Grounding and Earthing
of
Distributed Control Systems and Power Electronic Systems

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Chapter 1

Introduction

Improper grounding or earthing of “Distributed Control Systems (DCS)” or “Power Electronic Systems (PES)” can result in either mal-operation of the system / controller or failure of electronic control cards or sometimes even the embedded control software getting erased. Similarly, a bad quality of power supply also can cause similar damage.

Bad quality of power supply is usually associated with parameters such as large voltage / frequency variation, transients, sustained sags or swells, large voltage distortions, brown outs or blackouts. Similarly, bad quality of grounding / earthing is associated with large ohmic resistance of earth, improper connections from earth to the system / its cubicles, improper ratings of earth bus bars and cables, and finally the improper philosophy adopted for grounding and earthing.

While, the Power Electronic Systems (PES) handle low to high powers based on different applications, the Distributed Control Systems (DCS) handle relatively low powers or rather require low power for their functioning. However, the proper power quality, grounding and earthing become the necessity for their smooth functioning. These factors define their required availability, reducing the downtime substantially.

Apart form the Power Quality; the other important factor to be noted in this connection is the Electro Magnetic Interference (EMI) or Noise. The EMI or noise is more predominant in case of Power Electronic Systems as compared to the Distributed Control Systems. The Power Electronic Systems generate EMI or noise and can affect other electronic equipment in vicinity. On the other side, the Distributed Control Systems are more vulnerable to EMI or noise effects and can easily mal-operate due to its presence.

It is hence imperative to discuss the power quality, EMI, actual grounding and earthing, and philosophy of grounding and earthing in that order. This document hence is arranged in the same order and should form a proper guide for grounding and earthing of “Distributed Control Systems (DCS)” and “Power Electronic Systems (PES)”.

References [1] – [7] used for preparing this document are given at the end of this document.

Chapter 2

Power quality requirements

The commercial ac supply usually could be three-phase or single-phase, 50/60 Hz. The three-phase supply neutral needs to be firmly earthed in order to see that the equipment does not accumulate any floating or electrostatic charges.

There is always a ground plane, which passes through the neutral point, dc bus mid point, the motor neutral point, and neutral point of both ac side filters (if they are used). It balances both ac sides correctly like a two pan weighing balance. If neutral is not earthed, the balance and the symmetry are lost.

The power supply can have voltage transients (dips or sudden voltage rises / spikes), voltage variation (sag or swell), frequency variation, voltage distortion, and interruptions (brownouts or blackouts). It is hence necessary to protect the DCS and PES from such poor-quality parameters.

As far as PES are concerned, normally the design will take care of most of these parameters and also islanding in safe operating region, especially during brownouts or blackouts. However, it is essential to have adequate protection against transients or especially surges passed on from the incoming supply to the equipment. An appropriate surge suppressor network (Shunt R-C combination across the supply in case low kVA ratings and a diode rectifier dc capacitor based surge suppressor for higher ratings) hence needs to be employed in the PES. In case of DCS, an appropriately designed shunt R-C network across the incoming single-phase power supply is adequate to protect the system.

It is always a good practice to have the power supply to the "Distributed Control System (DCS)" or for the "Power Electronic Systems (PES)" obtained from a separate isolation transformer. The isolation transformer helps in reducing the impact of transients. The transformer should be installed as near as possible to the equipment.

The PES does operate with higher incoming voltage distortion (as, many times, these are designed for handling higher distortions such as 6 to 8%). However, such is not the case with DCS. For DCS, the recommended voltage distortion on load should not be more than 2.5%. To achieve this the DCS should make use of UPS of adequate capacity and installed as near as possible to the DCS.

The primary source must be free from non-repeating power interruptions greater than 20 milliseconds. Otherwise, it can cause loss of data, control, or erase the control software and cause mal-operation of the system. Normally, an UPS will not cause such interruptions.

Line conditioners or EMI filters, as described later, can be used while supplying power to the DCS or Control Electronics of the PES.

Chapter 3

EMI mitigation

Electro Magnetic Interference (EMI) is caused due to many electrical equipment or apparatus. Examples could be as below.

- Sudden change in cable currents (as observed when large rating motors start, especially on direct on-line)
- Switching frequencies other than the normal power frequency and associated sidebands
- Transformer inrush currents
- On / off control of current carrying power contactors, breakers, and solenoids
- Sudden loads being thrown off from the supplies

The sudden changing fields or even strong fields associated with the large power currents cause electromagnetic fields, which can cause circulating currents in other relatively small current carrying conductors in the vicinity and alter the electrical information. The EMI effect can hence cause mal-operation of near by small kVA equipment.

There are two important aspects of the EMI. First aspect is related to reliable functioning of electronic equipment in a given EMI environment developed by by equipment in vicinity. This is called as susceptibility. The other aspect is the acceptability level of generated EMI. This is called as acceptable emission level. These are governed by the IEC standards in series 61000.

Without getting into much detail, it is at least necessary to understand that PES should function with acceptable emission levels (as the power levels are high) and DCS should function with acceptable susceptibility levels.

In case of PES, normally the controls and cubicles are designed in such way that emission is kept at minimum. The cubicles function with internally taken care of EMI to see that the PES function properly. In case of DCS, major care needs to be taken in respect of the supply connections. The power supply cables should be routed away from motor or transformer or for that matter high current carrying power cables. The same is also valid or applicable for the field signals received or transmitted by the DCS. The UPS supplying power should be kept as near as possible to the DCS. Shielding of the signal wires with shield connected to the grounding bus bar (and hence to earth) at one end, gives reliable operation. The supply cable distance to DCS should be kept as minimum as possible. The grounding inside the cubicles and subsequent proper grounding and earthing of the cubicles helps in achieving proper performance against the EMI. It is also better to use field signals as current signals (0 to 20 mA or 4 to 20 mA) instead of low-level voltage signals (such as 5 V signals). This improves the immunity against the EMI. Particularly in DCS, which is low kVA sensitive equipment, it is better to use isolation transformers with three screen windings for internal power distribution (as discussed subsequently) and also for the incoming power supply. Such an isolation transformer is shown in fig. 1.

It is also necessary that EMI filters be used as part of the 24 V or 15 V or 5 V Switch Mode Power supplies. This offers necessary immunity, against the EMI, to the regulator cards or the control electronics.

Chapter 4

Grounding and earthing understanding

The basic difference between grounding and earthing is that when the system is grounded, it is still not connected to earth. The system has a ground bus bar inside or outside located at an appropriate place to which all internal grounding connections are returned. Once the final ground bus bar is connected to an actual earth pit or earth grid that the system gets finally earthed.

As an example, in a typical PES there could be many cubicles. Each cubicle can have an internal grounding bus bar to which internal components such as power module, shields of various input / outputs, fans, controller power supply transformer screens, cores of electrical components like power inductors etc. are connected. These bus bars then are returned to a final ground bus bar from where the connection is then taken to earth pit or earth grid.

Similarly, in case of DCS, each cubicle can have a ground bus bar to which the controller chassis, shields, transformer screens etc. can be connected. These bus bars then are returned to a final ground bus bar from where the connection is then taken to earth pit or earth grid.

The earth pit must have a very small earth resistance (much less than an one Ohm). Usually, the earth resistance can be measured by using a three-probe method as shown in fig. 2. The voltage here is applied between probes E and P, and the current is measured in the loop E, C, and in between earth path. The resistance is then calculated by using Ohm's law. The current should be accurately measured using milliampere meter.

Table -1 gives distances between probes E and P and probes E and C against the depth of ground probe at point E. For more details, please see the reference [7].

Table -1

Depth of ground rod at E	Distance between E and P	Distance between E and C
6 ft (1.83 meters)	45 ft (13.72 meters)	72 ft (21.95 meters)
8 ft (2.44 meters)	50 ft (15.25 meters)	80 ft (24.4 meters)
10 ft (3.05 meters)	55 ft (16.76 meters)	88 ft (26.82 meters)
12 ft (3.66 meters)	60 ft (18.3 meters)	96 ft (29.26 meters)
18 ft (5.5 meters)	71 ft (21.64 meters)	115 ft (35.05 meters)
20 ft (6.1 meters)	74 ft (22.56 meters)	120 ft (36.6 meters)
30 ft (9.15 meters)	86 ft (26.21 meters)	140 ft (42.7 meters)

Chapter 5

Overall recommendations for grounding and earthing

These recommendations are summarized as below.

- Use a separate power distribution system for each location containing the control systems. This needs to be strictly adhered to.

- Use good regulated power supply with distortion less than 2%. Tap the highest available power system voltage for feeding the isolation transformers used for electronics. If this is not possible, use UPS for supplying the power supply loads (control electronics in Power Electronic controllers and power supplies in Distributed Control Systems). However, keep the distance between UPS and the load to minimum or locate it locally.

- The power supply should be free from non-repeating interruptions greater than 20 milliseconds. Otherwise, it can cause loss of system data, damage to embedded software, and finally mal-operation of the control systems.

- Isolation transformers are recommended because they provide good line regulation and transient filtering.

- Use proper surge suppressor devices after the isolation transformers to feed the power to the control systems. EMI filters also need to be used to avoid common mode noise injected into the control systems.

  UPS with isolation transformer(s), surge suppressors, and EMI filters helps in deriving the proper power supply for the control systems.

- The signal and other control cables should run separately away from ac power lines, transformers, rotating electrical machines, solenoids, and other high power equipment. The recommended separation distance between signal and power cables is given in Table-2 below.

Table-2 (Recommended separation distance)

Voltage	Current	Minimum separation distance
0 to 125 V	0 to 10 A	30 cms
125 to 250 V	up to 50 A	38 cms
250 to 440 V	up to 200 A	46 cms

Note: For higher currents, the distance can be extrapolated with safety factor of 1.3.

- The signal wires should be shielded and the shield should be connected to earth only on one side.

- As far as power supply connectors are concerned, avoid ac and dc connections coming to the same connectors, especially in case of I/O boards. If not avoidable, use sufficient separation (skip few of the ways).

- Grounding and earthing: There are four layers required for proper and effective grounding and earthing. First is the "Dedicated Plant Earth Grid (G4)", second is "Control System Ground (G3)", the third is "Isolated Common Ground Reference (G2)" for local area, and the fourth is " Isolated Local Ground (G1)".

  Refer fig. 3 now.

  The "Isolated Local Ground (G1)" is where dc power supplies, internal power component enclosures, etc. are grounded on a bus bar. This refers typically to one control system.

  The "Isolated Common Ground Reference (G2)" is where the "Isolated Local Ground (G1)" connection from each of the control system in that area is terminated along with the frame or cabinet or over all enclosures are individually terminated for grounding. It should be noted that the enclosure grounding minimizes the effects of EMI.

  The "Control System Ground (G3)" is where the incoming power supply isolation transformer secondary is grounded along with the ground connection obtained from the "Isolated Common Ground Reference (G2)". This "Control System Ground (G3)" is considered as the final earth pit for that location.

  The "Control System Ground (G3)" or the final earth pit is then finally terminated on the "Dedicated Plant Earth Grid (G4)".

The “Dedicated Plant Earth Grid (G4)” may or may not exist. If exists, it is supposed to have the lowest earth impedance and is considered as the most stable ground or earth. It consists of many earth pits connected in a grid fashion.

All grounding connection lengths should be kept as minimum as possible. The cables to be used for grounding should usually be green (with yellow marks), should be made of maximum number of strands (rather than a single conductor), and the sizes should be as given below as in Table -3.

Table -3 (Earth connection cable sizes)

Up to 25 feet / 3.281 meters (≈3.3 meters)	**50 mm^2**
Up to 50 feet / 6.562 meters (≈6.6 meters)	**70 mm^2**
Up to 200 feet / 26.25 meters (≈26 meters)	**120 mm^2**

The size is also based on the incoming power supply conductors or cable size. Thus, between the two (power supply conductor or cable size and the size as per above Table –3), the size of earth connection cable should be selected based on whichever is of higher size.

Similarly, the ground bus bars to be used should be copper bus bars, with approximately 10 mm as the thickness and 50 mm as the width.

It is also important to note certain aspects in relation to effective grounding. These are to be considered as guidelines.

The “Control System Ground (G3)” or the final earth pit connected to the local control systems should be a separate earth pit, which then can be connected to the “Dedicated Plant Earth” system. This “Control System Ground (G3)” should not be shared with other plant systems.

Further, a high-quality ground should provide a ground point that measures much less than one ohm to the true earth.

If it is not possible to get the required resistance (particularly in cases where earth grid is not available), more than one pits need to be constructed and then paralleled to obtain the required earth resistance.

The field wiring cable shields should be terminated on shield bars, which are to be used along with the I/O carriers. These shield bars then should be connected to the “Isolated Ground References (G2)” and / or then to separate earth pit.

Chapter 6

Grounding and earthing of Distributed Control Systems

The Distributed Control Systems usually consist of following.

- Incoming 110 V AC, 50 Hz, single-phase supply normally obtained from UPS (please see the note at the end for 240 V single-phase AC supply)
- Controller and related housing panels / cubicles
- I/O's communicating with field equipment. These are also called as Field / instrumentation input / outputs
- Operator workstation

Grounding and earthing recommendations

- Overall recommendations to be adopted are as discussed earlier in Chapter 5.

- UPS: The UPS supplies power to the system at one location or sometimes two systems at different locations. This needs to be avoided. It should supply power to only one location. The UPS should be as close to the system as possible. The system load determines the kVA of the UPS and usually at one location it does not exceed 50 kVA. The UPS voltage distortion on no load (without system connected) should be less than 1% and on load it should not exceed 2.5%. Usually, the UPS has an inbuilt step up isolation transformer whose secondary side is 110 V ac. This is the supply taken for the control system. Cables from the UPS should be traceable, should run separately with proper separation distance in case required with respect to near by other power cables, and the neutral can be grounded provided isolation transformers are used after the Power Distribution Boards, as discussed later. The UPS body needs to be separately earthed, as shown in fig. 4.

- Power Distribution Boards: In each location, there are many panels / cubicles receiving the UPS power through these Power Distribution Boards. From these boards, further power distribution takes place to derive +24 V dc, and other dc regulated voltage required for the controller and I/O's. Isolation transformers (refer fig. 1(a)) of low kVA ratings need to be used to distribute the power supply to the DC power inputs. One terminal of the primary side of these transformers is connected to one screen, core is returned to earth and one of the terminals of the secondary is then connected to the second screen. Refer fig. 1(b) for the connections. One isolation transformer can supply power to one or two regulated dc power supplies.

- DC power supplies of SMPS type take isolated inputs as they have inbuilt EMI filters. The isolation transformers supply this power.

- The grounding and earthing scheme required is now shown in fig. 4. The individual components of the control system cubicles / panels are grounded to an “Isolated Local Ground (G1a)”. These components are chassis of power supplies, DIN rails of the controller, secondary side screen of the isolation transformer, etc. Since the power ratings are small, the cubicle / panel frames also can be connected to this ground. The operator station is connected to a separate “Isolated Local Ground (G1b)”. The field input shields are also connected to a separate and another “Isolated Local Ground (G1c)”. These grounds G1a, G1b, and G1c are basically isolated ground bus bars.

  Grounds G1a and G1b are now connected to another ground (ground bus bar) called as “Isolated Common Ground Reference (G2)”. The two grounds G2 and G1c are now connected to separate earth pits, which could be called as “Control System Grounds (G3a and G3b)”. The “Isolated Common Ground Reference (G2)” is defined here for the sake of convenience. However, it is not absolutely necessary. The two grounds G1a and G1b can be connected directly to G3a and the ground G3c is then connected to G3b.

  In case proper Earth Grid is available in the vicinity, the grounds G3a and G3b should be connected to this Earth Grid, called as “Dedicated Plant Earth Grid (G4)”.

- <u>The connections from grounds G3a and G3b to Earth pits 1 and 2 and are also to the “Dedicated Plant Earth Grid (G4)”, as shown in fig. 4, should be with aluminum bus bars. The minimum size should be 100 mm * 12 mm. If split bus bar is used (two numbers of bus bars instead of a single bus bar), each will have half the cross section (100 mm * 6 mm). This is preferred.</u>

- From fig. 4 the most important aspect to be noted is that all connections terminating on G1 grounds and finally terminating in “Dedicated Plant Earth Grid (G4)” are all radial connections.

- Usually, the UPS will have an output transformer delivering isolated single-phase ac power to the DCS system. The secondary of this transformer is available with ungrounded two wire cables. When new UPS is to be ordered, it is better to order it with mid point connection also available from this secondary. The mid point then can then be directly terminated on "Control System Ground (G3a)" in fig. 4. The neutral then gets earthed further through this ground G3a. The mid point grounding of the neutral gives the necessary ground plane symmetry as discussed in Chapter 2.

Note:

- If the single-phase AC supply is 240 V (or higher) and is derived from an UPS, the isolation transformer secondary voltage will be 110 V AC or as is necessary for the DCS to operate. Other technical treatment remains same as that for single-phase, 100 V AC supply.

Chapter 7

Grounding and Earthing of Power Electronic Systems

Most of the Power Electronic Systems (PES) involve an input converter or converter inverter set feeding power to dc or ac motors or acting as shunt converters. Typically, the system will take input power from a transformer or may be connected on the same ac power supply bus on which other power electronic systems are already present. Each system will have power electronic power modules (along with cooling system), controller, control logic (which can be an integral part of controller many a times), ac–dc switchgear and finally the load as the motor.

Depending upon the system or the drive rating, there may be a dedicated transformer or there may not be a one. There is also a possibility that many systems may exist in one location simultaneously. These could be from one manufacturer or from different manufacturers.

Accounting the scenario above, the earthing recommendations are given below.

Grounding and earthing recommendations

- Overall recommendations to be adopted are as discussed earlier in Chapter 5.

- The grounding and earthing scheme is as given in fig. 5.

- As far as possible, the system should receive isolated power as shown in fig. 5. The isolation transformer (separate from one used for control power supply) provides necessary isolated power and dedicated grounding and earthing for the Power Electronic / Drive System. As given in fig. 5, inside components of one given system (such as power modules, controller chassis, power supply chassis, cooling fans etc.) should be connected to an "Isolated Local Ground (G1a)". This is applicable to each system. The cubicles / panels are connected with each other and returned to a ground called as G1b, as shown in the fig. 5. The two grounds G1a and G1b are now connected to one ground reference called as "Isolated Common Ground Reference (G2)". This ground G2 is now connected to an earth pit, which is called as the "Control System Ground (G3a)". The incoming neutral of the power supply can be connected to this ground G3a (in case it is not earthed near the transformer. Preferably, it should be earthed near the transformer in a separate earth pit). The neutral should be sized based on minimum of half the rated line current rating.

In case proper Earth Grid is available in the vicinity, this ground G3a should be connected to this earth grid, called as “Dedicated Plant Earth Grid (G4)”. If the motor is placed near the drive, the motor body / frame should then be connected to this ground G3a. if not, then it should be connected to a separate “Control System Ground (G3b)” (as a direct and radial earth connection). It should then be returned to “Dedicated Plant Earth Grid (G4)”, if available in the vicinity and as discussed above.

If there are more than systems present in a location, one earth pit can be used to connect few of the systems based on the collective ratings. Large rating drives and associated motors should have separate “Control System Grounds (G3’s)”. All of them can then be returned to “Dedicated Plant Earth Grid (G4)”, if available in the vicinity.

- The cable connecting the inverter and ac motor (in case of VFD’s) should be an armored cable. It should be a three-core cable with symmetrically place current carrying conductors and three ground conductors, symmetrically embedded in it. The armor should be of corrugated aluminum. The armor and the ground conductors should be earthed at both ends (drive as well motor end). These end earth connections from the armor and ground conductors, and the motor frame / enclosure earthing connection should be returned separately / radially to the “Control System ground (G3a)”. If the motor is not near to the drive, then the armor earth connection and the motor frame / enclosure earthing connection should be returned separately / radially to “another” “Control System ground (G3b)” as shown in fig. 5.

- The incoming isolation transformer body or frame should be connected to a separate “Control System Ground (G3c)” and this then should be connected to a separate earth pit as shown in fig. 5. This Earth pit connection can now be returned to “Dedicated Plat Earth Grid (G4)”, if available in the vicinity. <u>The connections from grounds G3a, G3b, and G3c to Earth pits 1, 2 and 3 and also to the “Dedicated Plant Earth Grid (G4)”, as shown in fig. 5, should be with aluminum bus bars. The minimum size should be 100 mm * 12 mm. If split bus bar is used (two numbers of bus bars instead of a single bus bar), each will have half the cross section (100 mm * 6 mm). This is preferred.</u>

- From fig. 5 the most important aspect to be noted is that all connections terminating on G1 grounds and finally terminating in "Dedicated Plant Earth Grid (G4)" are all radial connections.

- Some reference to the VFD switching frequency versus cable length specification is given here in Table -4.

Table -4 (VFD switching frequency versus cable length specifications)

Switching frequency	Maximum cable length
1 kHz	60 meters
3kHz	50 meters
12 kHz	30 meters

The lower switching frequency also reduces the EMI effects considerably. Higher cable lengths also produce reflecting voltage waves. LC filters on the output side of the inverter allow increased length of the cable. Refer [2] for the same.

Chapter 8

Checklist for Distributed Control Systems (DCS)

- Confirm the UPS capacity is adequate from factory.
- Check that the UPS no load and on load voltage distortion is less than 1% and 2.5% respectively.
- Check as to how far the UPS is located from the DCS. It should be within less than 20 meters.
- If the same UPS is feeding two locations, check the capacity is adequate from factory and the no load and on load distortion is less than 1% and 2.5% respectively. Further check that both the DCS stations are in the vicinity of 20 meters.
- Check that cables from UPS are routed separately and are not in vicinity of any other power cables. The safe distance in from other power cables should be as per Table –2.
- Check that all the signal wires received from field are shielded and are grounded as in fig. 4. Further check that these wires are not in vicinity of any power cables. If so, the separation distance should be as per Table –2.
- Check that the grounding and earthing scheme is as per fig. 4 and all connections to grounds and to earth are radial as explained in Chapter 6.
- Check that the earth connecting bus bars from grounds G3's to earth pits and the earth grid G4 are sized as given Chapter 6.
- If the UPS has three-wire output (from secondary of its internal output transformer), the center-tapped connection should be taken to earth Grid as shown in fig. 4.
- Check that the earthing resistance is much less than one ohm for all the earth pits as discussed in Chapter 4.
- Check that there is an earth inspection schedule agreed and drawn for future use.

The site is now ready for further process of commissioning.

Chapter 9

Checklist for Power Electronic Systems (PES)

- Check that the incoming power to the PES is coming from an isolation transformer and that its neutral is earthed as shown in fig. 5.
- Check that transformer capacity is adequate for the PES and that voltage distortion at the Point of Coupling is within acceptable limits (less than 2.5%).
- Check that cables from transformer are routed separately and are not in vicinity of any other signal cables. The safe distance for the signal cables from the transformer cables should be as per Table –2.
- Check that all the signal wires received from field are shielded and are grounded as in fig. 5. Further check that these wires are not in vicinity of any “other power cables”. If so, the separation distance should be as per Table –2.
- Check that the grounding and earthing scheme is as per fig. 5 and all connections to grounds and to earth are radial as explained in Chapter 7.
- Check that the earth connecting bus bars from grounds G3’s to earth pits and the earth grid G4 are sized as given Chapter 7.
- Check that the earthing resistance is much less than one ohm for all the earth pits as discussed in Chapter 4.
- Check that there is an earth inspection schedule agreed and drawn for future use.

The site is now ready for further process of commissioning.

References

[1] David Brown, David Harrold, and Roger Hope," Control Engineering: Control system power and grounding better practice," published by Elsevier Inc., 2004.

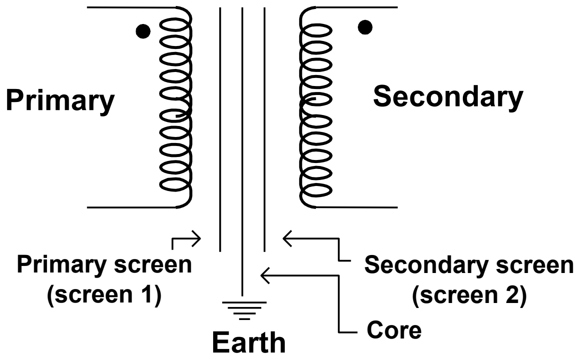
[2] IEEE standard 1100-2005: Recommended practice for power and grounding sensitive electronic equipment.

[3] IEEE standard 518-1982: Guide for installation of electrical equipment to minimize noise inputs to controllers from external sources.
Note: IEEE now has withdrawn this standard.

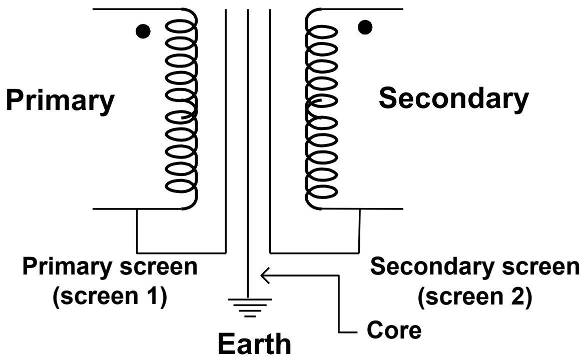
[4] IEEE standard 142-1991: Recommended practices for grounding of industrial and commercial power systems.

[5] IEEE standard 81-1983 and 81.2-1991: Guide for measuring earth resistivity, ground impedance, and earth surface potentials of a ground system.

Annexure -
Figures for Earthing and Grounding of DCS and PE systems



(a) Isolation transformer with screens



(b) Isolation transformer with screen connections

Figure 1: **Isolation transformer**

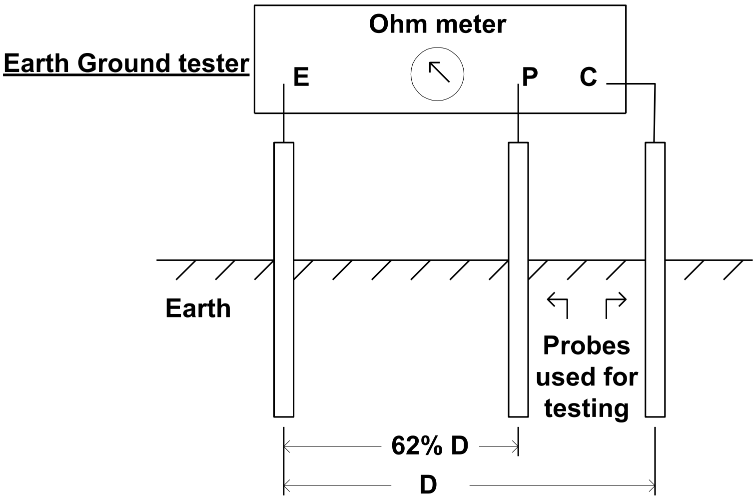


Figure 2: **Earth resistance measurement**

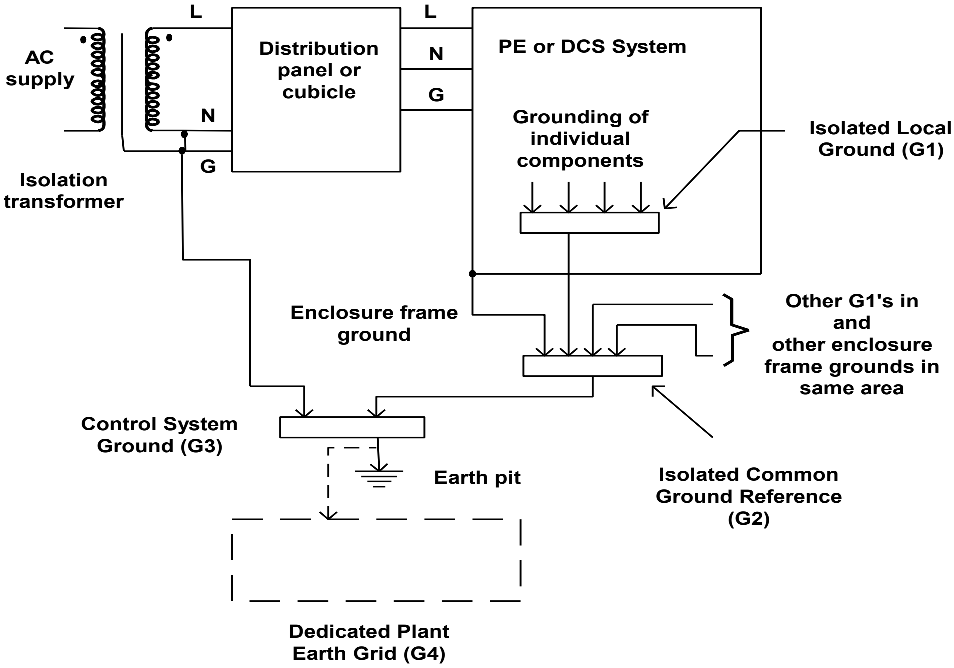


Figure 3: **Typical distribution system with grounding and earthing definitions**

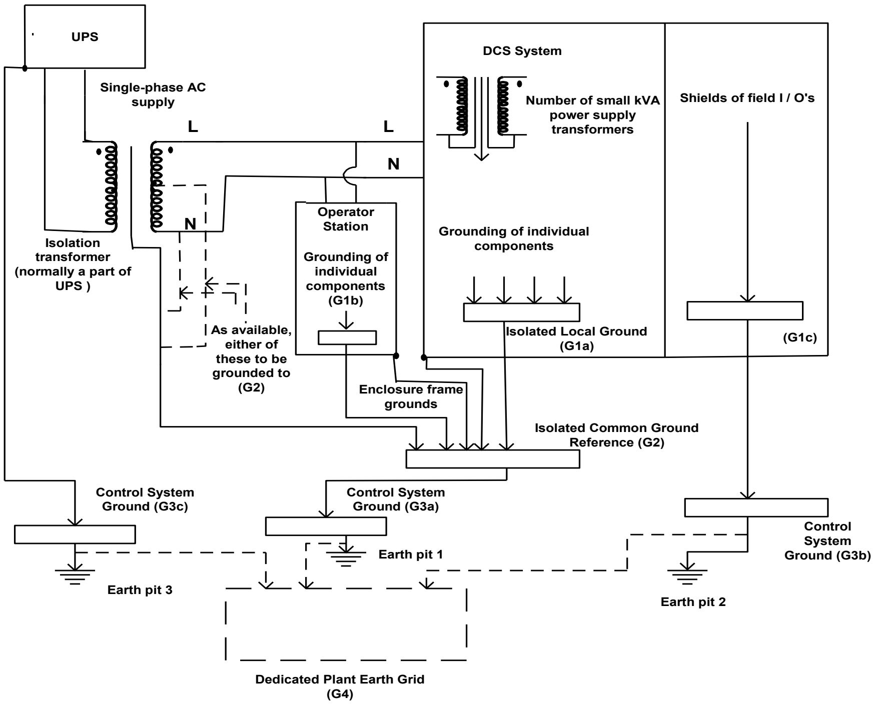


Figure 4: Grounding and earthing scheme for Distributed Control Systems

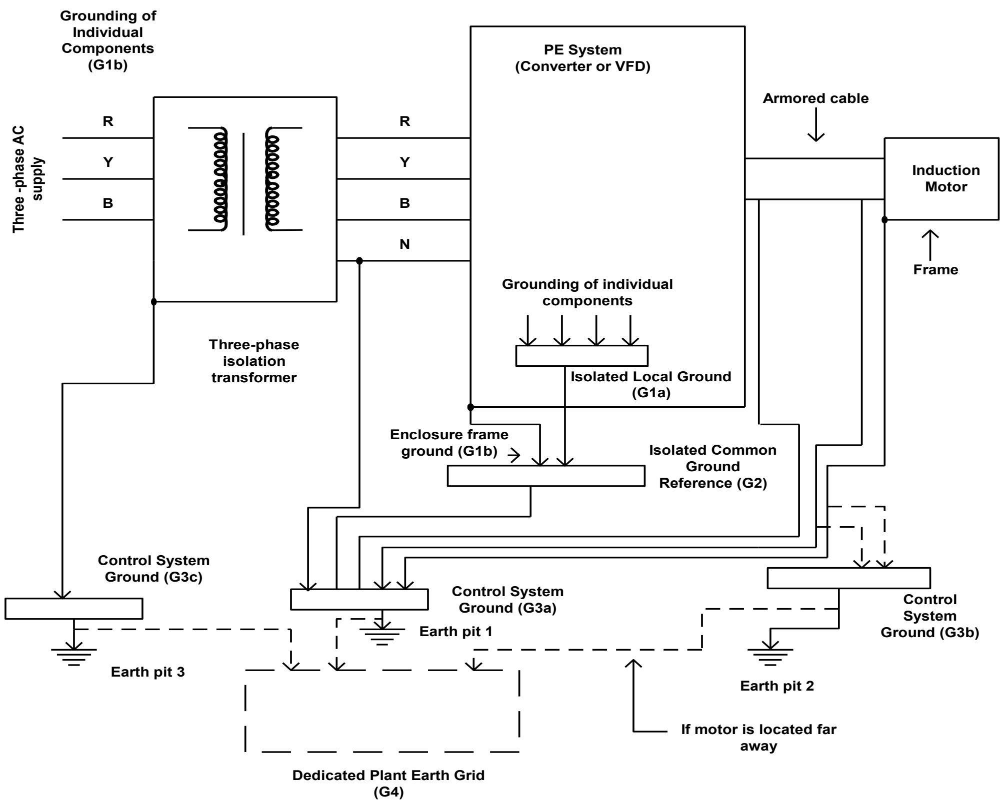


Figure 5: Grounding and earthing scheme for Power Electronic Systems