Power & Grounding for a Post Facility: Unconventional Approaches

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Over the years certain aspects of facility power and grounding have become well accepted. In particular, single-point grounding techniques have dominated as the best way to create a "clean" technical power system. The objective is to reduce hum, buzz and radio frequency (RFI) components on power and signal grounds, thus reducing noise impressed on audio and video signals.

Recently, however, there have been stirrings around the television and audio recording industries suggesting other approaches to solving noise issues. There have been articles and seminars dealing with the sources of noise, how noise gets into signal circuitry, and noise control through the use of balanced (symmetrical) AC power. My own experiences with conventional grounding techniques have been so unsatisfactory--both in terms of failure to solve problems and difficulty in implementation--that I have chosen to try some unconventional, but theoretically sound, ideas in recent installations.

Sources of Noise

The noise problems familiar to audio and video engineers range from audible hum, buzz and interference at various frequencies to visible hum bars and RF moiré in video signals. Many of these can be traced to coupling of environmental noise into signal cabling, while other noise originates in the incoming power or in equipment itself.

One primary source of ground-related hum is voltage differentials between different points in the power system. This is the classic "ground loop" phenomenon; two points are at differing potentials, so current flows between them. In the case of broadcast systems, ground currents can arise from several sources; commonly these include leakage currents from line filters and transformers in equipment power supplies, or devices which present an unbalanced load--that is, when some of the power delivered to the load leaves via a path other than the neutral, generally meaning the ground. Recalling Ohm's law, a voltage drop occurs when current flows through some resistance. The resistance component is the impedance of the grounding conductors themselves.

A second, minor, source of noise is induction of AC hum into signal wiring. Any conductor carrying a current radiates magnetic and electrostatic fields, which can induce current in a nearby conductor. The intensity of the induced current depends on proximity of the two conductors but even following good cable dress practices, such as keeping power and signal wires perpendicular to each other and using steel enclosures, there is enough AC field activity around equipment and signal wiring that this can be an issue. Even if your signal is carried in a shielded cable, a nearby AC field still induces a current **in the shield**, thus becoming a source of ground differential voltage.

The typical solution for ground differential hum is to try creating a system in which all equipment is grounded via only one path: the power cord third pin. This requires isolating chassis from racks, utilizing iso-ground power receptacles and lifting the shields of signal cables at one end. This last practice is absurdly difficult to maintain through patch fields and in systems, such as video facilities, with much unbalanced equipment (because the ground conductor is also the signal return). Additionally, it makes the shields into very appealing antennae for RF signals floating by. In either case--shields grounded on one or both ends--ground-borne hum appears at the "earth ground" of equipment to which the shield is connected. This is typically the enclosure, or some part of the internal structure, which should be protecting the circuitry from noise but instead allows the noise to be coupled in with signals due to poor design topology (the so-called "pin 1 problem"). This problem is so common it is shameful. (1)

You can try bringing all your shields to some central "earth ground" point in the hope of bleeding off the ground noise, but the noise does **not** "flow into" the earth! This is a common fallacy. Aside from safety, ground rods (or bonds to building steel) help to equalize any voltage potential between the technical power and utility power grounds, and reduce static charge buildup on shields, but they do not absorb ground noise. (2) In the end, single-point grounding and heavy earth grounds are attempts to treat the symptoms of noise, but not the source problems.

An important point to remember is the value of transporting signals on **pairs** of conductors because of their inherent ability to cancel unwanted noise; if all equipment used balanced/differential floating inputs and balanced outputs most ground noise issues would be moot. This applies to power signals as well; the hot and neutral conductors in a line cord carry equal and opposite currents which effectively cancel most radiated fields.

Balanced AC Power

The notion of balanced AC is not that new, it simply has been forgotten, particularly since modern electrical distribution (at 120V) relies on a single "hot" conductor and a grounded neutral. Balanced (symmetrical) power works much like balanced audio; there are two hot conductors each carrying the same AC voltage but 180 degrees out of phase. In the case of typical electrical systems, this translates to two conductors at 60V relative to ground. The end result at the line cord is still 120V but there is no "neutral".

The primary advantage of this approach is that, as with audio balancing, common-mode noise (which is equal and in-phase on both conductors) is nulled at the ground. Leakage currents in a power supply, particularly those from line filters (which are balanced by design), are summed and cancelled at the ground conductor. (3) In addition, distortion and noise caused by non-linear components in power supplies are also cancelled. Switching power supplies, ubiquitous in today's equipment, tend to introduce more of this type of noise due to their lack of a large transformer at the power input acting as a low-pass filter.

Installing a balanced technical power system is only moderately different from conventional power. The most difficult part is getting electrical contractors to **think** differently: "balanced" does NOT refer to balancing the loads on a three-phase service, and there IS NO NEUTRAL. Electricians are so accustomed to neutral and ground being effectively the same that there is no telling what might get connected wrong if they are unclear on the concept. More prosaically, the standard AC line tester with three lamps will not work normally.

Balanced power is created through the use of line transformers. Whatever incoming service you have, the end result is typically 120V at some amperage requirement (though it can be another voltage). Therefore the necessary transformer(s) should have a primary designed for the available service, perhaps 120V or 240V, and a capacity (stated in Volt-Amps, which is essentially watts into a purely resistive load) sufficient for your technical power needs.

The first step is to take a power inventory of your facility to determine the total tech power draw. Most equipment will state somewhere, on the rear panel or in the manual, either current or watts drawn. In general, it is wise to use VAs, rather than watts, when determining power consumption for a device. This is because watts can be misleading if the device's power factor is not known. Using VAs, based on a device's actual current draw, will ensure adequate power system size even for equipment with heavily reactive load characteristics (such as big motors). Add it all up, add in your expansion needs and throw in some extra for good measure. The reality is that most equipment draws less current than rated, most of the time, but startup surges (such as from 1" VTRs or film dubbers) must be considered, as well as changes in efficiency due to temperature. Plus, those big digital boxes, like DVEs and switchers, are real juice hogs and might not be fully loaded when first purchased.

The tech power can be derived from a single transformer or several, depending on the service. For instance, at Fast Cuts there was a 120/208V/100A three-phase service available, which can provide three 100A supplies. Three transformers were chosen which could be strapped for 208V primaries and **120V center-tapped** secondaries (thus creating the balanced 120V). The terminology of these transformers can be tricky, so be sure the supplier or contractor understands what you want. Purchasing transformers from a company such as Equi=Tech eliminates this problem and also provides precision-wound secondaries which are claimed to give better common-mode cancellation. However, precision transformers are significantly more expensive than common industrial models; the 8 kVA unit in this system was about $1500. (See *Figure 1* at end of article.)

For the Fast Cuts facility, Equi=Tech supplied toroidally wound transformers, which have higher power capacity for their size than conventional laminated-core designs (and well-contained magnetic fields), but had two peculiarities which caused trouble during installation. First off, if the transformer is mounted vertically, such as on a wall, support can be provided using the hole in the plastic core but there **must not** be a completed turn of electrically conductive material through the core (Fig. 2). The introduction of a closed electrical circuit through the core acts like a shorted winding turn and can damage the transformer.

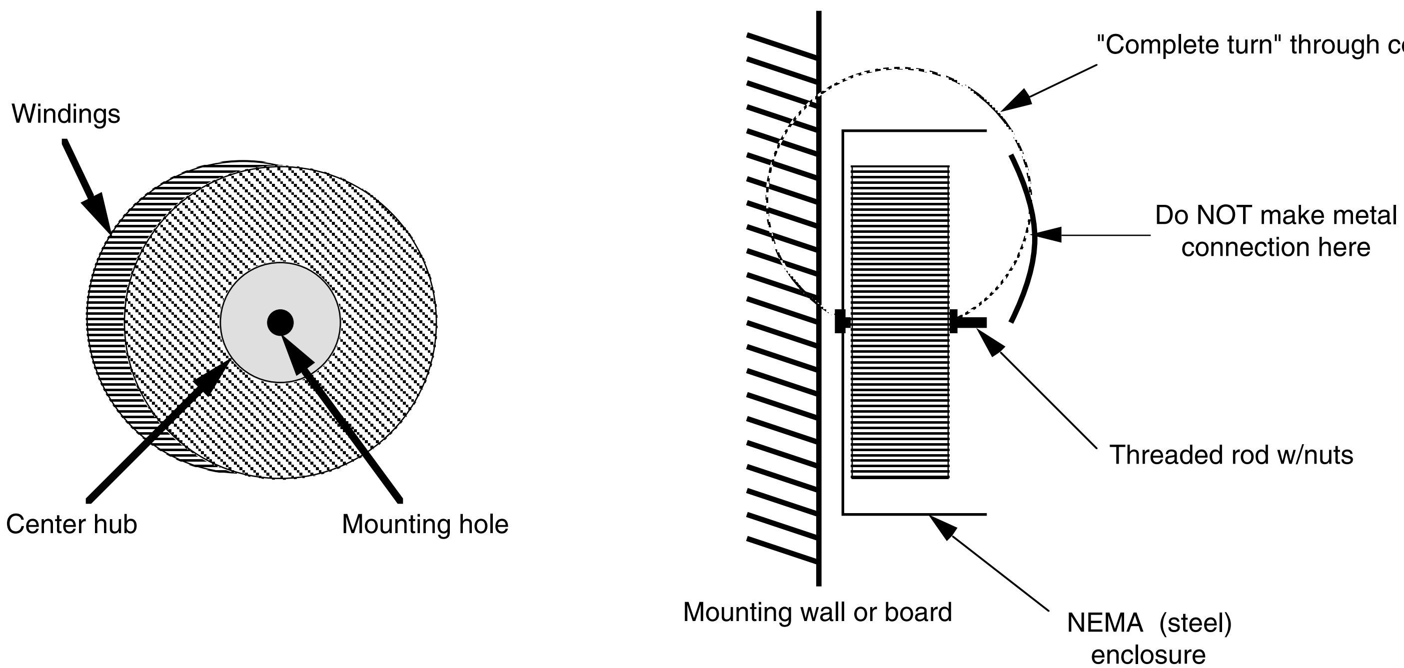

Fig. 2 Toroidal Transformer Mounting

Secondly, though the system in Fig. 1 was installed with a 90A three-phase main breaker ahead of the transformers, the breaker would not hold when powering up even one of the transformers. The transformer manufacturer quoted short-duration inrush currents as high as 5000 amps for the 5 kVA units! This was probably due to the transformer cores being somewhat undersized and reaching saturation too quickly at startup. Since it was not possible to get a circuit breaker with extremely high inrush specs a 90A fused disconnect was substituted. This brings up a good point: do not hesitate to contact the transformer manufacturer for technical help with installation, particularly in the areas of lead identification, mounting and cooling.

The Code and Other Issues

Balanced power is first addressed in the National Electrical Code with the 1996 revision (thanks to work by Equi=Tech's Martin Glasband). This legitimizes the practice, at least for audio and video facilities, and provides some specific directives. For the most part these directives are common-sense anyway, though sometimes tedious. Since the NEC's sole purpose is to ensure human safety it is wise to stick with the letter unless you can foresee the consequences of straying. In the end, a given electrical inspector may make unreasonable trouble about a balanced installation, even with support of the code, or may let things slide if he understands what is being done.

One aspect of the code requirements for balanced power which is problematic is that each branch circuit must be supplied with a Ground Fault Circuit Interrupter (GFCI or GFI). The reason for this is to protect against shock in the event that someone touches ground while also touching a device whose case is connected to the "neutral" line cord lead. The code addressed this problem in conventional power systems with the polarized two-prong plug, but with balanced power both sides are at 60V so the polarized plug does nothing. In practice, however, this scenario is very unlikely since most professional equipment has a three-wire cord or an isolated chassis.

More importantly, the typical GFI is designed to trip at only 5 mA of leakage current. Unfortunately, in any collection of average professional equipment a few devices will exhibit this much leakage just from shunt currents in their power supply filters or leaky capacitors. There is nothing functionally wrong with the equipment, but the GFI will trip the instant power is applied. One solution is to install GFI **circuit breakers,** with adjustable trip current, in the tech power panels, but this is very expensive. Another approach is to examine the offending equipment to determine and fix whatever is causing the leakage current. In the end, the actual danger is so minimal that one might consider a more obvious solution.

The code also specifies double-pole breakers for the branch circuits, which is important. Though it increases the cost marginally, without double-pole breakers a branch circuit is never truly OFF! From an overload or short-circuit standpoint the protection is the same as with conventional power; excessive current draw on either leg will trip the breaker. In addition, the panel box must have both power buses isolated from the box itself, such as for 220V distribution. Isolating the ground bus is not really necessary (see final section). Other code requirements, such as labeling circuits and receptacles, are actually a good idea anyway in order to maintain the integrity of the technical power system. That is, all equipment with system signal connections **must** be powered from tech power, and all non-production equipment (such as copiers) must be kept **off** tech power.

Clean Tech Power

A few issues about the power and grounding system remain. As far as line conditioning, regulation and backup power go, these must be addressed on an individual basis depending on budget. In the facility described here no attempt was made to provide voltage regulation. Most decent equipment already has internal regulation which is sufficient to handle minor fluctuations in line level. I have also known large tap-switching regulators to go haywire and wreak havoc with the power. Similarly, no backup system was provided, though individual UPS units may be added for specific vulnerable devices such as graphics computers and editors.

In terms of spurious noise and spike control, since balanced power is created using transformers there is the inherent benefit of an isolation transformer between your tech power and the power company. The transformer acts as a steep low-pass filter which reduces high frequency noise. Surge protection for Fast Cuts was handled by installing some very large MOVs (metal oxide varistors) at the breaker panels. These should be rated for the nominal RMS voltage (but also sized to handle potential long-duration power line fluctuations which would damage a MOV).

Another potential source of equipment damage is when power browns or blacks out then flickers on and off before returning. To alleviate this we installed some relays which monitor the incoming power phases. If any of the three phases drops out a giant master relay (a 90A industrial "contactor") disconnects all three phases. This relay must be reset manually, by pushing a button, which allows facility personnel to determine when the incoming power has stabilized.

Finally, what about grounding? As previously mentioned, I have lost faith in star grounds, ground rods, telescoping shields and the like. They are cumbersome to implement and solve little. In the facility described here a "brute force" approach was taken: all cable shields connected at both ends, power system grounds connected to racks via third pins and power strip cases, all racks bonded together with bolts and star washers as well as heavy ground straps to outlying racks, extra large ground conductors installed between transformer center-taps, breaker panels and distant sub-panels.

The idea was to create the lowest-impedance ground possible. This makes it easier for ground-borne noise to return to its source, and reduces the possibility of voltage differential problems by bringing all parts of the system closer to the same electrical potential. In practice, the use of balanced power and good layout and shielding practices are meant to prevent the admission of noise into the system, but a solid low-impedance ground is the foundation. The transformer center taps and electrical grounds are bonded to the building (power company ground) via a large conductor coming in with the three-phase from the electrical room (the three-phase neutral is not used).

The presumption here is that shields can always be lifted, or ferrite beads installed, if noise is found but so far this has not been necessary. The facility has been in operation since January of 1996, with technical areas covering about 2500 square feet, and there has been no sign of video hum or audible noise (apart from the occasional bad equipment). While there are plenty of balanced audio and video devices, there are also numerous unbalanced devices, some with two-wire line cords. It just doesn't matter. Admittedly, implementing this type of power and ground system in a very large facility would be more difficult, but I believe it is worth considering these "unconventional" approaches. One day they may be considered conventional.

Bibliography and Further Reading

1. Neil Muncy, "Noise Susceptibility in Analog and Digital Signal Processing Systems," Journal of the Audio Engineering Society, June 1995
2. Ralph Morrison and Warren H. Lewis, "Grounding and Shielding in Facilities," John Wiley & Sons, 1990
3. Martin Glasband, "Lifting the Grounding Enigma," MIX, November 1994

Author Bio

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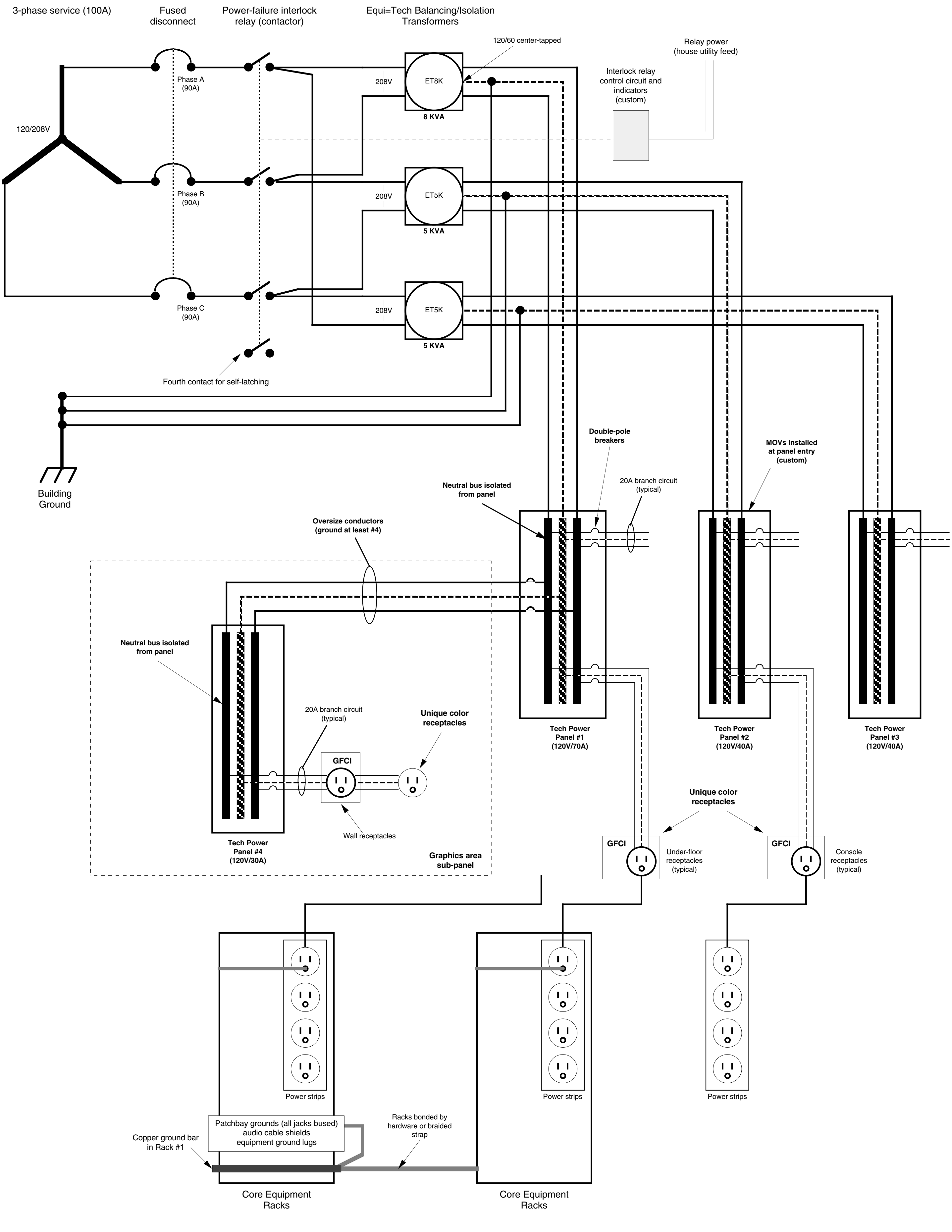

***Fig. 1* Power/Grounding Conceptual Block Diagram**

Fast Cuts, Inc. Washington, DC