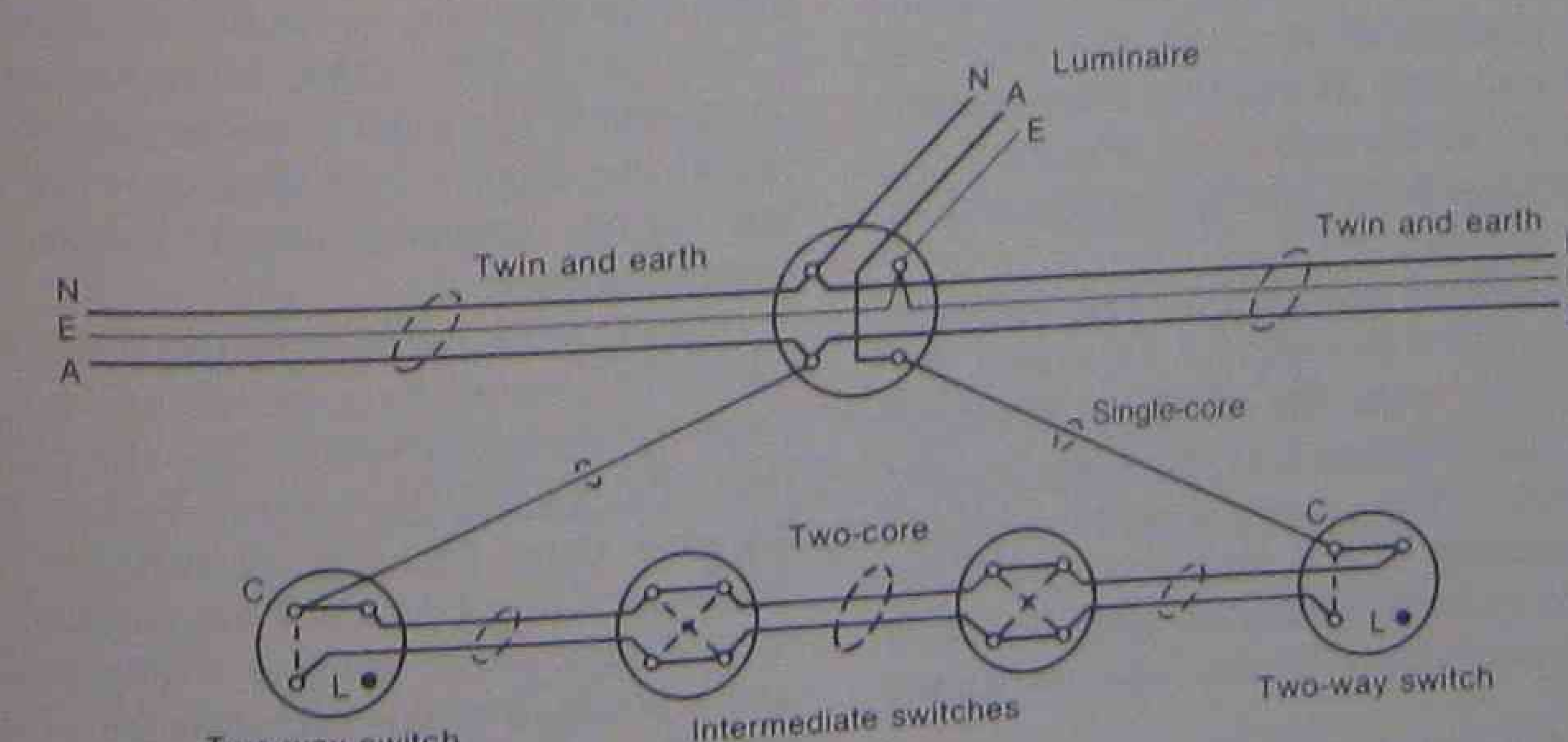
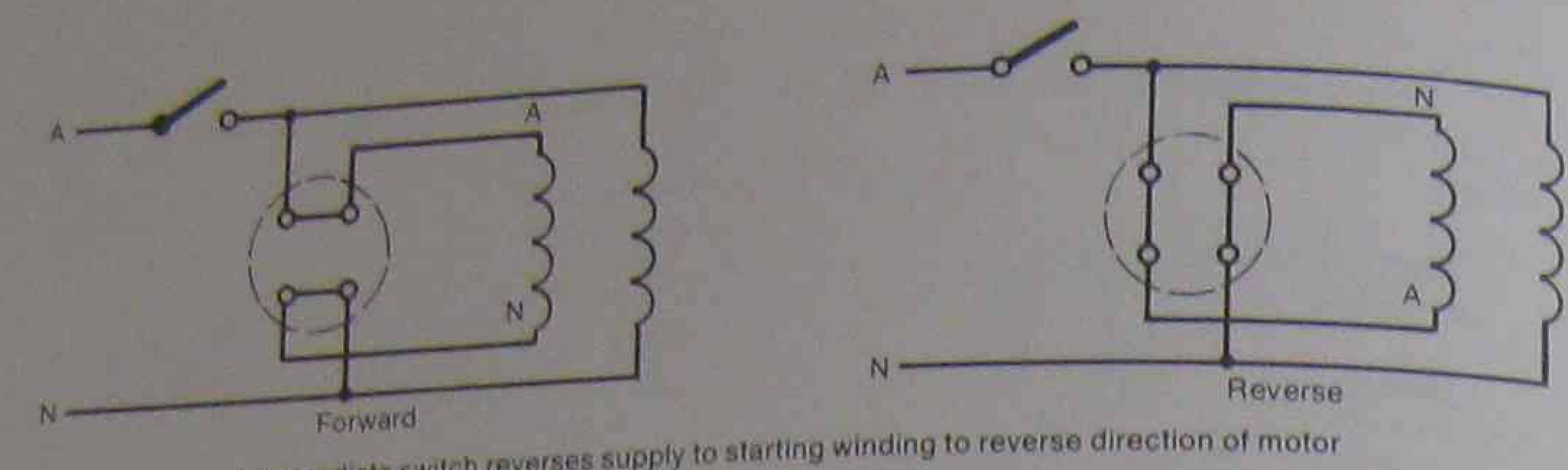


Fig. 7.23 *Multiposition control of a luminaire, using single-core, two-core and twin and earth. Connection of "strap" wires to intermediate switches depends upon the internal bridging positions of switches used*



Intermediate switch reverses supply to starting winding to reverse direction of motor

Fig. 7.24 *An application for intermediate switches*

Note that some switch designs may not be suitable for the circuit of Figure 7.14 due to the possibility of arc-over between active and neutral, within the switch, when it is being operated.

For any of these electrical controls, once the basic switch action is known, its circuit application is limited only by the ingenuity of the person employing it. Some illustrative examples for the two-way switch follow.

Figure 7.16 shows an application in a small polarity tester for power outlets.

Note that the circuit neutral must be disconnected when using the tester of Figure 7.16 (see Ch. 13: Testing).

There are many practical wiring layouts all based on the fundamental circuit of Figure 7.12. The three illustrations of Figures 7.17, 7.18 and 7.19 are typical of these. Again it must be stressed that each job is a variation on the basic theme and the manner in which the basics are applied is an "on-the-job" decision.

3. Control from more than two positions

This control is achieved by the use of two-way switches, one at each end of the control circuit, and as many switches at intermediate positions as required, there being no limit to the number of control positions. The type of switch necessary at the intermediate positions is quite logically called an "intermediate switch" and it has four connections or operative terminals; the rear terminal connections for one type of modern intermediate switch (HPM 770/1) are shown in Figure 7.20. The bridging arrangements shown correspond to those in Figure 7.21(a).

The two methods of bridging for two different switch types are shown in Figure 7.21(a) and (b).

The wiring is the same for all types, irrespective of the internal bridging arrangements for the switches. It is only when connecting the conductors interconnecting the two-way switches ("straps") to the switches that care must be taken to connect up correctly. Figure 7.22 illustrates this.

Figure 7.23 illustrates a typical circuit showing multiposition control of a lamp using twin and single TPS.

As with other switch types, the extent of the applications for the intermediate switch is again dependent upon the ingenuity of the electrician; an illustration is shown in Figure 7.24.

Many other applications exist where two-way or intermediate switches could be used to advantage. Some are included in Chapter 20 on community lighting control.

Tracing out a circuit using the many combinations of switch positions to check whether operating a certain switch will put the load "on" or "off" would require multiple and confusing diagrams. A practical method is to draw the circuit plainly and large enough so that portions of matchsticks (say half a match) may be used to simulate the bridges in the switches. To check, it is only necessary to shift the matches to the alternate switch bridging and trace the circuit through for "on" or "off" operation — try this! Each switch may be "operated" in turn to ascertain if it has correctly performed its circuit function.

7.4

Power wiring

Power outlets are perhaps the easiest parallel circuits with regard to the wiring, as usually they are looped from point to point as shown in Figure 7.3(b); twin TPS cable with enclosed earthing conductor is the most popular cable type used for the wiring. Figure 7.25 illustrates the same circuit but using single-insulated cables in surface conduit wiring.

Clause 4.14.5.4 permits the control of a power outlet, in general by a switch up to 1.5 m distant from the outlet, provided that the outlet is visible from the switch. A remote switch at a greater distance than 1.5 m is permissible if the conditions of *Clause 4.14.5.4* are fulfilled. The wiring to one such outlet using a "looping-in" method and a junction box is illustrated by Figure 7.26(a) and (b) respectively.

Notice that the circuit is essentially the same as that used for the control of a light outlet or appliance from one position.

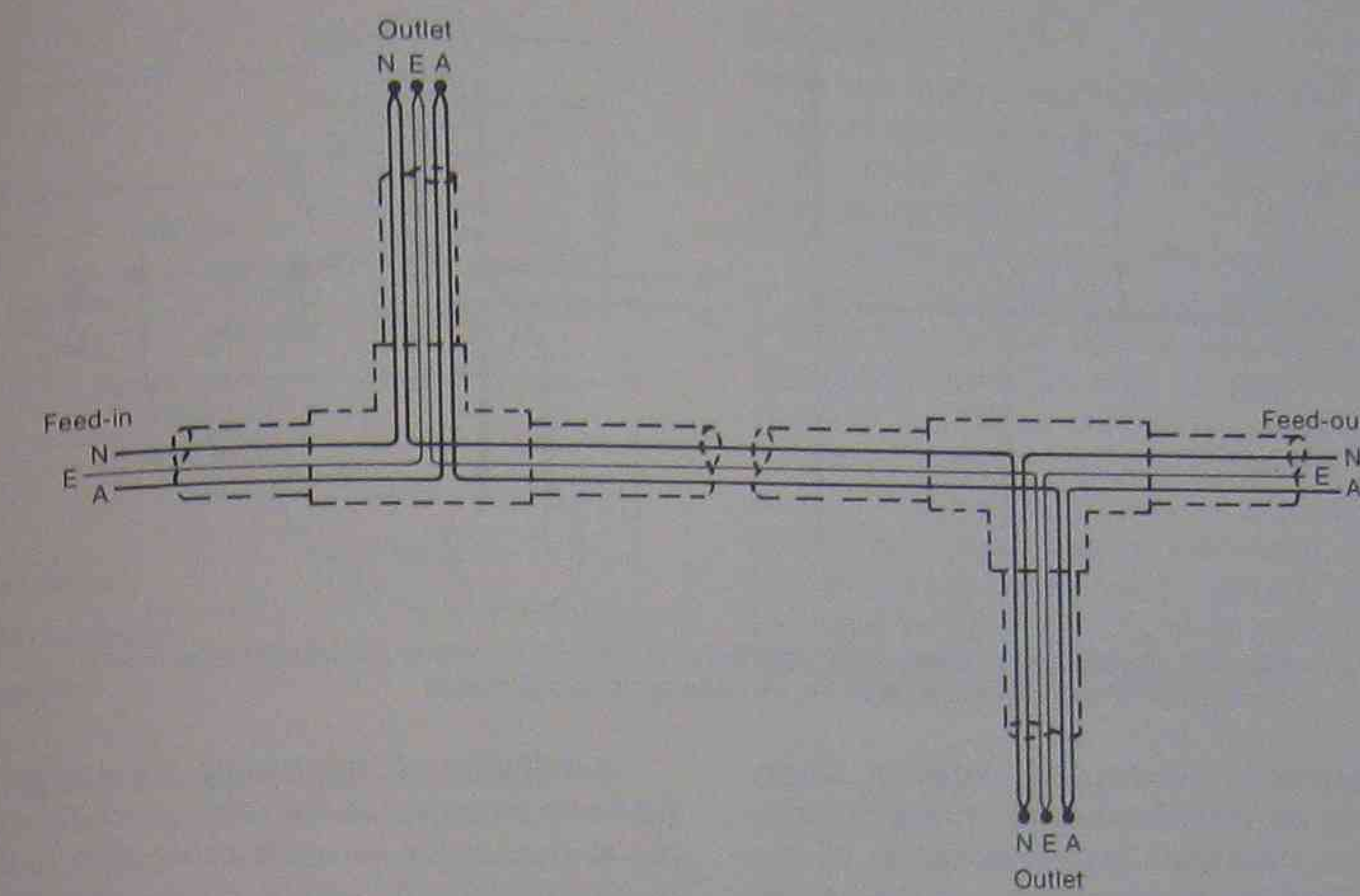


Fig. 7.25 *Wiring of power outlets in a surface conduit system*

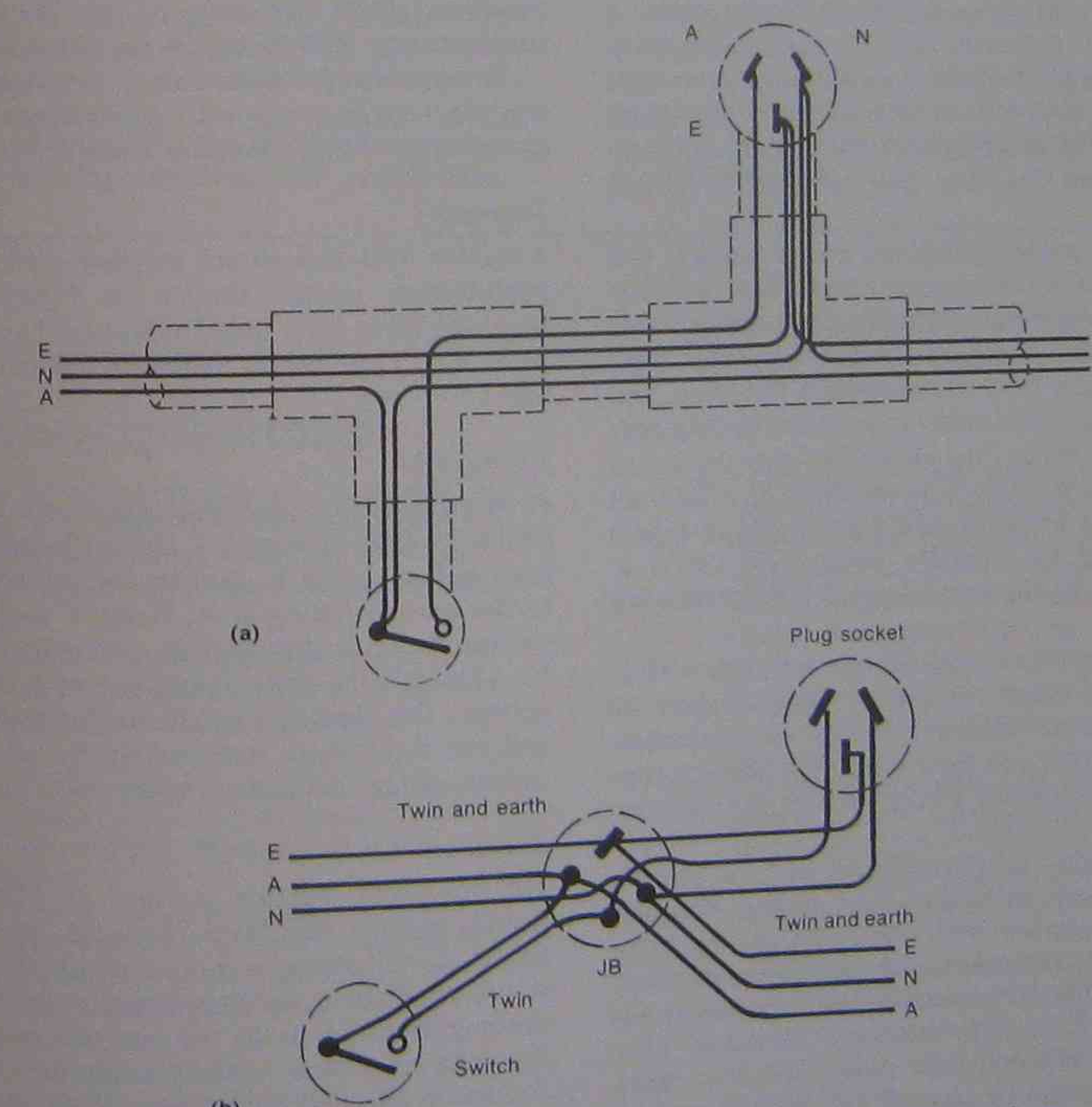


Fig. 7.26 (a) *and* **(b)** *A power outlet may be controlled by a switch up to 1.5 m distant from the outlet, provided the outlet is visible from the switch*

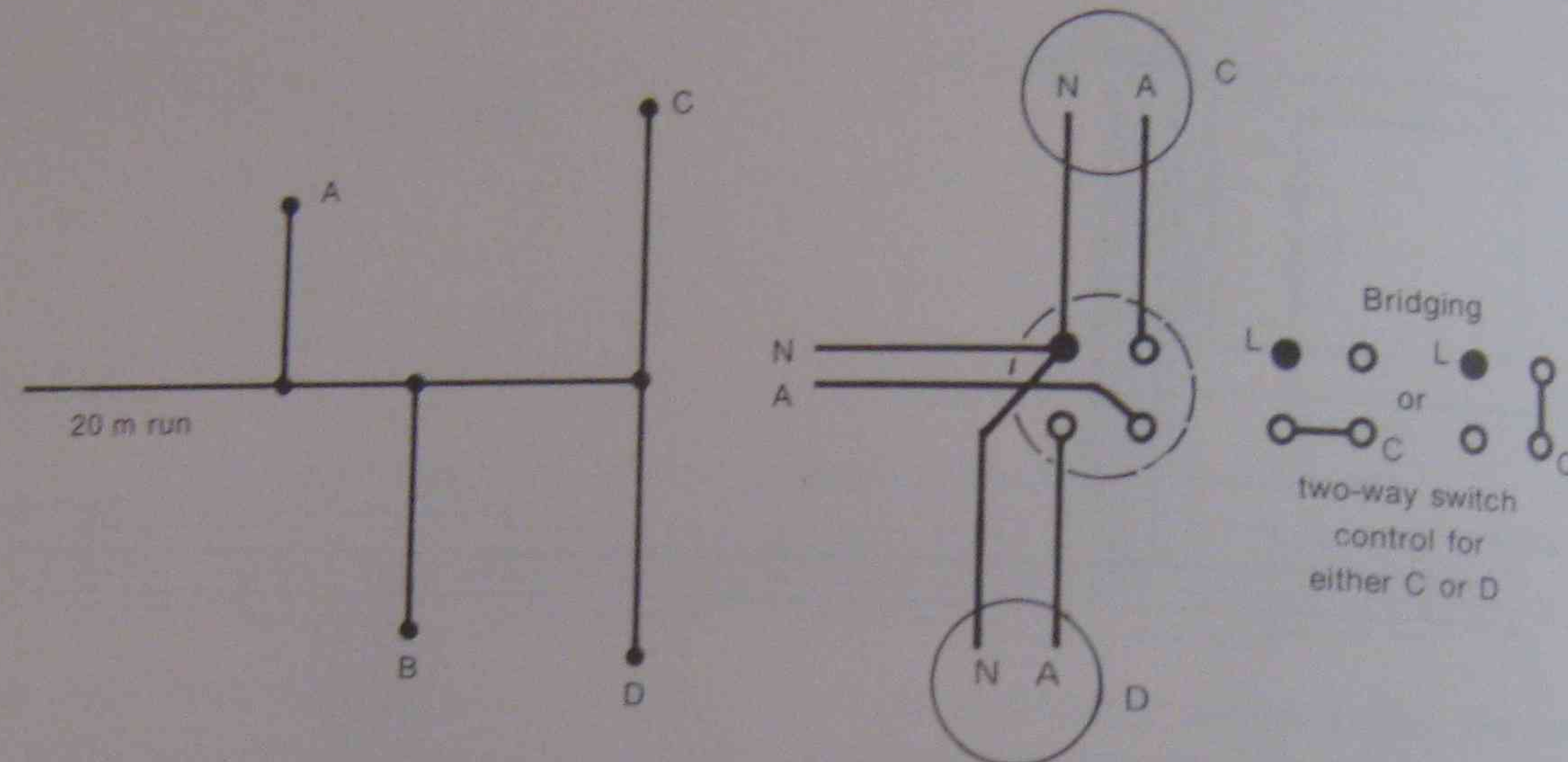


Fig. 7.27 *An additional power outlet installed at D has not increased the effective number of points on this circuit by virtue of the two-way switching provided*

This chapter is necessarily limited in scope, being simply an introduction to wiring circuits, but the same principles are employed in all the diverse applications met in practice. If the student absorbs these principles, they may be applied to any of the thousands of applications that occur in an electrician's experience. The principles are universal.

As an illustration of the above statement, a power circuit protected by a 20 A circuit-breaker and consisting of seven general purpose outlets (GPOs) on the end of a long run (say 20 m) of 2.5 mm^2 cable comprises the maximum number permitted for this size cable in a factory installation.

Let us suppose the factory owner requires one more outlet for convenience, and when told that this would require an extra circuit at considerable cost, expresses the view that "the Rules" are illogical, as the load would remain the same, and that the extra outlet exists to pr...

Installation of the wiring for motors follows the same sequence as for other circuits, commencing at the supply through protection and control to the device. A wiring circuit diagram for a motor is usually simpler than some other circuits, for example multiposition switching for lighting.

The majority of motors are on a separate circuit and the installation entails a single run, usually of three conductors from the source of supply to the starter or control panel.

The number of wires from the starter or control panel to the motor will be dependent upon the motor type. Some examples follow:

Example 1

A motor switched direct on line could have a push-button starter similar to Figure 7.1(d), requiring three lines into L_1, L_2 and L_3 and three lines out to the motor from the terminals A, B and C...

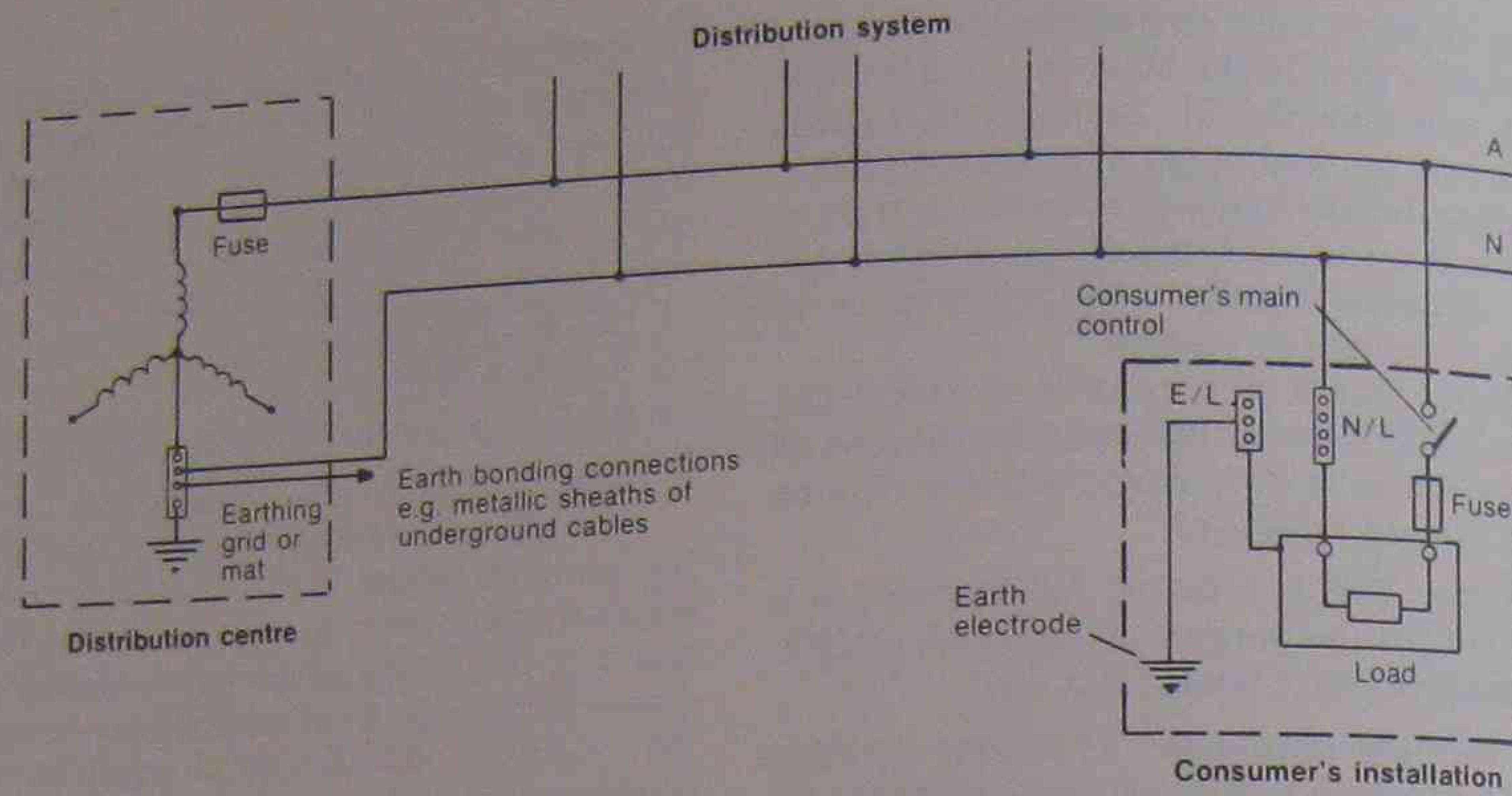


Fig. 8.4 *Direct earthing system*

low-voltage earthing grid or mat at the distribution transformer.

Method (a) is common, but still limited to areas where a metallic water reticulation scheme is installed. Method (b) is restricted to areas where supply is by metal-sheathed underground cables. Method (c) is the least used, and usually only installed when the supply source and the consumer's installation are adjacent. An example would be where a large factory takes its supply from its own substation and feeds direct into the main switchboard for the installation. Note that this is for the source of supply. The consumer's earthing arrangements are dealt with in Section 8.4.

In the **ELCB (voltage-operated) system** (see Fig. 8.5) the supply system is earthed at one point only as in the direct earthing system. Because this system does not depend for its operation on a low-resistance earth return circuit, the precautions and measures taken to achieve this low resistance on the other two systems are not necessary for the ELCB system.

In the **MEN system** (Fig. 8.6) the metallic return path is provided mainly by the supply neutral conductor, which is in parallel with any other return path such as the general mass of earth and bonded metallic water pipes.

Because there is a direct connection between the neutral and the consumer's earthing system, the neutral potential above earth must be kept low by having earth connections throughout its length, at each consumer's installation and at strategic points on the low-voltage distributors. To minimise further any voltage drop in the neutral, it must be of adequate cross-sectional area.

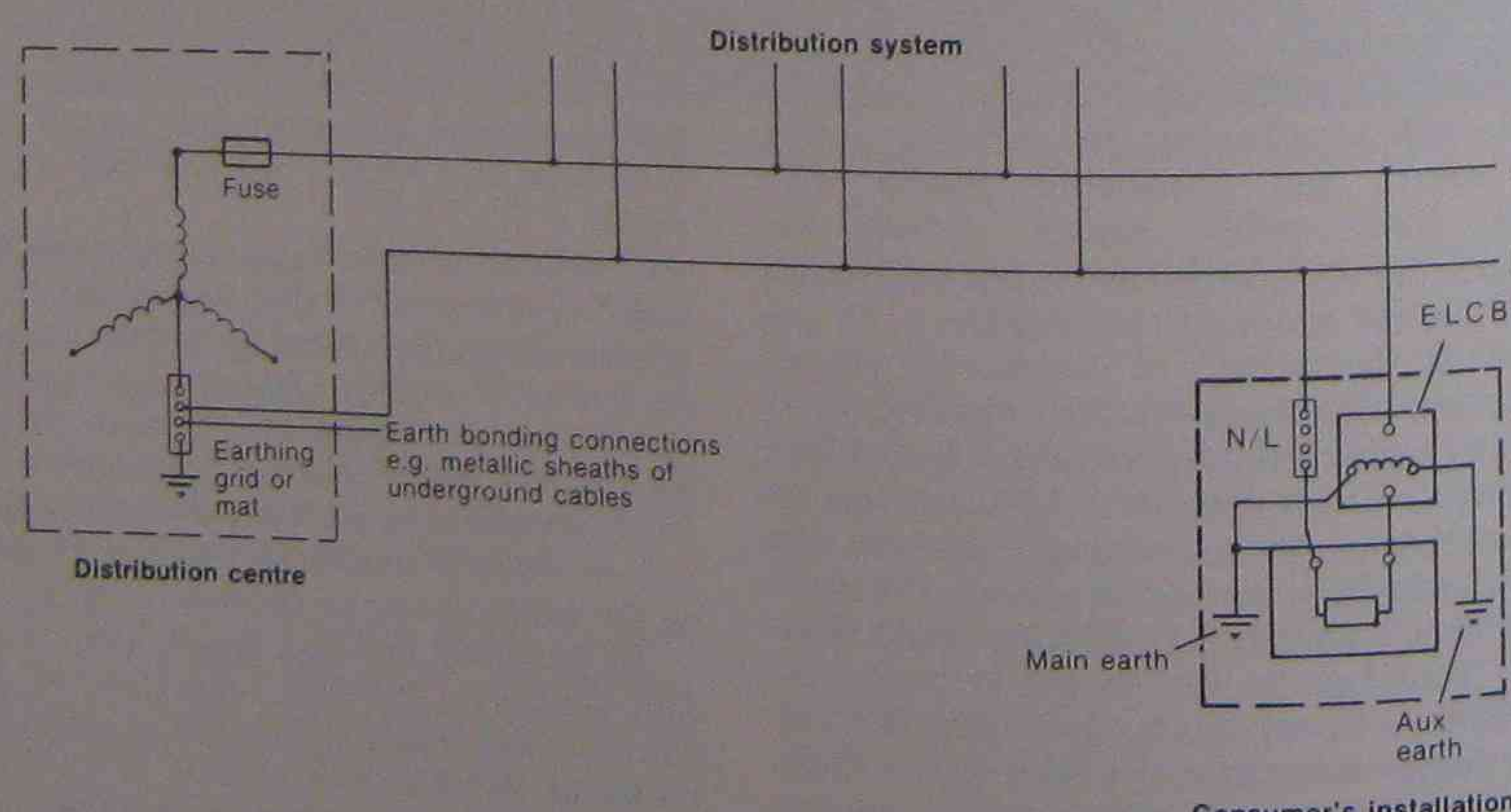


Fig. 8.5 *Voltage-operated earth leakage circuit-breaker (ELCB) system*
ENERGY AUTHORITY OF NSW

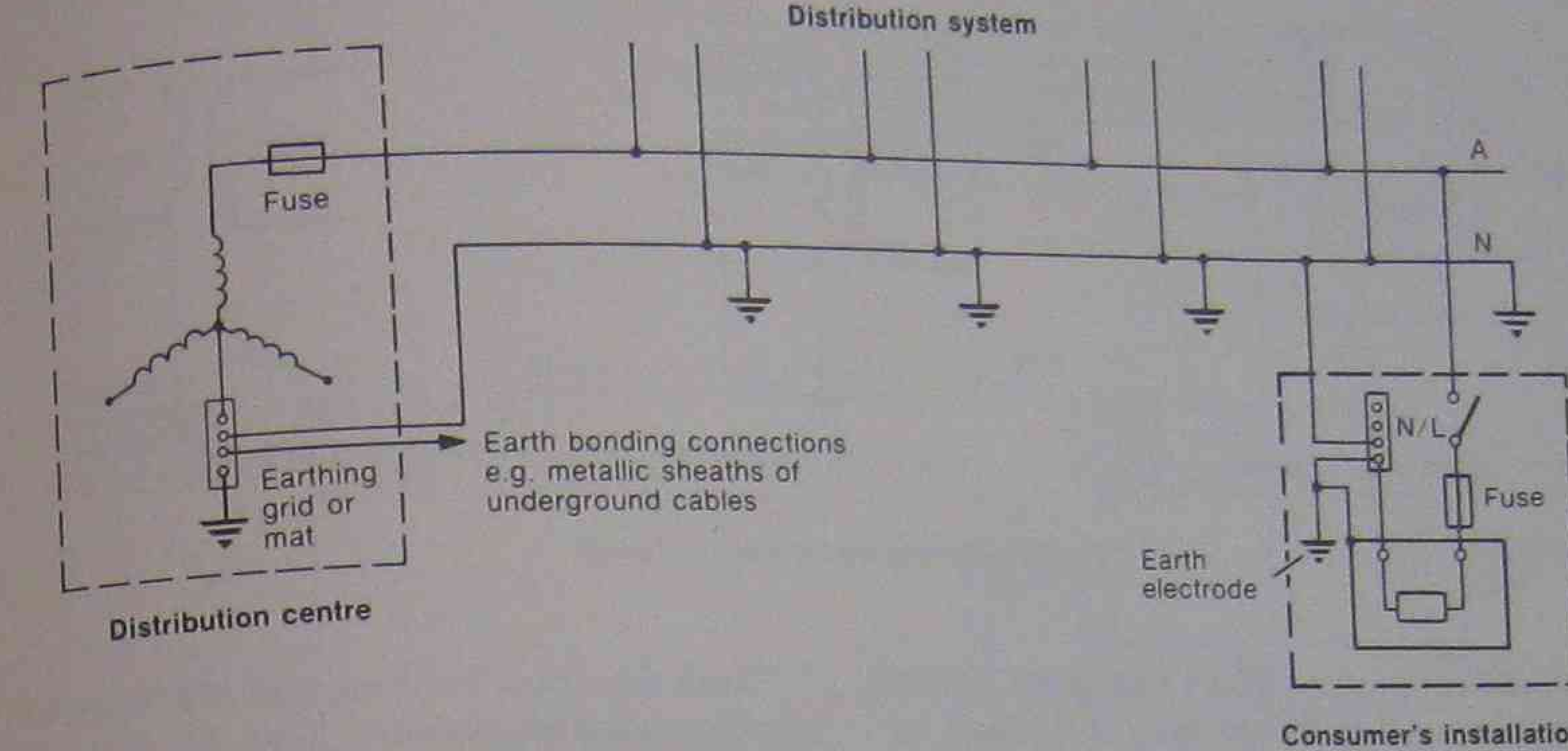


Fig. 8.6 *Multiple earthed neutral (MEN) system*

Provided that certain safety precautions are taken, one large energy authority's Code of Earthing Practice permits the coexistence of direct earthing and MEN within the same distribution area (mainly to facilitate change from direct to MEN systems).

These are the three accepted earthing systems in Australia, but the present position, from the supply authority's viewpoint, is that under most circumstances the MEN system has proved to be the simplest and best system to adopt. As background information, the brief history of its development follows, the main consideration being the current-carrying ability of the earth return circuit from consumer back to the point of supply.

The original system in common use was the direct earthing of equipment required to be earthed by connection to an earth stake or earth electrode driven into the ground.

Under these conditions, the resistance of the earth return path was often high, thus leading to the position that direct earthing was only used where a relatively low resistance metallic return path, such as a water supply system, could be pressed into service as an earth electrode. As the use of electrical power appliances increased and high fault currents were possible, even this arrangement became unsatisfactory.

The introduction of non-metallic water mains, such as fibro-cement, and pipe joints of non-metallic material, further aggravated an already unsatisfactory situation, so that supply engineers were faced with either:

1. finding means by which the return earth loop resistance path could be reduced; or
2. adopting a system of earthing that was not dependent upon high values of fault current for its operation.

The first line of thinking led to the adoption of the supply neutral as a low-resistance parallel earth return path for the fault current and the development of the MEN system. The potential between neutral and earth was kept to a minimum by earthing the neutral at the source of supply, at intervals along the supply routes and at each consumer's installation.

The ELCB system provided an answer to the alternative approach, where effective operation of the protective device was still possible with earth return loop resistances of up to 200 Ω. This system was first introduced in Germany about 1910, and was used in the inner city areas of some Australian cities until November 1966, but the modern trend is to restrict its use to special machines or circuits within an installation or to a situation within a supply area where difficult earthing conditions are encountered. Installation of the system is more costly to the consumer than the others, requires more maintenance and periodic checking and is prone to nuisance tripping by transient discharges, such as those that occur in electrical storms.

Limitations of the direct earthing system with regard to high earth loop resistance, and the problems of cost, maintenance and reliability of the ELCB system, has led to the adoption where possible of the MEN system by most supply authorities. The MEN system, however, also has disadvantages, some of which are discussed in Section 8.4, where earthing at the consumer's installation is considered.

In this chapter it is intended to deal only with the 415/240 "star system" of distribution in regard to earthing requirements and the SAA *Wiring Rules*. During the student's career, many other sources of supply will be encountered which are earthed mainly for safety reasons similar to those considered, and two of these are shown diagrammatically in Chapter 1, Figures 1.19 and 1.20.

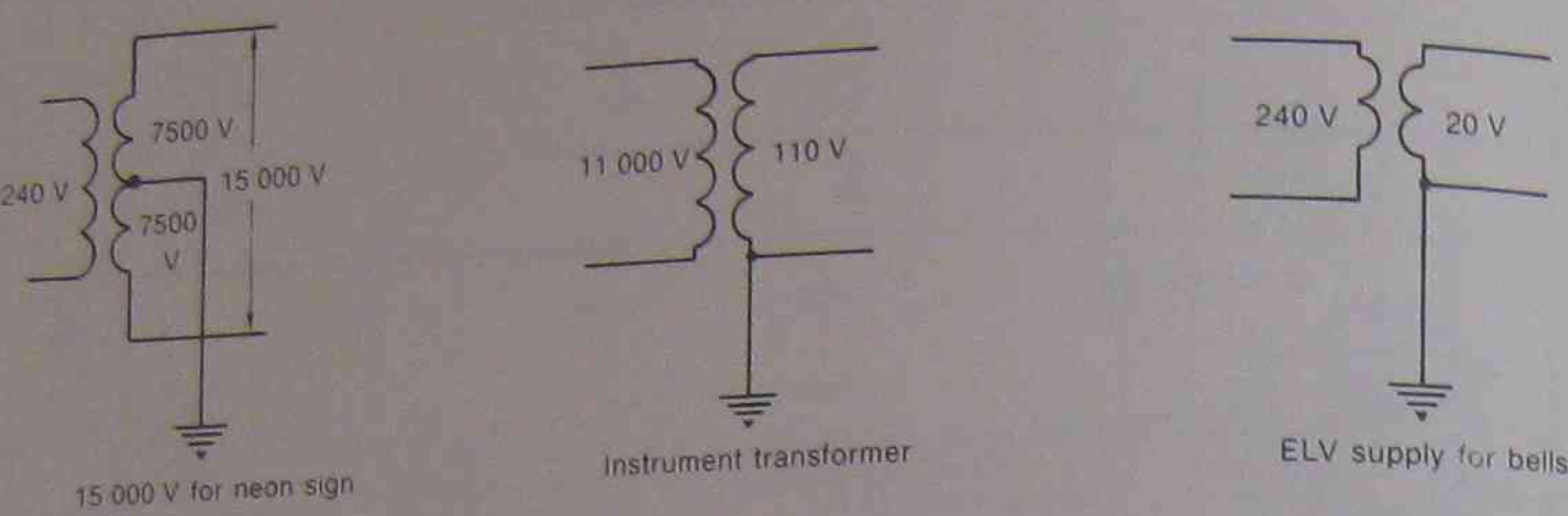


Fig. 8.7 *Earthed transformer supplies*

The student should be aware that some supply sources **within** an installation may sometimes be earthed. This is done primarily for safety reasons, but when testing or working on this type of circuit, the fact that the circuit is connected to earth at some point should always be borne in mind. Typical examples are shown in Figure 8.7.

8.4

Consumer's earthing systems

The most significant feature of the direct earthing, MEN and ELCB systems of earthing is the solid connection of the neutral star point to the general mass of earth at the source of supply. This maintains the supply voltage to earth at the usual value of 240 V. This connection would not, however, prevent exposed metal in a consumer's installation rising to a potential of 240 V above earth, if it were not for the fact that the equally significant feature of the consumer's earthing system is directly to connect this exposed metal to earth or neutral potential.

As specified in *Clause 5.2.1*, the supply authority decides upon the particular earthing system that will apply to a certain area.

As indicated above, in each of the three earthing systems considered here, the supply neutral is **solidly earthed** at the source of supply. On the rare occasion that a "neutral not solidly earthed" system is encountered (see *Clause 2.18*) the earthing requirements at the consumer's premises will be the same as those applying to the direct earthing system, only the control and protection requirements differ.

Note that the term "not solidly earthed" refers to the source of supply and not to the consumer's installation, which is earthed in the usual manner.

The three recognised systems of earthing for a consumer's installation are those shown in Figures 8.4 — Direct earthing, 8.5 — ELCB, and 8.6 — MEN.

Both the direct earthing and MEN systems are current-operated systems; that is, they do not operate to isolate the faulty section until the value of the fault current is sufficient to cause the fuse to rupture or the circuit-breaker to trip. This is the inherent weakness of these two systems because

$$I = \frac{V}{R}$$

and hence the resistance of the lead and return path may limit the fault current (see Fig. 8.15 in Section 8.5). The voltage-operated ELCB system overcomes this disadvantage but has serious practical shortcomings.

1. Direct earthing

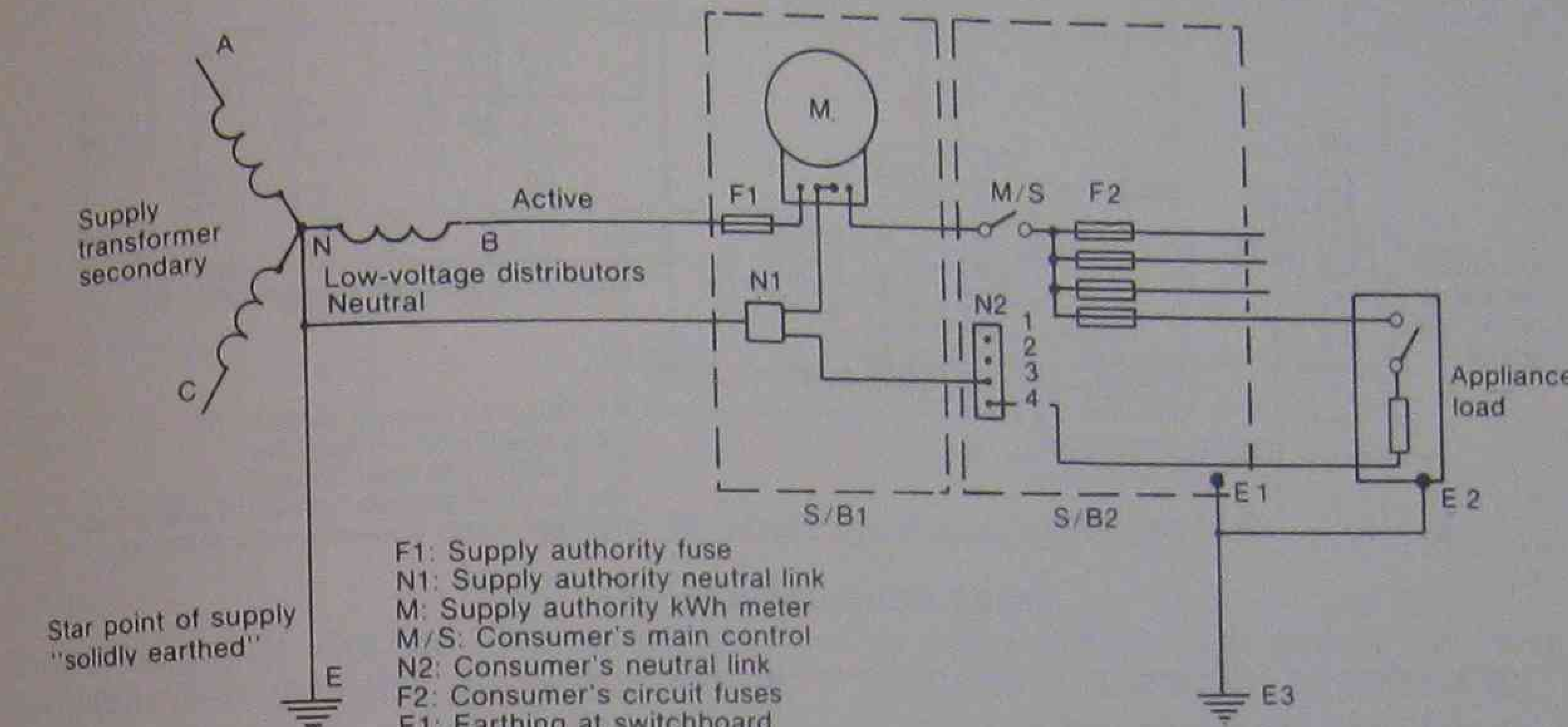
Figure 8.8 illustrates connections on a small consumer's switchboard for a simple direct earthing system. There is no connection between the neutral and earth at the consumer's installation. It is the simplest system, both from the view of the supply authority and the consumer, but the resistance of the return earth loop must be kept at a low value (see Section 8.5) and for this reason most supply authorities maintain the system only in areas where a solid water reticulation scheme exists. The system may have been adequate in past years when electrical loads were lighter, but today it has been superseded by the MEN system. Note *Clause 5.10.1*, specifying the electrode resistance (difficult to keep low in practice), and *Clause 5.10.2*, which allows the supply authority to nominate alternative main earth connections for this system.

2. MEN system

This is the most widely adopted system, as supply engineers consider that its practical advantages outweigh its disadvantages.

Reference to Figure 8.9 shows that the only difference to the previous system as far as the consumer's installation is concerned is that the main earthing conductor is taken direct from the earth electrode to the neutral link at the switchboard. The ...

Note: Actual wiring methods vary with the supply authority, e.g. N1 could be omitted and neutrals soldered and taped. Alternatively, the supply and consumer's neutral could be connected at the terminals of the kWh meter



F1: Supply authority fuse
N1: Supply authority neutral link
M: Supply authority kWh meter
M/S: Consumer's main control
N2: Consumer's neutral link
F2: Consumer's circuit fuses
E1: Earthing at switchboard
E2: Appliance "frames" earthing
E3: Main earth connection
S/B1: Supply authority's switchboard
S/B2: Consumer's switchboard

Basic single-phase direct earthing system (compare Fig. 8.4)

Fig. 8.8 *Direct earthing system*

is connected in the same manner, and this multiple earthing of the neutral, at each consumer's premises, together with numerous earthing points on the supply side, has given the system its name of multiple earthed neutral system.

3. ELCB system

With both the previous systems, it is necessary for high values of fault current to be present before the protection will operate. Hence they are "current-sensitive" systems, and neither is effective against voltage rise in the earthing system unless the rise is due to high currents. Because $V = IR$, low current coupled with high resistance may cause a high voltage and the possibility of electric shock; for example, a current of 1 A will produce a voltage drop of 200 V across a resistance of 200 Ω.

The ELCB system was introduced mainly as protection against shock, leaving the overload function to current devices such as fuses and circuit-breakers. Because of this it may be considered as an **auxiliary** or as **supplementary** protection added to the direct earthing system. The additional connections required to add voltage-operated ELCB protection to a simple installation are shown in Figure 8.10 of this book and in Figure 5.1 of *Clause 5.11.1.1* of the *SAA Wiring Rules*.

Main earthing connections are the same as for the direct earthing system illustrated in Figure 8.8, with no interconnection between neutral and earth. The supplementary protection consists of a ... 20 and 26 V, to open the circuit. This trip relay is connected between the earthing system and frames F and an auxiliary earth electrode E.

If for any reason the potential on the earthing system of an installation rises above 20 V to earth, the earth relay operates to isolate the supply, so that the system is that of direct earthing **plus** the ELCB as a sentinel on voltage rise in the earthing system.

As mentioned in Section 8.3, the system may be found installed in many older installations and is in current use:

1. for the protection of individual appliances or isolated circuits where voltage rise is likely, and in these situations has the advantage of being compatible with other systems for additional protection;
2. for a situation such as an isolated rocky ridge where earth resistance is high, direct earthing is not effective, and MEN not available; and
3. sometimes for the protection of installations in outbuildings to comply with *Clauses 5.10.3* and *5.11.2*.

Despite some advantages, the ELCB system has the following disadvantages:

1. the system is more expensive to install because comparatively elaborate methods of installation are necessary;
2. it requires periodic checking;
3. the resistance of the electrodes, although high at 200 Ω (*Clause 5.11.5*) is sometimes difficult to obtain and keep constant;
4. selective protection is difficult in practice;

Note: Connection methods vary with the supply authority. Two methods are shown below. In (a) the consumer's neutral link is used for the MEN connection and an earth link used for the laid-up earthing conductors; see Clause 5.9.3.1. In method (b) the MEN connection is the supply authorities neutral link

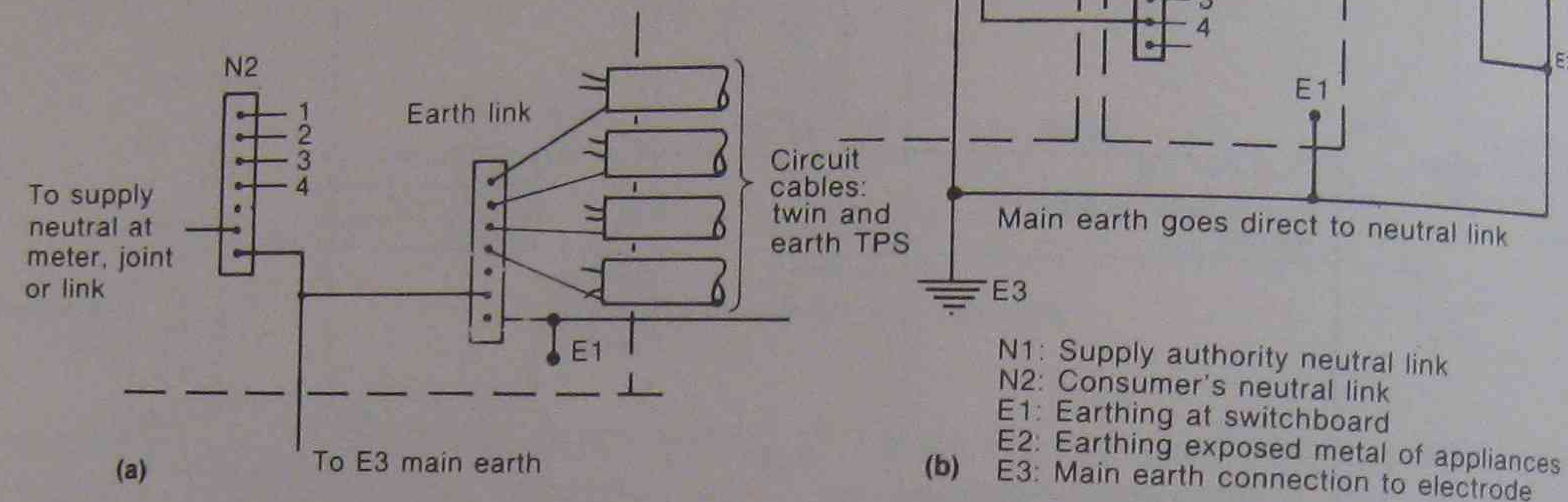


Fig. 8.9 *MEN system of earthing*

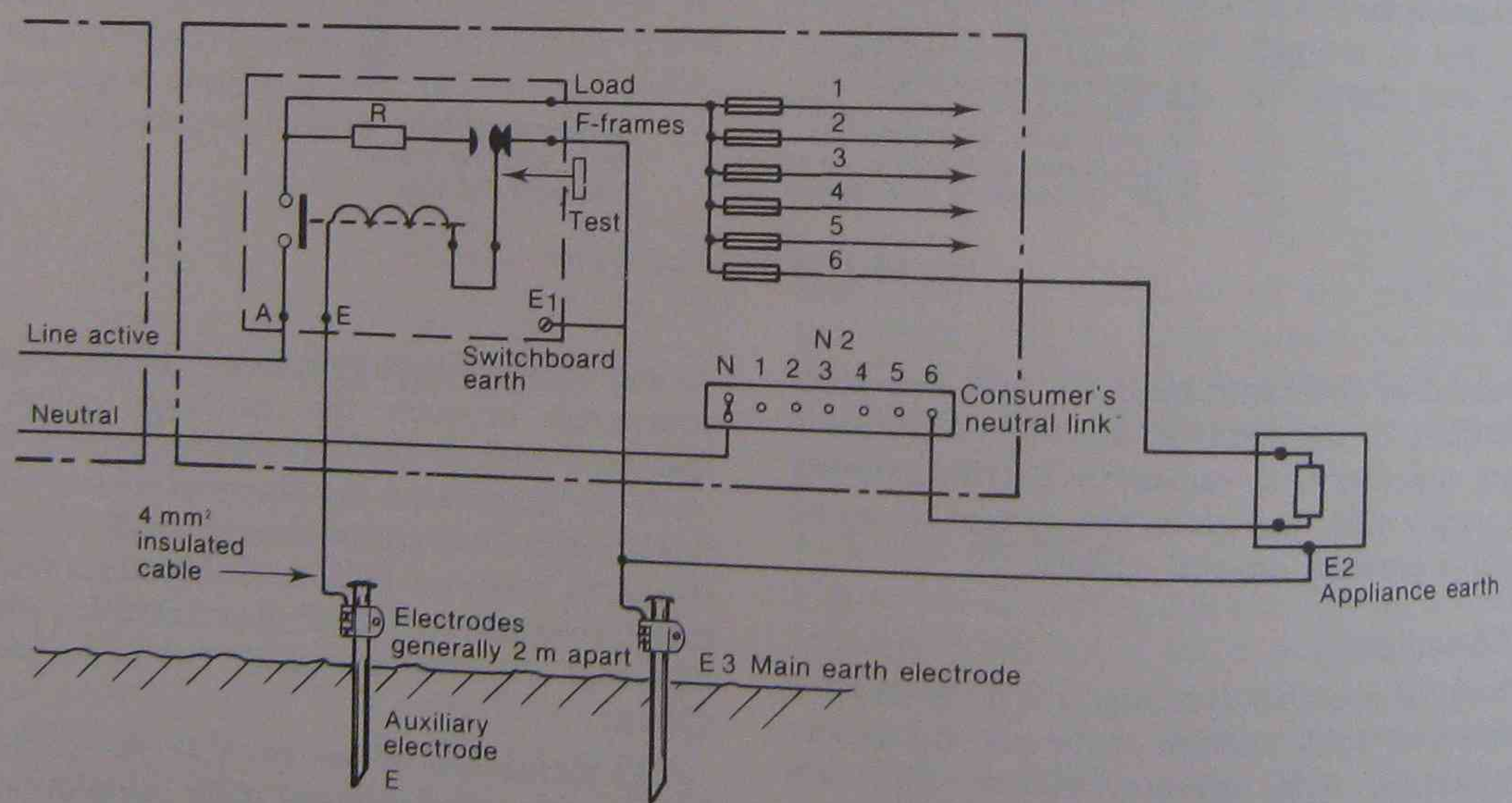


Fig. 8.10 *Connection of earth leakage circuit-breaker*

5. the system is subject to nuisance tripping through various causes.

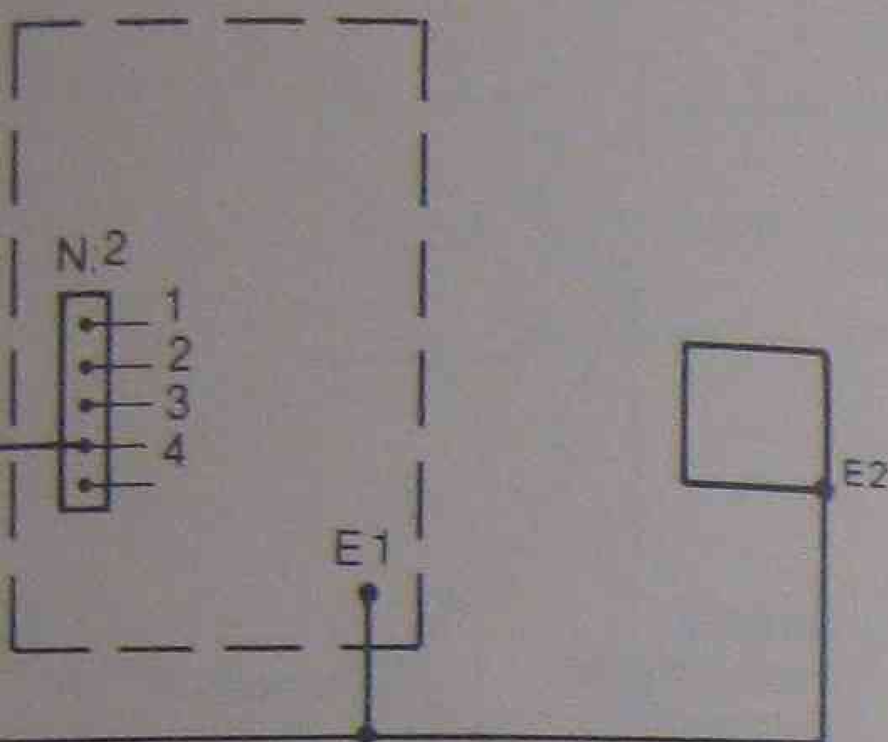
These disadvantages have resulted in the system falling into disfavour except for the special situations mentioned above.

8.5

The incidence of faults due to 1 or 2 is rare. Most faults are due to breakdown within the installation of items listed in 3, 4 and 5.

1. Supply system faults

If a fault occurs on the supply system, this should ideally operate the supply protection, leaving the



…arth goes direct to neutral link

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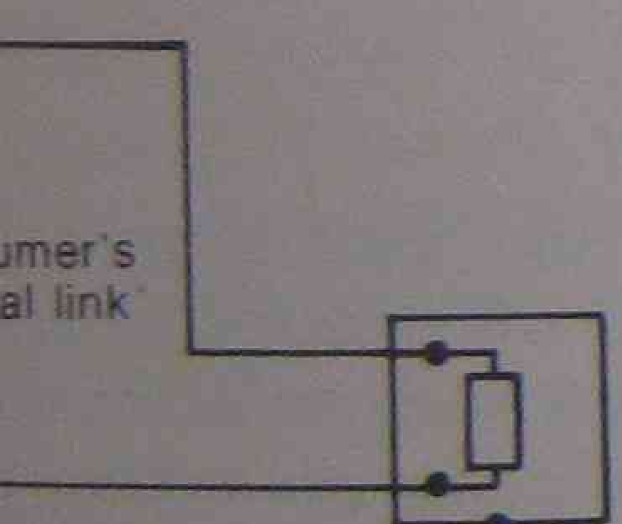

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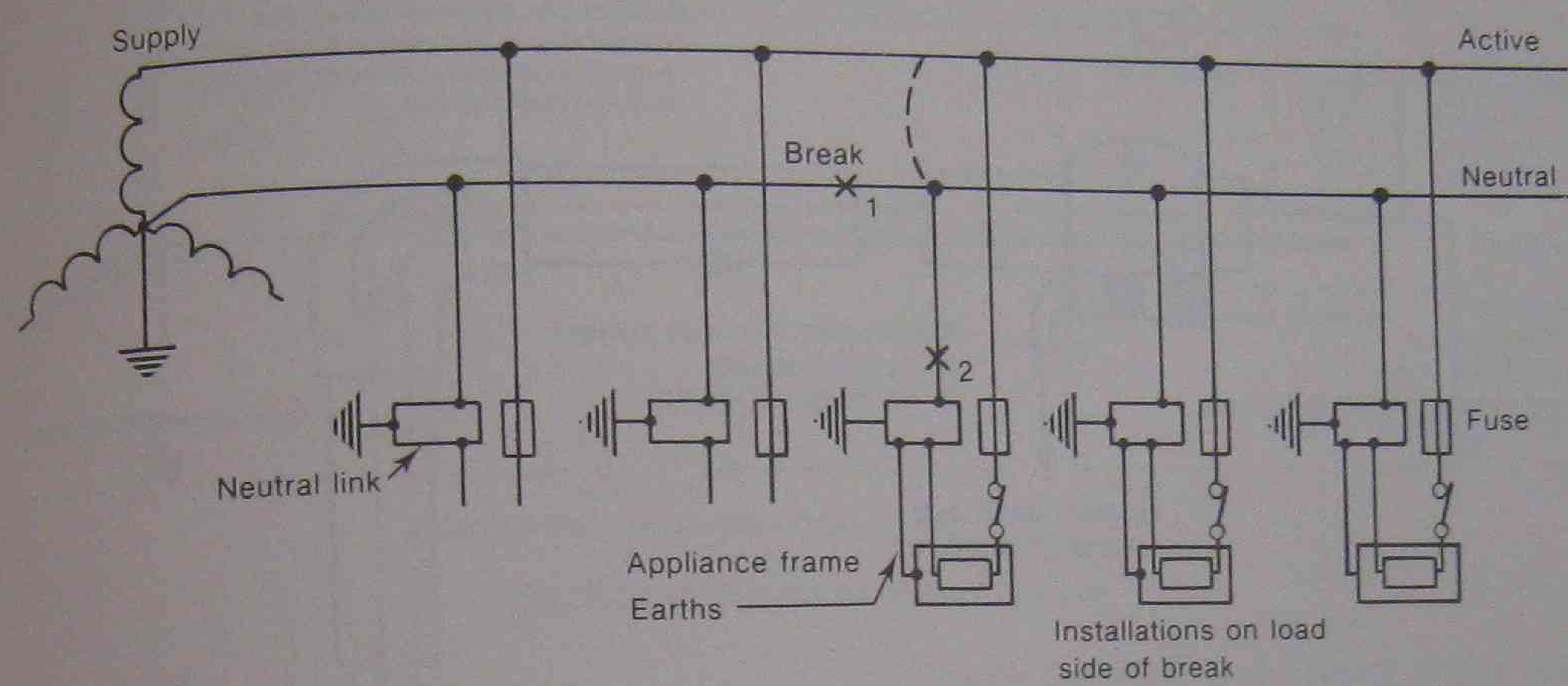

Fig. 8.11 *Earth faults on the supply system*

We shall deal first with the direct earthing system, recalling that the **only** connection between neutral and earth is at the star point of the supply transformer, the circuit being similar to that of Figure 8.11 **without the neutral to earth connection** at each of the five consumers. Due to the reversed connections, all single-pole switches would now operate in the neutral conductor, leaving a live active feed into an appliance with its control switch "off". Fuse or circuit-breaker protection is also in the neutral conductor with the load actives all solidly joined at the previous neutral link (now an active link), so there is no protection against overload due to an active-to-earth fault.

The earth fault current resulting from the active-to-earth fault could cause a dangerous rise in potential in the earthing system and frames of appliances resulting in shock and fire hazard.

If the system was ELCB protected (see Fig. 8.10), there would be no protection of the wiring against overload and a fire hazard would exist, as in the case of the direct earthing system. However, if the earth fault currents produced a voltage rise (20 V to 26 V) in the earthing system, the ELCB should trip, opening the neutral only, with no pro…

no connection between neutral and earth at the consumer's installation, so that supply will be interrupted, appliances and lights will fail to operate, and the fact that a fault condition exists will be clearly apparent.

Should the same fault occur when the installations are connected for the MEN earthing system, because of the connection between neutral and the main earth at the neutral link (see Fig. 8.11) there will usually be no indication that a fault condition exists. All the installations on the load side of the break are using their earthing systems instead of the supply neutral as the return path for the normal load current. The resistance of the earth return path that has taken on the function of the return neutral is usually higher than that of the neutral that it has replaced. The **load current** flowing in the earth return path instead of the neutral usually produces a voltage rise due to *IR* drop, which is impressed on the whole of the earthing system, including the frames of appliances, whether they are switched on or not. This is a highly dangerous situation.

To make matters worse, the earth wire is now carrying a much higher current than that for which it was designed (a load of up to 99 A may only have a 6 mm² earth wire rated at about 40 A) … itself is hazardous. … the consumer's

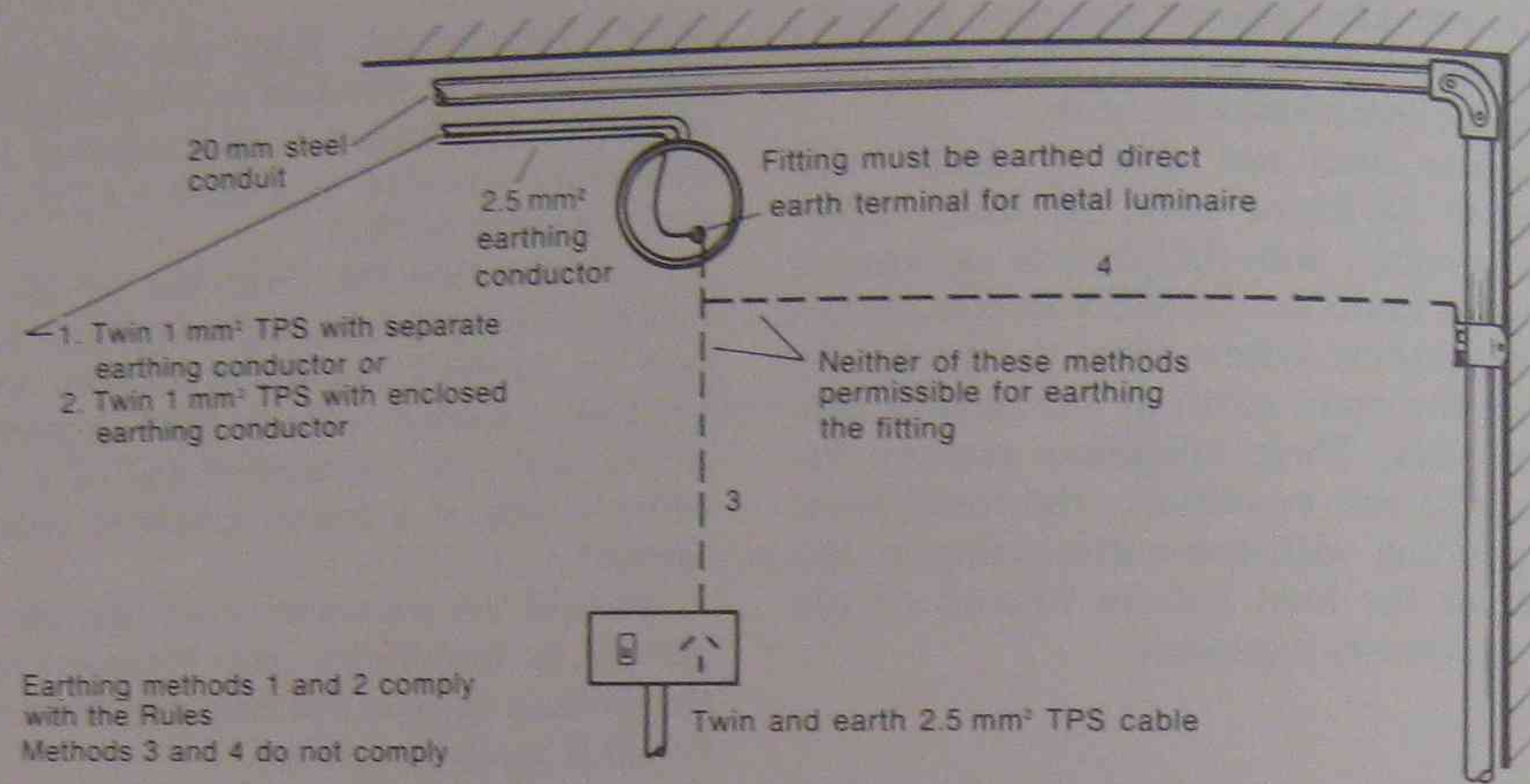

Fig. 8.18 *Correct and incorrect earthing provisions*

Observe that the current ratings of earthing conductors specified in *Table 5.1* are obviously intended as a very short period rating, while at the same time allowing sufficient time for the protective device to operate; for example, the current rating of 6 mm^2 cable enclosed in conduit in air and protected by a rewirable fuse is shown in *Table B2* as 27 A for a single-phase circuit, yet it may be used to protect a circuit supplied through a 25 mm^2 active conductor rated at 70 A.

The minimum size for a main earthing conductor is 4 mm^2 for copper, see *Clause 5.5.3.2(c)*. A minimum of 6 mm^2 applies to copper aerial earthing conductors, the size of which is governed by considerations of mechanical strength (see *Clause 3.14.2*) and which must be identified by the letter E or an earthing symbol (⏚) at each end.

Earthing conductors must be securely fixed in position and be protected against the weather and mechanical damage, and if run underground they are subject to the same Rules as insulated cables under similar conditions.

Joints in earth wires and methods of joining are outlined in *Clause 5.5.5*. Particularly note that only soldered joints are allowed in main earthing conductors up to 16 mm^2 in size, and that tunnel-type earth connections must in general have two fixing screws; however, one screw is permitted for a fixed terminal such as in a plug socket.

Clause 5.7 specifies that ...

The most important provision regarding the direct earthing system is the one which specifies the maximum resistance for the driven or buried electrode (*Clause 5.10.1*). For example, should the largest fuse or circuit-breaker be rated at 30 A, the earth resistance of the electrode must not exceed:

$$R = \frac{\text{voltage to earth}}{5 \times \text{current rating of largest fuse*}} = \frac{240}{5 \times 30} = 1.6\ \Omega$$

Electrode resistance figures of this order (and note the 30 A fuse used in the above example is a relatively small one) are difficult to attain in practice, and this is another reason for the use of the MEN system.

No specified earth resistance for the earth electrode is laid down for the MEN system. Note that *Clause 5.9.3.1* requires that the only position for interconnection of the main earthing conductor and the main neutral is at the main switchboard, either directly to the neutral link or to the earthing link and thence to the neutral link. Some supply authorities prefer it under seal in their link (see *Clause 5.9.3.1(c)*).

The ELCB system requires two earth electrodes, main earth and auxiliary ... special treat-

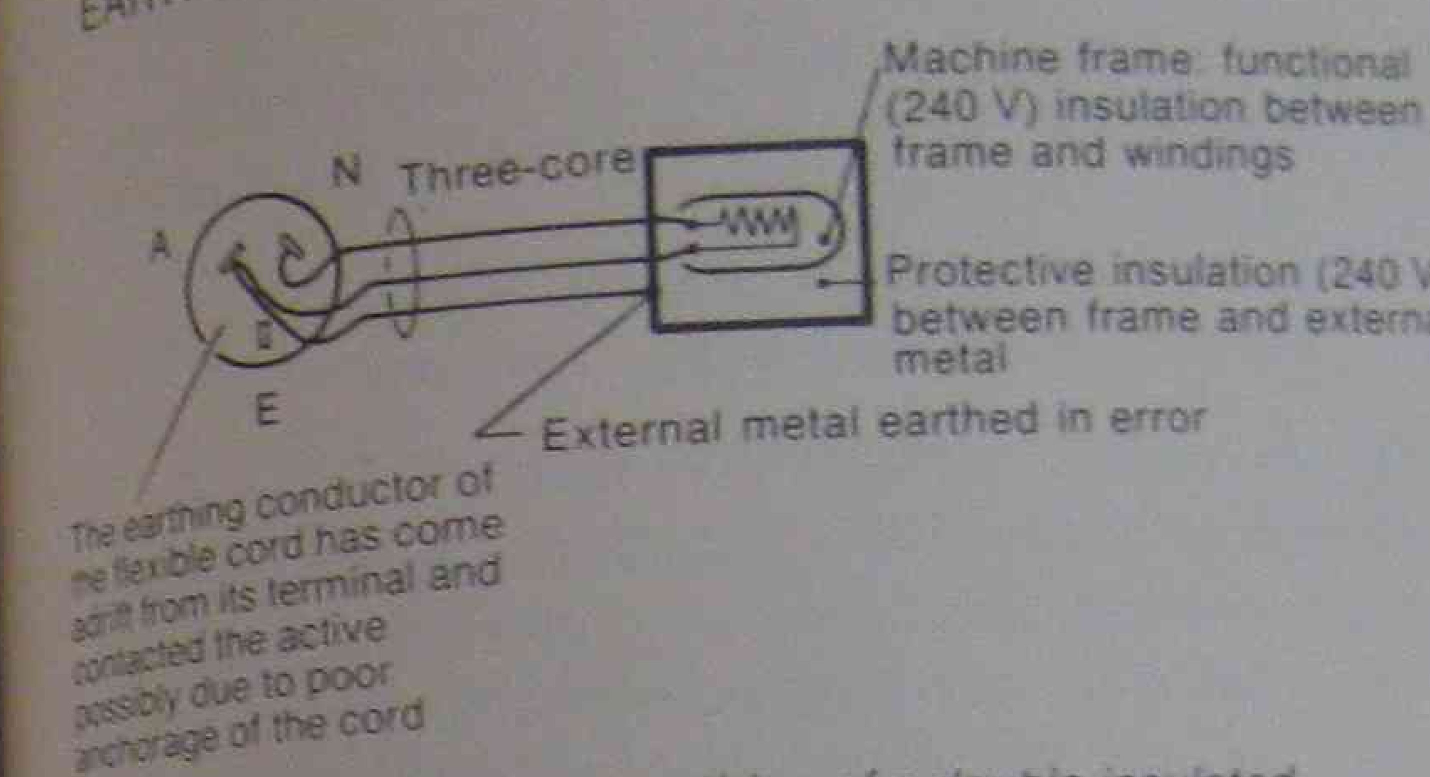

Fig. 8.19 *How the earthing of a double-insulated appliance could create a safety hazard*

8.7 Supplementary systems of earth protection

Many systems have been devised to give protection against shock hazard and earth faults. One line of approach is by isolation of live parts so that breakdown to earth is remote.

Three methods of achieving this isolation, all of which are in current general use, are:

1. by the use of all-insulated equipment;
2. by the use of double-insulated equipment; and
3. by isolation from supply using an "isolating transformer".

The above and other topics in this section are the subject of later detailed study, but are included here for their basic principles, and to bring them within the orbit of the apprentice's experience.

1. All-insulated equipment

This type of equipment is designed to ensure that there is no exposed external metal of any description. The whole of the electrical portion of the equipment is enclosed in a frame and casing of insulating material, and there is no means of access through holes or apertures by which a probe could make contact with live metal inside. Applications are limited, as design considerations would prevent the manufacture of, say, a 2 kW slip-ring motor as an all-insulated machine. Typical all-insulated equipment includes some hair

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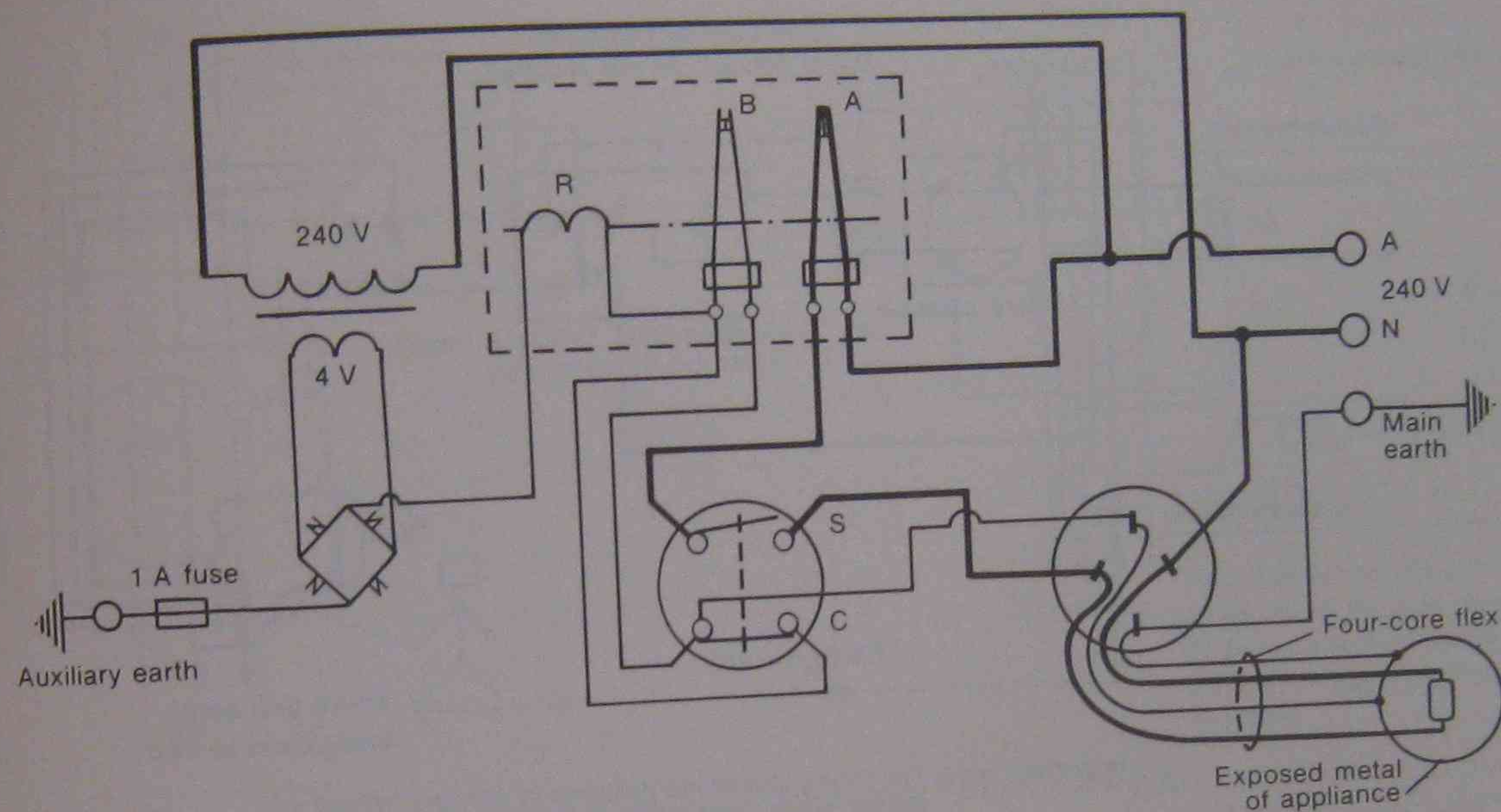

Fig. 8.21 *The Safe-T-Control has been energised and the appliance plugged in. Closing switch S energises the appliance*

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Closing switch S gives supply to the appliance and also opens switch C.

If the relay trips, due to an earth fault while in use, supply cannot be restored until:

(i) the earth fault has been repaired; or
(ii) the control switch has been first switched **off** and then back **on**.

The relay in the unit will not close unless the appliance is plugged in and the earthing system is functioning correctly, and will trip if:

(i) an open circuit occurs in the earthing conductor to the outlet, the main earthing conductor or the flexible cord;
(ii) any type of high resistance occurs in the earthing circuit; or
 frame occurs on the

"balance" and there is no resultant magnetic flux in the core (the phasor sum of the fluxes is zero).

Now trace out in Figure 8.22(a) the path of the earth fault current flowing from the faulty drill through the human figure represented in the diagram, and back to the neutral. This current bypasses the core, upsets the flux balance in the core and the resultant effect is detected and amplified by the unit to "trip" a relay which opens the supply to the protected circuit. **The total time taken to "trip" is less than half the normal time required for a fatal shock.**

The value of leakage current detected may be as low as 20 mA, and it has been established by medical research that there is little danger from electrocution below the limits of 20 mA for ten seconds and 80 mA for 0.1 second, so that the
 (20 mA) and the rapidity of operation

ng TPS cables

al approach to the installation of a TPS stem has similar commonsense rules to ther systems, that is:

runs should be planned for speedy ation and economic use of material. rance will also be a factor for surface see Fig. 10.5).

wiring is on the surface, it is usual to the pin clips or other fixing in short s, and then follow by clipping-in the making sure it is installed flat on the with no kinks. A flat piece of wood used to "dress" the cable in position. h concealed wiring, any fixing necess- done as the cable is placed in position. all the cables are fixed and secure, and ing into equipment complete, the final tions are made at junction boxes, oards and equipment, and the instal- is prepared ready for service.

putting into service, final testing is out.

gh essentially a surface system, TPS y be concealed in roof spaces, cavities n a floor and an uppermost ceiling. otected mechanically by a suitable it must not be buried in concrete, but uried in cement or plaster for vertical xceeding 3 m in length (refer to *Clause)(ii)*).

actor to be considered when installing is that the current-carrying capacity of influenced by environmental conditions, ambient temperature and ventilation. tors dependent on the method of instal-

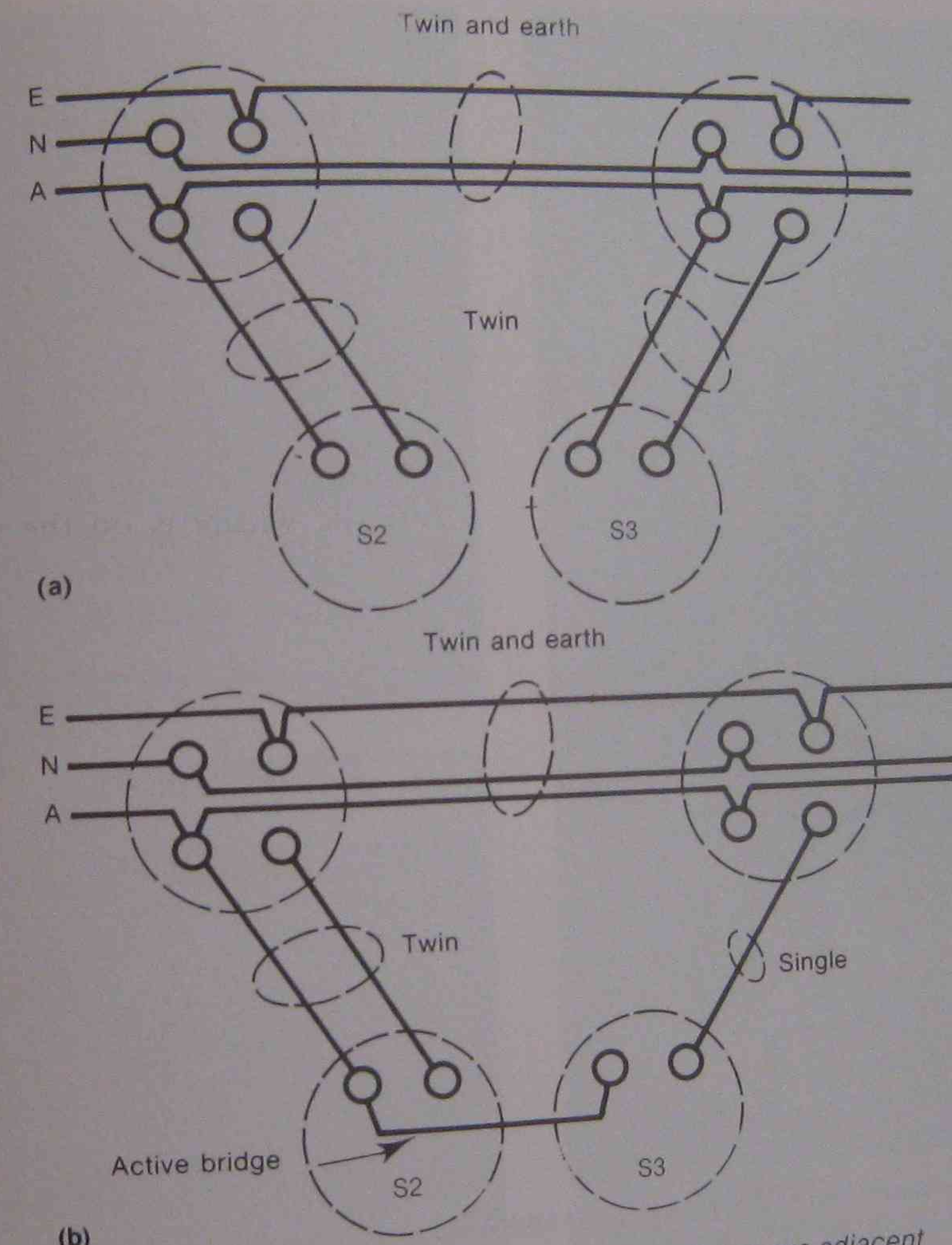

Fig. 10.4 *Two methods of wiring where switches are adjacent*

3. the type of enclosure;
4. the spacing between cables, circuits and the wall or adjacent surface;
5. whether run vertically or horizontally.

Figure 10.6 [illegible] of cable sup-

members, mechanical protection, say in the form of wooden battens, must be provided.

Note also in Figure 10.8 and in Figure 10.7 some positions for cables **not likely to be disturbed**. No fixing is required if the cables are laid on a continuous horizontal surface, otherwise fix- [illegible] not exceeding 2 m is required. [illegible] requirement