Power Line Impedance and Its Effect on Power Quality

When looking at a system to determine the best way to improve the quality of power delivered to sensitive computerized loads, one must look carefully at power and ground line impedances. Today’s computers have different solutions to power line noise problems. To properly understand the problem, we must look not only at voltage and current, but frequencies involved.

**Frequency Range of Interest: 5 kHz to 1 MHz**

Today’s computers have switching mode power supplies which effectively compensate for low-frequency (less than 5 kHz) variations in line voltage (sags and surges). But these power supplies also leave their electronic loads very vulnerable to higher frequency noise and spikes. Luckily, the power line effectively attenuates disturbances over about 1 MHz itself. Building wiring looks like many low-pass filters with much series inductance, some series resistance (skin effect) and considerable shunt capacitance. Step down and isolation transformers on the lines also do their share of filtering.

**Transformer Impedance: Less is Better**

At low frequencies, transformers look like the familiar equivalent circuit in Fig. 1. But Fig. 2 shows what happens at higher frequencies. The transformer’s leakage reactance and capacitance in the winding would lead the casual observer to conclude that high-frequency, normal-mode (line-neutral) noise could not get through to the load. This is true if one measures the frequency response of the transformer in a laboratory environment where all frequencies are reasonable sine waves.

Unfortunately, the real world isn’t always like that. When a transformer is subjected to a fast rise time transient like 0.5 s lightning strike, it will resonate at a frequency dictated by the values of its leakage inductance, $L_s$, and shunt capacitance, $C$. When the transformer is lightly loaded (high load $R$), a 6 kV input spike can become a 9 kV output disturbance. Its frequency may be modified, but its damage potential is not.

There are some that feel that if a little series inductance is good, a lot must be better. Such is not necessarily true. Most so-called highly shielded isolation transformers will have 4 to 5 times more $L_s$ than a well designed, low-impedance power conditioner.

In the case of the ferro-resonant transformer, this leakage inductance is orders of magnitude larger, and the problems are accordingly worse $X_L$ and $X_C$ in Fig. 2 are tuned to resonate at 60 Hz in a ferro-resonant unit, thereby storing energy in this tank circuit. The resulting voltage drop across $X_L$, however, makes this an inherently current-limiting device, which cannot supply high inrush current demands such as disk drive motor starts.

**Computers Are No Longer Simple 60 Hz Loads**

Modern switching mode power supplies draw their current directly from the power line through a set of diodes to charge a large dc capacitor. Current is drawn only when the rectified voltage peaks exceed the dc capacitor’s voltage. This has the effect of drawing current in short bursts of high amplitude, with an equivalent frequency of 500 to 1,000 Hz. If the power delivery system (including any transformers) has high impedance at this frequency, the result will be current starvation and flattening of the sine wave as shown in Fig. 3. This reduces peak voltages and introduces undesirable harmonics into the power system.

Some of the better power conditioner manufacturers now rate their products according to how much impedance their products add to the power line, measured at 1 kHz. This is variously called “transfer impedance” or “source impedance increment”, and less is better. A good, stiff source conditioner might add less than 1 Ω at 120 V. Measured another way, this means that the voltage sine wave peak will drop less than 10 percent under a load with a high crest factor (peak to rms current) of 4:1.

**Impedance Affects Load-Generated Noise**

Modern computer systems integrate an increasing number of noise-producing and noise-sensitive devices, and load-to-load interference is an increasingly important issue. As we attempt to protect our
A computer system from external noise and spikes, it's important to remember the role of impedance so that we don't inadvertently make matters worse through the selection of the wrong type of protection devices.

A low-impedance power conditioner enhances the ability of the power line to attenuate load-generated noise. High-impedance devices trap the noise on the load side, reflecting it to all devices in the secondary system. Figure 4 shows the results of various types of high- and low-impedance power conditioners.

**Power Line Impedance**

**A Good Solution**

Using an isolation filter power conditioner, it is possible to produce a fresh neutral-ground bond at the computer and filter out normal-mode noise and spikes as well. This is like having a dedicated building wiring system with its own neutral-ground bond for each computer system, and it is quite superior to typical “dedicated, isolated wiring” that is commonly installed for computer power. It achieves true isolation that doesn’t degrade over time and is easily transportable. Figure 5 shows a general schematic of an isolation filter.

The computer load should be located as close as possible to the isolation filter, minimizing impedance of the power line and the neutral-ground connection. Improvements of 100:1 or more in ground line noise reduction are possible in this manner. Enlightened manufacturers are even starting to achieve the ultimate in low-impedance design by building low-impedance isolation filters right into their systems as shown in figure 6.

**Conclusion**

Impedance is a critically important part of any power system analysis. The power line must have a very low impedance at frequencies up to 1 kHz, yet higher frequency disturbances must be stopped. Sensitive computer systems must see a very low impedance path back to ground, and modern power conditioners are now available which easily satisfy all these requirements - if the right one is chosen and properly used.