Power Quality and Efficiency Analysis Test

Application Notes

ANW01100-1220-0024

Introduction

With the application of fast-charge technology in new smartphones, GaN (Gallium Nitride) and SiC (Silicon Carbide)-based chargers have garnered significant attention. Due to the wide bandgap characteristics of GaN and SiC semiconductors, power supplies utilizing these materials exhibit higher switching speeds, lower switching losses, and higher conversion efficiency, enabling smaller and more energy-efficient chargers. These advantages have led to their widespread adoption in electric vehicles and portable electronics.

In the development of switching power supplies, the following critical factors directly impact the switching power supplies quality: conversion efficiency, output voltage ripple, and power quality.

- **Power Quality**
  Power quality is a fundamental test parameter for evaluating power supply performance. Key metrics include voltage RMS (V_RMS), current RMS (I_RMS), power factor (PF), and harmonic.
- **Conversion Efficiency**
  Conversion efficiency, the ratio of output power to input power, is a basic indicator of power supply performance. Optimizing the conversion efficiency is a primary goal in switching power supply design. High power conversion efficiency not only enhances energy-saving performance but also reduces operational costs. It is particularly beneficial for some large-power power supply equipment such as charging piles and photovoltaic power that focus on charging efficiency and energy conservation and environmental protection.
- **Output Voltage Ripple**
  Ripple refers to the AC component within a DC voltage. For DC power supplies, the stability of the output DC voltage will directly affect the working stability of the drive equipment. Ripple is the main indicator affecting the stability of the output voltage of a DC power supply. Lower ripple ensures more stable output voltage.

Principle Description / Operation Mode

A typical diagram of a switching power supply is shown below:

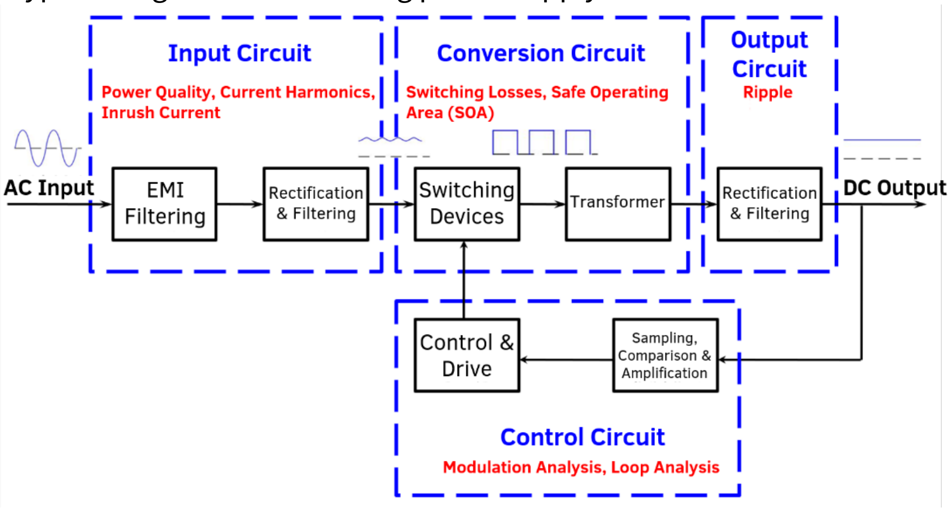

Figure 1 Diagram of a Switching Power Supply

- **Power Quality Parameters**

The following parameters are the main indicators for evaluating the power quality of switching power supplies. When performing power quality tests on switching power supplies by measuring the power input and quality on the power line, the following parameters are the primary test items.

- **V_RMS**: the RMS voltage of the AC input.
- **I_RMS**: the RMS current of the AC input when the switching power supply operates.
- **Apparent Power**: the product of V_RMS and I_RMS, representing the electrical capacity output to the switching power supply, with the unit of VA.
- **Active Power**: refers to the actual electric energy consumed by the power supply per unit time, or the electric power which is the conversion of electrical energy into other forms of energy, with the unit of W.
- **Reactive Power**: refers to the electric power required to establish alternating magnetic fields and induced magnetic flux in AC circuits containing reactive components (capacitors and inductors). This portion of energy is exchanged between the power source and inductive components, but is not converted into mechanical energy or heat. The unit is VAR.
- **Power Factor**: the ratio of active power to apparent power, indicating the utilization efficiency of the alternating current power supply by the switching power supply. A lower power factor means a larger reactive power. In addition to the reactive power generated by inductive and capacitive components, high-frequency harmonic components caused by nonlinear devices also contribute to a portion of the reactive power.
- **Phase Angle**: refers to the phase difference between the AC supply voltage and current during the operating state of the power supply.

- **Conversion Efficiency**

The primary factors affecting the conversion efficiency of switching power supplies include the switching loss and conduction loss of switching devices, core loss and copper loss of magnetic components, etc. Among these, switching loss is one of the most significant factors.

During the turn-on and turn-off processes of switching devices such as MOSFET and IGBT, with the influence of the electron drift velocity of inductive components and power devices in the circuit, the voltage cannot immediately drop to zero when the device turns on while the current has already started to rise. Conversely, when turning off, the current cannot instantly drop to zero while the voltage has already increased — resulting in switching losses.

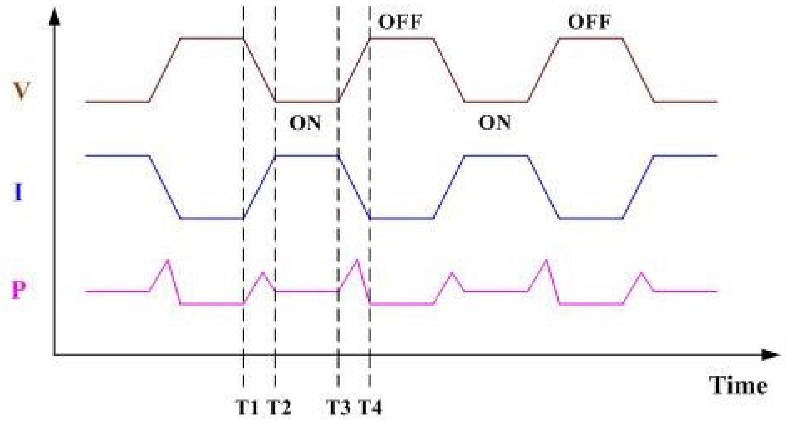

Figure 2 Conversion Efficiency of Switching Power Supplies

By optimizing circuit design, selecting power devices with ideal switching characteristics and adopting soft switching techniques can effectively reduce switching losses, thereby improving the conversion efficiency of switching power supplies.

- **Output Voltage Ripple**

The ripple in the output voltage of a switching power supply output voltage mainly originates from the voltage fluctuations generated by pulsating currents across the output filter capacitor during the turn-on and turn-off of power devices. This ripple usually occurs at frequencies above several hundred kHz. The low-frequency components primarily arise from power line frequency interference and its harmonics.

Harmonics generated within the switching power supply circuit can affect the normal operation of the load as well as other electrical equipment connected to the power grid. To regulate the harmonic emission standards for electrical equipment, the European Union has issued the IEC61000-3-2 standard, which specifies the current harmonic limits that switching power supplies must comply with.

Table 1 EN 61000-3-02 Standard

Category	Description
Category A	Balanced three-phase equipment, household appliances (excluding equipment listed under Category D), tools (excluding portable tools), incandescent lamp dimmers, audio equipment, and equipment not specified as Category B, C, or D.
Category B	Portable tools, arc welding equipment that are not intended for specialized use.
Category C	Lighting equipment.
Category D	Equipment with an input power lower than 600 W, including personal computers, monitors, and television receivers.

Table 2 Harmonic Limits Standards for Category A Equipment

Harmonic order n	Maximum permissible harmonic current A
Odd harmonics	
3	2.30
5	1.14
7	0.77
9	0.40
11	0.33
13	0.21
15≤n≤39	$0.15\frac{15}{n}$
Even harmonics	
2	1.08
4	0.43
6	0.30
8≤n≤40	$0.23\frac{8}{n}$

Test Environment Setup and Operation Procedures

Power Quality and Efficiency Test for Power Supplies

Test Environment Setup for Power Quality and Efficiency Test of Power Supplies

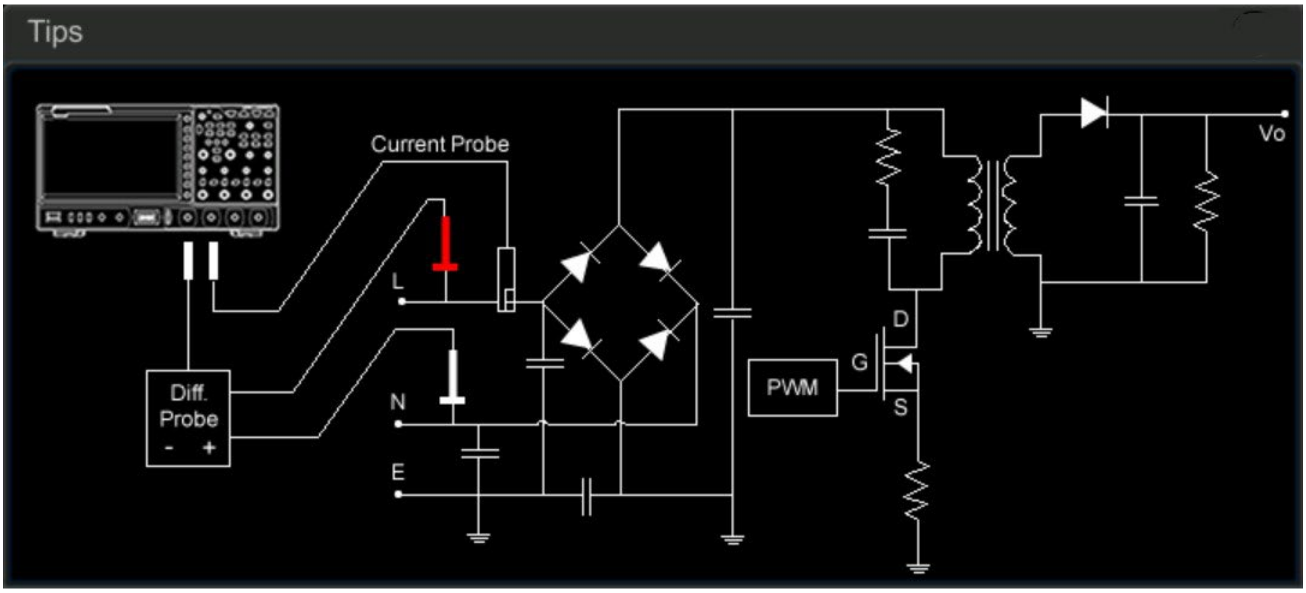

Figure 3 Power Quality Test Connection Diagram

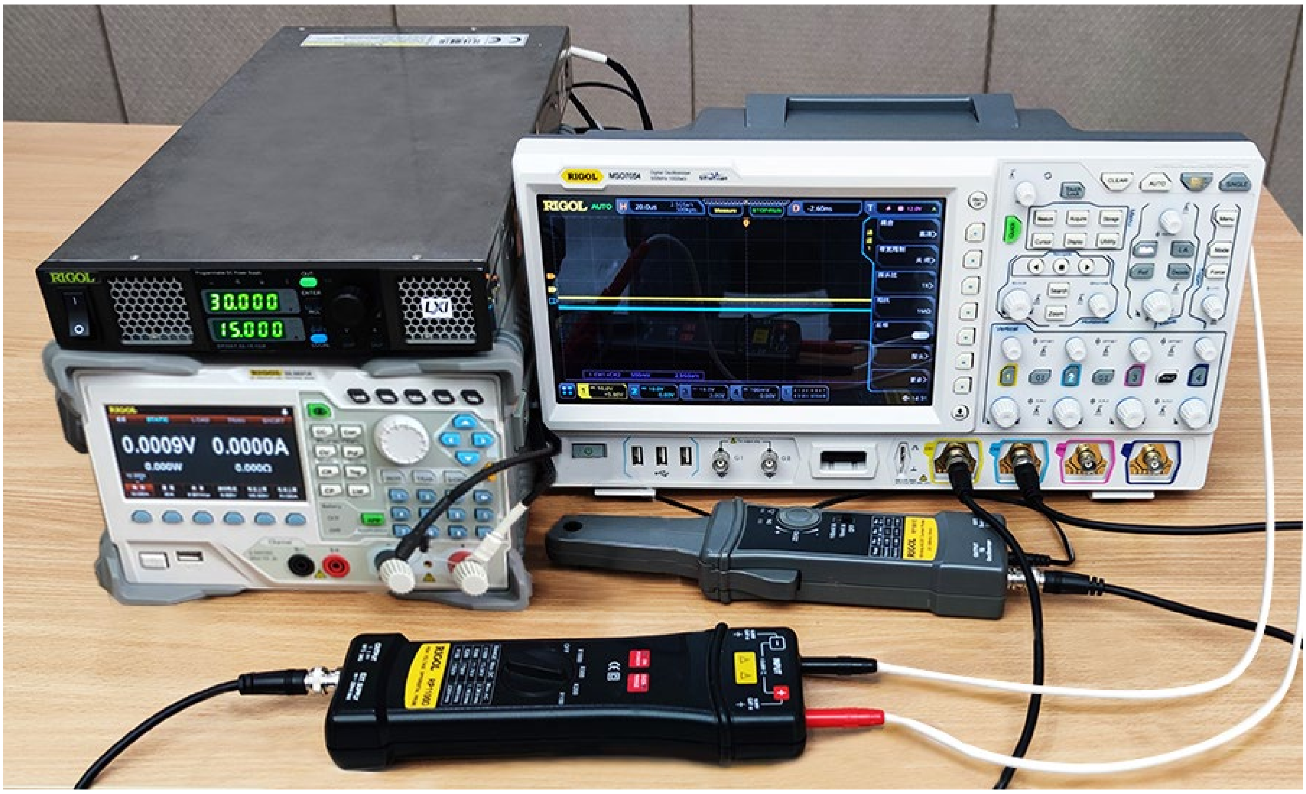

Figure 4 Power Conversion Efficiency Test Connection Diagram

Test Preparation:

1. Connect the RP1100D high-voltage differential probe to CH1 of the DS7054 oscilloscope. Attach the probe to the L and N wires of the power input port.

2. Connect the RP1001C current probe to CH2 of the DS7054 oscilloscope. Perform demagnetization and zero adjustment.
3. Clamp the RP1001C current probe onto the L line of the power input port.
4. The output terminal of the switching power supply is connected to the input terminal of the electronic load DL3031A.

Step 1 Perform Channel Delay Calibration

1. After powering the RPA246 offset calibration fixture via a USB cable, connect the positive and negative anodes of the RP1100D voltage probe to the corresponding positive and negative voltage anodes of the fixture. Clamp the RP1001C current probe around the fixture's current loop, as shown in the figure.
2. Then, adjust the oscilloscope and set the rising edges of the CH1 and CH2 signals at the center of the screen. Eliminate the time difference between the two channels by adjusting channel delay, aligning the signals of two channels precisely.
3. After completing the channel delay calibration, connect the RP1100D to the live and neutral wires of the AC input of the switching power supply. Set both the probe attenuation and the oscilloscope CH1 probe ratio to X200. Clamp the RP1001C onto the live wire, set the attenuation to 100 mV/A, and configure the oscilloscope CH2 probe ratio to X10.

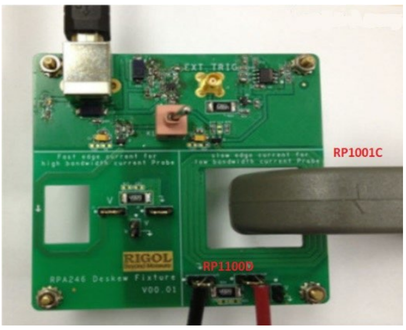

Figure 5 Channel Delay Calibration Connection Diagram

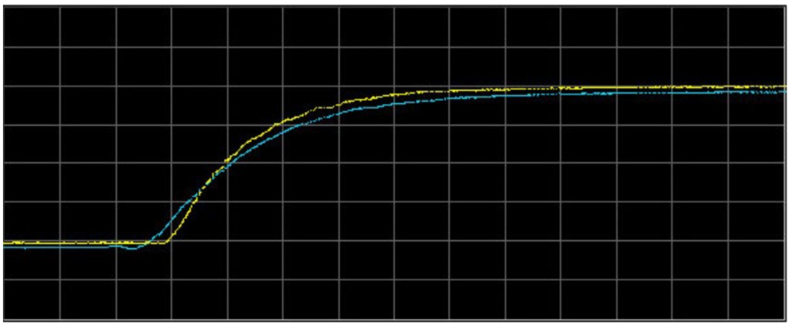

Figure 6 Channel Delay Calibration Display

Step 2 Load Configuration and Test

1. Press the CC (Constant Current) key on the DL3031A electronic load, then adjust the CC current to make the constant voltage power supply output its rated power or 50% of its rated power. Press the ON/OFF key to enable the CC function.

   For constant current power supplies such as LED drivers, press the CV (Constant Voltage) key on the DL3031A, then adjust the CV voltage to make the power supply output its rated power or 50% of its rated power. Press the ON/OFF key to enable the CV function.

2. Record the power value displayed on the DL3031A screen as the output power (Pout) of the switching power supply.

Figure 7 Electronic Load Configuration

Step 3 Perform Power Quality Test

1. Click or tap the function navigation icon at the lower-left corner of the screen. In the pop-up menu, select Power Analysis, and choose Power Quality as the analysis type. Set CH1 as the voltage channel and CH2 as the current channel. Enable the display function and the power quality test results will display on the screen.
2. Record the Real Power value as the input power (Pin) of the switching power supply.
3. Calculate the conversion efficiency of the switching power supply using the formula Pout / Pin.

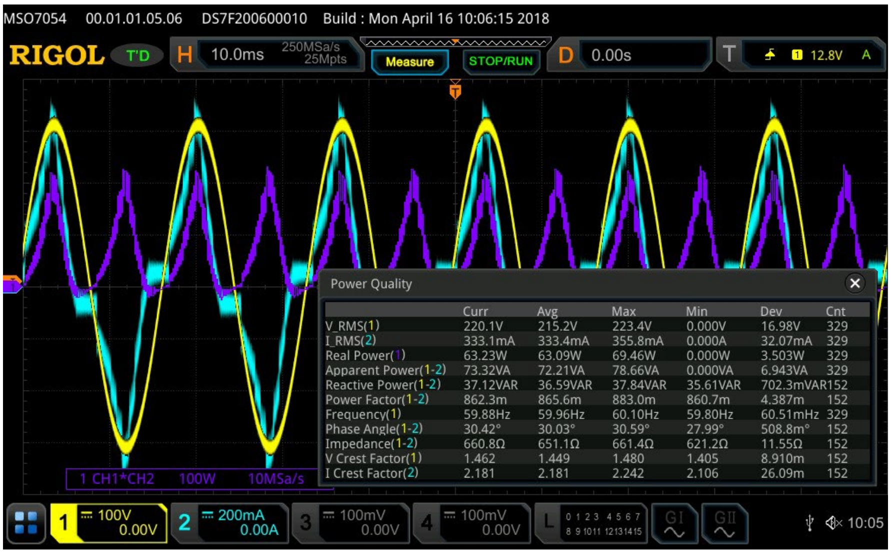

Figure 8 Power Quality Test Results

Step 4 Perform Current Harmonic Test

1. Connect the oscilloscope to the PC with a USB cable.
2. Launch the UPA software on the PC and configure the parameters for current harmonic test.
3. Perform test and the software will display the harmonic status.

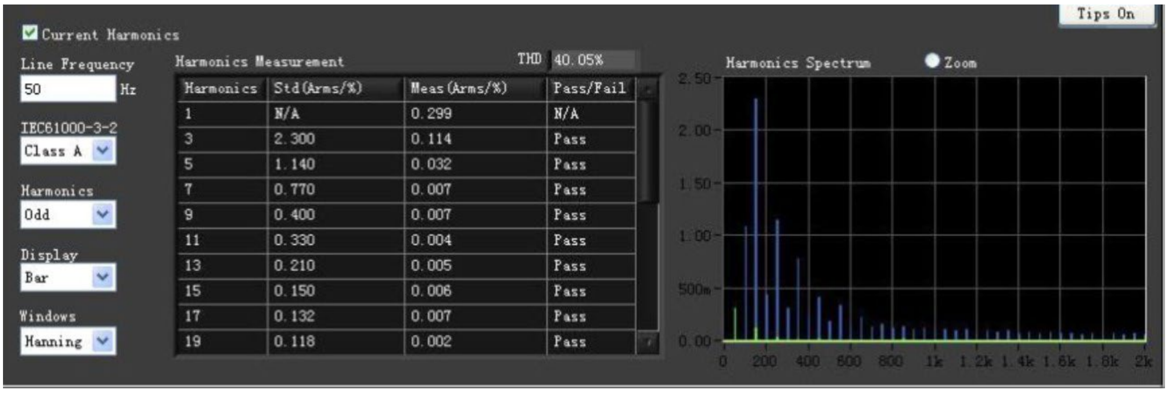

Figure 9 Current Harmonic Test Interface

Power Supply Ripple Test

Test Environment for Power Supply Ripple Test

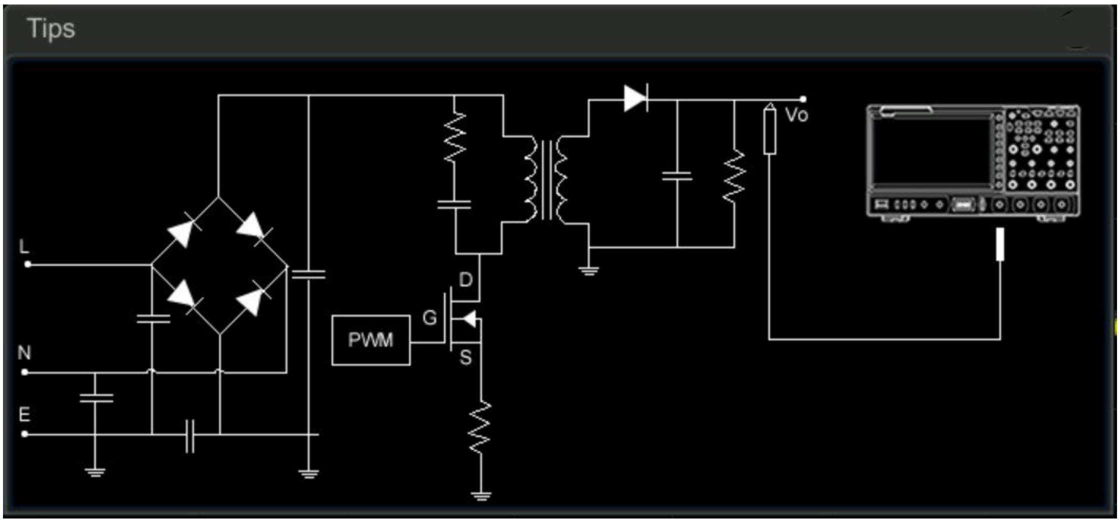

Figure 10 Power Ripple Test Circuit Diagram

Test Preparation:

1. Connect the output terminals of the switching power supply to the input terminals of the electronic load.
2. Connect the PVP2350 high-impedance passive probe to CH1 of the DS8104 oscilloscope.

Figure 11 Power Ripple Test Connection Diagram

Perform Power Ripple Test:

1. Set the oscilloscope bandwidth limit to 20 MHz.
2. To avoid noise coupling into the circuit through a loop formed by the probe and its ground wire, use the probe's built-in ground spring for grounding.

3. Set both the probe attenuation and the oscilloscope CH1 probe ratio to X1 to minimize oscilloscope noise interference.
4. Set the channel coupling mode of the oscilloscope to AC coupling to block the DC component and facilitate signal observation.
5. Select Ripple as the analysis type and enable the peak-to-peak measurement function of CH1 to obtain the ripple voltage peak-to-peak value.

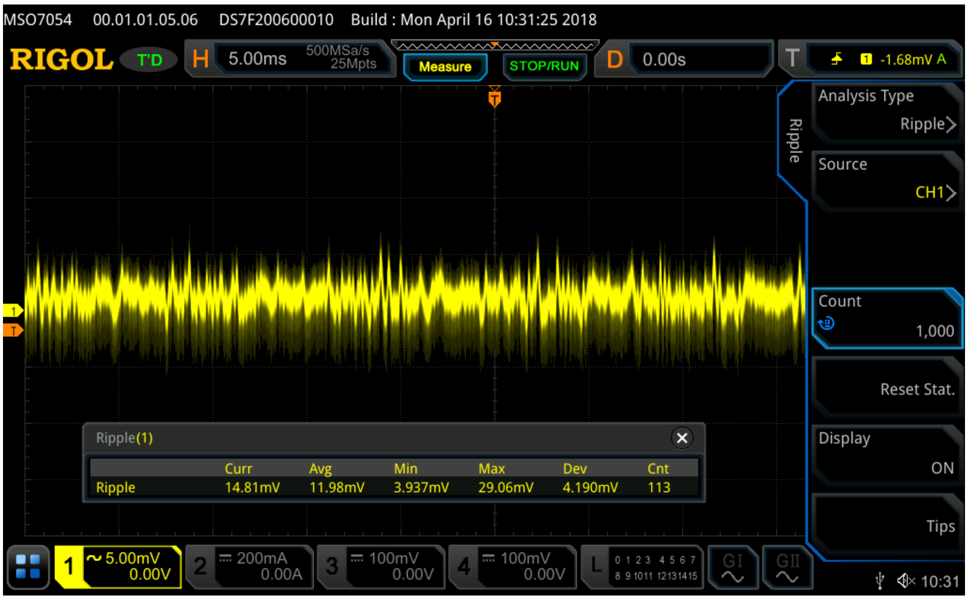

Figure 12 Power Ripple Test Results

Operation Points

- **Choice of Probe**
  For power quality testing, a high-voltage differential probe must be selected as the voltage probe. Single-ended probes must not be used for testing. In an AC power system, the neutral line forms a current loop with the live line and the load. Since the ground wire of an oscilloscope probe is connected to the power ground, using a single-ended probe to measure mains voltage would effectively short-circuit the neutral line to earth ground. It will increase the common-mode interference and produce the short-circuit risk, potentially damaging the test equipment.
- **Demagnetization and Zero Adjustment**
  Current probes need to be demagnetized and zeroed to prevent initial value errors from affecting the actual current measurement results.
- **Phase Calibration**
  Channel phase calibration must be conducted before performing voltage and current testing on the power supply. The phase error of the initial channel will be carried over to the final test results of the phase Angle ϕ of voltage and current, and the calculation results of active power and power factor are all related to the phase Angle ϕ. Once there is a phase difference between the voltage test channel and the current test channel, it will lead to the test error of the actual phase Angle, and ultimately result in the measurement error of active power, reactive power, and power factor (PF).

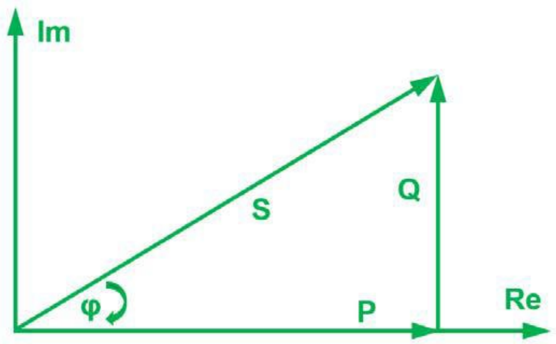

Figure 13 Relationship between Apparent Power and Active Power

Conclusion

This guide introduces the impact and testing methods for switching power supply power quality, power conversion efficiency, and ripple. By using oscilloscopes and DC electronic loads, test of power supply quality can be completed quickly, replacing the previous testing methods with power analyzers and complex software operations, significantly reducing testing costs.
The following equipment is recommended for testing power quality, conversion efficiency, and ripple:

Test Item	Equipment	Requirement
Power Quality & Power Efficiency	Oscilloscope: MS08000, MSO/DS7000, MSO5000	• Supports power analysis • ≥1 Mpts FFT
	DC Electronic Load: DL3000	• CC mode
	Probes: RP1000D (voltage),RP1000C (current)	
	Calibration Fixture: RPA246	Phase correction to current and voltage
Ripple Test	Oscilloscope: MS08000, MSO/DS7000, MSO5000	• Ripple analysis • Memory-based measurements
	Passive High-resistance Probe: PVP2000	• X1 attenuation • Ground spring

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