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Designing Electronic Devices to Survive Power-Quality Events

The most common electric power-quality events—sags, swells, and transients—have been identified and quantified in recent national studies by U.S. utilities and the Electric Power Research Institute (ERPI). Utilities are making efforts to improve power quality; however, it also makes sense to design loads, such as appliances, process control computers, and semiconductor manufacturing systems, to tolerate common power-quality events. This article suggests some design criteria for "power-quality-tolerant" designs, and suggests ways of achieving them. Warranty and service costs will be reduced and customer satisfaction increased.

Immunity, Tolerance, and Graceful Failure

In discussing how to design for power-quality events, we first need to define "survival." It is useful to distinguish three different modes of survival: immunity, tolerance, and graceful failure.

Immunity means that the user is unaware that a power-quality event has taken place. *Tolerance* means that the user may be aware that a power-quality event has impacted the device, but is not required to take any action to restore the device to its normal operating mode. *Graceful failure* means that the device may fail during a power-quality event, but it is relatively easy for the user to restore operation.

Here are three examples of survival modes:

- Immunity: a low-speed transient to 150% of nominal power line voltage for 0.1 cycles is delivered to a microwave oven, but the oven continues to function normally.
- Tolerance: a voltage sag to 60% of nominal for 5 s is delivered to the microwave oven. The cooking power is greatly reduced during that interval, but the timing functions continue to operate normally, and the oven proceeds with its programmed sequence.
- Graceful failure: a voltage swell to 170% of nominal for 5 min is delivered to the microwave oven, and a user-replaceable fuse or circuit breaker opens.

All three modes of survival provide useful customer benefits and reduced service and warranty costs.

Electric Power-Quality Studies and Standards

The electric power industry, led by ERPI [1], has been studying power quality for at least 15 years.

Photo courtesy of Power Standards Lab.

Fig. 1. The Electric Power Research Institute used PQNodes like this one to gather power-quality data at sites all over the United States. The three-year project provides a strong, statistically valid base of information about common power disturbances.

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The most extensive study is EPRI's recently completed *National Survey of Distribution Power Quality* [2], which recorded power-quality events at over 300 carefully chosen locations throughout the country for three years. Your local utility, if it is a member of EPRI, can provide a copy of this study.

The IEEE has several working groups that set recommended practices on power quality, including IEEE-519, which covers harmonics, and IEEE-1159 [3], which covers monitoring electric power quality. IEEE-1100 [4] covers powering and grounding for computers and similar equipment. It is a useful guide for thinking about power for devices that contain electronic controls. ANSI C84.1 defines various voltage tolerances, generally for longer intervals.

The semiconductor manufacturing industry has published an excellent standard for voltage sag immunity called SEMI F47. Free copies can be requested at http://www.PowerStandards.com.

The statistics in these national studies can be used to evaluate the economic return on improving the power-quality tolerance of a design. The statistics, combined with power-quality compatibility testing, will indirectly quantify the number of expected failures without modification; an economic benefit from reduced warranty cost and increased customer satisfaction can then be calculated.

Common Power-Quality Events

Although a huge variety of power-quality events can take place, the most common in a residential environment are:

- Voltage sags from a variety of sources (each source has an associated set of sag characteristics);
- Power-factor-correction-induced, low-frequency oscillatory transients;
- Momentary interruptions;
- Lightning-induced impulsive transients; and
- Neutral-failure-induced sustained overvoltages.

If you design to survive these events, you will have dealt with almost all practical problems; rarer events like bursts of high-frequency noise, and rarer problems like distorted voltage waveforms, can probably be ignored. Sustained power interruptions are generally not considered to be power-quality "events," and customers generally do not expect their devices to operate during a sustained interruption.

Voltage sags have two common causes: local loads (e.g., motor starting currents, heaters) that generally will not sag below 70% for more than 2 s and faults on the utility distribution system that generally will not sag below 80% and will generally be cleared by reclosers within 15 s.

Power-factor-correction-induced, low-frequency oscillatory transients appear whenever a switched power-factor-correction capacitor is activated at a nonzero instantaneous distribution voltage. The transient may typically rise to as much as 180% of the nominal voltage, but will decay within less than a single fundamental cycle.

Momentary interruptions are generally caused by proper operation of the utility distribution system. A fault (such as a tree branch, squirrel, etc.) causes an overcurrent; the utility's circuit breaker trips, then, the circuit breaker automatically recloses, typically in 5 to 15 s.

Lightning-induced impulsive transients can rise to as much as 6 kV for 1 or 2 ms. There are industry-standard waveforms for testing susceptibility.

Neutral-failure-induced sustained overvoltages can, in theory, be as high as 200% of nominal voltage, but in practical situations, rarely rise above 170% of nominal voltage. They are caused by a combination of unbalanced loads and a neutral connection failure in split-single-phase environments, the most common residential environment in the United States. A complete description of the causes and characteristics of this problem can be found in *PQ Today* [5].

Suggested Power-Quality Design Goals

Standards for power-quality tolerance (or electrical system compatibility) have not yet been developed and published. The suggestions below are based on the author's experience and judgment and are offered as a reasonable goal. It is likely that a design that meets these goals will have greatly reduced power-quality-related service and warranty costs.

Immunity: 80% to 120% of nominal voltage for an indefinite period; 150% of nominal voltage for a single cycle; 2-kV impulsive transient.

Tolerance: 0% to 120% of nominal voltage for 15 s; 180% of nominal voltage for a half-cycle; 3-kV impulsive transient.

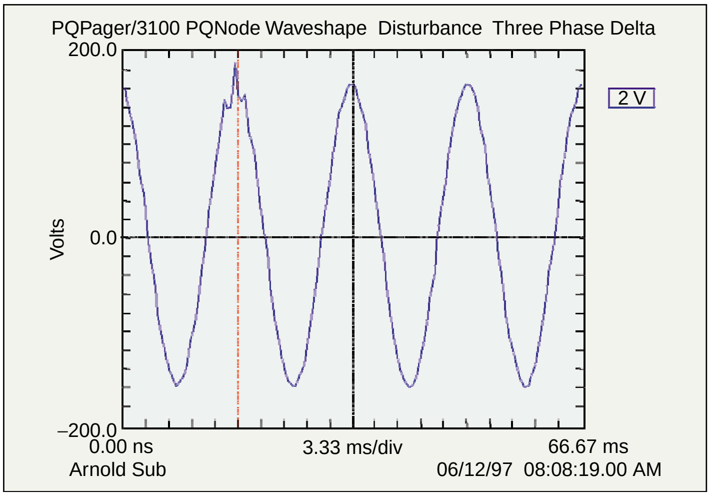

Fig. 2. A typical small disturbance. Power-factor-correction capacitors can induce low-frequency oscillatory transients like this one, the second most common disturbances. By far, the most common are brief reductions in rms voltage, called voltage sags.

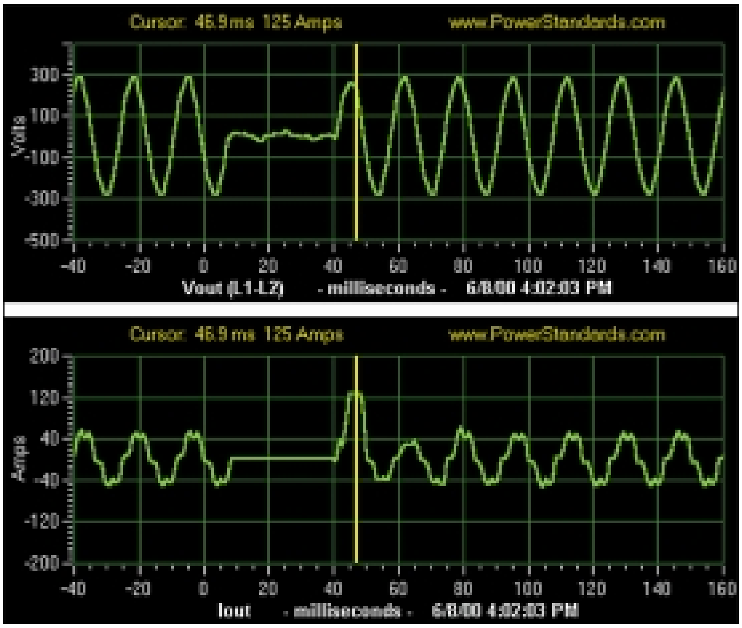

Fig. 3: Even a brief voltage sag (upper graph) can lead to a huge momentary current surge (lower graph) at the end of the sag. Subtle problems like this can be diagnosed with a sag generator.

Graceful failure: less than 80% or more than 120% of nominal voltage for an indefinite period; 6-kV impulsive transient.

How to Achieve Power-Quality Design Goals

First, ensure that you have the ability to test your design for power-quality tolerance and compatibility or engage a group such Power Standards Lab to perform your testing. You need to know how your existing designs behave.

Overvoltage Tolerance and Immunity

In general, this is simply a matter of selecting components that can tolerate brief and sustained overvoltages. Incremental costs are minimal. In some designs, an overvoltage sensor may need to be desensitized.

Sag and Interruption Tolerance and Immunity

This requires some form of energy storage in the design, typically a capacitor. The key here is to select and electrically isolate the parts of the design that will draw power from the energy-storage device. For example, in a washing machine, the electronic controls should be able to draw power from the storage device, but the motor, pumps, and valves should probably be ignored. In fact, there may well be sections of the electronic controls that can also be ignored, such as displays.

This approach implies rectifier isolation between power supplies for various parts of the design. Note that the increasing availability of dual 5-/3.3-V logic parts, including microprocessors, means that a simple, inexpensive diode/capacitor combination may be sufficient.

In general, you will not want to approach this section of the problem by increasing the size of the power-supply filter capacitor because that will generally lead to increased power-line harmonic currents. Instead, the energy storage should be incorporated within or downstream from the power-supply regulation circuits.

It is important to analyze the behavior of those parts of the system that do not receive power from the energy-storage device. Two common problems: those parts of the system may lapse into a state that is not expected by the microprocessor or there may be an unintended power leakage path through signal or control lines to the "unpowered" sections.

Sags are, by far, the most common power-quality event, so it makes sense to focus most of your efforts on this problem.

Two often-overlooked problems occur at the *end* of a voltage sag, when the voltage returns to normal. A discharged filter capacitor may suddenly cause a huge current surge—soft-start circuits are often disabled at this point—which, in turn, can disrupt other circuits. Otherwise, a power-on-reset circuit may interpret the sudden increase in voltage at the end of a sag as requiring the entire system to be reset. Be careful, and test your design with a sag generator [6].

Impulsive Transient Tolerance and Graceful Failure

In general, inexpensive suppression devices such as metal oxide varistors (MOVs) are used to accomplish this goal. These devices are placed across the power conductors after the fuse. They have a high impedance at normal voltages, but rapidly switch to a low impedance when the voltage rises above some threshold.

Coordination with internal devices, fusing, and (surprisingly) other loads is the key to proper MOV application. You must select an MOV with a voltage threshold that is lower than a voltage that will damage other components in your design, such as transformer insulation or electronic switches, and one that can dissipate the available energy in the expected impulsive transient. Yet, you want to select an MOV with the *highest* possible voltage threshold because all MOVs in a residence are essentially in parallel, and the one with the lowest voltage threshold is the "low bidder" during a lightning strike and draws more energy.

MOVs are applied downstream from fuses, so the fuse characteristics become important. For large impulsive transients, it is acceptable to blow the fuse; but for smaller transients, fuse operation is not necessary and annoying to the customer. These transients typically last for less than a millisecond, a time interval not covered by typical fuse data sheets. Air core inductors can be used to tune the MOV-fuse interaction.

Conclusions

Electronic designs can often be inexpensively modified to tolerate unavoidable power-quality events. The final design should be tested with disturbed power, such as that provided by a sag generator [6]. Utility power-quality statistics, now available from national studies, will allow economic justification of these modifications and tests. These modifications will reduce service and warranty costs and increase customer satisfaction.

References

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[3] *IEEE Recommended Practice for Monitoring Electric Power Quality*, IEEE Std 1159, 1995.

[4] *IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment*, IEEE Std 1100, 1992,

[5] *PQ Today Newsletter*, Summer 1997. Available: http://www.dranetz-bmi.com or call +1 800 372 6832.

[6] For more information on sag generators, including tutorials, see http://www.PowerStandards.com, or call +1 510 596 1784, fax +1 510 655 3902.