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Results from laboratory testing for the performance of desktop-computer power supplies operating at minimal loading.

Additional submitted attachment is included below.

ELECTRIC POWER RESEARCH INSTITUTE

January 29, 2016

To: Stakeholders of new policy for desktop power supplies

From:

Ecova – Jason Boehlke, Doug Mcilvoy (Consultant)

EPRI – Tom Geist, Baskar Vairamohan, Peyton Sizemore, Daniel Griffey

Subject: Results from laboratory testing for the performance of desktop-computer power supplies operating at minimal loading.

Dear Stakeholder:

As you are aware, the California Energy Commission (CEC) is currently drafting policy for the future energy consumption of desktop computers. Specifically being considered is a performance standard for Desktop computers under conditions of minimal loading—such as when the computer is in idle mode. EPRI and Ecova—who have tested and certified over 5,000 power supplies for desktop computers from over 200 manufacturers throughout the last ten years—is in a unique position to support this effort. This has already happened with stakeholders use of data from the 80 PLUS® program that is publicly available via the 80 PLUS website.[1] While helpful, the data is limited to higher power levels (10, 20, 50 and 100 % loading). To further inform the process, EPRI and Ecova have teamed to gather and make publicly available additional performance data of power supplies at minimal loading (<5%).

The objective of the testing was to investigate the performance of computer power supplies at 0 – 5% loading. Research goals include better understanding of the capabilities of the 80 PLUS test area—will the setup allow for measurement at low power—and better understanding of the performance of power supplies at minimal power in terms of efficiency and power factor. Finally, what conclusions and recommendations are possible based on the additional data.

The following information is not proprietary.

[1] http://www.plugloadsolutions.com/Default.aspx

Sample Description

Selected were 12 power supplies from various manufacturers recently submitted to the 80 PLUS program for testing and certification. All samples were submitted within the last six months, which suggests that each are the latest in power supply design. Diversity factors included form factor, 80 PLUS badge level, and power rating. Of the power supplies 10 had an ATX form factor, 1 had an EPS12V form factor, and 1 had a 1U form factor. The criteria for badge level is shown in Table 1. The breakdown of samples by badge level is shown in Table 2. The breakdown of power supplies by power rating is shown in Table 3.

Table 1, Badge levels and criteria of the 80 PLUS program.

	115V Internal Non-Redundant 80 PLUS Efficiency-Level			
Level	**10%**	**20%**	**50%**	**100%**
Standard	-	80%	80%	80% PF ≥0.9
Bronze	-	82%	85% PF ≥0.9	82%
Silver	-	85%	88% PF ≥0.9	85%
Gold	-	87%	90% PF ≥0.9	87%
Platinum	-	90%	92% PF ≥0.95	89%
Titanium	90%	92% PF ≥ 0.95	94%	90%

Table 2, Number of samples by badge level.

Badge Level	Number of Samples
Standard	2
Bronze	6
Silver	0
Gold	2
Platinum	1
Titanium	1

Table 3, Number of samples by power rating.

Power Rating	Number of Samples
200	1
300	1
350	2
400	2
450	2
500	4

Test Setup

Samples were measured on EPRI's 115 V, multi-output test bench, which is the same bench used to provide data to Ecova for certification (see Figure 1). The same instrumentation was used with the exception of the power meter. To provide greatest accuracy, a Yokogawa WT3000 was substituted for the Yokogawa WT2030, which is normally used. A comparison of the key accuracy metrics between the two meters—as well as the WT210, which is commonly used by others—is shown in Table 4. Note that the stated accuracy is applicable when the power factor is unity (1). The manufacturer does not provide a stated accuracy for conditions when power factor is not unity (1), which is the case for minimal loading. So, the actual accuracy for any of the instruments is not specified. However, these meters are standard within the industry.

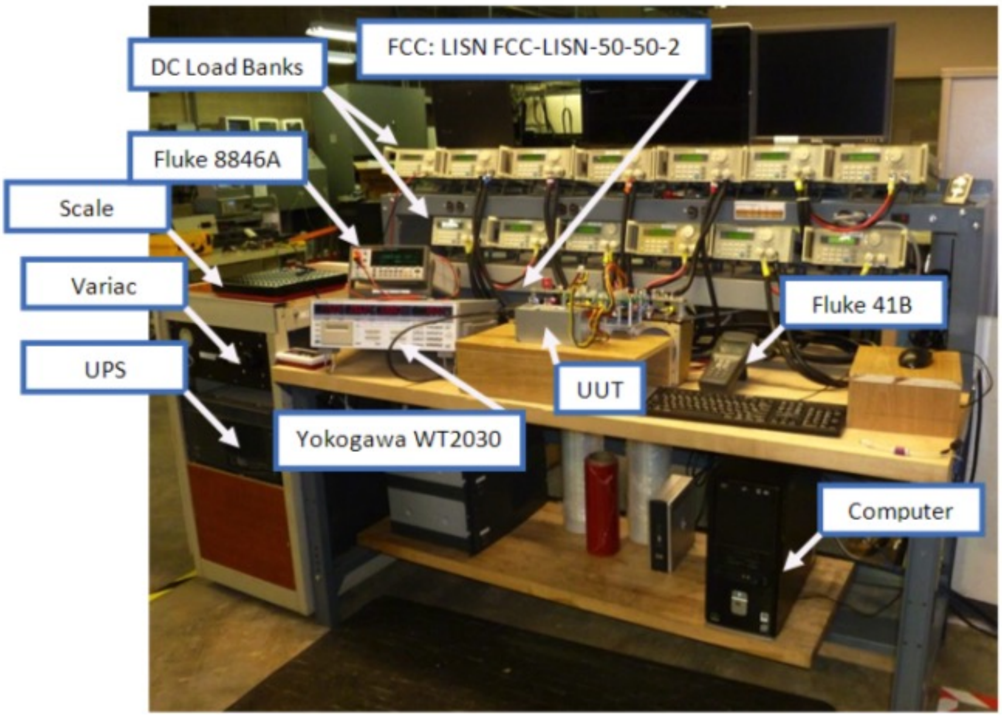

Figure 1, Photograph of EPRI's 115V, multi-output test bench for testing of desktop-computer power supplies.

Table 4, Comparison of key metrics between the WT2030, WT3000, and WT210 (115V, 60 Hz, single-phase input, and no line filter).

Parameter	WT2030	WT3000	WT210
Voltage	0.1% of reading + 0.05% of range	0.01% of reading + 0.03% of range	0.1% of reading + 0.1% of range
Current	0.1% of reading + 0.05% of range.	0.01% of reading + 0.03% of range	0.1% of reading + 0.1% of range
Power	0.2% of reading + 0.1% of range	0.04% of reading + 0.04% of range	0.1% of reading + 0.1% of range

Data was measured and recorded following the *Generalized Test Protocol for Calculating the Energy Efficiency of Internal AC-DC and DC-DC Power Supplies, Revision 6.7* and EPRI's internal test protocol.[2] However, power supplies were not powered for 15 minutes before data was recorded.

Measurements (input/output power and power factor) were taken under conditions of 6W loading[4], 1% loading, 3% loading, and 5% loading. Data at 10, 20, 50, and 100% was gathered from the existing database.[3] Data at no-load was measured and is presented in a separate section on input power. Data on fan power (see the section Fan Power) was collected using a Fluke 8846A. Various waveform data was gathered using a Lecroy oscilloscope (Waverunner 6030) and is in the section on impact of harmonics.

Results

Efficiency

For each of the 12 samples the measured efficiency at the loading points is provided in Table 5. A plot of the efficiency data is shown in Figure 2. As expected, efficiency decreases with lessening load. In general, efficiency of the power supplies begins tapering at 30% loading, drops appreciable as load decreases to 20%, and even further as the load nears 10%. Below 10% loading there is a dramatic decrease in efficiency. Surprisingly, the one sample rated titanium maintained efficiency at a level greater than 80% to about 3% loading, which is more clearly seen in Figure 3. The data shown in Figure 3 also suggests that badge level may predict efficiency performance above loading of 3%, but does not predict efficiency performance below 3% loading—as evidenced by the fact that several samples rated bronze outperformed the titanium sample at 1% loading.

For sample 1, which is rated 200 W, loading is the same for both the 6 W and 3 %. The power supply was measured two separate times. The difference in efficiency is 0.17% (58.16-57.99), which is within the repeatability specification of the test bench (+/- 0.3 %)—a number that represents the measured repeatability of the bench over ten years of testing—and well within the specification for repeatability within the published protocol (+/- 0.5%).

[2] Available from: http://www.plugloadsolutions.com/docs/collatrl/print/Generalized_Internal_Power_Supply_Efficiency_Test_Protocol_R6.7.pdf

[3] Manufacturers typically provide two identical samples for testing. No attempt was made to control for which of the samples were used for gathering the original data.

[4]Selected from Page 12, "ITI & Technet 9/29 F2F Presentation: ODD & Power Supplies" Chris Hankin ITIC.

Table 5, Measured efficiency of power supplies at various loading.

Sample #	Rated Power	80 PLUS Badge Level	Loading							
			6W Load	1%	3%	5%	10%*	20%*	50%*	100%*
1	200	Bronze	57.99%**	37.54%	58.16%**	67.50%	77.04%	83.27%	86.62%	83.81%
2	300	Standard	53.42%	41.93%	59.05%	65.59%	74.37%	81.63%	85.32%	83.54%
3	350	Bronze	52.78%	43.71%	61.76%	66.98%	77.10%	83.45%	86.57%	85.34%
4	350	Platinum	56.90%	45.17%	69.68%	77.81%	86.10%	91.00%	92.51%	90.18%
5	400	Bronze	59.89%	53.49%	68.28%	74.16%	81.44%	86.05%	87.62%	84.67%
6	400	Bronze	47.68%	37.89%	60.53%	69.93%	79.22%	84.46%	86.82%	85.06%
7	450	Gold	41.97%	35.68%	61.17%	71.47%	83.59%	88.57%	90.80%	88.10%
8	450	Standard	32.51%	27.85%	50.45%	61.72%	73.65%	81.40%	84.85%	82.53%
9	500	Titanium	34.98%	38.94%	83.08%	87.72%	91.98%	94.05%	94.21%	91.88%
10	500	Bronze	44.78%	40.30%	64.96%	73.82%	82.68%	87.17%	88.17%	83.65%
11	500	Bronze	43.19%	40.28%	61.77%	69.74%	79.27%	84.42%	86.32%	83.23%
12	500	Gold	43.76%	43.57%	50.47%	70.95%	83.38%	89.26%	90.77%	88.36%

*Data taken from previous set up, may not be the same device (one of two samples provided).
**Same loading level.

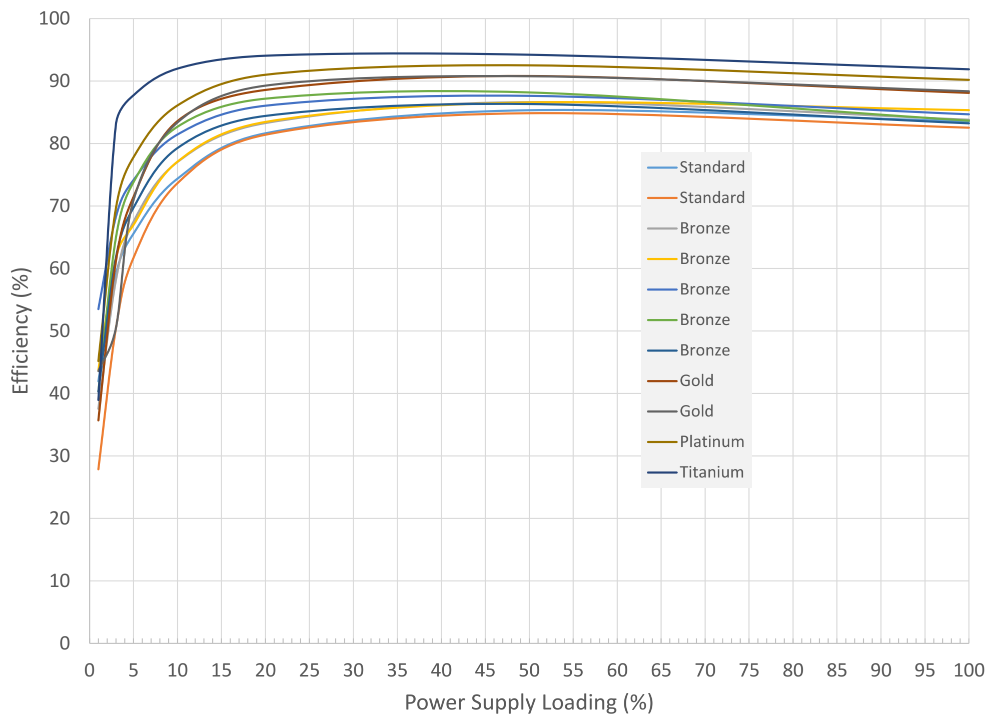

Figure 2, Loading versus efficiency with 80 PLUS badge level

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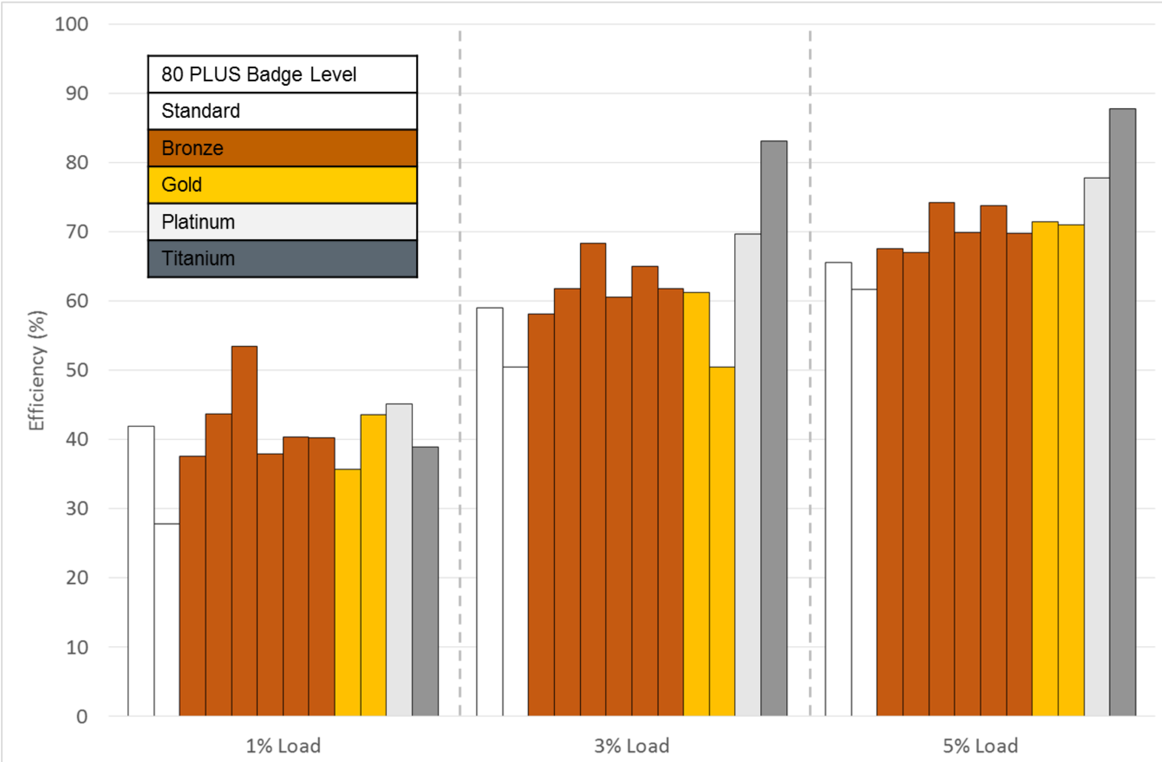

Figure 3, Bar chart with badge levels showing measured efficiency at 1, 3, and 5% loading.

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A bar chart showing the efficiency of each sample at 6 W is shown in Figure 4. None of the samples achieved an efficiency greater than 60%. The lowest efficiency was 32.51 %. Looking at the data from a group standpoint, the data suggests that on average the efficiency is slightly higher for power supplies rated below 450 W.

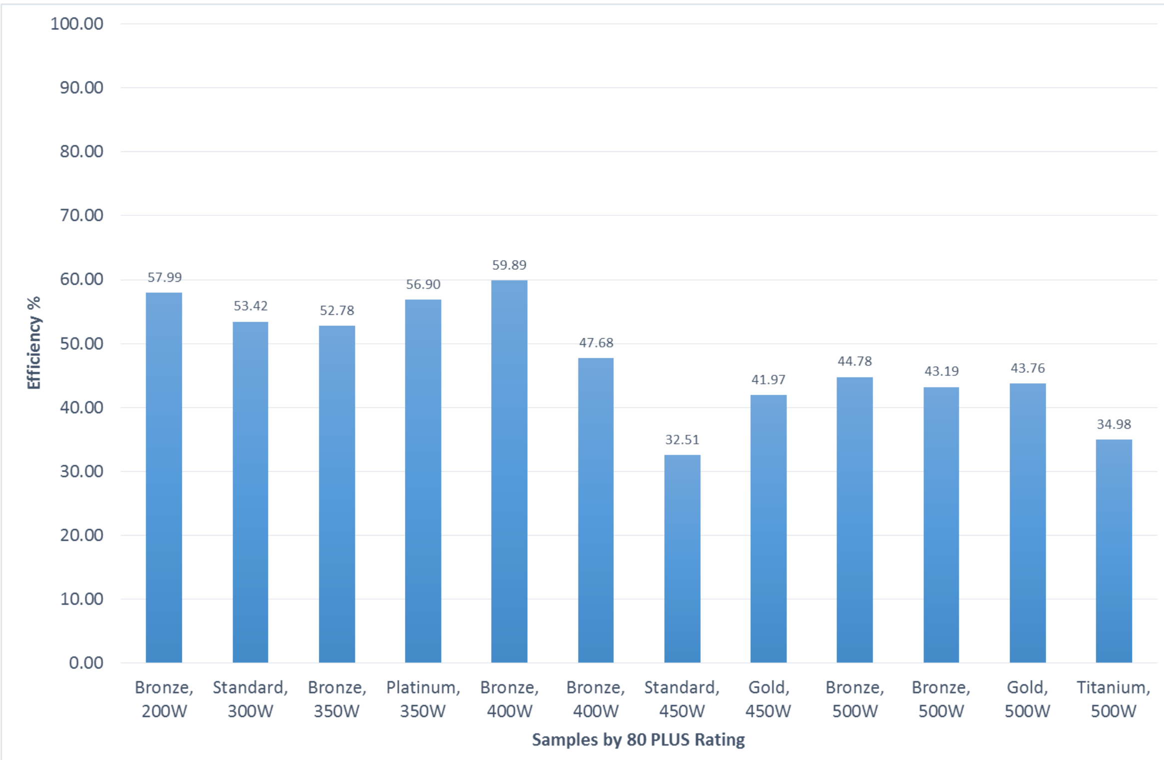

Figure 4, Bar chart showing measured efficiency for each of the samples listed by rated wattage for loading of 6 W.

Power Factor

For each of the 12 samples the measured power factor at the loading points is provided in Table 6. Similar to efficiency, power factor is relatively constant, and above 0.9, down to about 15% loading and below 10% loading falls appreciably. The data show in Figure 7 suggests that badge rating is not a predictor of power factor performance. Evidence of this is the fact that a sample with a standard badge rating has the highest power factor for 1%, 3%, and 5% loading.   A Power factor below 0.6 would indicate the Power factor circuitry is either not operating as intended, or is disabled.

Table 6, Measured power factor of power supplies at various loading.

Sample #	Rated Power	80 PLUS Badge Level	Loading							
			6W Load	1%	3%	5%	10%*	20%*	50%*	100%*
1	200	Bronze	0.6973**	0.5085	0.6999**	0.8012	0.9068	0.9591	0.9850	0.9897
2	300	Standard	0.6492	0.5102	0.7425	0.8151	0.8729	0.9031	0.9854	0.9945
3	350	Bronze	0.6566	0.5515	0.7880	0.8454	0.8732	0.9200	0.9895	0.9956
4	350	Platinum	0.5264	0.4285	0.6580	0.7821	0.8967	0.9663	0.9928	0.9980
5	400	Bronze	0.3713	0.3212	0.6685	0.8292	0.9207	0.9596	0.9728	0.9787
6	400	Bronze	0.5183	0.4692	0.6695	0.7826	0.9253	0.9733	0.9860	0.9948
7	450	Gold	0.5058	0.4761	0.6270	0.7326	0.9247	0.9626	0.9919	0.9972
8	450	Standard	0.7581	0.7152	0.8463	0.9002	0.9537	0.9812	0.9949	0.9949
9	500	Titanium	0.6937	0.6093	0.7219	0.8365	0.9346	0.9678	0.9751	0.9910
10	500	Bronze	0.6354	0.6121	0.7750	0.8334	0.9049	0.9493	0.9788	0.9906
11	500	Bronze	0.5396	0.5010	0.7400	0.8553	0.9726	0.9671	0.9870	0.9926
12	500	Gold	0.5146	0.4503	0.7410	0.8230	0.9244	0.9748	0.9936	0.9973

*Data taken from previous set up, may not be the same device (one of two samples provided).

**Same loading level.

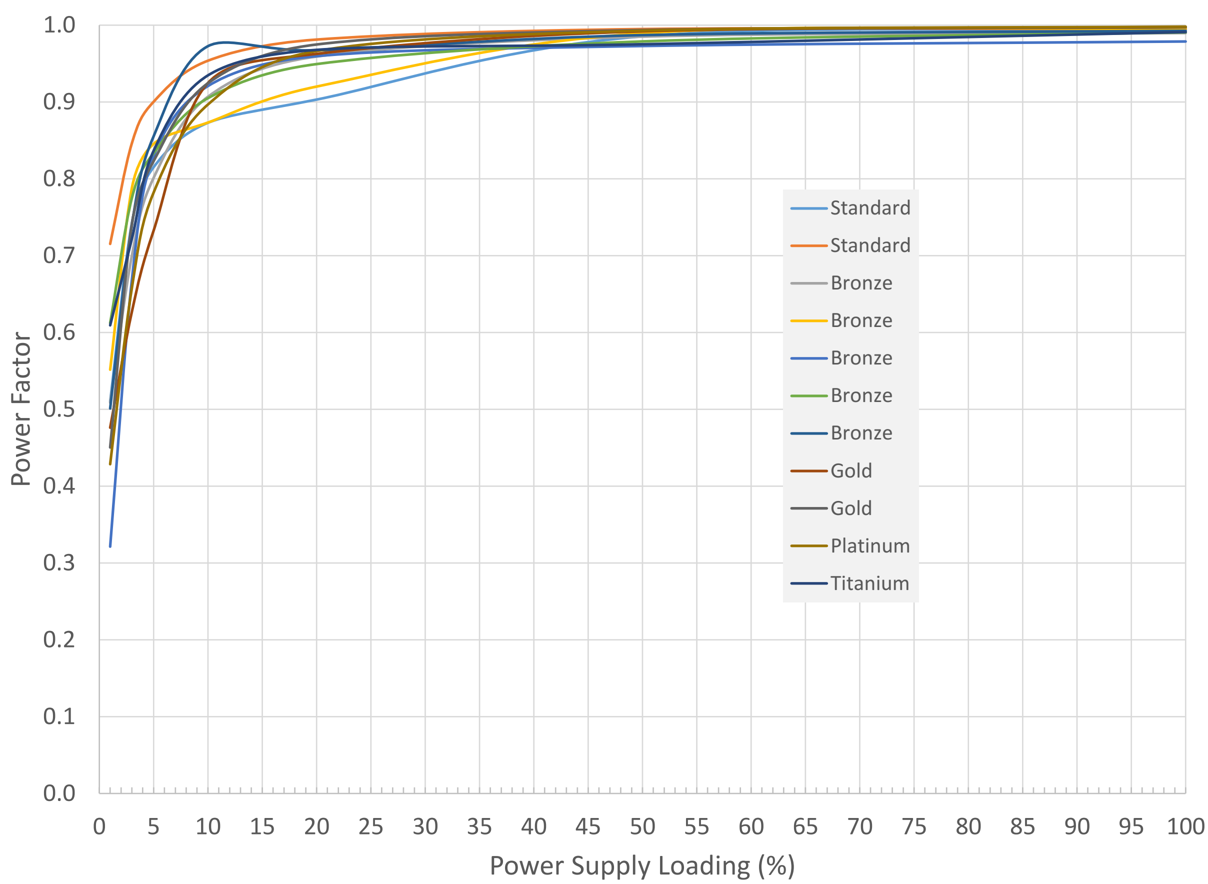

Figure 5, Plot of power supply loading versus power factor.

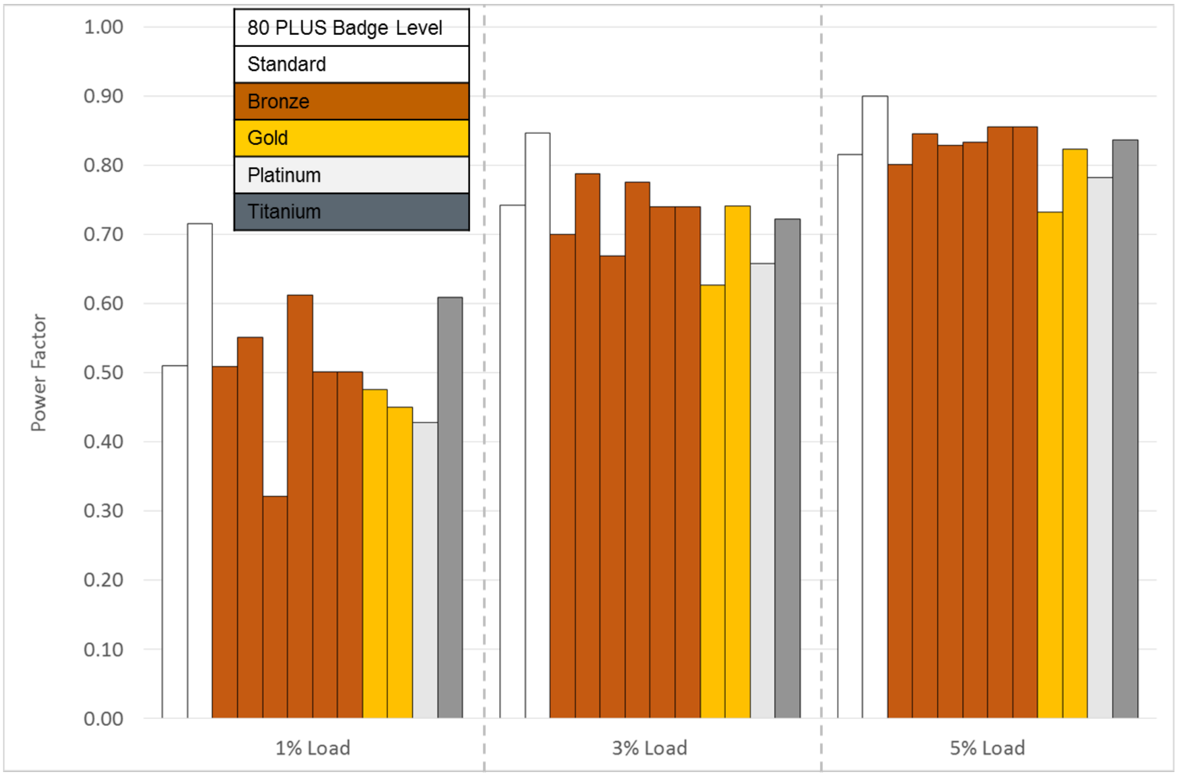

Figure 6, Bar chart with badge levels showing power factor at 1, 3, 5% loading.

Input Power

For each of the 12 samples the measured input and output power for loading conditions of no-load, 6W, 1%, 3%, and 5%, is shown in table 7. Note, for samples 9 and 11 no-load input power was not recorded because the readings were not stable. Power readings are provided instead of efficiency in order to inform the stakeholders considering an absolute power number not to exceed rather than an efficiency number. The power supplies were measured at no-load to inform the discussion regarding no-load, which is relatively easy to measure, is sufficient to specify performance in lieu of measured efficiency, which is relatively difficult.

Figure 7 is a scatterplot of the input power versus the output power for all loading conditions. Figure 7 shows that at no-load 9 of the power supplies had an input power less than 10 W, two were not stable enough to allow measurement, and one power supply measured more than 10 W. At 6 W the input power ranged from 10 W to just under 20 W. The data suggest that a 60% efficiency or better at 6 W (6 W out/10 W In) performance is at the high end of the current state of technology (although the sample set is small and not statistically significant). The other loading conditions (1%, 3%, and 5%) do not coincide. Nevertheless, the scatterplot of Figure 7 provides an indication of the range in input power, especially below 5 W in output power where the grouping is closer, to be expected.

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Table 7, measured input and output power (W) at each loading condition.

Sample #	Loading									
	No-Load Input Power (W)	No-Load Output Power (W)	6W Input Power (W)	6W Output Power (W)	1% Input Power (W)	1% Output Power (W)	3% Input Power (W)	3% Output Power (W)	5% Input Power (W)	5% Output Power (W)
1	2.83	0.00	10.60	6.14	5.55	2.08	10.57	6.15	15.17	10.22
2	2.65	0.00	11.63	6.21	7.45	3.12	15.76	9.31	23.65	15.49
3	2.94	0.00	11.69	6.17	8.26	3.61	17.32	10.70	26.95	17.95
4	4.39	0.00	10.80	6.14	7.95	3.59	15.40	10.73	22.94	17.85
5	1.56	0.00	10.17	6.09	7.60	4.06	17.77	12.13	27.21	20.18
6	5.41	0.00	13.03	6.21	10.95	4.15	20.53	12.43	29.64	20.71
7	8.28	0.00	14.59	6.12	12.90	4.60	22.41	13.71	31.98	22.83
8	11.93	0.00	18.38	5.97	16.10	4.48	26.58	13.41	36.21	22.35
9	N/A*	0.00	17.70	6.19	13.20	5.14	18.46	15.33	29.13	25.55
10	7.75	0.00	13.39	5.99	12.43	5.01	23.03	14.96	33.74	24.91
11	N/A*	0.00	14.17	6.12	12.69	5.11	24.71	15.26	36.42	25.40
12	4.46	0.00	14.16	6.20	11.86	5.17	27.27	13.76	36.29	25.73

*Data not available. Measurements were not stable.

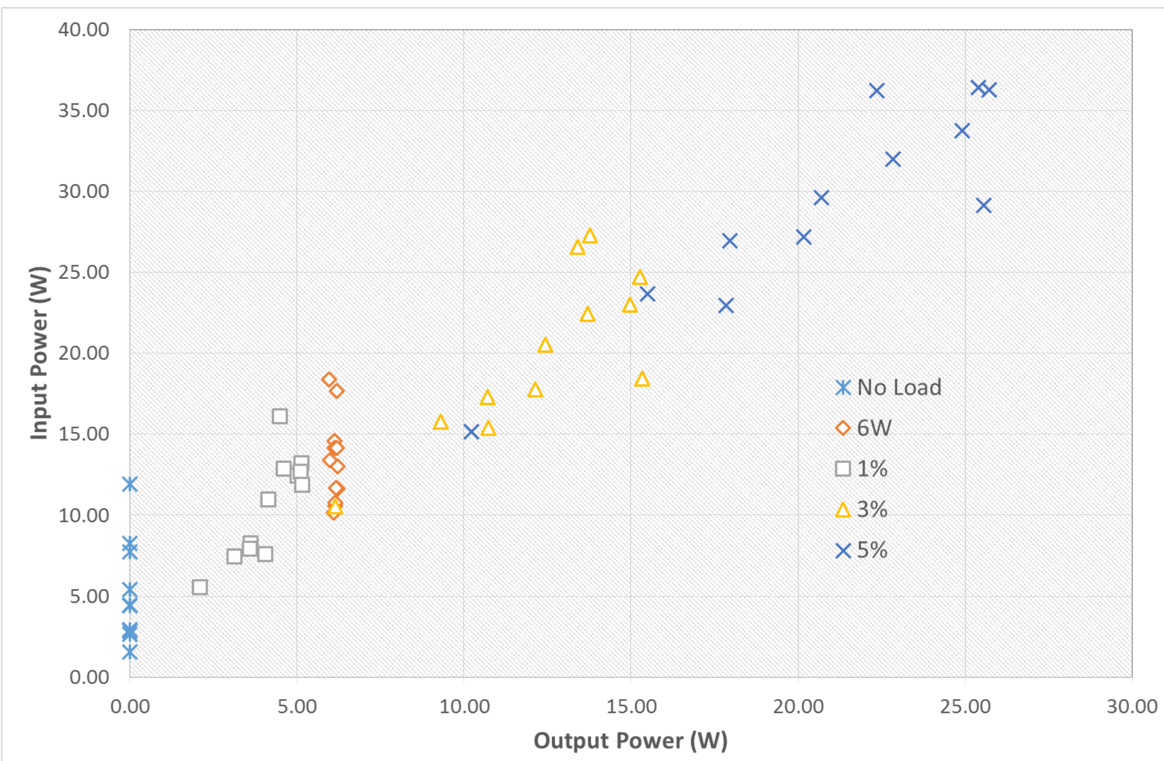

Figure 7, scatterplot showing input power versus output power for all loading conditions.

Fan Power

To provide insight into a possible reason for the variation in power supply performance EPRI decided to measure fan performance. Table 8 shows the status of the fan in terms of on/off for each of the samples. Note that the fan status was consistent for all loading points at least up to 5%. Table 8 shows that all of the fans were enabled except for the sample rated titanium.

In an ad hoc test, EPRI measured the efficiency of sample 12 (gold) at the low-power loading points with and without the fan connected. The results are shown in Figure 8. Power saved ranged from 1.53 W at no load to 2.79 W at 5% load. The fan data suggests that simply turning the fan off at 5% load would save almost 3 W of power. More work is needed to determine how best to encourage manufacturers to adopt more aggressive energy strategy for controlling fan operation.

Table 8, Fan status for all loading conditions (no load, 6 W, 1%, 3%, and 5%)

Sample #	Rated Power	80 PLUS Badge Level	Fan On
1	200	Bronze	Yes
2	300	Standard	Yes
3	350	Bronze	Yes
4	350	Platinum	Yes
5	400	Bronze	Yes
6	400	Bronze	Yes
7	450	Gold	Yes
8	450	Standard	Yes
9	**500**	**Titanium**	**No (Off)**
10	500	Bronze	Yes
11	500	Bronze	Yes
12	500	Gold	Yes

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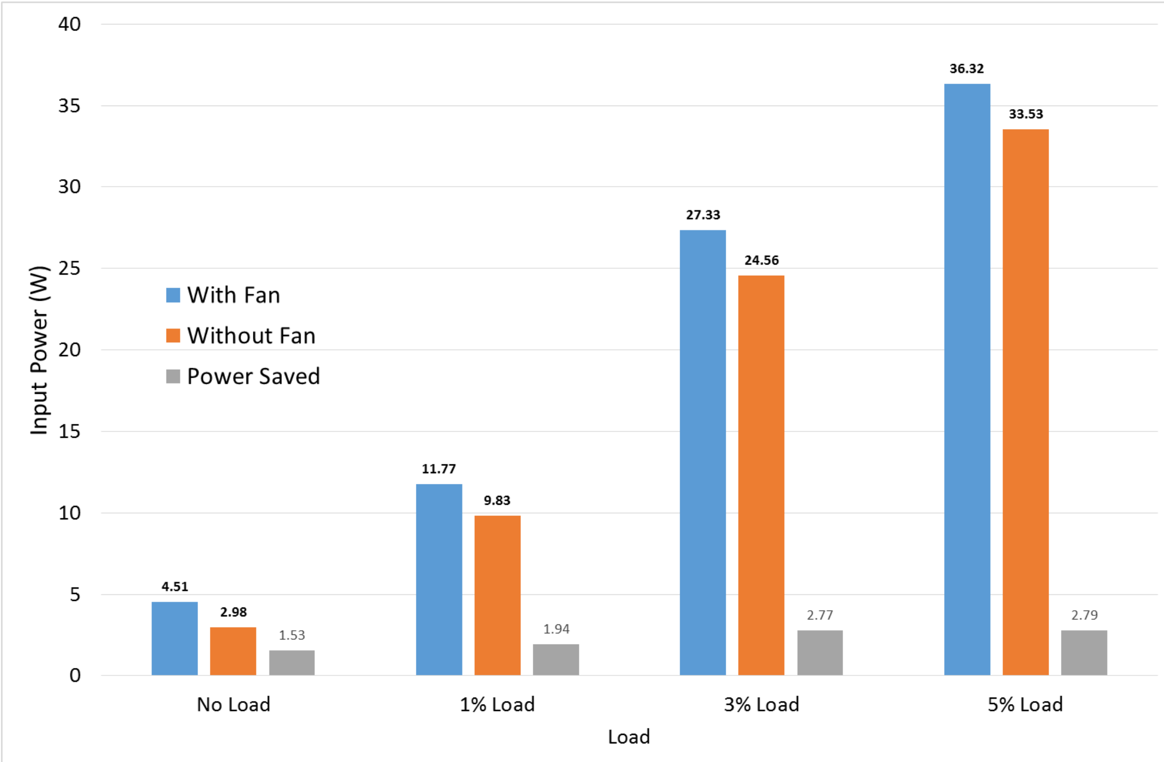

Figure 8, Input power versus load with and without the fan connected for sample 12 (Gold).

Impact of Harmonics

Capture of the waveforms for input voltage and current indicate a significant difference in harmonic current when the power supplies operate at minimal loading compared to traditional loading (20-100%). To illustrate, Figure 6 shows the input voltage and current for a representative power supply loaded at 20%. Figure 7 shows the same power supply loaded to 1.2% (6 W). The significant amount of distortion at minimal loading affects the ability to measure power factor mandating the use of sophisticated equipment to make the measurement because of the complex calculations involved to determine power factor. Repeatability between laboratories is a concern given that line impedance may affect measurement value. Given this, any specification for power factor at minimal loading may require a tolerance wider than is typical or than expected.

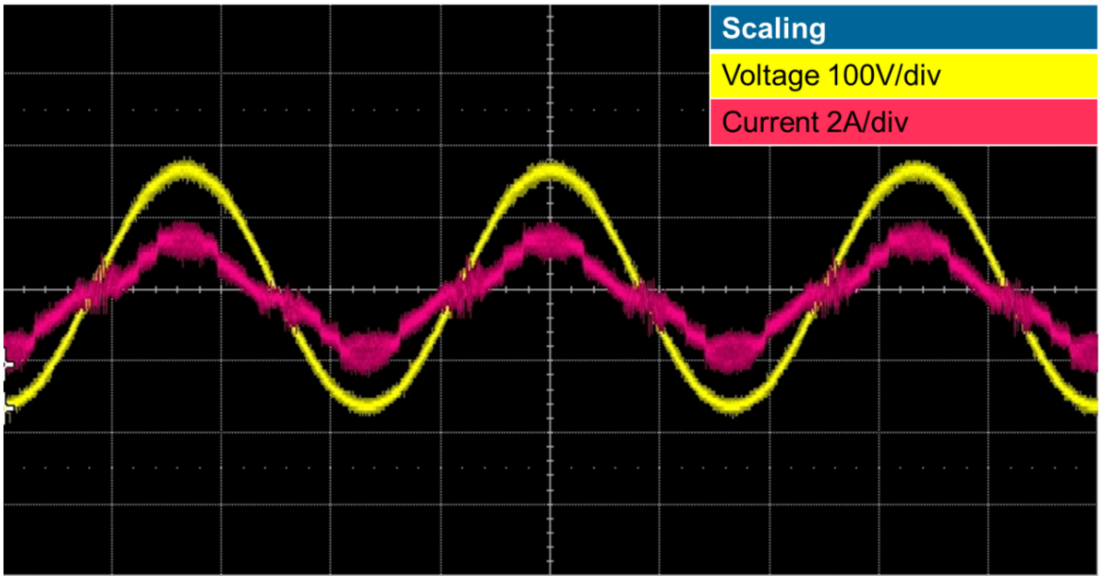

Figure 9, Screen capture of the input voltage and input current of a power supply loaded to 20% (100 W) Note the current is shown at 2 A/division.

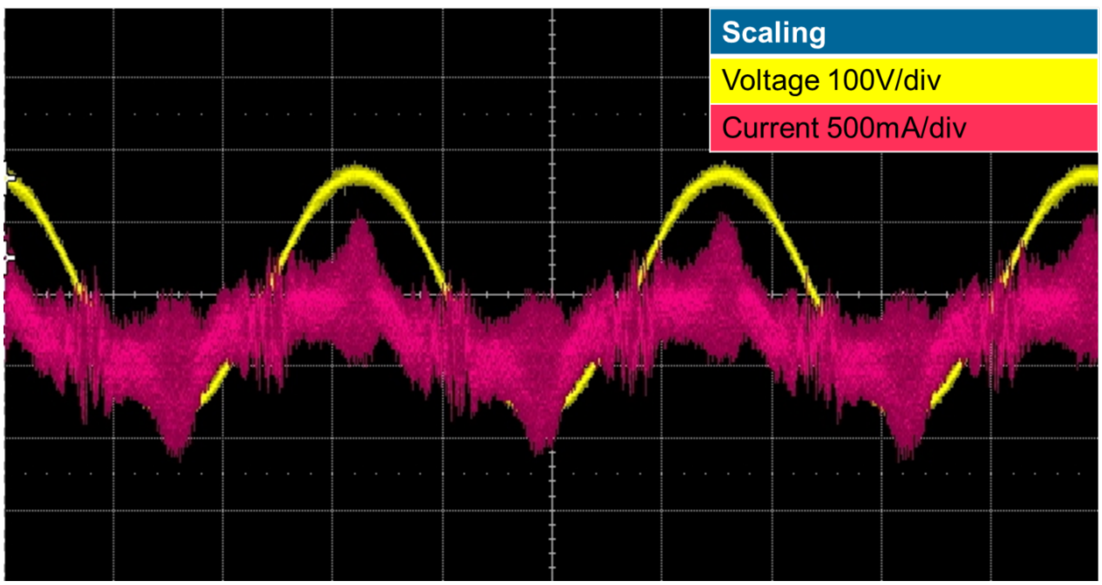

Figure 10, Screen capture of the input voltage and input current of a power supply loaded to 1.2% (6 W). Note the current is shown at 500 mA/division

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Summary

The data suggests it is viable to perform the measurements and efficiency calculation at minimal loading using EPRI's existing test bench and efficiency test protocol. The operation of the electronic load equipment is stable at the minimal power levels.

With an output load of 6 W none of the power supplies achieved 60% efficiency, which is the minimum required to limit input power to 10 Watts during desktop idle operation. It is reasonable to assume that for designers to improve efficiency at 6 watt loads to above 60% requires investment for development of power devices with lower leakage currents and switching losses as well as new techniques for addressing emissions through better filter designs or switching algorithms.

The data suggests that one relatively easy way to improve efficiency at low power, and for relatively low cost, is for manufacturers to implement more aggressive strategies for fan control. Approximately 2 W of power is saved by turning off the fan at minimal loading.

All power supplies delivered good power factor correction (>0.8) down to and below 10% loading. Near 3% loading PF correction circuits begin to cease operation or go into a burst mode of operation. A specification that held PF to above 0.8 at 10% load could be easily met. At minimal loading measurement of power factor is complicated by the shape of the current waveform, which is not sinusoidal, and may mandate specification of a loose measurement tolerance in order to insure measurement repeatability.

No Load power consumption is of interest because it summarizes the losses occurring just to make the output voltages available for use. No-load power consumption is the power used to operate various circuits within the power supply, such as the input filter, fan (although the fan is likely not needed at minimal loading), switches, switching losses, bleeder string losses, and excitation losses. The data suggests that no-load power consumption measurements do not correlate to either power supply rating or to badge level and is not a predictor of performance. Moreover, 2 of the 12 samples failed to stabilize at the no-load condition. However, measurement of no-load data was useful for insight into the variation of incremental conversion efficiency and the data suggests an opportunity among manufacturers for improvement.

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