Keysight Technologies
Characterize DUT Response to Power Disturbances

Application Note
If you are involved in the design, manufacture, or verification of any device that is subjected to power disturbances or that creates power disturbances, you need to understand the ramifications of those disturbances to ensure a reliable, high-quality product for your customers. Products such as inverters and converters, uninterruptible power supplies and battery systems, automotive, rail, and aircraft transportation systems, lighting systems, and appliances are all susceptible to these power disturbances. Your product may have to comply with a regulatory standard or your company’s own internal standard regarding power disturbances. In any case, a reliable, safe, reputable product will continue to operate properly when subjected to minor power disturbances, and when subjected to major power disturbances, the product must perform as expected and must not fail. This application note focuses on ways to measure these power disturbances. Specifically, this application note compares using an oscilloscope with using a power analyzer with dynamic measurement capability for measuring power disturbances.

What is DUT power disturbance response and why is it important?

A power disturbance can be defined as any change in stimulus that affects either the input power of a device, the output power of the device, or both. What that device does as a result of the disturbance is the DUT (device under test) response to the power disturbance. Probably the most common power disturbances devices encounter are those caused by unintended variations in input power. Utility companies throughout the world that provide AC grid power do their best to ensure the integrity of the power they supply to homes and businesses. However, the power they provide in the form of regulated, constant, AC voltage is not perfect. Power surges, sags, brownouts, cycle dropouts, and transients can occur, and waveform distortion and frequency variations also happen. See Figure 1 for some examples of these disturbances. In some countries, these power issues are rare, while in other countries, they occur regularly.

Some devices create their own power disturbances during operation, such as an electric heater cycling on and off as its thermostat regulates the temperature or a computer monitor going from sleep mode (power-save mode) to wake mode (full-power display mode). In both of these cases, the input power consumed changes depending on the operating state of the device. This power change is really a change in input current, as the input voltage should be relatively constant. If the input current change is large enough, the current change will produce a significant voltage drop across the building wiring impedance, resulting in an input voltage change. Engineers need to know the impacts of these voltage and current changes on the device itself or on any other devices connected to the same AC circuit branch.

![Surge](image1.png) ![Sag](image2.png) ![Brownout](image3.png)

![Cycle dropout](image4.png) ![Noise](image5.png) ![Frequency variation](image6.png)

Figure 1. Examples of some AC power line disturbances.
How is DUT power disturbance response measured?

The key to evaluating whether or not a product is susceptible to a power disturbance is to clearly define the disturbance itself and then establish pass/fail criteria by defining the acceptable level of performance of the product when it is subjected to the disturbance. For example, when the disturbance occurs, normal performance within the product’s specified limits may be expected or a temporary loss of function or degradation of performance that ends when the disturbance ends may be acceptable. Sometimes, the device may have to be reset after exposure to a disturbance, and you could define that as acceptable or consider it a failure. In most cases, product damage would be considered unacceptable. A case where product damage may be considered acceptable would be a blown fuse as a result of an extended exposure to a high surge of input voltage – the fuse is expected to blow and is protecting the DUT. Clearly, you need to carefully consider the DUT and desired results for these definitions to be meaningful.

Once you define the power disturbances and DUT pass/fail criteria, you can begin testing. For AC line disturbances, there are various instruments available that can produce many of the disturbances. You can create many AC line disturbances with an advanced AC source such as the Keysight Technologies 6800B Series AC power source/analyzers. The Keysight 6812B from this series was used to create all of the power disturbances shown in this application note. AC line disturbances are voltages or currents that vary over time, so you need an instrument that can measure voltage and current over time. Two instruments capable of such measurements are compared here: oscilloscopes and power analyzers with dynamic measurement capability. The requirement is to easily capture AC line voltage and current waveforms having a typical AC line fundamental frequency of 50 or 60 Hz. Of course, higher-frequency measurements are also necessary, as the waveforms are rarely purely sinusoidal and they may contain many higher-frequency harmonics.

Using an oscilloscope to measure power disturbances

An oscilloscope is probably the first instrument you would consider to look at variations in the AC line voltage or to view varying line current such as AC inrush current at turn-on. Scopes are great at providing visualization of voltage waveforms from DC to very high frequencies (MHz to GHz). While a scope’s bandwidth may be exemplary, its voltage measurement accuracy is mediocre, stemming from a typical design that offers 8-bit vertical resolution. Additionally, there are two main drawbacks to using a scope for this application: ground-referenced inputs and the lack of direct current measurement capability.

Most oscilloscope inputs are referenced to earth ground; as the AC line voltage is also referenced to earth ground, you must make provisions to accommodate the ground-referenced input. Either the scope AC input must be isolated from ground with an isolation transformer (the scope must “float”) or you must use a differential probe on the input. Floating the scope is a safety hazard, as this application requires a scope input connection to the AC line, which will cause the scope case to be at line voltage potential. Using a differential probe avoids the grounding issue but adds complexity and expense to the setup and can add an additional 1% or more of gain inaccuracy to the scope specification. See Figure 2 for a picture of a scope with a differential probe and a current probe looking at the AC line voltage and current powering a DC power supply, and another differential probe and current probe looking at the output of the supply.
Oscilloscope inputs measure voltage, so for measuring line current you need to use some type of current transducer to transform the current signal into a voltage signal. The most common ways to measure current are to use either a current shunt or a current probe (or a current transformer). When carefully designed, a current shunt can be very accurate. However, much thought and design time are required to avoid unanticipated errors such as those caused by self-heating, temperature gradients, and thermo-electric effects. Also, a current shunt must be inserted into the circuit, meaning the path of current flow must be broken. When inserted into the AC input line powering your device, the current shunt is again at line voltage potential, causing a conflict with the earth-ground-referenced input of most scopes. You would need yet another differential probe to eliminate this problem. A current probe is more convenient to use, as the current path need not be broken and the probe provides isolation from ground. However, current probes are notorious for drifting and do not provide the accuracy attainable with a good shunt.

Figure 2. Example of an oscilloscope with a differential probe and a current probe looking at the AC line voltage and current powering a DC power supply. Another differential probe and current probe show the output of the supply.
Using a power analyzer with dynamic measurement capabilities to measure power disturbances

A power analyzer with dynamic measurement capabilities can offer advantages over using an oscilloscope to measure AC power disturbances. Although the bandwidth of the power analyzer will not match that of a scope, the power analyzer bandwidth is usually high enough to capture the type of waveforms encountered in 50- and 60-Hz power disturbance analysis including harmonics. Power analyzers have much better voltage measurement accuracy with up to 16-bit vertical resolution. Also, the power analyzer inputs are typically floating from earth ground, eliminating the need to use an isolation transformer or differential probes. A high-quality power analyzer will also provide current inputs using carefully designed internal shunts to provide high-accuracy current waveform measurements. Of course, to make use of the internal shunts, the current path must be broken, but the isolated shunts and increase in accuracy far outweigh the minor inconvenience of breaking the path. If you prefer a current probe over internal shunts, use a power analyzer that offers both current shunt inputs and a current probe input.

For example, the Keysight PA2201A IntegraVision power analyzer has all of the features necessary to accurately and easily display power disturbance waveforms. You can look at voltage, current, and power waveforms on each of two channels and see all six waveforms simultaneously. The IntegraVision’s 5-MSample/second, 16-bit digitization shows you waveforms in real time with up to 2-MHz bandwidth. Voltage and current inputs can float to 1000 V above or below earth ground. Each channel has two current shunt inputs (2 Arms and 50 Arms) and a current probe input to give you the flexibility to choose your preferred method to make accurate and reliable current measurements.

Figure 3. Keysight’s IntegraVision power analyzer displays an AC line voltage full-cycle dropout with one channel and the corresponding response of a DC power supply output with a second channel. The 20 V DC output drops about 0.6 V and then recovers in around 10 ms.
For power disturbance measurement applications, the dynamic measurement capabilities are ideal. You can trigger on any of the voltage, current, or power waveforms, or trigger on an external signal with the external trigger input. Figure 3 shows an example of the Keysight IntegraVision power analyzer measuring the response of a DC power supply to a power disturbance. The AC input voltage of the DC power supply is subjected to a full-cycle dropout and the corresponding response of the DC output voltage is measured. Figure 4 shows an inrush current measurement displaying the AC input voltage turn-on and corresponding current and power waveforms. The IntegraVision power analyzer makes capturing these waveforms simple because you can set the trigger source to trigger on the current waveform. You can easily make these AC line power disturbance measurements without an isolation transformer or differential probe because you connect directly to the floating voltage and current inputs. In addition to displaying waveforms, you can accurately measure watts, VA, VAR, power factor, crest factor, efficiency, watt-hours, amp-hours, and harmonics with the IntegraVision power analyzer.

Figure 4. Keysight’s IntegraVision power analyzer displays inrush current and power following an AC line input voltage turn-on. The cursors show a peak of 6.75 A (Y2) during the first cycle.

Summary
Measuring your DUT’s response to power disturbances is important to guarantee proper and reliable operation of your DUT to better satisfy your customers. You especially want to ensure your device responds well to AC line disturbances, as your device is likely to encounter them. Measuring power disturbances can be done with an oscilloscope or a power analyzer with dynamic measurement capability. Each measurement instrument has advantages and disadvantages, but for power disturbance measurements, a power analyzer with dynamic measurement capabilities has more to offer than a scope. The Keysight IntegraVision power analyzer model PA2201A is one such instrument that can allow you to gain quick insight into your device’s power consumption and dynamic behavior when it is exposed to power disturbances.
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