Electronic products must pass some level of immunity tests when subjected to conducted or radiated energy. Some of those tests include subjecting the equipment under test to electrical impulses: short-duration single events using defined voltage and current waveforms. Engineers also use impulse tests to verify electrical spacings on PCBs (printed-circuit boards) and to periodically check motor insulation.

Several international standards define impulse voltage and current waveforms, but only at certain points. The waveform shape, peak voltage, impedance, and application of the pulse vary among standards. So, the test pulse you use will depend on the standard you apply.

**Waveform definition**
The IEC (International Electrotechnical Commission) has at least two standards that define impulse tests and their waveforms. You would use IEC 60060-1, “High-Voltage Test Techniques,” when testing insulation systems, and you would use IEC 61000-4-5, “Testing and Measurement Techniques – Surge Immunity Test,” when performing switching and lightning-transient tests. Many end-use standards that define the testing of specific products reference one of these two standards.

In some end-use standards, both the insulation system of the DUT (device under test) and the ability of the device to withstand lightning and switching transients are important. The requirements of IEC 60060-1 and IEC 61000-4-5 are different, though, so the authors of an end-use standard must decide which is the better standard to reference. A relevant example is IEC 61730-2, a standard that covers safety qualification testing for PV (photovoltaic) panels.

In the PV standard, the authors note that the purpose of the test is “To verify the capability of the solid insulation of the module to withstand over-voltages of atmospheric origin. It also covers over-voltages due to switching of low-voltage equipment.” While this scope seems to be closer to that of IEC 61000-4-5’s surge-immunity test, the authors elected to conduct the test under the requirements of IEC 60060-1’s insulation-impulse test, which they deemed a better definition of their test program.

**Insulation system testing**
IEC 60060-1 defines a waveform by a rise time, peak value, decay time, and tolerances. These parameters can completely define a voltage or current waveform. Since the insulation tests are conducted on open circuits, this is all the definition that is needed, and IEC 60060-1 notes that the specified wave shape should be delivered to the DUT. Footnotes to Paragraph 19.2...
allow some deviation in waveform shape and peak voltage for instances when the DUT is capacitive or reactive. But because the waveform will check an insulation system, no significant capacitance or reactance is anticipated, and the standard gives no impedance specification. Thus, no current requirement exists in the case of a voltage tester.

This may seem to be a problem if the DUT is capacitive, but raising power offers little improvement in the resulting waveform. Furthermore, these tests are always conducted on equipment that’s not connected to mains power or otherwise energized.

**Lightning and switching transient testing**

IEC 61000-4-5 defines a waveform by a rise time, peak value, decay time, impedance, and tolerances. Because tests can be conducted in many configurations, the waveform is specified into an open circuit (voltage waveforms) or short circuit (current waveforms). IEC 61000-4-5 specifies only a 2 Ω, 1.2x50/8x20 combination generator. Appendix 2 of the standard, however, gives guidance regarding the tester’s impedance depending on the location of the test application:

- 2 Ω, mains testing;
- 12 Ω, mains to ground testing; and
- 42 Ω, secondary to ground testing.

Annex B of IEC 61000-4-5 provides for powered and unpowered testing and gives guidance for maximum impulse levels depending on the application. In Annex C, the standard provides guidance for judging the DUT’s performance. The authors of an end-use standard define these points.

While the IEC gives organizations that develop end-use standards the tools to administer impulse tests in a standardized fashion, the organizations are under no requirement to adopt the tools in their standards. For example, IEC 60601-1, which defines safety requirements for medical equipment, implements an impulse test that simulates a defibrillator. The input voltage and circuit components are defined, while the output waveform and voltage aren’t. Although the guidance in IEC 60060-1 and 61000-4-5 is well-written and well-received, the standards can’t cover every instance.

In addition, standards may use different impedance values for their testing. In some cases, the impedances provide a special current level at a breakdown voltage. Sometimes, a standard’s authors choose an impedance value to minimize breakdown damage, or they show a value in response to a known circuit parameter. For example, a standard might specify that a purely resistive load such as a meter socket be tested with a 500-Ω impedance tester.

**Impulse waveform uses**

If an end-use standard references either IEC 60060-1 or IEC 61000-4-5 or a standard otherwise defines a pulse by rise time, peak, decay time, and possibly impedance, the resulting waveform will be as shown in Figure 1a. One of the most popular voltage waveforms is the 1.2x50, where the rise time is 1.2 μs and the decay or duration time to half value is 50 μs. Tolerances for this waveform are 1.2 μs to rise from 30% to 90% of peak ±30%, and time to half value is 50 μs ± 20%.

Both reference standards use the same definitions and tolerances for this waveform, but IEC 61000-4-5 specifies delivery into a short circuit and IEC 60060-1 requires this waveform be applied with the DUT attached. Voltage impulse testing is used to find dielectric breakdowns in insulation systems and to test for performance when transients are present.

Figure 1b shows that the popular current waveform of 8x20 has a rise time of 8 μs ±20% into a short circuit (IEC 61000-4-5) or with the DUT attached (IEC60060-1). The waveform has a decay to half time of 20 μs ±20%. Use a current pulse with a known breakdown voltage. The test is designed to stress the breakdown components with a specific current. In these cases, the impedance requirement of the tester may be tailored to provide the desired test current to the DUT at the breakdown point. Specifically, one of the impulse tests for gas-tube devices requires a 100-Ω impedance to provide a 10-A pulse at a breakdown voltage of 1000V.

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**FIGURE 1.** a) Specifications such as rise time, peak value, and time to decay to 0.5 of peak define voltage and current test waveforms. The “U” in the vertical scale indicates portion of peak value. b) The waveform for test current into a short circuit rises within 8 μs ±20% (value of T) and can go negative by as much as 30%.
IEC 61000-4-5 defines the popular combination waveform impulse tester as well as both the voltage and current waveforms. As noted above, the standard defines only a 2-Ω tester, but it notes other output impedances as well. The impedance of a surge tester is defined as the ratio of the peak open-circuit voltage to the peak short-circuit current. These values will change when a device is being tested.

**Coupling-decoupling networks**

When conducting a powered test in accordance with IEC 61000-4-5, you should use a CDN (coupling-decoupling network) to present a high back impedance to the surge waveform toward the supply. That still lets the impulse flow to the DUT. The standard presents circuits for CDNs used for various tests, and the CDNs have to be designed to provide a waveform that is within tolerances specified in IEC 61000-4-5. Because of these performance requirements, CDNs have to be designed for specific waveforms, voltages, and currents, or there is a chance the CDN may not perform to the specifications. Always use a CDN when performing mains-powered tests. IEC 61000-4-5 has various schematics that illustrate how to use a CDN with other ports as well. A CDN isn’t required for unpowered tests because there’s no power supply to protect.

Depending on which of these two standards your end-use standard references, the tester you select can vary greatly. If the end-use standard uses IEC 61000-4-5 as the referee document for impulse waveforms, then the pulse will be defined without the device being tested in place. That is, the tester's voltage pulse will be evaluated when delivered into an open circuit, and the current pulse will be evaluated into a direct short. If the end-use standard uses IEC 60060-1 as the referee document, then the pulse will be evaluated with the device being tested as part of the circuit.

This can cause huge differences in the pulse if the device being tested presents anything other than an open circuit to the impulse tester in its tested configuration. Although IEC 60060-1 does allow waveforms to vary when the load is capacitive, these variances are limited. In these cases, the limiting factor may not be impulse tester power but the lead and internal tester impedance, which may be difficult to decrease.

**Waveform verification**

There are many definitions of impulse waveforms, and different referee documents differ in the way they treat the application of the impulse to the device being tested. Some waveforms are used to evaluate insulation systems, or determine behavior at an expected breakdown voltage, or to evaluate systems when presented with a mains transient.

The different definition schemes may make it difficult to verify whether the waveform was delivered correctly. If an end-use standard covering the equipment being tested specifies either IEC 61000-4-5 or IEC 60060-1 as the referee document, then you can verify correct operation by using an oscilloscope and comparing the waveform to the standard. Some waveforms in end-use standards, however, are defined by specifying the input voltage and circuit components. These pulses have undefined output peak voltage. While this is a valid method for defining a pulse, it is difficult to verify correct pulse delivery unless you can access the source voltage and can check component tolerances.

Some end-use standards use proprietary circuits that include the impulse tester and a CDN. The tester controls component values and input voltages. In these testers, you may have difficulty finding the correct output as well, so comparing the waveform to a waveform record taken at the last equipment calibration may be the best verification method.

Check the scope of your end-use standard to see which standard defines the impulse waveforms used. Be sure to read that standard to make sure your test will be in compliance with all required standards. T&MW

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