Circuit protection basics - Part 1: Issues and design solutions

Rich Pell - December 22, 2011

The use of electronic equipment in industrial, commercial and residential environments continues to grow exponentially. All require power to operate and all are significantly impacted by complex power disturbances. As a result, the inconsistency of the power grid places the reliability and efficiency of equipment in constant jeopardy.

In Part 1 of this two-part series, I will lay out the issues and the component and design solutions that you can use to resolve them. In Part 2 I will look specifically at predictive analysis: how it works and typical implementation.

Two Core Issues
I see two major issues putting electronic equipment and the circuits at risk:

First, education and training within our industry about the engineering behind the grid and circuit protection leaves a lot to be desired. Historically, not a lot of people have studied the real problems of the power grid. The fact is, electronics have grown increasingly sophisticated, yet the grid and the outlet designs powering them are seriously antiquated. Circuit protection has advanced little, making us limited in the ability to meet the protection requirements demanded by today's increasingly digital world.

When designing a power supply, you assume that the power coming out is going to be 120 V or 60 Hz, but never have we really explored the irregularities that are common with today's grid and its damaging affects to modern day electronics. The bottom line: our industry is working mainly within an outdated system and little is being done to research big-picture solutions, putting both devices and the aging grid at risk.

The second most significant problem related to the grid and circuit protection today is the "silent killer," otherwise known as voltage sags. Voltage sags, which happen quite often, are a secondary effect of a very common problem, which, for the sake of this article, I'll call "The Squirrel Problem." A squirrel knocks out a line and within a one mile radius of where that fault occurred everyone's power goes to zero. However, the entire grid in a 20-30 mile radius immediately begins trying to feed that one-mile fault radius to keep the power on for all affected. That action, however, drags the entire area down, reducing voltage.
When a voltage sag occurs, capacitors inside your equipment are discharged. When the voltage returns to normal levels, the capacitors draw in current to recharge. This current inrush can reach levels five to 10 times higher than the normal current draw, negatively affecting circuits.

Now, the fault can usually be fixed pretty quickly but within the fix lies the problem: those voltage sags create a huge current "inrush" as the voltage returns to normal, negatively affecting most pieces of electronic equipment. Today's devices pull a huge amount of current at start-up. However, the device used to limit current at start-up does not reset fast enough when a voltage sag occurs, so a huge current inrush enters unabated. The inrush far exceeds the component ratings of the electronic device and over time that device is weakened. As a result, the device fails, experiences abnormal events and the manufacturer gains the reputation of poor quality.

The fact is that no two disturbances are the same, and the increased complexity of these disturbances in combination with one another have been proven to be catastrophic to the lifespan and reliability of electronics. It's time to recognize and fix these issues.

**Protection Choices**

Before we get ahead of ourselves, let's cover the basics of circuit protection. Circuit protection refers to a variety of devices that safeguard electrical circuits from the power disturbances. The most basic device is a fuse, a type of low resistance resistor that acts as a sacrificial device to provide over current protection, of either the load or source circuit. A fuse protects the circuit, but once it's utilized, it's kaput. The next device is a circuit breaker, which is a resettable device for stopping the flow of current in an electric circuit as a safety measure.

Over the years, technologies such as fuses and circuit breakers have led to the development of supplementary power protection devices, beginning with the surge protector and then uninterruptable power supply (UPS) technology. Unfortunately, however, the surge protection industry wasn't based on advanced engineering; instead it used a huge marketing machine painting a picture that lightning strikes meant death to your equipment.

The reality is that less than 0.05% of power related events that damage electronics are caused by voltage surges and spikes. But the industry was selling surge devices with metal oxide varistors (MOVs) that were very unprepared for overvoltage conditions. These devices were lacking advanced engineering, started to cause fires and did not protect electronics from 99.5 percent of the disturbances in the grid. As a result of the fires, UL, a global independent safety science company, stepped in and changed protection requirements. Today if a surge protector is to be UL certified, it
must demonstrate it will not cause a fire due to overvoltage.

The majority of today's protection components are limited to only protecting from voltage surges and spikes. According to I-Grid.com, less than one-half of one percent of power disturbances are caused by such disturbances, leaving today's electronics at risk.

So what are we to do? When it comes to modern power protection, there are both external and internal solutions, each with their own pros and cons.

**External Solutions**
The majority of today's external electronics protection choices are limited to either under-functioning surge protectors for the aftermarket consumer or unwieldy and expensive technologies, such as UPSs, for use by large enterprise systems. As I highlighted above, surge protection is an external solution designed to protect electrical devices from voltage surges and spikes.

Another more complex external solution is UPS, which provides emergency power to a load when the input power source fails, differs from an auxiliary or emergency power system or standby generator. The main difference being that it will provide instantaneous or near-instantaneous protection from input power interruptions by means of one or more attached batteries and associated electronic circuitry for low power users, and or by means of diesel generators and flywheels for high power users.

In order to increase perceived value, surge suppressor manufacturers started including power line filters within their devices. Although line filtering is probably already inside equipment containing an SMPS, per the FCC requirement, surge suppression device manufacturers often insert additional power line filters to their products, claiming the addition enhances protection. This is misleading for a couple of reasons. First, if the line filtering is already present, the redundancy of an additional filter is unnecessary. Second, the power line filtering doesn't protect from the real killers of electronic equipment: voltage sags, over voltages, brownouts, line instability during a power outage, and last but not least, voltage surges. The filtering is an important internal component, it prevents the noise from going back to the brand circuit, but from a defense standpoint, it simply doesn't protect.

Traditionally, UPS technology is quite effective from a technical standpoint, protecting against
disturbances on the higher end by isolating electronics from the grid and powering them by battery. However, early generations of UPSs didn't do a great job of creating a real clean power outlet. Some of the early UPSs would take a square wave, which alternated regularly and instantaneously between two levels, and try and turn it into a sine, or single frequency, wave. The problem with these modified square waves, which introduced so many harmonics on the line, is that they worked mostly on lower-range UPSs.

Today, however, the sine wave is king. The highest-quality UPSs produce a true sine wave output, which is effective but requires very expensive components in the inverter. True sine wave UPSs are normally found only in higher-end models, and the user must consider how long they can support 120 volts at a particular current level. A tiny UPS can run a cable router, but if you put your refrigerator on it, the device will probably run for 30 seconds before it runs out of juice.

What this all means is that UPSs are prohibitively expensive for most enterprise applications and too large to integrate into consumer and enterprise electronics. As a result, users either use nothing or turn to inexpensive surge protection that shields electronics from less than one percent of damaging power disturbances.

Internal Solutions
It's true we have made great strides in power supply design and internal protection technology. Modern electronic equipment utilizes switch mode power supplies (SMPS), an electronic supply that incorporates a switching regulator in order to be highly efficient in the conversion of electrical power. Since the power supply is the link that connects a piece of electronic equipment to the grid, it might contain some type of protection elements. There are a variety of internal solutions for voltage surge suppression, but the three main choices are Metal Oxide Varistors (MOV), Transient Voltage Suppression (TVS) Diodes, or Gas Discharge Tube (GDT). Each has different characteristics that make it ideal for different applications. In general, the solutions work by shorting when its internal voltage threshold is satisfied and provides a by-pass path for surge current to discharge.

However, one thing these solutions have in common is that they do not know the difference between voltage surges and over voltages. In other words, an over voltage can just as easily satisfy the threshold as a voltage surge can. The only difference is that the over voltage lasts much longer, which can end the usable life of some of these devices. In some cases, extended over voltages can cause the devices to burn.

Advances in Creating a Real Solution
Dr. Deepak Divan of The Georgia Institute of Technology has spent the past 20 years studying the power grid. His research included studying data collected from more than 5,000 power grid sensors positioned across the North American power grid. Dr. Divan's research shows that more than 99% of grid-based disturbances were events other than voltage surges. It turns out that voltage surges have been wrongly accused all these years.
The Electronic Power Research Institute reports these loss-generating disturbances are costing hundreds of billions of dollars annually to businesses in the United States alone. The frequency and variety of power disturbances are more complex than the industry once thought.

While a voltage surge event packs an extremely destructive blow, the data shows that on average, it is not as common as believed and reported by the surge suppression community. The likelihood of receiving a voltage surge hit is less than once in 10 years on average. While the likelihood of experiencing a grid-based voltage sag: 30-100 times per year; over voltage: 1-2 times a year; brownout: 2-3 times per year; and a power outage: 2-3 times per year. Each of these events causes current inrushes upon recovery. In addition, over voltages can cause instantaneous damage. Brownouts cause erratic behavior and lockups.

Now that I’ve detailed the issues and the component and design solutions that you can use to resolve them, I challenge you to take some time to evaluate the basics of circuit protection. How are you protecting your products? What components and solutions are you utilizing today? As the grid continues to age and product innovation leads to more complex devices, advances in protection technologies and effective implementation are essential. Dr. Divan’s experience and research has led to the development of advanced protection technologies. In part 2, I will specifically look at new, predictive technologies that address the technical problems designers and end-users are faced with.

About the author:
David McGirt joined Innovolt in spring of 2011 as the senior vice president of engineering. He has nearly 20 years of experience in technology and operational management within telecommunications and data center environments around the world. McGirt is focused on leading Innovolt’s technology development and expanding the technology to fit new markets, as well as develop its cloud capabilities. Previous to Innovolt, McGirt was the Founder and Chief Technology Officer of Xiocom Wireless, a global broadband company, as well as the Chief Technology Officer of ITC^Deltacom & Quality Technology Services. He earned his Bachelor of Science from Auburn University.