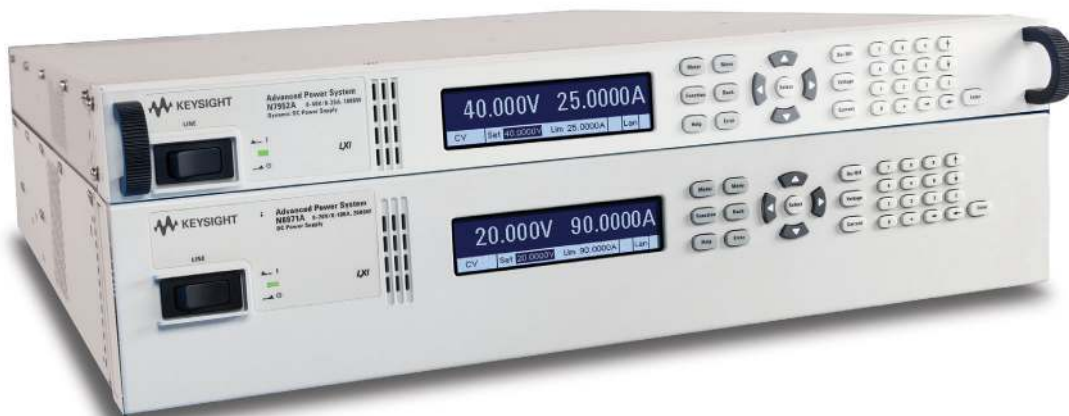# Keysight Technologies
Methods for Characterizing and Tuning DC Inrush Current

Application Brief

Introduction

Inrush current or input surge current refers to the momentarily large surge current that occurs when you first turn on power to a device. Inrush current often occurs in devices with a large amount of parallel capacitance at the input, such as DC-to-DC converters or devices with extremely low imped-ance under transient conditions, such as electric motors. Inrush current can be several times larger than the device's steady-state current. For instance, electric motors can have inrush current levels 25 times greater than their steady-state current levels.

When you characterize inrush current, you either capture a high-resolution digitized profile of a device's inrush current or just capture a reliable peak current reading. The traditional method for characterizing inrush current combines a power supply, a digitizer or scope, and a current shunt or current probe. In this measurement brief, we will look at using a modern performance power supply for characterizing inrush current and compare it with the traditional method.

Snapshot

An automotive company is updating its test system for electronic control unit (ECU) testing. Its engineering team scrutinizes the test plan to find ways to increase throughput and reduce test system complexity without reducing test integrity. The team identifies the inrush current measurement as a candidate for improvement. The system currently employs a power supply, a current shunt and digitizer, and switching to automate the inrush current measurement. The team decides to replace this setup with the Keysight Technologies, Inc. N7951A dynamic DC power supply. The N7951A is a fast power supply with a built-in high-resolution digitizer. N7951A provides them with a single-instrument solution that speeds up test, reduces test system complexity, and delivers higher accuracy than their old method for measuring inrush current.

Methods for Characterizing Inrush Current

Main reasons why characterizing inrush current is necessary in many test applications:

1. Device protection – You need to ensure inrush current does not reach levels that could possibly damage the device or impact reliability. Characterization allows you to determine if you need to reduce inrush current using techniques such as adjusting circuit hardware or reducing voltage ramp rates at turn on.
2. Battery drain and sizing – Because inrush current is so large, it can affect battery performance, depending on the battery's chemistry and internal impedance.
3. Fuse or circuit protection selection – Inrush current is significantly higher than steady-state current, so any high-current protection measures must be able to withstand the high momentary inrush current.

If we just consider the first reason from the above list, device protection and reliability concerns, it is not surprising that inrush current characterization is important in applications where reliability is paramount such as automotive, avionics, and satellite test.

As we mentioned earlier, the traditional method combines a power supply, a digitizer or scope, and a current shunt or current probe. Figure 1 shows an implementation of the traditional method for characterizing inrush current. In the figure, a shunt is used to measure the current rather than a current probe.

The traditional method for characterizing inrush current shown in Figure 1 looks fairly straightforward to set up, but it presents several challenges:

– You need to use a quality power supply, as you need a fast voltage ramp rate to understand the worst-case or peak inrush current. To accomplish a fast rate with a low-performance power supply, you would need to add a switch in series with the supply's output. With this setup, you would turn on the supply output with the switch open to allow the supply to ramp-up to the set voltage level. Once that is accomplished, closing the switch would apply the voltage to the DUT. Even with the switch, problems can still surface. If the supply's transient response is poor, its voltage level will droop while the inrush current sharply rises. If the voltage level droops too far, it may trip the DUT's reset circuit.

– One way to capture the dynamic profile of the inrush current is to use a current probe and a scope. The advantage of using a current probe over a shunt (discussed next) is you do not have to break the circuit to make the measurement and, for the most part, you are not electrically changing the circuit. The disadvantage is current probe measurements have poor accuracy due to drift and DC offset, and they need to be manually zeroed, which makes them tough to automate.

– Current shunts are low cost and do not suffer from the drift problems of current probes. The issue with shunts is they have to be inserted into the circuit and they electrically change the circuit. Since they change the circuit, the resulting inrush current profile changes slightly so you are not getting a true representation of the inrush current. Finally, heating caused by the sharp rise of current will raise the temperature of the shunt and change its resistance, which makes it difficult to determine its exact accuracy at any point in time.

– Because this solution requires multiple pieces of measurement hardware, it adds complexity to any test system compared to a single integrated solution.

Modern high-performance power supplies are simplifying power-related test and measurement challenges like inrush current characterization with features such as measurement digitizers, fast/adjustable turn-on voltage ramp rates, fast transient response, and advanced triggering. Having all the capabilities needed to characterize inrush current in a single instrument eliminates the drawbacks associated with the traditional methods by delivering increased measurement accuracy and reducing test complexity.
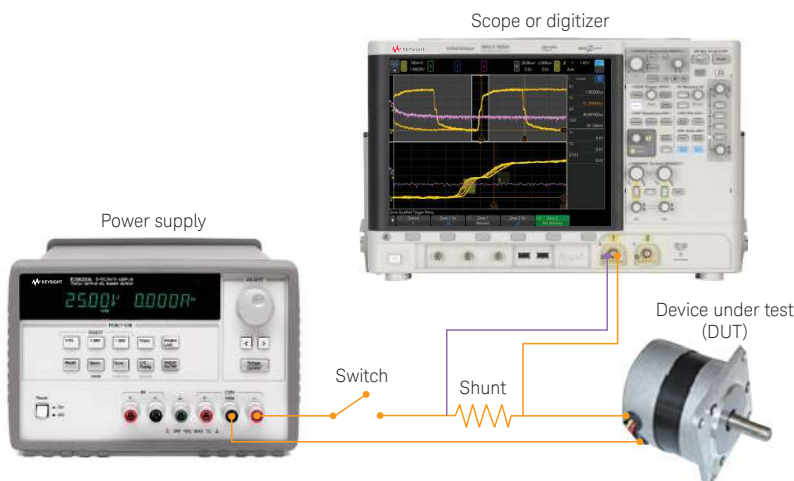

Scope or digitizer

Power supply

Device under test (DUT)

Switch

Shunt

Figure 1. Inrush current characterization test setup

Charactering Inrush Current with a Power Supply

Let's look at an example inrush current measurement on a DC electric motor. For this example, we will use Keysight's Advanced Power System N7951A dynamic DC power supply to characterize the inrush current. The N7951A is a great solution for characterizing inrush current because it provides:

– Adjustable sample rate current digitizer
– 18 bits of resolution (well beyond that of a scope)
– Level triggering for properly timing your measurement
– Ability to measure current levels 2.25x its rated output current

The motor is going to be operated at 15 V and has a steady state current of about 1.3 A. The N7951A's current digitizer is set for a sample period of 5 µs (200 KS/s) and a sample count of 20 K samples. The measurement trigger is set for a positive current slope and a level of 1 A. Figure 2 shows the resulting inrush current profile of the DC motor and Figure 3 shows a zoomed in view of the peak current.

The built-in high-resolution current digitizer of the N7951A allows us see the peak inrush current (54.55 A), the duration of the inrush current (~100 ms), and the sinusoidal behavior of the current due to the rotation speed of the motor. Using the N7951A, you get higher accuracy and resolution capture of the inrush current than you do with a shunt or current solution, all in a single instrument.

Measurement Tip #1

When choosing a high-performance power supply to capture inrush current look for one that has a current measurement range that is significantly higher than its output current range. For instance if a power supply's output current is rated for up to 50 A its current measurement range should extend to at least 75 A. This extra measurement margin ensures you will capture any inrush peaks that go beyond the rated output current of the power supply. As an example of why the inrush current peaks may extend above the rated output, power supplies have a lot of parallel capacitance at their output with stored energy. This energy can lead to short current bursts above the supply's output rated current.
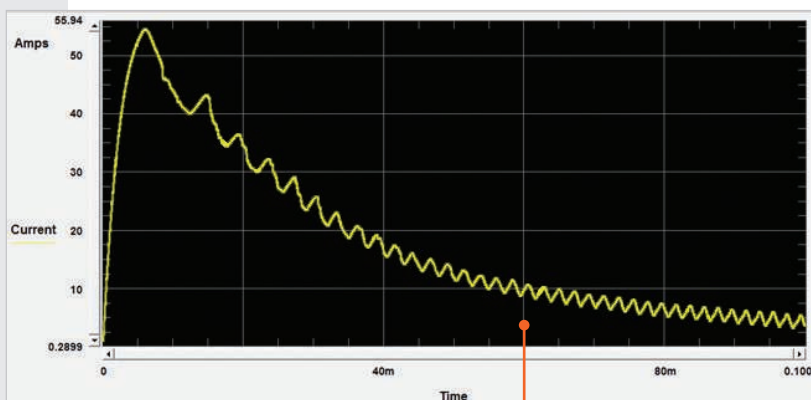
Figure 2. Inrush current capture from DC motor with a N7951A dynamic DC power supply
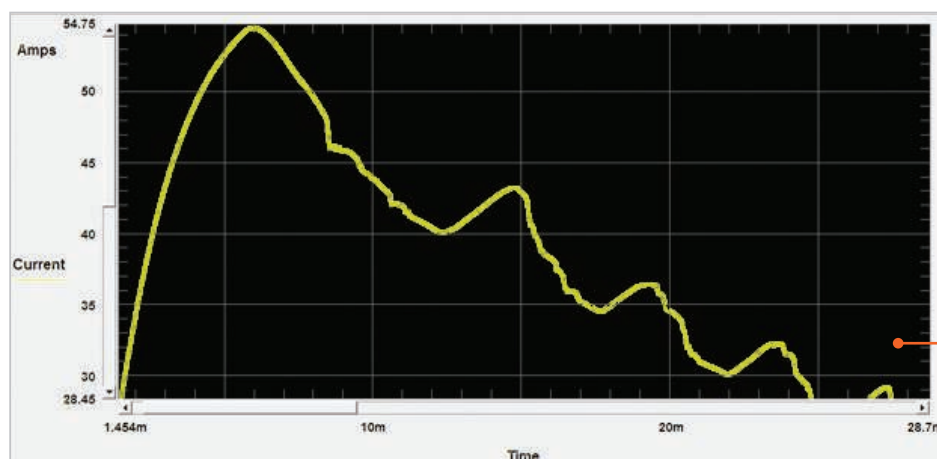
Figure 3. Inrush current capture zoomed in to peak

Tuning Inrush Current with a Power Supply

Let's say this DC motor is going to be used in a new design and the peak inrush current cannot exceed 40 A and we want to have a 5-A safety margin from the average value. We can tune the peak inrush value by changing the N7951A's turn-on voltage ramp rate. By slowing the ramp rate down, we can reduce the peak of the inrush current with the tradeoff that the motor's current takes longer to settle to its steady state. To achieve the 35-A average peak current target, the N7951A's ramp rate was adjusted so it took 40 ms to ramp from 0 to 15 V. The N7951A's output voltage ramp rate and the resulting inrush current were captured and plotted. The voltage ramp is shown in Figure 4 and the inrush current is shown in Figure 5.

Notice we achieved our goal of ~35-A peak inrush current. To keep inrush current peaks at about 35 A, we must ensure the design's supply power turn-on ramp rate to 15 V must be 40 ms or less.

Measurement Tip #2

If you need to duplicate in test a non-linear power supply turn-on ramp to simulate a real world condition you can do this by using the arbitrary waveform capability found in most modern high-performance power supplies. For instance the Advanced Power System N7900 series used in the example has arbitrary waveform capabilities that allow you to create customer voltage waveforms up to 64 k points. You can create a custom waveform that can be triggered at turn-on to replace the power supply's turn-on ramp to simulate a non-linear power supply turn-on condition.

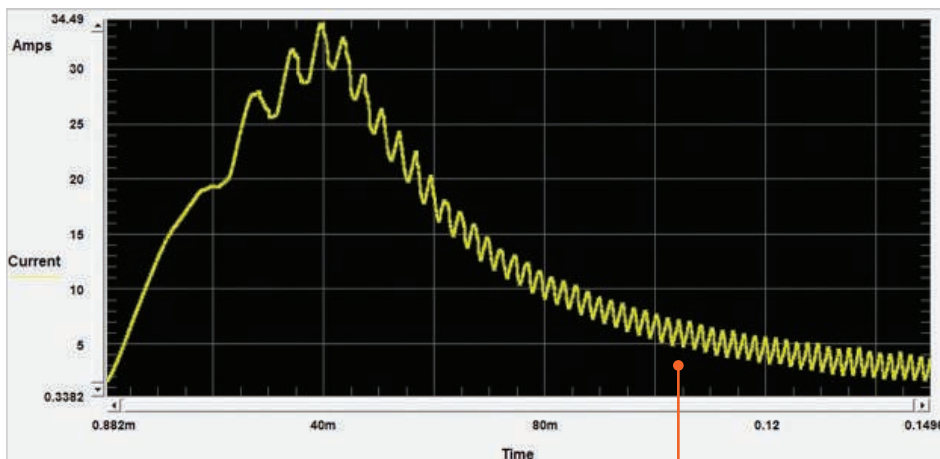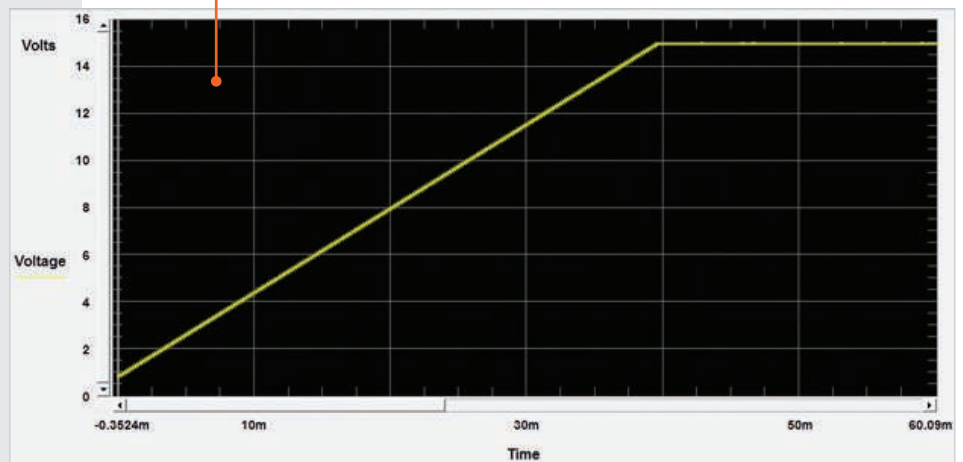Figure 4. Reduced voltage turn-on ramp rate to lower peak inrush current

Figure 5. Inrush current capture with reduced peak

Summary

In this measurement brief we looked at how a modern high-performance power supply with features such as measurement digitizers, fast adjustable turn-on voltage rates, and advanced triggering, and fast transient response makes an ideal tool for characterizing inrush current. It provides advantages such as improved accuracy and resolution as well as reducing test complexity by providing a single integrated solution versus multiple pieces of hardware used in the traditional methods for characterizing inrush current. An example high-resolution inrush current characterization was done with Keysight's N7951A dynamic DC power supply. We were then able to tune the peak inrush current down deterministically by adjusting the voltage ramp rate of the supply.

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