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EMC design of Switching Power Converters Part 7 - Suppressing RF emissions from converter inputs

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EMC design of Switching Power Converters

Part 7 (continued 6) —
The suppression benefits of LF mains isolating transformers, plus noise suppression for "floating" power networks and "floating" electronics

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Contents

Issues 93-101 of The EMC Journal carried the preceding parts of this "Stand Alone" series – my attempt to cover the entire field including DC/DC and AC/DC converters, DC/AC and AC/AC inverters, from milliwatts (mW) to tens of Megawatts (MW), covering *all* power converter applications, including: consumer, household, commercial, computer, telecommunication, radiocommunication, aerospace, automotive, marine, medical, military, industrial, power generation and distribution, in products, systems or installations.

Hybrid & electric automobiles, electric propulsion/traction; "green power" (e.g. LED lighting); and power converters for solar (PV), wind, deep-ocean thermal, tidal, etc., are also covered.

Issues 93-95 used a different Figure numbering scheme from the rest, for which I apologise.

I generally won't repeat material I have already published, instead providing appropriate references to the EMC Journal [14] and my recently-published books based on those articles [15], so that you don't get bored by repetition.

7 Suppressing RF emissions from inputs and outputs

I began Section 7 in Issue 98 [72] and so far it has continued up to Issue 103 [108]. Despite my aim to only publish 'stand-alone' articles, each covering a single topic, the issue of suppression is so large that it is impossible to publish it all in a single issue. However, I have – mostly – succeeded in compartmentalising individual suppression topics in each article.

7.12 EMC benefits of AC mains (LF) isolating transformers

Where a power converter shares an AC mains power distribution network with other electronic equipment (which are probably fitted with mains filters) – a number of EMC issues arise that might be best dealt with by fitting the converter with a dedicated LF mains isolating transformer.

In earlier articles in this series I called mains transformers "Low Frequency (LF) transformers", to distinguish them from the High Frequency (HF) transformers that can be used to provide galvanic isolation at the switched or chopped outputs of power converters.

Nominal mains power frequencies range from 16⅔ Hz, through the more familiar 50Hz and 60Hz to the 400Hz generated by the electrical generators fitted to aircraft engines.

One of the main reasons for using switched-mode power conversion technologies is to achieve galvanic isolation for safety reasons with lower cost and weight, by replacing the large, heavy, costly LF isolating transformers used in traditional "linear" power converters with much smaller HF transformers. The EMC issues associated with HF isolating transformers were discussed in section 6 of this series, in [66].

However, LF isolating transformers can provide valuable benefits for EMC that are not available from HF isolating transformers. So although they are large, heavy and costly components (especially because of the high price of copper these days) they can sometimes be the lowest-cost EMC mitigation solution.

To help achieve cost-effectiveness in our EMC work (see [11], [12], and section 1.4 of [13]) we should therefore ensure that LF isolating transformers are considered early in the design process, along with all the other EMC design and mitigation issues. (Later in this Section I give an example of the many very costly incidents that have been caused by leaving EMC design issues to the end of a project.)

In section 7.3 in [72] (and later) I showed how a power converter's DM and CM noise currents were 'steered' by the capacitors and inductors in its input and output filters – and by their low-impedance bonding to the power converter's chassis/frame/enclosure/etc. which is designed to provide a low impedance over the frequency range to be controlled by the filters.

The result of this "noise current steering" is that they flow mostly in the power converter's assembly; with so little DM and CM noise current flowing outside of the converter that the limits for conducted noise emissions are met, and also to help comply with the limits for radiated noise emissions by reducing the noise that is radiated from any cables.

Where an AC mains power distribution network feeds two or more items of equipment spread over a site or vessel, the DM impedances of the phases can become different from each other due to unequal loading, and the CM impedance between the phases and the earth/ground – which is usually quite high (kΩ, possibly even MΩ) – can become quite low (10s of Ω, possibly even less) due to the stray capacitances of the long cables and the CM filters in other equipment.

Resonance effects in the mains power distribution can also cause unbalanced DM impedances between its phases, and the CM impedances between phases and earth/ground can become very low indeed at resonant frequencies.

Such impedance characteristics associated with a mains power distribution network can degrade the performance of a power converter's mains filter (see [109]).

For example, when the CM impedance of the mains supply is low, the ratio between the impedance of the local noise loop (i.e. the one that is good for EMC) achieved by shunt capacitors in the mains filter, and the impedance of the external noise current loop in the mains supply (the loop that is bad for EMC) might not be as high as we would like. Figures 7.12-1 and 7.12-2 try to show this problem.

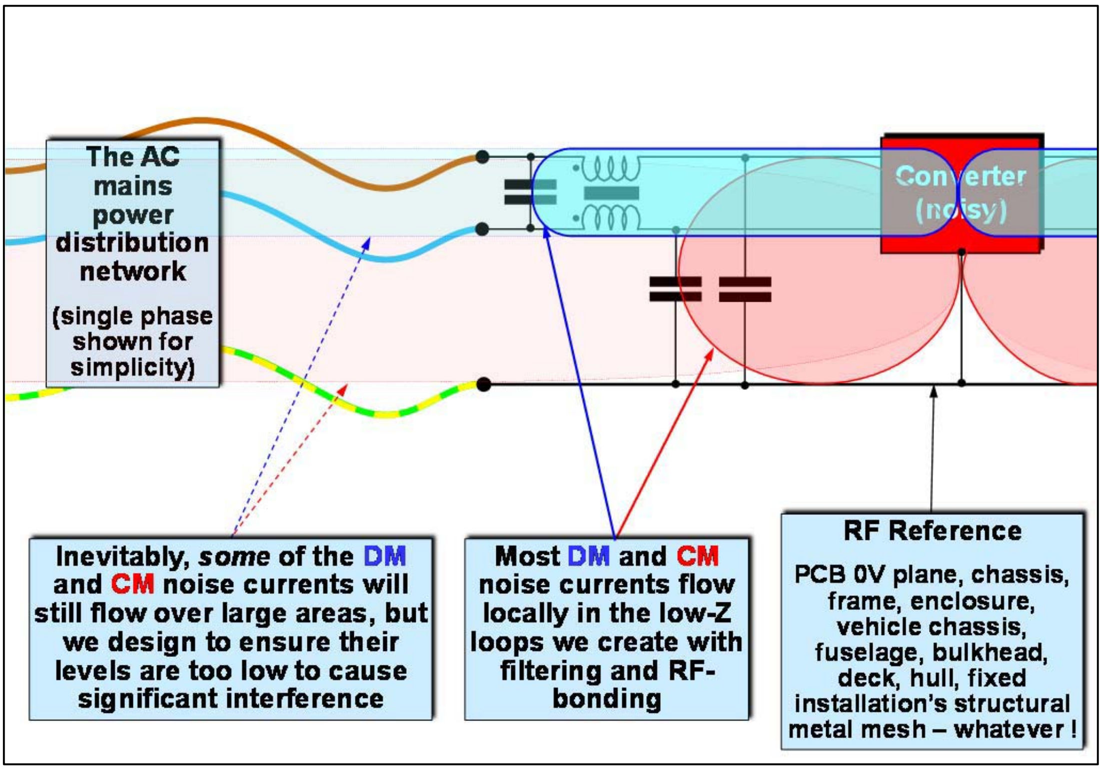

Figure 7.12-1 The intended situation: mains filtering and RF-bonding provide low-Z local paths for noise generated by the power converter

Figure 7.12-1 is a copy of just the “mains side” of Figure 7.3-8 from [72], with a little more detail added to the AC mains supply to indicate a power distribution network. It tries to show how, by using a comprehensive mains filter (single stage filter shown, most practical filters will have two stages or more, see Figure 7.3-9 in [72]) we design so as to create small area, local, low-impedance paths for DM and CM noise currents across their whole frequency ranges.

Then, by Faraday’s Law of Magnetic Induction (one of Maxwell’s four famous equations) the noise currents will “prefer” to flow in the local loops we have created, rather than flow in the mains distribution network where they can cause conducted and radiated emissions problems.

(For more on this important EMC design technique, which works *with* the laws of nature rather than against them and so achieves the greatest cost-effectiveness, see [32], [33], [85] and [111]).

Figure 7.12-1 also shows how we like to use CM chokes in our mains filters to increase the apparent CM impedance of the AC mains power supply, to help to discourage CM noise currents emitted by the power converter from flowing in the mains supply network.

But we have a problem at lower frequencies, where CM chokes behave inductively rather than resistively (see Section 5.2.6 in [5]), because their inductance can series-resonate with the CM capacitance that naturally arises in the mains distribution network (the stray capacitance between mains cables and earth/ground structures).

Series-resonant current loops have very small impedances: just the resistance of their conductors. Because the CM capacitors in the mains filter have relatively high impedances at low frequencies, most of the CM noise current can end up flowing in part of the supply distribution network, possibly causing interference, instead of circulating locally as we want.

Also, if the mains filters fitted to other equipment connected to the same mains supply have capacitive CM inputs (instead of the inductive/resistive inputs provided by series CM chokes such as used in Figure 7.12-1), this extra capacitance can add to the distribution network cables’ capacitances to create lower resonant frequencies.

So we can see that in real applications, mains filters can be significantly less effective at certain frequencies, than EMC laboratory tests would imply, and can even amplify noise emissions rather than suppress them! The result can be real-life interference problems, and these issues were all previously discussed in sections 7.3.3, 7.3.7, 7.3.12 and 7.3.13 of [84].

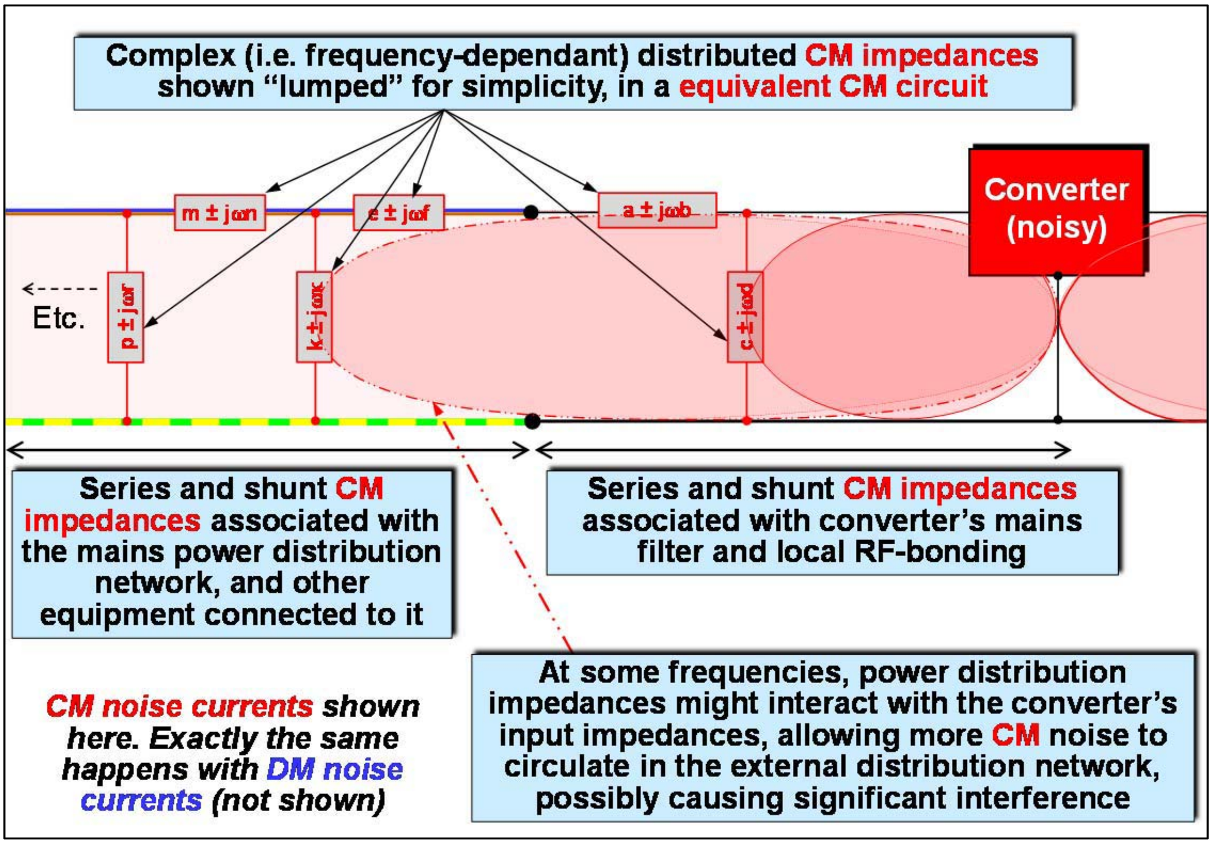

Figure 7.12-2 CM impedances in the power distribution can degrade mains filter CM attenuation at some frequencies

Figure 7.12-2 reduces the above discussion to a set of "lumped" complex impedances, trying to show that at certain frequencies the effects of the mains distribution (and other equipment connected to it), can cause mains filters to be less effective at certain, lower frequencies.

Fitting an LF isolating transformer, as shown in Figure 7.12-3, restores balance to three-phase DM impedances, which helps to keep mains harmonic emissions low and DM filters operating optimally (but note that Figure 7.12-3 only shows a single-phase system).

It also ensures that the power converter's external power supply has a high CM impedance from DC up to some low-ish frequency – perhaps several hundreds of kHz, even one or two MHz, for a low-kW-rated transformer, decreasing in frequency as the power rating increases – helping its mains filter to achieve its designed noise suppression whatever the impedance characteristics of the power distribution network over this frequency range.

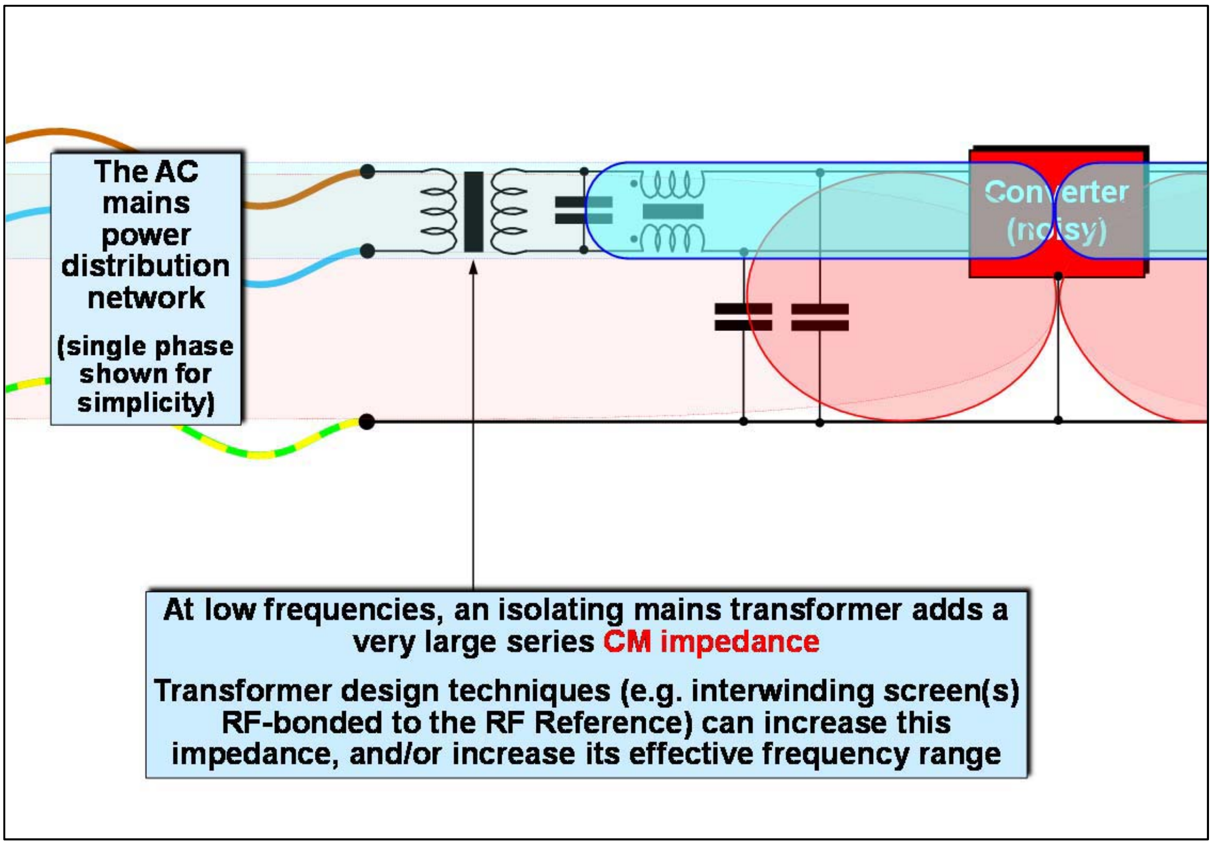

Figure 7.12-3 Using a mains isolating transformer

Because the main problem is that RF-suppressing CM chokes are predominantly inductive at low frequencies and so can series-resonate with the CM capacitances naturally present in the power distribution network and/or other equipment connected to it, there are three alternatives to fitting a large and costly transformer as discussed above:

a) Dampen the converter's mains filter
b) Increase the inductance of the power converter's input
c) Add line-ground capacitance to the network

Selecting mains filters so that they do not resonate when supplied or loaded with complex impedances in real life (as distinct from the resistive 50Ω impedances that are used in all EMC test laboratories for mains sources and loads), was covered in Sections 7.3.7 and 7.3.8 of [84], so I won't repeat that material here. When we are constructing our own mains filters, we need the damping information given in Chapters 5.2.8 and 5.2.9 of [5].

Items b) and c) in the above list both have the same aim, and may be applied individually or together: to reduce the resonance frequency of the distribution network so that it is much lower than the lowest noise frequency (f_{MIN}) emitted by the power converter, which is its lowest switching/chopping frequency.

There are two main concerns with manipulating the resonances caused by the interactions between the impedances in the power distribution network and those in the converter's mains input:

i. This type of approach is unsuitable where the configuration of the power network could change, unless so much line-ground capacitance or series inductance is added that in all possible configurations the series resonant frequencies are much lower than f_{MIN}.

ii. We should not try to be too clever by carefully tuning the series resonances to lie between two of the line spectra in the converter's noise emissions.
Natural variability in the capacitance of the power distribution network and its connected equipment could cause this frequency to change over time and Murphy's Law tells us that it is bound to end up co-incident with a converter noise emission frequency – but only when it causes us the greatest possible trouble, cost and embarrassment.

Increasing the line-ground capacitance is a rather obvious thing to do, so I won't say any more about it here, other than to mention that the capacitors used should be appropriately Y-rated for safety reasons, and should cope with the ripple current from the AC supply and its harmonic and inter-harmonic waveform distortions (which can be up to 30% in some offshore platforms, see [54]) plus the noise voltages created by the emissions from electronic equipment – for the anticipated operational lifetime – despite their worst-case exposure to the physical and climatic environment (shock, vibration, humidity, temperature, etc.) and reasonably foreseeable lapses in maintenance.

If you think I'm being a bit alarmist about the importance of ensuring the high-reliability of capacitors fitted to a mains distribution network, please read [113]. This reference is to a case study of the catastrophic failure of power factor correction capacitors on board the Queen Mary, that left that vessel – with thousands of passengers and crew on board – in the pitch dark and without any electrical power, drifting entirely at the mercy of ocean tides, currents and winds, for about an hour.

We can increase the inductance of the power converter's mains input by adding series inductors commonly known as "line reactors", which are often used to decrease the mains harmonic emissions from power converters.

These series inductors were mentioned in Section 7.2 and shown on Figures 7.2-3 and 7.2-4 in [72], and will be discussed in more detail in the future section on suppressing mains harmonic emissions. In this situation they are used to reduce the frequencies of any resonance with network CM capacitances until they are so low that they are well below the lowest frequency emitted by the power converter and so do not influence its emissions.

But all series chokes reduce the mains power supply voltage to some degree, which can reduce the power available from the converter, can make it too inefficient (by wasting more heat) and also might cause an increased rate of undervoltage tripping due to sags or dips in the supply.

An alternative to large, heavy, costly high-power line reactors, is to fit a series inductor in the earth/ground connection to the power converter. This appears in series with the CM current and so has the desired effect of reducing CM resonant frequencies, but of course it does not have to carry the converter' electrical power so can be smaller, lighter and cost less.

Earth/ground inductors can only work when fitted in series with the one, single conductor connecting the power converter's chassis/frame/enclosure/etc. to the earth/ground structure of the site or vessel, as shown in Figure 7.12-4 (also see Figure 7.3.7 in [72]). In practice, it is easy for such installations to suffer from the accidental addition of earth/ground bonds over their operational lifetimes, defeating this inductor and potentially causing interference problems to suddenly start to occur for no obvious reason. Such installations need careful maintenance.

To ensure that there are no other earth/ground connections, some designs of power converters will need their chassis/frames/enclosures/etc. galvanically isolating from their support metalwork and other local metalwork, including the shields of any cables connecting to them (causing problems for cable shielding effectiveness). Isolated power converter chassis/frames/enclosures/etc. should be made touchproof for safety reasons.

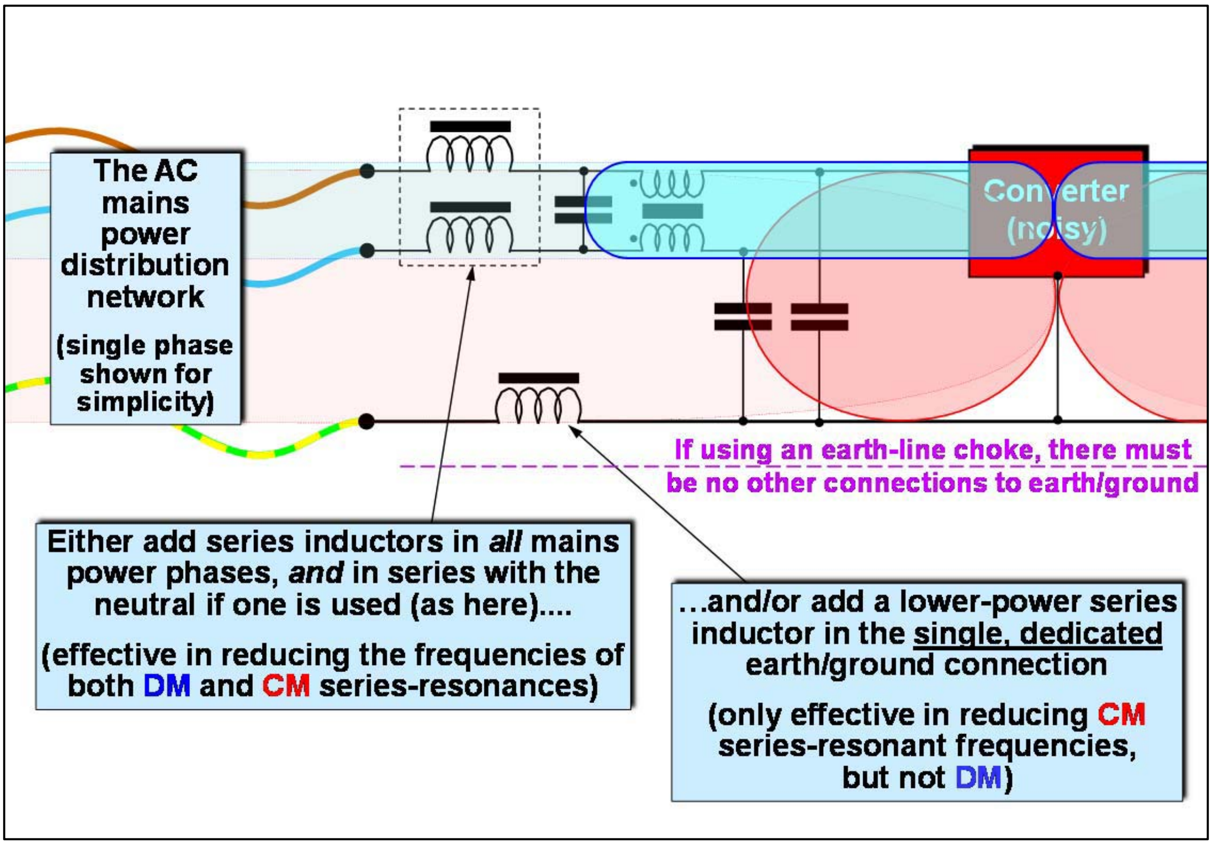

Figure 7.12-4 Using series inductors instead of a mains isolating transformer

Even where series inductors and/or shunt capacitors have been added to successfully reduce the series resonant frequencies to below the noise spectrum of the power converter without causing any of the problems mentioned above, we still have a resonant power network structure that will amplify any CM noises at its resonant frequencies.

Noises at these low resonant frequencies might exist in the mains distribution network, either emitted by larger power converters (due to their lower switching/chopping frequencies) or caused by lightning surges (most of the energy in a lightning stroke is contained in the spectrum below 10kHz) or surges caused by electrical faults.

Generally speaking, there is more energy available from continuous and transient noises on power distribution networks, at lower frequencies. So, tuning the network resonances to lower frequencies by increasing the series inductances at a converter's mains or earth/ground terminals might well reduce its noise emissions to the supply network, but could make the power converter more likely to suffer interference (even damage) due to the increased levels of noise and/or overvoltage surges at the network's resonant frequencies.

So, a less complicated solution, with far fewer unwanted side effects, is to use a large, costly mains isolating transformer dedicated to the power converter, and located immediately adjacent to it.

LF mains isolating transformers can use special design techniques (e.g. increased physical segregation of primary and secondary windings and/or adding one or more interwinding shields RF-bonded to the local RF Reference, etc.) to increase the frequency range over which they provide high CM impedance.

Remember, they only need to provide high CM impedance up to the frequency at which the RF CM chokes start to behave predominantly resistively (see Section 5.2.6 in [5]).

When using an isolating mains transformer, it may be possible to reduce the cost of the power converter's mains filter's CM filtering circuits, possibly even eliminating them entirely.

A mains isolating transformer might also prove to be sufficient on its own, without any mains filter at all, to prevent the CM noise from a power converter's mains input from circulating widely in the power distribution and exceeding limits or causing interference.

Of course, without an associated DM mains filter, an isolating transformer would do little (possibly nothing) for the power converter's DM noise emissions, or the resulting mains waveform distortion, but this is often not as much of a problem as the CM noise emissions anyway.

Where a power converter is fitted with a mains filter that deals with CM noise as well as DM, the majority of problems with widely-circulating CM currents occur at lower frequencies, below 150kHz. In this case experience seems to show that the normal type of construction for an isolating transformer is adequate for controlling CM currents in this frequency range.

A recent example of using a mains isolating transformer to fix a low frequency conducted emissions problem, was a new offshore gas drilling rig which cost US$ 500 million to build. It suffered from two separate EMC problems, one of which caused its large and powerful cranes to go out of control, causing very real safety hazards.

After four months without drilling and a great deal of lost production, a power quality expert was called in, who quickly fixed the safety problem by installing a 1MW isolating transformer. After both issues were resolved the manufacturers of the rig counted the real costs of the EMC problems, which exceeded US$ 54m.

Figure 7.12-5 shows the noise generated by the worst of the 700kW 3-phase drives fitted to its cranes, before and after fitting the 1MW isolating transformer to that crane drive.

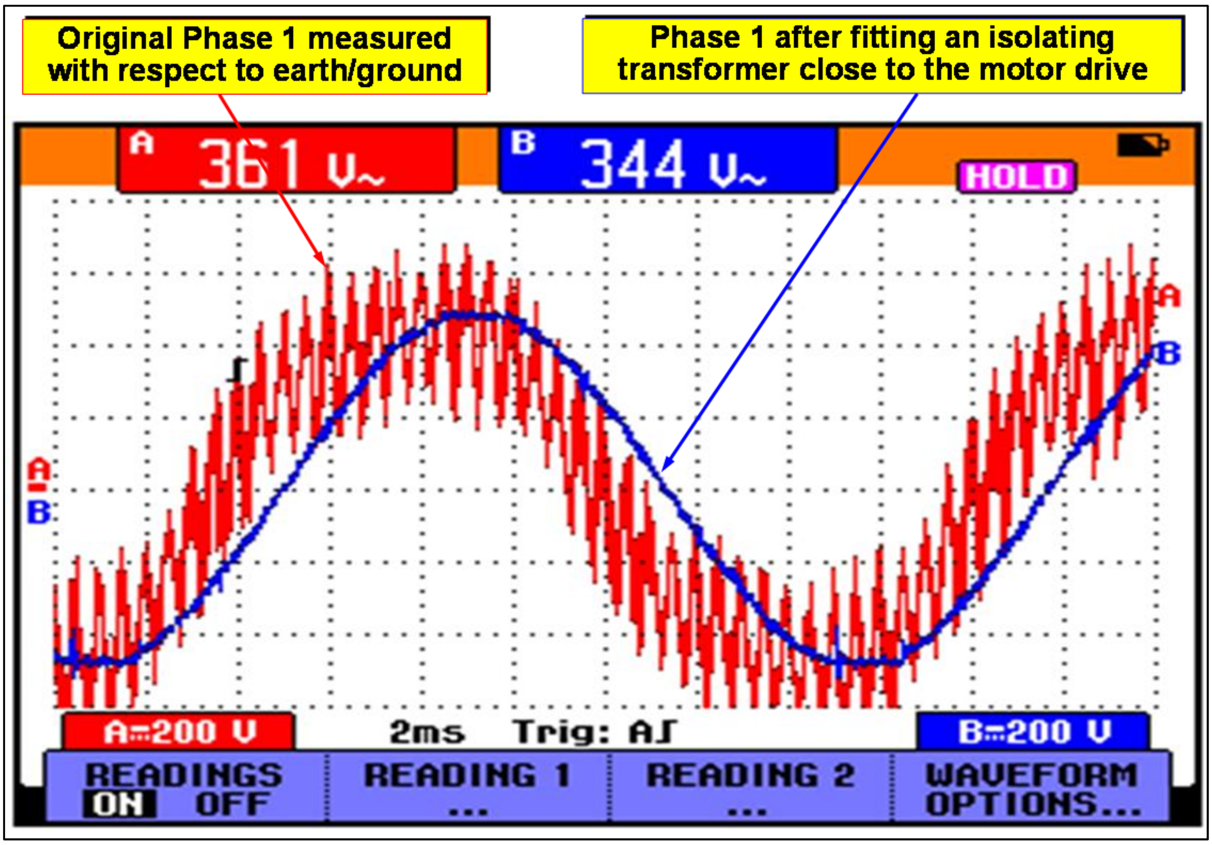

Figure 7-12-5 Example waveforms from a generator with a 700kW 3kHz AC motor drive load (Courtesy of Ian C Evans of Harmonic Solutions Co.Uk)

Marine vessels and offshore platforms; aircraft; non-electric trains, and road vehicles all have the problem that their AC power supplies come from generators, which have between three and five times the source impedance of an onshore high-voltage-grid-connected transformer having the same power rating. So the non-linear currents that electronic equipment draws from mobile AC power supplies generally causes three to five times the level of DM voltage disturbances that they would when powered from the AC mains power in a fixed installation on land.

But this problem was caused by CM currents from the crane's 700kW drive flowing in an uncontrolled manner all over the structure of the drilling rig, which had not been constructed to act as an RF Reference at such frequencies, resulting in the gross phase/neutral-earth/ground noise shown by the red trace on Figure 7.12-5 plus many problems with stray coupled noises on sensor and control cables due to the large noise voltages arising between different parts of the rig's structure, which caused the crane control gear to lose control – in turn causing major safety hazards that prevented the use of the rig.

The switching frequency of the crane's 700kW motor drive was 2kHz, as is the noise on the red trace of Figure 7.12-5. A spectrum analysis of the noise showed that it continued at significant levels up to about 2MHz, which is typical for unsuppressed high-power switch-mode power converters: 1000 times the switching rate.

Figures 7.12-6 and 7.12-7 are pictures of the transformer that was added, to give the blue waveform in Figure 7.12-5, and its installation.

Figure 7.12-6 The new 1MW isolating transformer that cured the CM waveform distortion

Figure 7.12-7 Another view of the new transformer, now in its weatherproof cabinet

The power quality expert complained that the drilling rig's manufacturer constrained him to use "quick-and-dirty" methods to remove the most obvious problems, rather than solve the problems at source (as he wanted to, and should have been done during the rig's original design and construction) by properly suppressing the power inputs and motor outputs of all of the crane motor drives.

He said that much of the rig is still suffering the full force of the CM voltage noise caused by the absence of mains filters on any of its variable-speed motor drives, including the 700kW drives for the cranes. (Figures 7.12-5 through 7.12-7 are only associated with one of the crane motor drives, the other motor drives associated with cranes, pumps, and other functions all still creating similar types of CM noise on the power distribution, but had not been seen to cause the safety problems with crane control that meant the rig could not be operated.)

The manufacturer of the rig had made many similar offshore drilling rigs beforehand, and never fitted any of their variable-speed motor drives with mains filters because, they said, "they were not needed" and so they saved their cost.

Well, like most such bad-EMC-engineering cost-cutting decisions, it only took one EMC problem to cost very much more than all the money that had ever been saved by deviating from good EMC design principles for the sake of reducing costs.

Quite possibly, the reason why they had crane control problems on this rig, when they hadn't seen any similar problems on previous rigs, was because of a change in the design of the electronic control equipment and/or silicon die shrinks for most/all of the integrated circuits (ICs) used on the printed circuits boards (PCBs) that resulted in them having lower noise margins.

This example of an EMC incident was previously reported in [110], which adds no more information to that given above.

Transformers aren't the only mains isolation technique, others that are commonly used include motor-generator sets and certain kinds of uninterruptible power supplies (UPSs), which can both reduce emissions of CM and DM noises into the mains power distribution networks. "M-G Sets" provide a very high degree of CM isolation between their input and output circuits due to their large physical separation, and with careful segregation of their input and output cabling and the equipment connected to them (and *their* cabling) could achieve high CM impedances to tens of MHz. They also provide a very high degree of DM isolation – something that a transformer cannot do.

To be effective in reducing DM and/or CM emissions, UPSs must be isolating continuous-on-line double-conversion types. UPSs are marketed using a wide variety of technical-sounding marketing terms, some of which are proprietary and most (all?) of which create the impression of much more technical capability than we actually get when we purchase them. So I have found that it is best to completely ignore all marketing hype and instead focus on the products' detailed technical descriptions.

Figure 7.12-8 shows a simple block diagram of the type of UPS that is needed to suppress DM and CM noise emissions to the mains network. It is important that it continually charges a battery (or other electrical energy store, such as a supercapacitor) and – from that battery (or whatever) voltage synthesises the AC power to drive our converter.

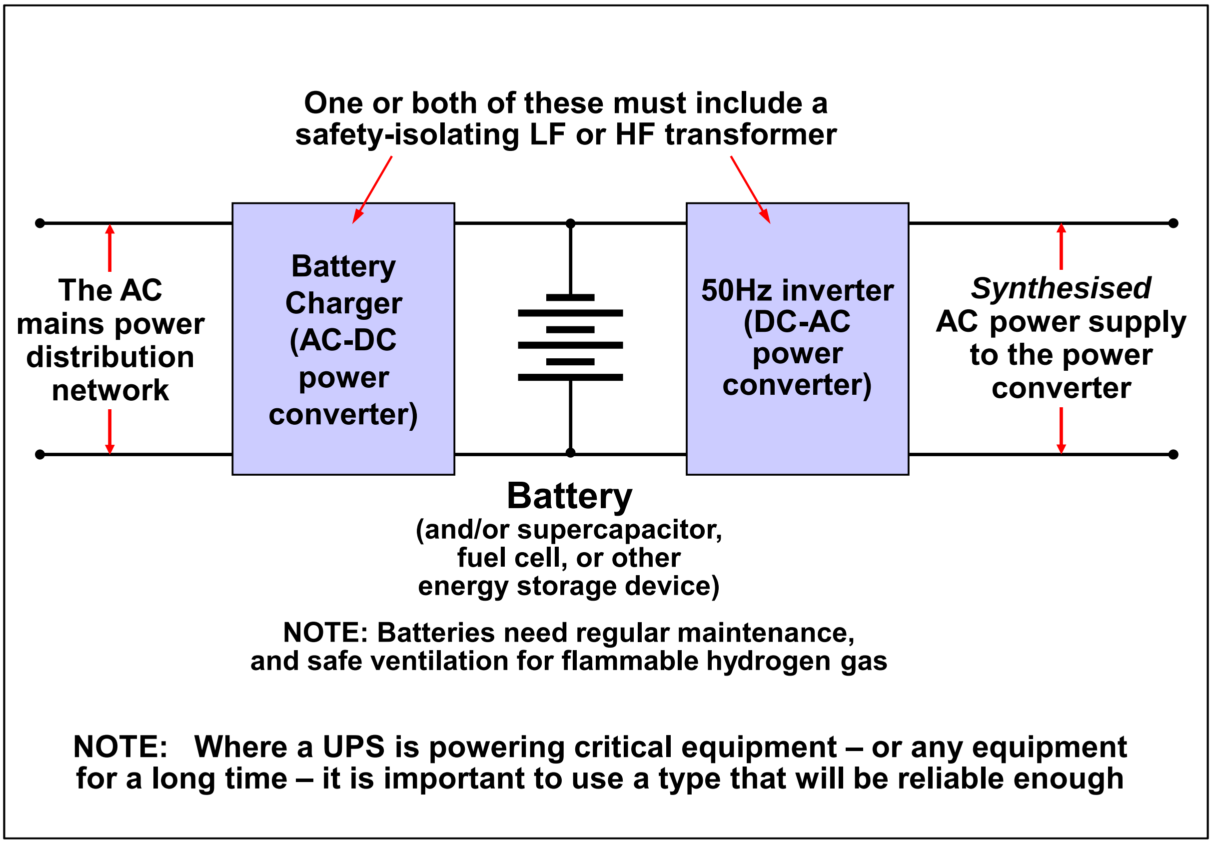

Figure 7.12-8 Overview of a 'double-conversion continuous-conversion' UPS

The UPS's battery charger circuit, AC power generator circuit, or both, must contain an LF or HF isolating transformer. Like the LF isolating transformers discussed earlier, and the HF isolating transformers discussed in Section 4 in [64], their effectiveness for suppressing CM emissions depends on their design and construction, with special high-frequency high-isolation techniques being available (often at extra cost).

DM suppression is achieved by passing all the power via the battery (or other energy store). Like the DC Link suppression capacitors discussed in Section 7.6 in [99], the lower their shunt impedance at the frequencies of interest, the better their DM noise suppression. It may be necessary to parallel a number of different technologies, for e.g. batteries, supercapacitors and high-value metallised film capacitors, to achieve the required DM suppression across the whole frequency range of converter noise.

Continuous-on-line double conversion isolating UPSs are generally effective at low frequencies (say, up to 100kHz) but models with higher-frequency specifications are available, and I have seen some UPS products that specified no less than 80dB attenuation for both DM and CM noise at all frequencies from DC to 1GHz! Obviously, we pay extra for such specifications, and most "commodity" UPSs do not even include noise attenuation specifications in their data sheets, so we should always assume such performance to be quite poor until we have seen independent evidence that proves otherwise.

It is important to beware that some M-G Sets and UPS's generate so much noise they make EMC worse overall, or create poor power quality (e.g. by emitting excessive harmonic or inter-harmonic waveform distortions), or are too unreliable.

Someone who worked at a '24/7/365' continuous-steel-strip-production mill once told me that after losing costly production due to mains interruptions and outages, they installed *very* large, powerful and costly high-power UPSs to power their *entire* production line, only to find that the UPSs were less reliable than the raw mains supply they had been using!

We must remember to always ask for trustable evidential proof of any/every specification or feature that we need from anything that we purchase, and never make assumptions no matter which supplier we deal with.

7.13 Noise suppression with "floating" power networks or "floating" electronics

7.13.1 Converters powered from floating AC power networks (insulated neutrals)

Ships and other vessels generally use mains supplies that do not have the neutral of their mains power supply directly bonded to their earth/ground structure (see [60]), and some land-based installations also use this practice. This is known as an IT power network (nothing to do with Information Technology!), and is often described as a "floating" mains supply.

It is a common mistake (that even appears in some standards, for example EN/IEC 61800-3) to assume that mains filters require a connection to an earth/ground, and so cannot be used with floating mains power networks.

(A safety technique used with earthed/grounded mains power network is that they open fuses or circuit breakers to remove electrical power from a circuit that has suffered from an insulation fault. However, in some especially aggressive environments – such as marine – insulation faults are quite common and the power networks would fail too often. When controlling a vessel like a ship, an interruption in the power that impairs the control can cause huge safety risks (e.g. running onto rocks). So they use floating mains power networks fitted with sensors to measure the (normally high) impedance between each phase or neutral and the earth/ground of the vessel or site, to determine when insulation failures have occurred and be able to fix them before another one happens. Mains filters have leakage currents in their “earth/ground labelled” terminals, which would prevent the insulation-failure detectors from working correctly.)

The common mistake goes on to say that in such situations the only mitigation possible is to ensure that all the other equipment on the site is immune enough to the noise suffered by the power distribution system (which is easier said than done if they can’t use mains filters).

This mistaken approach ignores the possibility of interference with other equipment (on other vessels or off-site) and with radio receivers used anywhere, so is far from being any kind of real EMC solution.

Anyway, as the offshore drilling rig example above showed (see Figures 7.12-5, 6 and 7), it can be very difficult to predict whether unfiltered power converter noise emissions will cause interference problems with the rest of the system until everything is installed and operating. By which time, of course, any fixes will be time-consuming and very costly indeed.

The common mistake, of course, is to confuse the RF Reference terminal of a mains filter with the earth/ground electrode that is stuck a few metres into the soil, or the metal hull of a vessel that provides the exact same function by being in direct large-area contact with a body of water lying on the surface of our planet (e.g. lakes, rivers, seas).

It isn’t helped by the fact that most (if not all) mains filters (and many other types too) incorrectly identify their RF Reference terminal with the IEC symbol for earth/ground, and sometimes actually label it as Earth or Ground! And most data sheets, application notes, articles, guides and books describe the RF Reference terminal of a mains filter as its Earth or Ground terminal.

This isn’t the only situation in which the confused jargon associated with the terms Earth or Ground in circuit and EMC design has caused costly mistakes – which is why in all my articles, training courses, guidebooks and textbooks I always strongly recommend *never using the terms Earth or Ground for anything that is not actually an earth/ground electrode* (metal rod stuck in the soil) or its marine equivalent (metal hull or structure of a vessel such as a ship or drilling rig, oil/gas production platform, etc., that is in direct large-area contact with a river, lake or sea).

All of the conductors and conductive structures that are connected together, and usually (but not always) connected to actual earth/ground electrodes for safety reasons, should be called electrical Bonding Networks, or BNs; or electrical Common Bonding Networks, or CBNs (as per the terminology in IEC 61000-5-2, which is concerned with good practices in cabling and earthing/grounding).

No electronic DC power rails, such as “zero volt” rails (0Vs) should ever be called earth or ground rails, and nothing should ever be said to be at earth or ground potential.

No circuit diagrams should ever use the words Earth or Ground, or their related symbols (unless they *really do mean* an actual metal rod that is stuck a few metres into the soil, or the marine equivalent.

Serious problems caused by the confusion arising from the jargon use of the words Earth or Ground have been well-known for decades, especially in system, circuit and EMC design. Figure 7.13-1 is copied from slide 42 of [112], and I have seen its creator, Dr Bruce Archambeault of IBM, use it many times in similar presentations and articles in earlier years.

From Slide 42 of: "The "Ground" Myth", Bruce Archambeault, Ph.D., IBM Distinguished Engineer, FIEEE, 18 November 2008, http://ewh.ieee.org/r6/phoenix/phoenixemc/PCB-Design.pdf

Figure 7.13-1 Some of the many types of symbols for different grounds (not really!)

Regular readers of this series might remember Figure 7.2-4 in Section 7.2 of [72], where I first introduced the concept of "noise current diversion by working with the laws of Physics", which make noise currents "prefer" to flow in the loops with the lowest overall impedances, that cause the least emissions. Well, I have duplicated Figure 7.2-4 as Figure 7.13-2 so that you don't have to look it up.

Figure 7.13-2 shows the typical way we use input and output filters and RF-bond local metal structures to use them as RF References, to help divert noise currents generated in the power converter's devices so that they "prefer" to flow in small, low-Z, local loops and not in the mains power distribution network.

These two figures (7.2-4 and 7.13-2) use the local metal structures as the RF Reference simply for reasons of saving cost by using existing metal structures for EMC purposes.

Converters that contain their input filters, LF rectifiers, DC Links, output switchers/choppers (and any LF or HF isolation transformers, HF rectifiers, output filters, etc.) within a single metal enclosure, use that enclosure (or an internal chassis or frame) as their RF Reference and have no need for an external RF Reference.

If you remembered Figure 7.2-4 without me having to tell you, you might also remember that the figure that preceded it was (of course) Figure 7.2-3, which I have duplicated in this article as Figure 7.13-3.

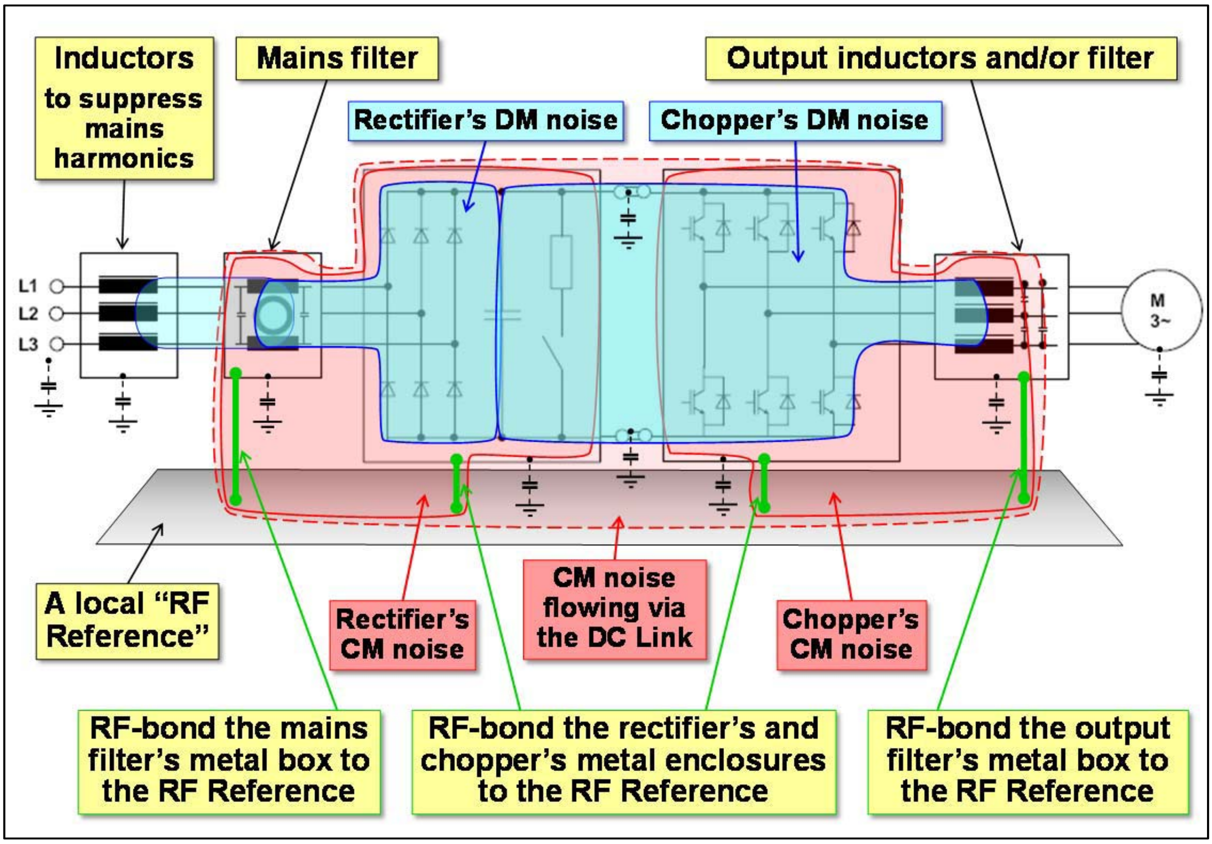

Figure 7.13-2 Example VSD fitted with filters and RF-bonded to an RF Reference

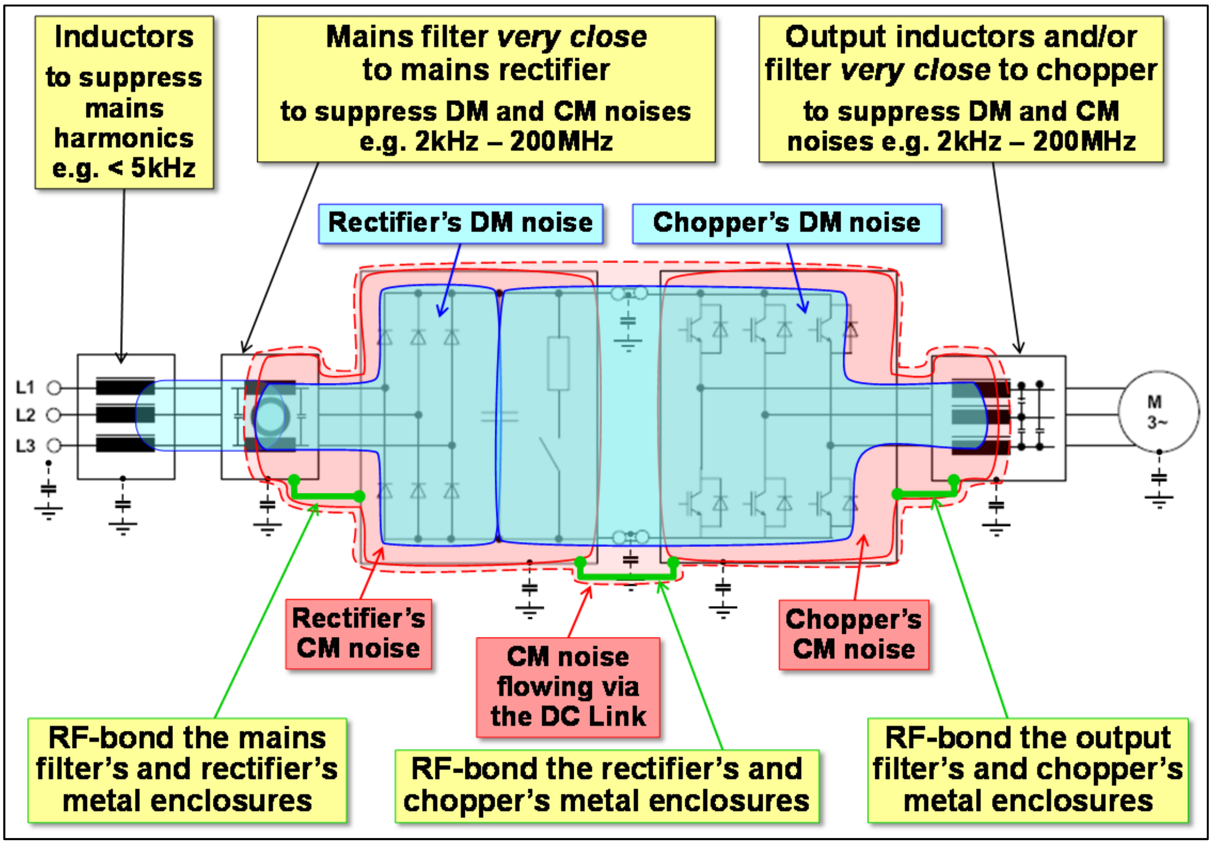

Figure 7.13-3 Example VSD fitted with filters and RF-bonded together

Notice that Figure 7.13-3 shows no connections to earth or ground, because earth or ground electrodes (rods stuck in soil, etc.) have *no relevance at all* for the noise emissions generated by any electronic devices, such as the power converters that are the subject of this series.

So, there are no EMC problems at all in using mains filters on power converters that are powered by “floating” mains power distribution networks.

However, there can be some practical issues that need to be taken into account. Because the filters fitted to the inputs and/or outputs of power converters must be RF-bonded to the converters’ metalwork (usually their chassis, frames or enclosures), using them as RF References to provide small, low-Z current paths – when using floating mains supplies, this metalwork must not connect directly to the earthed/grounded structure of the vessels or sites.

This is so that the filters’ leakage currents will not flow into the earth/ground structures and compromise the correct operation of the insulation failure detection systems on the floating mains power distributions.

So, for safety reasons, the floating converter metalwork that the mains filters are RF-bonded to must be made touchproof to prevent personnel from suffering electric shocks. This can add extra design complexity and cost, but it is certainly a much preferable solution than trying to use power converters and other electronic equipment without any mains filters at all!

Figure 7.13-4 provides a simpler view of the arrangement of the filtered floating power converter sketched in Figure 7.13-3.

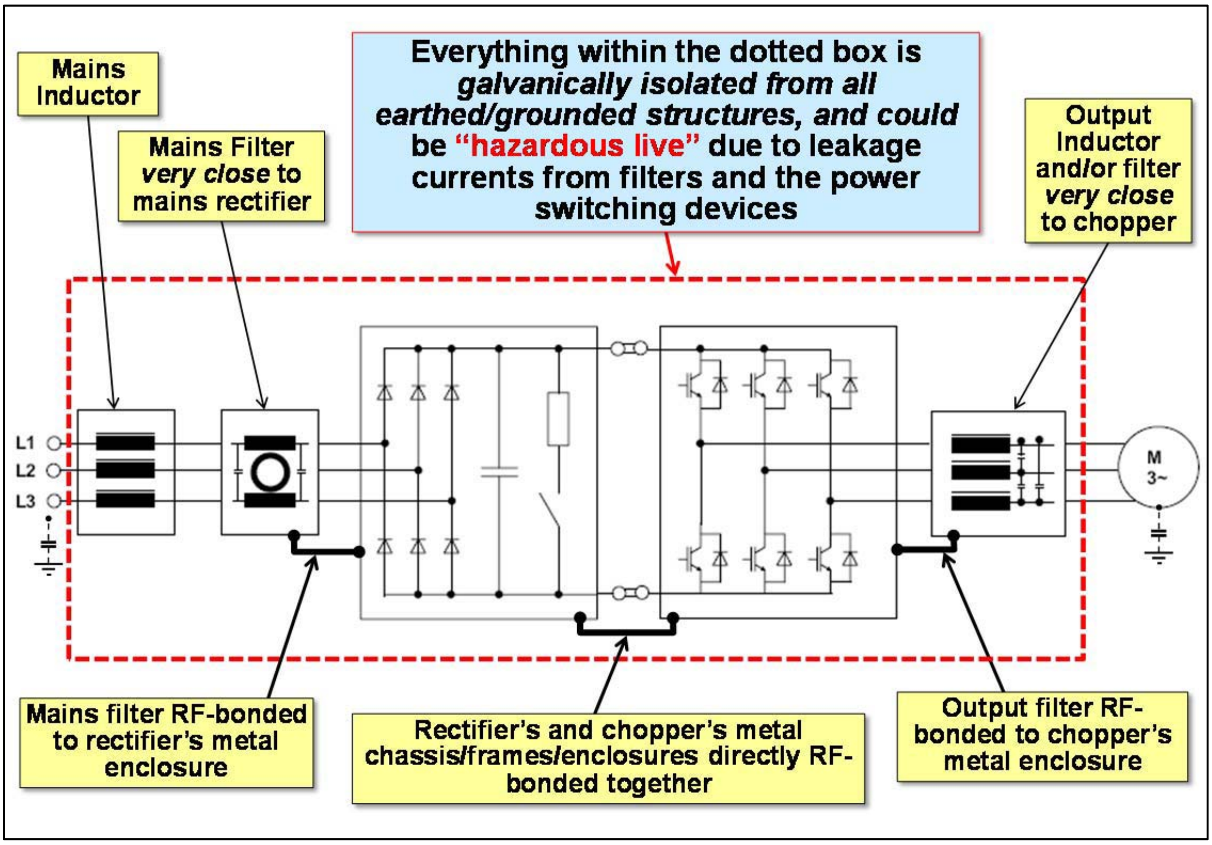

Figure 7.13-4 A simpler view of the floating power converter technique

When using floating power distributions and floating power converters, higher-frequency noise emissions can be a little more difficult to control than when everything is directly bonded to the earthed/grounded metal support structures.

These high-frequency noise emissions can often be usefully reduced by connecting one or more low-value capacitors from the floating RF Reference that has been created (see Figure 7.13-3) to the local metal support structure (which is usually earthed/grounded) as shown in Figure 7.13-5.

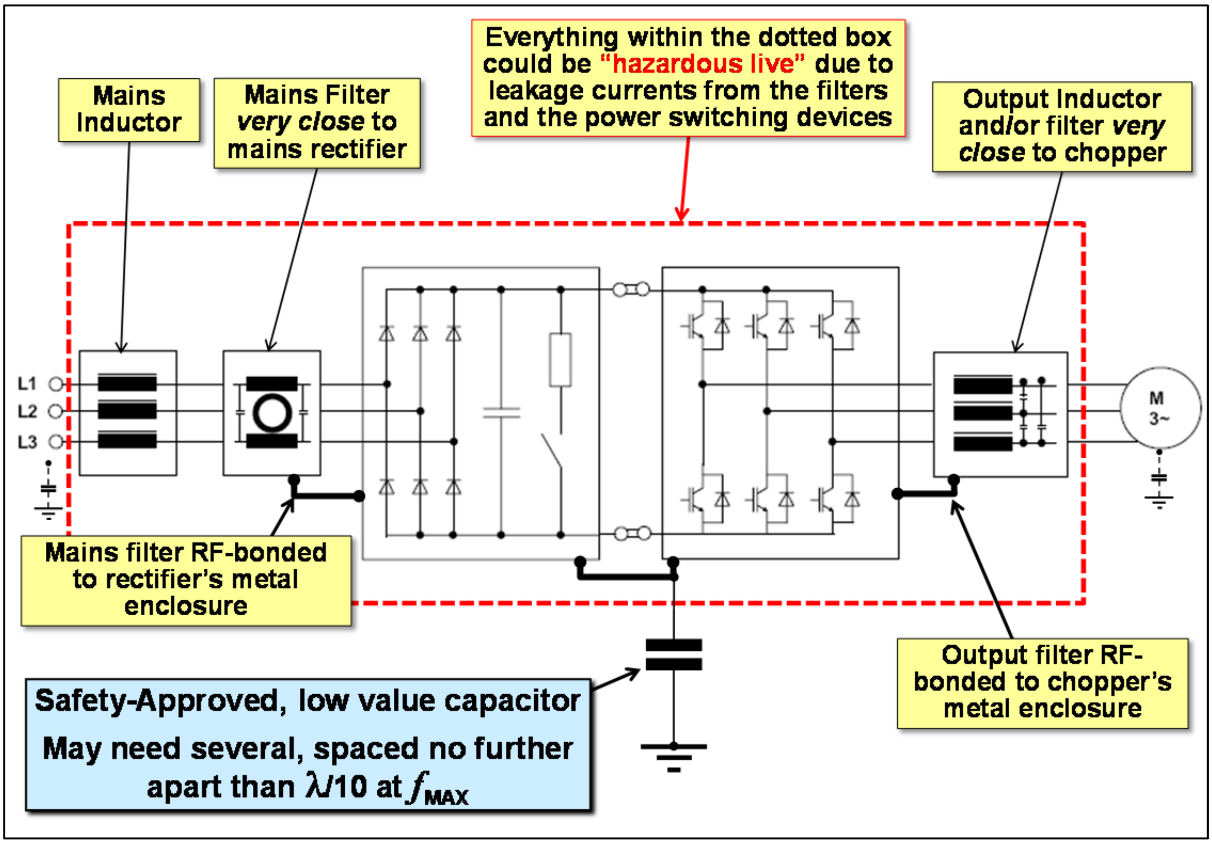

Figure 7.13-5 Indirectly RF-bonding a floating power converter to its local earth/ground

Because it only has to provide a low-Z path for higher-frequency noise currents, the capacitor values can be reduced so that they do not compromise the correct operation of the insulation failure detection systems, whilst still providing useful RF noise suppression.

For more detail on suppressing floating power converters with indirect RF-bonding capacitors, see Section 7.13.2 below – bearing in mind that this section is not concerned with floating AC supplies with their insulation failure detection systems.

When using cable shields/armour instead of output filters (as discussed in Section 7.5 in [92]), capacitive RF-bonding could be used for the output cable's shield/armour, fitted either at the power converter's output or the load's (e.g. a motor) terminal box, or both.

Capacitive shield/armour RF-bonding will not be as effective as a proper 360° shield-bonding (described in full detail in Section 4.6 in [5]), but may be good enough if the lead lengths of their RF-bonds are kept very short. Such shield/armour-bonding capacitors should be safety-approved and rated for the full phase-to-phase voltage, and the values of the capacitor(s) used where a floating converter drives an earthed/grounded load (such as a motor) may have to be a compromise between the value needed to control the *lowest* noise frequency to be controlled (f_{MIN}), and the value above which the leakage current is considered excessive by the relevant safety standards, or which compromises the operation of the insulation failure detection circuits on the floating power distribution.

This is pretty much the same set of design compromises as when adding noise suppression capacitors as sketched in Figure 7.13-5. It is of course very important indeed to always ensure that all relevant safety standards are fully complied with, and that the product, system or installation will be safe over its anticipated lifecycle.

There is a way to completely eliminate the safety and construction problems of having to float power converters and their filters when using floating mains supplies, as well as avoiding the compromises and non-idealities of capacitive cable shield RF-bonding: fit the converter with an isolating LF mains transformer, as discussed in Section 7.12 above.

With a co-located LF isolating transformer in series with the power converter's mains input, the converter's chassis/frame/enclosure/etc. and all of its associated filters and cable shields/armour can be directly RF-bonded to the local earth/ground metal structure (and use it as an RF Reference), without compromising the floating mains distribution in any way (except for the small CM leakage current from primary winding to secondary and the transformer's enclosure, which can be reduced by appropriate transformer design techniques if necessary.

This is the same scheme that is sketched in Figure 7.12-3, and is also merely Figure 7.13-2 with an isolating transformer attached in series with its mains input.

Where a power converter is connected to a high-voltage power distribution network, with its own dedicated, co-located step-down isolating mains transformer, our work is already done! The HV distribution network is floating, and on the other side of the step-down transformer the power converter and its filters and any shielded cables can be directly RF-bonded to the local earth/ground structure and use it as an RF Reference as discussed above and shown in Figure 7.12-3.

Sorry, but I feel the need for a little tirade on earthing/grounding jargon, before I can leave the issue of filtering converters that are run from floating supplies.

Looking again at Figure 7.13-3, we see that it shows stray capacitances to the earth/ground, but no actual connections. No electromagnetic noises generated by the electrical activities in electronic circuits have ever been reduced or eliminated by connecting them to an earth/ground electrode. The earth/ground is not a "sink" for noise, and it never has been and never can be. The concept of diverting noise currents so that they are absorbed in the earth/ground is simply a misunderstanding and a myth.

Anyone who ever "got rid" of noise by "earthing/grounding it" had actually improved the local RF Bonding and allowed noise currents to flow in lower-impedance, more local loops that caused less interference. But because of confusion caused by the use of jargon terminology, the EMC benefits were mistakenly thought to have somehow had something to do with the earth/ground electrode stuck in the soil acting as a sink of some kind, which is actually impossible in this universe.

Ah, I feel better now, and can get on with the rest of this little article.

7.13.2 Isolated converters powered from DC power networks

Isolated DC-powered electronics are typical of many automotive, marine and aircraft applications, where the chassis/hull/fuselage/etc. of the vehicle is used as the battery return conductor (a very bad EMC practice which dates from pre-electronic times but seems impossible to get away from).

The DC supply is connected to the chassis/hull/fuselage/etc., but the RF References of electronic units cannot be directly connected to them in case bad connections between metal parts allows large battery currents to flow through the electronics, probably causing damage or even a fire.

The solution that allows the return current paths to flow with the smallest loop areas, which is the best for EMC, is to RF-bond the electronics' RF Reference (e.g. its metal chassis/frame/enclosure, PCB 0V plane, etc.) to the vehicle's chassis/hull/fuselage/etc., using capacitors and their connections that achieve low-enough impedances at the lowest frequency to be controlled (i.e. at f_{MIN}), and also at the highest frequency to be controlled (i.e. at f_{MAX}), as sketched in Figure 7.13-6.

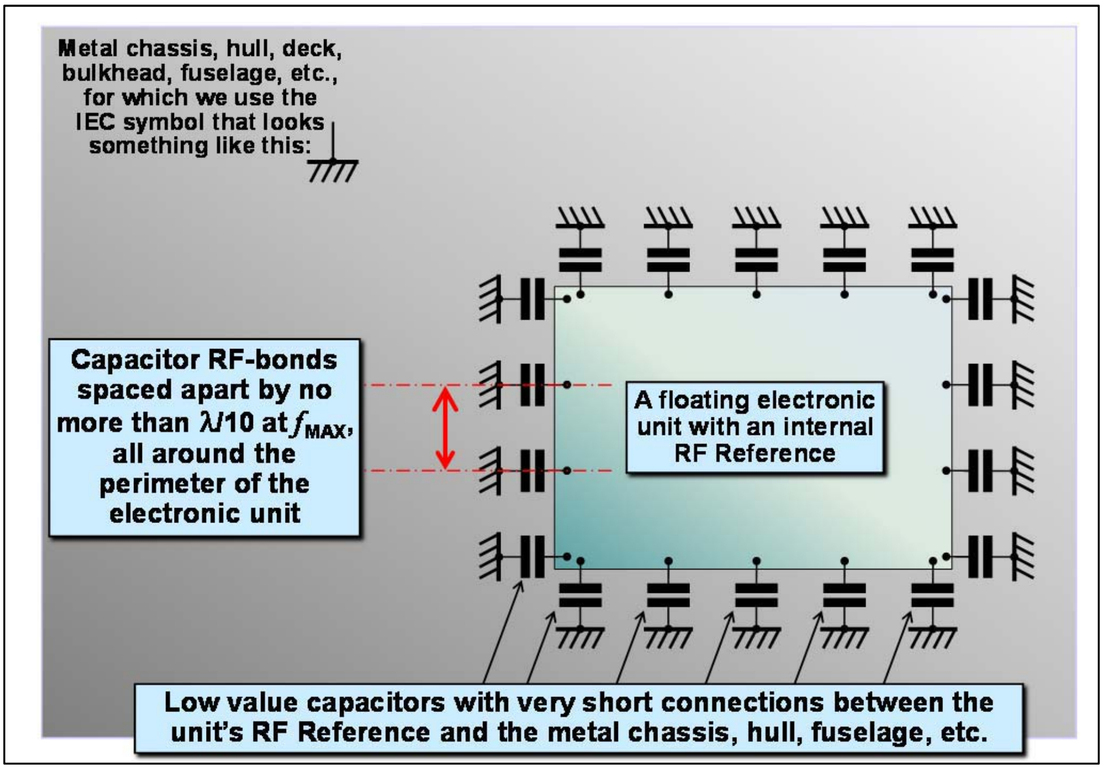

Figure 7.13-6 Capacitive RF bonding for isolated electronics powered from a non-isolated DC power network

These capacitors should be spaced no further apart than λ/10 at the highest frequency to be controlled (f_{MAX}). Another way of stating this is: $\leq 30/f_{MAX}$, in air, with f_{MAX} in MHz giving the maximum spacing in metres, whereas f_{MAX} in GHz gives the spacing in millimetres.

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