Protective Measures against Hazardous Contact Voltage – Course: Basic Skills and Knowledge of Electrical Engineering. Trainees' Handbook of Lessons

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Protective Measures against Hazardous Contact Voltage – Course: Basic Skills and Knowledge of Electrical Engineering. Trainees' Handbook of Lessons

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Introduction

The present handbook is meant for training in electrical engineering trades.

It describes the activities and equipment required for protective measures against hazardous contact voltage.

The required methods are described in self–contained sections. The required knowledge and skills are explained in the necessary sequence of actions in each section. The illustrations included support the text and broaden the contents of the individual sections.

In support of the learning process questions are included for the trainee to check his knowledge.

1. The Necessity of Protective Measures against Hazardous Contact Voltage

The protection of human life, health and capacity for work is a basic human concern. Therefore, in electrical plants with or without earthed net point, it is necessary to take protective measures against hazardous contact voltage if the conductor–earth voltage exceeds

- 50 V with alternating current or
- 120 V with direct current!

Accidents due to electricity are often caused by improper installation or missing and/or defective protective measures.

Manufactures of electrical equipment are obliged to insulate this equipment for the respective working voltage.

Why is it still necessary to take protective measures, even if cables, electrical equipment and plants are sufficiently insulated?

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The protection of man against hazardous contact voltage has priority over function!

2. Potential Equalization

The voltage of a conductor or body to earth is called the "potential" of this conductor or body. The earth is electrically neutral and thus has the potential "zero". The unit of measurement for the potential is volt.

A conductor or body has the potential "zero" – earth potential – if it is conductively connected with the earth.

As a consequence of damages to the insulation, voltages may be transmitted to metal parts which do not belong to the service circuit.

This causes the development of potentials between the metal parts which might be dangerous for man.

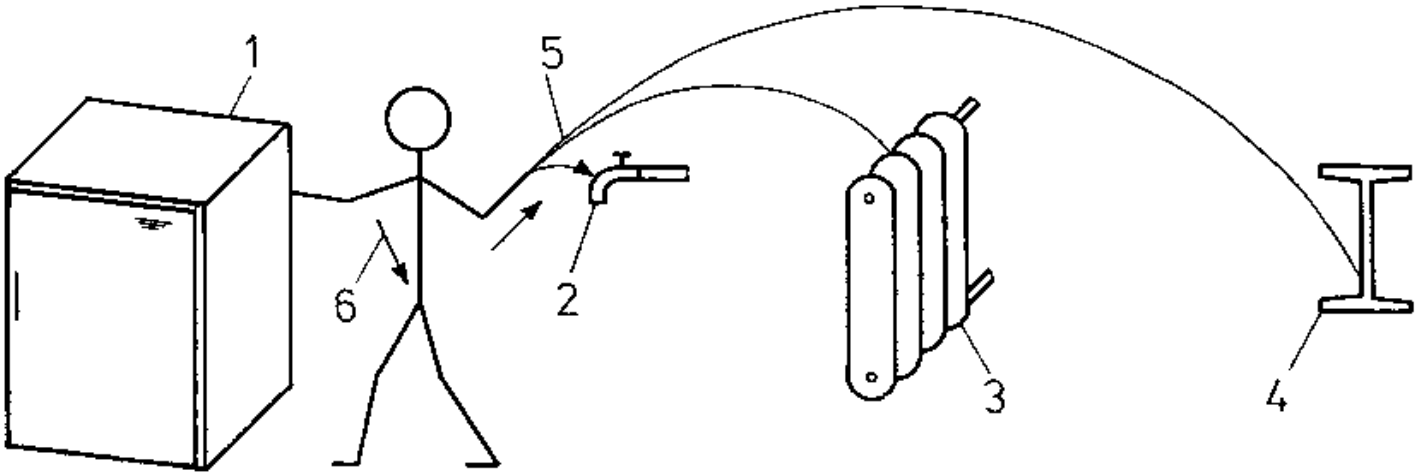

Figure 1 – Potential development between metallic parts with insulation damage – *1 defective device, 2 pipe conduites, 3 central heating, 4 metallic constructions, 5 potential developed, 6 current through human body*

If a man touches two different metal parts at a time – for instance an electrical device and a water pipe – he bridges the existing potential and a current flows through his body.

If an electric current flows through the body of a human being, this might be mortal.

A remedy to this is a potential equalization to zero potential.

How can a potential equalization to zero potential be achieved?

The potential equalization must not be broken by the removal or demounting of parts.

What line cross–sections should be used for potential equalization?

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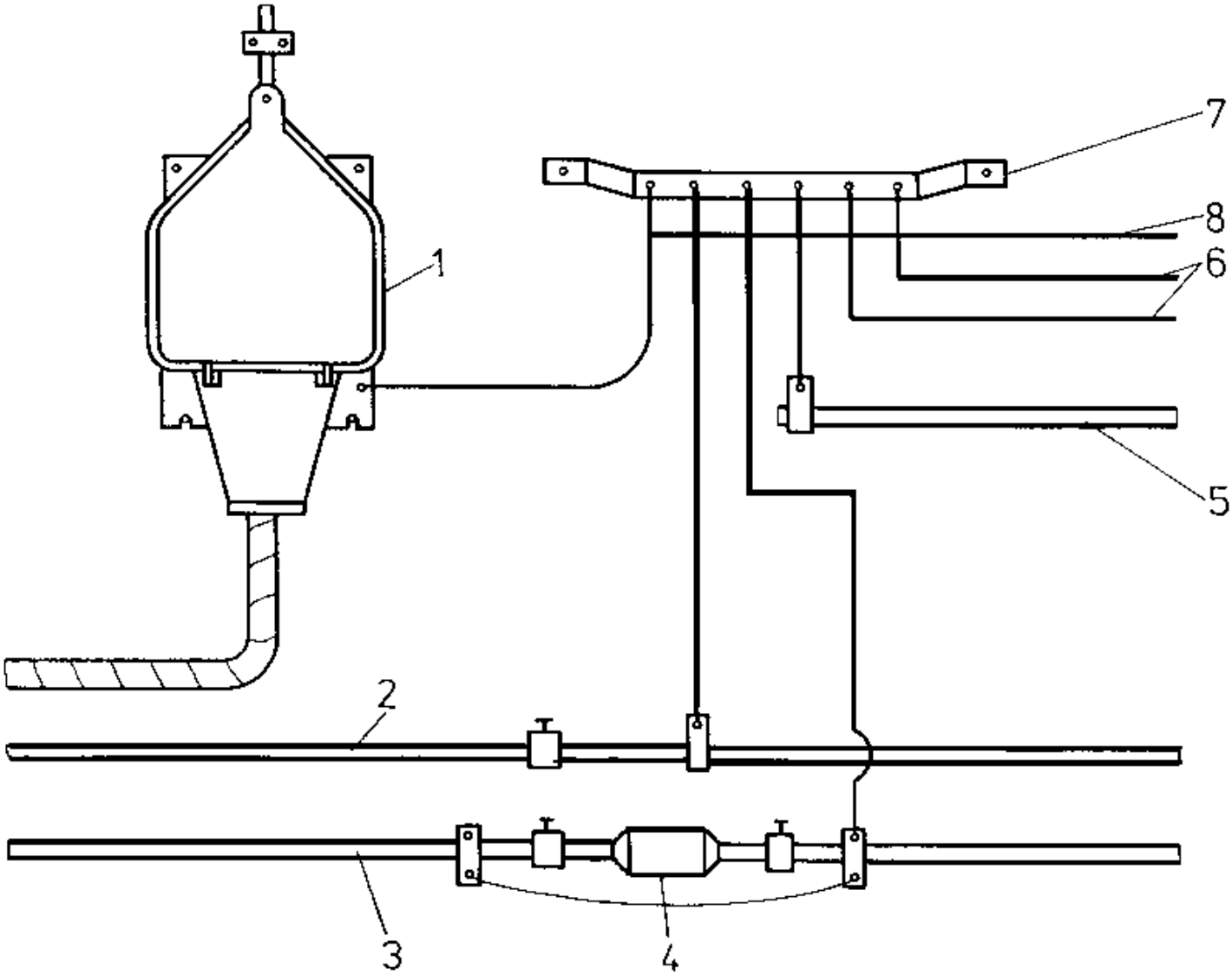

Figure 2 – Potential equalization – *1 service box, 2 gas main, 3 water pipe, 4 water meter, 5 heating pipe, 6 leads for further metallic parts, 7 potential equalization bar, 8 potential equalization leads*

3. Protective Measure against Hazardous Contact Voltage

These are subdivided in two groups.

Group 1: Protective measures preventing the development of hazardous contact voltage.

- protective insulation
- protective low voltage
- protective isolation
- protective conductor system

Group 2: Protective measures which prevent that hazardous contact voltage continue to exist.

- protective earthing
- connection to neutral
- fault–voltage protective system
- fault–current protective system
- isolating fault–current protective system

If the protective measures are categorized with respect to the presence of a protective conductor, the following subdivision results:

Protective measures "without" protective conductor

– protective insulation
– protective low voltage
– protective isolation

Protective measures "with" protective conductor

– protective conductor system
– protective earthing
– connection to neutral
– fault–voltage protective system
– fault–current protective system
– isolating fault–current protective system

Technical terms recurring with the individual protective measures have to be used according to Figure 3:

– contact voltage (1)
– fault–voltage (2)
– fault–current (3)
– body resistance between current entry and exit points (4)
– transition resistance of the station point (5)
– resistance of earth (ground) (6)
– resistance of earth bus (7)

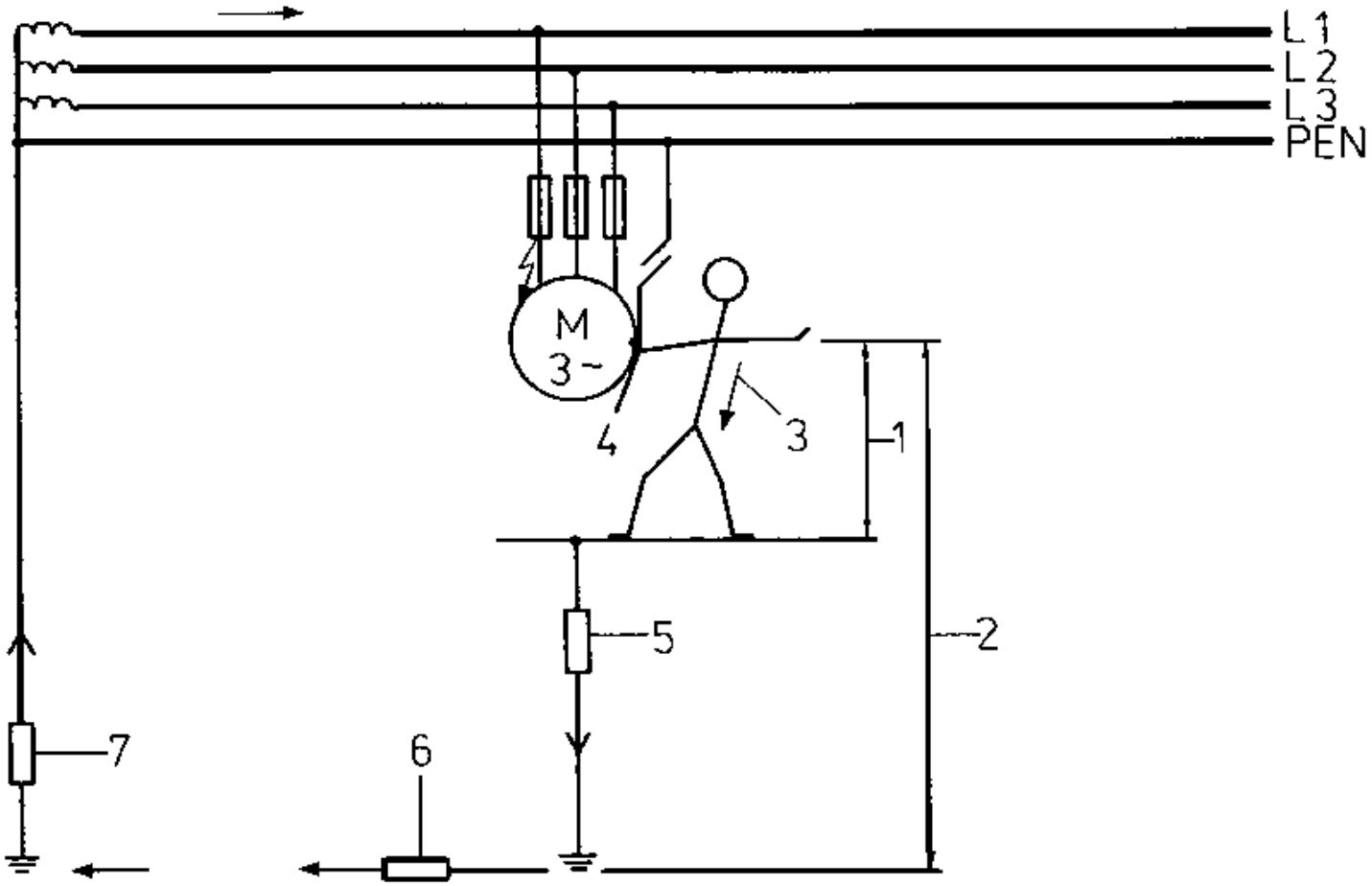

Figure 3 – Fault–current circuit – *1 contact voltage, 2 fault voltage, 3 fault current, 4 body resistance between current entry and exit points, 5 transition resistance of station point, 6 resistance of the ground, 7 resistance of earth bus*

3.1. Protective Measures Preventing the Development of Hazardous Contact Voltage

Protective insulation

Criteria of the protective insulation

– The protective insulation is used in addition to the operating insulation.

– The protective insulation must stand an alternating current test voltage of at least 4 kV for one minute without any damage to the insulation being visible afterwards.

– Protection–insulated electrical equipment is not provided with safety plugs by the manufacturer. If a repair should require that such a plug is fitted and if the connecting line should have a protective conductor, this has to be connected to the plug – not to the device.

– Protection–insulated electrical equipment is marked by a double square on the casing.

Protection–insulate electrical equipment is not connected by a safety plug.

Forms of protective insulation are:

– protective insulation sheathing
– intermediate protective insulation
– reinforcing insulation a b c

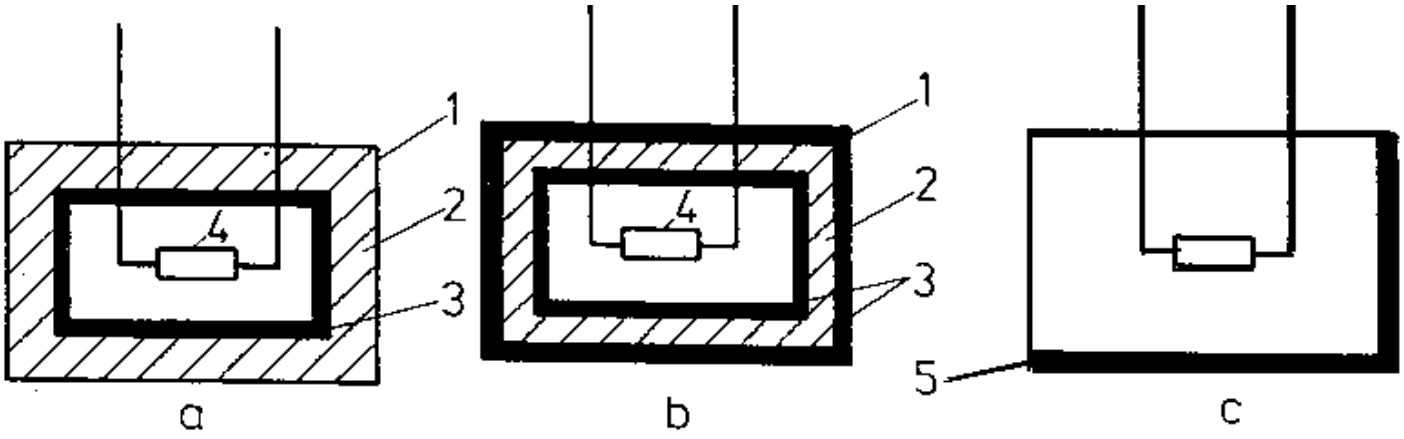

Figure 4 – Forms of protective insulation a protective insulating sheathing, b intermediate protective insulation, c reinforcing insulation – *1 casing* (*metal or plastic*)*, 2 protective insulation, 3 service insulation* (*normal*)*, 4 live parts, 5 service insulation* (*reinforced*)

Where is the protective insulation preferably used?

_____
_____
_____

Checking of the protective measure of "protective insulation"

Inspection:

– visible defects of the protective insulation
– no connection of protective conductor
– marking by double square

Measuring:

– measuring of the insulation resistance between life parts and accessible conductive parts

The resistance of the insulation must be at least 1.5 megaohms with a measuring voltage of 100 V direct current voltage

Protective low voltage

Criteria of the protective low voltage

– The protective low voltage must not exceed an alternating current voltage of

- 25 V with load and
- 50 V without load.

– The parts generating the protective low voltage as well as the conductors must not be secondary–earthed.

– The secondary side must not be connected with leads of other circuits.

– Plug connections must have no secondary protective contacts.

– Electrical equipment operated with protective low voltage must have no connecting points for the protective conductor.

– Accumulators have to be disconnected from the circuit of protective low voltage by all poles during the process of charging.

For protective low voltage, only special plug–in devices must be used.

Devices for generating protective low voltage are:

– insulation transformers
– generators
– transformers with electrically separated windings
– accumulators
– galvanic cells

Where is the protective low voltage used?

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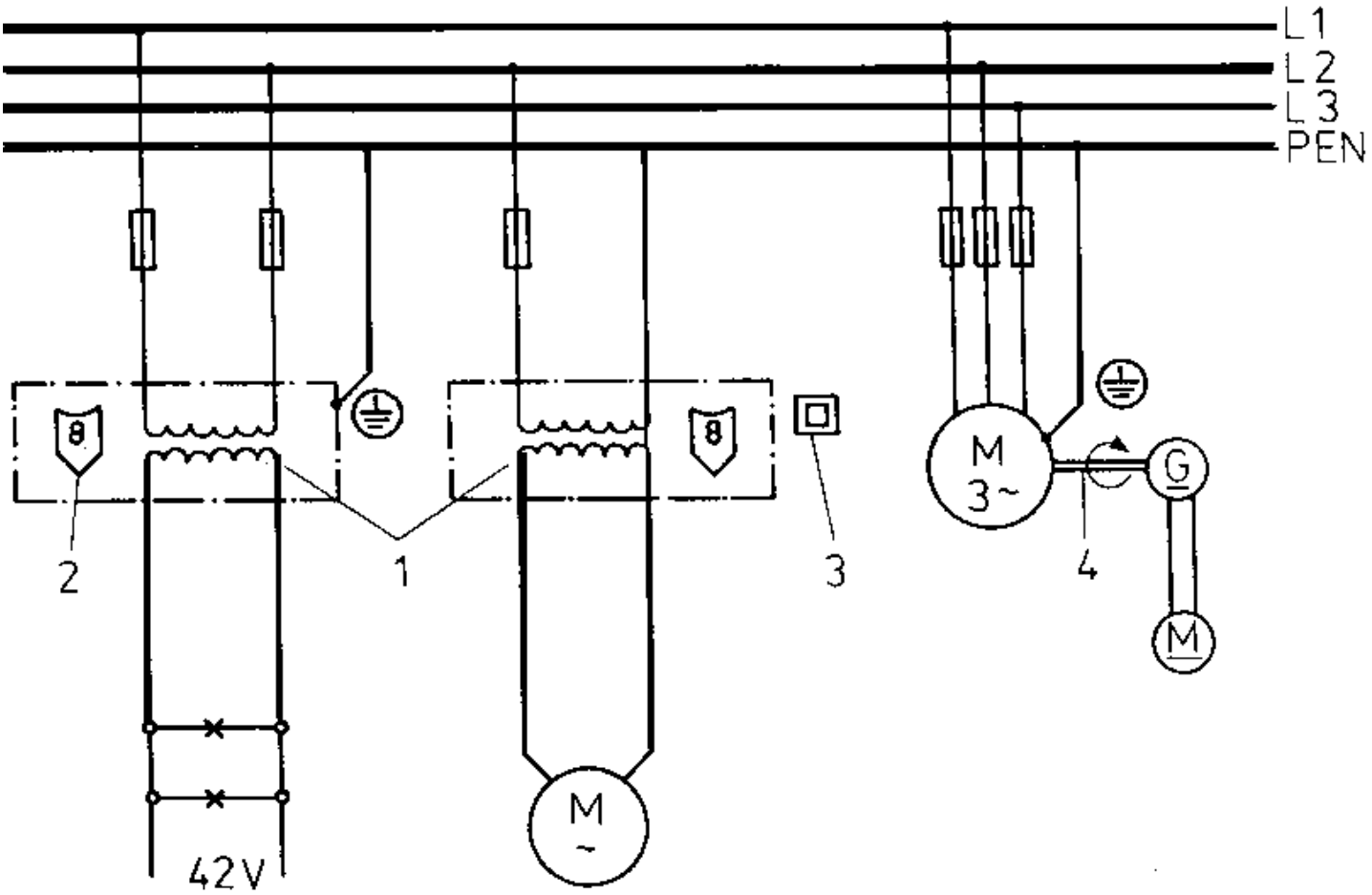

Figure 5 – Generation of a protective low voltage by protective transformer or motor generator – *1 protective transformer, 2 symbol of protective low voltage, 3 symbol of protective insulation, 4 motor generator*

Checking of the protective measure of "low voltage"

– By inspection whether the plant and devices meet the required criteria.
– By measuring whether the permissible voltage is not exceeded.

Protective isolation

Criteria of protective isolation

– The protective isolation is accomplished if there is a galvanic isolation between the service circuit and the circuit supplying the energy. (The input end and the secondary end must be connected only through the magnetic flux!)

– When isolating transformers are used, only one device must be connected to each secondary winding.

– Circuits with protective isolation must not be earthed or connected with conductors of other circuits.

– Metal casings of electrical tools, which are used in boiler plants or other kinds of metal constructions, have to be connected in a conductive way with the latter. (Potential equalization has to be created!)

– The working voltage with load must not exceed 380 V three–phase current.

With the protective isolation, no electric connection must come into existence between the input end and the secondary end!

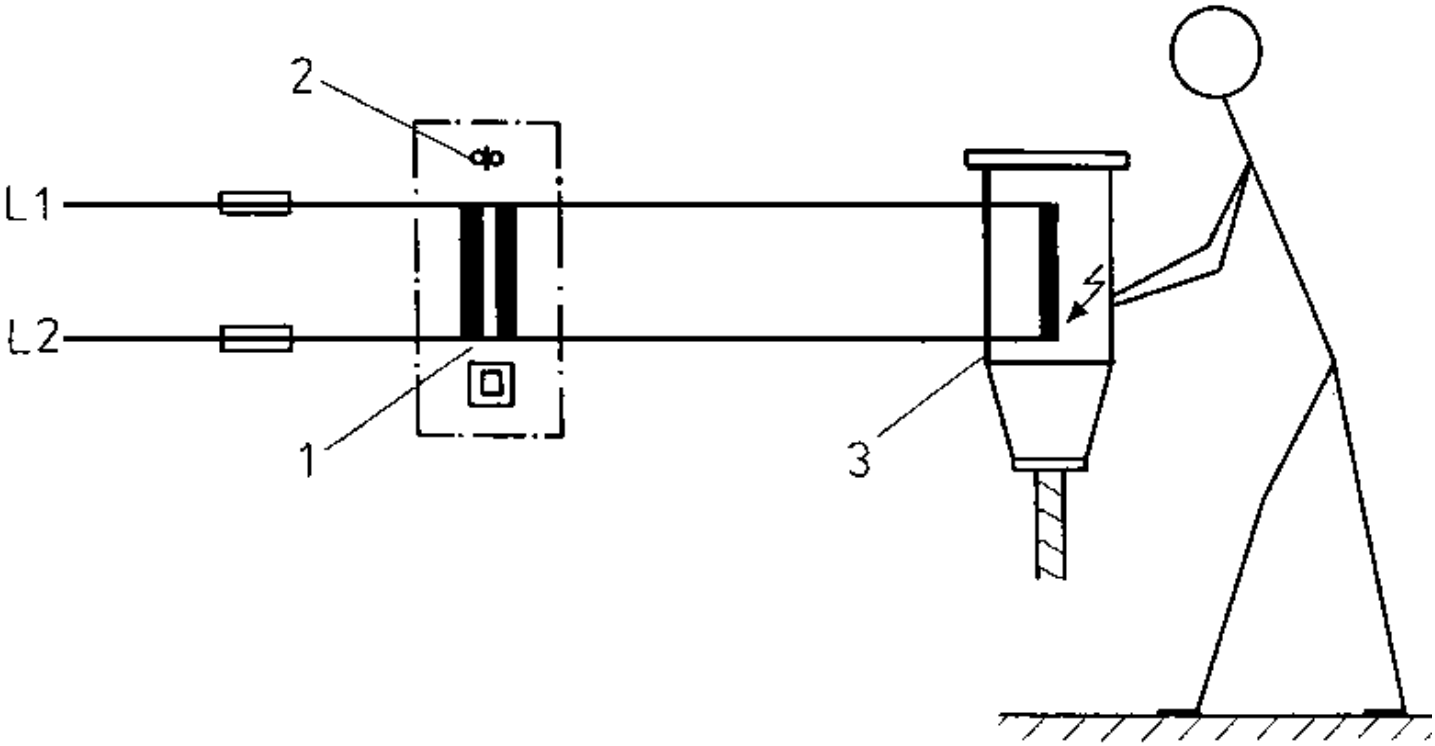

Figure 6 – Protective isolation – *1 isolating transformer, 2 symbol of protective isolation, 3 device*

Devices for creating the protective isolation are:

– isolation transformers with a transformation ratio 1:1
– motor generators
– transformers with galvanically isolated windings

Where is the protective isolation used?

Checking of the protective measure of "protective isolation"

– By inspection whether the plant and devices used meet the required criteria.

Protective conductor system

Criteria of the protective conductor system

– The protective conductor system can only be used in plants with an own transformer.

– The neutral point of the transformer must be earthed through a fusible cut–out.

– All metallic parts and casings that do not belong to the service circuit, have to be connected with each other through the protective conductor.

– The protective conductor must not be connected with the neutral conductor.

– The maximum value of the earthing resistance of the protective conductor is 20 ohms.

– The supervisory equipment must switch off or signalize if the insulation resistance of current–carrying conductors towards the earth falls below 25 ohms/volt.

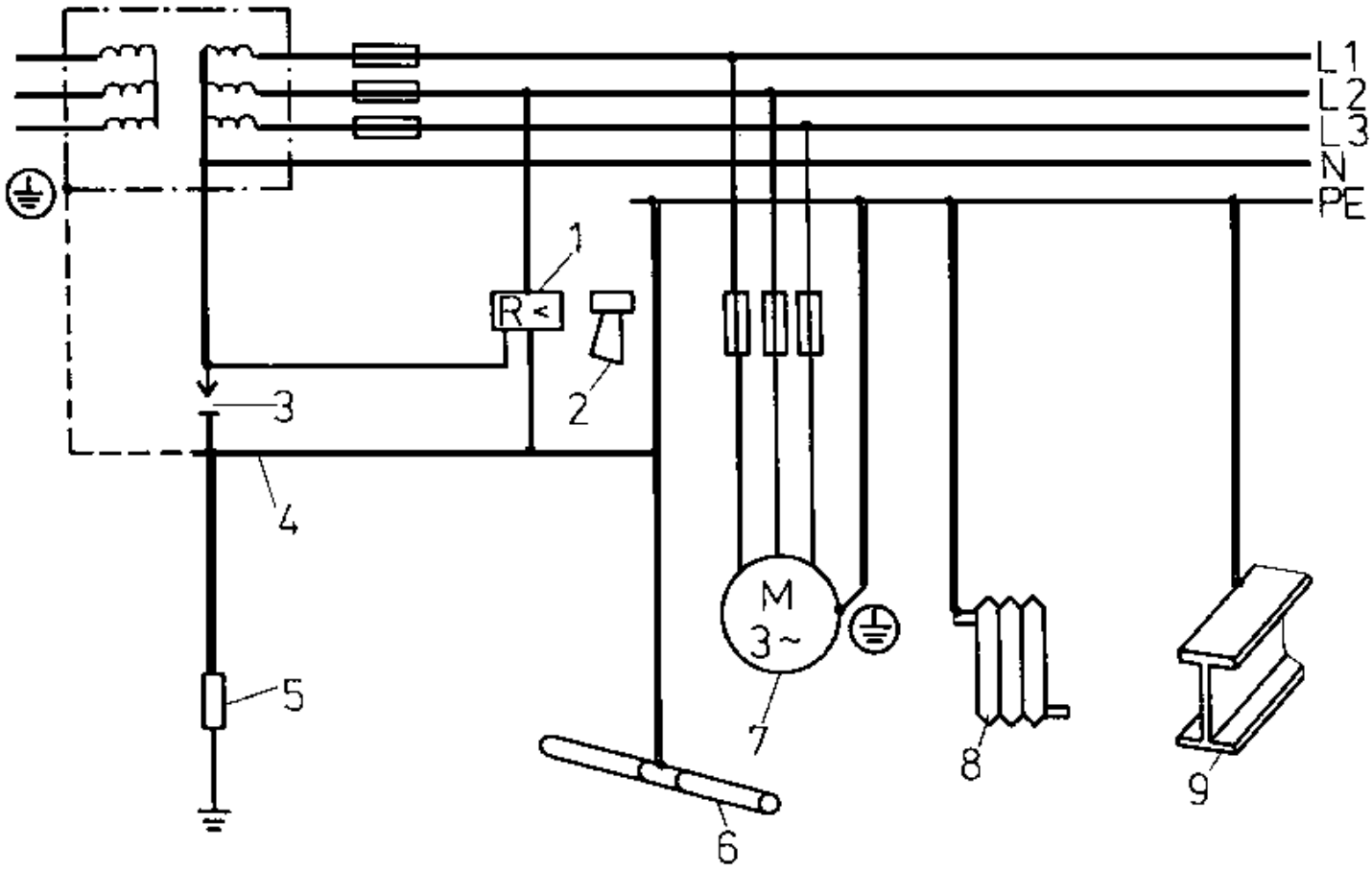

Figure 7 – Principle of the protective conductor system – *1 supervisory equipment, 2 alarm, 3 fusible cut–out, 4 protective conductor, 5 resistor, 6 water pipe system, 7 motor, 8 heating system, 9 metal construction*

Where is the protective conductor system used?

_____
_____
_____

Checking of the protective measure of "protective conductor system"

– The criteria of this protective measure are checked by visual inspection.

– By measuring, the insulation resistance between current–carrying conductor and earth as well as between the metallic parts is checked.

With the insulating test 25 ohms/volts are required. If this level is not achieved, the supervisory equipment must switch off the plant and/or circuit.

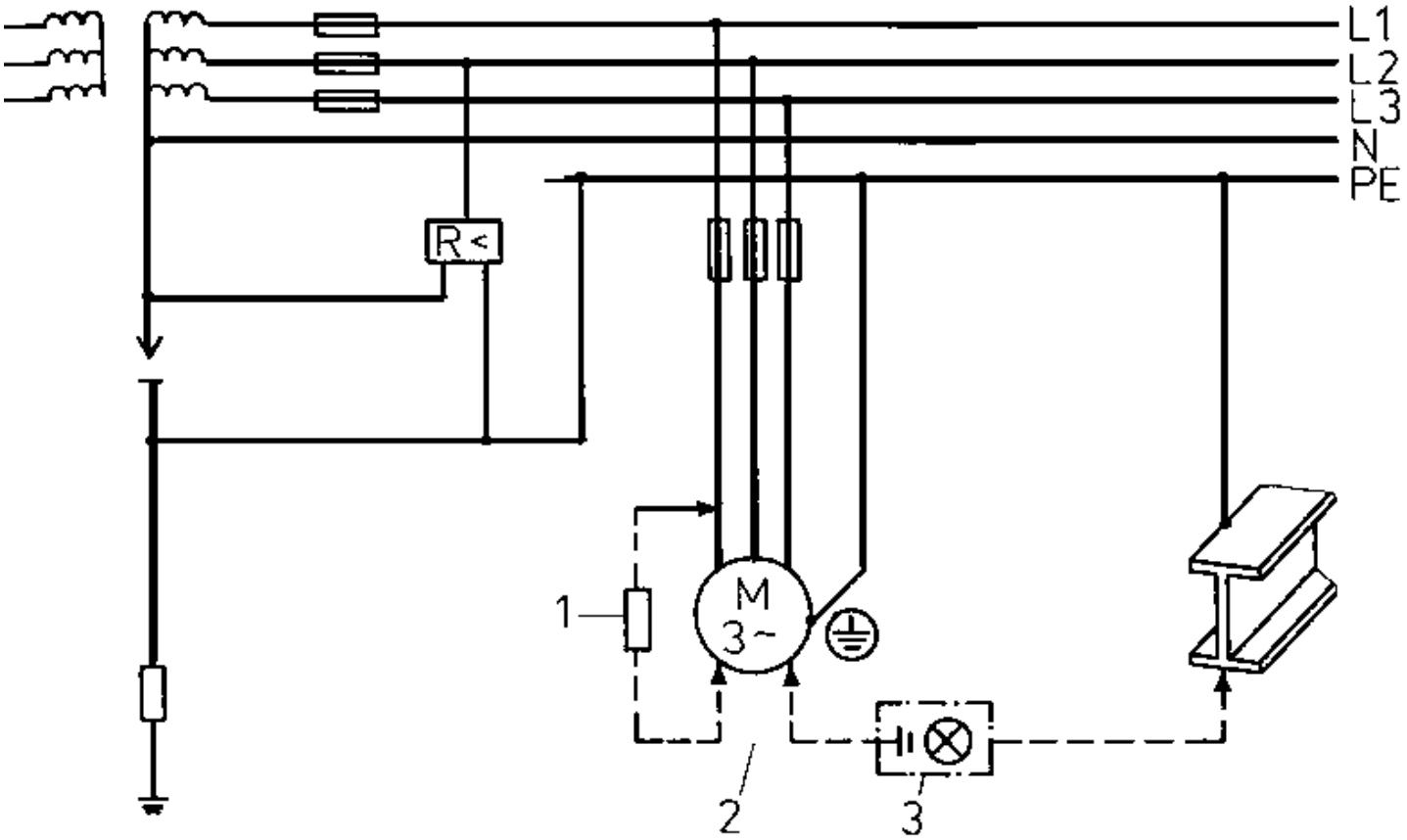

Figure 8 – Testing process – *1 test resistance, 2 test prods, 3 continuity tester*

What must be the value of the test resistance with a mains voltage of 220 V?

_____

_____

3.2 Protective Measures which Prevent that Hazardous Contact Voltages Continue to Exist

Protective earthing

Mode of action of the protective earthing – When it comes to fault current, the fault–current circuit is closed by

- earth or
- via metallic conductors, such as water pipes or cable sheathings

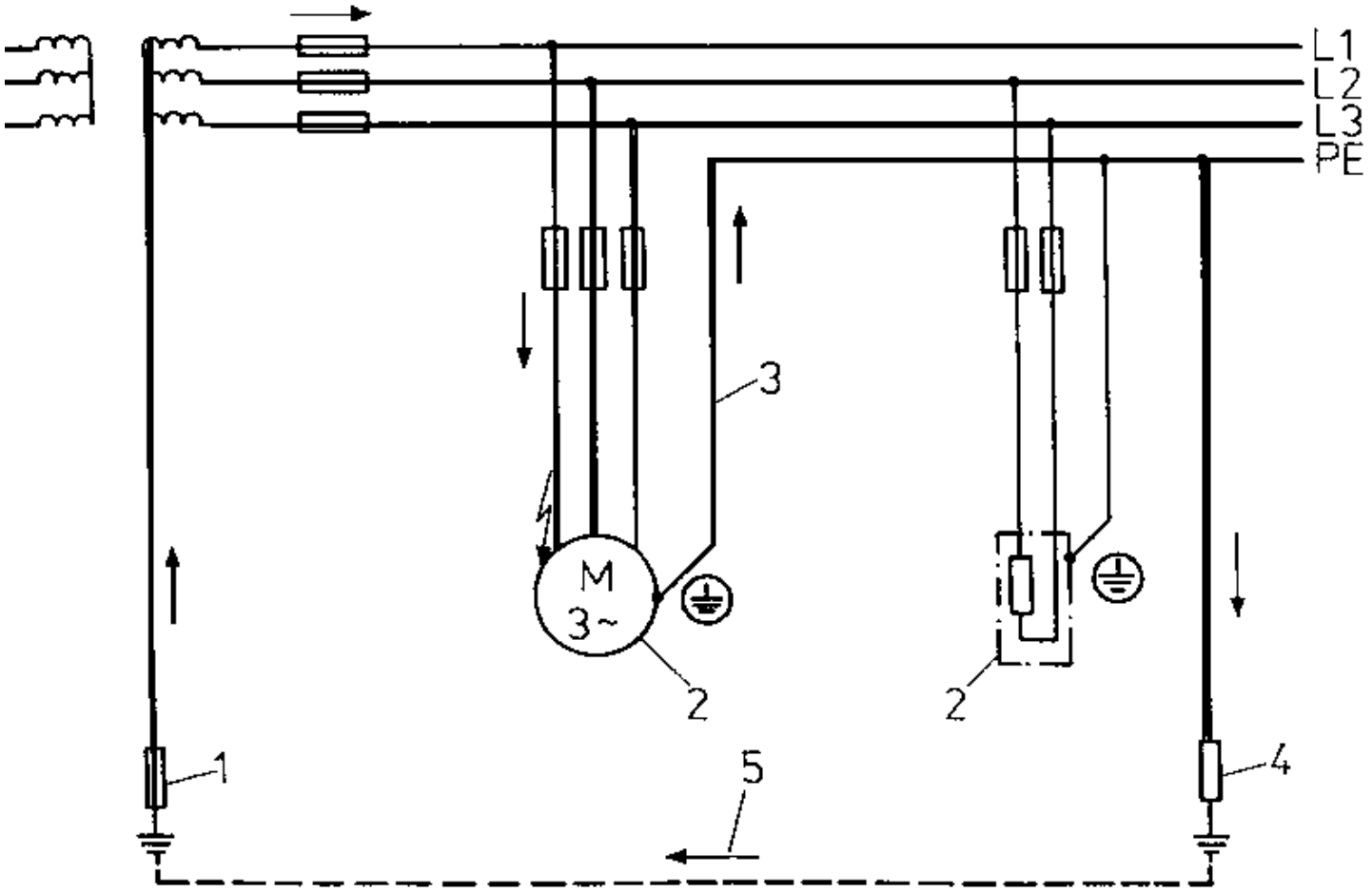

Figure 9 – Protective earthing (return flow of the fault current through the ground) – *1 resistance of the service earthing, 2 devices, 3 protective conductor, 4 resistance of the protective earthing system, 5 fault current*

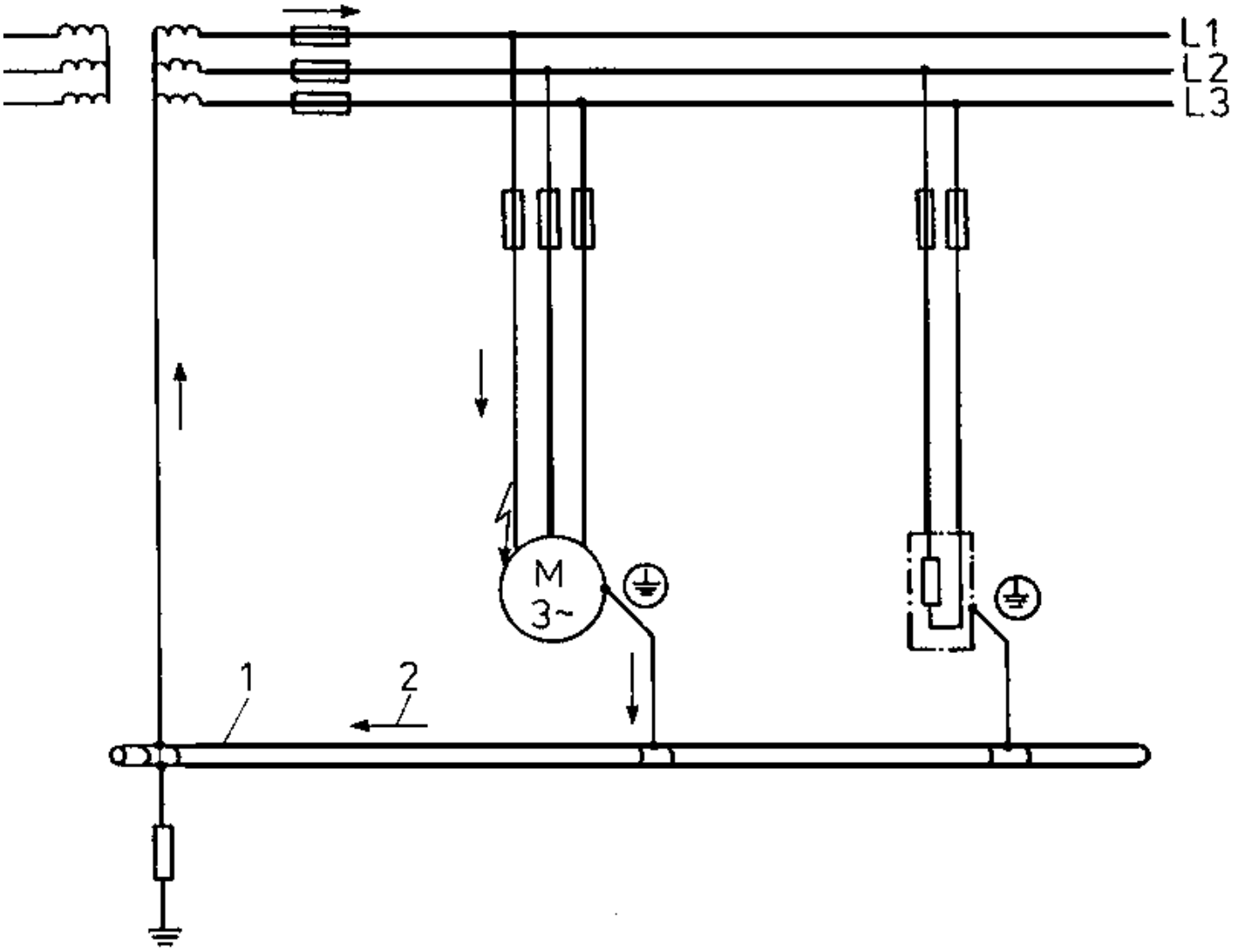

Figure 10 – Protective earthing (return flow of the fault current through the water pipe system) – *1 water pipe system, 2 fault current*

Criteria of protective earthing

– All metallic casings and metallic parts of electrical equipment must be connected with one another through a protective conductor.

– The protective conductor must be connected with the earth electrode.

– With the return flow of the fault current through the earth, the resistance must not exceed a certain value (Fig. 9./Legend 4).

This has to be calculated according to the following equation:

$$R = \frac{U_B}{K \times I_n} \text{ ohm}$$

The symbols have the following meaning:

Rs Resistance of the protective earthing

U_B Permissible contact voltage

k Factor for the switching off

k = 3.5 for fuses up to 50 A

k = 5 for fuses over 50 A

In Amperage of the uses of the protected device

With the return flow of the fault current over the water pipe system, the resistance must not exceed the value which is calculated by the following equation:

$$R = \frac{U_{LE}}{K \times I_n} \text{ ohm}$$

U_{LE} – stands for voltage between conductor and earth.

Where is the measure of protective earthing applied?

_____
_____
_____

Disadvantages of the protective earthing

– The earth transition resistance is subject to climatic influences.

– The required earthing resistances are achieved only with great difficulties.

– The unipolar switching off of devices consuming three–phase current may lead to damage to the electrical equipment.

Checking of the protective measure of protective earthing

– The required connections of the protective conductor are checked by visual inspection.

– By a continuity test the connections of the metallic pans between each other are checked.

– The earthing resistance has to be calculated and tested by measuring.

Connection to neutral

Mode of action

– Instead of being returned to the earthed mains point through the earth or the water pipe system, the fault current is returned through the "neutral conductor with protective function" (PEN) – the neutral conductor.

– A body contact that might occur as a result of a fault is turned into a unipolar short circuit by the connection between casing and neutral conductor.

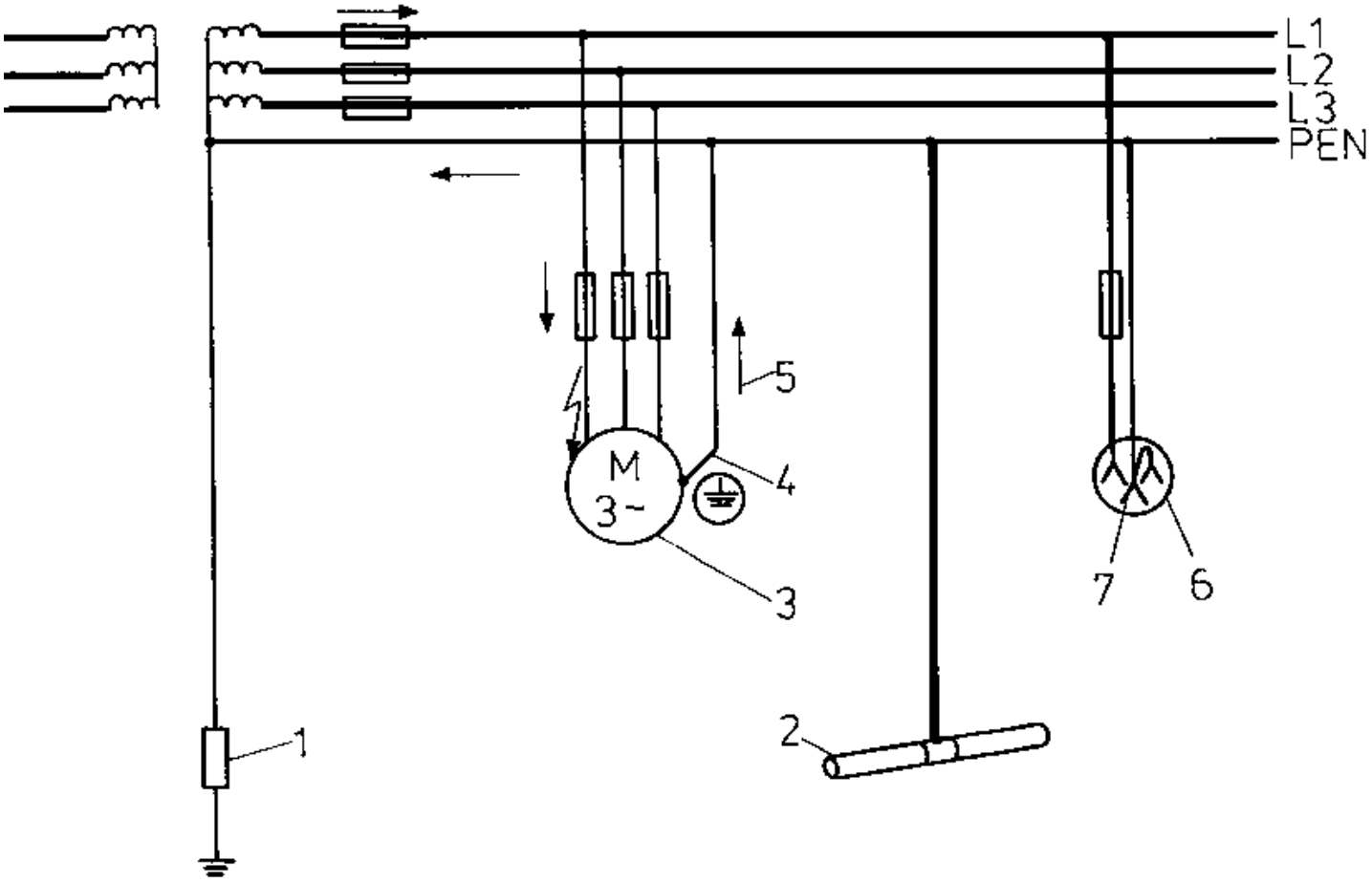

Figure 11 – Protective measure of connection to neutral in a threephase four–wire system – *1 resistance of the service earthing, 2 pipe system, 3 motor, 4 protective conductor, 5 fault current, 6 socket with protective contact, 7 protective contact*

Criteria of the connection to neutral

– All metallic casings of electrical equipment are connected to the neutral conductor through the protective conductor.

– The neutral conductor has to be earthed at the neutral point of the transformer, at the ends of the mains and evenly distributed in the mains.

– With cables with metallic sheathing, the latter has to be connected with the neutral conductor.

– With plastic cables, the neutral conductor has to be earthed at the casing connection.

– With the connection of the neutral conductor to electrical equipment, the protective function must be accomplished first. Only then it is connected to the operating contact.

– The protective measure is accomplished, if – with short circuit between external conductor and neutral conductor – a current flows that is 2.5 times the rated current of the fuse connected before.

The neutral conductor, at the electrical equipment, must be bridged from the protective contact to the operating contact.

Where is the connection to neutral used?

_____
_____
_____

Checking of the protective measure of "connection to neutral"

– It has to be inspected whether the protective conductor is connected according to the required conditions.

– The fault current with short circuit between external conductor and neutral conductor can be measured.

Fault–voltage protective system

Mode of action

– Similar to the protective earthing. Only that here the release, in the case of fault, is not actuated directly through the connection of the parts of the plant to be protected with the earth but all–polarly over a trip coil.

– The fault current flows through the voltage coil and excites it. The coil actuates the control element, and the part of the plant which is at risk is switched off in an all–polarly way.

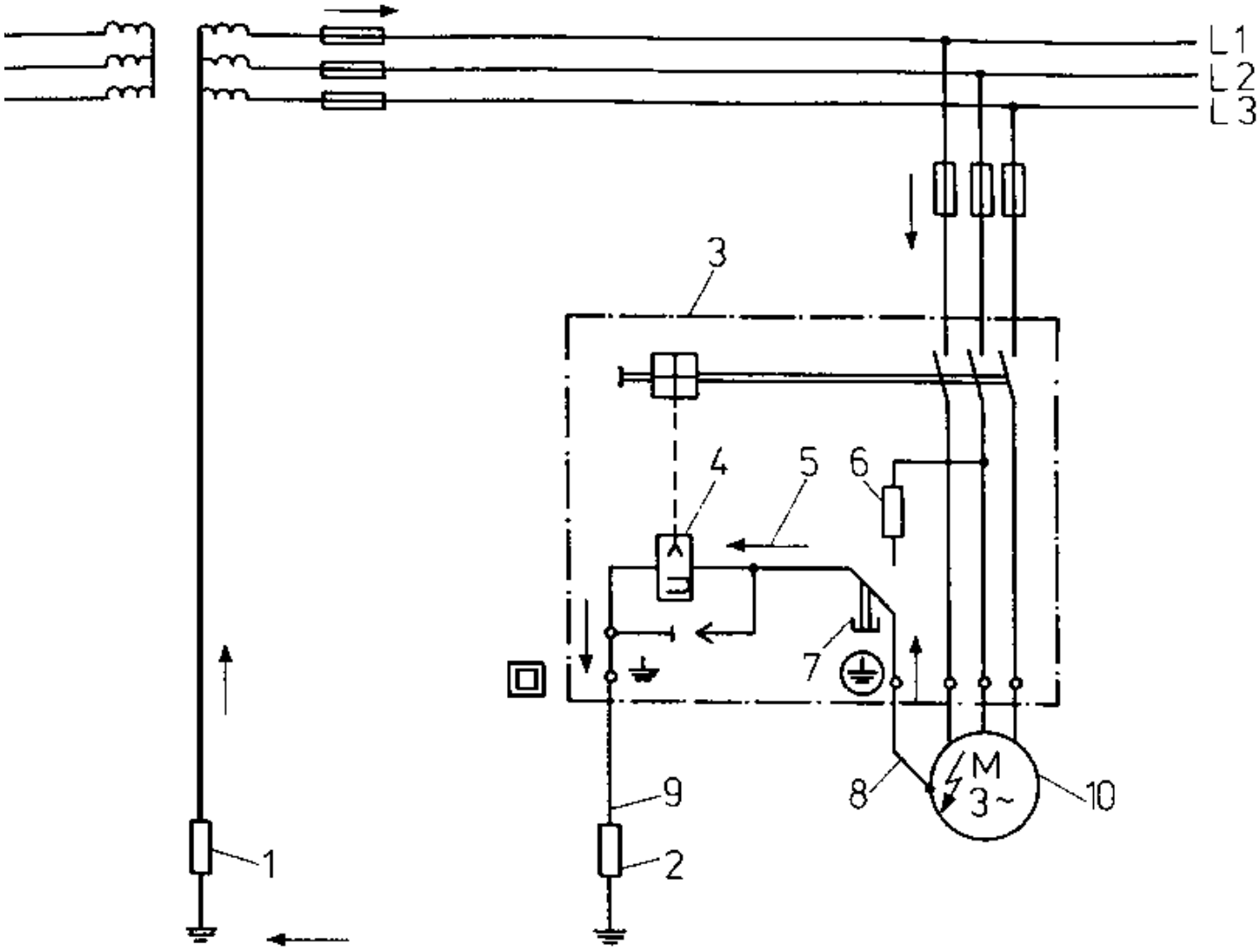

Figure 12 – Fault–voltage protective system in a threephase system – *1 resistance of the service earthing, 2 resistance of the auxiliary earthing, 3 protective switch, 4 voltage coil, 5 fault current, 6 test resistance, 7 test key, 8 protective conductor, 9 auxiliary earth lead, 10 motor*

Criteria of the fault–voltage protective system

– The protective conductor has to be connected with the casing of the equipment and with the voltage coil.

– The protective conductor has to be insulated against earth.

– The protective conductor has to be led separately from the auxiliary earth.

– The auxiliary earth has to be connected over an auxiliary earh lead.

– The resistance of the auxiliary earthing, with a highest admissible contact voltage of 24 V must not exceed 200 ohms and with 65 V or 100 V 800 ohms.

– The cross section of the protective conductor and of the auxiliary earth lead with fixed protected laying must not be greater than 1.5 mm^2 copper or 2.5 mm^2 aluminium and with fixed unprotected laying not greater than 4 mm^2 copper or 10 mm^2 aluminium.

– Pipe systems may be used as auxiliary earthing, if they provide the required resistance value.

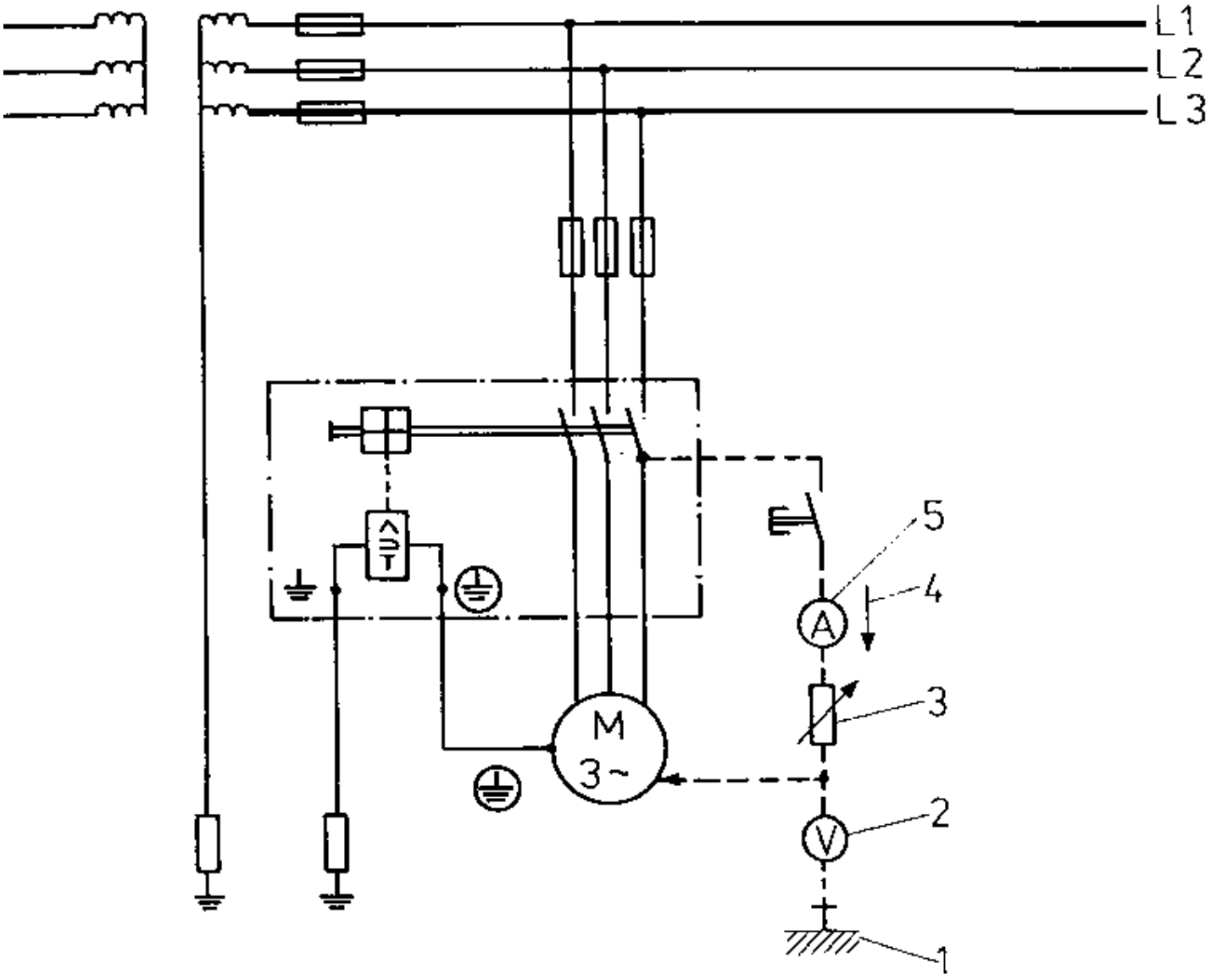

Figure 13 – Testing of the fault–voltage protective system by probe *I probe, 2 voltmeter for test voltage, 3 test resistance, 4 test current, 5 amperemeter for test current*

Where is the fault–voltage protective system used?

_____

_____

_____

Checking of the protective measure of "fault–voltage protective system"

– Inspection whether the required conditions are fulfilled.

– Checking of the fault–voltage protective switch by actuating the test key.

– Measuring the resistance of the auxiliary earthing with the help of a probe.

Fault–current protective system

Mode of action

– If the operating current of a consumer is led through the summation transformer of a fault–current protective switch, the sum of the currents flowing in both the directions is normally zero.

– In the case of fault, the equilibrium of the currents is disturbed and the trip coil of the fault–current protective switch causes the all–polar switching off of the part of plant that is at risk.

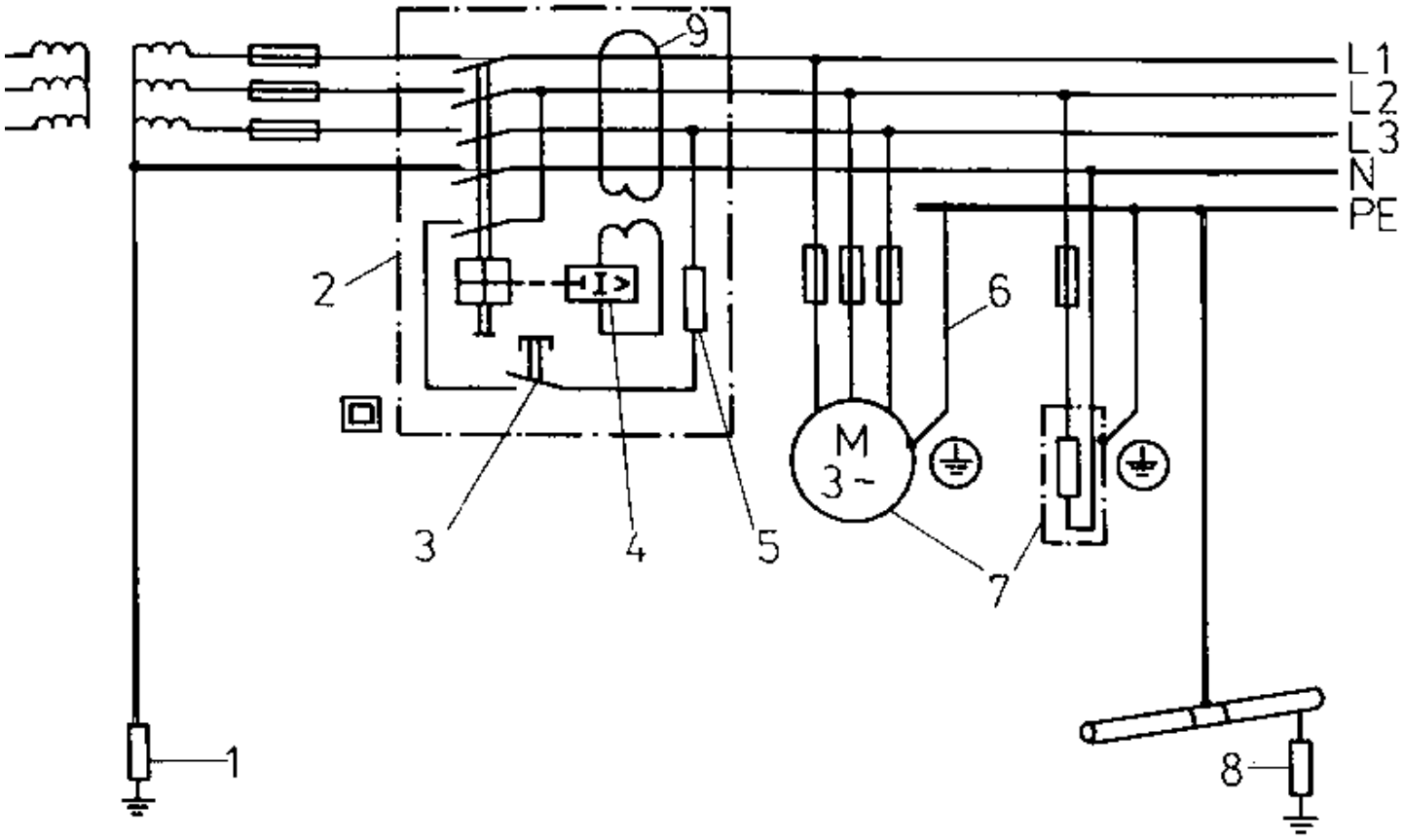

Figure 14 – Fault–current protective system in a threephase system – *1 resistance of the service earthing, 2 protective switch, 3 test key, 4 current coil, 5 test resistance, 6 protective conductor, 7 devices, 8 resistance of the protective earthing system, 9 current transformer*

Criteria of the fault–current protective system

– All metallic casings of the electrical devices have to be earthed by a protective conductor.

– The protective conductor has to be layed separately.

– The switching–off time must not exceed 0.2 seconds.

– The resistance of the earthing system of the fault–current protective system must not exceed a certain value.

This is calculated with the help of the below equation:

$$R_S = \frac{U_{Bzul}}{I_{fn}}$$

The letters read:

UBzul highest admissible contact voltage

I_{fn} rated fault current of the fault−current protective switch

Where is the fault−current protective system used?

_____
_____
_____
_____

Checking of the protective measure of "fault−current protective system"

− Inspection as to the required conditions.

− Testing of the functioning of the fault−current protective switch by repeated actuation of the test key.

Isolating fault−current protective system

Mode of action

− Similar to that of the fault−current protective system.

− In the case of fault, the fault current flows through the current coil of the isolating fault−current protective switch, the coil is excited and causes the all−polar switching−off of the plant.

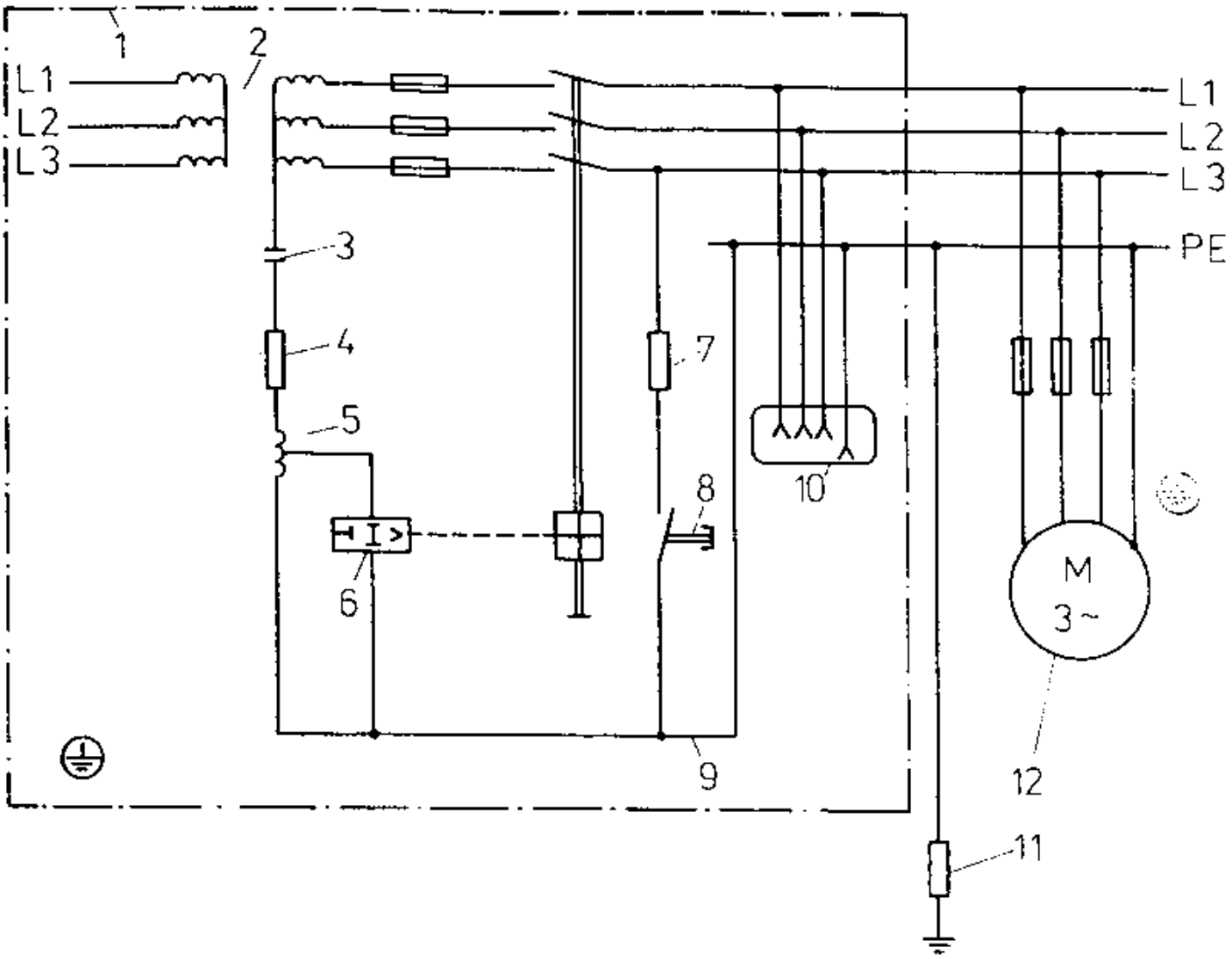

Figure 15 – Isolating fault–current protective system in a threephase system – *1 isolating fault–current protective switch, 2 isolating transformer, 3 capacity between conductor and ground, 4 ohmic resistance, 5 coil, 6 current coil, 7 test resistance, 8 test key, 9 protective conductor, 10 test socket, 11 resistance of the protective earthing system, 12 motor*

Criteria of the isolating fault–current protective system

– The plant is operated through an isolating transformer.

– The neutral point of the secondary side of the transformer is earthed through a coil.

– This coil is switched as a voltage divider and limits the fault current to 7 mA.

– The switch switches the plant off all–polarly with a fault current of

6 mA with alternating current and
10 nA with direct current.

– All conductive pans of the plant which do not belong to the service circuit have to be connected to a protective earthing.

Service life conductors, with this protective system, must not be earthed.

– The protective conductor has to be earthed near the supply device. (With plants on ships, it has to be connected with the metallic body of the ship.)

On principle, the protective conductor has to be separated from leads before the isolating transformer!

– The resistance of the protective earthing must not exceed 500 ohms.

– The resistance of the insulation between a conductor and the protective conductor must not fall below 20 kiloohms.

– The capacity between conductor and earthing must not exceed 100 nanofarads.

Where is the isolating fault–current protective system used?

_____
_____
_____

Checking of the protective measure of "isolating fault–current protective system"

– Inspection as to the required criteria.
– Function test – the protective switch must switch the plant off.

Necessary measures:

– The isolating transformer has to be separated from the supply system at its primary side.
– A release current of 6 mA a.c. or 10 mA d.c. has to be applied to the protective conductor.