Power Line Impedance and Its Effect on Power Quality

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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 requirements than those of only a few years ago, which results in different solutions to power line noise problems. To properly understand the problem, we must look not only at voltage and current but the 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, disturbances over about 1 MHz are effectively attenuated by the power line itself. Building wiring looks like many lowpass 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 a 0.5 μs 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 who 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 ferroresonant 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 ferroresonant 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

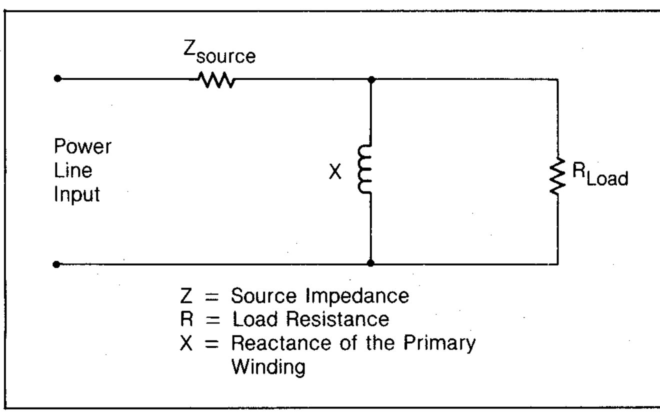

Figure 1—Low-frequency Response of an Isolation Transformer

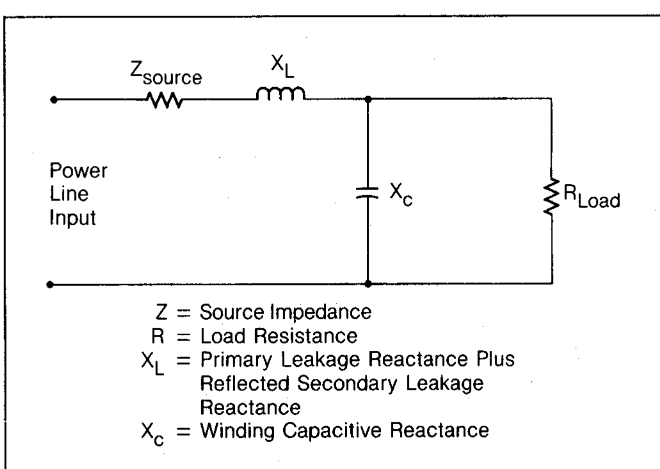

Figure 2—High-frequency Response of an Isolation Transformer

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 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.

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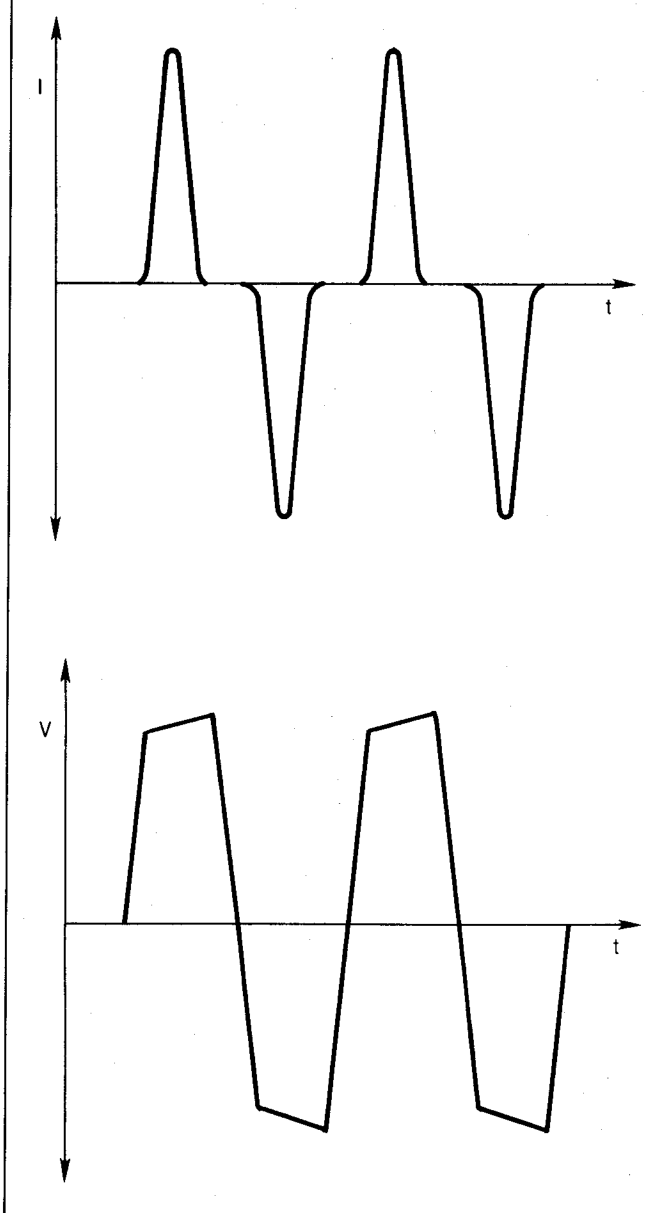
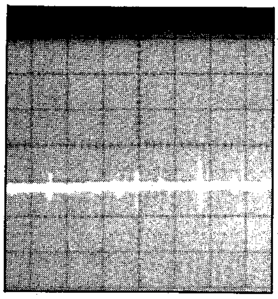
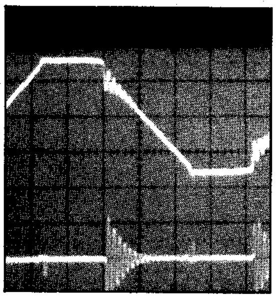


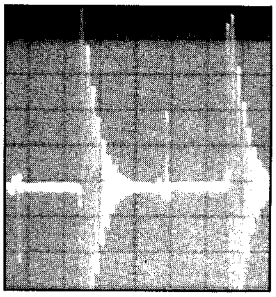
Figure 3—High Crest Factor Loads Distort the Voltage Sine Wave of a high-Impedance Source



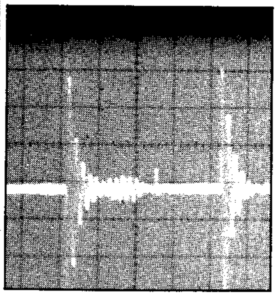
a. Most of the noise on the power line shown here without a conditioning device is created by a typical computer load. (1 V/div, 1 ms/div)



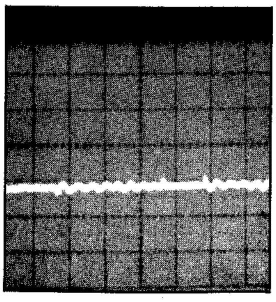
b. When a ferroresonant power conditioner is added, the voltage waveform is distorted by the computer load. The second trace has the 60 Hz filtered out so the high-frequency noise can be better seen. (100 V and 5 V/div, 1 ms/div)



c. Load-induced noise is magnified by a high-impedance ferroresonant conditioner. (1 V/div, 1 ms/div)



d. Noise from the computer is also amplified when it's trapped by a typical high-impedance isolation transformer. (1 V/div, 1 ms/div)



e. Load-induced noise is reduced in both amplitude and disruptive higher frequencies by a good low-impedance power conditioner. (1 V/div, 1 ms/div)

Figure 4—Noise at the Computer is a Function of Power Line Impedance

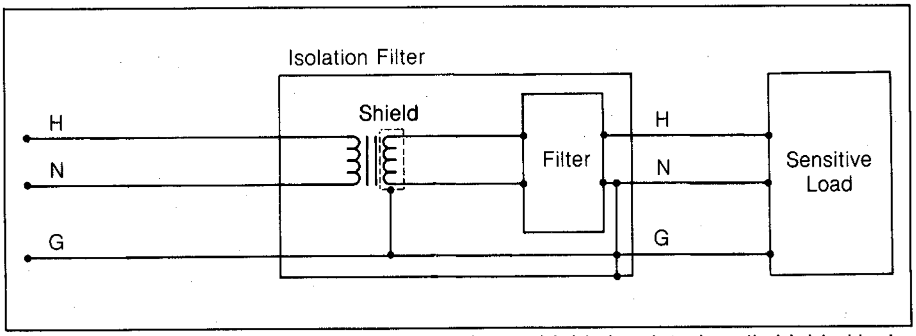
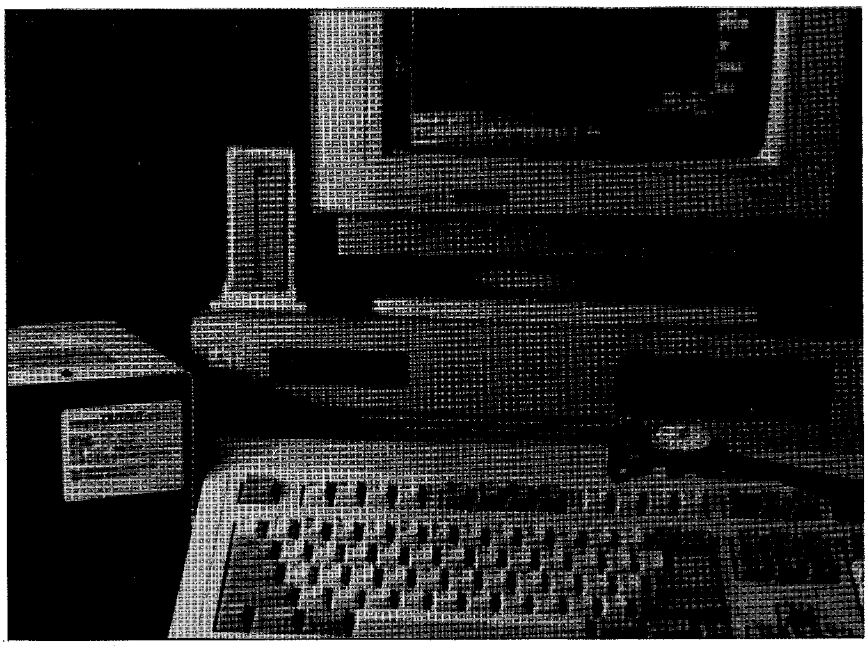
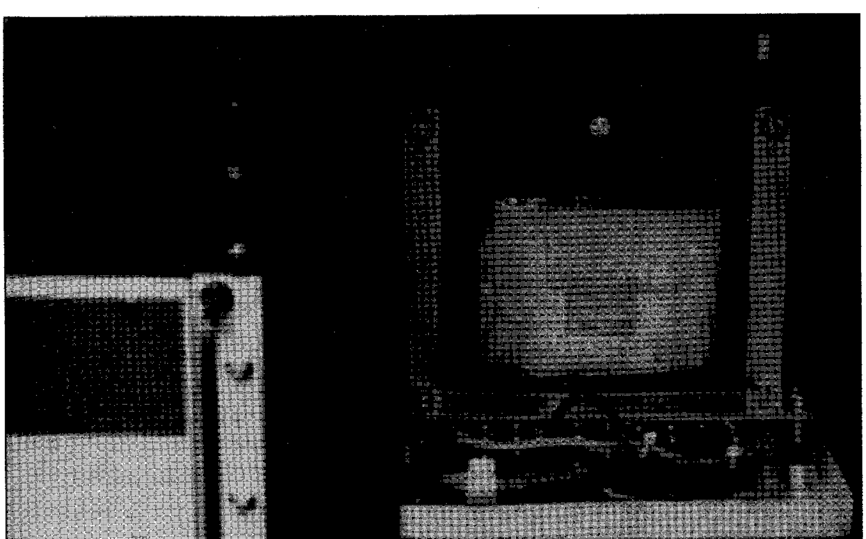


Figure 5—The Isolation Filter is a low-impedance, highly insulated, well-shielded isolation transformer with a nonlinear filter/surge suppressor.



a. Plug/receptacle conditioners should be located as close as possible to sensitive computerized systems.



b. Increasingly, manufacturers are building conditioning into their systems, minimizing line impedance and maximizing reliability.

Figure 6—Power conditioning should be as close to the load as possible.

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.

Robert C. McLoughlin has degrees in physics and electrical engineering and was on the faculties of Penn State and Harvard Universities. He has been president of several corporations specializing in magnetics, power, semiconductor testing, acoustics and weapons effects. The original founder of Topaz Electronics, Bob started TEAL Electronics in 1985. TEAL specializes in systems which solve power line noise problems.