THE IMPACT OF AC POWER CONTAMINATION ON TOTAL SYSTEM RELIABILITY

The use of appropriate mitigation technology can solve the ac power contamination problem and can increase total system reliability.

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INTRODUCTION - THE POWER ENVIRONMENT

In today's organization, computers are no longer toys; now they are critical to the efficient and effective running of the operation. Too often, computers go down, leading to lost productivity, lost business, and increased costs of operation. Often local area networks (LANs) are used to optimize computer performance by connecting stand-alone computers to interactive networks of CPU power.

LANs are found in virtually every area of an organization in both administration and manufacturing. Particularly in manufacturing, local area power (LAP) protection can minimize the impact of ac power contamination on both LANs and the individual computer elements. Achieving congruence between the application, the cause and severity of the AC power contamination, and appropriate mitigation technology will improve productivity and return-on-investment.

To assess the impact of the ac power contamination problem, it is important to understand the power environment and its current management. Traditionally engineers and technicians have focused on lightning, grid switching, and power factor connection as the prime causes for power spikes and notches. Actually, a more insidious source, and often a more damaging one, is the manufacturing facility itself. Inductive loads, such as heating, ventilation, and air conditioning (HVAC) motors, are among the worst offenders when spikes are kicked back into the power line with every switching operation. Also, most computer-driven manufacturing or test systems contribute to the contamination level; the system, in effect, destroys itself through "auto-cannibalistic" action. Thus, the ability to control the process is degraded; and quality, cost of manufacturing, repeatability, testability, yield, throughput and system availability suffer. Figure 1 illustrates some of the noise characteristics of the ac line.

POWER INTERFACING AND VOLTAGE REGULATION

Power interfacing is not synonymous with voltage regulation. Voltage regulation and noise isolation properties of the power supplies which run modern computers must be considered before determining the need for regulation or interfacing. Linear power supplies feature low ripple, good dc regulation, line isolation, and low noise emissions. On the negative side, linears operate at low efficiencies (typically 50 percent), contain large (60 Hz) transformers, and offer a limited dc holdup time and line regulation (typically 100 to 125 V).

Switching power supplies feature high efficiency -- up to 85 percent. Typical dc holdup time is 25 msec (1.6 cycles). Absence of 60 Hz components allow for compact size, and switchers do not require voltage regulation because they can operate over a wide voltage range. However, low transfer or source impedance is an absolute requirement for any device which precedes a switching power supply. Otherwise, the effective regulation range of the switcher itself is downgraded, and its efficiency is lowered. Thus, if a power supply is fed from a high impedance source, a reduction of peak current results. This reduction forces the power supply to extend its duty cycle and reduces the effective range of voltage regulation. Disadvantages of switchers include high dc ripple and limited dc output regulation, as well as high noise emission.

Another power supply characteristic important to voltage regulation is non-sinusoidal current transfer. Figure 2 illustrates a resistive load and switch mode power supply load. Each load draws the same 10 amperes rms current, but the similarities end there. The resistive load draws a peak current of rms times 2 (10A x 1.414 = 14.14A) and has a duty cycle of 8.3 msec. The supply load demands a peak of 30 amperes, and the current transfer is completed in just 2 msec -- i.e., four times faster than the resistive load drawing the same amount of rms energy.

Why are there misconceptions regarding the need for regulation? Many current line monitors misrepresent the facts and thus cause the choice of inappropriate solutions. The following statement from the ac power and grounding technical document of a major interconnect company illustrates this problem. "A partial dropout may cause the monitoring equipment to record a sag of one or two cycles with a level of anywhere from zero to the nominal voltage. Because of averaging the voltage over the cycle, a 1/4-cycle dropout is recorded as a one-cycle, 90-volt sag; a 1/2-cycle dropout is recorded as a one-cycle, 60 volt sag. Depending on the portion of the sine wave which is missing, dropouts (of less than one cycle) are reported as sags of various voltage levels."[1] The conclusion is that regulation is a concern in less than 10 percent of cases and that switching power supplies deal most often with the low or high line condition. In fact, a switcher is far more effective in re-establishing nominal voltage than are either electronic tap switchers or ferroresonant transformers. Both these devices tend to aggravate the problem.

Ferroresonant Transformers

Over 50 years ago, ferroresonant transformers were invented to regulate voltage for neon lights and electric motors. The transformers offer good noise and transient rejection and are good voltage regulators when they operate with a stable resistive load. Since they contain no solid-state components or moving parts, they are reliable; but there are trade-offs.

Ferroresonant transformers need to be sized at more than twice the steady-state load if the the load includes devices which draw high inrush currents. They are least stable at half-load and result in poor system stability. Extending short-term power interruption, typically by one cycle, they often lead to system shutdown. On recovery, overshoots and undershoots create further instability for several cycles. With a switching power supply, 60 to 80 volt noise spikes every half-cycle are common. These spikes result from the mismatch between the high impedance transformers and the low-impedance switcher and lead to load disruption, degradation and eventual destruction.

These transformers are inefficient (75 to 80 percent), and they generate excessive heat and audible noise. The magnetic synthesizer is an improvement but still has many of the shortcomings of the traditional ferroresonant transformer.

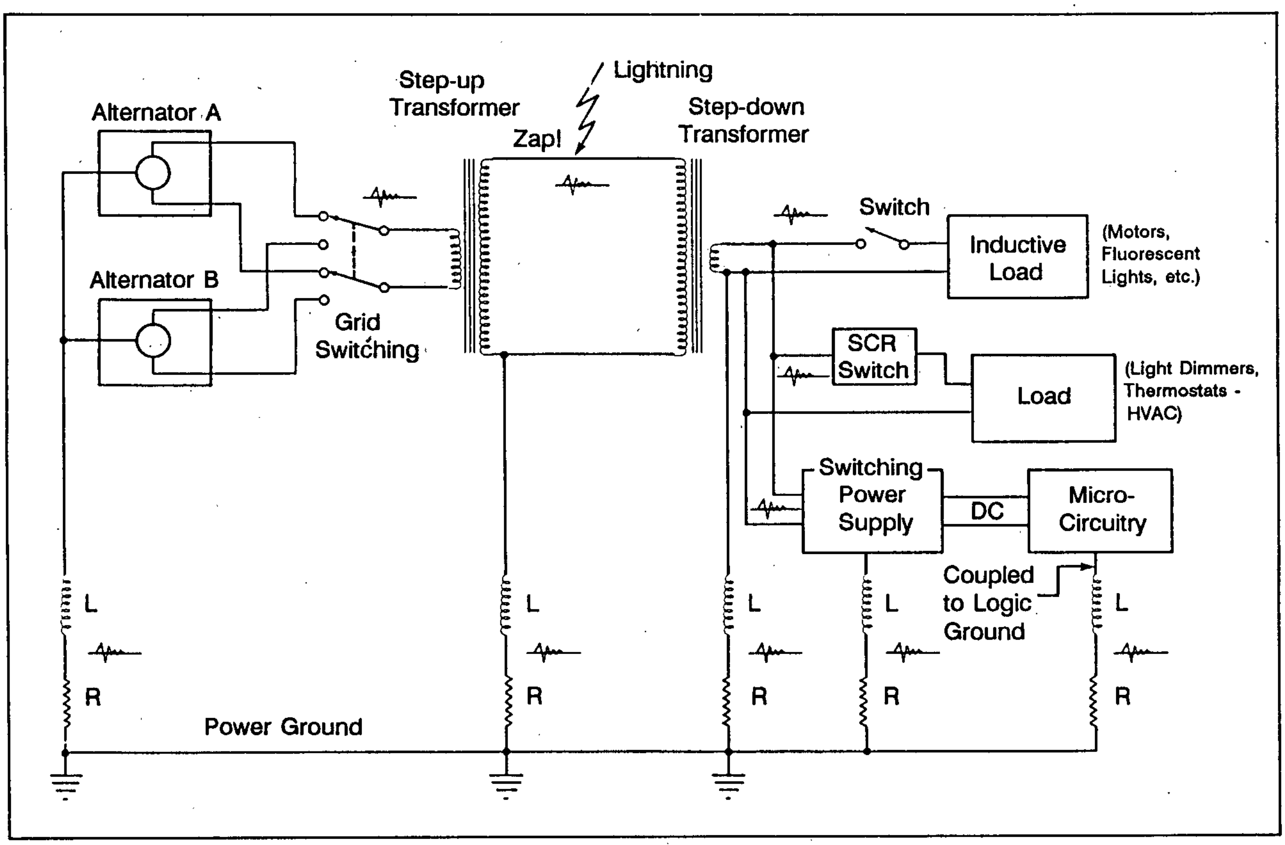

Figure 1. Sources of AC Power Line Noise.

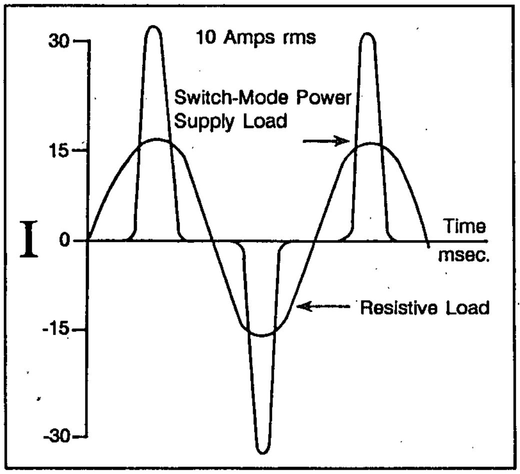

Figure 2. Comparison of Resistive and Switch-mode Power Supply Load.

Electronic Tap Changers

Tap changers control the primary-to-secondary turns ratio by switching electronically the boost or buck taps to compensate for line-voltage fluctuations. With an efficiency of 93 to 96 percent, tap changers are more efficient than ferroresonant transformers. There are two main types of tap changers. The most common is transformer-based and eliminates common-mode noise voltages on the tap switcher's changes. Line isolation provides an important safety benefit; but with high-impedance and ultra- and super-isolation transformers, significant output noise can be generated. A less popular tap changer is based on the auto-transformer. Auto-transformers provide low output impedance for switching power supply loads, but the lack of line isolation means that real common-mode noise attenuation is low.

Both types of tap changers experience tap dancing, an instability between conditioner and load with the tap moving constantly between taps. Tap dancing can trigger failure mechanisms -- e.g., circulating currents of several hundred amperes. Under extreme circumstances, such current can destroy SCRs and other control electronics. Tap changers do not recover well from line notches. Some microprocessor-controlled units drop their output for several line cycles after a half-cycle interruption and thereby cause virtual shutdown of all computers. Since a half-cycle notch will not, on its own, shut down a system, the tap changer solution has, in this case, become the problem.

Surge Suppressors

Surge suppressors are totally unacceptable for these applications as they deal only with transients over 200 V and always dissipate the energy to ground. Energy is passed through to the computer-driven system and results in degradation and destruction. On the odd occasion where low or high line conditions persist, they are most often a facilities issue and must be dealt with on a facilities-wide basis. Normally a basic change to the power distribution system is required, rather than local mitigation.

APPLICATION/MITIGATION CONGRUENCE

Traditionally the ac power environments have been viewed as relatively static, with limited differences between facilities. With new tools which examine the environment in real time and at different points in the distribution system, it has become apparent that not only do environments differ dramatically but that the dynamics of the environment also change significantly over time.

Figure 3, developed from IEEE data, shows all possible electrical environments. Most commercial and industrial locations will fall within the exposure channel. Through monitoring, the quality of the power environment can be plotted as an indicator of the severity, frequency and types of problems which are possible.

Once the severity of the power environment has been defined, the next step is to identify the application.

Computer-Driven Systems

A new technology, consistent with the needs of organizations which use computer-driven systems in either manufacturing or administration, has recently been introduced. The ac power interface was developed by engineers from the test industry; their prime objective was protection of semiconductors and other sensitive electronics during fabrication, assembly, test, integration and final usage. This technology called a "Low Impedance AC Power Interface" features the following capabilities:

- Repeated protection from catastrophic transients up to IEEE 587 - 6000 V level with less than 10 V normal mode and 0.5 V common mode passing into the system.
- Very low (1 kHz) forward transfer impedance to allow delivery of energy to the load on demand with no clipping or starvation.
- High inrush current rating (10 to 20 times steady-state current requirements) to ensure adequate current on startup.
- Fast response to load current changes to maintain computer operational stability without overshoot or undershoot.

- Efficiency of 98 percent to minimize operating expenses and heat generation.
- Load induced noise is virtually eliminated to prevent destructive interaction between loads or noise reflection back into the originating system.
- Transparency to power switching to allow natural ride-through after notching which might otherwise cause shutdown.
- Minimum neutral-to-ground voltage drop to prevent system malfunction and disruption.

This technology was recently EMP tested to MIL-STD-461C and MIL-STD-462 with the following results: "The EUT did not display performance degradation or malfunction due to the injected pulses. This constitutes a passing of the EMP test. It can, therefore, be concluded that the power conditioning system can operate in and survive an EMP environment as described in MIL-STD-462, Notice 5, Method CS10." It was also shown that the power conditioner provides excellent attenuation of conducted transients in the EMP frequency range as evidenced by the parameters listed in the table.

Frequency (Hz)	Peak Current (mA)	Attenuation (dB)
10k	75	14
100k	29	35
1.0M	32	50
10M	210	34
30M	96	31
100M	48	26

MOTOR CONTROLLERS AND POWER SEMI-CONDUCTORS

A significant number of motor controller malfunctions and failures could be prevented if process control systems were provided with an electrical environment suitable for their sensitive new components. The motor controller is the workhorse of the automated factory; and when it fails or malfunctions, the cost can be high. The changing technology on the plant floor has led to a re-evaluation of the type and quality of power needed to protect modern process control systems.

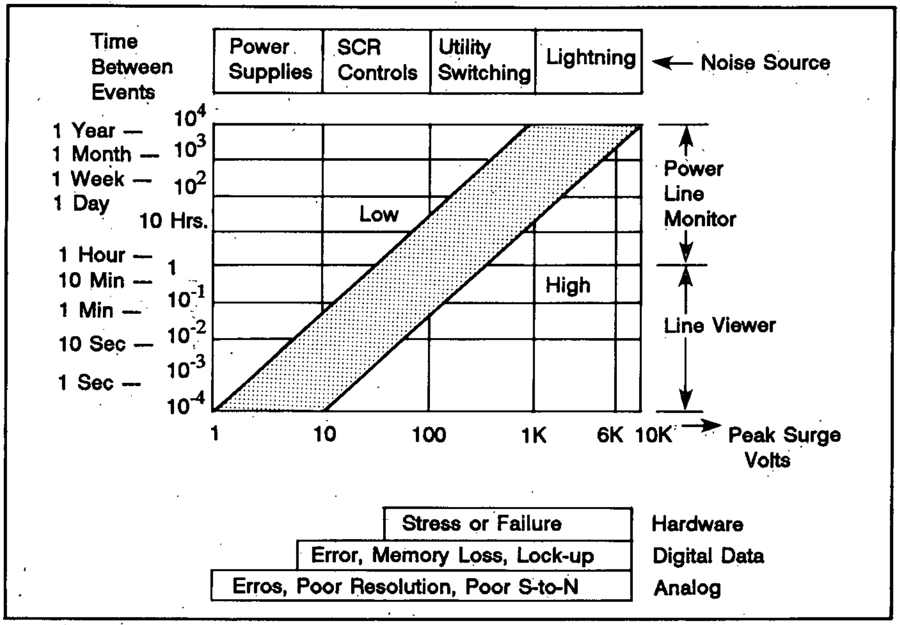

Figure 3. Power Line Noise Exposure Chart.

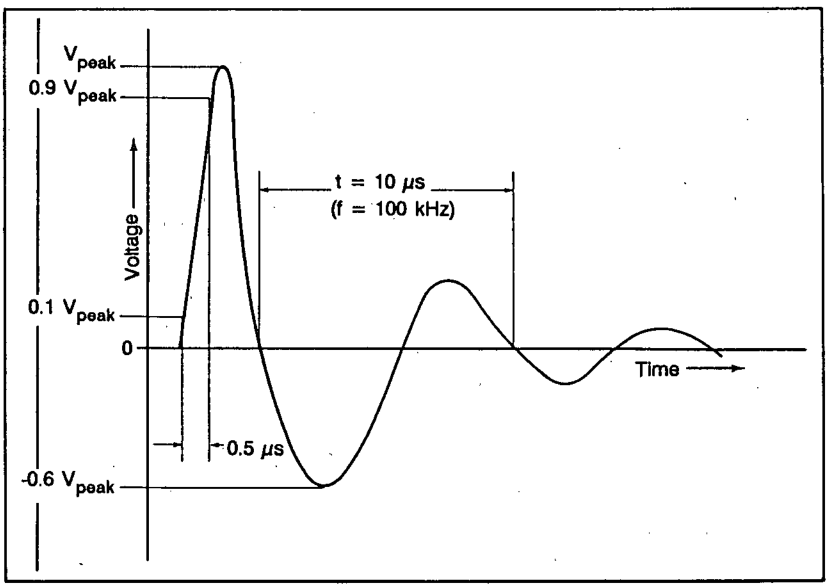

Figure 4. Worst Case Noise Transient.

Electrical Noise

A major source of motor controller failures in systems today is electrical noise. Excess power line voltages exist at extremely high frequencies and can occur in nanosecond time frames. Depending on the energy levels, the impact on the semiconductor can range from malfunction to destruction. The IEEE has shown that surge voltages occurring in normal ac power circuits originate from two major sources. Transients, in which sources are external to the building, result from lightning and from major power switching disturbances such as grid or capacitor bank switching. Internally, transients result from switching near the point of application including the turnoff of other loads in the same or adjacent system or resonating circuits associated with switching devices, such as SCRs or thyristors.

Occurrence of Transients

Surges occur randomly. Data collected from many sources across North America and Europe have been integrated to produce the power line exposure chart discussed previously and shown in Figure 3. The chart shows that every day of the week a 100 to 1000 volt disturbance occurs in the electrical environment. Actual measurements in operating facilities show that this estimate is quite conservative.

Transient Waveshape

IEEE further defined the waveshape and the rise time (dv/dt) of typical surges in industrial applications. The conclusion was that the broad range of transients could be simulated by a limited set of test waves for the purpose of evaluating the effects on equipment. The waveshape chosen as reasonably representative (Figure 4) rises from 10 percent to 90 percent of its maximum voltage in 0.5 microseconds, then decays while oscillating at 100 kHz; each peak is 60 percent of the preceding peak. IEEE suggests that the fast rise time will produce effects associated with semiconductors and that even shorter rise times are found in many transients.

The IEEE oscillatory waveshape, or ring wave, has a rise time (dv/dt) of 9,600 volts per microsecond, probably 30 times faster than the protection of the most resilient SCRs.

The Power Semiconductor

Because of the obvious advantages of reducing maintenance costs and increasing productivity, the use of solid state controls for mechanical processes has grown rapidly. Semiconductor power switching devices have been available commercially since the early 1960's; but now ongoing technological improvements and reduced costs have made them very cost-effective. The various types of power switching semiconductors available today include SCRs (thyristors), TRIACS, MOSFETs, and bipolar transistors. While each device exhibits its own operating characteristics, all of them tend to have very similar failure modes.

Critical Rate of Rise of Forward Voltage (dv/dt)

Controlled rectifiers in process controls are repeatedly subjected to fast-rising wave fronts. These fronts result from neighboring controls and from the reactive kickback from nearby or associated motors. The SCR is sensitive to a fast-rising forward applied voltage, and the specification for the the maximum dv/dt capability of such devices is always given. A high dv/dt can cause premature triggering and can allow excessive inrush current which will destroy circuit components. SCRs typically have a dv/dt capability less than 300 volts/microseconds, and a dv/dt as low as 20 to 50 volts/microsecond is common. These figures should be compared against the IEEE representative pulse with a dv/dt of 9,600 volts/microsecond, which is more than 30 times greater.

Rate of Rise of Anode Current (di/dt)

When the gate signal is applied to an SCR, it cannot conduct its full rated current instantaneously. If the allowable rate of current rise (di/dt) is exceeded, the current density is concentrated close to the gate terminal. Hot spots are generated, and this local heating can destroy the device.

Load and Line Characteristics

For a power protection device to provide the proper interface between the power system and the motor controller, it must eliminate power problems while remaining stable during operating changes. The process control system is a dynamic load which must interact with an equally dynamic power system. Power factor correction, grid-switching, and the addition or reduction of loads occur throughout the day over the entire system as the power line changes its high frequency impedance on a routine basis. A motor control system can interact with the power system during these changes without difficulty; however, the device which provides the protective interface must be able to match the dynamic impedance of the line with the dynamic load characteristics of the control system.

Low Interaction Ratio

If it is to dampen transients on the power line effectively, the power protection device must have an output impedance, compared to the transient, which is low in comparison to the impedance found in the equipment being protected. In any discussion of impedance, consideration must always be given to the noise frequency of concern. The interaction ratio of a power protective is the ratio of its input impedance to its output impedance at a stated noise frequency, typically 100 kHz or higher. Such a quoted ratio can be used to determine the effectiveness of a device.

CONCLUSION

To achieve optimum performance from computer-driven systems, all productivity degraders must be removed or rendered benign. Too often the ac power driving the system is ignored, and this oversight results in diminished system performance. The final result may be loss of process control, poor product quality, or high costs of operation and manufacturing. With the use of appropriate mitigation technology tailored to the application and the cause and severity of the ac power contamination, system performance is enhanced and will deliver improved system availability, higher yields and throughputs, better data integrity, and increased process control.■

REFERENCE

1. Rolm AC Power and Grounding Technical Document #300245.