Recommended Ground / Net Current Testing Methodology & Equipment

Lou Vitale, B.S.E.E. Senior Engineer
Revised January 22, 2021
www.vitatech.net

Recently constructed buildings fully compliant with the National Electrical Code (N.E.C.) should have low levels of circulating ground/net current less than several amps (2.5 amps) measured on the secondary feeders unless there are serious N.E.C. violations (i.e., grounded neutrals and wiring errors) in the electrical distribution system. Older buildings generally have elevated (10 to 100 amps) and higher levels exceeding 100 amps of circulating ground/net current from various sources such as leaky motor and / or transformer coils, VFDs, grounded neutrals (i.e., electrical outlets, kicked insulation on neutral wires) and wiring errors. Errant ground/net currents travel on numerous electrically conductive MEP paths back to the source transformer "wye" N.E.C. grounded connection via metal conduits, pipes, cable trays, HVAC ductwork, gas lines, metal rebar and building steel. Common N.E.C. violations are addressed in sections 300-3(b) and 310-4 requiring all conductors of each circuit to run together, including the neutrals and equipment grounding conductors (no separate neutral home runs). Another problematic N.E.C. violation is addressed in sections 250-23(a) and 250-61(b) prohibiting grounded neutrals on the load side of the service entrance, which can generate elevated magnetic field emissions and life safety problem depending on the magnitude of the problem.

In new and older building's, I recommended implementing a Ground/Net Current Mitigation Program to identify and fix (correct) National Electrical Code (N.E.C.) violations in the electrical distribution system. The objective is to reduce the magnitude of the circulating ground/net currents, and thereby, reduce the potential electromagnetic interference (EMI) impact from the circulating ground/net currents on MEP conductive paths upon EMI sensitive research and diagnostic medical instruments (i.e., TEMs, SEMs, FIBs, E-Beams, NMRs, MRIs, EEGs, EKGs, etc.).

Vitatech recommends securing one or two (preferred) locally licensed electricians who must be supplied with protective facemask and Kevlar provided by the client as required to open distribution and electrical panels, measure/identify feeder circuits and panels with excessive ground/net currents and to generate a list requiring corrective measures. The electricians should have a flexible current probe to measure ground/net currents in the electrical panels and branch circuits (see www.aemc.com and next page for example).

I recommend the 24-inch flexible current probe (~$400 USD) for testing metal conduits, pipes and inside electrical panel conductors for net/ground currents.

AmpFlex-30/300A, 24", 100mV/10mV/A
Model: 300-24-2-10 Cat#: 2112.88

Your electricians should follow the detailed testing and remediation procedures described in *Tracing EMFs in Building Wiring and Grounding* by Karl Riley (purchase from www.lessemf.com). This is an excellent book describing the salient testing methods and remediation issues. The objective is to test all electrical panels within the building and to record the feeder/branch circuits test results in a Ground/ Net Current Testing Log with notes showing the panel number, testing results (passed or failed) and corrective measures (branch circuits traced and problem fix) to achieve full compliance with the N.E.C. Also, it is absolutely critical to test all MEP sources within and adjacent to EMI sensitive research areas (i.e., TEMs, SEMs, FIBs, E-Beams, MRIs, NMRs, EEGs, EKGs, etc.). Once all the panels, branch circuits and MEP N.E.C. violations are remediated within the EMI sensitive research areas, the magnetic field levels within these areas should be reduced and any AC ELF magnetic shields will perform as designed without compromise.

Ground/Net Current detection work should first commence in the Main Switchgear Room and then proceed to electrical closets on each floor measuring busways and panels from the highest floor down to the lowest floor below grade. First, record the total current on the panel conduit feeder: if it measures less than 2.5 amps, the panel/branch circuits are considered acceptable, and move to the next panel. However, any circuits greater than 2.5 amps could have ground/net currents on the branch circuits, so the panel must be opened, and the net sum (three phases and neutral currents) must be measured and compared to the conduit measurement. If no difference is measured, then record the data and proceed to testing the net currents on all branch circuits (remediate any branch circuits with net currents exceeding 2 amps).

It should be noted that ground/net current testing is not a trivial task and depending on the size of the electrical distribution system, areas to be tested and complexity requires more time than estimated to successfully complete and mitigate.

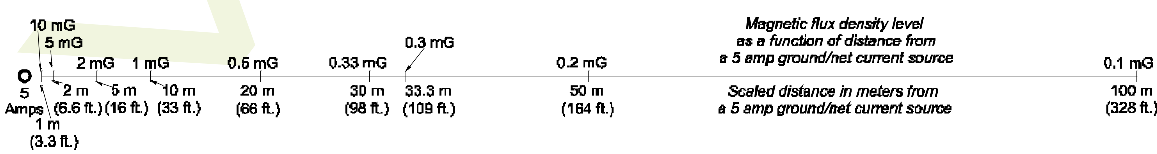
Net/Ground Current Issues

Ground and net currents are due to N.E.C. violations (i.e., grounded neutrals, wiring errors, leaky induction motor coils, etc.) in the electrical service, distribution and grounding systems of a building and N.E.S.C. violations (i.e., grounding problems, etc.) on distribution and transmission lines. Unbalanced phases on medium voltage distribution lines and low-voltage 480V/277V & 208/120V feeders generate zero-sequence currents, which return on the neutrals, grounding conductors and conductive MEP. Most utilities maintain 5% and less unbalanced phases on high voltage transmission lines and 10-15% unbalanced phases on distribution lines (power quality issues) except in local neighborhoods where unbalanced phases may exceed 20%.

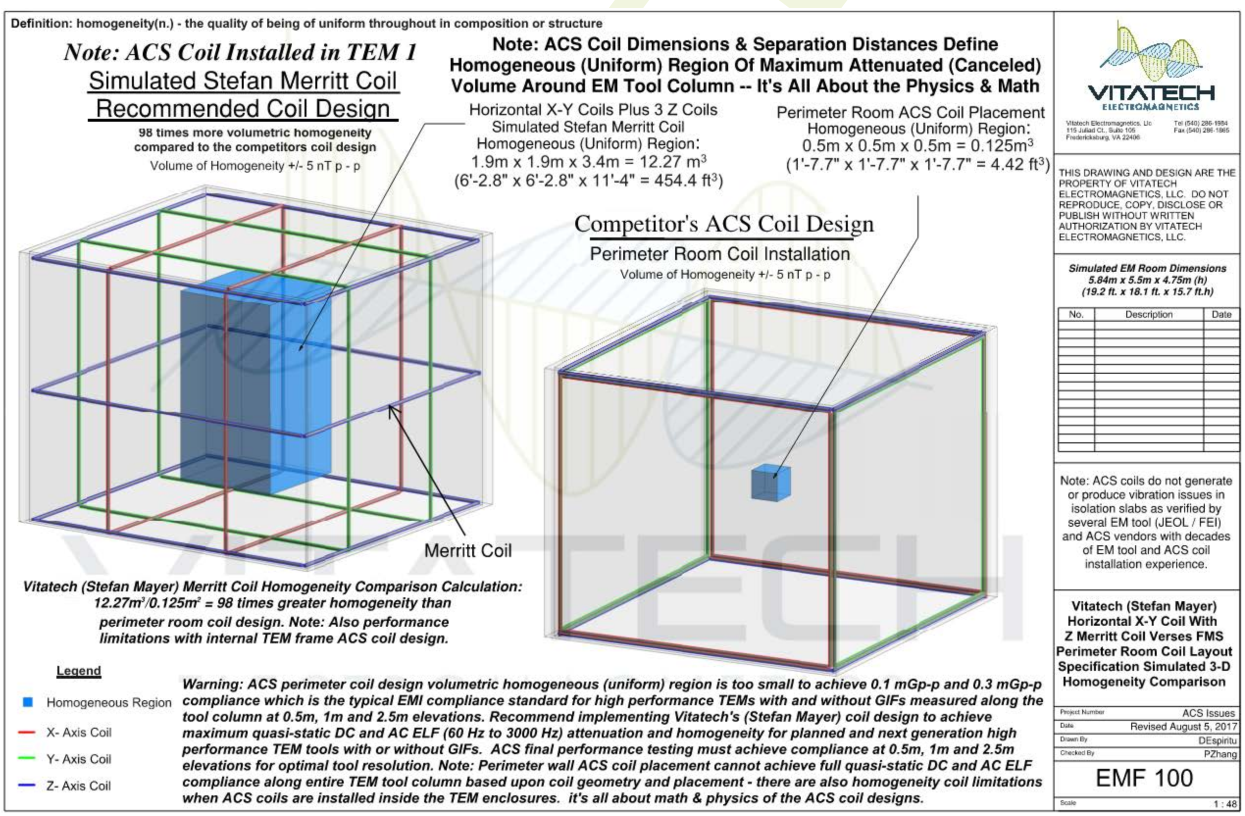
A percentage of the zero-sequence neutral currents on primary distribution and secondary low-voltage 480V/277V & 208V/120V circuits travel along other electrically conductive paths (i.e., underground water pipes, earth channels, grounded guy wires, building neutrals/grounding systems, etc.) back to the transformer grounded "wye" in the building and substation. If all the zero-sequence currents were to return via the multi-ground neutral system (MGN) wire mounted on the pole under the three phase conductors (sum of all phase and neutral currents are zero), then the magnetic fields would decay at the normal inverse square rate ($1/r^2$ in meters) from the single-circuit distribution line (same for transmission lines and low-voltage feeders). However, if only a fraction of the zero-sequence current returns on the MGN system or low-voltage neutral conductor, then there is a net current missing (amount of current returning via other paths) – this net current emanates a magnetic field in units of magnetic flux density (mG) similar to a ground current (electrical current of low voltage returning on a ground wire, water pipe or other conductive path) that decays at a linear 1/r (in meters) rate based upon the following formula:

$$\mathbf{B_{mG(RMS)} = 2(I)/r} \text{ where I is amps}_{(RMS)} \text{ and r meters}$$

Magnetic fields from ground and net (zero-sequence) currents decay at a slow, linear rate illustrated below, using a 5 amp ground/net current source: 10 mG is 1m away, 1 mG is 10 m away, 0.5 mG is 20 m away and 0.1 m is 100 m away:



Since there is a proportional relationship between current load and magnetic flux density levels, the above chart can be used to predict the emission levels based upon ground/net current loads. Using 2.5 amps of ground/net current, the levels above the selected decay distance are calculated by dividing by 2, which is 50% of 5 amps. The ground/net current decay chart is indispensable in ascertaining the acceptable operating distance from ground and net (zero sequence) currents based upon a specified instrument performance criterion (i.e., 1 mG, 0.1 mG or 0.01 mG). Ground and net current magnetic field emissions are difficult to shield using passive flat or L-shaped ferromagnetic and conductive shields -- the most effective shielding method for AC ELF ground/net current emissions requires a six-sided instrument room, seam welded aluminum plate shielding system. Wide-bandwidth (0.01 Hz – 10,000 Hz) Active Compensation System (ACS) technology can also attenuate ground / net current 60 Hz with higher harmonics and quasi-static DC (moving ferromagnetic masses - elevators, vehicles, carts, etc.) magnetic field emissions. However, special consideration is required when calculating and designing the ACS cancellation coil system to include the appropriate gradient turns and Merritt coil to maximize attenuation, homogeneity, image resolution and stability along the EM tool column because ground/net current magnetic field emissions change instantly in magnitude and phase with the equipment and building loads.



Finally, low ambient magnetic field levels can be achieved inside a research laboratory, cleanroom and lithography suite by adhering to the N.E.C. and good wiring practices. However, these low levels can only be achieved under the most pristine conditions without circulating ground/net currents present on the primary electrical distribution system outside of the building, low-voltage distribution feeders and branch circuits inside the building and the building grounding and MEP systems otherwise a six-sided highly conductive passive AC ELF magnetic shielded room is required to obtain a guaranteed low 10 nTp-p (0.1 mGp-p) and less AC ELF environment for sensitive research instruments and high performance ion-beam electron microscopy (EM) imaging tools.

Please call Vitatech if you have any AC ELF & Quasi-Static DC EMI issues