Key grounding and voltage considerations in the data center

While grounding is a known necessity amongst IT professionals, as a concept it is often misunderstood. This expert e-guide from SearchDataCenter.com explains the many reasons for implementing grounding methods and the problems that can occur if it is done incorrectly. Find out how to design your data center’s power system with key components like voltage in mind. Discover the differences between power used in North American and European data centers and determine how much power to implement in your data center.

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Grounding -- the 'black art'

By Robert McFarlane, SearchDataCenter.com

We all know that grounding (or "earthing" as the Europeans call it) is a necessity. It's required by electrical codes; it's required by equipment manufacturers; and we all know it would be "good practice" even if it wasn't required. But exactly how to do it has probably been the subject of more debate and difference of opinion than any other aspect of the infrastructure. "Isolated grounds" are still called for by many people, even though they are actually counter-productive in the data center. And top-name manufacturers have even been known to stipulate grounding methods in their installation specifications that are just plain illegal and unbelievably dangerous. Why is it that this fundamental, and seemingly straightforward subject, is so misunderstood?

It's misunderstood because there are so many different reasons for doing it, each with its own set of concerns, considerations and installation methods. It's also misunderstood because the problems that can occur when it's done wrong are essentially invisible, difficult to comprehend, often without a good explanation and hard to track down when they happen.

Most professionals deal with only one or two types of grounding in their careers. The majority don't necessarily know that the communications industry has its own set of requirements, and don't realize that, while there are similarities, what is fine in one field doesn't always do the job in another. Let's identify some of these grounding specialties and what they're for, then pull the concepts together to get a better understanding of the principles of telecommunications grounding.

**Electrical safety grounds:** Probably the most fundamental of all grounds, these are required by code to protect people from injury in the event of a short or "fault" that puts current onto an equipment housing. That's why the "U-ground" pin is found on lots of appliances. One of the power wires, called the neutral (white conductor), is also grounded, but if something goes amiss with it, the "U-ground" keeps you safe. It's really bad to cut it off or to use a three-pin adapter in a two-pin socket without actually grounding the green wire or ground lug. (Appliances like power tools that just have a standard two-blade plug
are "double insulated" to make sure a fault doesn't electrify the part you're holding. Because they use special construction, the manual will tell you not to disassemble it yourself.) The building power ground goes to an "earth terminal," is bonded to building steel and is also carried to every electrical panel in the building. Code requires a building safety ground to have a ground resistance of 25 Ohms or less. (It takes special equipment and techniques to measure this.) Keep this figure in mind.

**Lightning grounds:** These are designed to conduct lightning strikes directly to ground so they don't damage the building or its electrical systems, or injure people. Spiked rods on top of the building (called "air terminals") are the most commonly recognized form of protection, although not necessarily the best. But whatever technique is used, the intent is to carry the lightning strike to earth through the building steel or through wires run down the outside of the structure to rods driven into the ground. These ground rods are also bonded to the main electrical ground, as is the building steel. Lightning, by its nature, includes a large high frequency component. (If you studied mathematics, you will recall the Fourier Series, which defines the attributes of a sharply rising pulse, and understand why.) Therefore, it doesn't bend corners very well. All lighting wires are run with long radiused bends -- no right angles. Keep this in mind as well for later in our discussion.

**RF shielding and grounding:** Radio frequencies are very high, (though not as complex as lightning) and therefore have very short wavelengths. Despite the experience we have daily with cell phone dead zones, RF tends to find its way into everything, especially where it is not wanted. The only way to stop RFI (radio frequency interference) is with a virtually continuous grounded shield -- often called a "brute force ground." This might be thought of as the opposite of an isolated ground. Commonly seen in broadcasting, this type of grounding is achieved by making sure all metal parts are solidly bonded together -- essentially grounded everywhere. If you have, or have ever seen, an RF shielded cabinet, you may have noticed that the doors close against hundreds of small, spring bronze fingers or against some sort of metallic braid that forms a continuous electrical connection around the entire door edge. (These cabinets are sometimes used to meet FCC regulations for RF emission from equipment and are usually labeled as such.) Keep this concept in mind as well as we proceed.
Electro-static grounds: After the mandatory electrical safety ground, this is what we want in our data centers. It's the reason we wear (or should wear) wrist straps when we work on micro-electronics and why we use anti-static floor tiles in data centers instead of carpet. Static discharge is just a personal lightning bolt. It's obviously much lower in power than nature's cloud-borne version, but it's exactly the same phenomenon -- a build-up of free electrons that suddenly finds a path to something with fewer electrons -- usually the earth, or "ground" -- and very rapidly discharges those electrons to equalize the balance. The problem is, it may find its ground path right through our sensitive and expensive hardware, where even a minute discharge, if it doesn't actually damage something, can cause data errors and even memory loss. And the smaller and faster our hardware becomes, the more vulnerable it is to static problems, either airborne or arriving as power line anomalies when our UPS is in bypass.

What we want to accomplish with an electro-static ground is not all that different from lightning protection; we want to draw those electrons away from anything important and get them to ground as quickly and as completely as we can. Recall that we said lightning, or any static discharge, is very high-frequency energy. We also said RFI, which is also high frequency, is best dealt with by grounding everything to everything. Recall also, probably from high school science, that electricity always seeks the path of least resistance. These three concepts should help us understand the requirements of the Joint TIA/EIA/ANSI Standard J-STD-607-A Commercial Building Grounding (Earthing) and Bonding Requirements for Telecommunications (ANSI/J-STD--607-A-2002)" and the concept of "equal potential grounds" that we try to achieve in a data center telecommunications environment.

If everything is well bonded to a robust and virtually omnipotent grounding system, that's the path any static discharges are going to take if the system leads back to the main building ground through a very low impedance path. This includes nearly all the stuff that might get onto your grounds from outside sources. I say "nearly all" because a sufficiently powerful lighting strike is going to go where it darn well pleases, perhaps even taking a hunk off the building in the process. As we well know, nature is more powerful than our abilities to fend her off, and once in a while she outdoes us. This is why we need good lightning protection on our building, as well as a top quality surge protector on our power
system. We're now getting beyond the scope of this article, but some good information can be found here.

There are two main things we're trying to accomplish: provide a very low impedance path to ground from everything metallic in our data center; and avoid creating "circulating ground currents" in the process. Let's take these one at a time. They're really not that difficult.

Impedance is the electrical term we give to resistance when we're not dealing with direct current (DC). I'll use the proper term "impedance" in this article, but if you're more comfortable thinking of "resistance," that's fine. A low-impedance path is created in three ways: large copper conductors; short wire lengths; and clean, solid connections. The principles are simple. Longer paths require larger conductors, and good connections require the proper hardware, strongly pressure-connected to surfaces that have been well cleaned beforehand. There are many products for doing this. One of the best sources of both information and products on this subject can be found Panduit.com. There are also some excellent seminars and courses you can attend. Lyncole and MikeHolt.com.

There are two characteristics specific to the particular type of electrical energy we are dealing with, and these both go back to one concept we mentioned earlier in this article -- namely, static discharge is, by nature, a high frequency phenomenon. The two characteristics are: static energy tends to travel on the surface of the wire, rather than through it ("skin effect"); and it does not like to turn sharp corners. This is why we use stranded copper wire for most grounding and bonding connections, and why we should never make sharp bends in ground wires. They should always curve smoothly with a minimum bend radius of 8 inches. Stranded conductors provide more surface area than solid conductors for the same gauge of wire, and curves keep the energy in the wire, rather than letting it bleed off into the air or to some other metal from the corner of a sharp bend. Unfortunately, the reason for radiuses bends is very difficult for most electricians to grasp, and it takes virtually constant supervision to achieve a proper installation.

Circulating ground currents create their own electrical noise, so are to be avoided. In principle, they're easy to stop. Just keep everything at the same electrical potential or voltage. Current will only flow between two points that have a difference of potential. (Recall how static discharge occurs.) If we ground everything together with heavy wires,
then everything should be at "equal potential" and no current will flow. Not surprisingly, this is called an "equal potential ground" and is exactly what J-STD-607-A is trying to achieve. The difficulty is doing it in a practical way. It's unrealistic to weld everything in the building or even in just the data center, together with heavy copper bars. We need to use practical wire sizes and attach them the right way, and at the best places, to everything in the room and then run those wires the shortest reasonable distances to solid ground bars. We also need to get all of our grounding bars connected together with heavy gauge wires so they are at essentially the same potential and then get them run to the primary building ground -- the same point to which the building electrical service is connected -- so that everything stays at the same electrical level. This is where the "art" of grounding design comes in.

It should by now be obvious why "isolated grounds" have no place in the data center. The minute a metal chassis is screwed into a metal cabinet, another ground path is established and not a very good one either. Each piece of equipment does the same thing, until there are multiple ground paths, none of them very low-impedance, all running through small-gauge wires and ending up at the building ground via different paths of all different lengths. The result is a poor static ground and loads of circulating currents due to the many different electrical levels that result. It's a waste of money on something that will be counter-productive in the end.

We must also talk about the business of connecting to building ground. This is a safety issue, absolutely required by code. A good telecommunications ground can be built as a "separate system" all the way to the electrical vault, although it should really be bonded to building steel and local electrical panels at various places along the way. It can even have its own set of ground rods if that becomes necessary to approach the lower 5-Ohm ground resistance recommended for telecommunications services. But these ground rods had better be bonded to the main electrical ground for the building. If you have a vendor who tells you they require a "separate ground" connected only to its own ground rods, tell them to consult a qualified engineer or code authority. God forbid there should ever be something called a "ground fault" in your incoming, high-voltage, building electrical service. The soil resistance between the separated grounds will result in a huge voltage difference if a "fault" occurs, and the resulting current will instantly boil the earth. The force of the explosion could put the basement slab on the second floor, and the resulting power surge on your "separate
ground" could fry everything, and everybody, that's in contact with a grounded device. In short, this is not a wise approach.

There's one more factor we will mention, but not try to explain because it's really the province of the electrical engineer to determine. This is the code requirement for a "neutral bond" on the secondary ("load") side of a transformer. The code defines a transformer, such as is often found in a large PDU and a full-time UPS, as a "separately derived source." This means that a neutral-to-ground bond is required. How this is connected to the telecommunications static ground is sometimes a little tricky and can require some analysis as well as a thorough understanding of equal potential grounds in general and the UPS and PDU designs in particular. We have often found ourselves advising the electrical engineer on this issue at the same time we provide advice regarding the telecom ground.
We should not close this discussion without at least mentioning the "ultimate" in telecommunications grounding practice -- the "PANI" ground. This approach actually divides the ground bar into four sectors identified as "producers," "surge arrestors," "non-isolated" and "isolated" ground networks (PANI). This is an even more exacting method of ensuring that ground currents flow within the ground bar in a way that further avoids ground current interaction. PANI grounds are used in major telecommunications carrier installations and are often required by the military. The photographs show a superb PANI ground installation. If you look closely, however, you may notice a couple of connections made after the fact by unknowledgeable electricians who must have thought that the care taken in the original installation was by someone far too anal-retentive. The electrical trades just don't understand telcom grounding.

In short, good data center grounding requires understanding, careful planning (as does any technical design), proper execution and good supervision. It is not inexpensive, but it could easily make the difference between reliably functioning equipment and never-ending data errors and failures. Take your choice.
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Which data center power distribution voltage should you use?

By Julius Neudorfer, Contributor, SearchDataCenter.com

Designing a data center's power system consists of numerous decisions about the components in the power path. In most of the world, there are two primary voltage schemes (three-phase) available, which are based on either the North American 480/208/120 V (600/208/120 in Canada) or the 400/230 V system in used Europe and some parts of Asia. In all systems, much higher voltages are used to deliver power from the utilities to the site, but these are not part of this discussion. Also note that we are generically referring to the 400/230 V system (this is the midpoint voltage that represents 380/220 V through 415/240 V). While some data centers are exploring the use of direct current (DC) to improve overall efficiency of the entire computing ecosystem, alternating current (AC) power is still the predominant form of power in the data center. (Follow this link for more on the AC/DC data center debate.)

Rack-level power density and distribution

Rising data center power density is one of the big factors driving the re-examination of voltage choice to IT equipment and which voltage to use in distribution systems.

Here in the North America, the common use of 120 V worked fine when a rack used 1-2 kW per rack and a single 20 A circuit was all that was needed (two for A-B redundancy). With the advent of blade servers, which typically require 208 V or 230 V circuits and use five or more kilowatts as well as racks full of 1U servers, the new baseline is now 5 kW per rack.

Ten to 20 kW is not uncommon anymore, and even 30 kW or more is not unforeseeable (we can provide power at these levels, but cooling is a much greater challenge). Moreover, almost all IT power supplies are now autosensing and universal voltage-capable (100-250 V) to allow the same product to operate worldwide. In fact, they are also more efficient at 208 V or 230 V than at 120 V (or even lower at 100 V in Japan).
We can increase the power delivered to each rack by increasing the voltage (or amperage) and also by running three-phase power to the racks. The diameter of the cable determines its "ampacity," or the number of amperes it can safely carry (and its cost). The voltage that is used will determine how much power can be delivered at different voltages over the same conductor size (example: 12-gauge wire, typically used for 20 A feeds for distances of up to 50 feet).

Note that under North American Electrical codes, the branch-level circuit breakers are 80% rated, so that only 16 A can be delivered to the load.

### Branch circuits: Single-phase power distribution

<table>
<thead>
<tr>
<th>Amps</th>
<th>Voltage</th>
<th>KVA</th>
<th>Three conductors</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>120</td>
<td>1.9</td>
<td>L1 + N + G</td>
</tr>
<tr>
<td>16</td>
<td>208</td>
<td>3.3</td>
<td>L1 + L2 + G (across any two of three phases)</td>
</tr>
<tr>
<td>16</td>
<td>230</td>
<td>3.7</td>
<td>L1 + N + G</td>
</tr>
</tbody>
</table>

### Branch circuits: Three-phase power distribution

<table>
<thead>
<tr>
<th>Amps</th>
<th>Voltage</th>
<th>KVA</th>
<th>Five conductors</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>120</td>
<td>5.7</td>
<td>L1 + L2 + L3 + N + G (120 V any phase to neutral)</td>
</tr>
<tr>
<td>16</td>
<td>208</td>
<td>5.7</td>
<td>L1 + L2 + L3 + N + G (208 V across any two of three phases)</td>
</tr>
<tr>
<td>16</td>
<td>400/230</td>
<td>11</td>
<td>L1 + L2 + L3 + N + G (230 V any phase to neutral)</td>
</tr>
</tbody>
</table>

Note that by making three-phase power available in the rack, you will increase the available power by a factor of 300%, yet increase your cable conductor count and its cost by only 66%.

Moreover, by deploying three-phase 208/120 V power to the racks, you can supply either 208 V single-phase or 208 V three-phase power and also provide 120 V for older or specialized IT gear (that may only work on 120 V).

In fact, by running three-phase power, some rack-level PDUs (aka the rack power strip) can provide **208 V and 120 V simultaneously** from the same strip.
Instead of hardwiring, also consider using three-phase connectors such as NEMA "Twist-Lock" L21-20 or L21-30 (20 A/5.7 kVA or 30 A/8.6 kVA, respectively) or the larger IEC 309 40-60 connectors (also called "pin and sleeve"), or even Russell Stove for higher power. This will permit you to change power strips as your equipment changes, without rewiring. While this is somewhat more expensive up front, it can save a lot of money in the long run by providing an easy and lower-cost solution to moves, adds and changes during equipment upgrades.

While on the subject of rack-level PDUs, please consider using units that allow remote monitoring to prevent overloads and also allow for energy management and capacity planning.

In the 400/230 V system, all output circuits are 230 V single-phase (from any phase to neutral and ground).

**Floor or row-level power distribution**

Depending on the size of the data center and the amount of power required (and power density), power can be distributed at 480 V or 208/120 V in North America. Assuming that you have larger installation, 480 V is the most common and preferred choice for the UPS and all major power distribution until it gets to the data center floor.

Once the 480 V power has been delivered to the floor or row PDU, it needs to be transformed down to 208/120 V for use by the computer equipment. The type of the transformer will impact its efficiency and the overall efficiency of the data center.

**Transformer types and the K-Factor**

No discussion of power distribution would be complete without a mention of transformer types and the "K-Factor." Check out this tip for more info on data center transformers. In a 400/230 V distribution system, there is no transformer required, only circuit breakers to protect the branch circuits. European sites sometimes specify a transformer in the PDU to provide addition isolation and also to mitigate the effects of phase imbalances on the upstream UPS, especially if it is a transformerless UPS.
The North American 208/120 V distribution system also does not require a transformer, only circuit breakers to protect the branch circuits. However, data center designers will sometimes specify a transformer in the PDU to provide additional isolation and mitigate the effects of phase imbalances on the upstream UPS, which is especially true if it is a transformerless UPS.

As noted in the discussion of the rack-level power, the higher the voltage, the lower the current required to deliver the same power to the load. The lower amperage will also lower the size and cost of the electrical switchgear, UPS, distribution panels and copper cabling used throughout the entire system. This can amount to a significant overall savings.

### Current required to deliver 300 kVA to PDU at different voltages

<table>
<thead>
<tr>
<th>Amps</th>
<th>Voltage</th>
<th>KVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>833</td>
<td>208/120</td>
<td>300</td>
</tr>
<tr>
<td>433</td>
<td>400/230</td>
<td>300</td>
</tr>
<tr>
<td>360</td>
<td>480/277</td>
<td>300</td>
</tr>
</tbody>
</table>

Conversely, here is a chart to show the effect of a fixed current capacity (such as based on existing wire size) versus voltage.

### Power delivery to PDU at different voltages*

<table>
<thead>
<tr>
<th>Amps</th>
<th>Voltage</th>
<th>KVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>208/120</td>
<td>144</td>
</tr>
<tr>
<td>400</td>
<td>400/230</td>
<td>277</td>
</tr>
<tr>
<td>400</td>
<td>480/277</td>
<td>332</td>
</tr>
</tbody>
</table>

*Example uses 400 A-rated circuits and feeder cabling.*
This is useful if you are considering a voltage upgrade by retrofitting the distribution system and want to save money and construction time by re-using the existing cables and conduits to the PDUs. For example, converting existing feeder cables from 208 V to 480 V, you can deliver over twice the power over the same cable -- just make sure the panels and switchgear are rated for the higher voltage.

**Safely hazards and voltage**
In North America, we commonly use 208/120 V to end-user equipment using standard plugs and receptacles. It is also a common practice for electricians to add circuits to live 208/120 V distribution panels. The 480 V service has a much higher potential for an electrical arc to occur and is therefore not considered safe for plug-in equipment. At 480 V, the danger of Arc Flash is substantially greater -- electricians require additional safety gear to work on 480 V circuits, and the possibility of service interruptions is higher due to an arc occurring during electrical work in the panel.

**Will European voltages work in U.S. data centers?**
In Europe, only single-phase 230 V is distributed to plug-in devices via standard IEC C13- and C19-type receptacles and plugs, at up to 16 A. However, three-phase 400 V power is also commonly available via the larger IEC type 309 receptacles at up to 60 A. Also in Europe, 400 V work in the panel is commonly done (with appropriate safety gear), since that is the basis of all their power distribution systems.

Historically, which side of the ocean you occupy has dictated which voltage has been used in a given country and in data centers. However, the inside of the data center has become its own microcosm, sometimes independent of its location. It is clear that European data centers will continue to use the 400/230 V system since it is already native to their overall existing power system.

One of the major advantages of the 400 V European system is that there is no voltage conversion; therefore there are no additional transformers required for voltage conversion (other than the main utility transformer). This makes the entire power system potentially smaller and more efficient overall.
In North America, several vendors now offer 400/230 V products as a higher-efficiency alternative to traditional 208/120 V distribution systems. They typically use an "autotransformer" (which is smaller, lighter and more energy efficient than a traditional stepdown/isolation transformer) in the floor- or row-level PDU. This allows these PDUs to work with a standard 480 V UPS and 480 V distribution system that is carried to the PDU, and the PDU then outputs 230 V (single-phase) to the IT racks. It offers greater efficiency and a smaller footprint on the data center floor. Some vendors have created 400/230 V "touchless" modular PDU systems that shield the main buss, allowing circuit packs (breakers and cabling) to easily and safely be added and removed.

In a more advanced 400 V power scenario, the UPS would be fed at 400 V and there could be no transformer in the PDU. The main input power to the data center and all the power equipment’s switchgear, generators, etc., would be 400 V; potentially it would be just like a European data center -- the North American high-utility voltage would be transformed only once to down 400 V (instead of 480 V). Afterward, there would be no need for a transformer to step down the voltage, theoretically avoiding all transformer losses and minimizing copper cabling losses while allowing the IT power supplies to operate at 230 V, at which they are the most efficient.

In so far as 400 V power taking hold in North American data centers, it may take many years or it may never take hold as a mainstream system. There is massive mindset change required by all those involved in the designing, building and operating of the data center. Moreover, the existing equipment has inertia and very few people or equipment makers may want to make such a major change in the hope of gaining a 2-5% potential increase in energy efficiency. Then again, stay tuned -- if energy prices continue to rise, it may cause everyone involved in the data center to examine every option.
Resources from Schneider Electric

Tackling Today’s Data Center Energy Efficiency Challenges – A Software-Oriented Approach

Low Voltage Circuit Breaker Guidelines for Data Centers

Case History of Data Center Ground Fault Protection Optimization

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