Standard Performance Evaluation Corporation (SPEC)

The Tester's Guide to Measurement Uncertainty

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1. Introduction

1.1 What is Measurement Uncertainty?

Measurement uncertainty is an estimate of the dispersion of an instrument’s measured values relative to the true value. Although accuracy is often used in the context of physical measurements, uncertainty is the more correct term.

1.2 Why is Uncertainty Important?

Setting an upper limit on measurement uncertainty allows us to support SPEC’s goal of “fair benchmarking” by providing measurements that ensure results are repeatable and comparable across vendors and systems.

SPEC has chosen a limit of 1% for power measurement uncertainty based on existing industry standards and a desire to maintain a balance between affordability and repeatability.

2. Uncertainty Calculations

Power analyzer vendors provide uncertainty specifications for their devices based on extensive testing and complex calculations. SPEC’s PTDaemon uses the published device specifications to calculate an uncertainty value for every reading taken during a test.

Most uncertainty formulas have the basic form of

Uncertainty (watts) = x% of reading + y% of range

There are often additional terms based on the frequency of the power source, power factor, and other values, but the percent of reading and percent of range are the primary sources of uncertainty.

As an example, take a hypothetical power analyzer whose uncertainty in the 45-65 Hz AC power range could be specified as

Uncertainty (watts) = 0.2% of reading + 0.2% of range

This device has AC voltage ranges of 150 and 300 Volts, and current ranges of ½, 1, 2, 5 and 10 Amperes.

In a sample test, let’s assume we have a system under test (SUT) plugged into a 120VAC supply, drawing 0.75 A at 120V with a power factor of 1, for resulting wattage reading of (0.75 * 120 * 1) = 90W.

If the analyzer were configured in the 300V and 10A ranges, the uncertainty calculation becomes:

Uncertainty (watts) = 0.2% of 90W + 0.2% of (300V * 10A)
= 0.18W + 6.0W
= 6.18W
Uncertainty (percent) = 6.18W / 90W
= 6.9%

If the analyzer were configured in the more appropriate 150V and 1A ranges, the uncertainty calculation becomes:

Uncertainty (watts) = 0.2% of 90W + 0.2% of (150V * 1A)
= 0.18W + 0.30W

= 0.48W
Uncertainty (percent) = 0.48W / 90W
= 0.53%

As you can see, simply changing the voltage and current ranges gives a 13x improvement in uncertainty, from a value almost seven times the allowable 1% maximum, down to a value well below the maximum allowable. The above examples demonstrate the **key to minimizing measurement uncertainty**:

Use the lowest ranges appropriate for the current being measured!

3. Range Selection with SPEC's PTDaemon

PTDaemon has the ability to select the closest range appropriate for a requested value. The information is maintained on a per-analyzer basis. For example, if you specify a range of 2.2A and the analyzer in use has ranges of 0.5, 1.0, auto and 5.0A, PTDaemon will set the analyzer to the 5.0A range. This feature allows test configurations to be reused across different models of power analyzer without requiring changes to range configuration parameters.

It is always a good idea to know the ranges supported by the analyzers in use. This information may be found in the power analyzer's user guide, and is also found in section 2.7 of the SPEC Measurement Setup Guide. One important note: wherever SPEC uses voltage and current values, both for measurements and ranges, they are RMS values; some vendors specify their ranges in peak-to-peak values but PTDaemon works only with RMS.

There are three ways to set the voltage and current ranges of the analyzer; **the third technique listed is the only one recommended and supported by SPEC**:

- **manual range setting**: For instructions read the manufacturer's manual. PTDaemon cannot read all range settings for some power analyzers such as the Instek GPM-8212 and the Chroma 6620x series; compliant runs cannot be produced using manual range settings for these analyzers.

- **fixed range setting via PTDaemon command line input parameters**: When starting the PTDaemon the volt and ampere ranges can be set by selecting the command line flags –A and –V. For example, using the parameter "-A 1.6" will cause PTDaemon to set the current range to the next highest range that can legally measure 1.6A for the analyzer model in use.

- **dynamic range setting via benchmark command interface:** Most benchmarks and tests using SPEC's PTDaemon provide the ability to set ranges dynamically through configuration parameters. For instructions read the user guide for the associated benchmark and see later sections of this document. This is the **only** recommended technique since it gives the ability to set different ranges for different load levels.

3.1 Autoranging

Selecting auto-range mode does not provide compliant measurement results for any currently accepted analyzer types. There are two main reasons:

- Changing the range in auto-range mode often needs so much time that several samples of the active measurement may be missed during the setting.

- In auto-range mode the current ranges have to be read by the analyzer to compute the current uncertainty value. Not all analyzers provide this capability, and even those that do are not able to guarantee that the range readings were those used for the measurement values at that point of time.

Therefore, measurements taken with autoranging enabled will not produce valid uncertainty values and cannot be used for valid results.

4. Uncertainty Errors Reported by SPEC's PTDaemon

4.1 Invalid Uncertainty

There are several conditions that can cause PTDaemon to report invalid uncertainty.

- Any sample with calculated uncertainty over 1.0% will be reported as "invalid". A measurement interval showing invalid samples typically indicates that the selected ranges were too high.
    - Fix: adjust range settings to values that match measurement conditions.

- If the calibration date of the analyzer provided to PTDaemon on the command line is more than a year ago, all samples will be marked with invalid uncertainty.
    - Fix: check that calibration date was entered correctly; if calibration date was over a year ago, the device needs to be recalibrated.

4.2 Unknown Uncertainty

PTDaemon reports "unknown" for uncertainty in a number of different cases where it is unable to do an uncertainty calculation:

- Autoranging is enabled
- Measurement outside manufacturer's specifications
    - For example, current or voltage outside allowable values for a particular range
- Error while reading the current measurement
- PTDaemon is unable to determine the actual range settings for the current measurement

5. Best Practices

To configure a test to minimize uncertainty, a few simple steps should be followed:

- First, run the test with the power analyzer voltage range set to the voltage in use, and the current range set to either "auto" or the highest range expected.
- Next, examine the output files to determine the average current used during each benchmark load level
- Finally, set the benchmark-specific power analyzer range configurations to values appropriate for the current of each load level. A small amount of margin should be maintained so that the measurement does not end up "over-ranging". For example, if the average current during a measurement is 0.95A, it may be necessary to set the range to a value larger than 1.0A, to ensure the next higher range above 1.0A is selected to cover potential current peaks greater than 1.0A.

5.1 SPECpower_ssj2008

Applying the previous process to SPECpower_ssj2008, you could do a test run with the following settings in the ccs.props file:

ccs.ptd.pwr1.current_range_settings=auto
ccs.ptd.pwr1.voltage_range_settings=auto

A sample power detail report for such a run is shown below:

Power Details for Device pwr1

Target Load	Voltage (V) Avg	Voltage (V) Range	Current (A) Avg	Current (A) Range	Avg Power Factor	Avg Active Power (W)	Power Measurement Uncertainty (%)
Calibration 1	207	auto	1.33	auto	0.980	270	--
Calibration 2	207	auto	1.34	auto	0.980	272	--
Calibration 3	207	auto	1.34	auto	0.980	272	--
100%	207	auto	1.30	auto	0.979	264	--
90%	207	auto	1.09	auto	0.969	218	--
80%	207	auto	0.942	auto	0.964	188	--
70%	207	auto	0.850	auto	0.955	168	--
60%	207	auto	0.728	auto	0.940	142	--
50%	207	auto	0.644	auto	0.921	123	--
40%	207	auto	0.597	auto	0.904	112	--
30%	207	auto	0.507	auto	0.896	93.9	--
20%	207	auto	0.446	auto	0.871	80.4	--
10%	207	auto	0.402	auto	0.836	69.7	--
Active Idle	208	auto	0.310	auto	0.744	47.9	--

The simplest method to use these results to create range settings for a valid run is just to use the current and voltage values from the results file, increasing the current values slightly to give a margin of safety so that the analyzer does not go into an overrange condition. Only a single value is allowed for voltage, so simply use the maximum value seen in the measurement.

Keep in mind that the format of the current range values is, as shown in the comments in ccs.props, a list of 14 values, in the same order that they are run in a standard run (which matches the order in the table):

```
# The load levels are in this order:
#  cal1, cal2 cal3, 100%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, idle
```

Thus, an appropriate change to ccs.props would be:

```
ccs.ptd.pwr1.current_range_settings=1.4,1.4,1.4,1.4,1.2,1.1,1.0,0.9,0.8,0.7
,0.6,0.5,0.5,0.4
ccs.ptd.pwr1.voltage_range_settings=208
```

A more sophisticated method to choose settings would be to take into consideration the ranges supported by your particular power analyzer. For an example, we can use the hypothetical analyzer from section 1 with AC voltage ranges of 150 and 300 Volts, and current ranges of ½, 1, 2, 5 and 10 Amperes.

```
ccs.ptd.pwr1.current_range_settings=2,2,2,2,2,2,1,1,1,1,1,0.5,0.5,0.5
```



```
ccs.ptd.pwr1.voltage_range_settings=300
```

Either of the previous methods should provide results with valid uncertainties; however, the second method is more readable and makes it clear what range is actually in use.

5.2 SERT

The SERT tool includes an automated process for setting ranges appropriate to a system under test. This process implements the technique described at the beginning of this chapter, namely running the SERT test using autoranging and then calculating the most appropriate settings for each load level. A major improvement is the use of an abbreviated test with a subset of workloads which has proven sufficient to select appropriate ranges for the entire full-length test.

