

THEORY AND RECOMMENDED PRACTICE

ELECTRICAL POWER DISTRIBUTION FOR TECHNICAL FACILITIES

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Introduction

This paper is intended as a guide for anyone involved in designing or installing electrical power systems for technical facilities. It is divided into three sections. The first section details the underlying reasons why electrical power systems require exceptional attention in technical facilities. The second section shows how problems arise and what techniques can be applied to address them. The third section is a group of recommended specifications for inclusion in construction documents and may be copied or paraphrased by permission of David Carroll Associates. This information is the culmination of years of practical experience, experimental verification, and corroboration with a number of other industry sources. Implementation of the concepts described herein is a process of iterative design and is highly dependent on application and job conditions. It is provided here for informational purposes only.

Disclaimer

David Carroll Associates makes no warranty or claim that the information herein is accurate or applicable to any particular situation. All electrical systems must be designed and constructed in accordance with the NEC and other locally applicable electrical codes. Consult a licensed electrical engineer regarding the application of any of the concepts described herein.

Background -- electrical requirements for Technical Systems Performance

Technical systems include audio, video, and computer installations. All of these systems involve interface between equipment with a variety of signals, which are susceptible in varying degrees to interference from extraneous noise. Professional audio systems fall into this classification, and because of digital audio techniques, have become the most sensitive of all.

Modern audio systems are required to provide an *audio path* noise floor approaching -90 dBu (voltage ratio expressed as decibels referred to 0.775V RMS, equivalent to a noise voltage of 24.5 microvolts (0.00000245 V)). The noise performance of an audio interconnect is dependent on two factors of concern to the electrical system. First, what is the noise voltage present between the chassis ground of the source equipment and the chassis ground of the destination equipment. Second, what is the nature of the audio interconnect as characterized by its CMRR (common mode rejection ratio), which is a measure of how well the equipment will reject (cancel) the ground noise. The effective noise floor presented to the input of an audio device is equal to the ground voltage difference expressed as dBu less the CMRR ratio, expressed in dB.

Various different topologies are in common usage as interfaces between equipment. The best

circuits provide over 60 dB of rejection and the worst only 20 to 30 as in the case of unbalanced sources feeding balanced inputs, a common situation arising in the world of real facilities. If we design for the worst case, then in order to provide -90 dBu effective noise floor, with a circuit providing only 20 dB of CMRR, then we must ensure that the voltage potential between the two items of equipment does not exceed -60 dBu (0.775 millivolts). This voltage level is so low as to be very difficult to measure, much less achieve, however not impossible if we follow certain proven techniques.

There is one bit of relief from this situation: poor audio interfaces are usually only found within small areas of a facility: for example from the rear of the control room to the front. When it comes to interfacing audio between rooms, or accross a campus, higher quality interfaces are commonly used, and we can relax the ground noise requirement. A good rule of thumb is to keep ground noise below -60 dBu (0.7 mV) within control rooms, and below -30dBu (24.5 mV) from room to room.

Measuring and verifying these low voltage levels is extremely difficult for several reasons. Stray AC magnetic fields from power wiring, transformers, etc., induce voltages not only into the ground wires, but also into audio cables and test probes, affecting measurements. For audio purposes, what we really care about is the net voltage as measured through the audio wiring itself. Therefore, meaningful measurements of resultant ground potentials can only be made after technical systems installation is complete, and then made using the actual audio wiring as a test probe. Further, wide band meters typically read high due to RF fields, where we are really interested in the power line frequency and it's harmonics. For measurements down to -60 dBu it is necessary to use a sensitive spectrum analyser.

If an inadequate ground is provided at the power receptacles then end users may be tempted to "correct" the problem by disconnecting the third wire grounds and replacing them with separately run ground wires to the equipment, or no ground at all. This is a violation of safety practices which we seek to avoid through proper planning.

It is possible to provide a high quality, low noise ground while maintaining compliance with the letter and intent of the National Electrical Code. The primary goal of all electrical codes is electrical safety and fire prevention. It is not the intention of these recommendations to circumvent any of the provisions of the NEC or other locally applicable codes.

Common Problems and possible solutions

IR drops cause noise voltage at receptacle ground

The safety purpose of the ground conductor is to provide a fault path for short circuit current. In technical systems the ground conductor is responsible for keeping all circuits at equal potential. Normally, there should be no current flow in the ground conductor. However, practically speaking, certain equipment exhibits leakage currents into the ground conductor from internal sources. These currents are usually minute, but can add up to be noticeable, and translate to voltages due to the resistance of the conductor.

Solution: increase the size of the grounding conductor. Many installers and engineers recommend this on "general principles". On 20A branch circuits, use 10AWG insulated

ground conductors. On 30A, use 8 gauge. The larger the better, since as conductor size goes up, resistance goes down.

Solution: eliminate leakage currents in the iso ground conductor by using isolation transformers at suitable places in the distribution system. An isolation transformer allows the creation of a new, “derived neutral” and thus can return leakage currents back to the source quickly without contaminating the rest of the system.

Multiple grounds cause circulating currents from external sources

Common grounding practice allows the use of conduit as the ground conductor. Unfortunately, conduit can contact building steel, water or gas pipes, or other apparatus at any point along the path it travels. Due to present electrical bonding practices, large circulating currents are commonly found in building mechanical systems. Each point of contact provides a path for noise currents to flow from building equipment, etc. These currents translate into noise voltages (See IR drops above).

Solution: Use fully Isolated ground system to prevent grounds from being corrupted by circulating currents injected from mechanical equipment or induction

Solution: Ensure that all audio and technical equipment is isolated from building steel or other mechanical ground.

Inductive coupling of AC fields from wiring causes noise voltage at receptacle ground.

Ground conductors and power conductors must be run in the same conduit for code reasons. However, this contributes to a major source of noise voltage: inductive coupling from the power conductors to the ground conductors. Ultimately it is important to reduce AC magnetic fields to a minimum as much as possible. Incidentally, this is in keeping with upcoming health standards for E.M.F. emissions.

Solution: Twist power conductors, separately from grounds. By twisting each "hot" conductor together with it's own neutral conductor, the loop area between the conductors is reduced and the external field is effectively canceled. Practically speaking this requires the purchase of pre-twisted cable. It also may require larger conduit for a given number of circuits.

Solution: Use MC Cable. This wires inside of MC are twisted and tape wrapped tightly and the loop area is very well controlled. MC is available with an isolated ground conductor. The ground is twisted with the power conductors, which is not as ideal as twisting the power conductors separately with a straight ground. This technique is not as desirable as the above but is a great improvement over standard conduit with untwisted wire.

Solution: Keep the length of branch circuits short. This rule should be followed religiously because it improves response from inductive coupling as well as IR drops. We recommend placing a local power panel in each technical area and carefully routing branch circuits to the equipment via the shortest available path.

Solution: Run a single ground wire for all branch circuits in an area. The key to reducing inductive coupling in any electrical circuit is to keep the loop area minimized.

The classic audio "star ground" configuration often requested for technical services dictates a separate ground wire from each receptacle to the technical power panel. That topology

actually increases loop area and at counter purposes to the intent of this section. A better topology is a single, large gauge ground wire, run around the room with taps at each device outlet.

Neutral current build up due to non-powerline frequency components

This subject doesn't directly affect noise in the ground but nevertheless is of concern in large technical installations. Modern computer and other technical equipment use switching power supplies which take current "gulps" at high frequency intervals, unrelated to the 60hz line frequency. In very large installations, these currents can combine in the neutrals to approach the sum of the individual branch currents. Standard operating procedure, following codes, indicates that a single neutral can serve for both legs of a 120/240V circuit, or all three of a 3-phase circuit. In large computer and technical facilities this should be avoided to prevent excessive IR drops and resultant heating in the neutrals.

Recommended Practices

The following specifications can be incorporated into construction documents piecemeal or in their entirety. Each practice adopted will make a degree of improvement. Best results will be achieved if the entire program is implemented and monitored through completion. We recommend that construction documents include a complete schematic of the power system, showing detail down to the individual conductor and devices, as opposed to the usual block diagram (single line diagram) which is subject to interpretation and mis-understanding by contractors. The requirements outlined herein require subtle changes in the standard operating procedure of the electrician, and it is often difficult to transmit the information unless it is explicitly stated and drawn. We recommend that the electrical plans and specifications be reviewed by the technical systems installer prior to release for bidding.

TECHNICAL POWER SYSTEM. Provide a separate technical power distribution system for technical loads only. No motor loads, fluorescent or dimmed lighting loads, or any other intermittent duty "utility" loads should be fed from the technical power system. Do not share current carrying or ground feeder conductors between technical and utility panels.

TECHNICAL LOAD CENTERS. Provide a separate subpanel for technical power distribution for each local technical area. For example, a control room with associated machine room or closet should be served by a small sub-panel, located on the wall between the rooms.

FEEDER CONDUCTOR SIZES. If feeder neutral conductors are shared by two or more power conductors from different phases, provide neutral wire one gauge larger than the conductors. Alternately separate neutrals may be provided for each power conductor in which case they may be the same gauge size as the power conductors.

ISOLATED GROUND SYSTEM. Provide an isolated ground bus in the main technical feeder panel. The isolated ground shall be bonded to neutral, mechanical ground, and any additional earth indicated, at the service entrance, in accordance with applicable codes. There shall be no

electrical continuity between the isolated ground system and the building mechanical ground system other than the bonding connection at the main technical feeder panel. Each technical load center shall also have an isolated ground bus bar. Connect load center iso ground busses to the main technical feeder panel iso ground bus with a conductor one AWG size larger than the power conductors.

PROVISION FOR GROUND ISOLATION TESTING. The electrical contractor should, as a part of contract close out, prove isolation of the ground system by the following means. After electrical inspection, disconnect the main feeder ground bus from the mechanical ground. Measure resistance from the iso ground bus to mechanical ground. If the reading does not show 100 meg ohm or higher, trace through the system to find and correct the source of the short or leakage.

DEVICES. Each branch circuit connected to technical load centers shall be fitted with isolated ground receptacles. 20A circuits with multiple receptacles shall be fitted with specification grade, 15A 125V devices such as Hubble IG-5262 or approved equal. Receptacles with a dedicated circuit shall be specification grade, 125V devices such as Hubbell IG-5362 (20A) or approved equal. 30A circuits shall employ twist lock isolated ground devices.

TECHNICAL BRANCH CIRCUITS. All technical circuits shall be run in metallic conduit with the power and neutral conductors twisted together at least 4 turns per foot. Provide one neutral conductor for each power conductor -- do not share neutrals. Each conduit or raceway run from a load center to a service area shall include an isolated ground conductor one size larger than the largest current carrying conductor in the wireway. Each receptacle's ground terminal shall be connected to this ground conductor via a tap which allows the ground conductor to continue without discontinuity. All receptacles and other devices in a given technical area should be served by a single conduit and isolated ground conductor. Route the conduit via the most direct path from device to device, with the goal being to minimize overall length of any branch circuit.

METALLIC EQUIPMENT RACKS. Free-standing metallic equipment racks housing audio/video/control equipment should be mounted and braced with non-conductive hardware. Ensure that there is no electrical connection between racks and building steel or mechanical ground. Install multi-outlet strips (plugmold) with non-isolated power receptacles. Connect multi-outlet strips to technical power distribution with an insulating bushing, or a section of non metallic conduit, to prevent continuity of the mechanical ground to the rack. Provide an additional ground link from the isolated ground conductor to the metal of the rack at the entrance to the multi-outlet strip.

LABELING. The cover plate of all receptacles connected to technical power shall be identified in a permanent manner with the words "Technical Power" and the circuit number. Utility power receptacles should be clearly different from tech power receptacles to avoid inadvertent technical use of utility power.

AUDIO GROUND. Provide an additional isolated ground bus bar, housed in a separate enclosure in a location noted on the plan set for the electronic equipment ground wires which will be routed through the low voltage wire ways. Connect this bus to the isolated ground bus in the technical load center with a wire minimum 2 AWG.

TECHNICAL POWER CONDITIONING. In most cases it is not necessary to provide power conditioning. If desired, it should be installed upstream of the main technical feeder panel, or locally at each technical load center.

SURGE PROTECTION. Provide a high power shunt-type surge protection at the main technical feeder panel. Do not use surge protector receptacles, or individual surge protector power strips commonly available at computer stores.

UTILITY POWER. Utility power shall be defined as power which is circuited from ordinary building distribution as opposed to the technical power system, and is intended for use by building mechanical systems, lighting, and convenience outlets. To minimize normal mode noise on the power line from switching motors, noisy equipment, etc., the utility power distribution should be separated from the technical power distribution as far upstream (close to the service entrance) as possible. Do not share current carrying conductors, grounds, conduit or wireways downstream of the separation between technical and utility services. Twist power carrying conductors minimum 4 turns per foot for branch circuits where they enter technical areas such as for lighting and convenience outlets. It is not necessary to provide isolated grounds for utility power.

LIGHTING DIMMERS. Phase control dimmers may be used if provided with inductors to limit current rise time to greater than 50 microseconds. Dimmer units must be powered by utility power circuits and load circuits must be routed to fixtures via metallic conduit or MC cable. Do not share any conduit or raceway with technical power circuits.

SINGLE PHASE SAME PHASE DISTRIBUTION. For extremely high quality installations, noise can be further reduced by putting the entire technical power distribution on one 120V phase of the incoming service.

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After re-reading this article (written sometime around 1995) I feel that it is still valid, but needs some additions. At the time of the writing, our experience included a lot of recording studios. The requirements for noise performance of the AC system in a recording studio is extreme.

In many commercial A/V facilities, for example a corporate boardroom, it is not necessary to achieve the same target. Pro audio facilities are now going digital, which is nearly impervious to interference. So I began to wonder if making the electrician jump through hoops was really necessary.

When I built the EA project I was hired too late to have power systems design input. It “looked good” on paper. And most of the audio interconnect was digital: AES was the primary signal path. So I relaxed a bit... and regretted it later. The first problem was that the electrical work itself was sloppy and there was apparently no quality control. Which leads me back to one of the A/V/C systems integrator’s main duties in this respect, quality assurance and acceptance. Test, Test, and Test some more. I experienced a new one there: some electrician had swapped the

ground and neutral conductors in a pull box handling about 5 load circuits. Nobody was the wiser, as both neutral and ground were bonded together back at the service... but the entire LOAD was passing through the ground conductor! With that amount of “leakage” (see the section on leakage above) the IR drop in that ground conductor was developing VOLTS of difference on all of the circuits serviced by that pull. So... Test, Test, Test!

But even so, after I went through it all and corrected everything we found, we still experienced hum in the system. And it wasn't in the audio... we were using high quality audio balancing and or digital interfaces. It was showing up on the video! I had forgotten the video! Many of the video circuits were unbalanced source/destination. Many high quality video D/As etc have differential inputs, solving this problem, but we were not so lucky. Video is not so picky as analog audio as far as noise level is concerned, but if I'm not mistaken you need about -40 db, and with an unbalanced interface, that requires really good grounding especially in a multi-room facility.

I think that the problems could have been avoided if the electrical had been built with small local panels, and if the feeders and loads were twisted.

It's true, with digital audio you can get away with murder. But there are still many signal paths in a large facility which cause signal ground connections from room to room, for example control and video signals. These connections can inject ground currents into equipment internal to a room and cause all sorts of grief. Additionally, the requirements are magnified when the area is enlarged. A multi-room facility with tie lines is the worst. This is due to the larger loop area of power and signal ground connections.

Things to test and watch out for:

Ground Isolation: Before you accept power and start to plug in your equipment, have the electrical contractor accompany you for a thorough test. Presumably he has already confirmed that Hot and Neutral are in the right places on all of the receptacles. That's a good start and if it hasn't been done, you should go ahead and do it.

Now, have him shut off the main tech panel feed and lock it off. Then have him disconnect the isolated ground feeder from the Iso Bus Bar at the main technical panel. Now, measure the resistance from the Iso Bus Bar to the mechanical ground of the technical panel. It is normal for your ohmmeter to momentarily read a low resistance, climbing up until it says “OL”. This is the capacitance of the wire charging from the battery in your meter. The reading should stabilize on an open circuit of 100 megohms or better. If it's shorted, then someone put a screw through the isolated ground conductor somewhere and it's your job to find it. (see “tip” below)

Don't stop here, though. Your next task is to confirm that Isolated Ground is actually getting to all of the receptacles. It's possible that somewhere in the system, someone mistook the green conductor for the green with yellow stripe... anything can happen. So it's Best to Test. With the iso bus bar disconnected, you have the ideal test bed, one that you will never have when the facility opens.

Testing for iso ground continuity:

- Make sure all power sources are OFF and LOCK THEM DOWN.
- Get yourself a DC bench power supply.
- Connect the supply between the mechanical ground and the isolated ground buss. Apply about +10 DC VOLTS to this junction.
- Go around to all of the AC receptacles with a voltmeter. Measure the DC voltage between the 3rd wire (U-fer) and the conduit ground. All receptacles should measure +10 volts on the 3rd wire. If the polarity is reversed or if there is no voltage, you have a problem on that branch.

Now, if you're brave, you can add your technical system to the mix and see if it's isolated also. Remove the DC power supply, but leave the Iso Bus Bar disconnected from the ground feeder. Plug in all of your racks and equipment. Now measure the resistance from mechanical ground to Iso ground. This time, you will see some resistance which is the leakage current from neutral to chassis in all of the connected equipment. Nevertheless the total resistance should be high (megohms) and if you see a short, it is somewhere in your racks, not the AC system.

Testing for Isolated Ground to Mechanical Ground shorts.

OK so let's say that you are testing the "isolated ground" system and you find that it's shorted out. Where is the short? You could start by disconnecting all of the green wires from the iso bus bar in the technical panel, then ohmming them out. Problem here is, they are not labeled, so how to find them in the field? I developed a handy way to trouble shoot this problem:

- Make sure all power sources are OFF and LOCK THEM DOWN.
- Get yourself a DC bench power supply.
- Connect the supply between the mechanical ground and the isolated ground buss. Feed about 1 AMP of DC current into this junction, using the constant current capability of the supply.
- Go around to all of the AC receptacles with a voltmeter. Measure the DC voltage between the 3rd wire (U-fer) and the conduit ground. The receptacle with the lowest voltage is on the shorted branch.