Understanding Transients: A Primer

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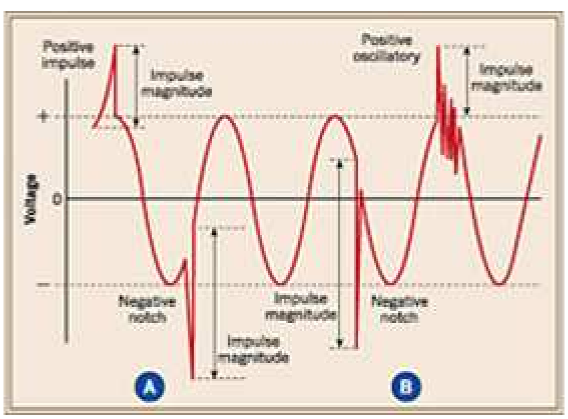
Mar 1, 2006 12:00 PM

Identify potential transient exposure on your system to ensure a reliable power quality environment

We've all heard the term “transient” used in discussions of possible power quality problems, yet we still seem to have a lack of understanding of what a transient truly is. There is no precise standard definition of a transient in the context of an electrical system. We generally say that a transient is a change in the steady-state condition of voltage, current, or both. In fact, transients vary widely in current and voltage waveshapes as well as magnitudes.



Let's take a closer look at these electrical phenomena.

Types of transients

Transients are categorized as either impulse or oscillatory.

Impulse transients

These transients typically have a fast rise time, a fairly rapid decay, and a high energy content, rising to hundreds and even thousands of volts. Their duration can be from a few microseconds up to 200 microseconds.

Area A of **Figure 1** shows a typical impulse transient. Note that its impulse magnitude is measured from the point it occurs on the sine wave — not from the zero voltage. We commonly call this type of transient a spike if it *adds* to the sine wave or a notch if it *subtracts* from the sine wave.

Oscillatory transients

Sometimes called ring wave transients, this type of disturbance has a fast rise time, oscillations that decay exponentially, and lower energy content than impulse transients (250V to 2,500V).

A typical oscillatory transient, as shown in area B of Figure 1, can last up to one cycle (16.7 milliseconds or 0.0167 seconds) or longer, and can have frequencies that vary from a few hundred Hertz up to many mega-Hertz.

Waveform characterization

To provide consumers with a logical and methodical means for selecting electrical transient disturbance protection, the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers (IEEE) developed C62.41-1980/IEEE Standard 587-1980 as an electrical transient exposure level/surge severity categorization guideline.

This standard was updated in 1991 and 2002 and is now referred to as ANSI/IEEE C62.41-2002, "Guide on the Surge Environment in Low-Voltage (1,000 V and less) AC Power Circuits." It is also a part of UL Standard 1449 Revision.

Described in the standard are six different waveforms that approximate the majority of transient disturbances, but not necessarily worst-case conditions. These waveforms aid in measuring and testing transient suppression components and systems in AC power circuits with rated voltages of up to 277V line-to-ground. The waveforms, shown in **Figure 2** on page 40 are duplicated by manufacturers for transient analysis by using the source impedances and short-circuit current values noted in the standard.

In the ANSI/IEEE standard, the AC power distribution system is divided into three location categories (A, B, and C), according to its physical distance from the utility power distribution lines and/or outdoor locations.

Category A

This category includes receptacle outlets more than 30 feet from a Category B location or 60 feet from a Category C location. Be careful here: Many homes and small commercial buildings have outlets that fall into Category B, not Category A, because of their close proximity to the main distribution panel.

Category B

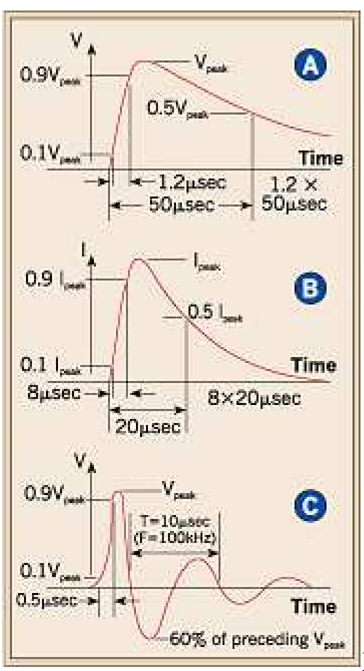
This category includes main and subdistribution panels, industrial bus and feeder systems, commercial lighting branch circuits, and high-wattage utilization equipment.

Category C

This category includes the service drop from the utility pole to the building service entrance, a run between the meter pan and main distribution panel, or overhead lines to detached buildings.

In going from Category C to Category A, the transient voltage and current levels become progressively smaller because of the inherent impedance of a building's power distribution system.

Sources of transients



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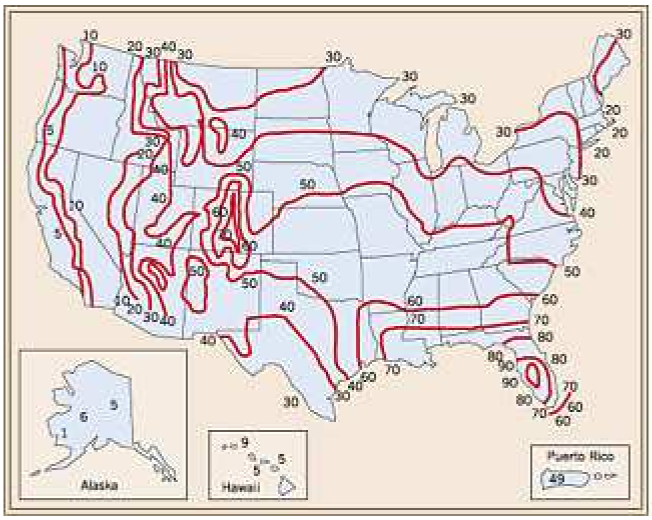
What triggers a transient? Lightning strikes and faults are common causes of transients. But, they can also occur when someone opens or closes a switch. To complicate matters, transients can also readily transfer from one conductor to another by means of electrostatic or electromagnetic coupling.

Lightning



This weather-related phenomenon is often thought to be the principal cause of most transients because it is known to strike overhead power lines. So, it causes problems in facilities having solid-state electronic equipment. While this is only partly true, you still must protect against lightning. The extent of protection you may need is a function of the geographical location of your facility. **Figure 3** on page 40 is an Isokeraunic map showing the mean annual number of days with thunderstorms in the United States.

A lightning stroke, which averages about 25,000A at 30 million volts, produces high currents in lines that take a direct hit. Only the lightning voltage and the impedance looking into the system limit the current in these cases. A traveling wave will move through an overhead cable at a speed of about 500 feet per millisecond and will reflect positively if the far end of the cable presents a high impedance (such as a transformer or open switch).

A characteristic of traveling wave phenomena is the instantaneous voltage nearly doubling during reflection. It's this voltage that can damage connected equipment. However, direct lightning strikes do not account for all disturbances on overhead lines. We frequently overlook the high electromagnetic field produced by the lightning. This field oscillates at a very high frequency. So a lightning stroke that misses an overhead line and strikes some nearby object or the earth induces high currents and voltages into the overhead distribution system. The magnitude of the induced voltage depends on the flux through the circuit, per Faraday's Law: $E = di/dt$. In other words, the amount of energy is equal to the instantaneous rate of change of current relative to time.

As you can see, lightning can produce extremely powerful, short-duration transients either by a direct strike or a near miss. Maximum lightning voltages on unprotected indoor low-voltage systems are proportional to residual voltages on the primary power system, when primary arresters operate. Lightning on power lines is diverted to ground by arresters, sparking over to conduct the build-up of energy before damage occurs.

Switching

Switching of electric utility or onsite loads also causes transients of a magnitude depending on the instantaneous rate of change of current relative to time (di/dt). In typical inductive systems, the voltage developed across an inductance (L) is described in the equation $E = L \times di/dt$.

Switching capacitors can cause severe transient voltages, and even normal system stray capacitance can cause transient oscillations. The timing of the switching can be problematic for some sensitive industrial loads. Let's say that a facility picks up a load on the same time each day. The serving electric utility may decide to switch its capacitors to coincide with that load increase. There have been several cases where this coincides with the beginning of a work shift, and the resulting transient causes several adjustable speed drives to shut down shortly after the process starts.

A simple and inexpensive solution to the scenario described above is to find a switching time that's more acceptable. For example, you could arrange for the capacitors to be switched on a few minutes before the beginning of the work shift and before the load actually increases.

According to the book “Electrical Power Systems Quality,” by Roger Dugan, Mark McGranaghan, Surya Santoso, and H. Wayne Beaty, McGraw-Hill (ISBN 0-07-138622-X), the use of preinsertion resistors can significantly reduce capacitor-switching transients. The first peak of the transient is usually the most dangerous, so the idea is to insert a resistor into the circuit briefly so that the first peak is significantly damped. The effectiveness of the resistors is dependent on the capacitor size and available short-circuit current at the capacitor location.

Switches with preinsertion reactors have also been developed for this purpose. The inductor is helpful in limiting higher-frequency components of the transient.

Still another popular, and relatively new, strategy for reducing transients on capacitor switching is to use synchronous closing breakers. Synchronous closing prevents transients by timing the contact closure such that system voltage closely matches the capacitor voltage at the instant the contacts mate. This avoids the step change in voltage that normally occurs when capacitors are switched, causing the circuit to oscillate.

RFI/EMI noise

Electromagnetic interference (EMI) or radio frequency interference (RFI) can be impressed on power lines as well as data and communication lines. Usually called "noise," this interference can cause errors in, or loss of, transmitted data. It can come from car ignition systems, mobile radios, and power transmission lines. This noise can also accompany high-voltage surges traveling along power lines.

A high-speed spike traveling down a wire into a coil generates an inductive "kickback" that opposes the amplitude of the spike, making it lower. In other words, these two forces are in series, thus canceling and reducing the effect of the spike.

Figure 4 on page 40 depicts a noise source having only positive spikes. It couples the impulses it's carrying onto the nearby conductor (depicted in the center of the diagram). This nearby wire acts like a coil. The coupled impulses and the reaction of the wire do not oppose each other. Instead, they show themselves as separate spikes on the wire. In other words, there are now twice as many surges because there is no canceling (see waveform on the right side of the diagram). This is no longer a linear relationship as per Ohm's Law. Now, the voltage through the nearby conductor is described by the equation $E = L \times di/dt$.

Note that in this equation, as the speed of data signal increases, di/dt becomes smaller, and E becomes larger. As time is reduced from milliseconds to microseconds, voltage can increase to several thousand volts. As you can see, induced noise can be even more powerful and potentially more damaging than wired noise.