# Guidelines for Earthing in UPS installations

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## 1. Introduction

Sensitive loads like computers, servers etc requires a continuous and quality supply in order to avoid data loss and to afford safety of such sensitive loads. This is accomplished by making the continuous availability of UPS supply in normal mode and the availability of raw power sources like transformer or generator in bypass mode when there is a prolonged power outage or when the UPS supply has become faulty.

This is achieved by the provision of a changeover of supply using an interlocking arrangement between the raw power sources like transformer and generator for making the continuous availability of raw power supply at the bypass circuit of the UPS so that the UPS can automatically transfer its loads to such a raw power supply source.

As the interlocking arrangement involves the mandatory avoidance of mixing of phase as well as neutral between the different raw power supply sources, there is a likely-hood of momentary open neutral condition. Further any inadvertent neutral opening at the raw power source for test purpose or due to fault is also possible. Since this situation will harm the phase to neutral loads fed by UPS due to any unbalance in three phase loading, the integrity of the neutral should always be ensured for the UPS loads. Hence such a change-over arrangement practiced between the different raw power sources can not be adopted between the UPS and the bypass supply. That is why the neutral of the raw power should be permanently connected to the neutral of the UPS circuit in order to achieve the integrity of the neutral. However, this method causes a minor circulating current which may raise to an objectionable level. Isolation transformers are therefore required to be introduced in the bypass circuit and UPS output circuits to address these issues effectively.

Though the introduction of isolation transformers involving various configurations in the bypass and UPS output greatly enhances the performance and safety of the other upstream installations and personnel, the method of neutral and earth connections shall vary according to the type of configuration**. In this article, basic principles and the method of connections are explained for the widely used configurations based on the standards, regulations and more importantly, the IEEE 1100 and IEEE 446 standards.**

## 2 Factors influencing requirement of isolation transformers

Requirement of isolation transformers in an UPS circuit is decided on the basis of the following factors:

i) Preference of an isolation transformer in the bypass circuit and in the output circuit after the UPS, is decided on weighing the options between the economy and performance based on the sensitiveness of the loads fed from the UPS.

iii) Necessity of an isolation transformer in the bypass circuit and in the output circuit after the UPS, is decided depending upon the neutral to earth voltage and effectiveness of TNS type earthing of the raw power source.

iii) Necessity of isolation transformer when the source earthing is not a TNS type earthing, for the avoidance of circulating current in the neutral circuit which could affect the earth fault/ELCB devices in the upstream circuits.

v) Avoidance of open neutral condition at any point of time for protecting the UPS loads.

## 3 Commonly practiced earthing systems

In order to apply the correct measures, it is first necessary to understand the type of earthing and secondly the source as to whether it is a separately derived source or a non-separately derived source, should be understood.

The type of earthing adopted in most cases is TNS as depicted by the following figure:

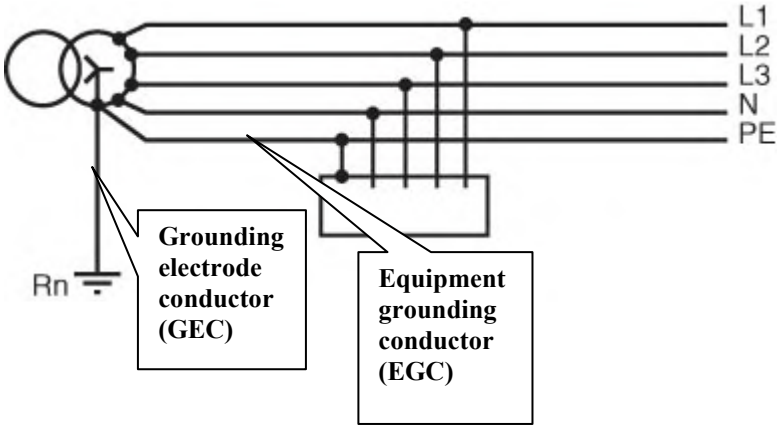


**Fig:1 TNS Earthing System**

In the TNS system earthing, the source neutral is connected directly to the earth electrode near the source itself. This neutral should not be connected to earth at any other location in order to avoid circulating currents due to multiple neutral earth connections. The frame of the equipments are connected to an earth bus which is brought up to the source and bonded to the neutral earth connection at a single point. This single point bonding minimises the neutral to earth potential rise. Another advantage is the availability of sufficient earth fault current to actuate the over current protective device for the earth faults in view of the low earth fault loop impedance.

Another type of earthing system preferred, especially, by the industrial consumers is TT system as depicted by the following figure:

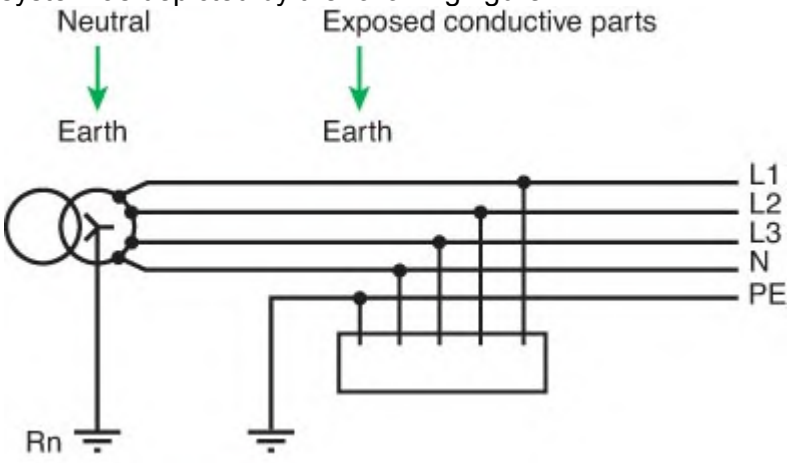


**Fig.2 TT Earthing system**

In this system, the fault current reaches the source through the general mass of earth since there is no direct connection between the neutral and equipment earth connection. In this case the fault loop impedance will be higher than that of the TNS system and hence the fault current will be lower than that of the TNS system for the actuation of the over current protective device for earth faults. However, this problem is overcome by the ELCBs etc. Since discrimination can be comfortably achieved between successive fault clearing devices, power supply outages on healthy feeder during faults are minimised.

In reality, the TT system unintentionally ends into an imperfect TNS system in view of the practice of interconnections between the body and neutral earth electrodes of the source which is in turn connected to the equipment earth bus through the cable armour or body of the bus duct which emanates from the source.

The other types of earthing systems are not discussed here since any type of earthing shall have to be ultimately converted into a TNS system in UPS installations.

## 4 Separately derived and non-separately derived sources

When supply to a circuit is derived from a source like transformer, generator, UPS etc (having its own neutral) and has no direct electrical connection to any supply conductor (including a connection to the solid neutral earth connection) of another supply source, it is called a separately derived supply. A separately derived source shall become a non-separately derived source once its neutral is solidly connected to the neutral of another source.

In the Separately derived and non-separately derived sources, the neutral earthing point and its interconnection with the body or a nearby earth electrode among the different sources are governed by the following factors:

Separately derived sources are always interlocked using four pole change over switch gears for avoiding mixing of neutral also along with the phase conductors. Hence a momentary open-neutral condition will exist during changeover which would harm the loads connected to the UPS during the bypass mode. This situation should be avoided by creating a neutral by means of an isolation transformer at the bypass circuit and connecting it permanently to the neutral of the UPS output. **This neutral point should be bonded to the body of the UPS and connected to its own nearby earth electrode** close to the UPS itself. The body earth connections of the UPS loads should be brought up to this combined body-neutral earth connection at this single point. The neutral conductor should not be provided with any other earth electrode at the downstream load side in order to avoid circulating currents. This arrangement results into an effective TNS system earth at the UPS itself.

In small installations like domestic or small office use etc where economy is considered relying an effective TNS system earth which is normally closer and easy to access by the user, isolation transformer can be avoided at the bypass circuit. In such cases, integrity of neutral is ensured by connecting the UPS neutral solidly to the neutral of the source which is already connected as an effective TNS earthing system. **In this situation, the UPS which is actually a separately derived source will become a non-separately derived source. Hence the neutral of the UPS should not be connected to the body of the UPS.** All the body earth leads should be connected to the earth bus which is in turn brought up to the source neutral earth connection point.

## 5 Creation of Circulating currents

In the following figure, the neutral of two separately derived sources are interconnected and then connected to earth electrodes in a TNS system at both the source ends (we may assume the on-site generator source as UPS and transformer source as raw power).

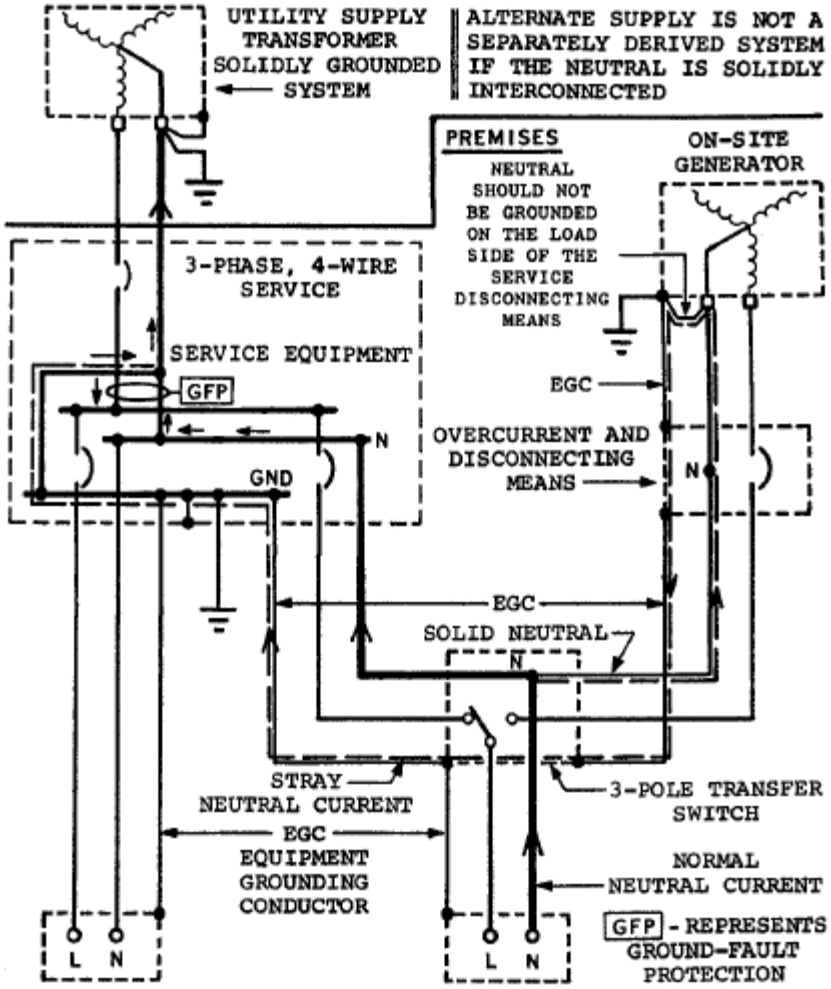


**Fig.3 Stray Neutral Current Circulation when both the neutral conductors are interconnected and earthed at both ends**

It can be seen that the neutral current reaches the raw power source in two different paths (the value may depend upon the impedance offered by the paths) when the load is fed by raw power. One path is directly to the raw power source through the circuit feeding the load and the other path is through the neutral of the generator/UPS(assumed) and body earth conductor. This results in to a circulating current which creates a neutral to earth potential. Further, a differential current is also created in the neutral core of the other circuits in the upstream of the load which will trip the ELCB and affect the performance of the earth fault relay provided at the raw power source end. This situation will get worse if there is an unbalanced load or harmonics. **In order to avoid this situation, TNS system earthing is adopted using neutral earth connection provided at the transformer raw power source alone and earthing of UPS neutral at the UPS end should be avoided.**

## 6. Mitigation between the circulating current and open neutral condition

It is a standard practice insisted by the Electrical Inspectors to provide a change over arrangement using an interlocking arrangement for the avoidance of mixing of neutral also along with phases between the separately derived raw power supply sources for the following reasons:

i) Regulation 43 (iii) of Measures relating to the Safety in Electric Supply regulations, 2010 states "where two or more supplies are not intended to be operated in parallel, the respective circuit breakers or linked switches controlling the supplies shall be inter-locked to prevent possibility of any inadvertent paralleling or feedback"

The neutral switching in the changeover arrangement eliminates the stray neutral current and the undesirable earth fault current paths.

ii) (a) When the different separately derived sources are earthed at a single point in any one of the sources only and the neutrals are permanently connected while the phases alone are separated, neutral circulating currents will flow.

ii) (b) When the different separately derived sources are earthed at a single point in any one of the sources only and the neutrals are also separated along with the phases, one of the derived sources will become unearthed after the changeover.

iii) When the different separately derived sources are earthed at a single point in both the sources and the neutrals are also separated along with the phases, a momentary open neutral condition will occur which will harm the single phase loads (in an unbalanced three phase and neutral supply) or other critical loads like fire safety and emergency lighting etc of the installation during the changeover.

Item ii) (a) and ii) (b) of the above issues are related to the raw power and UPS sources which can be satisfied by adopting various configurations as explained in the subsequent sections of this article.

Item iii) (c) of the above issues is related to the raw power sources and the related distribution in the circuits upstream to the UPS. It can be satisfied, if a make before break overlapping neutral contact is ensured in the interlocking mechanism.

## 7 Measures to be followed relating to the performance and safety

In the supply arrangement for the sensitive equipments like computers, servers etc. bypass (raw power) circuit comes to the rescue when there is a failure in the UPS. But this bypass circuit is usually fed from the remote transformer or generator sources which are already having neutral earth connections in a TNS earthing system and are interlocked using four pole change over switch gears for avoiding mixing of neutral as well as the phase conductors of the different sources. Due to such combinations, inherent hazards are also present and hence the following requirements are to be satisfied for the safe performance of upstream and downstream circuits and safety of personnel:

(i) In the bypass mode, safety of downstream circuits fed from the UPS against any momentary open-neutral condition during changeover to the bypass supply source is to be ensured. Open neutral condition is possible since neutral of the separately derived sources are not permitted to be connected in a changeover arrangement or when the neutral of the source is disconnected by mistake for testing purpose or neutral continuity is interrupted by any fault in the upstream distribution system which normally feed other critical circuits also in addition to the UPS.

(ii) Interference to the proper operation of the upstream earth leakage protective devices like ELCB/Earth fault relays, (due to circulating current) which are feeding other circuits should be avoided.

iii) Neutral to earth potential rise due to circulating currents and hence common mode noise coupling should be attenuated so that reference earthing of power electronic devices is not affected.

iv) Protection from lightning and switching line surges as well as personal protection against any hazardous earth potential rise should be ensured.

## 8. Various Configurations

In order to fulfill the above requirements, some of the commonly adopted configurations are explained as follows: Any isolation transformer within the UPS of the older version (whether before the rectifier portion or after the inverter portion) need not be taken into account since these transformers are integral to the manufacture of UPS for voltage transformation compatible with the power electronic devices and the technology unlike tranformerless UPS of modern versions.

### 8.1 Configuration-1

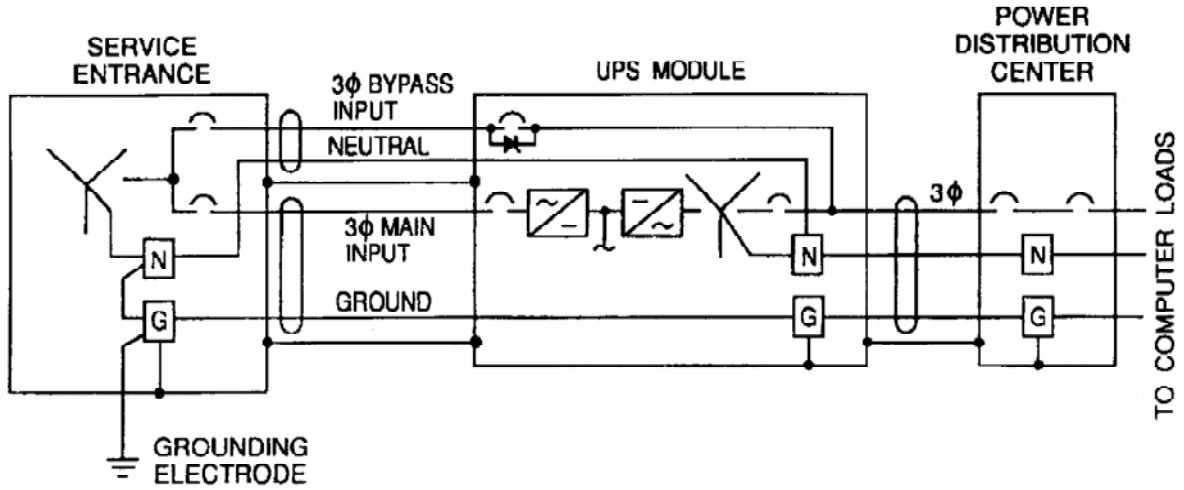


**Fig.3 Configuration-1**

This configuration is an economical one and it is commonly practiced for small installations like domestic and small business centres where the TNS earthing system of the source is closer to the UPS and effective and if any small neutral to earth voltage is tolerable to the UPS loads. There are no isolation transformers in this system. Even though the UPS module is a separately derived source, it becomes a non-separately derived source since its neutral is connected to the raw power source neutral. The method of connections for the neutral and earth of such non-separately derived UPS units should be as follows:

The neutral of the UPS unit should be interconnected with the bypass neutral of the source (i.e. transformer/generator) which is already earthed at the source in order to avoid any momentary neutral disconnection during bypass mode. The body frame of the UPS should not be connected to the neutral in order to avoid multiple neutral earthing which will create a circulating current thereby tripping unnecessarily the earth leakage tripping device in the upstream circuits.

The body earth connections of various equipments should be interconnected to an earth bus which in turn should be brought upto the neutral earth flat of the source and connected at this single point only for avoiding any earth potential rise due to line and lightning surges for the protection of personnel.

## 8.2 Configuration-2

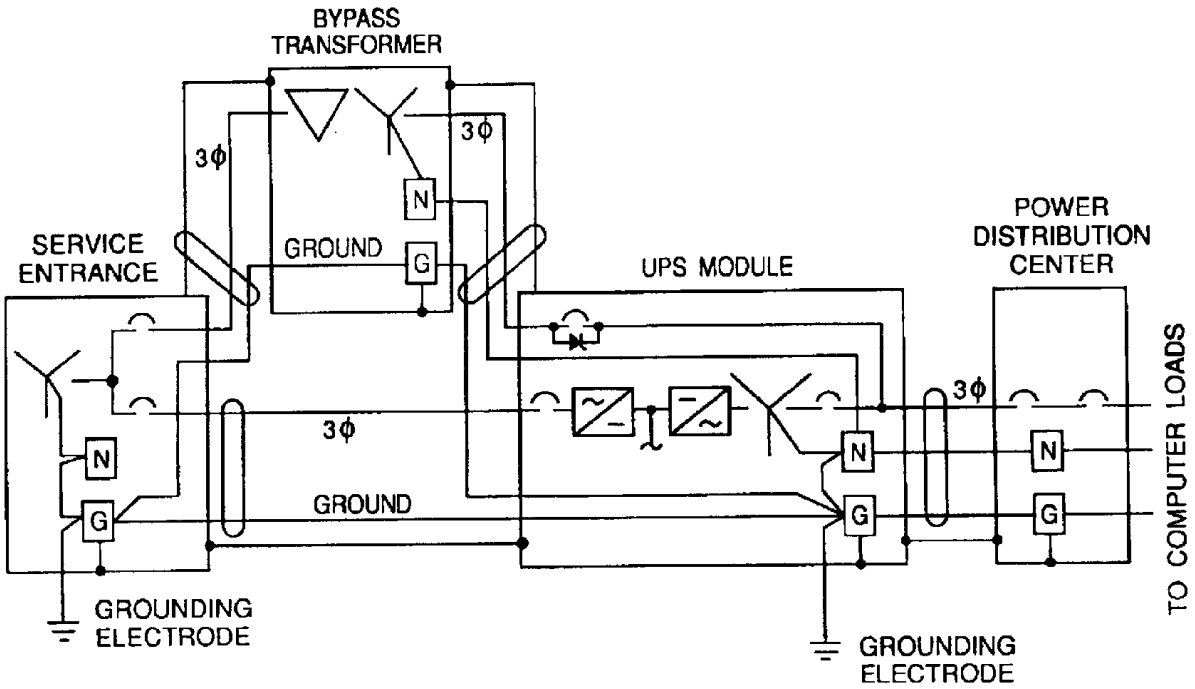


**Fig.4 Configuration-2**

This configuration is recommended when the earthing system of the transformer/Generator supply source is not a TNS system or when the TNS earthing system is very remote and ineffective or the source has serious power quality issues like harmonics, line surges etc. Since a local neutral is created by the isolation transformer, source neutral need not be brought to the UPS module. In this arrangement, isolation from the input source is obtained and hence the common-mode noise attenuation can be achieved for the sensitive loads as the UPS and bypass transformer are located electrically close (say 15m or less) to the sensitive loads.

The method of connections for the neutral and earth of such separately derived UPS units should be as follows:

Since the bypass transformer and UPS module together constitute a separately derived system, there is no direct electrical connection between the circuit conductors of the input source and the UPS output circuit conductors. The neutral of the UPS units and the isolation transformer at the bypass circuit should be interconnected in order to avoid any momentary neutral disconnection during bypass mode. The frame of the UPS should be connected to the neutral of the UPS and then to a nearby earth electrode in order to create an effective TNS earthing system at the UPS itself for avoiding neutral to earth potential rise.

The body earth connections of various equipments should be interconnected to an earth bus which in turn should be brought upto the neutral earth flat of the source and connected at this single point only for avoiding any earth potential rise due to line and lightning surges for the protection of personnel.

### 8.3 Configuration-3

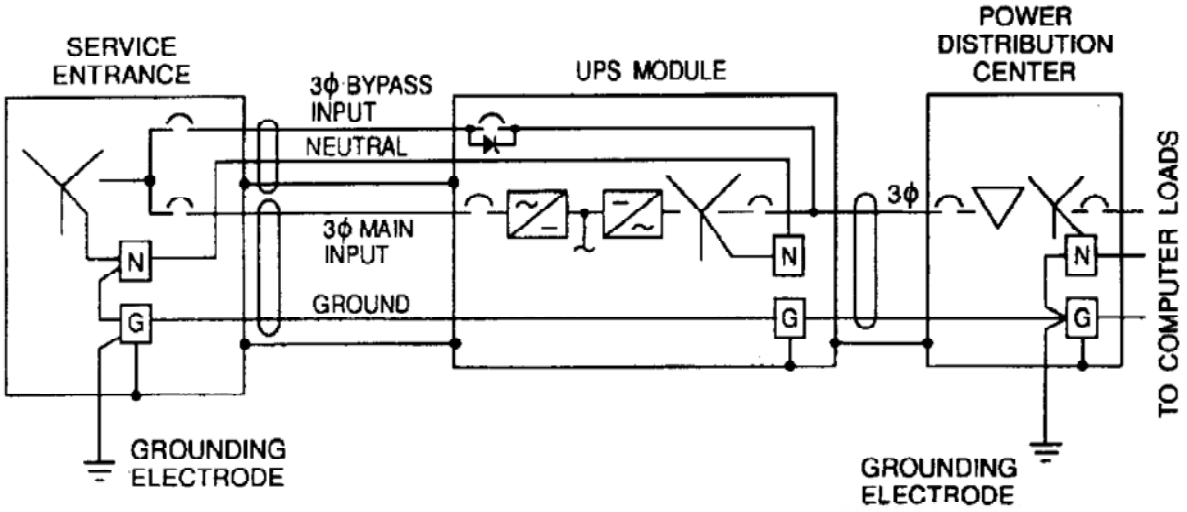


**Fig.5 Configuration-3**

When the loads fed by UPS are remotely placed due to site conditions or larger installations, a delta-star isolation transformer positioned at the load side is introduced after the UPS. The common-mode noise attenuation of this arrangement is better than Configuration 1 or Configuration 2, since the isolation (common-mode rejection) occurs as close to the load as practical. In this configuration, the UPS module is not a separately derived source since its output neutral is connected to the source neutral. Hence the neutral of the UPS should not be interconnected with the frame of the UPS. Further, this neutral should not be connected to the neutral of the said load side delta-star isolation transformer.

In such configuration, the neutral of the source before the UPS as well the neutral of the UPS is not required for the said delta-star isolation transformer. Since this delta-star isolation transformer feeding the UPS loads is a separately derived source, the neutral of the load side isolation transformer should be interconnected with the frame of the transformer which is connected to a nearby earth electrode.

The body earth connections of various equipments should be interconnected to an earth bus which in turn should be brought upto the neutral earth flat of the source and connected at this single point only for avoiding any earth potential rise due to line and lightning surges for the protection of personnel. The frame earth of the UPS or any equipment should not be isolated.

**9. Some of the commonly practiced configurations only are explained in this article. However, a specific advice will be given if there is a new variant in the configuration or any adverse effects to the loads fed from the UPS is met in practice.**

**Inviting your valuable comments for further improvements,**

**Regards,**
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