GROUNDING

And Ground Fault Protection

A Tutorial Presentation

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PREFACE

A Tutorial on **GROUNDING AND GROUND FAULT PROTECTION**

Grounding is a very important aspect in electrical or electronic design. But it is least understood by most engineers. This tutorial is a much-enlarged version of a lecture I gave nearly 5 years ago to Telangana DISCOM engineers on grounding. It provides a comprehensive overview of grounding and ground fault protection for the safety of life and property. It will explain the purpose of grounding, types of grounding systems – TT, TN S, TN CS, their features. It will cover the principles of neutral grounding, equipment grounding, neutral break, substation grounding, grounding for electronic systems and grounding for protection against lightning and switching over voltages. The factors to be considered and the design of grounding components and system are dealt with. The importance of single neutral to ground connection, avoiding ground loops, prevention of back feed from standby power home inverters are covered. In the second half of the tutorial, the principles and methods of ground fault detection and protection including RCDs, snapped overhead power lines are explained. Ground potential rise, Step voltages, transfer potentials are briefly discussed. The tutorial gives technical information not found in Indian Standards and CEA Regulations on Electrical Safety required for practical application. A couple of case studies from the field are analyzed.

Everything changed with COVID 19 and now it is not possible to offer this tutorial physically in a class room type. Some organizations are using the medium of webinars. The problem with webinars is the knowledge is not retained and not used as a reference during the working lives of engineers. So I thought of getting this tutorial released as a printed or digital booklet and the subject is prepared in a way suitable for self-study. My wish is to see that every (or most) power engineer and worker, contractor, government electrical inspector in industry, utilities, CEA, BIS studies what I have developed and becomes a more knowledgeable professional.

I wish to acknowledge that I learnt many things about earthing from John Nelson, Massimo Mitolo, Vittal Rebbapragada – all experts from USA. I also wish to thank the IEEE Hyderabad Section's SIGHT, Asia Power Quality Initiative for sponsoring and supporting respectively this digital flip book.

I welcome your feedback by e-mail to me.

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ABOUT THE AUTHOR

C. Satish presenter of this tutorial received the B.E. in Electrical Engineering from Osmania University, Hyderabad, India in 1965 with his final year project as “Neutral Grounding”. Mr. Satish's retirement as Manager (Electrical) follows 30 years service in Indian Drugs and Pharmaceuticals Limited and 6 years in AP State Electricity Board. His areas of interest include the application, operation and maintenance of electrical equipment and energy systems, electrical safety, power quality, energy efficiency / conservation. He presented many papers in these areas in IEEE and other conferences.

C. SATISH

He is a member of IEEE and its Industry Applications Society for 47 years. He has organized 5 IEEE workshops on electrical safety since 1998 in 5 cities in India. The first ever conference on Power Quality in India was organized by him in 1995. His accomplishments include:

2002 IEEE Industry Applications Society's Petroleum and Chemical Industry Committee Electrical Safety Excellence Award with the citation, “for outstanding dedication and contributions made to the advancement and accelerating the dispersion of information and knowledge impacting electrical safety ”

2002 IEEE Educational Activities Board Meritorious Achievement in Continuing Education Award with citation, “for dedicated service and sustained leadership for over 20 years in the planning and delivery of a large number and variety of industrially oriented continuing education programs in an IEEE Section”

IEEE Electrical Safety Awareness film - https://www.youtube.com/watch?v=a_7rRUxhvVs
Satish produced and directed this fifteen-minute film in Telugu with subtitles in English, Spanish, French and Portuguese.

TABLE OF CONTENTS

PART I

EARTHING / GROUNDING

Grounding is a very important aspect in electrical or electronic design. But it is least understood by most engineers.

The goal of grounding in electronic systems is mainly to provide a clean return path for the signals. But its goal in power systems is shock, fire and over voltage prevention due to insulation to ground failures, lightning & switching surges.

Improper Grounding often causes ground loops and EMI problems like common mode noise in electronic systems

The term Ground or Grounding is quite confusing

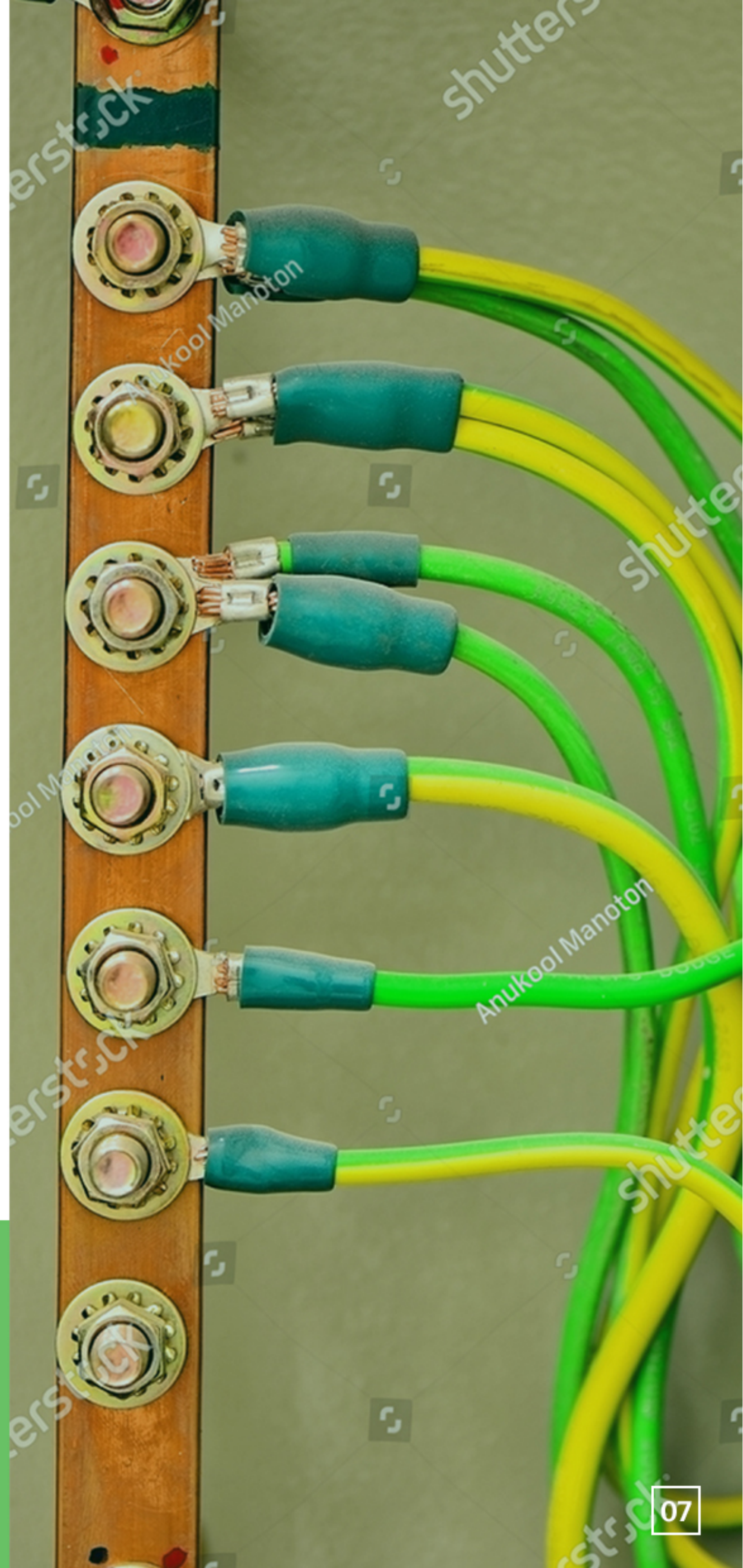
IEEE & National Electrical Code (USA) define 'grounding' as "any conducting connection between an electrical equipment and earth **'or to some conducting body'** of relatively large extent that serves in place of earth."

In the case of an airplane, this **conducting body** is - the frame of the plane.

A 4 wire Wye distribution system uses the star point as reference

Many electronic circuits use the frame they are mounted on for their reference

The negative terminal of car battery is connected to the body & used as reference



PURPOSE OF GROUNDING

1 Return path for signals in electronic circuits

2 For diverting lightning & surge voltages/currents

3 To use earth as return path for load current in rural SWER high voltage power distribution

TYPES OF GROUNDING

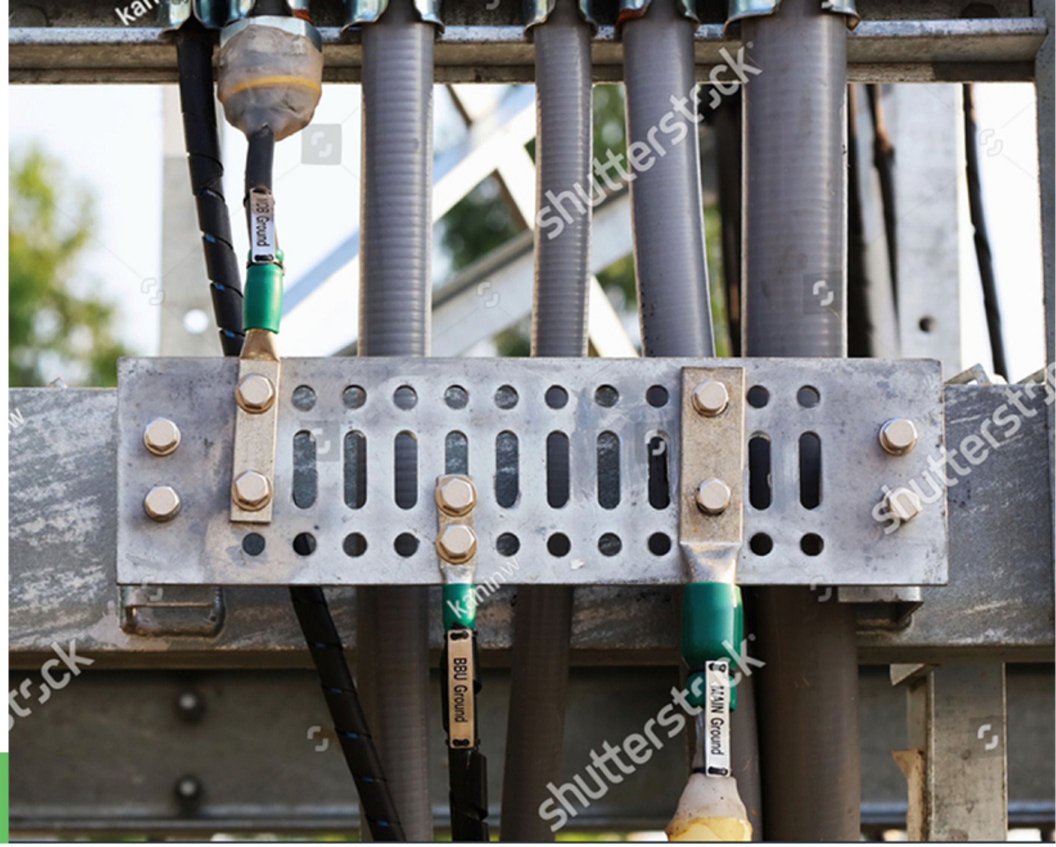
Power Systems Grounding

In Power systems grounding the aim is to prevent overvoltages and shock, and enhance safety through low resistance paths. Other aim is to protect against lightning and surges.

Electronic Systems Grounding

In Electronic grounding however the main purpose is to control electromagnetic interference (EMI) and avoid ground loop problem.

POWER SYSTEMS GROUNDING



Systems Grounding – Security of Systems

To limit voltages to ground due to earth faults and lightning/switching.

To permit the flow of enough current in the event of a fault to earth so that a protective device operates and isolates the fault by providing a low impedance path to earth.

Equipment Grounding – Security of Humans, Animals & Property

In case of earth fault, to prevent enclosures, frames from attaining dangerous potentials with respect to ground so that living beings coming in contact with such enclosures will not get shocks.

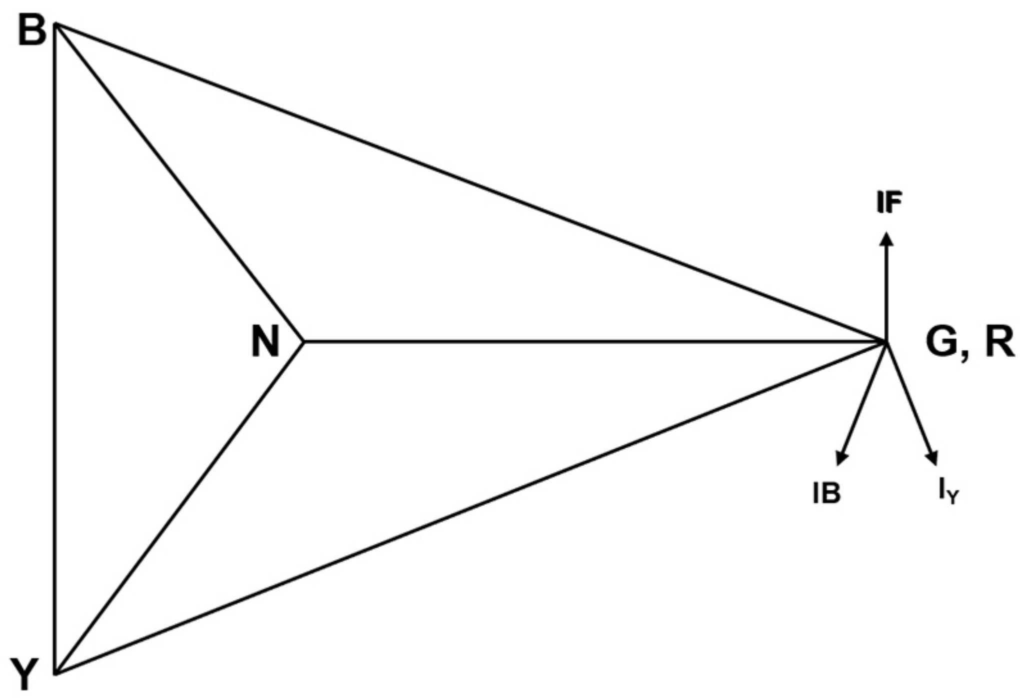
SYSTEM GROUNDING

System grounding means connection of transformer Neutral to Ground. Neutral and Ground are not the same always.

- The **GROUND** is always at **ZERO** potential
- The **NEUTRAL** is generally at **GROUND** potential

But, in some cases like a line to ground fault in 3-Phase 4-Wire systems, the Neutral is at a higher potential than Ground.

This is called **NEUTRAL SHIFT**.
This shift is more if the neutral is not grounded.



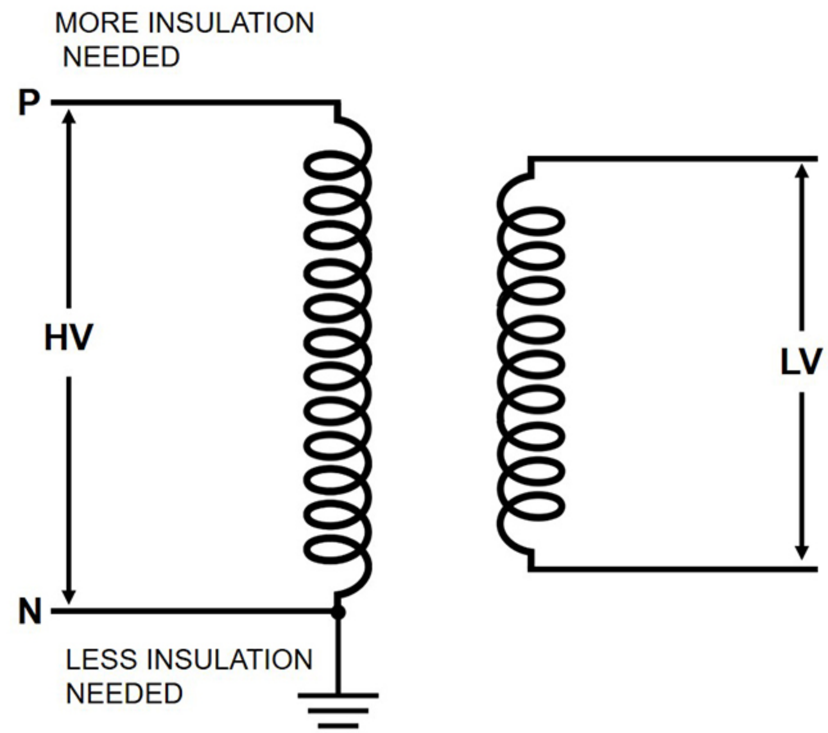
PURPOSE OF NEUTRAL GROUNDING

Providing a path of high current to flow in the case of earth fault and operate over-current device – fuse/breaker

Limiting over-voltages on healthy phases when one phase develops ground fault. If neutral is not grounded the over-voltages can reach 1.73 times normal line to ground voltage and up to 5 times in the case of arcing ground faults.

If neutral is grounded, graded insulation can be used in high voltage transformer windings and insulation costs reduced.

HV Transformer



METHODS OF SYSTEM GROUNDING

1 **UNGROUNDED**
(Capacitance Grounding)

2 **SOLID**
Grounding

3 **LOW RESISTANCE**
Grounding

4 **HIGH RESISTANCE**
Grounding

ADVANTAGES & DISADVANTAGES - SYSTEM GROUNDING

The advantage of solid grounding is that one avoids any incident of transient over voltage.

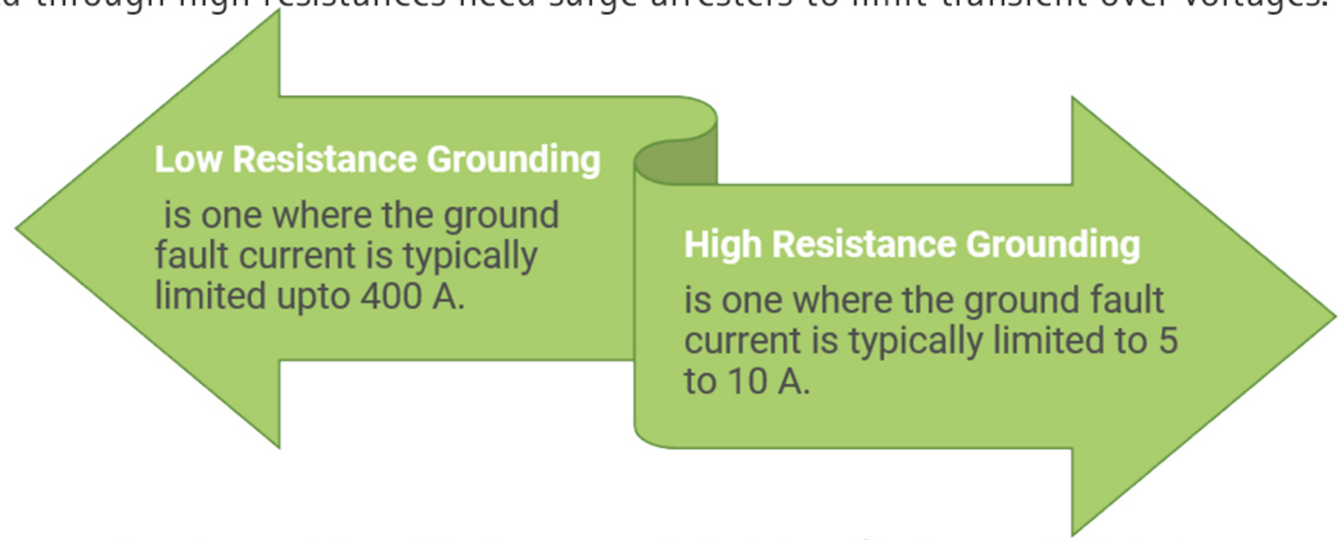
With resistance grounding one can limit the transient over voltage to less than 250% (two and half times).

Avoid ungrounded systems as they produce hight transient overvoltages due to **a)** System Capacitance and Inductance in Series, and **b)** Restriking in Breaker or System during Earth Faults.

Single phase to earth fault current may be more than 3 phase S.C. current in solid grounding systems. Breakers rated on the 3 phase S.C. Current basis may not handle single phase to earth faults in such a system.

High Resistance grounding reduces such currents but there can be transient over-voltages on earth faults.

Systems grounded through high resistances need surge arresters to limit transient over voltages.



High resistance grounding is used in critical process industries. Costly unscheduled process interruptions are reduced.

The arc flash energy is reduced drastically by high resistance system grounding in the case of line to ground faults. The arc flash hazard and fire hazard are thus minimised.

Generators are usually star connected & designed to withstand only 3-Phase S.C. currents. Generator bolted ground faults exceed 3-Phase S.C. currents. So, it is better to earth the generator neutral through an impedance.

COMPARISON OF GROUNDING METHODS*

* Peter Sutherland, FIEEE

	Ungrounded	High R	Low R	Solid
Fault Current	$<1\%$ of I_{3ph}	$3I_{c0} \geq I \geq I_{3ph}$	100-1000A	100-125% I_{3ph}
Transient OV	High	Low	Low	Low
Arrester Rating	Ungrounded	Ungrounded	Ungrounded	Grounded Neutral
Typical System Voltages	--	< 600V and Generator Neutrals	2.4 - 15kV	< 600V and > 15kV
System Continuity	Good	Good	Trips on first GF	Trips on first GF
Fault Location	Feeder Switching	Needs Fault Tracer	Isolated by Trips	Isolated by Trips
Fault Damage	Minor	Minor	Low	May be High

EQUIPMENT GROUNDING

Bonding of all non-electrical metallic elements like frames of electrical equipment, metal conduit etc. and connecting to ground.

The purpose is to prevent electric shock due to contact of parts which may become live due to insulation faults.

EQUIPMENT EARTHING

Standards and Regulations worldwide require all exposed metal parts like frames of motors, panel boards, transformer tanks to be connected **PROPERLY** by earthing conductors to main earth terminal/electrode.

As per IS 5613 on up to 11 KV overhead lines, all metal & RCC poles need to be connected by running earth wire to each pole. This wire is to be connected to earth at 3 points per Km.

EQUI-POTENTIAL BONDING

IEC defines
Exposed Conductive Part (ECP)
as a conductive part of an electrical equipment which is not live but can become live if basic insulation fails.

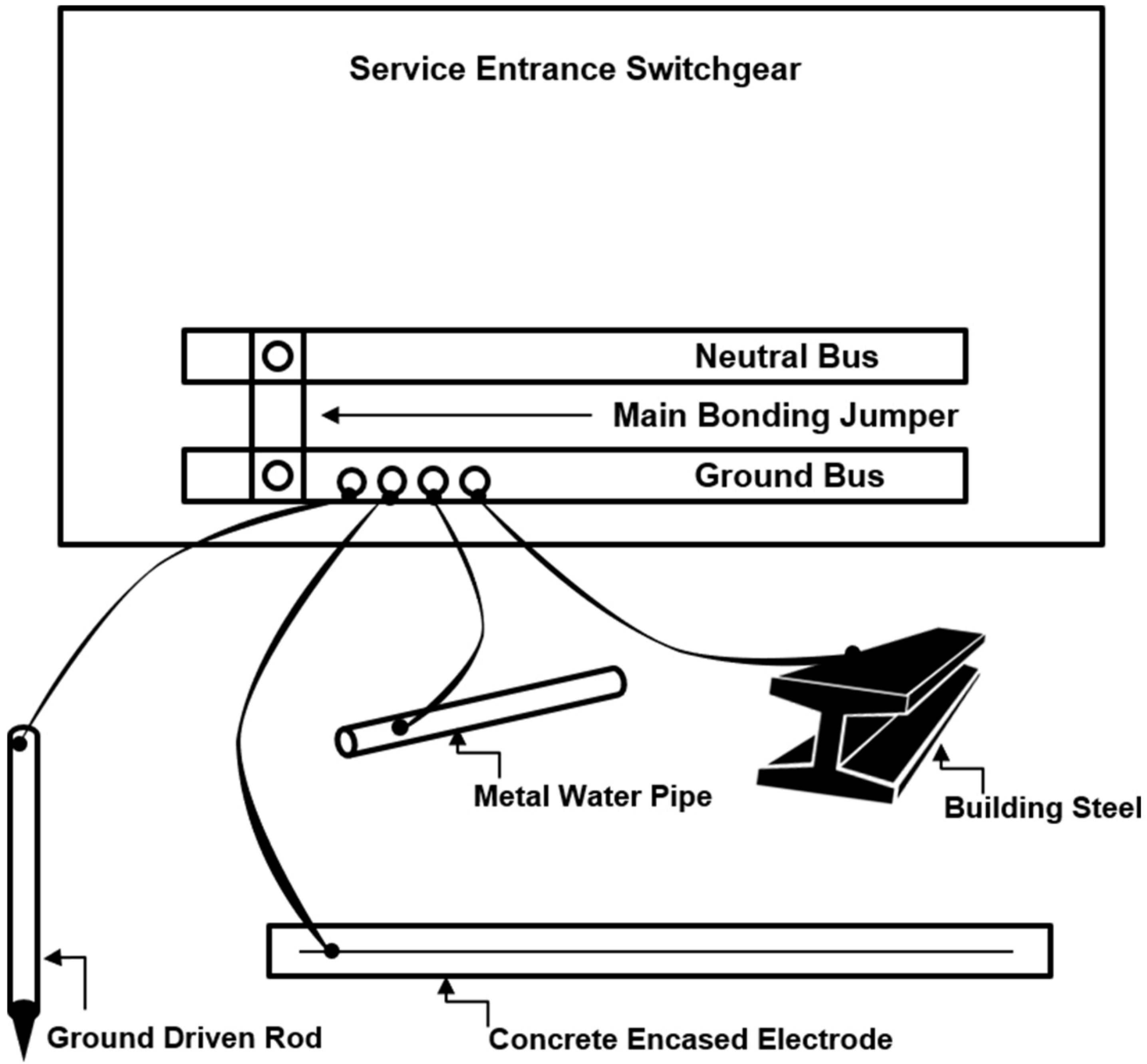
Examples – Motor Frames, Panel Board Enclosures

IEC defines
Extraneous Conductive Part (EXCP)
is a conductive part, not part of an electrical system located in the vicinity of an electrical system.

Examples – Metal Gas Water Pipes, Fences

All ECPs and EXCPs should be grounded and bonded together to reduce any potential difference between them & electrical shock risk when there is an earth fault.

GROUNDING & **BONDING** ALL METALLIC ITEMS



EARTH ELECTRODE

The conductor that connects the grounding system to earth is called Earth Electrode.

The measure of its effectiveness is the earth electrode resistance. This is the resistance between earth electrode and a distant remote earth say 25 ft. away.

Earth Electrodes are of two types:

1 MADE ELECTRODES

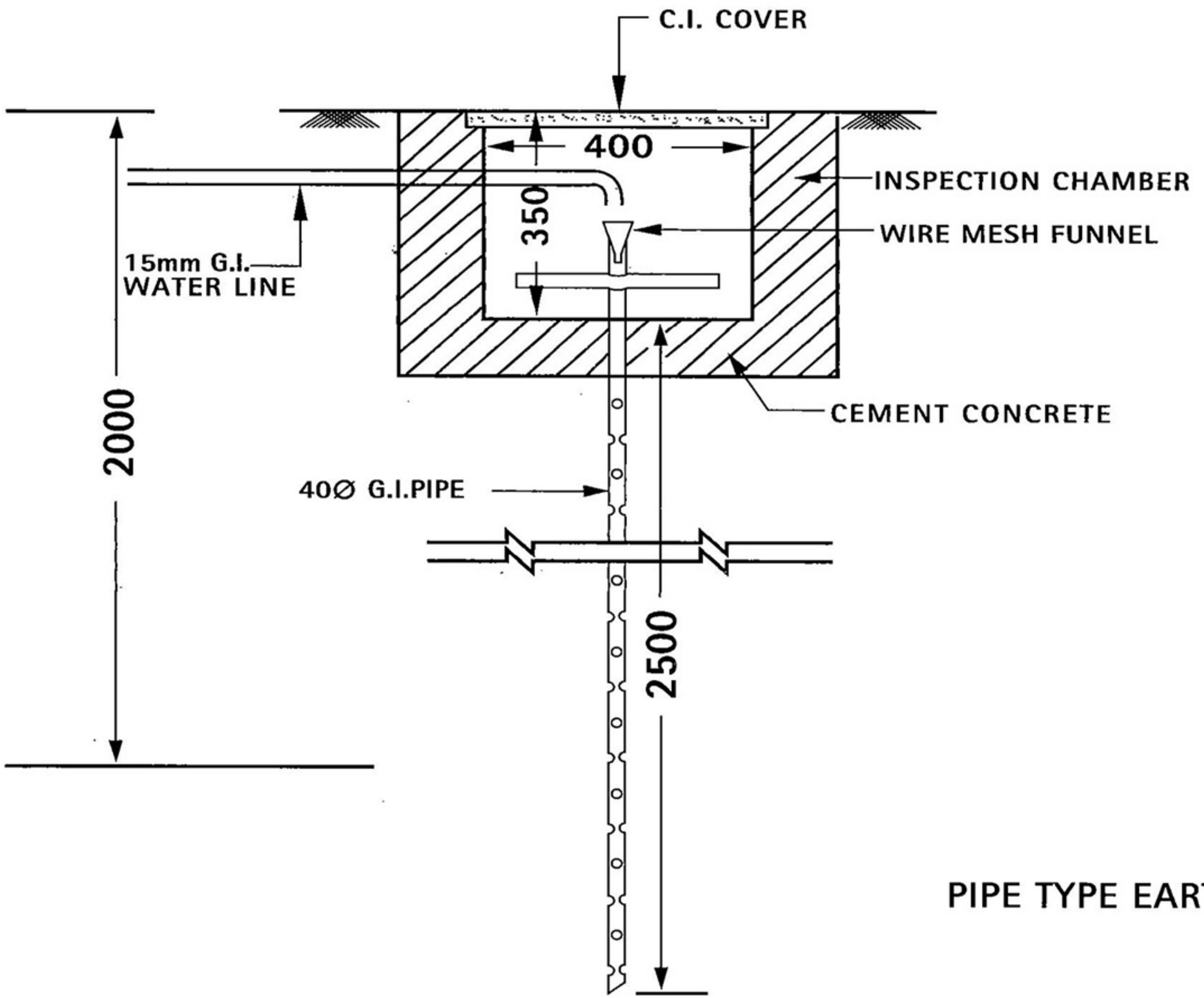
These are driven rods / plates

2 NATURAL ELECTRODES

These are buried metal pipes or concrete encased steel reinforcements of building foundations.

MADE EARTH ELECTRODES

Design points and typical sketches with dimensions of different types of made earth electrodes –pipe, plate is given in Indian National Electrical Code.



PIPE TYPE EARTHING

EARTH ELECTRODE

Earth resistance depends on soil type and:

Drastically decreases with **moisture content**

Drastically decreases by **addition of some chemicals**

Decreases with **temperature rise**

By adding chemicals to soil, earth resistance can be reduced substantially. Such soil conditioning agents include sodium or calcium chloride, copper or magnesium sulphate or Bentonite, Marconite. The effect will be more by keeping the earth pit wet.

The material for earth electrode and the connections and chemicals added need to be corrosion resistant. Sodium chloride (Common Salt) being corrosive is not used now.

SOIL RESISTIVITY & SOIL CONDITION

Moisture %	Relative Value of Soil Resistivity
2.5	100%
5	46%
10	2%
20	0.5%
30	0.2%
Salt %	**Relative Value of Soil Resistivity**
1	100%
10	30%
20	25%
Temperature °c	**Relative Value of Soil Resistivity**
30	60%
20	72%
10	100%

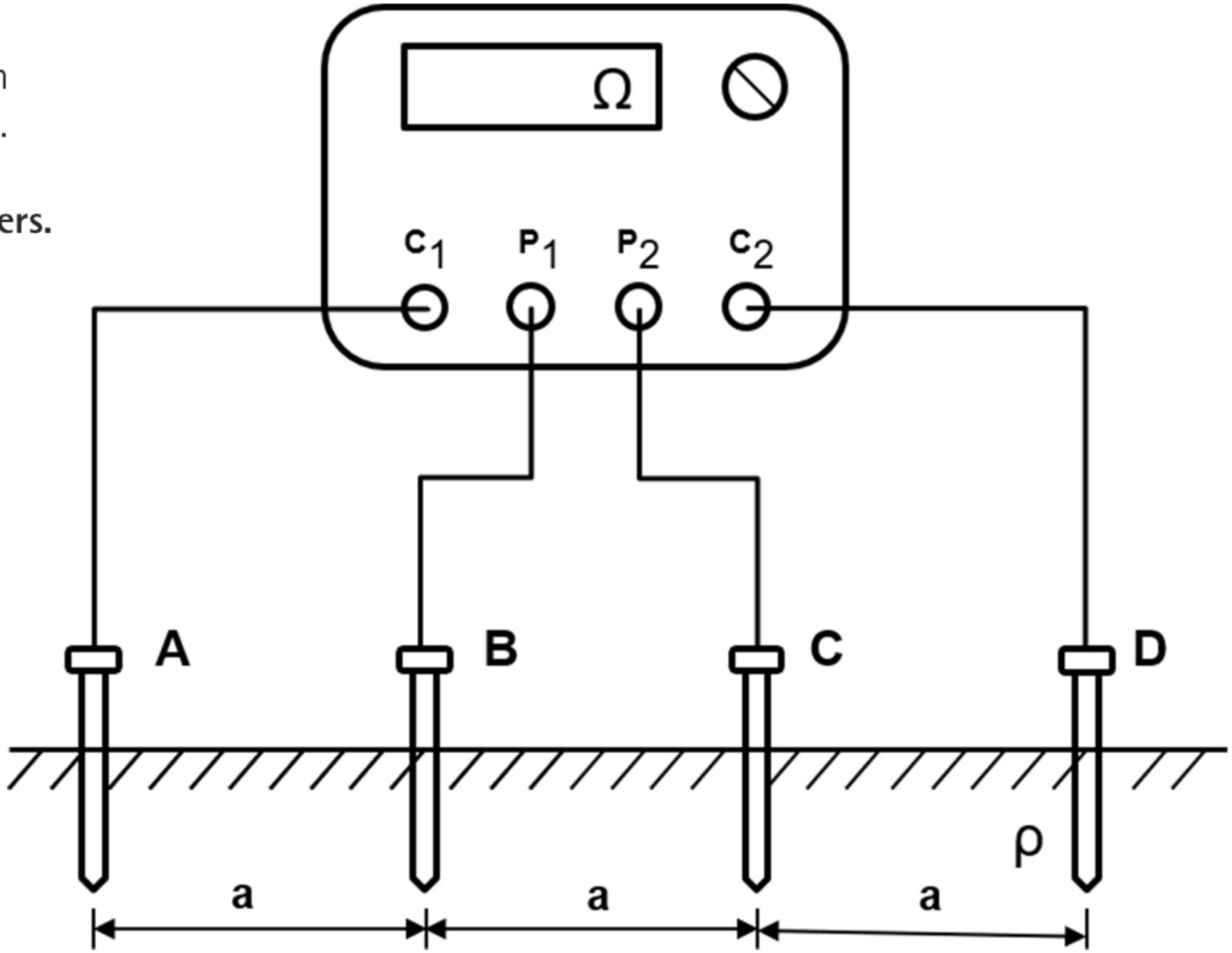
MEASUREMENT OF SOIL RESISTIVITY

Soil resistivity is measured by 4 PIN Weiner Method as below. Meter gives the value of R in ohms.

Soil Resistivity $\rho = 2\pi.a.R$

where 'a' is the distance between any two temporary spikes in cms.

'a' should be about 2 to 3 Meters.



PREDICTING EARTH RESISTANCE

Once we find soil resistivity of a given location, we can estimate the earth resistance 'R' of any size earth rod or pipe and choose optimum size using the formula from clause 14.2.2 of IS 3043-2018 Code of Practice for Earthing.

$$\mathbf{R} = \frac{100\,\rho}{2\,\pi\,l}\ \mathbf{log_e}\ \frac{2\,l}{d}\ \mathbf{ohms}$$

Where,
l = *length of rod or pipe (in cm),*
d = *diameter of rod or pipe in cm, and*
ρ = *resistivity of the soil (in Ω. m)*
(assumed uniform)

l – is driven length of electrode in centimetres (cm)	In cm	200
ρ – is the resistivity of soil, in ohm meters	In Ohm – Mtr.	25.00
d – is the diameter of electrode, in Centimetre (cm)	In cm	3.81
Resistance of one electrode [R]	In Ohm	9.2550

EARTH ELECTRODE DESIGN

The effect of diameter is small. Tests showed **increasing diameter from ½" to 1"**

Increased
Cost by 400%

BUT ONLY

Reduced
Earth Resistance by 10%

If earth resistance cannot be made low due to soil condition or rocky conditions, a number of rods in parallel can be used. But they must be spaced equal to the length of the rod.

Periodic maintenance & measurement of earth electrode resistance and earth loop resistance is to be done.

EARTH RESISTANCE

Grounding electrode system shall have a resistance to ground low enough to minimise hazards to personnel and to permit operation of circuit protection device.

- National Electrical Safety Code of USA Sec 9.96 A

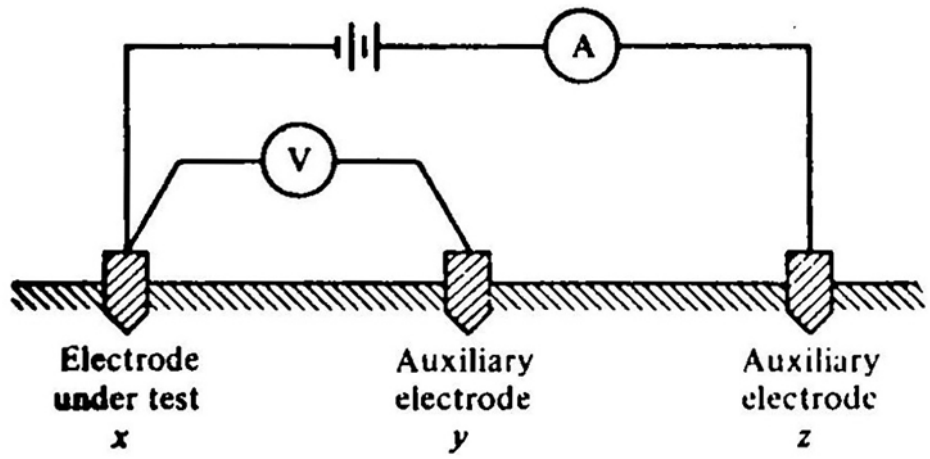
< 1 Ohm for large Substations, 1 - 5 Ohms for others is Ok.

- IEEE Std 142

EARTH RESISTANCE MEASUREMENT

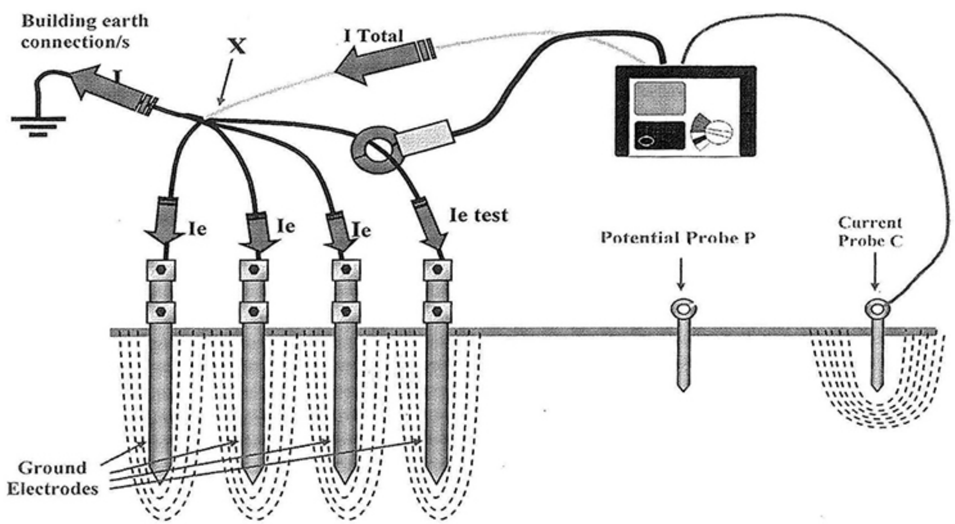
FALL OF POTENTIAL METHOD:

A known A.C. current is passed through the earth electrode under test and a auxiliary electrode and measuring the potential drop between first electrode and one more auxiliary electrode in the middle. This method is subject to error, if stray ground currents are present.



CLAMP ON EARTH RESISTANCE METER:

Modern measuring systems allow the meter to measure earth electrode resistance without disconnecting it from the neutral and other grounding conductors safely. These meters also measure leakage current and earth voltages, diagram below shows the operation.



EARTH ELECTRODES

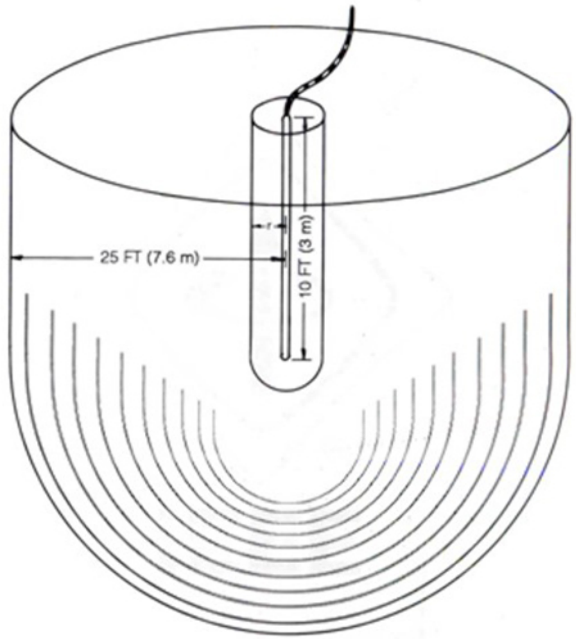
Earth is a poor conductor, its resistivity is one billion times that of copper. Earth resistance consists of shells of earth, the inner shell has bulk of the resistance. As we move away resistance becomes less as the dia of the outer shell increases.

Half of resistance value is contained within say one feet dia shell around the earth electrode.

IEEE STD 142

Electrode Resistance at a Radius 'r' ft from a 10 ft Long by 5/8 inch diameter rod

Distance from Electrode (ft)	Approximate % of Total Resistance
0.1	25
0.2	38
0.3	46
0.5	52
1.0	68
5.0	86
10.0	94
15.0	97
20.0	99
25.0	100



RESISTANCE OF SOIL AROUND AN EARTH ELECTRODE

The above shows that majority of the resistance to remote earth occurs within 25 ft from the electrode.

Contrary to popular notion, **National Electrical Code of USA gives first preference to underground metal pipe, concrete encased steel reinforcement of building foundation and only where these are not available, use of rod or pipe earth electrodes is advised. The Concrete absorbs and retains moisture better than actual earth.**

The above are not only effective ground electrode systems but cost effective too, compared to external to building grounding rods / pipes in earth pits.

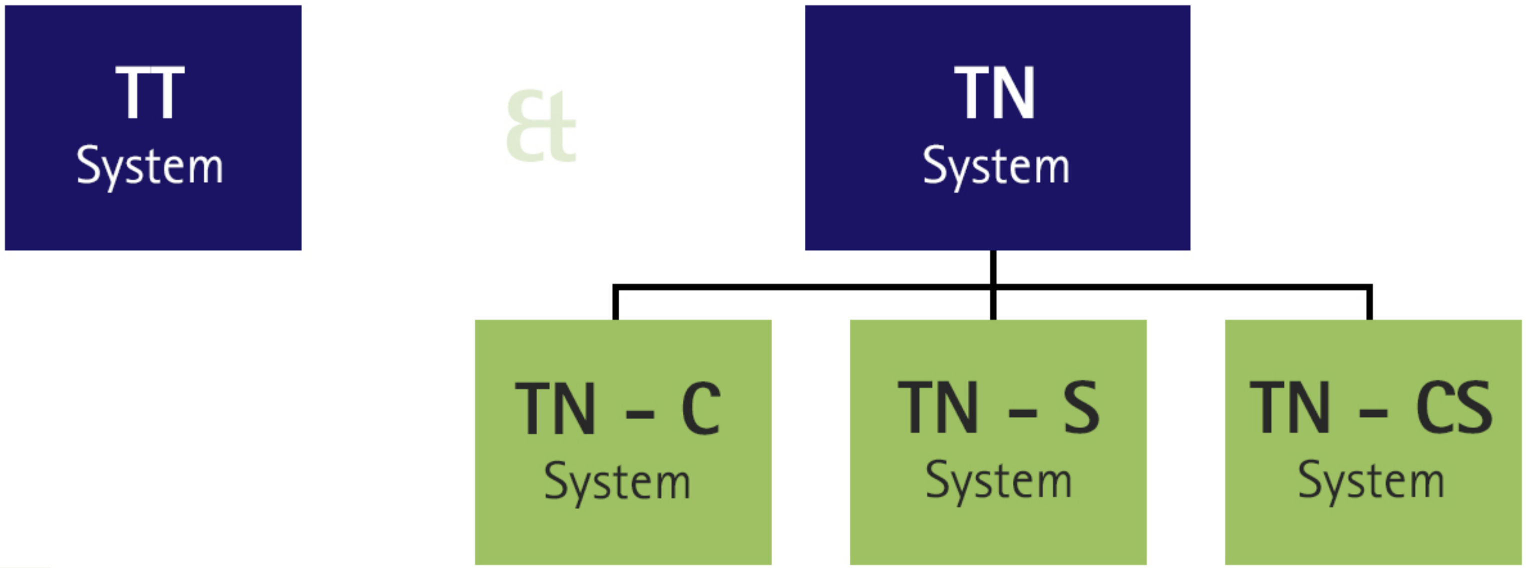
In India, grounding generally means separate / externally visible earth pits. To get low earth resistance with the latter is often and in many soils is difficult and costly.

Have you seen concrete encased reinforcing rods in deep (about 10 ft minimum) foundations and footings in tall buildings being used as main building earth?

PART II

TYPES OF GROUNDING SYSTEMS

As Per IEC 30364-1, National Electrical Code (India) 2011



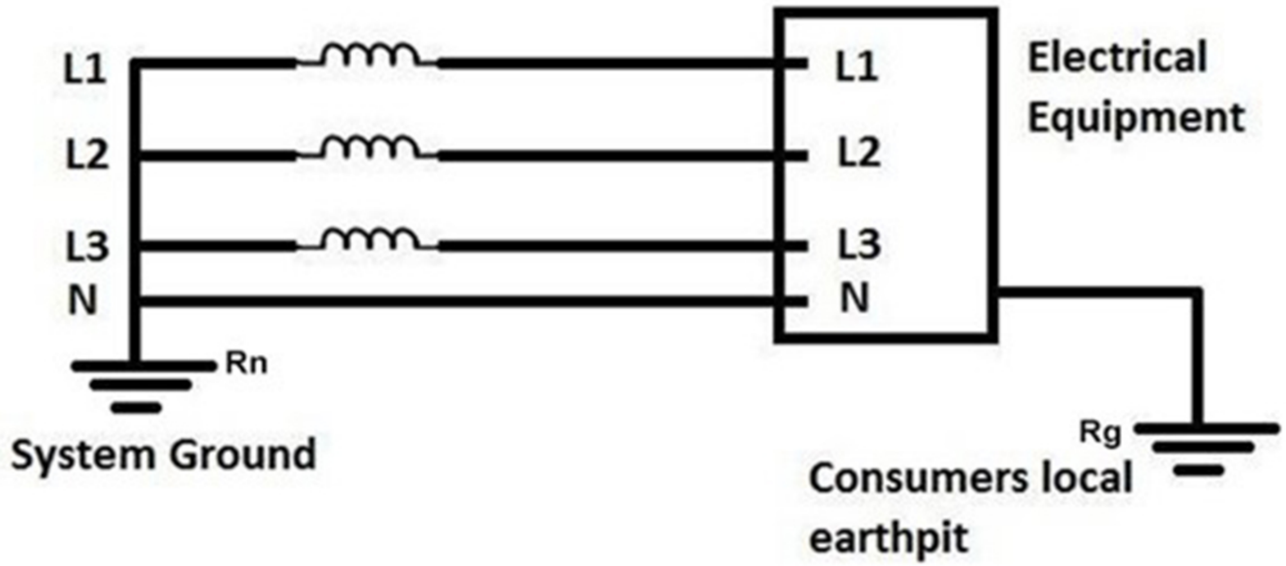
First Alphabet 'T' stands for System Source Neutral connected to 'Terre' (Earth)

Second Alphabet 'N' or 'T' stands for how Equipment Metallic Body / Frame is connected to Neutral 'N' or Local Earth ('terre') T.

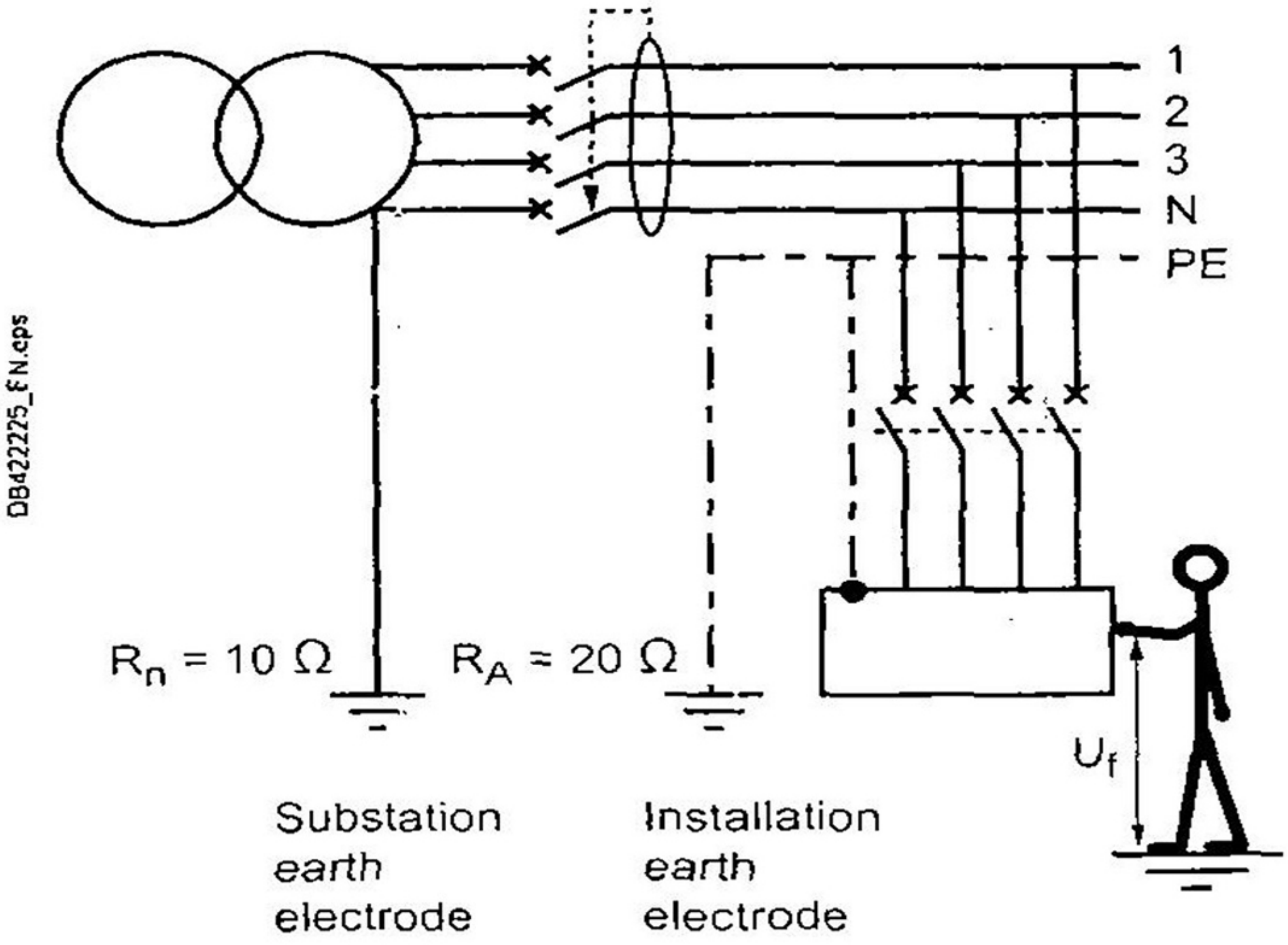
TT SYSTEM

TT Configuration is used when utility does not provide an earth terminal to consumer though as per CEA Regulation 16, providing earth terminal at consumer premises by utility is mandatory.

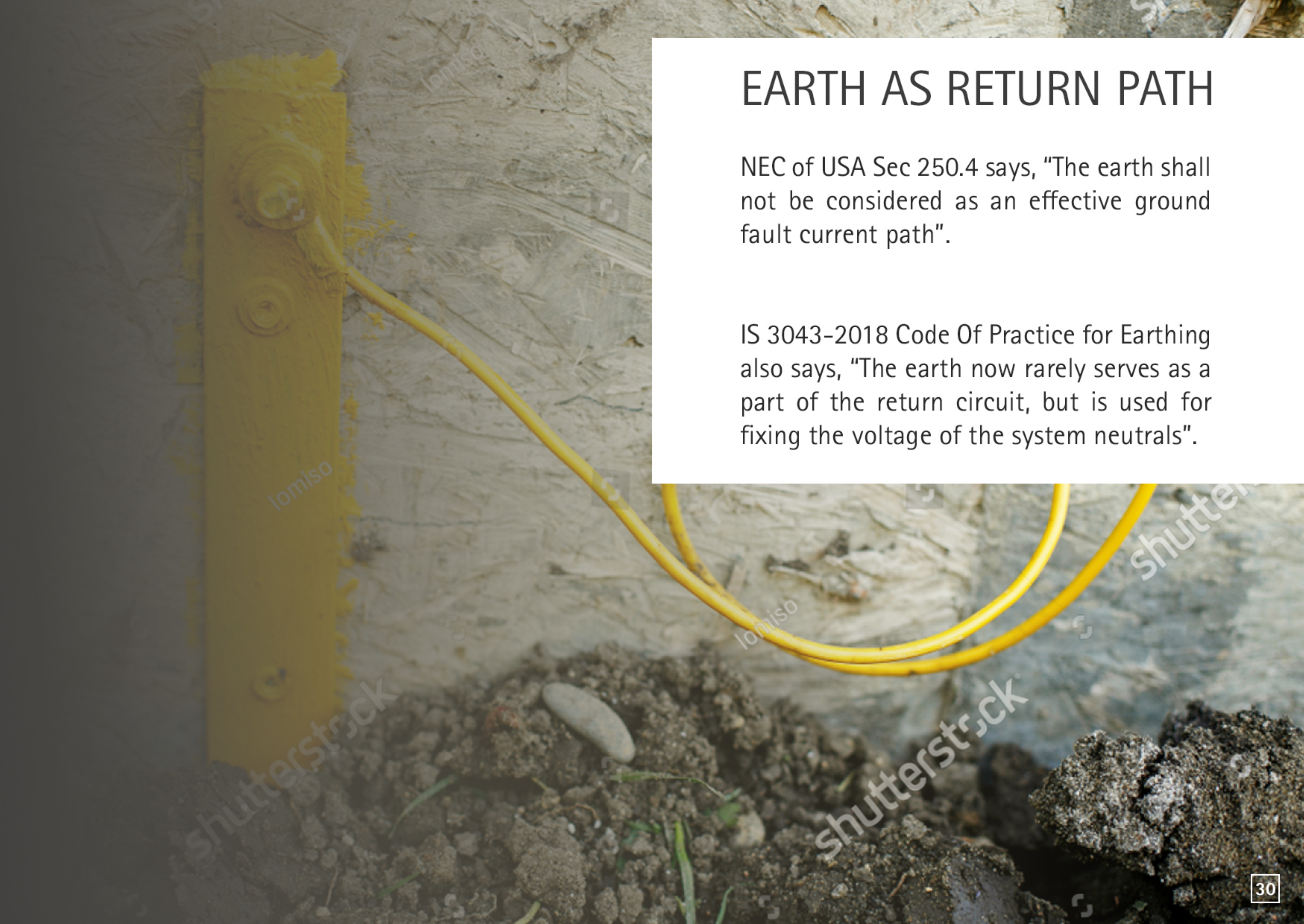
TT System requires earth fault current to be very high to trip the over load protection. Also for the touch voltage to be less than a safe value, **Rg << Rn**. For 230 Volts System, if Rn is 1 ohm, Rg has to be less than 0.12 ohms. This is extremely difficult to achieve. Also as earth resistance is often 10-15 ohms, fault current is low and normal over current protection will not trip. So **a Residual Circuit Device is required for TT System to sense such low currents and trip.**



TT SYSTEMS



Automatic disconnection of supply for TT system

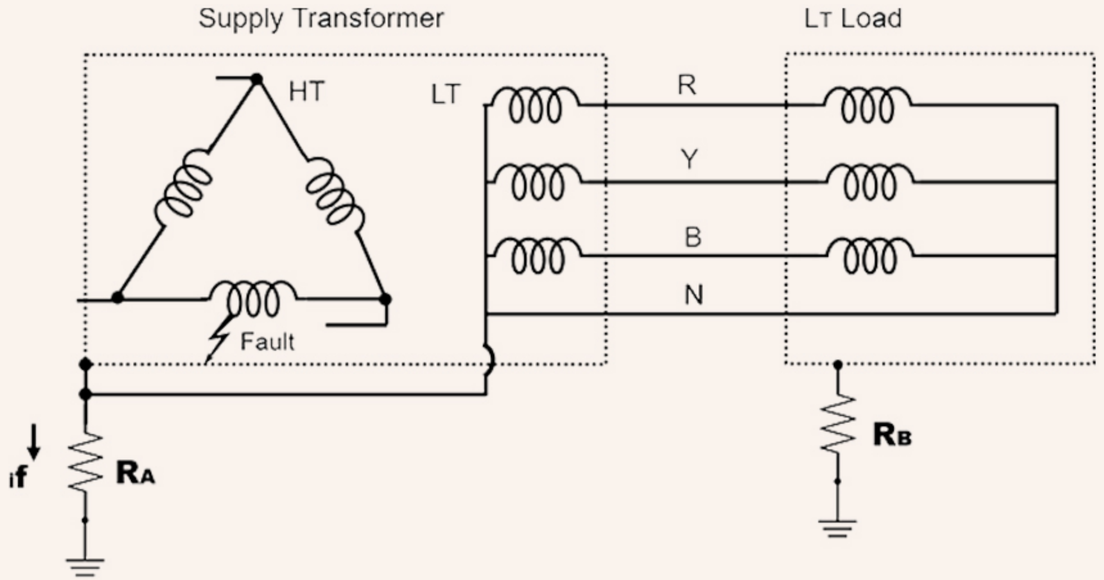


EARTH AS RETURN PATH

NEC of USA Sec 250.4 says, "The earth shall not be considered as an effective ground fault current path".

IS 3043-2018 Code Of Practice for Earthing also says, "The earth now rarely serves as a part of the return circuit, but is used for fixing the voltage of the system neutrals".

OVERVOLTAGE IN LT DUE TO EARTH FAULT IN HT TRANSFORMER

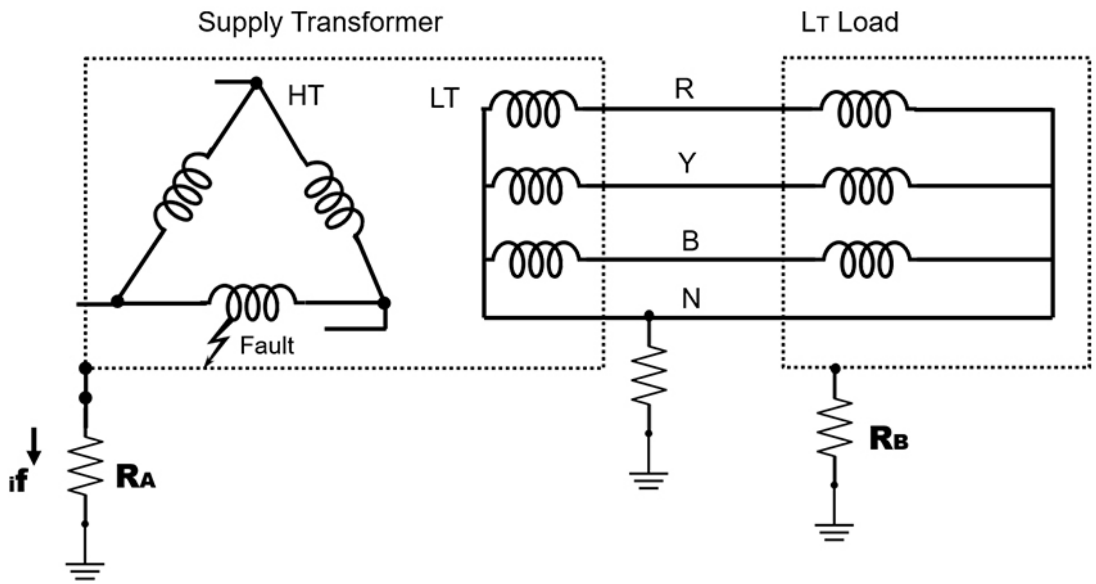


TT System - LV neutral and transformer body both connected to same earth pit. Result overvoltage in LT loads due to transfer of voltage from HT side earth fault till the earth fault is cleared. This overvoltage depends on the earth resistance.

If earth resistance is not less than 1 ohm, the regulations is some countries require two separate earth pits and at considerable distance from each other.

TT System - LV neutral is not connected to transformer body / tank, and there are two separate earth pits for them spaced at a distance.

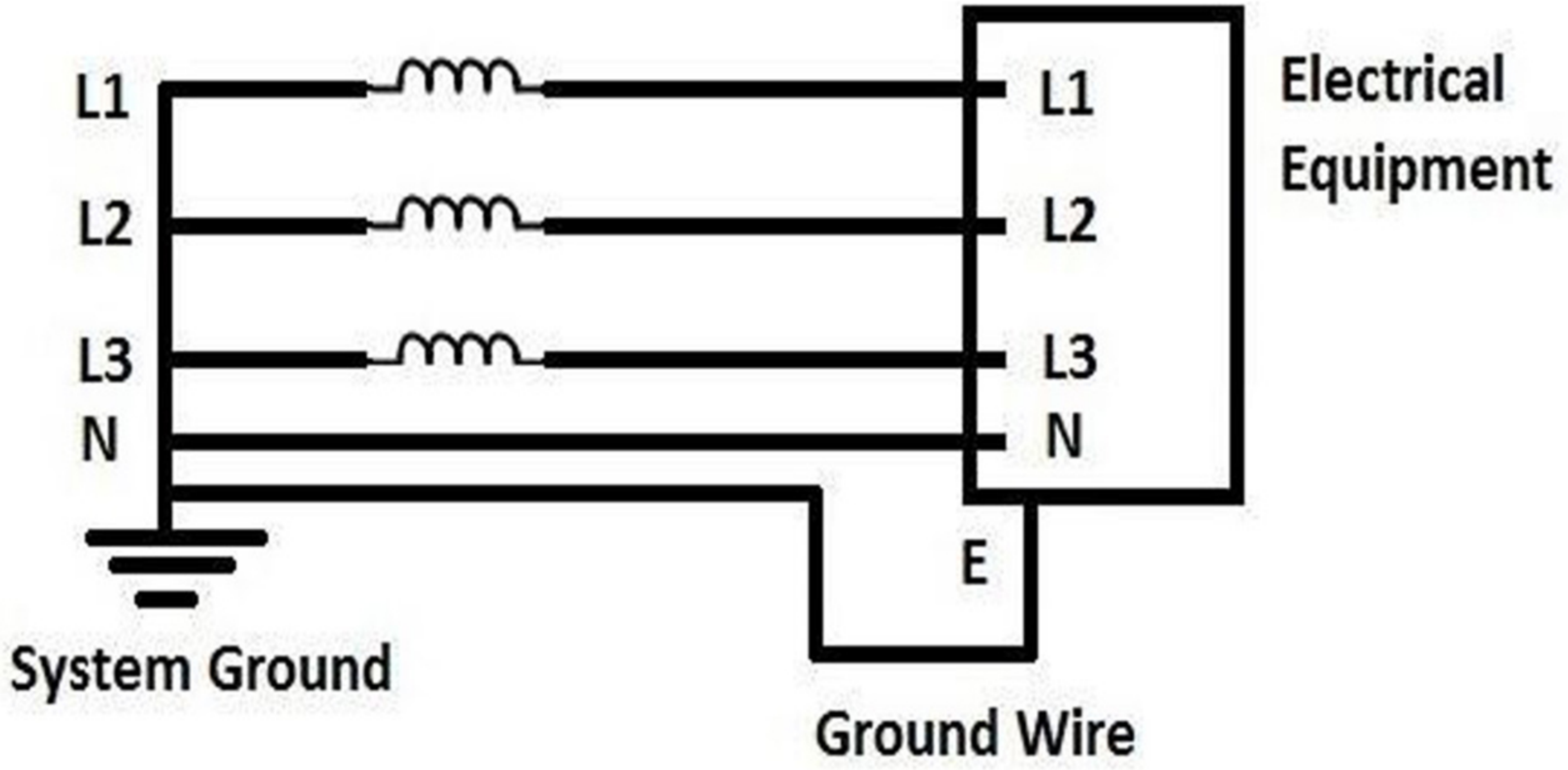
In this case there is no transfer of high voltage to LT loads.



TN - S SYSTEM

By providing continuous ground wire separately, we have a low impedance return path for high earth fault current to flow when earth fault occurs and normal overload protection to trip.

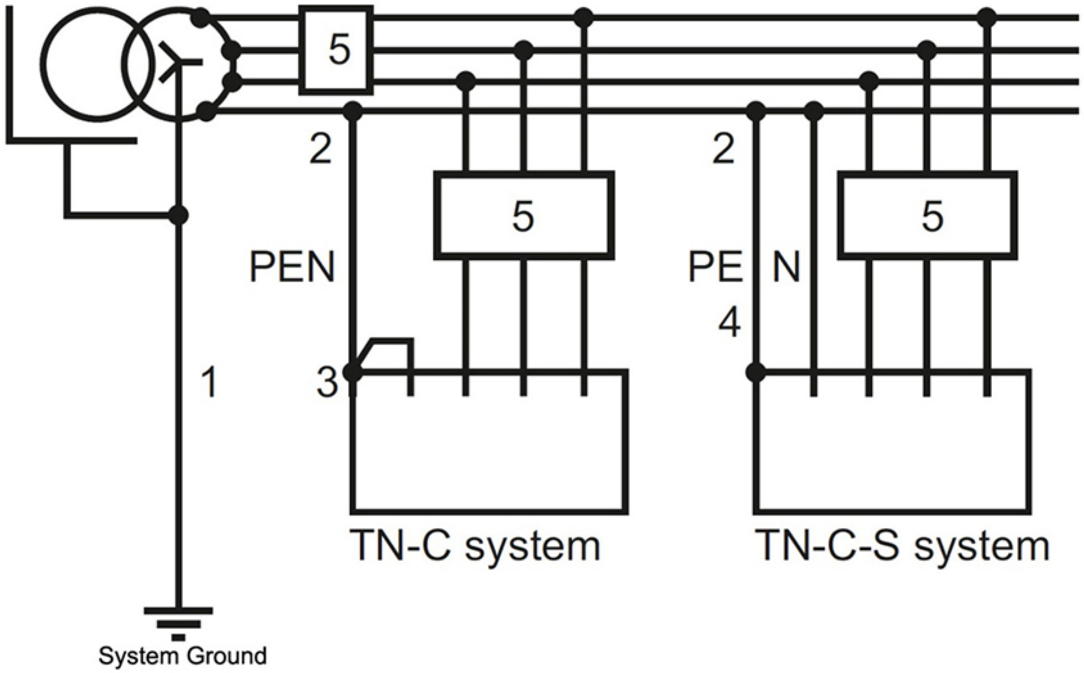
RCD is not needed. To ensure ground wire inductive impedance does not increase, it should not pass through ferromagnetic conduit or mounted on steel work.



TN - CS SYSTEMS

In TN-CS System, the function of neutral conductor and earth are combined in a single conductor in a part of the system – from utility system neutral to consumer's mains.

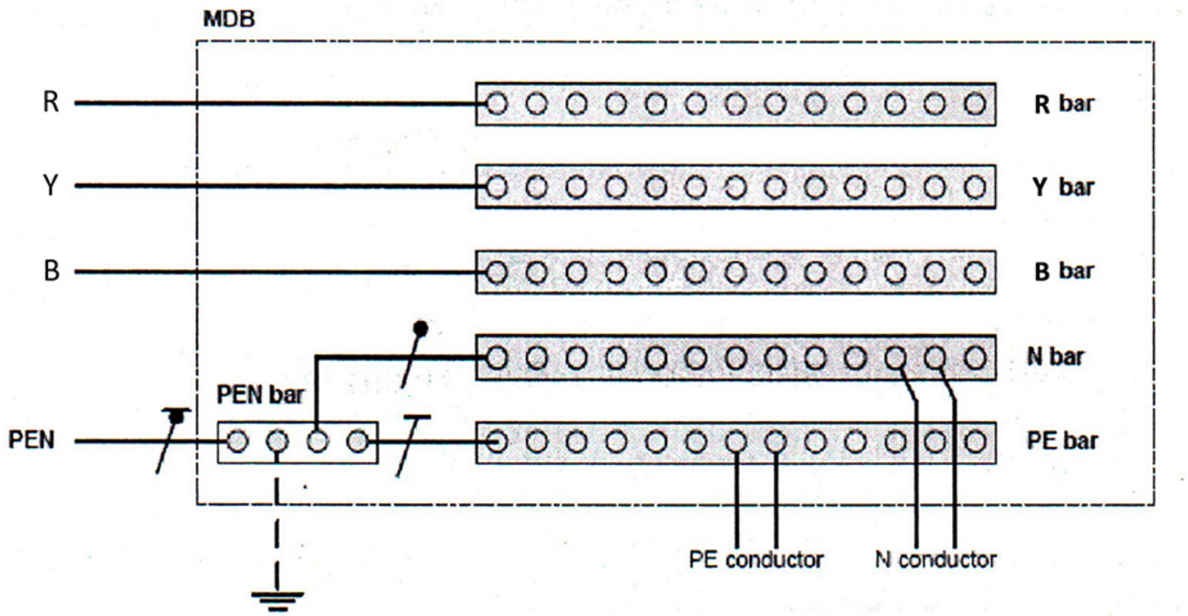
In TN C-S System, also known as **Protective Multiple Earthing (PME)**, the neutral is connected to user equipment frames. This reduces loop impedance and makes high current to flow on line to frame faults. So, in TN C-S Systems, over current protective devices disconnect supply quickly compared to TT systems to avoid any shocks.



TN - CS SYSTEMS

This is also called

Protective Multiple Earthing (PME)



MDB—main distribution board

TN CS System

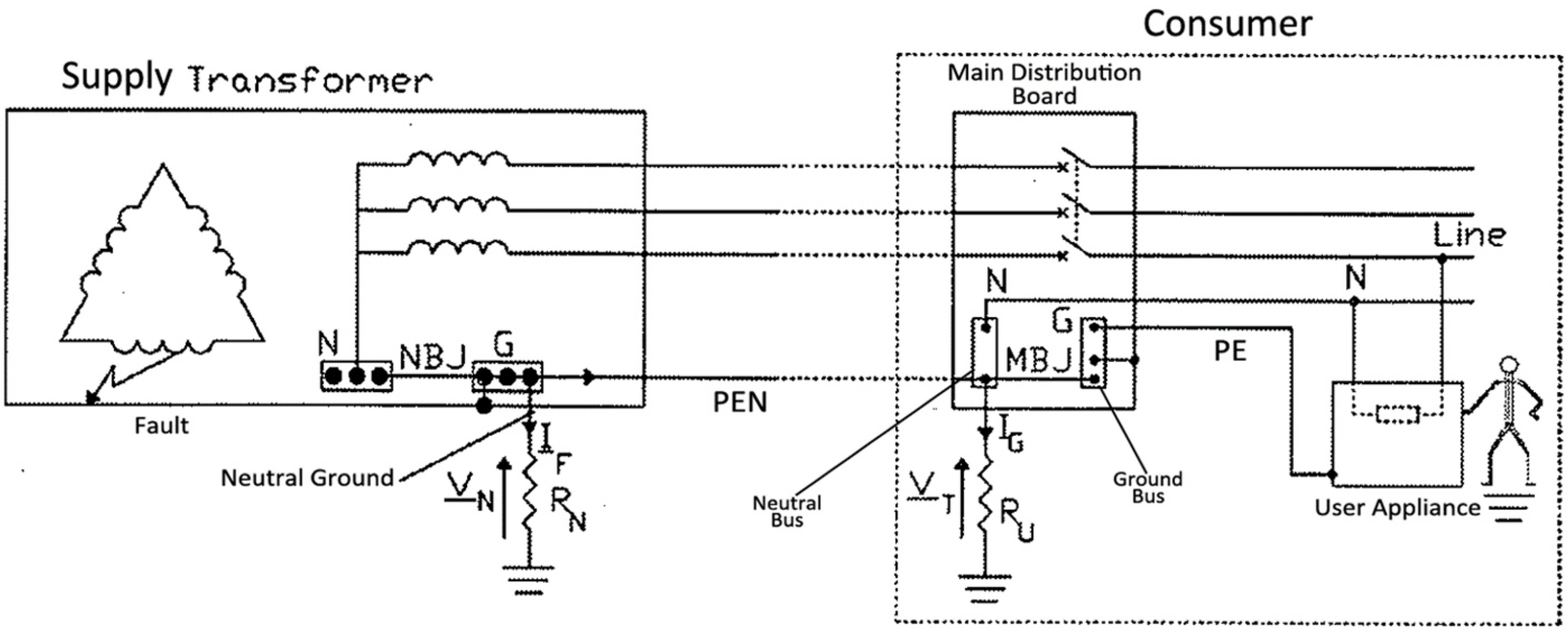
TN-CS has some dangers also. Firstly it can raise neutral to ground voltages. As neutral is connected to frames, this can cause shocks to people coming in contact with frames. One example is an earth fault on HT side of DTR.

Here the fault current flows through DTR's earth pit resistance R_N and goes back to upstream source. A voltage V_N proportional to R_N is developed across R_N. This voltage can get transferred through L V side neutral conductor to user equipment's frame till it is cleared by utility protection. See the figure in next slide.

TN - CS SYSTEMS

Regulations in many countries require that where the earth electrode is common to HV and LV side of the DTR and the combined earth resistance is over 1 ohm, the HT and LT neutral earthing systems should be separate to guard against LT equipment frame potential rise to dangerous value.

When utilities cannot guarantee low transferred potentials, consumers shall not use TN-CS. While TN-CS is adopted in USA, UK, Germany, etc., TN-CS is not permitted in France, Italy, China, Japan etc.



MBJ: Main Bonding Jumper
NBJ: Neutral Bonding Jumper

HV side ground fault energizing the frames of consumer appliances causing pausible electric shock

COMPARISON OF EARTHING SYSTEMS

	TT	TN-S	TN-CS
Fault Current	Low	Very High	Very High
Fault Current Path	Earth	Ground Wire	Ground Wire & Neutral
Normal Over Current Protection	May Not Protect	Protects	Protects
RCD	Required	Not Required	Not Required
Neutral Integrity	Important	Important	Critical and Most Important
EMI Problems	Less	Can be Severe	Can be Severe

GROUNDING OF NEUTRALS

Can we earth the neutral at consumer side in TT system?

No. Neutral from utility can attain dangerous potential some times. So if neutral is connected to earth, the user's enclosures can also attain unsafe potential. The connection therefore is not permitted.

In TN system, the earth fault current does not flow through the earth. Why then is neutral earthed at source ?

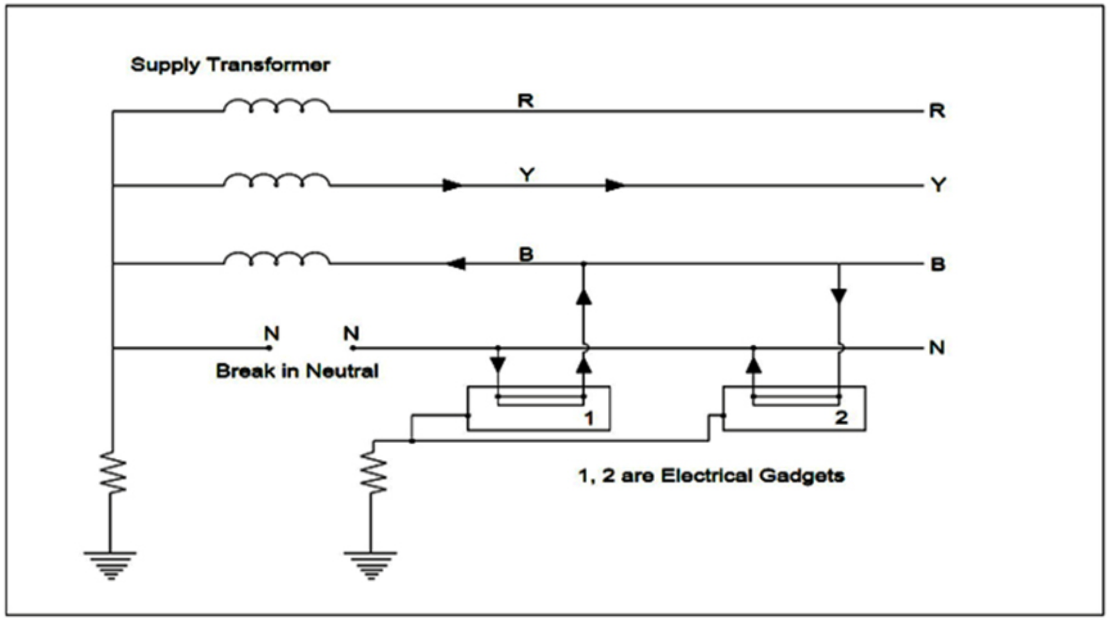
The neutral at source is earthed mainly to limit the phase to ground voltages during earth faults.

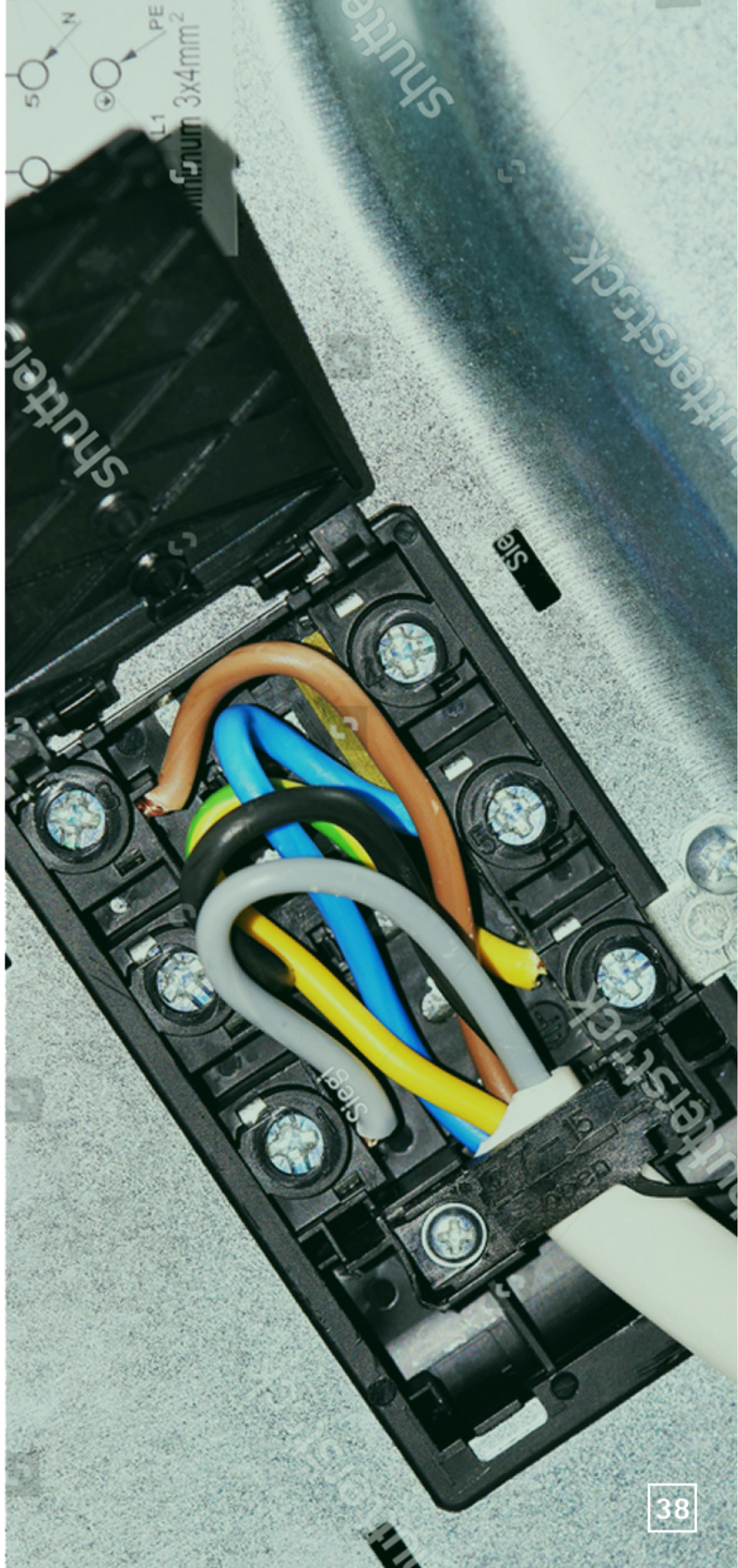
INTERRUPTION OF NEUTRAL WIRE IN TT SYSTEM

Accidental interruption of neutral conductor occurs often in supplies from DISCOMS.

If neutral conductor breaks, neutral wire downstream becomes live and will be at 240 volts in single phase circuits. Also in 3-Phase systems a neutral interruption causes bigger hazard.

Trace the current path between two appliances when there is a neutral break. Phase to phase voltage will get divided unequally between the two appliances as impedances of the two gadgets may be unequal. The one which is overstressed can fail, create an insulation fault and fire accident.

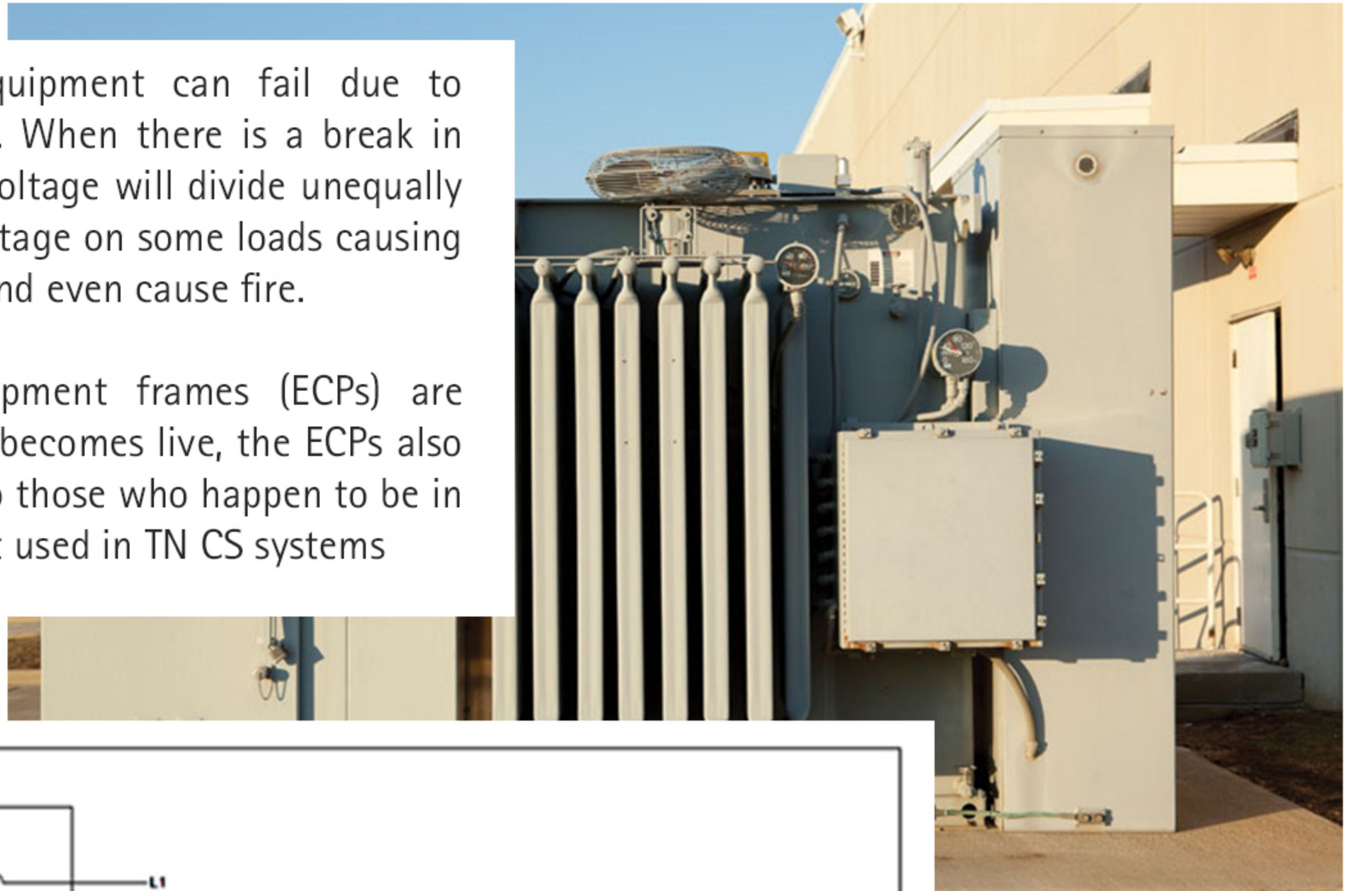




INTERRUPTION OF NEUTRAL WIRE IN TN - CS SYSTEMS

In TN C-S systems also, user equipment can fail due to over-voltages and consequent fires. When there is a break in neutral conductor, the line to line voltage will divide unequally between loads with a risk of overvoltage on some loads causing those equipments to overheat, fail and even cause fire.

In addition to this, as the equipment frames (ECPs) are connected to neutral and if neutral becomes live, the ECPs also become live and shocks can result to those who happen to be in touch with the ECPs as RCDs are not used in TN CS systems



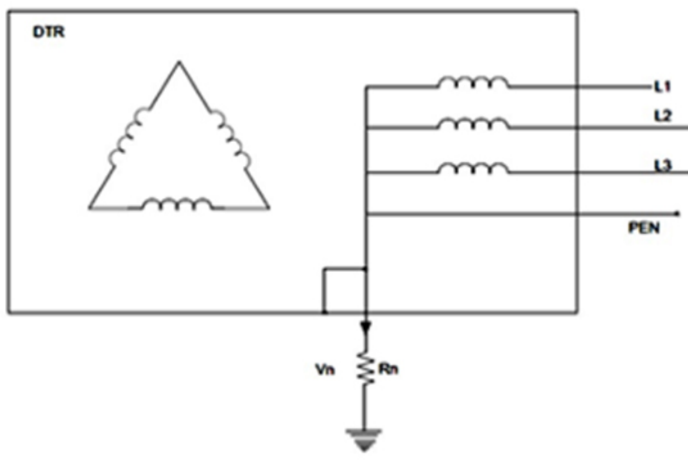
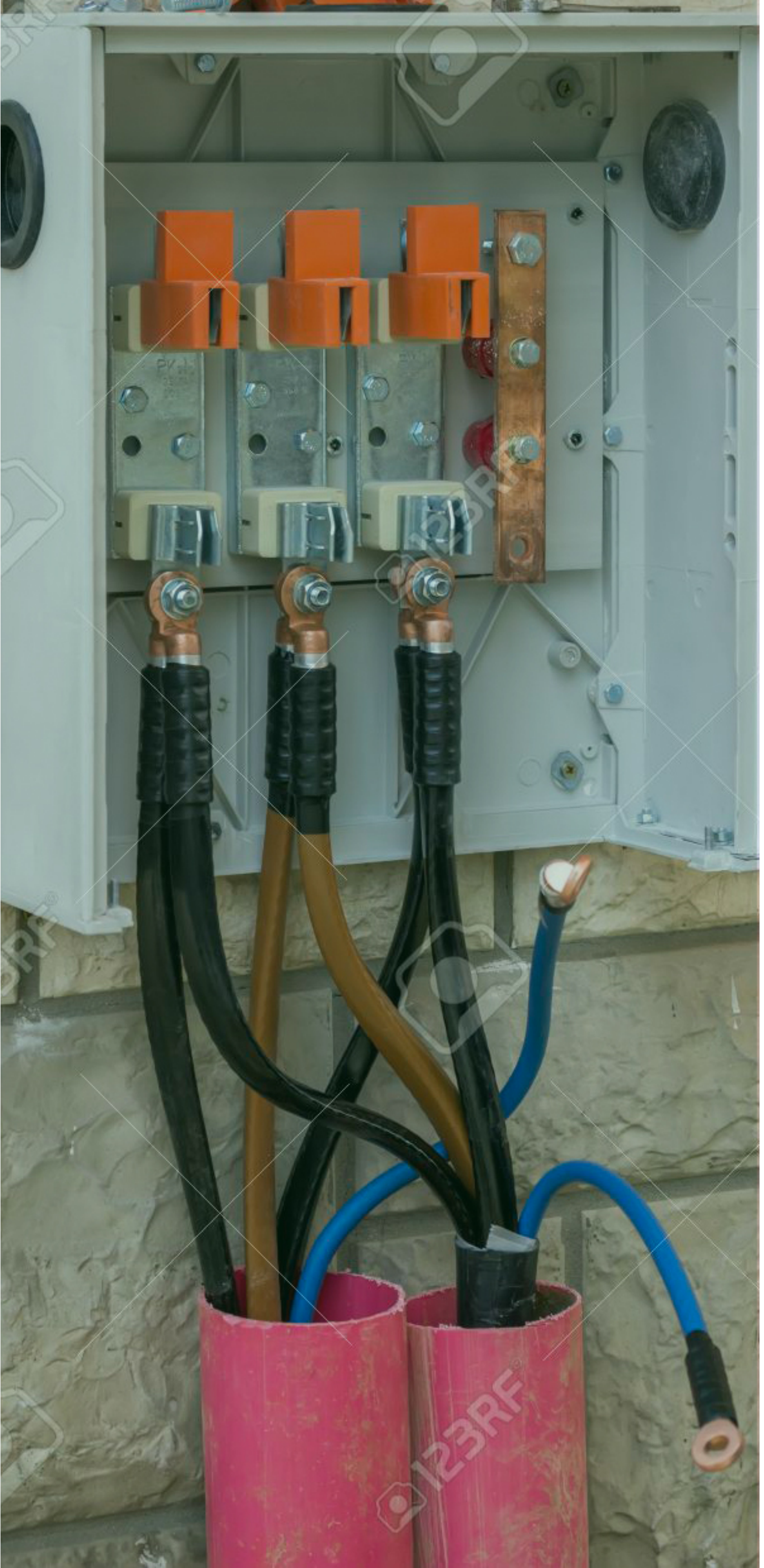


Fig-3 - Break in Neutral / PEN



INTERRUPTION OF NEUTRAL WIRE IN TN - CS SYSTEMS

In TN C-S Systems, there is a high responsibility on the part of the utility to maintain neutral integrity. As we know for this, it is not possible to depend on the utility in India. In TN C-S systems there are stray currents which are said to cause interference problems in sensitive electronic and communication systems.

For reducing the probability of neutral interruption, in TN CS system the IEC Standards require its **cross section to be not less than 10 Sq. mm Copper or 16 Sq. mm Aluminium.**

In TN C portion of the TN CS system, the neutral conductor must never be switched off.

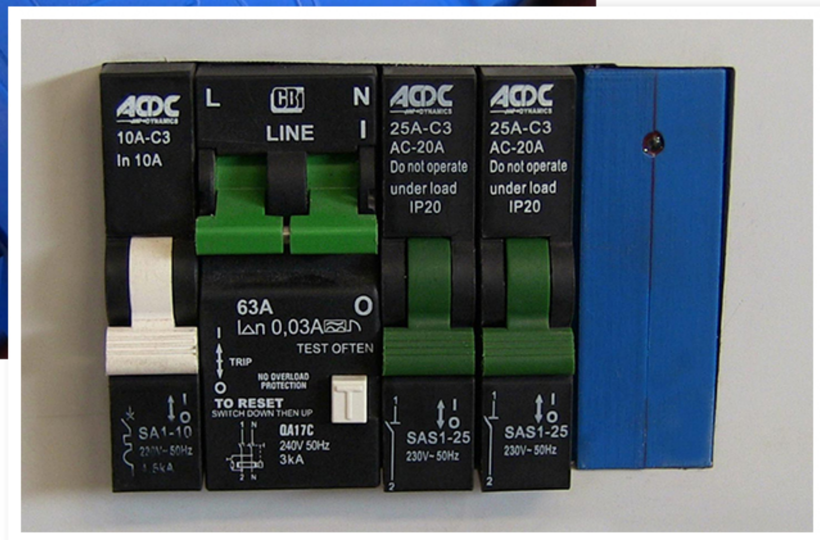
In TN C system, the switchgear must be 3 pole.

BROKEN NEUTRAL

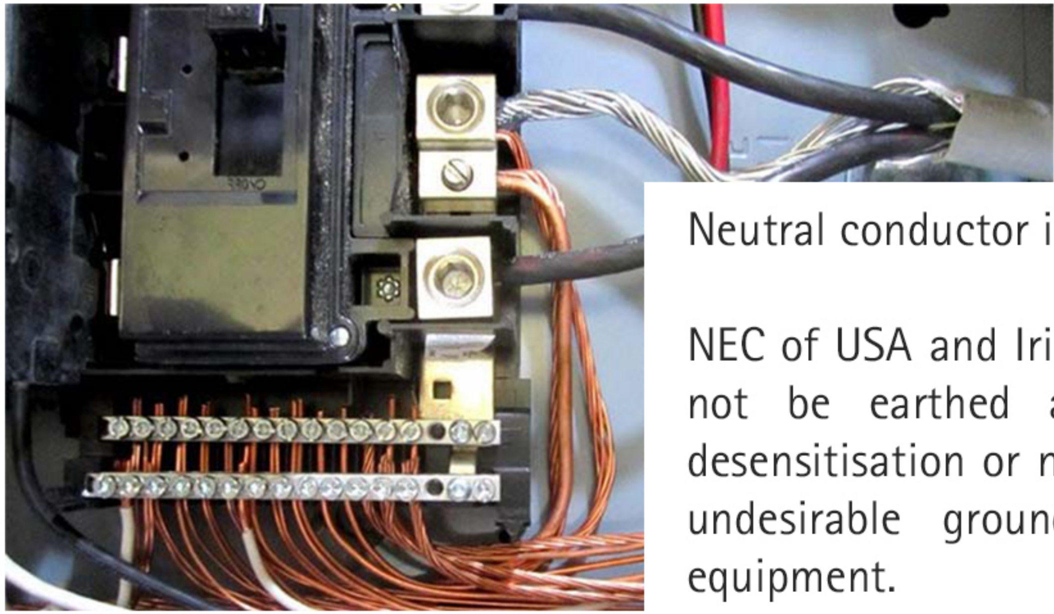
In 3 phase 4 wire systems, a break in neutral (very common in India) can result in electrical appliances failure due to over-voltages. It also exposes the possibility of electric shock.

RCD will not operate and trip supply in such a condition.

Broken neutral detection devices are available in Europe and if these are retrofitted to RCD, RCD will trip.



MULTIPLE NEUTRAL TO GROUND CONNECTIONS



Neutral conductor is needed for single phase loads.

NEC of USA and Irish standard ET214:2005 state neutral should not be earthed after main disconnect. This is to avoid desensitisation or nuisance tripping of RCD. Apart from causing undesirable ground loop problem for sensitive electronic equipment.

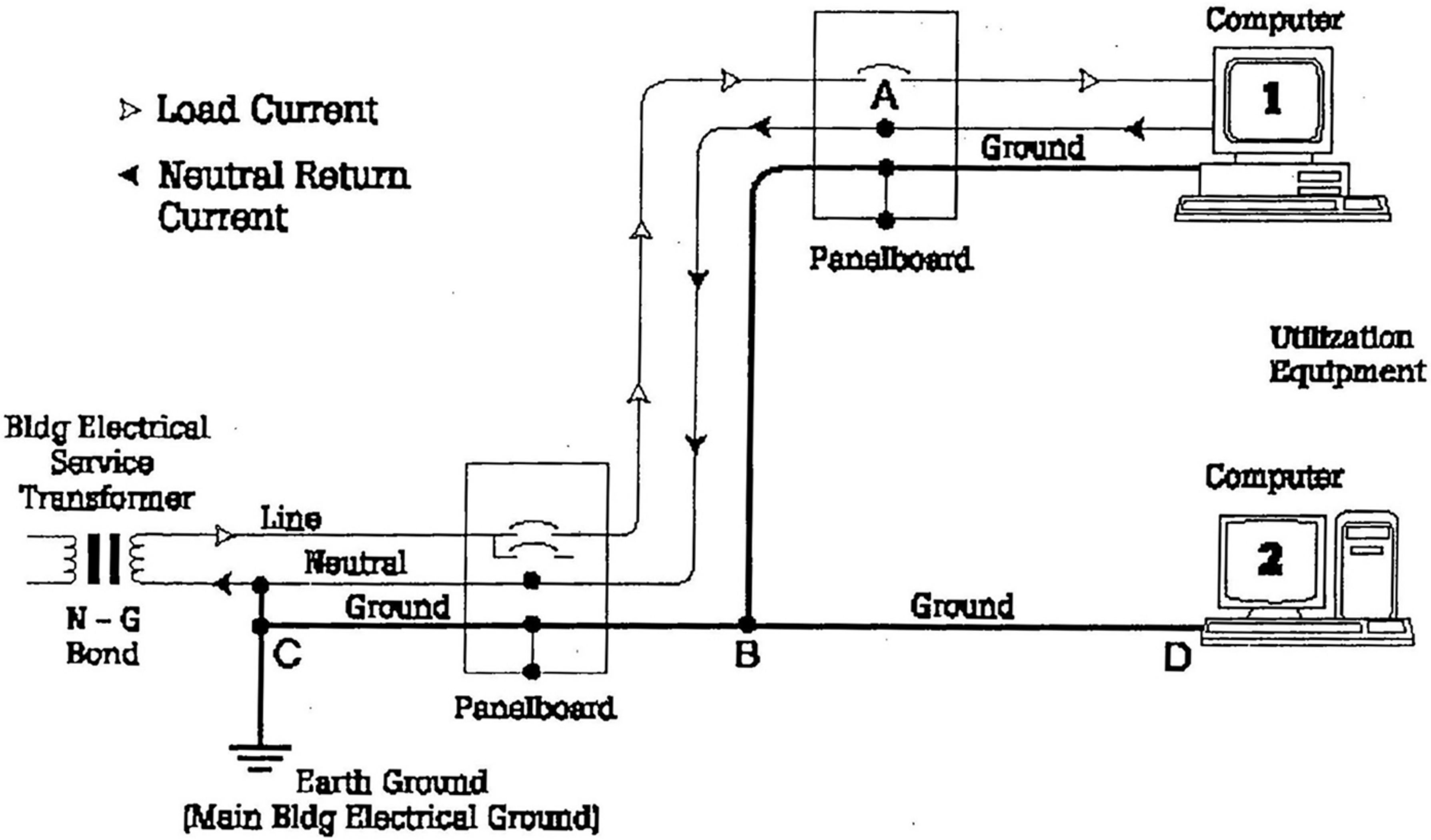
In some cases the current flowing between ground and transformer neutral was found to be 10% of phase current. Obviously it is due to multiple neutral to ground connections or neutral to ground faults.

Neutral to ground voltages result from flow of return currents via neutral wire and earth continuously. These currents are due to a) unbalance of loads on 3 phases and b) connections between neutral and ground by wrong wiring or ground faults. Currents of 150 HZ (3rd harmonic) due to use of non linear loads flow in neutral wire.

Common Mode (CM) noise is any unwanted potential occurring between a phase conductor and the earth. Ground loops are a major source of CM interference problems in electronic circuits.

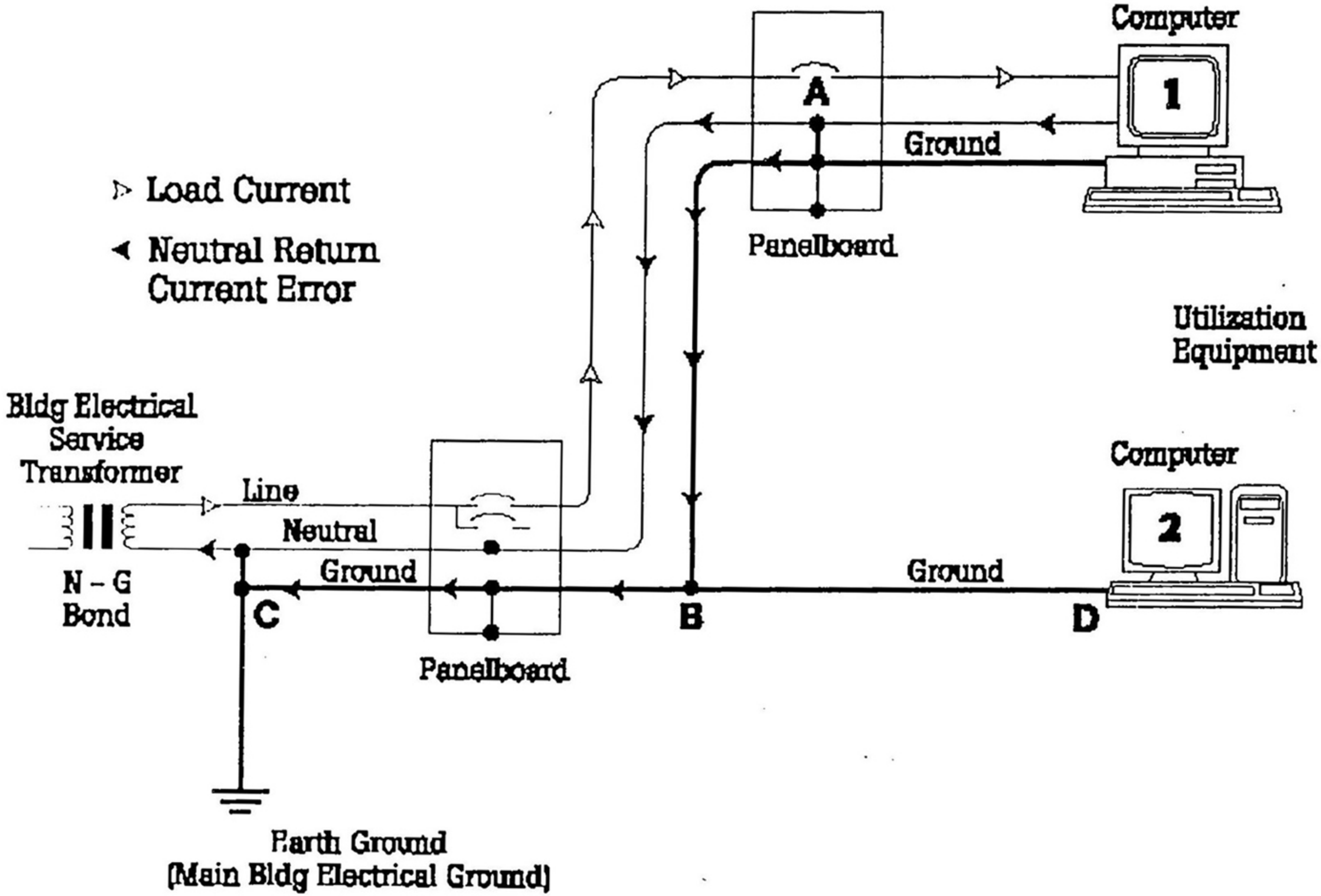
CORRECT EQUIPMENT GROUND (NEC)

SINGLE N-G BOND AT THE SOURCE



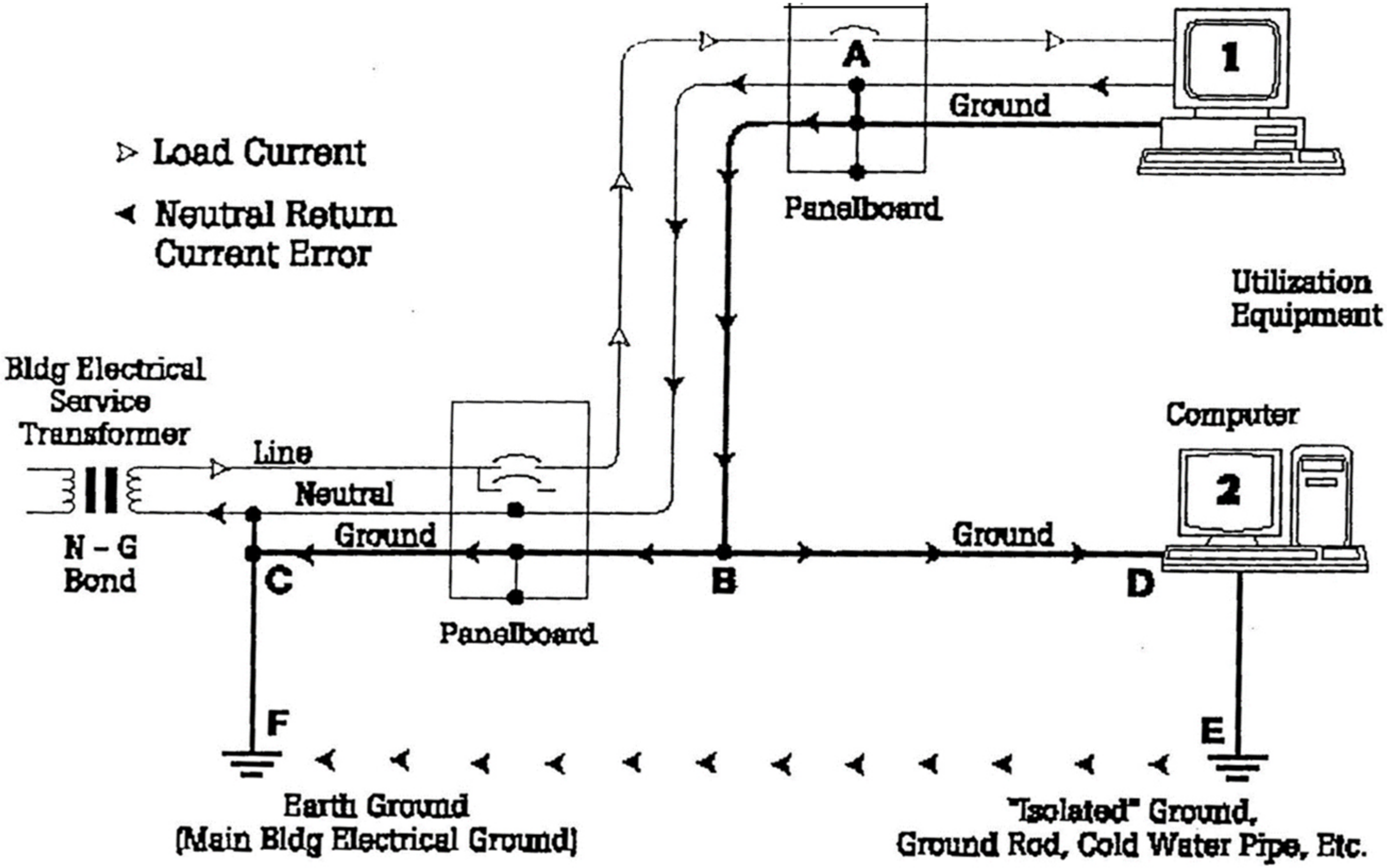
MORE THAN ONE N-G BOND:

GROUND CURRENT CAUSES CM NOISE



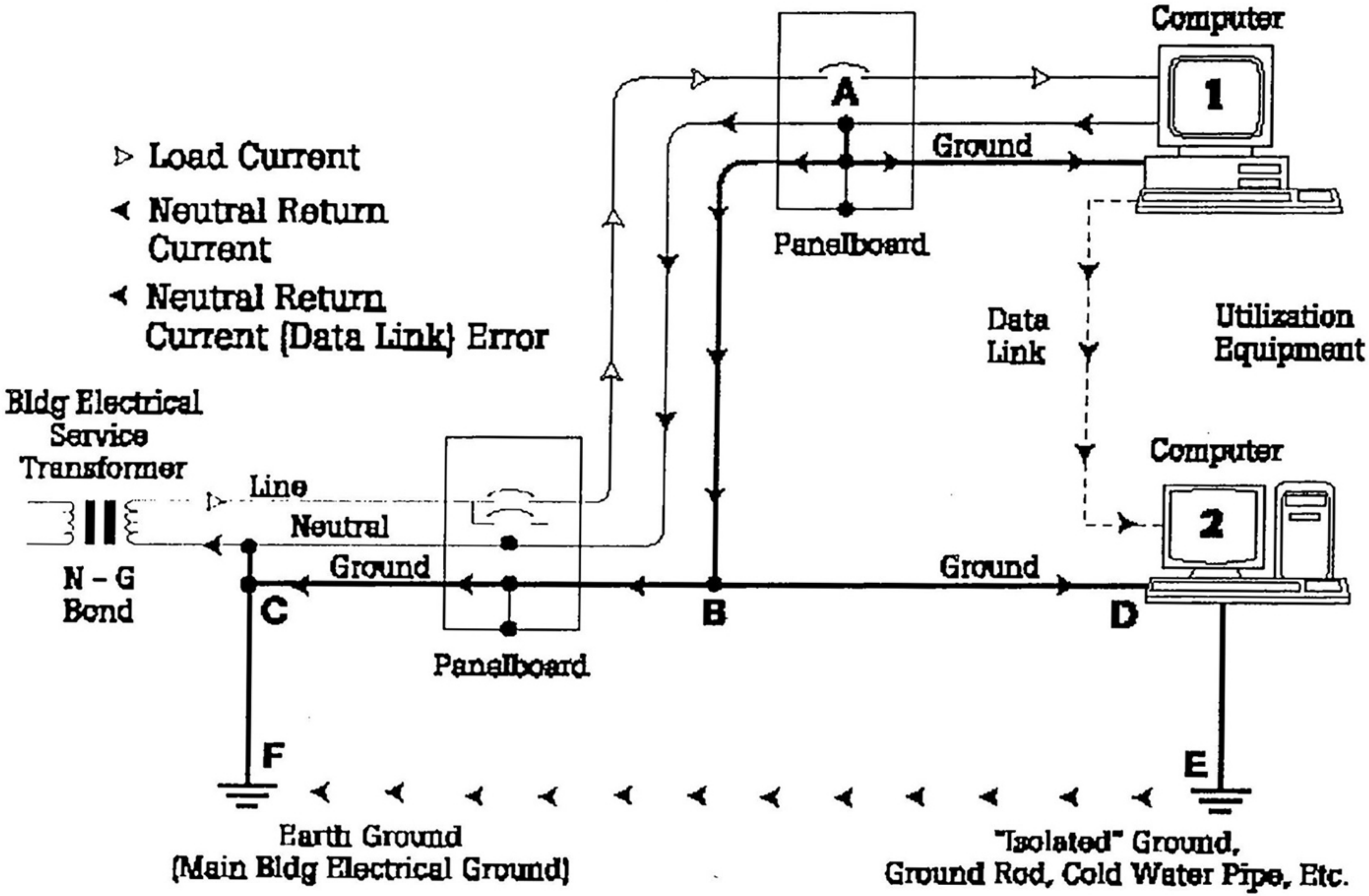
MULTIPLE GROUNDS:

GROUND LOOPS CAUSE CM NOISE



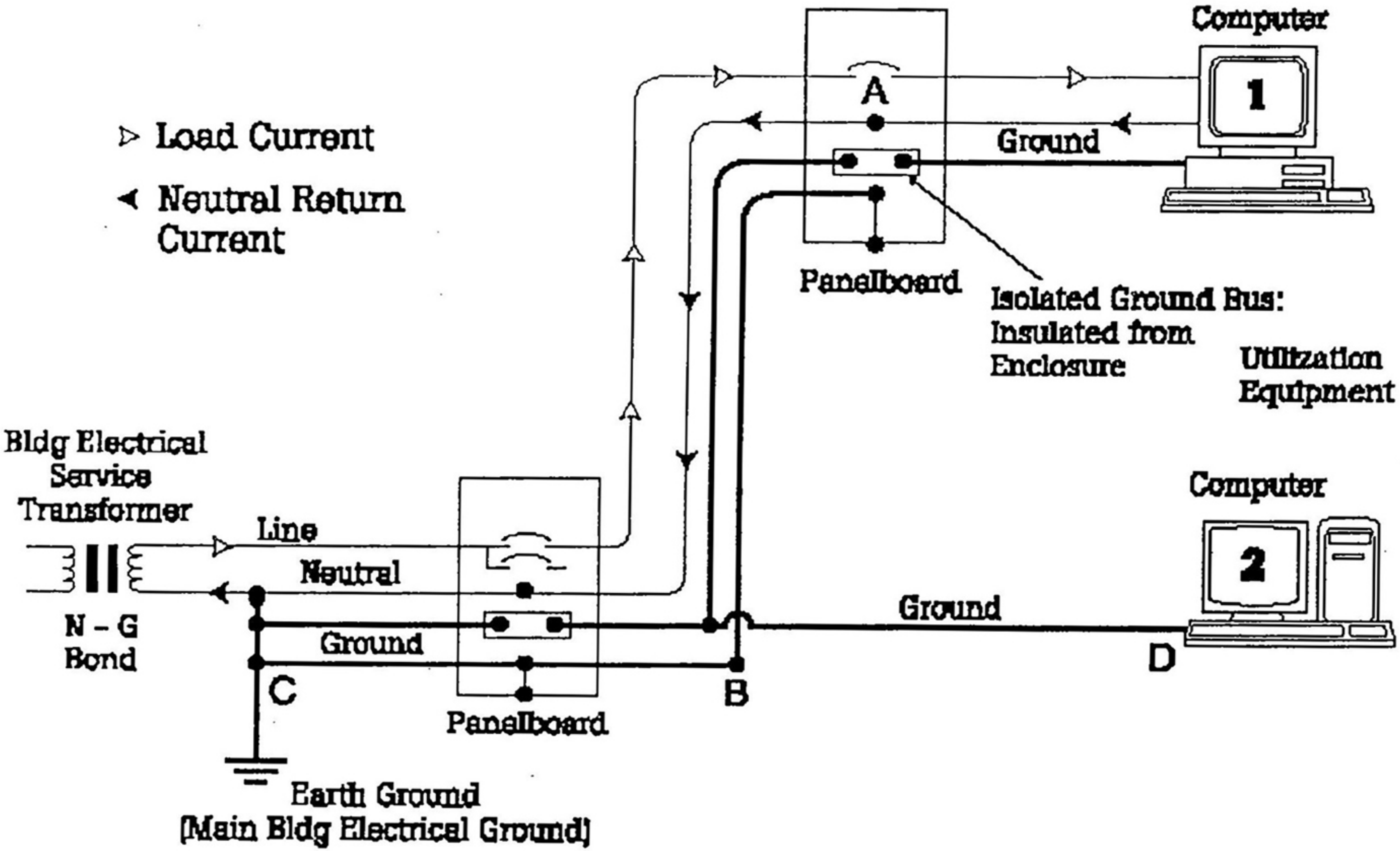
DATA LINKS:

ADDITIONAL GROUND LOOPS



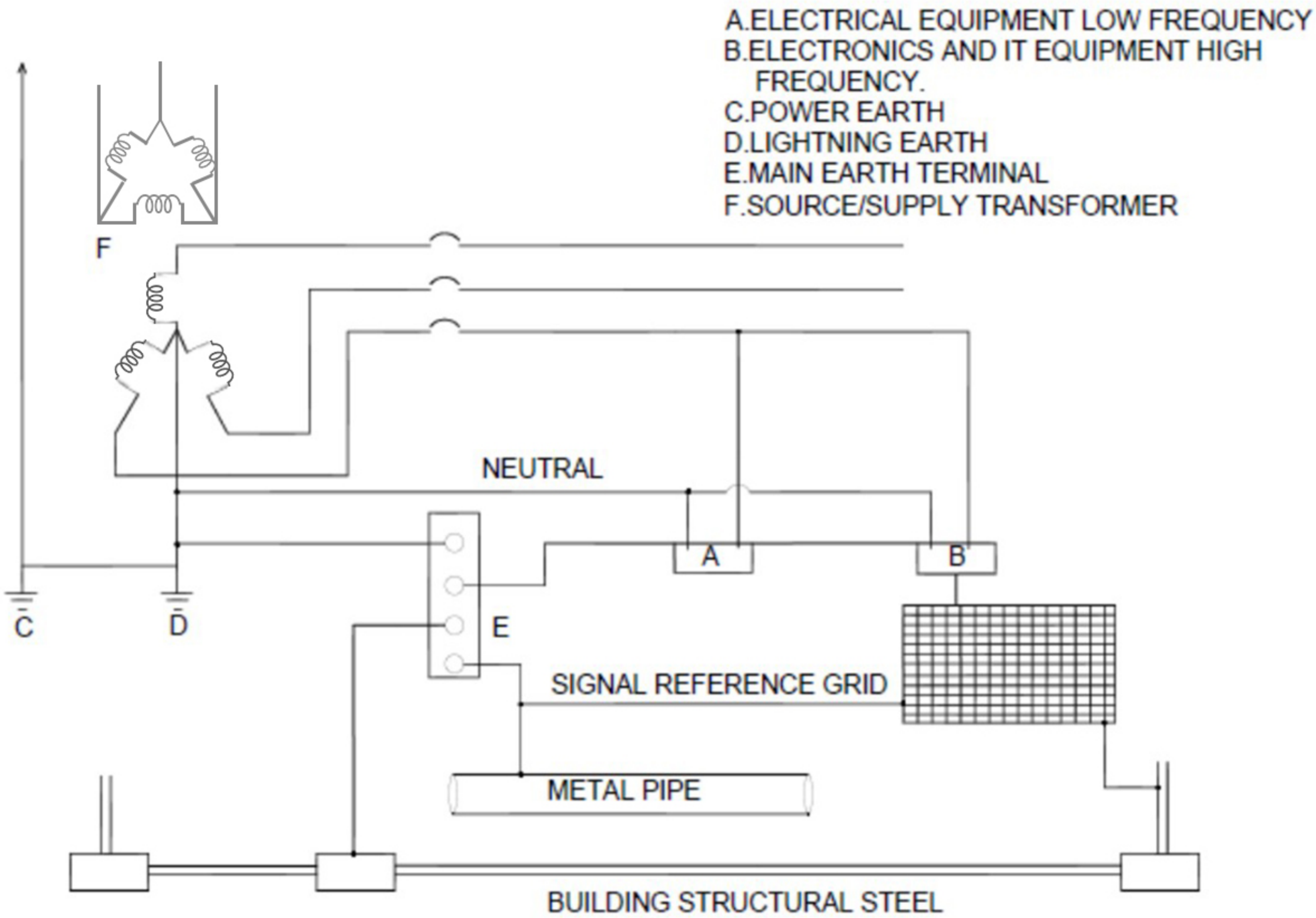
GROUNDING FOR SAFETY AND SIGNALS:

CORRECT USE OF ISOLATED GROUND



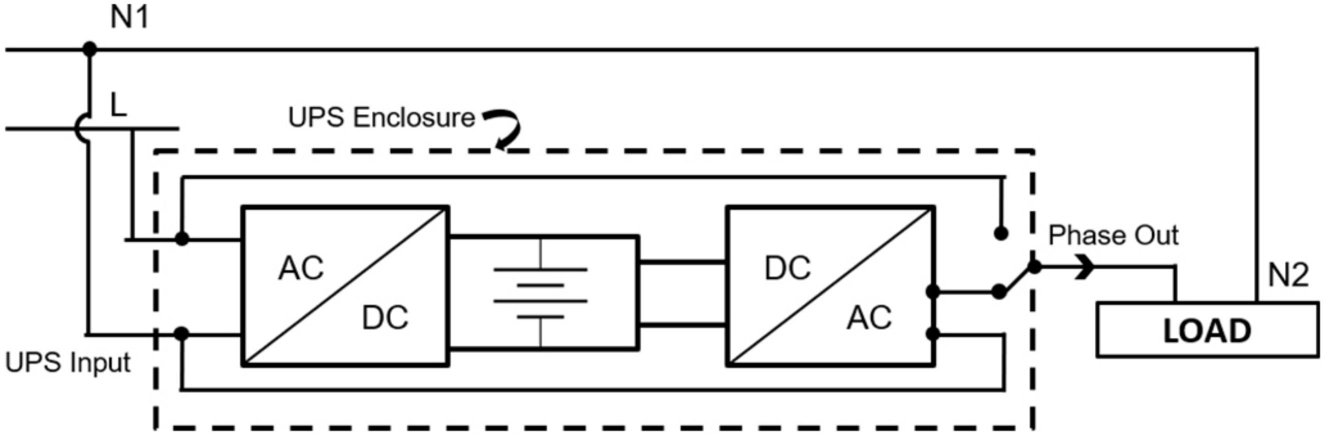
INTERCONNECTION OF GROUNDING SYSTEMS

NEC of USA & IEEE Standards & NFPA 780 require a single point interconnection of the grounding of power, lightning protection, electronic systems as shown in the below figure.



EARTHING AND BONDING SYSTEM IN BUILDINGS

A CASE STUDY OF AN UNSAFE HOME INVERTER / UPS



N1 to N2 existing neutral wire of house is used

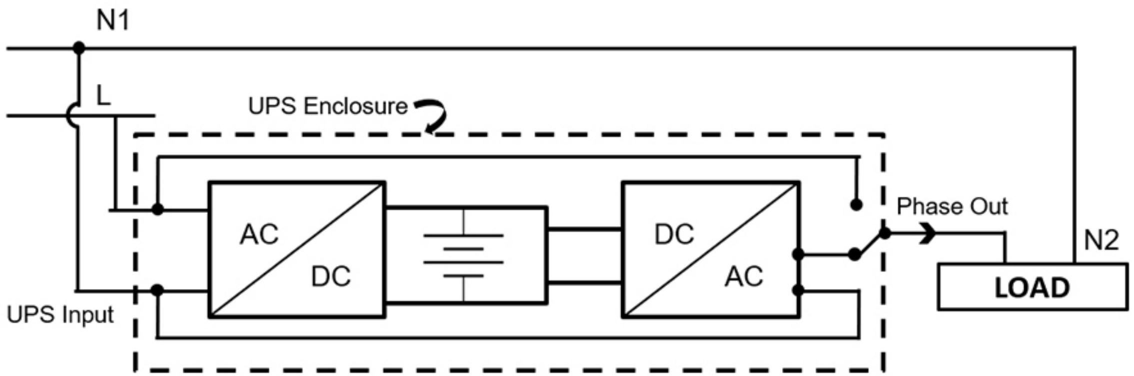
Fatal shocks occurred to linemen while doing maintenance on their LT overhead lines even after switching off the fuses at DTR's LT side.

Preliminary indications showed back feed from consumer's home inverter. When I analysed the connections I found the cause as

a) break in earthing of neutral wire and

b) use of single pole transfer switch only in the phase in inverter.

To understand it, study the schematic and explanation in the next slide.



N1 to N2 existing neutral wire of house is used

A CASE STUDY OF AN UNSAFE HOME INVERTER / UPS

The neutral wire from supply side to load at the top of the figure is pre existing in home wiring even before UPS is put. The right most item inside UPS in the figure is the transfer switch and it is for the position when utility power is interrupted.

Notice that only one wire is coming out of UPS output side. The other end as you can see at the bottom is shorted to the neutral on incoming side inside the UPS enclosure by the manufacturer of UPS.

For current to flow from the single wire coming out of UPS there is a path –

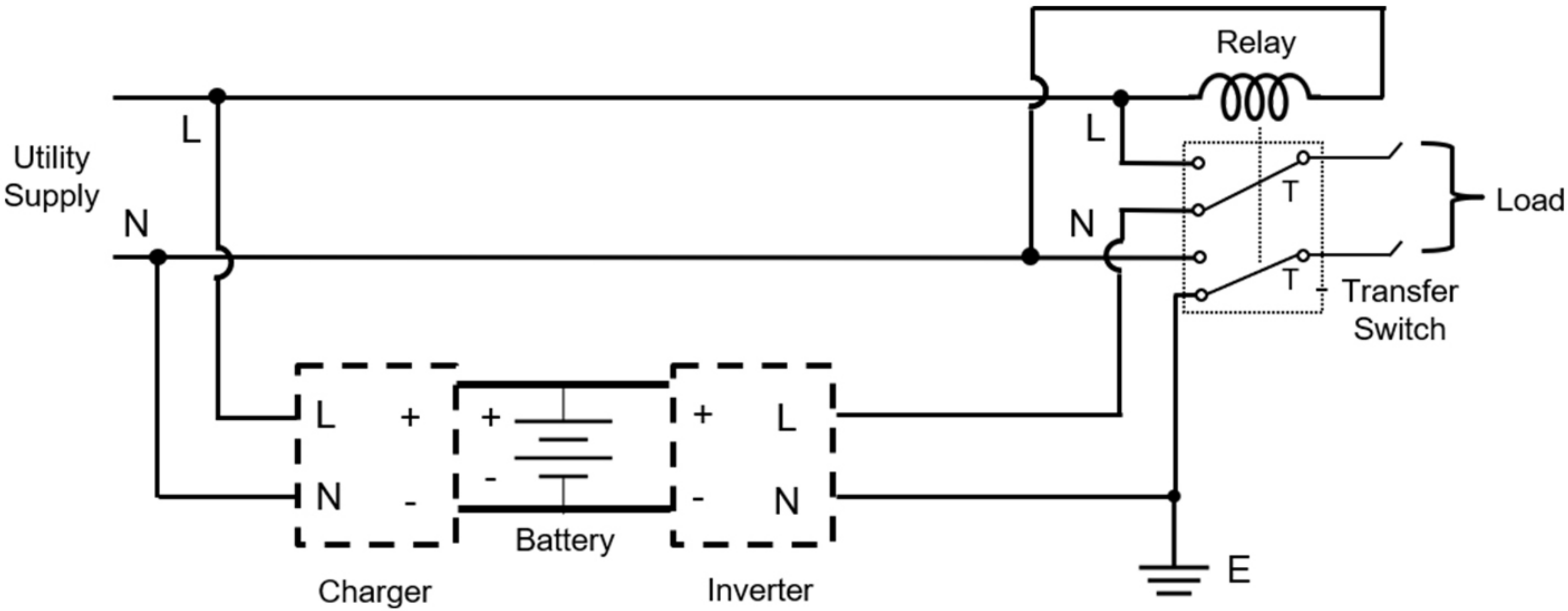
N2 >> N1 >> UPS Input Neutral >> UPS Output Neutral

which is at or near zero potential as N1 is coming from utility transformers grounded neutral. But if any switch/ breaker is opened for maintenance, there is a break in the neutral wire connection to supply neutral and UPS neutral will not be at zero potential. This potential can back feed upto the outgoing of above switch or breaker. It is due to neutral not getting connected to ground.

SAFE HOME INVERTER / UPS

There will be no potential in the neutral of utility side or on UPS incoming supply.

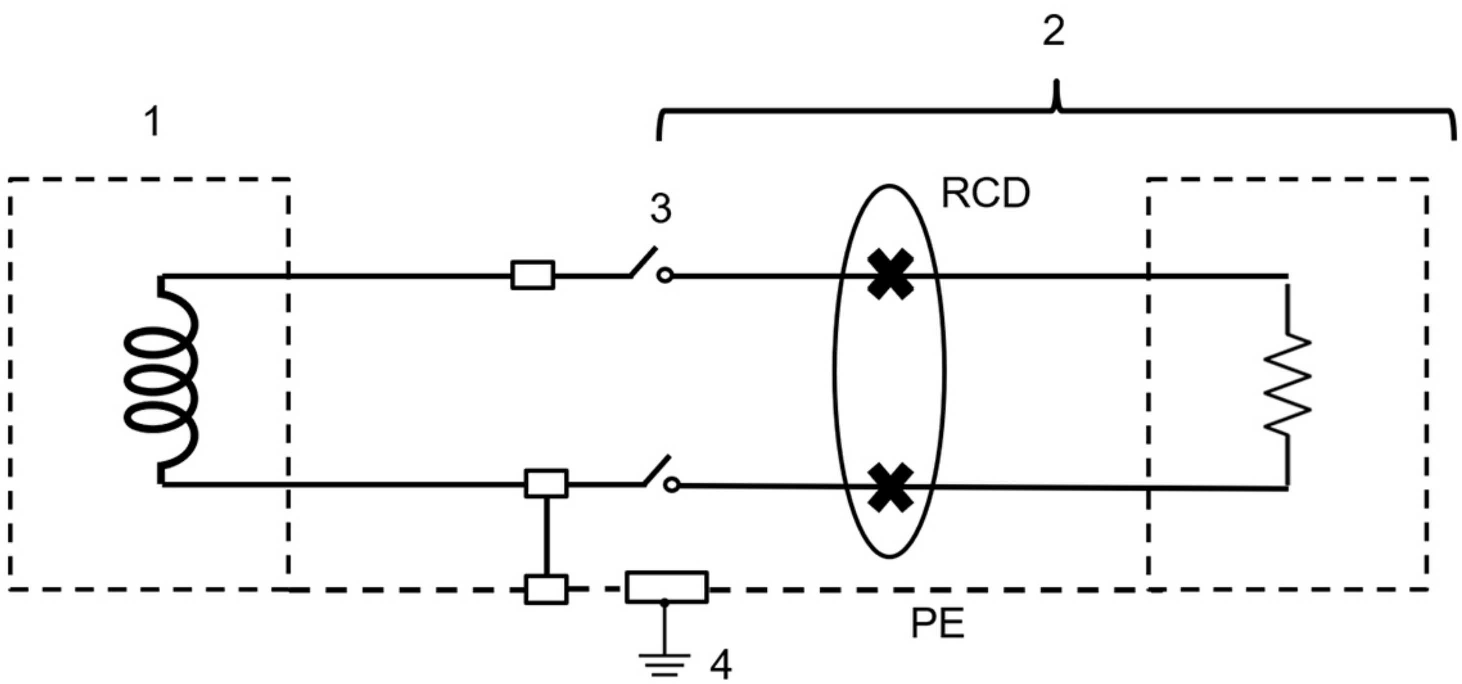
Fatal electrical shocks due to back feed into utility overhead line when linemen are working can be prevented if the inverter manufacturers employ 2 pole transfer switch instead of present use of 1 pole switch.



Schematic for off-line UPS to avoid backfeed

SAFE HOME INVERTER / UPS

The modification I suggested to make the UPS safe also meets the requirement of IS 3043-2018 (figure 36) and IS 732-2019 (fig 41)



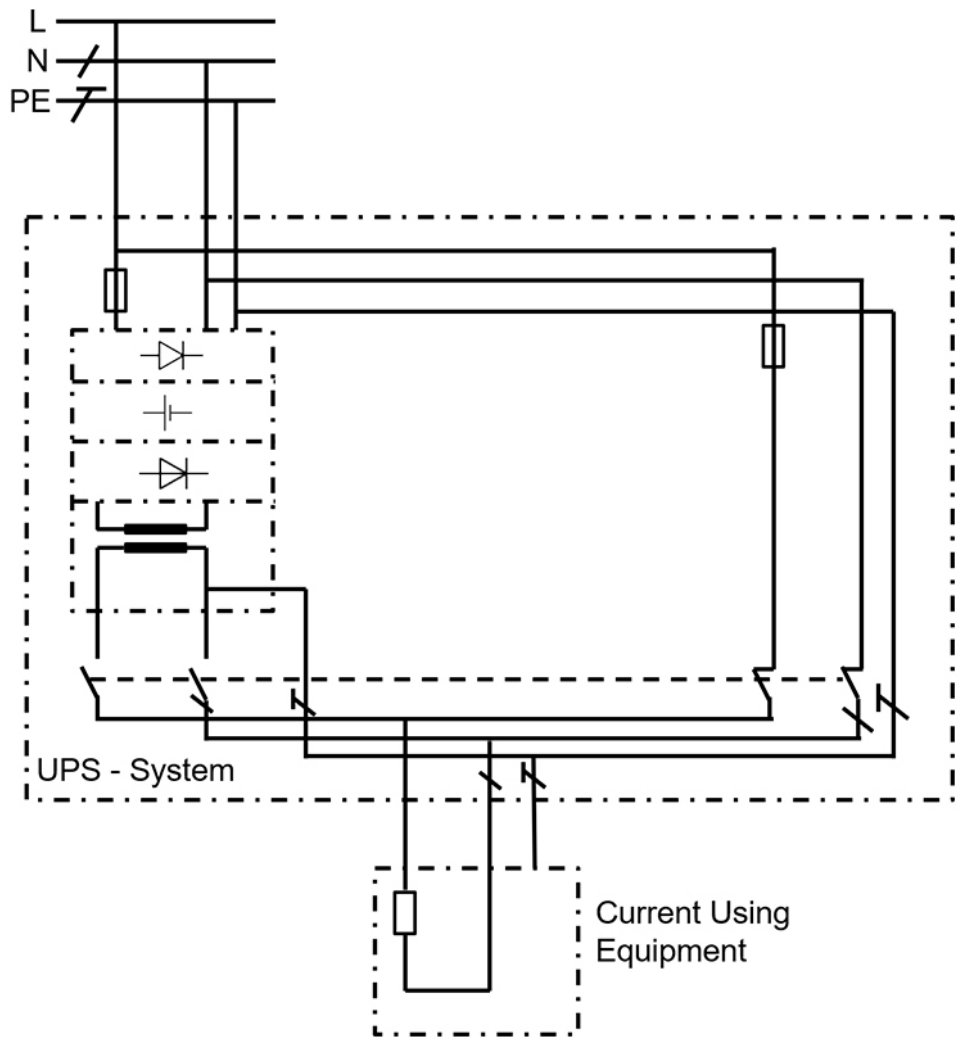
KEY

1 – Unearthed Generator
2 – Electrical Installation
3 – Isolator
4 – Main Earth Terminal

SMALL LOW VOLTAGE GENERATOR SUPPLYING A FIXED INSTALLATION

TWO POLE TRANSFER SWITCH

Fatal electrical shocks due to back feed into utility overhead line when linemen are working can be prevented if the inverter manufacturers employ 2 pole transfer switch instead of present use of 1 pole switch. Fig. 41 of IS732-2019 insists on 2 pole transfer switch.



SINGLE-PHASE ALTERNATIVE POWER SUPPLY WITH 2-POLE SWITCH

STANDBY GENERATING PLANTS

Utilities do not normally allow parallel operation of consumer's generators with Utility supplies.

Standby generators of consumers without above said paralleling is permitted. In this case 4 pole changeover switching between the two supplies should be used as per IEEE 142 and IS 3043. This is for providing isolation of generator and DISCOM supply neutral earths needed for safety.

IS 3043 : 2018

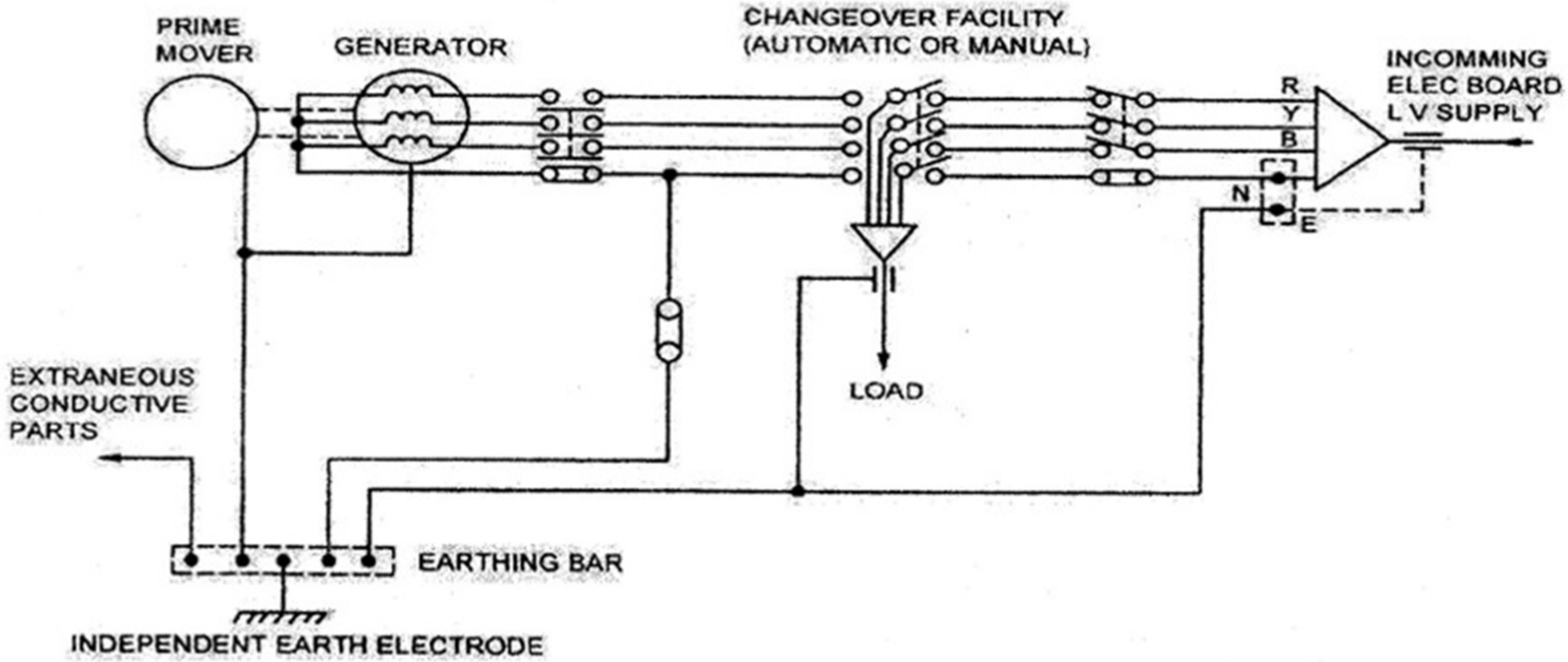


Fig. 38 Single Low Voltage Standby Generator (Without Parelleling Facility)

PROBLEMS IN LIGTHNING PROTECTION GROUNDING

Electrical safety grounding involves power frequencies 50 or 60 Hz. Resistance is the main design factor in this grounding

But in higher frequencies like lightning, dominant factor is inductive impedance rather than resistance. To reduce such impedance in lightning protection systems and surge arrestors, the grounding wires must be short in length and with fewer sharp bends.

The Central Power Research Institute of India (CPRI) examined the practice of having a common ground for the distribution transformer tank and the neutral of lightning arrestors (LAs). The CPRI tests in their HV Lab on such practice indicated a high potential rise of the tank when the LAs conduct due to Lightning leading to internal flash over. CPRI recommended separate earthing for the tank and LAs.

SIDE FLASHES IN LPS

When lightning current flows in a down conductor of the LPS, it can result in a voltage

$$L.di/dt + iR$$

If there are metallic grounded objects like water or gas pipes close by to the lightning current path, a side flash can occur between them and lead to fire and property damage.

Side flashes can be reduced by -

1 **Increasing the separation** distance between the above two

2 **Bonding to the LPS** all metal objects close by

The effects of lightning are also reduced by -

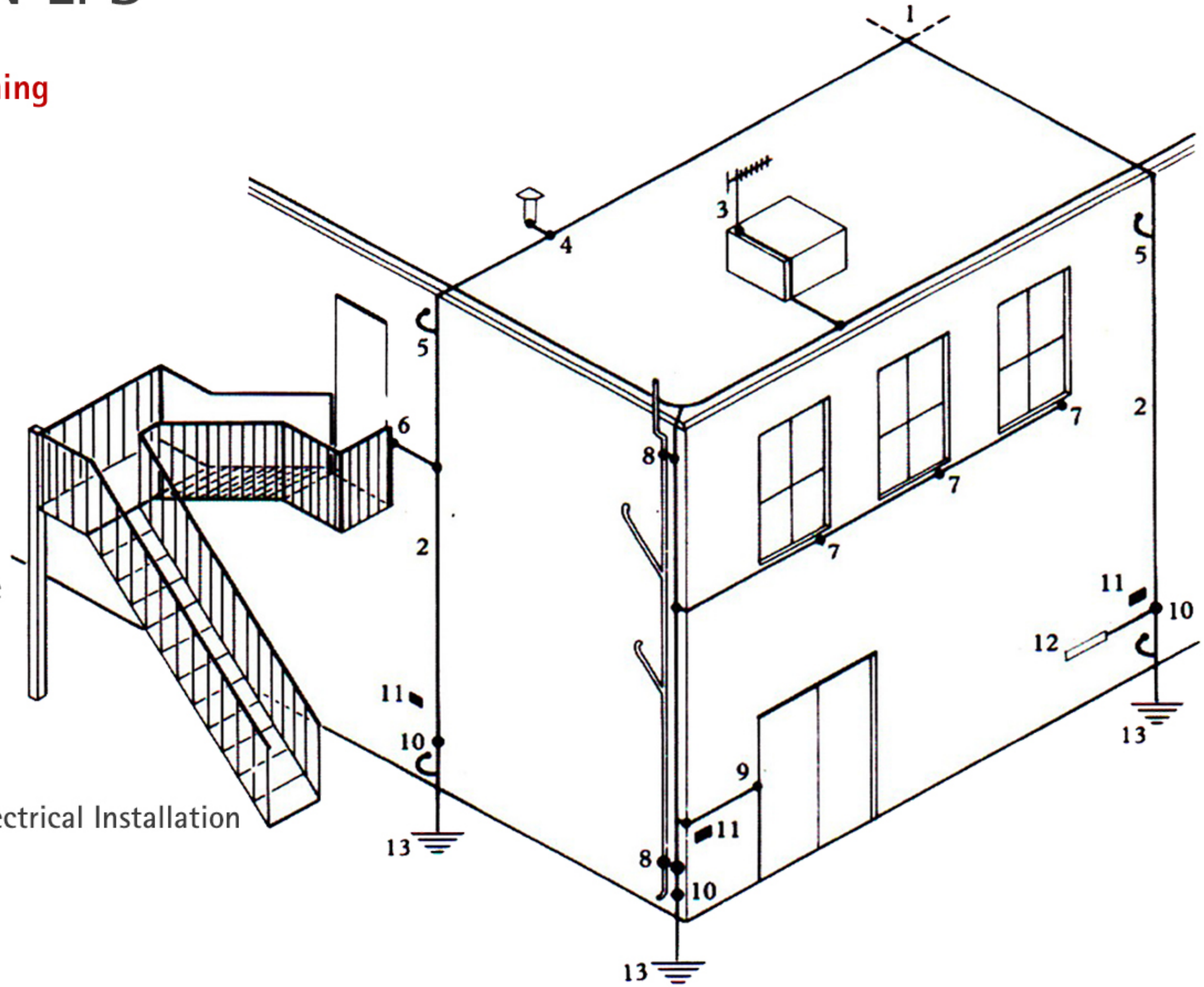
A) Increasing the number of down conductors to divide the lightning current, and

B) Avoiding down conductors near sensitive electronic equipment

SIDE FLASHES IN LPS

Bonding to Prevent Side-Flashing

01 – Air Termination
02 – Down Conductor
03 – Bond To Aerial
04 – Bond to Vent
05 – Bond to Re-Bar
06 – Bond to Metal Staircase
07 – Bond to Metal Window Frame
08 – Bond to Vent Pipe
09 – Bond to Steel Door/Frame
10 – Test Clamp
11 – Indicating Plate
12 – Main Earthing Terminal of Electrical Installation
13 – Earth Termination Point



PART III

IEEE HYDERABAD SECTION

APQI ASIA POWER QUALITY INITIATIVE

GROUND FAULTS

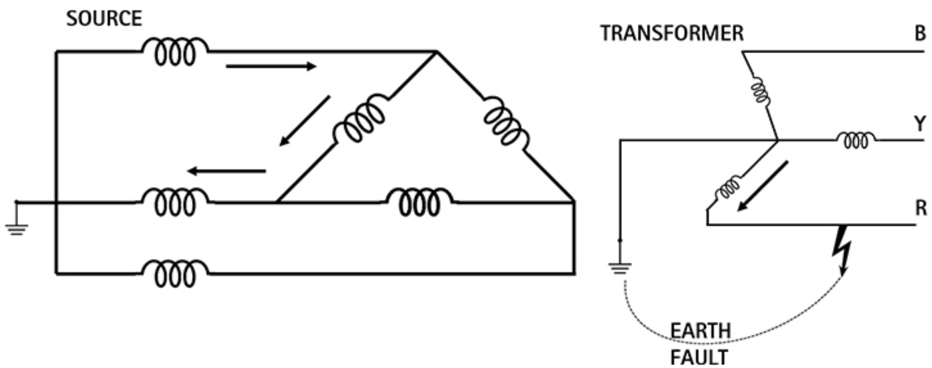
80% of the faults on overhead power lines are phase to ground faults, many of them self clearing

Nearly **90%** of the faults in industrial power systems are ground faults.

Ground faults result in huge loss of property and lives

Switchboards meltdowns occurred by low level arcing ground faults. Conventional over-current protection often will be unable to protect for ground faults.

The concept of residual current sensing even small leakage currents is perhaps the best technological breakthrough of our times to prevent shocks and fires.

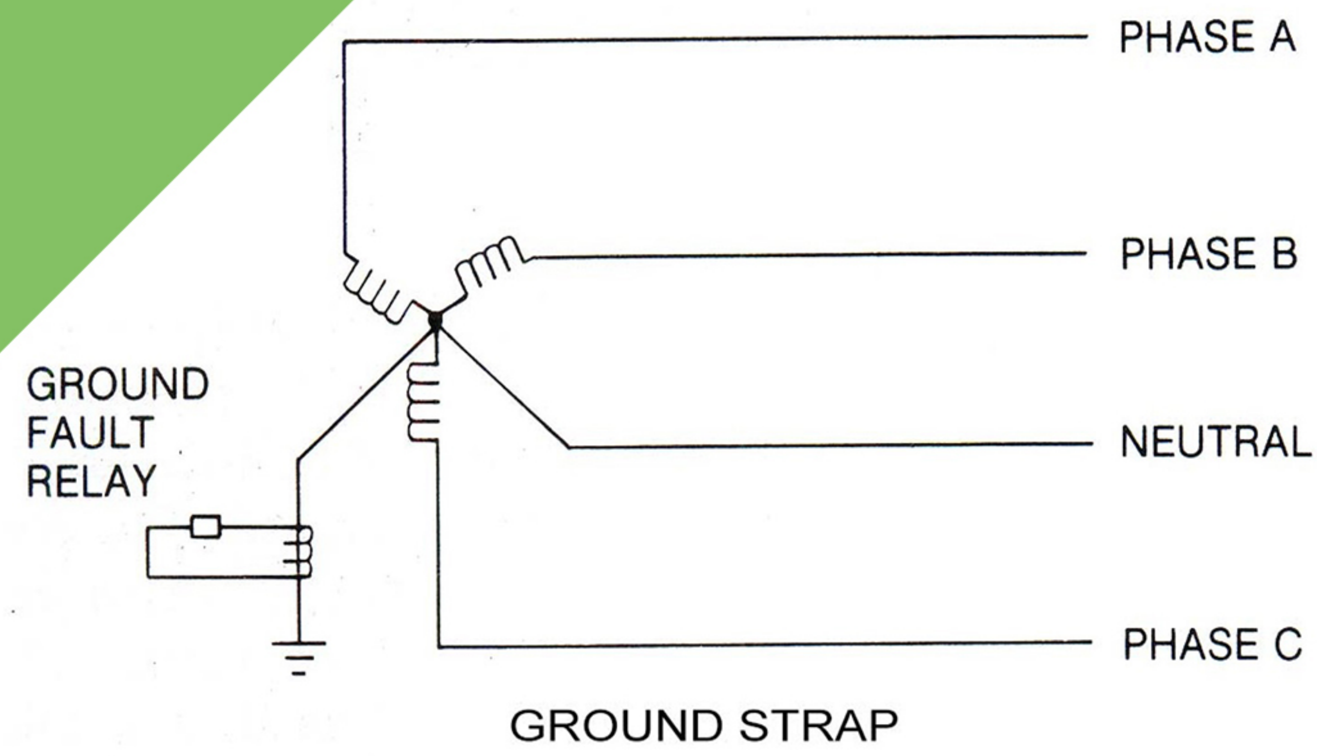


Notice that earth fault current of secondary side of a delta / star transformer is reflected not as a ground fault but as line to line fault current in the primary side.

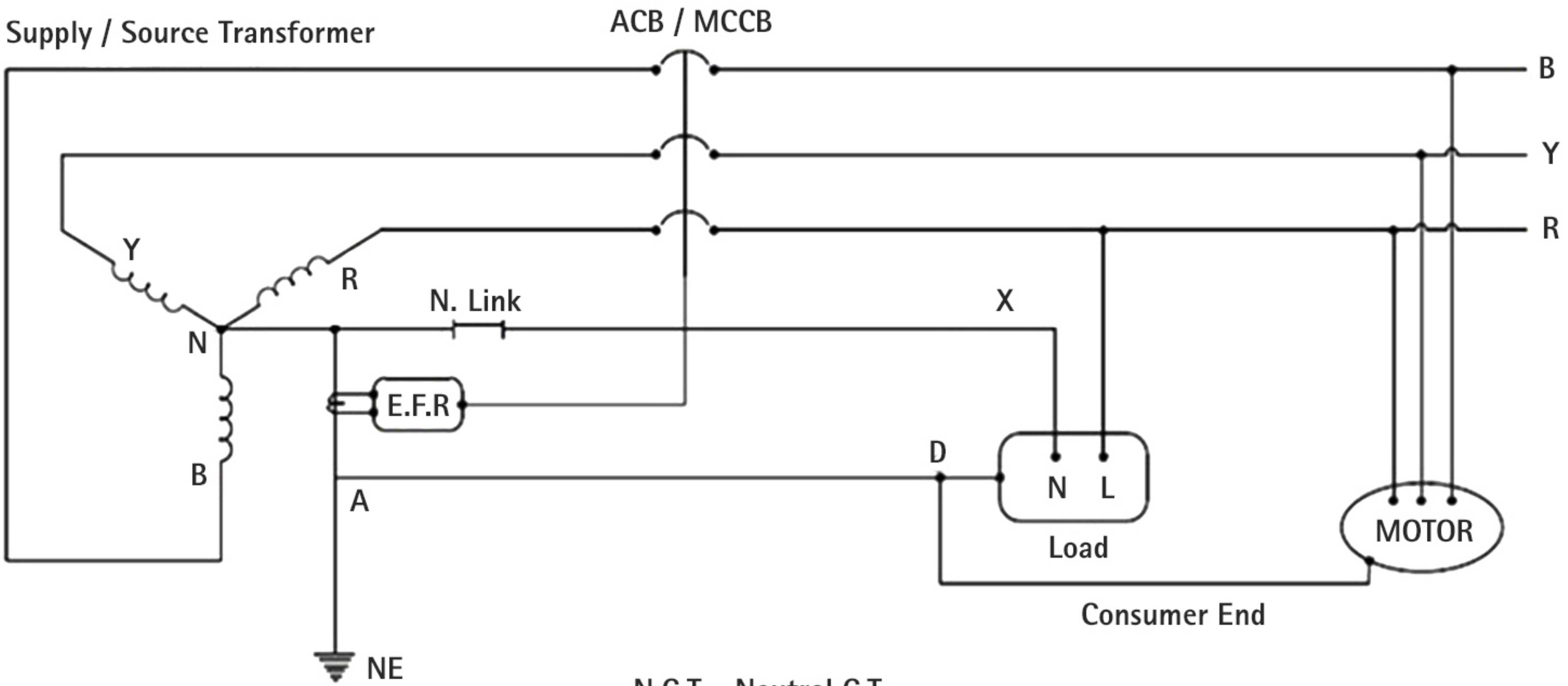
The usual problem of relay coordination between upstream and downstream overload / fault currents does not arise in such a case.

GROUND FAULTS PROTECTION

Ground fault protection involves use of symmetrical components specially zero sequence currents / voltages



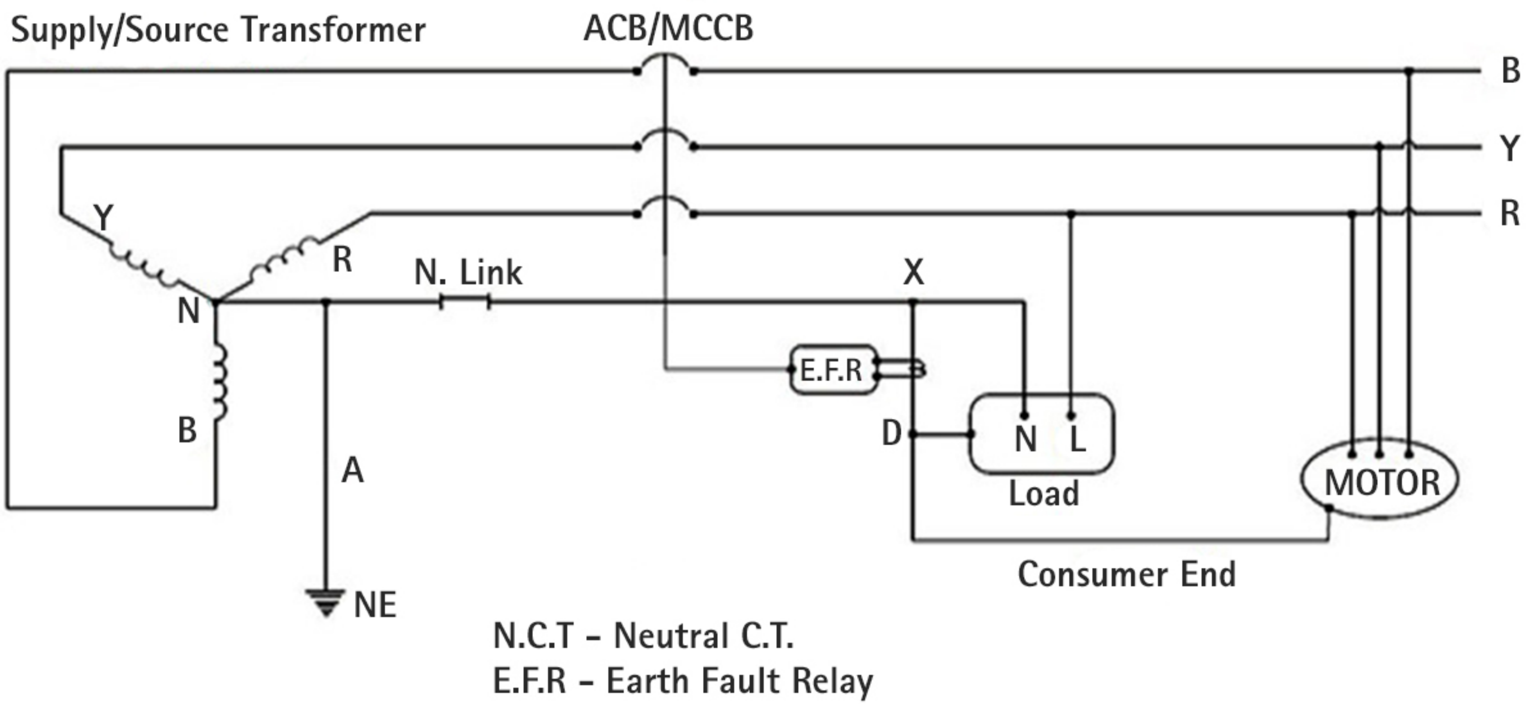
3 PHASE 4 WIRE L.V. SYSTEM
EF PROTECTION IN TN-S SYSTEM



N.C.T - Neutral C.T.
E.F.R - Earth Fault Relay

The above scheme is used in TN-S System. If there is no earth wire from A to D, we have to use TT or TN-CS and the earth fault protection schemes as in the following slides.

3 PHASE 4 WIRE L.V. SYSTEM FEEDERS EF PROTECTION IN TN C-S SYSTEM

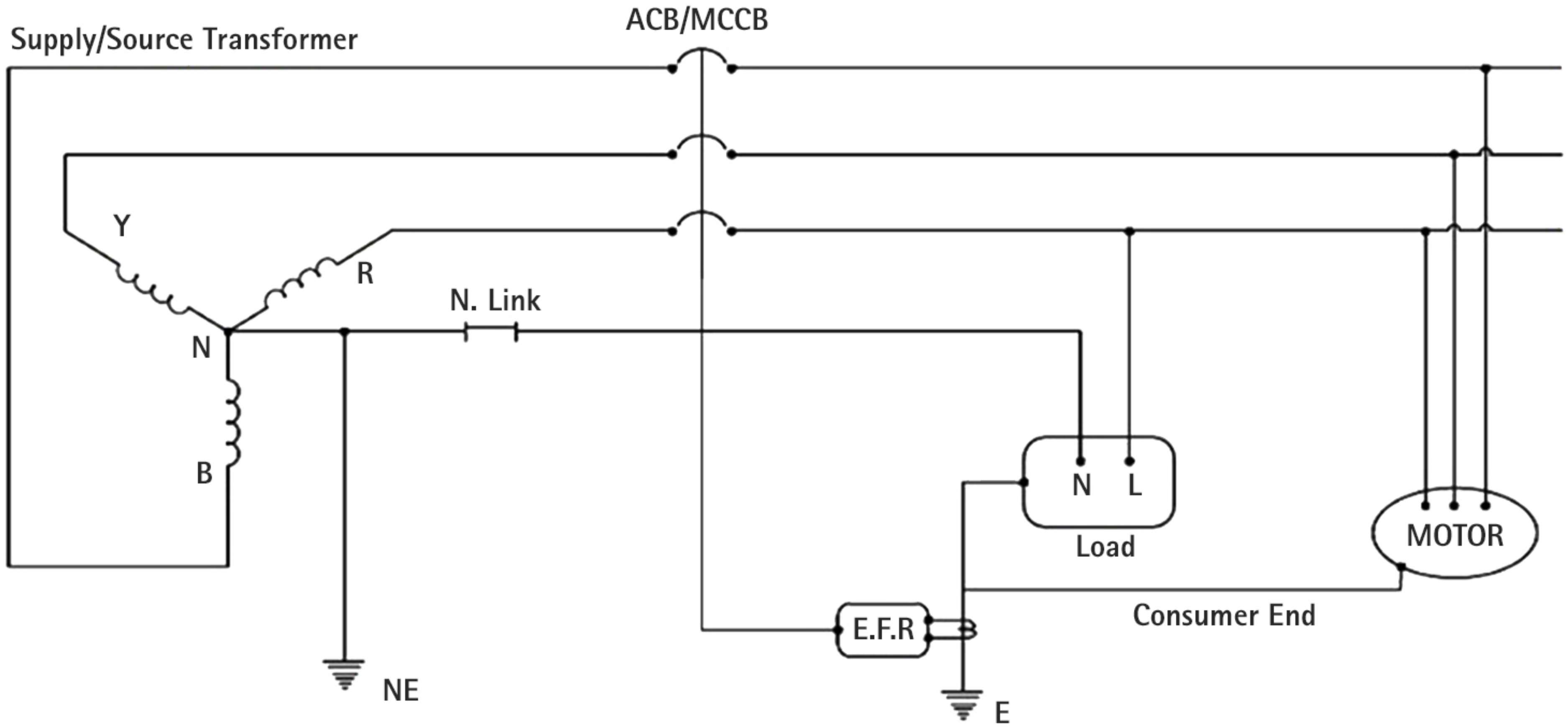


XD is called Main Bonding Jumper. In TN CS system neutral and earth wires are common between star point of supply transformer and main disconnect of consumer. But downstream in consumer's system, they are separate.

Also at D the steel frame of building structure and all metal objects like gas, water pipes, conductive floors need to be bonded together (equi- potential bonding).

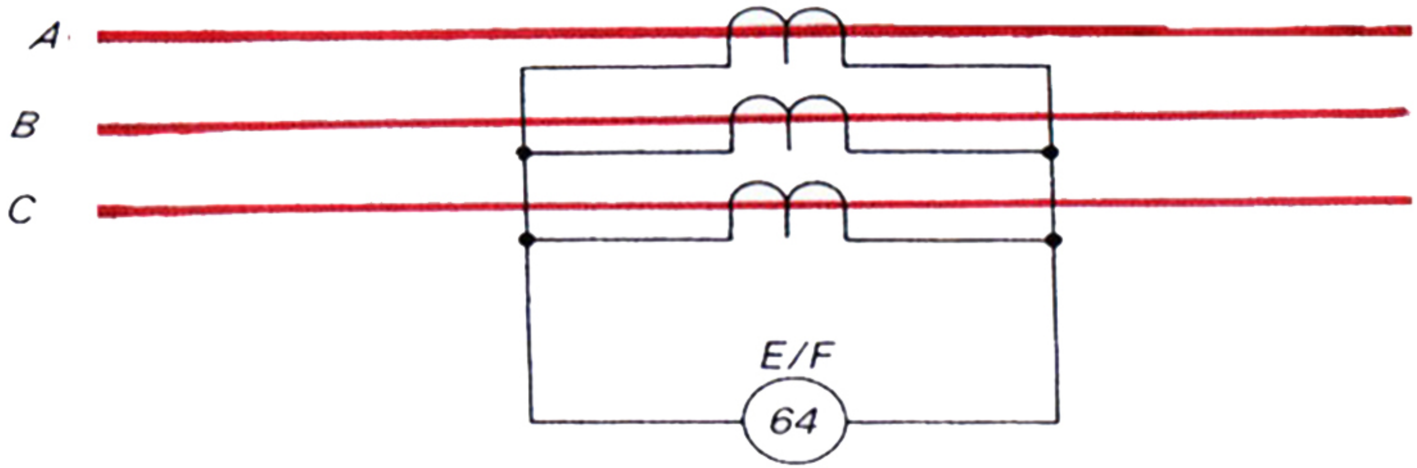
Important TN CS should not be used if Neutral continuity and potential free neutral cannot be guaranteed by supplier. The positioning of neutral CT must be on the main bonding jumper only for the EFP in consumer's ACB / MCCB

3 PHASE 4 WIRE L.V. SYSTEMS
EF PROTECTION IN TT SYSTEMS

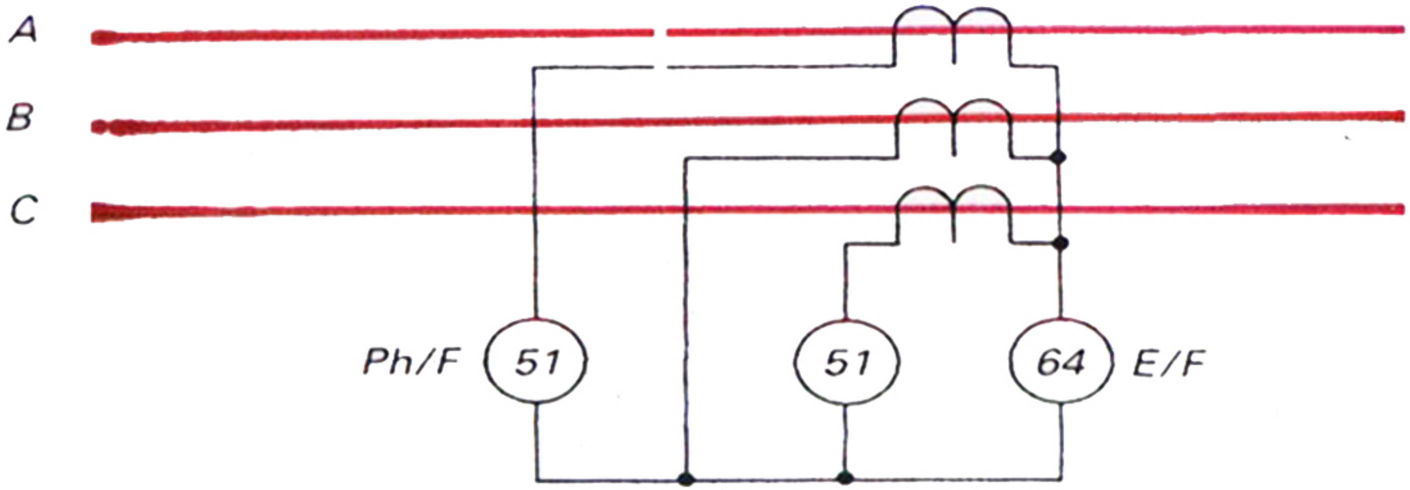


N.C.T - Neutral C.T.
E.F.R - Earth Fault Relay

3 PHASE 3 WIRE H.V. FEEDERS
EF PROTECTION - RESIDUAL CURRENT METHOD



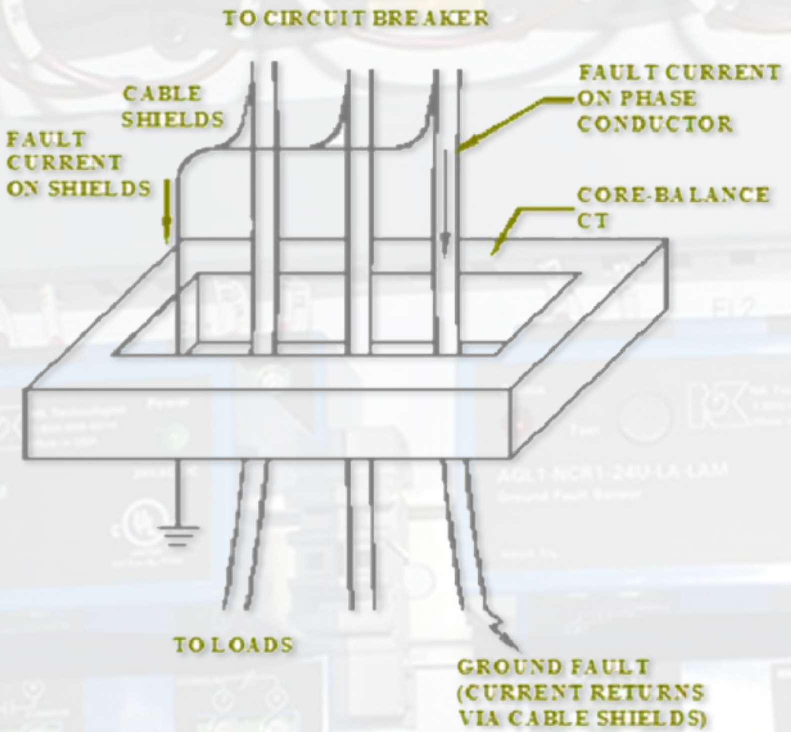
(a) only E/F Protection

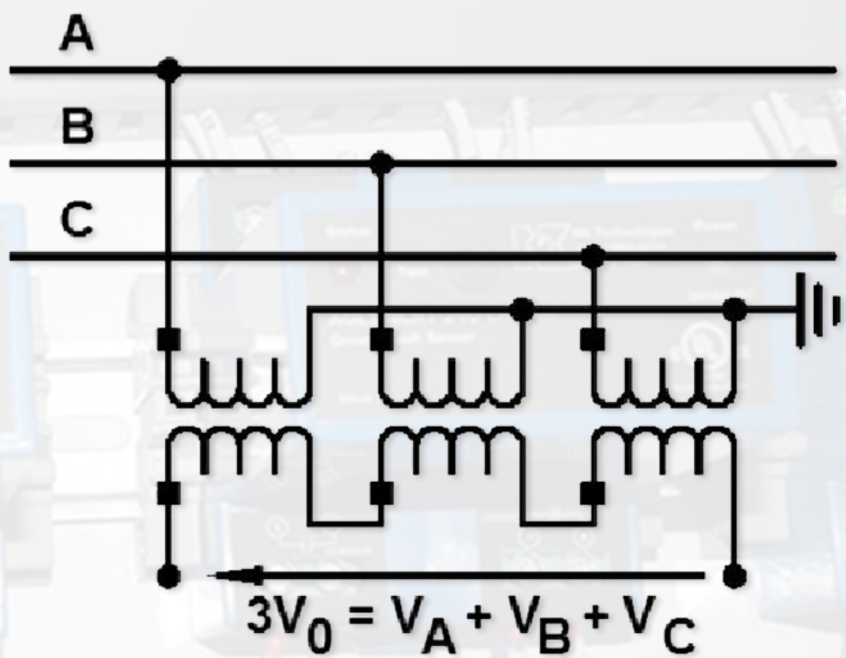


(b) both E/F and O/L protection

GROUND FAULT DETECTION

ZERO SEQUENCE CURRENT TRANSFORMER – CORE BALANCE TYPE





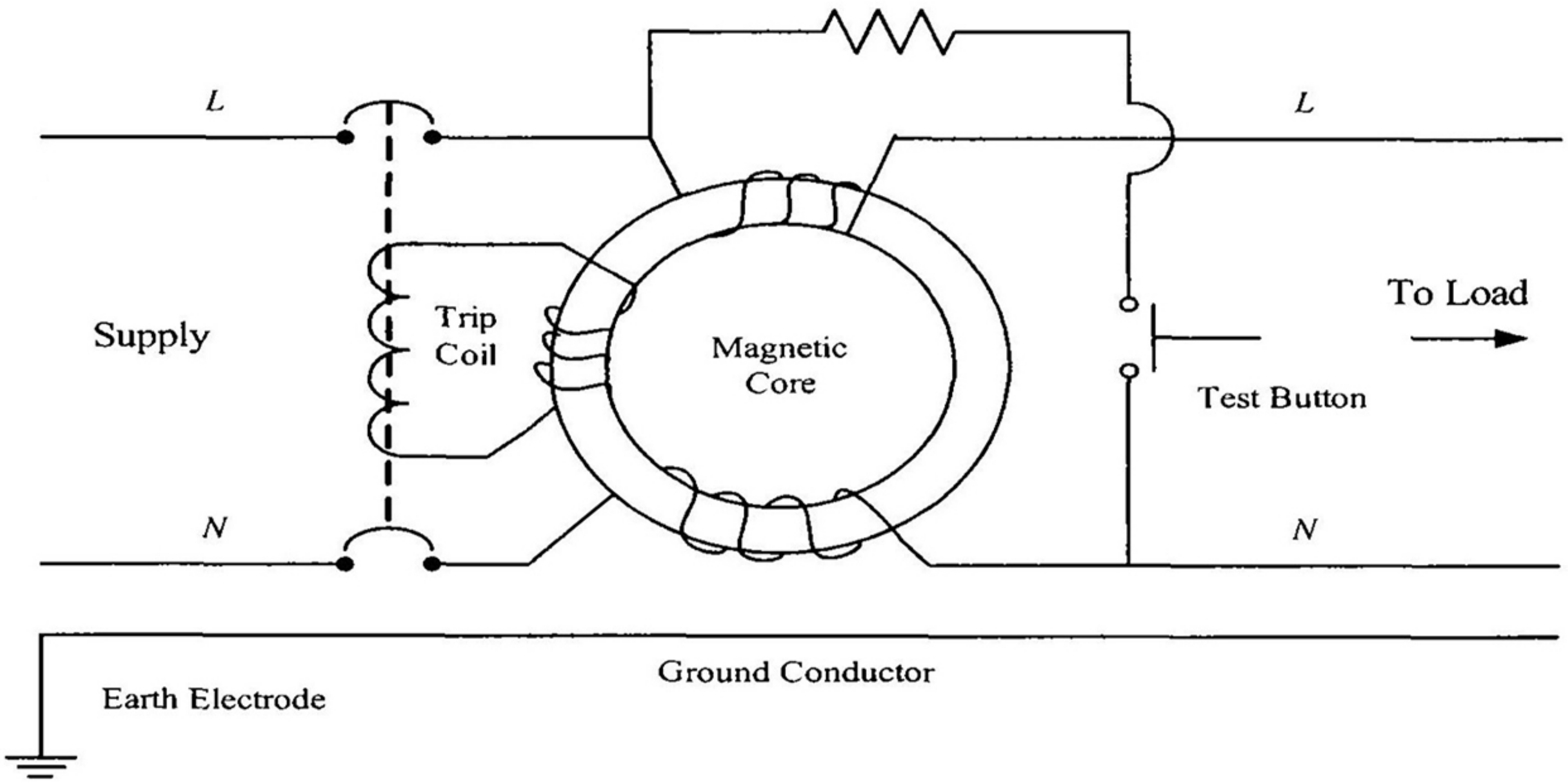
ZERO SEQUENCE VOLTAGE CIRCUIT 3 PTs IN BROKEN DELTA

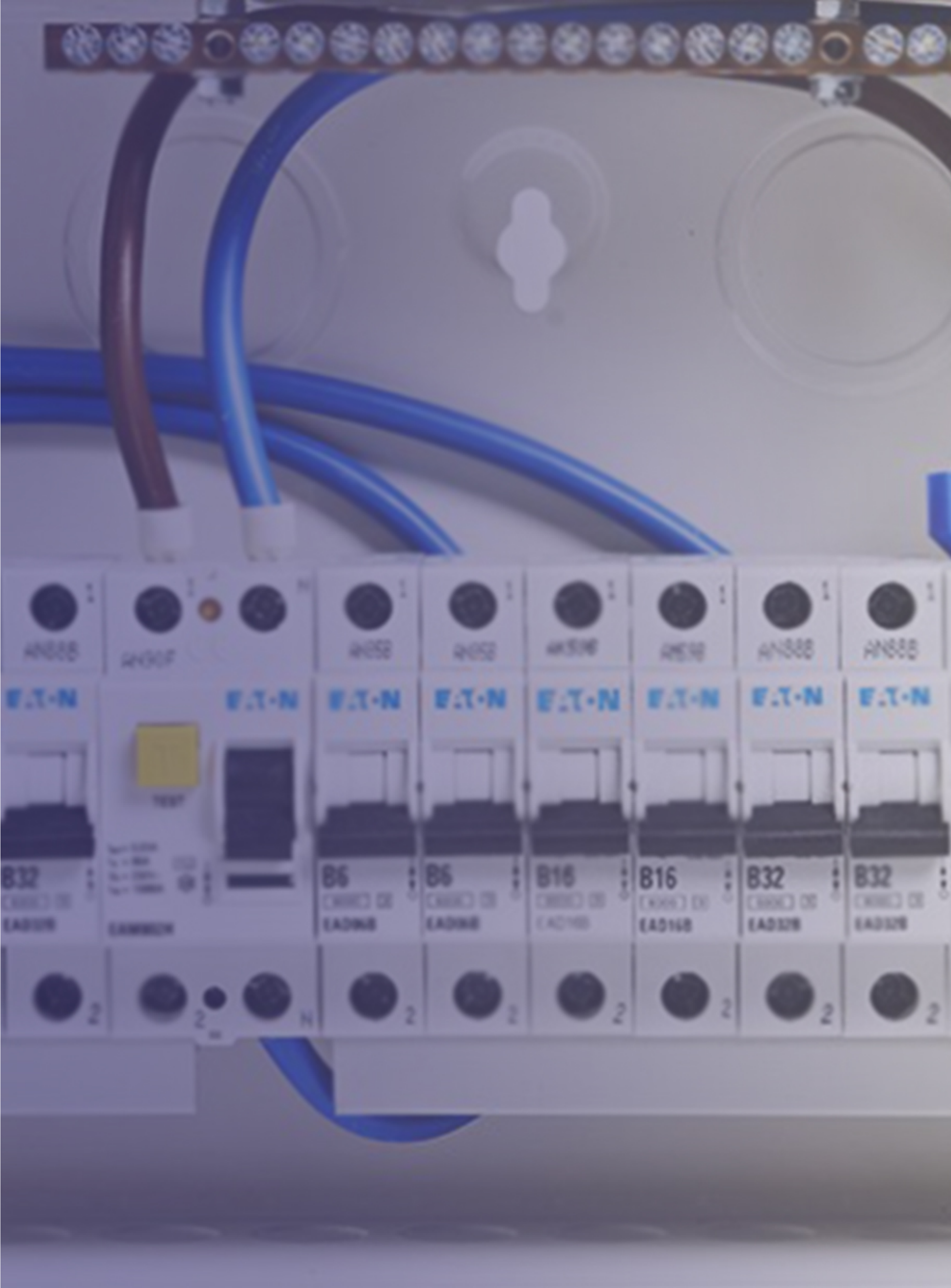
RESIDUAL CURRENT DEVICES (RCDs)

As earth resistance when measured is often found in the field between 10-15 ohms, fault current is low and normal over current protection will not trip when there is an earth fault. An RCD is required in such a situation in TT System. The principle of RCD may be seen in the figure below.

RCD will trip even if the earth resistance is </=50 volts/30 milliamps which comes to 1667 Ohms.

50 Volts is reasonably safe touch voltage and 30 milliamps is the sensitivity of RCD. RCDs help in preventing shocks and fires due to arcing.





RCD (Called GFCI in USA)

Since the introduction of GFCIs by USA's NEC in early 1970s, there has been a dramatic decrease (upto 80 % by 2010) in electrocutions.
As per USA's NEC 2017 GFCI is a mandatory requirement for bathrooms, kitchens, outdoor receptacles.

In India as per Regulation 42 of CEA Safety Regulations it is mandatory to provide a Residual Current Device for earth leakage protection with a sensitivity not exceeding 30 mA for all installations of 1 KW and above.

But over 95 % of homes in India the above provision is not enforced. There is no awareness among even power engineers let alone in general public on the need for an RCD

RCDs RATINGS FOR TRIPPING

- Hospitals 10 mA as per ET214:2005 Irish Guide
- For fire prevention, IEC upper limit 300 mA
- RCD will not work in TN-C Systems
- RCDs will not provide over current protection. Hence MCBs are to be added in series before MCBs.
- General purpose RCD for protection against shock trips in less than 200 milliseconds if leakage current just exceeds 30 mA

NUISANCE TRIPPING BY RCD

RCDs are criticised for nuisance tripping. In electronic equipment for EMI control, input filters using capacitors are connected from line to enclosures. Since enclosures are earthed, a small current of 3.5 mA flows – from line to earth.

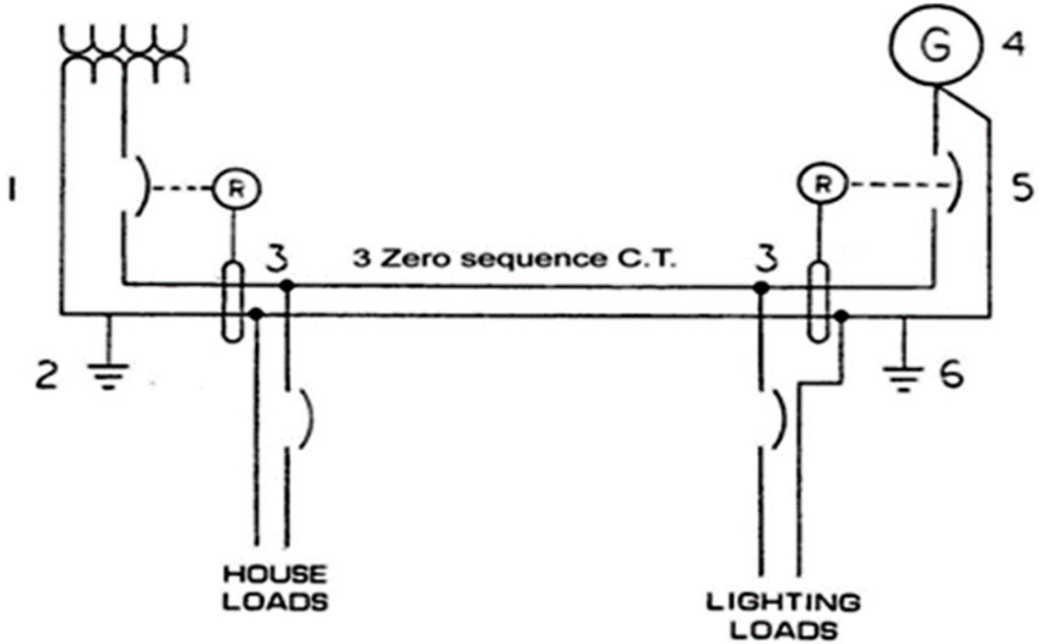
If there are too many such equipment connected from a common RCD the total leakage current can exceed 30 mA and cause nuisance tripping. A solution for the above is to use dedicated RCDs to each of the electronic items and not a single RCD at the main DB.

Nuisance tripping can occur where transient protective devices (TPDs) are used. To overcome that RCDs are put after and not before the TPDs.

CASE STUDY

The System below trips when on Emergency

Two Breakers are inter locked so that only one can be ON



WHAT IS WRONG WITH THE INSTALLATION AND HOW WILL YOU CORRECT THE PROBLEM?

"The return current from load side neutral on emergency supply is not passing through core balance CT."

OHP LINE SNAPPING & FALLING ON GROUND

In such cases, normal overcurrent protection will not disconnect the supply.

This is due to high contact resistance of fault.

Special relays are proposed but their complexity and cost make their use impracticable.

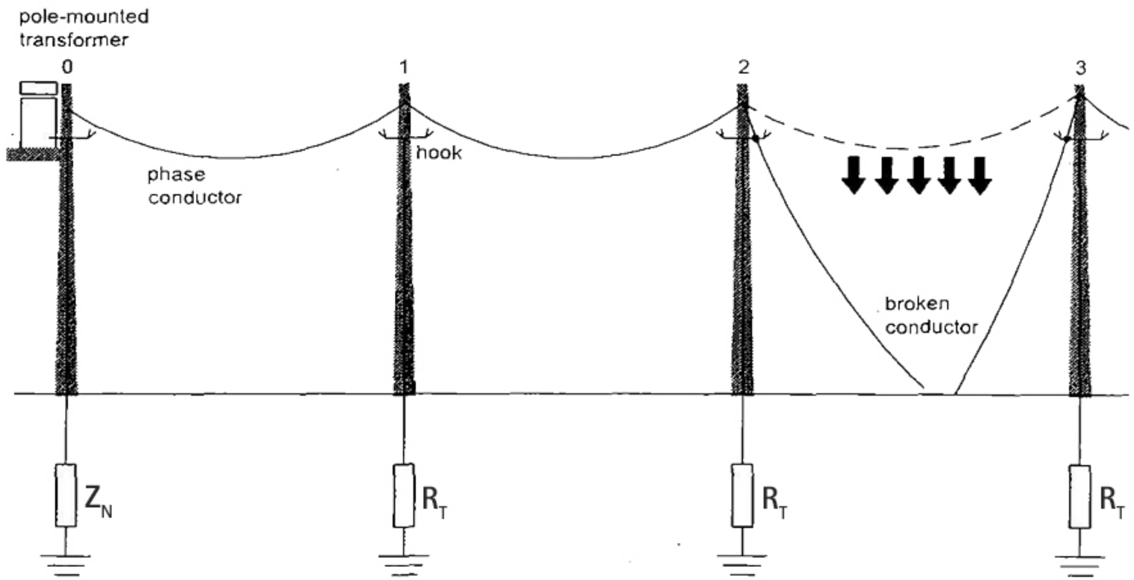
In an IEEE paper, Massimo Mitolo etc. recently proposed a low cost solution for low voltage lines with neutral.

This method consists of fitting metal hooks under the line conductors on the poles and connecting the hooks to neutral.

MASSIMO's PAPER

When a line conductor snaps and falls it contacts the hook and a line to neutral short circuit is created.

- Such a short of high fault current will make the over current device to disconnect supply
- Years ago I am told such a method was tried in Tamil Nadu Electricity Board



Contact between the broken phase conductor and the hook

PART IV

IEEE HYDERABAD SECTION

apqi ASIA POWER QUALITY INITIATIVE

HT SUBSTATIONS & LINES

Hazardous Potential Gradients due to ground faults

Ground Potential Rise (GPR), High potential gradients are created on and around any object in touch with ground when a current passes through it to the ground. Such objects can be earth electrodes, a crane touching a live power line or a de-energised line accidentally getting energised.

GPR is the maximum electrical potential that a substation grounding may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage, GPR, is equal to the maximum earth fault current times the earth resistance

Example:

A 1000 amps ground fault current through a 5 ohms earth resistance causes 5000 volts ground potential rise at the earth electrode. In large Substations the ground fault currents are generally high and GPR can be high. Apart from that people work in the Substations.

REDUCING DANGEROUS POTENTIAL GRADIENTS

- Limiting earth fault currents
- Decreasing earth grid resistance
- Diverting a greater part of earth fault current to other paths like overhead ground wire, metallic sheathing of cable
- Reducing ground fault tripping times

STEP AND TOUCH VOLTAGES

IEEE Standard 80-2006 defines Step and Touch voltages as follows:

STEP VOLTAGE

The difference in surface potential experienced by a person bridging a distance of 1 m with the feet without contacting any grounded object.

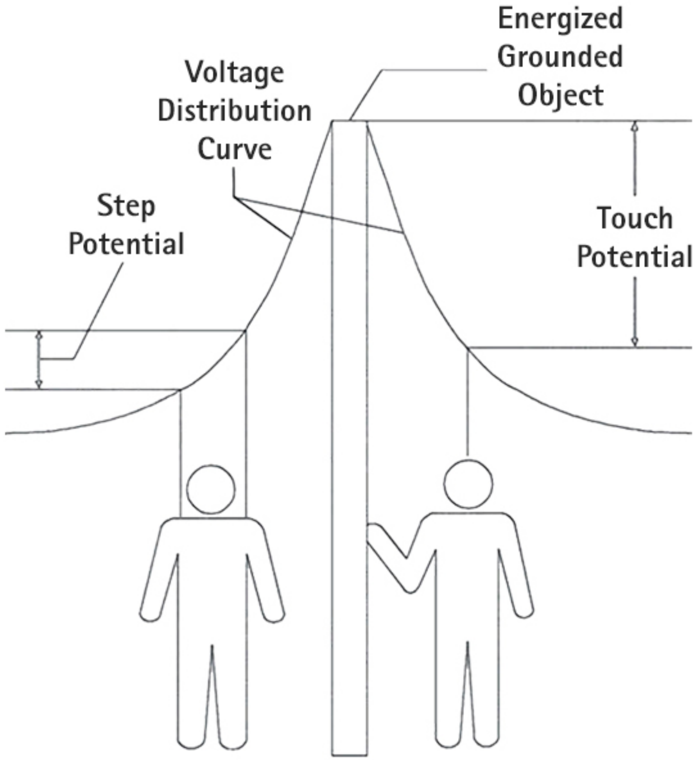
Step voltages can cause fatal electric shocks even when the victim has not touched any earthed object.

TOUCH VOLTAGE

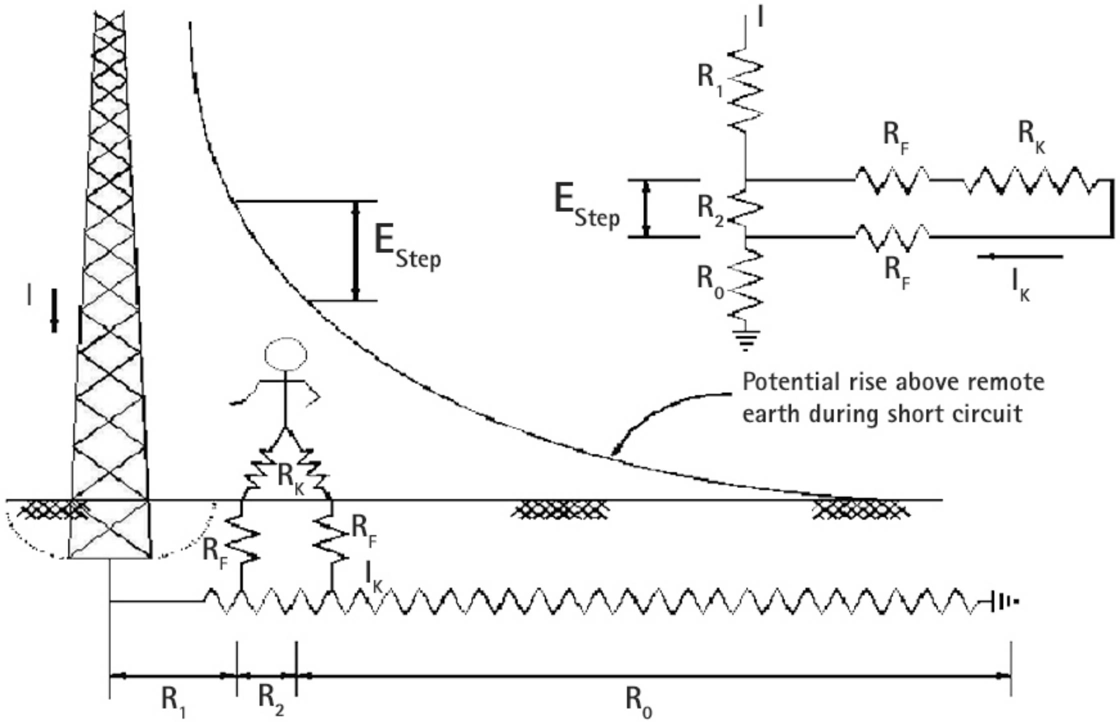
The potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure.

STEP & TOUCH VOLTAGES

Step and touch voltages are more at/near the point of earth fault and decrease as one moves away from that point.



Step Voltage at the base of the line that could be hazardous to the ground worker – IEEE Std 1048-2003



STEP & TOUCH VOLTAGES

National Electrical Safety Code of USA gives the formula for step and touch voltage limits.

$$E_{step} = (1000 + 6\rho) \times 0.116 / \sqrt{t}$$

$$E_{touch} = (1000 + 1.5\rho) \times 0.116 / \sqrt{t}$$

where ρ is soil resistivity in ohm-metres, t is time in seconds for ground fault protection to trip

IEEE Standard 80 – 2006 is the most universally used reference to understand and design the data for reducing/dealing with GPR, Step, Touch, Transferred potentials.

REDUCING THE EFFECT OF STEP/TOUCH VOLTAGES

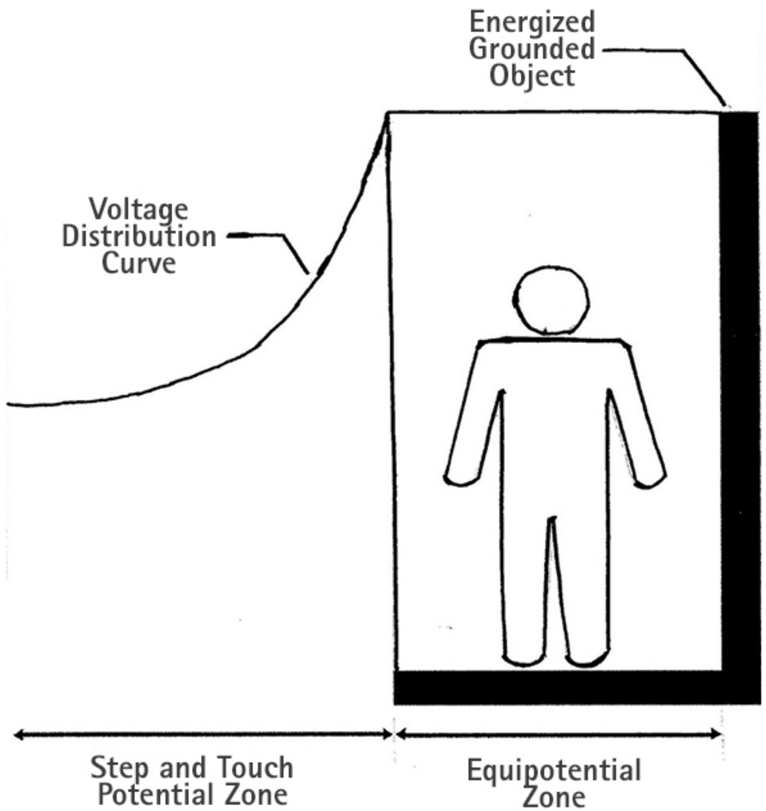
An effective way to reduce the effect of such step and touch voltage gradients is to put top of electrode much below the top soil and using insulated conductor for connecting to the earth electrode.

The voltage gradient over a 2 metre span adjacent a 25 mm diameter electrode reportedly got reduced to 20% when the electrode was buried 0.3 metres below ground level.

Another method is spreading of crushed granite on the soil resulting in high surface resistance even when wet.

PROTECTION FROM STEP & TOUCH VOLTAGES

- Restricting entry to areas where step / touch voltages can arise.
- By using insulating equipment like rubber gloves.
- By creating an equipotential zone.

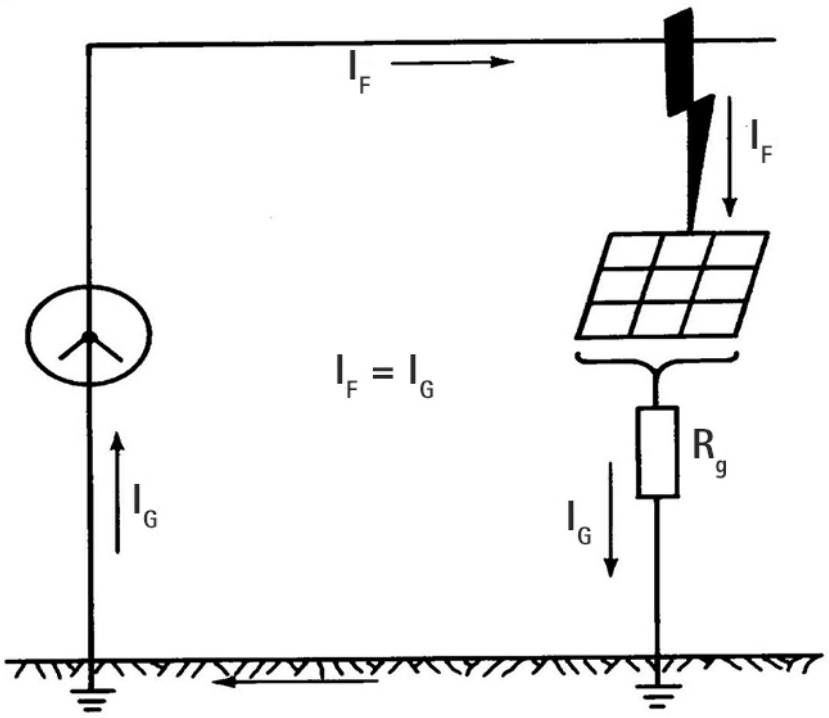


During earth faults, the earth fault currents can produce high step touch potentials in HV Substations even when a large costly earth grid is used. But this grid becomes an equipotential zone and to persons inside this zone, there is no danger of potential differences. But means for safe entry and exit into the Substation have to be provided.

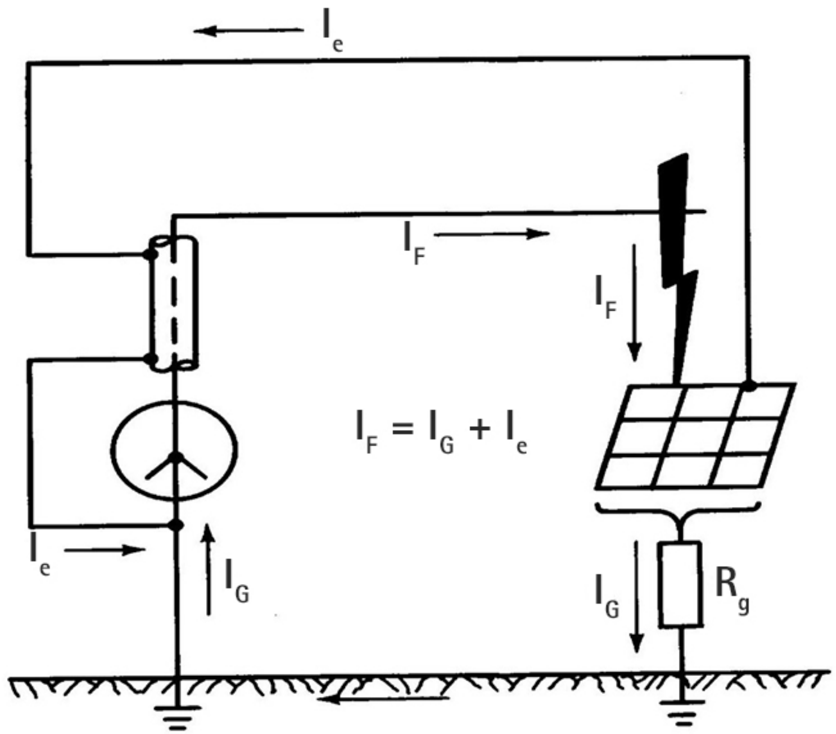
A low substation ground resistance need not mean better safety. An Substation with higher ground resistance can be safer or made safer.
See the figure in the next slide.

PROTECTION FROM STEP & TOUCH VOLTAGES

A low earth resistance alone is not a guarantee for safety or low GPR



(a)



(b)

Most of the ground fault current enters the earth causing a high rise in ground potential in the scheme at left.

But in the scheme at right, a large amount of fault current returns to the source through an external ground wire, metallic sheath or armour as this path offers lower impedance parallel to earth.
In this case the GPR is less.

TRANSFERRED EARTH POTENTIALS

As seen in an earlier slide, earth potential in a substation can rise to 5000 Volts under a line to ground fault. This voltage may be transferred to a non fault location if there is a metallic connection between the two via a communication line or ground wire, metal pipe. These voltages are called Transferred Earth Potentials.

Fatal accidents occurred in India while doing shutdown work on 11 KV lines and when investigated transferred earth potentials from source substation ground fault elsewhere were suspected to be the cause.

PART V

IEEE HYDERABAD SECTION

APQI ASIA POWER QUALITY INITIATIVE

TEMPORARY PROTECTIVE GROUNDING

When working on de-energised lines, voltages may appear on lines due to:

1 **Accidental switching ON**
of isolating device or contact
with any live wire

2 **Electrostatic or Magnetic Coupling**
from adjacent live lines
or lightning

Temporary protective grounding by creating an equipotential zone is used during de-energised maintenance of overhead lines to limit the voltage across the worker due to pt. 1 and 2 above.

All phase conductors including neutral and overhead ground wire, steel, concrete, wood, fibre glass poles are bonded together and grounded. The size and quality of the clamps and wire for bonding and grounding need to be high enough to carry short circuit current.

TEMPORARY PROTECTIVE GROUNDING

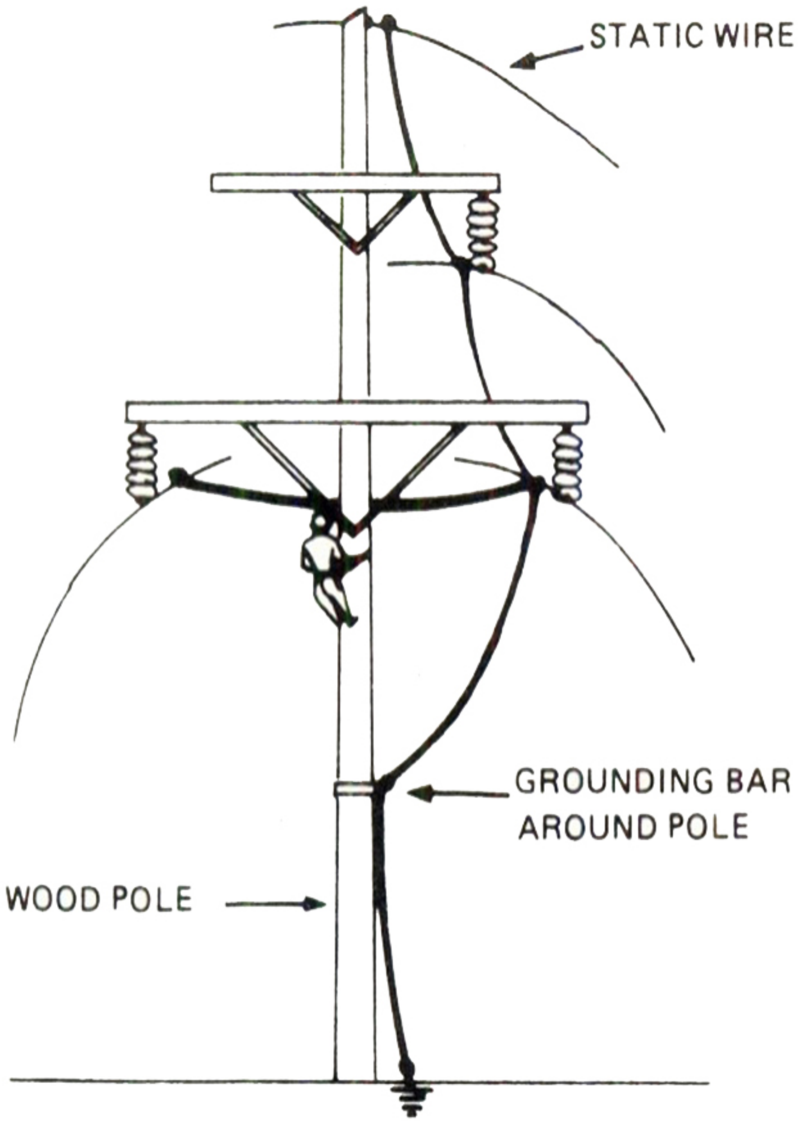
A temporary protective grounding (TPG) is an assembly consisting of clamps, cable of large enough size and low resistance especially the joints, so that the voltage to which a worker is exposed is low and safe. The TPG must be inspected and tested periodically, and before each use.

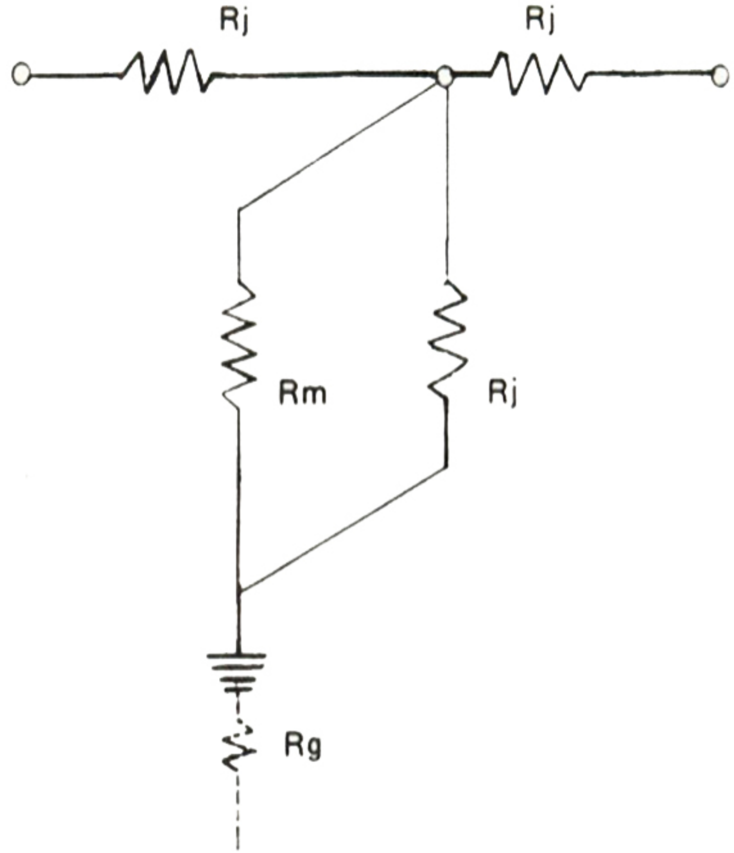
Refer IEEE Std 1048-2016 Guide for protective grounding of power lines.

Before starting maintenance the procedure is, first connect the ground end of TPG followed by connection to conductor or equipment to be grounded.

After maintenance work is over and before re-energising line, the sequence is reverse - remove line side of the protective earthing first and then remove ground end connection.

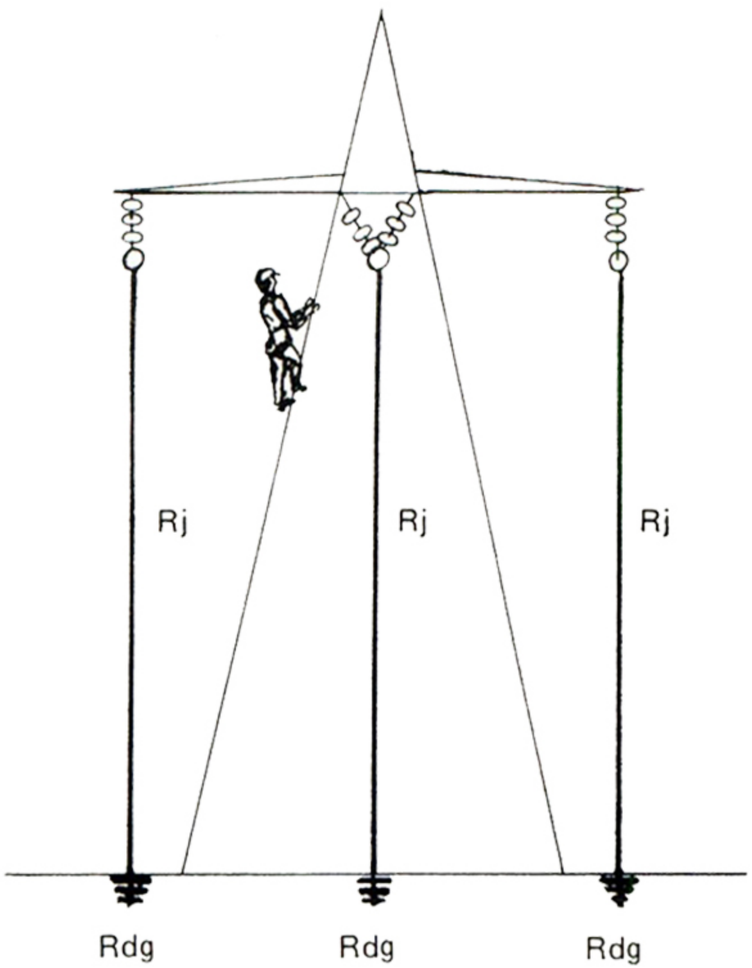
PREFERRED TEMPORARY PROTECTIVE EARTHING - NFPA 70B



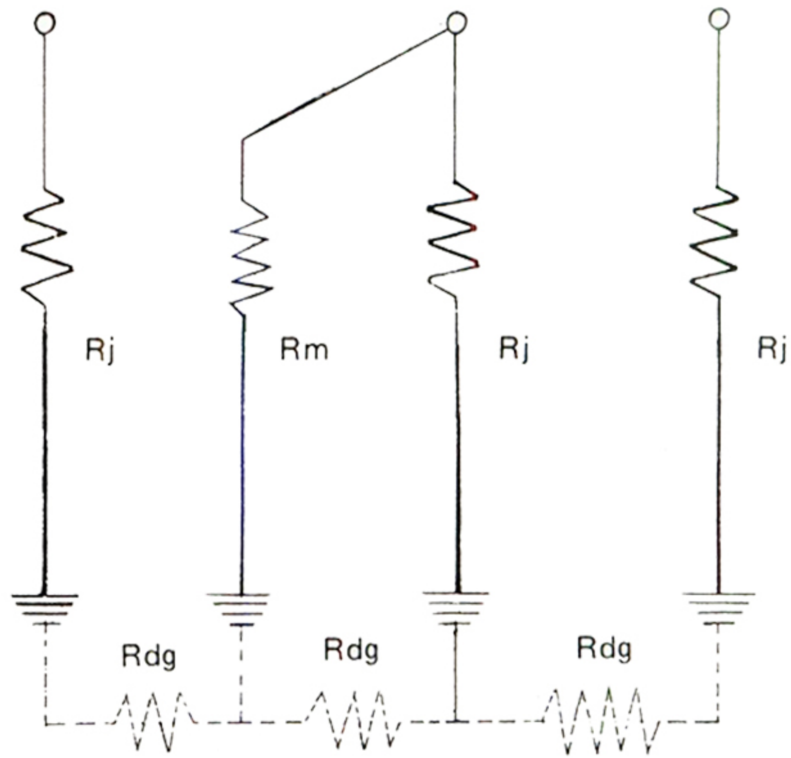


ELECTRICAL EQUIVALENT

NON PREFERRED TEMPORARY PROTECTIVE EARTHING - NFPA 70B



Driven grounds

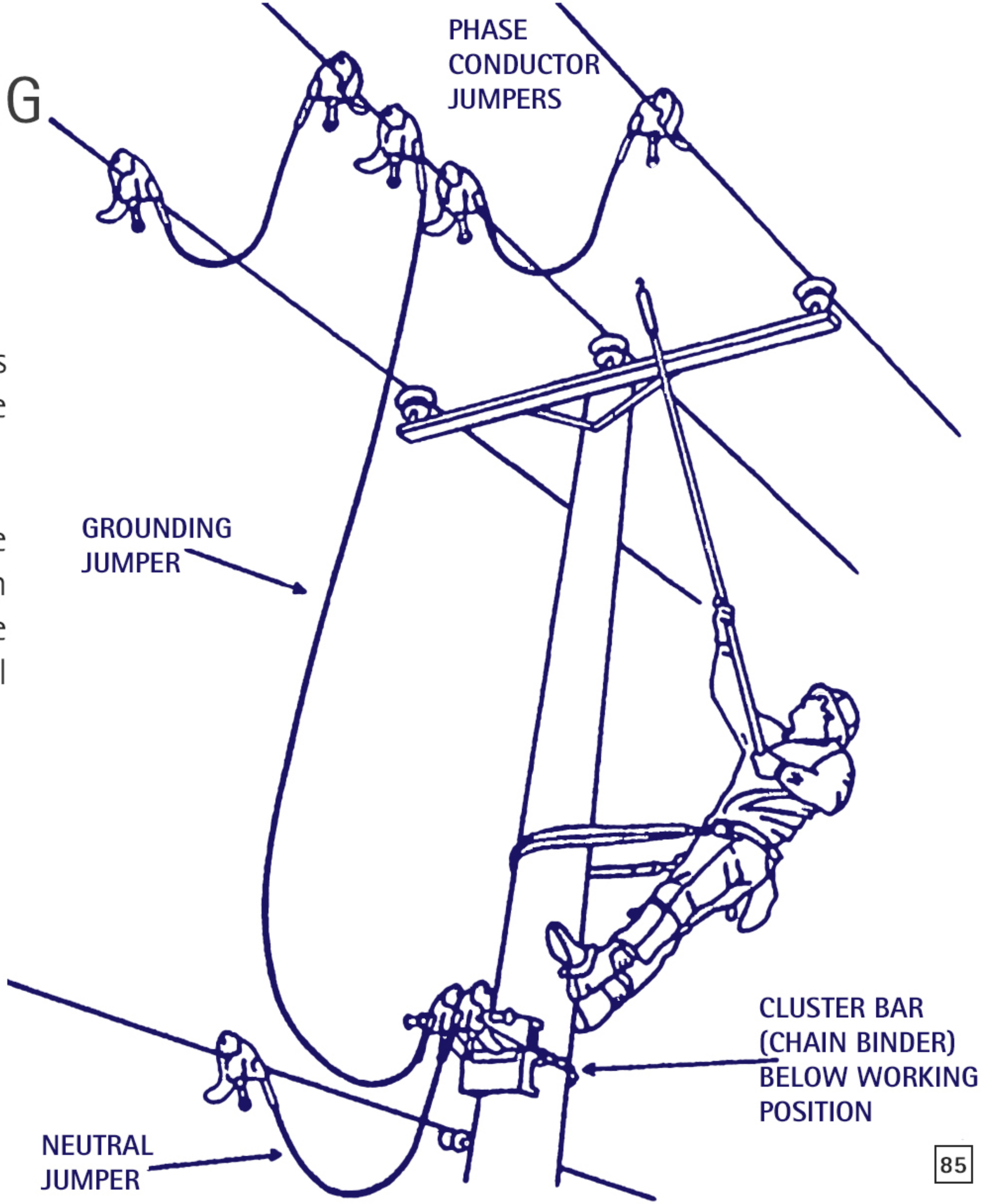


ELECTRICAL EQUIVALENT

PROTECTIVE GROUNDING WHILE DOING MAINTENANCE

Protective grounding for distribution lines should be accomplished as shown in the Figure.

The grounding cluster bar must be positioned just below the lowest elevation of the lineman's feet for the work zone and shall be bonded to the neutral conductor and pole ground lead.



REFERENCES

- IEEE Standard 3003.1 and 3003.2 Recommended Practices for System earthing & equipment earthing
- IEEE Standard 80-2006 Guide for safety in A.C. Substation grounding
- IEEE Standard 1048-2016 Guide for protective grounding of power lines
- Indian Standard 3043-2018 Code of Practice for Earthing
- OSHA 1910.269 Appendix C Protection from hazardous potential differences
- IEEE Standard 1100 – 2005 Recommended Practice for Powering and Grounding of electronic equipment
- Massimo Mitolo, "Electrical safety of low voltage systems", McGraw-Hill 2009
- Elya B Joffe, Kai-Sang Lock, "Grounds for Grounding" IEEE Press 2010
- IEC Standard 60364-5-54 Electrical Installations of Buildings - Earthing

Thank You

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IEEE HYDERABAD SECTION

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* The health benefits claimed may not be scientific.

In a lighter vein -

Go Bare Foot in the Park
And Earth Your Body for Health Benefits*