Suggested Protocol for School Electricians for Correcting Wiring Errors Causing Net Current Magnetic Fields

by Karl Riley

Introduction

The California Health Services magnetic field school survey identified internal wiring circuits as a major source of elevated magnetic fields in school buildings. Since correctly wired circuits will not produce these elevated fields a Pilot Study was conducted to pin down the causes of these fields. Five schools were carefully investigated and it was found that in most cases net current fields were caused by wiring connection errors. Some net currents were due to an allowable grounding method for separate structures (no longer allowable as per the 1999 Code).

Definition: **"net current,"** when referring to wiring, is the unbalanced resultant current carried by a circuit when **some of its neutral return current has been diverted to another circuit or conducting path.** It also applies to the current on the diverted path, which can be metallic paths such as water pipes, or another circuit's neutral conductor. Net currents are potent because they create a high field to start with and they weaken only slowly (directly with distance). The magnetic field (mG) at one meter from a net current source will be twice the net current amps. ($B = 2i/d$).

Note: The term **"neutral"** is used in the protocol for the **grounded circuit conductor,** which is the more accurate but lengthy term. Since this common usage of "neutral" is generally accepted, it is used in this protocol.

The National Electrical Code© (NEC) prohibits the shunting of neutral current away from its dedicated circuit in several sections:
Section 250-24(a)(5) - 1999 – prohibits connecting of neutrals to any grounding connection on the load side of the service entrance main disconnect. Formerly this was 250-61(b).
Section 310-4 prohibits connecting a neutral to another neutral such that a parallel return path to the panel is set up, unless the conductors are 1/0 or larger and meet exacting conditions.
Section 300-3(b) requires all conductors of a circuit to run together in whatever channel they are using. This reinforces Article 310-4.
Section 300-20(a) repeats the above requirement with attention to circuits running in metallic enclosures such as conduits, pointing out the inductive heating effect on the conduit.
The 1999 NEC Section 250.-32(b) no longer allows the neutral bus in the panel for a separate building to be bonded to ground at the panel unless there are no grounded metallic connections between the buildings. There must be a separate equipment grounding conductor run with the feeder and the neutral bus must be isolated from the panel box. This replaces the former 250-24(a) which had allowed this bonding, with the effect that neutral current from the separate building could return on water and gas pipes, etc. run to the building. In two schools of the Pilot Study this net current was seen in extensive areas of the school, on gas pipes.

The hazards resulting from violation of these Code sections:

The NEC's requirements are based solely on danger of fire and shock. There is no other criterion for Code articles. The Code does not spell out these hazards. For this reason we have books such as Designing Electrical Systems, based on the 1993 NEC[1].
Commenting on 300-20, "All AC conductors run in a metal conduit or raceway are required to be grouped together in the same raceway to prevent induced currents in the conduit. When alternating currents flow in a conductor, a varying magnetic field is set up around the conductor. The magnetic field sets up induced currents in the metal of the conduit surrounding the conductor, and these currents cause the metal to heat. The heating of the metal can melt the insulation of the conductor, causing a short. If all the conductors of a circuit are grouped together in the same conduit or raceway, the magnetic field of one conductor will neutralize the fields of other conductors. The currents will be in opposite directions; therefore there will be no magnetic field and no induced currents in the conduit or raceway." - p. 37

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[1] *Designing Electrical Systems, based on 1993 NEC*, by Jams G. Stallcup, American Technical Publishers, Inc., p. 37.

Commenting on 250-61(b), "One major reason that the grounded circuit conductor ["neutral"] is not permitted to be grounded on the load side of the service is that, should the grounded service conductor become disconnected at any point on the line side of the ground, the equipment grounding conductor and all conductive parts connected to the equipment grounding conductor will carry the neutral current, raising the potential to ground of exposed metal parts not normally intended to carry current. This could result in arcing in concealed spaces, and it could pose a severe shock hazard, particularly if a single point in the path should be opened inadvertently by a workman. However, even without an open grounded conductor (usually referred to as an open neutral), the equipment grounding conductor path will become a parallel path with the grounded conductor, and there will be some potential drop on exposed and concealed dead metal parts. The size of this potential drop will be determined by the relative impedance of the equipment grounding conductor path, but all parallel paths not depended on as an equipment grounding conductor would be affected. This could involve current flowing through metal building structures, piping, and ducts." - p. 181

The NEC does not directly address power quality problems leading to malfunctioning of computers and other electronic devices; however electrical contractor journals are full of articles dealing with the increasing incidence of EMI (Electromagnetic interference). Magnetic field levels of 5-10 mG (milligauss) are known to cause "jitter" on computer screens. These levels are created by net currents of only 750 mA - 1.5A in conductors one foot away. Very small voltages on grounds due to connection of neutral to ground on the load side of the service often cause computer malfunctions. A copy machine on a circuit with a net current wiring error will produce huge spikes in the magnetic field when it switches on.

Protocol

Background:
If your school was part of the California Health Services study, the areas affected by internal net current fields have been mapped out by a survey conducted using a gaussmeter to record the field levels and trace their paths. If not, a walk through with a gaussmeter will identify the areas affected. This in turn shows you which panel to check to identify the circuits causing the fields.

Most net current wiring errors can be identified as to circuit at the breaker panel using a clamp-on ammeter. This is because every correctly wired cable or group of conductors will give a "0.0" reading on a clamp-on ammeter. If you get a reading, you are measuring net current and have located a faulty circuit. A small percentage of net currents will not be seen at the panel because they begin and end out in the circuit (such as incorrect 3-way switch wiring) and can be found either with a gaussmeter or by a routine check of all conduit runs with a clamp-on ammeter.

Description of typical errors you will be looking for.
You will be looking for any connections which shunt neutral return current to another path other than the dedicated conductor. When the condition is **neutral current on grounding conductors** and other metallic paths (water pipes, gas pipes, heating pipes, HVAC ducts, building steel, metal lath, ceiling panel grids, window frames, conduits) the most common place to look is in the subpanel where the neutral bus is sometimes mistakenly bonded to the panel either deliberately with a strap or conductor or else by turning in the bonding screw in the neutral bus. Equipment grounding conductors may also be connected to the neutral bus - violation: 250-24(a)(5).1999.

Another way neutral is shunted to grounding paths is by the pinching of neutrals, nicking the insulation, such as at fluorescent light fixtures improperly mounted, in receptacles, occasionally by sheet rock nails, and sometimes deliberately by bonding the neutral terminal of a receptacle to the grounding screw.

The second type of error is the **wire-nutting of neutrals from two branch circuits together** when they happen to share a junction box. This allows neutral return current from loads belonging to one circuit to return to the breaker panel through both the dedicated neutral as well as the neutral in the second branch circuit. Thus both circuits will have an identical net current; one because of an excess of neutral, the other because of an equal deficit of neutral. The magnetic field created is the same. The heating effect on the conduits is the same. **This** is **the most common cause of net current fields in buildings.** Clearly, many electricians are not aware that by malting this connection they are violating 310-4, 300-3(b), and 300-20(a) if in conduits. They are also creating a situation where another electrician preparing to work on a circuit opens the breaker on the circuit, but instead of the conductors being dead, the neutral sparks when he disconnects it, since it is still live. Not a good situation.

Additional errors of a grosser nature will cause high fields. At a junction box neutrals may be mixed up and the wrong neutral run with the wrong hot. Sometimes a neutral may be dead for some reason and another neutral has been pulled in from another circuit or even another subpanel, causing a high net current. All of these variations put neutral return current in the wrong conductors, and all will be found by following the suggested protocol.

Panel protocol:

Cautionary note. It is assumed that only authorized personnel are using these suggestions. Opening panels and junction boxes under live conditions exposes the workman to live conductors with the possibility of severe shock. All professional cautionary measures should be taken.

In order to check the circuits in a panel, there should be loads on as many circuits as possible. For that reason, checking panels during a normal operating day is best. Otherwise someone must go around turning all the lights and usual appliances on.

After taking the cover off a panel stop and check it out visually. If this is not the service entrance panel, look for any bonding of the neutral bus to the panel box. Look for any green or bare conductors in the neutral bus. Check the neutral bus bonding screw to be sure it is either backed out or removed. Subpanel neutral/ground bonds should be removed. Equipment grounding conductors should be provided with their own bus. The neutral bus must be electrically isolated from the panel box.

To find wiring errors in circuits first identify the circuit with the net current. This can usually be done at the panel for that area. The technique is to clamp an ammeter around each circuit or group of circuits leaving the panel box by way of a conduit. In a crowded box this may be impossible using the usual medium-sized clamp-on. For panel work the right sized jaws are a necessity. See **Resources, Instrumentation** below for recommended sizes of clamp-ons, from mini to extra large. Also note that there is a book available which fully explains this entire measurement/mitigation process in detail *(Tracing EMFs in Building Wiring and Grounding).*

Secondly you need a clipboard with a rough diagram of the box and a place to write down your measurements. See an attached form that has been useful. You have to draw in circles wherever there is a conduit leaving the panel and number them. Then when you measure that group of conductors you enter the measurements next to the same numbered list.

As you measure each group of conductors the ammeter will read 0.0A if the circuit is correct. Write 0.0 on the sheet after "group". That's all. But if you get a reading, say 2.6A, write that down after "group" and go on to the next step. You will now determine if the 2.6A net current is due to missing neutral or excess neutral. Clamp around the hot or hots. Record. Then clamp around the neutral or neutrals. Record.

The two numbers should have been equal. If not you will see if there is missing or excess neutral. Now measure any equipment grounding conductors that may be running with the circuit. Record. If there is more than, say, 0.1A there may be a neutral/ground connection somewhere in the circuit. A general finding of a tenth of an amp or so on many equipment grounding conductors may simply mean some neutral flowing on grounds somewhere. But you don't chase the currents on the grounds, which are too elusive; you stick to the source of the currents in missing neutral.

To determine exactly which circuit has the error, if there is more than one circuit in the group, you need to measure each conductor separately. Measure each hot and record, noting its color. Then measure each neutral. Record. How do they match? Do you have one hot which matches with a neutral and one which does not? Then follow that hot to its breaker and identify the circuit. Usually it will be a lighting circuit, since most net current sources are lighting circuits with their many junction boxes.

If one neutral appears to go with two or three hots, then clamping around the group of hots should yield the same resultant in amps as the accompanying neutral. Sometimes you may suspect a mix-up in neutrals. This can be determined with your clamp-on. Suppose you have a hot carrying 5A and its neutral also carrying 5A. Clamp around both and you should read 0. But instead you read either 10A or something like 7A. If you get 10A that neutral was from the other "phase" or hot leg in a single phase service. It's the wrong neutral. If it is 7A or so, it is from another phase of a two or three-phase panel. Also the wrong neutral. In any case the neutrals are mixed up and need to be sorted out back in the junction box where they were incorrectly connected.

If there is either excess or deficit of neutral in a circuit, as you continue to clamp around groups of conductors be on the lookout for a second circuit carrying the missing neutral deficit or excess. It will be the same net current, unless more than two circuits have been mixed up. Usually they come in pairs. Later you can trace these circuits out to find where they are sharing a junction box, and lo and behold, you may see one beefy wire nut binding all the neutrals together. All you have to do is use two wire nuts and separate the neutrals so that each is wired to the appropriate load circuits, with no connections between the branch circuits.

If you do not find a circuit that pairs with the first net current one, it may be because the other circuit it is sharing neutral current with came out of another subpanel. In that case this net current will be seen by clamping around the feeder for the panel. The missing or excess neutral will give the same net current as in the circuit. Clamping around the feeder hots and comparing with the neutral will give more information. Once again instrumentation is the key to being able to do this. I use the flexible clamp-on LEM or AmpFlex which will fit around any feeder cable or conduit. See **Instrumentation.**

A more common reason for neutral deficit measured around the feeder would be a neutral/ground connection, shunting some return neutral to pipes, other conduits, etc.

Tracing down the error location:
Once you have identified the circuit or circuits with net current you can go looking for the error, which is usually but not always in a junction box. If it is a neutral/neutral error, almost certainly it is in a junction box. If it is a neutral/ground error it may well be accidental and you may be lead to the error area by this protocol but **visual** inspection may be the key to finding it, unless you get into more sophisticated instrumentation.

If you have a good knowledge of the circuits and you have an idea where two neutrals have been connected from two branch circuits, you may go right to that area and start looking for the junction box. If not, proceed as follows:

Usually the conduits will go up into the ceiling area and be accessible by removing ceiling panels. You will be able to clamp on your ammeter around conduits until you find one with net current. Visually note where the first junction box is located. Go to that spot. Open the box. Clamp on the circuits. Follow the net current. Keep going until you find the box where the misconnection of neutrals exists and use your second wire nut to separate them out. When you have fixed the error your clamp-on ammeter will read zero, and the net current with its magnetic field will be gone. A walk through with a gaussmeter will show that the field has disappeared.

Tracing neutral/ ground connections can be more difficult if due to accident. The net current on the circuit may either stop or attenuate markedly at a certain point. Here is where you look for pinched neutrals in a fixture or receptacle or a possible nail shorting neutral to equipment grounding conductor. Luckily that is a rare occurrence. Sometimes the neutral/ground connection is deliberate, as when an electrician has connected a wire between neutral screw and grounding screw in a receptacle. Sometimes an electrician may not have had a piece of green conductor with him and used a white one, and someone else assumes that is a neutral and adds a receptacle, connecting neutral to the white (now ground). There is no end to creativity of this type and it is up to you to figure it out.

Note: If all the conduits from a panel come out in an accessible ceiling, it is possible to bypass the opening of the panel and start directly with the conduits, clamping around each until you find the net current ones. Then follow as above.

There are more tracing instruments you **can** use which are described in *Tracing EMFs in Building Wiring and Grounding*, This protocol is based on the simple use of two or three sizes of clamp-on ammeters to do the job.

Resources

Instruments:

Clamp-on ammeters: For measuring circuits and conduits up to 3/4" the **Yokogawa CL-611** has a jaw opening of 7/8" and has a digital display that reads from 10mA to 200A. Price is around $150.00. Listed in the Jensen catalog, (800) 426-1194. Or call Yokogawa for local distributors at (800) 258-2552.

For measuring feeder cables, large conduits, water pipes, etc. a very inexpensive and versatile clamp-on with a jaw opening of 2 1/4" is the **Tenma 72-555** clamp on accessory. It needs to be plugged into a digital multimeter with at least 10 Mohm impedance with a mV AC setting. The clamp-on produces 1 mV per amp, so it is best to have a multimeter with a 0.1 mV resolution, which means usually a 200mV setting on the face (sometimes 400 mV). The Tenma 72-555 sells for less than $30.00 and is presently available from MCM Electronics at (800) 543-4330. MCM also carries a mini clamp-on similar to the Yokogawa in the same price range (Item 72-6184). They have a good selection of inexpensive digital multimeters. So does any Radio Shack.

For measuring large feeder cables and conduits, service cables, some bus ducts and large water pipes, etc., there are two excellent probes with a rubberized flexible clamp-around which will snake around conductors and are very accurate. The clamp-around is 2' in length though you can get a 3' one to measure around larger bus ducts. This accessory also must plug into a digital multimeter as it reads out on the AC volts scale. One is the **AEMC AmpFlex**. Specify the 30/300 Amp range. Can (800) 343-1391 for dealers. The other is the **LEM-300D** (do not get the less sensitive 3000D). It sells for around $300. Call LEM at (847) 4376444.

Books:

Tracing EMFs in Building and Wiring and Grounding by Karl Riley, 133p. 1995, MSI. $27.50. Order from kriley3@ix.netcom.com or (800) 749-9873 (MSI).
This book covers every stage from measurement through tracing and correcting errors. Also covers reducing fields from some grounding situations.

Old Electrical Wiring by David E. Shapiro, 413 p., 1998, McGraw-Hill, $39.95. Not an EMF guide but a general encyclopedia of electrical problems found in older buildings and how to deal with them.

Gaussmeters:

For accurate area surveys I recommend the **Bell 4080** triaxial gaussmeter since it is small, has a good display area, meets accuracy standards, and at present can't be beat at $199.50. The **Bell 4090** triaxial has tighter accuracy (1%-2%) for $395.00. To order: (800) 749-9873 or www.magneticsciences.com.

A single axis digital meter with a separate probe is useful in trouble shooting. One with the highest accuracy available is the **MSI-AJK-95** for $235. Available from Magnetic Sciences International. (800) 749-9873. (www.magneticsciences.com).

For those who prefer to watch a needle rather than digits another excellent single axis gaussmeter with a separate probe is the **ELF Sense** for $340 available from ExpanTest, (207) 871-0224 or email to r.r.wagner@ieee.org.

The Emdex II triaxial recording gaussmeter for over $2,000 is excellent for recording, over time or over space by walking a constant speed. It downloads to a PC and produces graphs and statistics. Not easy to use for surveys because of the small and slow display. Call Enertech at (408) 866-7266.

Try surfing the Web by**,** punching in "Gaussmeters." Also find a list on www.microwavenews.com. But beware. many guassmeters are inaccurate and cannot deal with typical harmonics.
