Draft Test Protocol for Measuring the Energy Efficiency of Server Power Supplies

Revision 1.2

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Revision History

Version	Release Date	Notes
1.0	Jan 31, 2007	First draft released.
1.1	May 4, 2007	Provided clarification on the incorporation of cooling fan power consumption in active mode efficiency measurements. Revised language related to “standby mode” measurements to more accurately reflect test conditions. Measurements previously referred to as “standby mode” are now referred to as “no load” since no loads are connected the power supply’s dc outputs.
1.2	August 29, 2007	Included language to provide guidance on the measurement of standby mode ac power consumption in server power supplies for those parties who wish to undertake this measurement in a standardized fashion.

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1. Scope

This document specifies a test protocol for calculating the energy efficiency of server power supplies. A power supply is a device that converts high-voltage ac electricity into lower voltage dc electricity used by electronic devices. For the purposes of this document, server power supplies are a subset of these power conversion devices used specifically in servers employed in enterprise and data center environments. They are typically located in server racks and often have a single dc output voltage. (See Appendix B for further discussion regarding typical characteristics of server power supplies). Other power supplies used in personal computers – often referred to as internal power supplies or "silver boxes" – are used exclusively for desktop computers or desktop-derived servers and are not included in the scope of this document. A test protocol suitable for measuring other types of internal power supplies such as those used in desktop computers can be obtained from the website www.EfficientPowerSupplies.org.[1] Other power supplies, such as ac-ac voltage conversion equipment (i.e. ac transformers) and dc-dc point-of-load (POL) converters are not included in the scope of this document.

The test protocol in this document applies specifically to server power supplies that meet the following criteria:

i. Power supplies that have a single ac input from the mains, otherwise referred to as a single-phase server power supply

ii. Power supplies that have detailed input and output ratings on their nameplate or in available literature from their manufacturer, specifying the maximum loads that can safely be loaded on each individual dc output voltage bus and, where necessary, groupings of those voltage busses

iii. Power supplies that easily detach from the housing of the product they power without causing harm to other circuits and components of the product

Power supplies physically integrated onto server motherboards are specifically not covered by this test procedure, as are the on-board power supplies that have both ac and dc output voltage busses. Building upon the efficiency test protocol outlined in Section 4.3 of IEEE Std. 1515-2000, *IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods*, this test protocol establishes consistent loading guidelines for ac-dc server power supplies.

1.1 Intent

The intent of this document is to use existing industry standards that have been created for electronic test and measurement to develop a consistent and repeatable method for measuring the energy efficiency of single- and multiple-output ac-dc server power supplies. Existing standards occasionally give conflicting approaches and requirements for efficiency testing, all of which this test protocol seeks to clarify.

[1] EPRI Solutions and Ecos Consulting. "Proposed Test Protocol for Calculating the Energy Efficiency of Internal Ac-Dc Power Supplies." Revision 6.1, May 2006. Available at http://www.efficientpowersupplies.org/pages/Latest_Protocol/Generalized_Internal_Power_Supply_Efficiency_Test_Protocol_R6.1.pdf

2. References

The following list includes documents used in the development of this proposed test protocol. If the following publications are superseded by an approved revision, the revision shall apply:

1. IEEE Std 1515-2000, *IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods*.
2. IEEE Std 519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*.
3. IEC 62301 Ed 1.0, *Household Electrical Appliances – Measurement of Standby Power*
4. Draft IEC 62018 Ed. 1, *Energy Management Requirements*.
5. UL 60950, 3rd Edition, *Information Technology Equipment – Safety – Part 1: General Requirements*, April 1, 2003.
6. IEC 61000-4-7 Ed.2, *Electromagnetic Compatibility (EMC) - Part 4-7: Testing and Measurement Techniques - General Guide on Harmonics and Interharmonics. Measurements and Instrumentation, for Power Supply Systems and Equipment Connected Thereto*.
7. IEC 61000-3-2, *Electromagnetic Compatibility (EMC) – Part 3-2: Limits – Limits for Harmonic Current Emissions (Equipment Input Current ≤ 16 A per Phase)*.
8. IEC 60050, *International Electrotechnical Vocabulary - Electrical and Electronic Measurements and Measuring Instruments*.
9. IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*.
10. *Server System Infrastructure (SSI) Power Supply Design Guidelines* (available at http://www.ssiforum.org/), Intel Corporation

3. Definitions

For the purpose of this document, the following definitions apply. For terms not defined here, definitions from IEC 60050, IEC 62301, and IEEE 100 are applicable.

3.1 Ac-Dc Power Supply

Devices designed to convert ac voltage into dc voltage for the purpose of powering electrical equipment.

3.2 Ac Signal

A time-varying signal whose polarity varies with a period of time *T* and whose average value is zero. (ref. IEEE Std 1515-2000)

3.3 Ambient Temperature

Temperature of the ambient air immediately surrounding the unit under test (UUT). (ref. IEEE Std 1515-2000)

3.4 Apparent Power (S)

The product of RMS voltage and current (VA). Also called the *total power*.

3.5 Dc Signal

A signal of which the polarity and amplitude do not vary with time. (ref. IEEE Std 1515-2000)

3.6 Efficiency

The ratio, expressed as a percentage, of the total real output power (produced by a conversion process) to the real power input required to produce it, using the following equation:

$$\eta = \frac{\sum_i P_{o,i}}{P_{in}} \times 100 \qquad \textit{Eq. 3-1}$$

where $P_{o,i}$ is the output power of the i^{th} output. The input power (P_{in}), unless otherwise specified, includes all housekeeping and auxiliary circuits required for the converter to operate, including any integrated cooling fans.

3.7 Enclosed-Frame Modular Power Supply

A power supply encased in a modular enclosure (intended for use in a rack), as shown in Figure B-1. The power supply slides into the server rack and has easily accessible inputs and outputs.

3.8 No Load Mode

No load represents the mode during which no dc load is connected to the dc output buses of the power supply.

3.9 Multiple-Output Power Supply

A power supply designed to provide more than one dc voltage level or bus.

3.10 Output Voltage Bus

Any of the dc outputs of the power supply, to which loads can be connected and current and power supplied. These busses may supply power at different voltage levels depending on the design of power supply and the product being powered.

3.11 True Power Factor

True power factor is the ratio of the active, or real, power (P) consumed in watts to the apparent power (S) drawn in volt-amperes, with

$$PF = \frac{P}{S} \qquad \textbf{\textit{Eq. 3-2}}$$

and

$$S = \sqrt{P^2 + Q^2} \qquad \textbf{\textit{Eq. 3-3}}$$

Where

PF is power factor,

P is active power in watts,

Q is reactive power in volt-amperes,

S is total power in Volt-amperes.

This definition of power factor includes the effect of both displacement and distortion in the input current (and/or voltage) waveform. (ref. IEEE Std 1515-2000)

3.12 Crest Factor

The crest factor is defined as the ratio of peak current to rms current (or peak voltage to rms voltage). For a pure sinusoidal waveshape the crest factor is 1.414, while for a pure constant dc load the crest factor is 1.0.

3.13 Rated Ac Input Voltage

The supply voltage declared by the manufacturer in the specification of the power supply. For a single-phase power supply, this refers to line-to-neutral voltage, and for a three-phase power supply, this refers to the line-to-line voltage.

3.14 Rated Ac Input Voltage Range

The supply voltage range (minimum/maximum) as declared by the manufacturer in the specification of the power supply.

3.15 Rated Dc Output Current

The dc output current for each output dc bus of the power supply as declared by the manufacturer in the specification or nameplate of the power supply. If there is a discrepancy between the specification and the nameplate, the nameplate rating shall be used.

3.16 Rated Dc Output Current Range

The dc output current range (minimum/maximum) for each output voltage bus of the power supply as declared by the manufacturer in the specification of the power supply.

3.17 Rated Dc Output Power

The maximum dc output power as specified by the manufacturer. This may apply to the total power for all voltage busses, some subset thereof, or a single voltage bus.

3.18 Rated Dc Output Voltage

The dc output voltage for each output voltage bus of the power supply as declared by the manufacturer in the specification of the power supply.

3.19 Rated Input Frequency

The supply ac input frequency of the power supply as declared by the manufacturer in the specification of the power supply.

3.20 Rated Input Frequency Range

The supply ac input frequency range (minimum/maximum) of the power supply as declared by the manufacturer in the specification of the power supply.

3.21 Rated Input Current

The input current of the power supply as declared by the manufacturer in the specification of the power supply. For a three-phase supply, rated input current refers to the input current in each phase.

3.22 Rated Input Current Range

The input current range (minimum/maximum) for a power supply as declared by the manufacturer in the specification of the power supply. For a three-phase supply, rated input current refers to the input current in each phase.

3.23 Rms (Root Mean Square)

The square root of the average of the square of the value of the function taken throughout the period. For instance, the rms voltage value for a sine wave may be computed as:

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T V^2(t)dt} \quad \textbf{\textit{Eq. 3-4}}$$

where

T is the period of the waveform,

V(t) is the instantaneous voltage at time *t*,

V_{RMS} is the rms voltage value.

(ref. IEEE Std 1515-2000)

3.24 Server Power Supply

For the purposes of this document, a server power supply is a type of ac-dc internal power supply specifically used to power servers used in data centers. These power supplies are typically designed to be mounted in server/telecommunication racks and adhere to rack form factors (e.g. 1U, 2U, etc.) rather than desktop or desktop-derived server chassis form factors (e.g. ATX12V and EPS12V). Server power supplies are also frequently operated redundantly with multiple power supplies sharing the load to a single server or server bank in case an individual power supply fails. For photographs with examples of common server power supplies, refer to Appendix B.

3.25 Single-Output Power Supply

Power supplies designed to provide one dc voltage level on one output voltage bus.

3.26 Standby Mode

Standby represents the mode during which all dc power is delivered through the standby voltage rail of the power supply (see Section 3.27).

3.27 Standby Voltage Rail (Vsb)

The standby voltage rail is the output voltage bus that is present whenever ac power is applied to the ac inputs of the supply. (ref. Intel Power Supply Design Guidelines Rev. 0.5). The standby voltage rail is optional in server power supplies.

3.28 Steady State

The operating condition of a system wherein the observed variable has reached an equilibrium condition in response to an input or other stimulus in accordance with the definition of the system transfer function. In the case of a power supply, this may involve the system input or output being at some constant voltage or current value. (ref. IEEE Std 1515-2000)

3.29 Test Voltage Source

The test voltage source refers to the device supplying power (voltage and current) to the unit under test (UUT).

3.30 Total Harmonic Distortion (THD)

The ratio, expressed as a percent, of the rms value of an ac signal after the fundamental component is removed to the rms value of the fundamental. For example, THD of current can be defined as:

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + ...I_n{}^2}}{I_1} \qquad \textbf{Eq. 3-5}$$

where I_n is the rms value of nth harmonic of the current signal.

3.31 UUT

Unit under test. (ref. IEEE Std 1515-2000)

3.32 Voltage Unbalance

The maximum difference between rms phase-to-neutral or phase-to-phase voltage amplitudes at the UUT input terminals. For example, for a wye-connected, three-phase system

$$V_{UNB} = (\max[V_{AN}, V_{BN}, V_{CN}] - \min[V_{AN}, V_{BN}, V_{CN}]) \qquad \textbf{Eq. 3-6}$$

where

V_{AN}, V_{BN}, V_{CN} are the phase voltage magnitudes, and

V_{UNB} is the maximum phase voltage unbalance.

Percent voltage unbalance is calculated by multiplying the maximum voltage unbalance by 100 and dividing the result by the average of the three phase voltages.

$$V_{UNB\%} = \frac{V_{UNB}}{\left(\frac{V_{AN} + V_{BN} + V_{CN}}{3}\right)} \times 100$$ ***Eq. 3-7***

(ref. IEEE Std 1515-2000)

4. Standard Conditions for Efficiency Testing

4.1 General Provisions

Input voltage, frequency, output bus loading, and in some cases, the duty cycle of the fan inside the power supply are among the variables that can impact the efficiency of a server power supply. Sections 4.2, 4.3, and 4.4 recommend a minimum set of requirements in order to control these variables while measuring server power supply efficiency.

The original device manufacturer must provide a cooling solution for the UUT that allows for safe, continuous operation at maximum nameplate loading conditions. This cooling solution must draw any required power from the UUT itself.

Beyond these minimum conditions, the manufacturer and user of the power supply may determine additional requirements, such as harmonic distortion or voltage unbalance as needed to ensure proper function of the device.

4.2 Input Voltage and Frequency

An ac reference source shall be used to provide input voltage to the UUT. As is specified in IEC 62301, the input to the UUT shall be the specified voltage ± 1% and the specified frequency ± 1%. The UUT shall be tested at 230 V, 60 Hz because the typical IEC-compliant three-prong ac connector[2] is limited to 15 A of current at 115 V, which means that most server power supplies cannot be tested at their maximum rated power at the 115 V condition. If voltage and/or frequency ranges are not specified by the manufacturer (or the nameplate value is unclear), the UUT shall not be tested.

4.3 Power Supply Loading

The efficiency of the UUT shall be measured at 5%, 10%, 20%, 50% and 100% of nameplate output current. Efficiency measurements at lower loading conditions (less than 20% of nameplate output current) are required to estimate the operational efficiency of server power supplies that are typically operated in redundant configurations. The ac power consumption of the power supply shall also be measured under no load (0%) conditions. Other loading conditions may be identified that are relevant to the manufacturer and user of the power supply. Procedures for precisely determining load points for server power supplies are described in detail in Section 6.1.1.

In some cases, the manufacturer may specify a minimum current requirement for each bus of the power supply. In these cases, it is important to ensure that calculated current load for a specific load point is not lower than the minimum current requirement (this is of particular concern in lower load conditions such as 5% and 10%). In cases where the minimum current requirement exceeds the test method's calculated load point for a given voltage bus, the value of the minimum current requirement should be used to load the bus rather than the calculated load current. The percent load of the load point shall be properly recorded in any test report based on the new load values used for the busses with minimum loading requirements.

Prior to power measurements, the UUT shall be allowed to operate at each load point for at least 15 minutes in order to allow the power supply to reach a steady state of operation. A steady state

[2] IEC connector refers to C13 and C14 connectors as specified in IEC60320.

of operation has been reached if the total input power reading over two consecutive five-minute intervals does not change by more than ± 1%

4.4 Duty Cycle of Power Supply Fan

In some server power supply designs, the duty cycle of a cooling fan (the percent of time that the fan is in operation) is controlled by the temperature of the heat sink inside the power supply. If the heat sink reaches a certain set temperature value, the fan switches on. If the heat sink cools down below the set temperature value, the fan switches off. The duty cycle of the fan can then influence the efficiency of the power supply especially during the time of measurement. In order to capture the effect of the fan's duty cycle on the efficiency of the power supply, the input and output power measurements shall be integrated over a period of 30 minutes[3] (after thermal equilibrium of the power supply is reached) or five fan cycles, whichever is reached first (one fan cycle consists of one "on" period followed by one "off" period). For a more detailed description of this method of integrated power measurements, refer to section 4 of IEC 62301 (*Measurement of Standby Power).*

[3] Also known as the "accumulated energy approach". Please refer to section 4.3, IEC 62301 Ed 1.0: "Where the instrument can accumulate energy over a user selected period, the period selected shall not be less than 5 minutes. The integrating period shall be such that the total recorded value for energy and time is more than 200 times the resolution of the meter for energy and time. Determine the average power by dividing the accumulated energy by the time for the monitoring period."

5. Instrumentation and Equipment

5.1 General Provisions

These procedures are meant to ensure the accurate and consistent measurement of power supplies across testing laboratories. Please refer to Annex B of IEEE 1515-2000, *IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods*, for guidelines for general test practices and to section 4, Annex B and D of IEC 62301, Ed. 1.0, *Measurement of Standby Power*, for a discussion on evaluating measurement uncertainty.

5.2 Test Voltage Source

The input voltage source shall be capable of delivering at least 10 times the nameplate input power of the UUT where practicable (as is specified in IEEE 1515-2000). The input voltage source shall be deemed inadequate and a different voltage source shall be used if the input voltage varies at any point during the test by more than ± 1% of the specified source voltage for the test.

Regardless of the ac source type, the THD of the supply voltage when supplying the UUT in the specified mode shall not exceed 2%, up to and including the 13^{th} harmonic (as specified in IEC 62301). The peak value of the test voltage shall be within 1.34 and 1.49 times its rms value (as specified in IEC 62301).

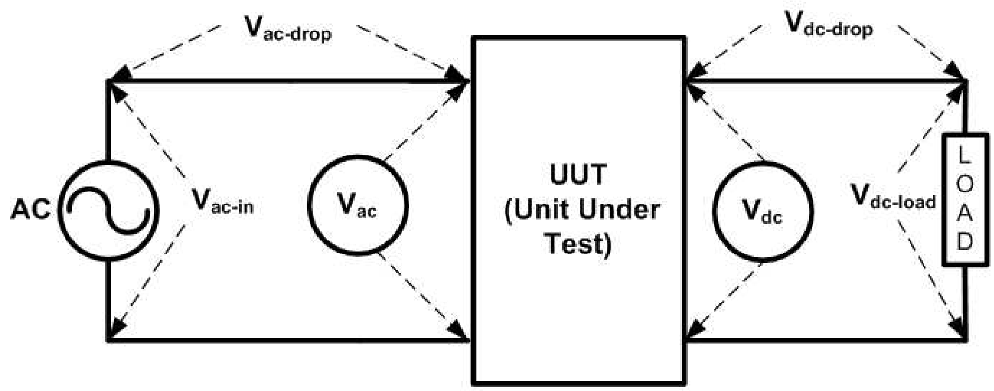
The voltage unbalance for a three-phase test source shall be less than 0.1%.

5.3 Test Dc Loads

Active dc loads such as electronic loads or passive dc loads such as rheostats used for efficiency testing of the UUT shall be able to maintain the required current loading set point for each output voltage within an accuracy of ± 0.5%. If electronic load banks are used, their settings should be adjusted such that they provide a constant current load to the UUT.

5.4 Test Leads and Wiring

Appropriate American Wire Gauge (AWG) wires have to be selected for different parts of wiring connections depending on the maximum current carried by the conductor in order to avoid overheating of wires from excessive loading and to reduce excessive voltage drop across the wires which may lead to incorrect efficiency measurements. For detailed information and guidance on measurement and wiring, please refer to Annex B in IEEE 1515-2000. The Table B.2, "Commonly used values for wire gages and related voltage drops" in IEEE 1515-2000 gives the relation between the voltage drop across the conductor as a function of three variables: current carried by the conductor, conductor AWG, and conductor length. The voltage drop across the conductor carrying the current must be added or subtracted to the appropriate voltage measurements (please refer to Figure 1) if the input and output measurements of the UUT are not taken directly at the connector pins.



$$V_{ac} = V_{ac\text{-}in} - V_{ac\text{-}drop}$$
$$V_{dc} = V_{dc\text{-}load} + V_{dc\text{-}drop}$$

Figure 1. Input and Output Voltage Measurements

The generic test setup can be made as shown in Figure 2. The ac power meter used in the efficiency test should be capable of measuring the ac voltage (rms), ac current (rms), ac power (true rms power), power factor, and total harmonic distortion of current. The dc power meter should be capable of measuring dc voltage, dc current, and dc power on all dc voltage outputs of the device. All power metering equipment should meet the accuracy requirements described in Section 5.5. The dc load(s) shall be capable of drawing constant current during the course of the test and shall meet the tolerances specified in Section 5.3.

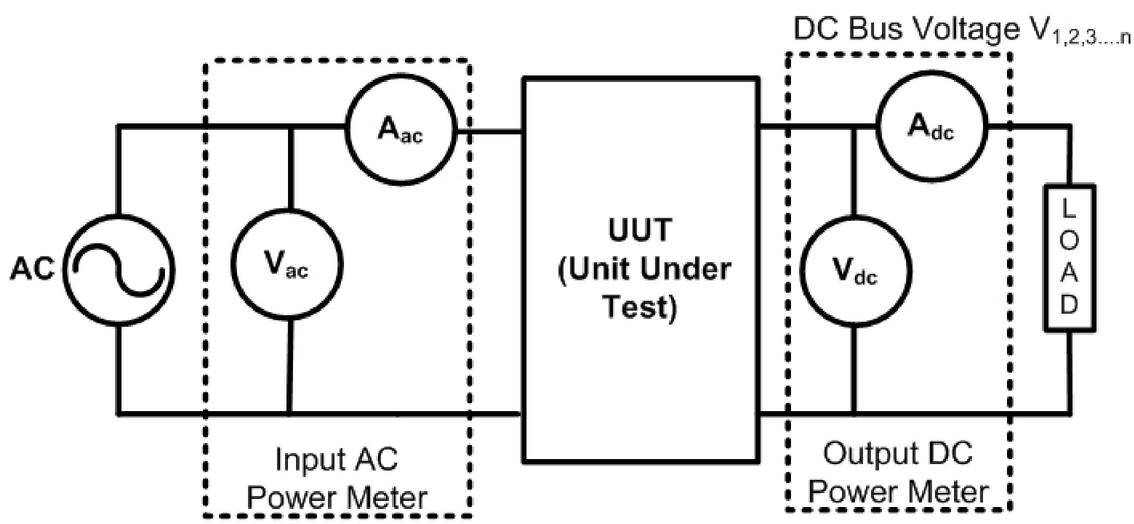


Figure 2. Generic Efficiency Test Setup

5.5 Measurement Instrumentation Accuracy

Power measurements shall be made with a suitably calibrated voltmeter and ammeter or power analyzer as specified under IEC 62301. Measurements of power of 0.5 W or greater shall be made with an uncertainty of less than or equal to 2% at the 95% confidence level. Measurements of power of less than 0.5 W shall be made with an uncertainty of less than or equal to 0.01 W at the 95% confidence level. The power measurement instrument shall have a resolution of:

i. 0.01 W or better for power measurements of 10 W or less;
ii. 0.1 W or better for power measurements of greater than 10 W up to 100 W;
iii. 1 W or better for power measurements of greater than 100 W.

All power figures should be in Watts and rounded to the second decimal place. For power levels ≥ 10W, three significant figures shall be reported. For further details please see Annex D of IEC 62301 and ISO Guide to the Expression of Uncertainty in Measurement.

5.6 Test Room

As is specified in IEC 62301, the tests shall be carried out in a room that has an air speed close to the UUT of ≤ 0.5 m/s, and the ambient temperature shall be maintained at 23°C ± 5°C throughout the test. There shall be no intentional cooling of the UUT by use of separately powered fans, air conditioners, or heat sinks. The UUT shall be tested on a non-metallic, thermally non-conductive surface.

5.7 Warm-up Time

Internal temperature of the components in a power supply could impact the efficiency of the unit. As a general recommendation before testing, each UUT shall be loaded up to the test load for a period of at least 15 minutes or for a period sufficient that the total input power reading over two consecutive five-minute intervals does not change by more than ± 1%.

5.8 Output Voltage Sensing

Most server power supplies have a special output voltage sensing feature commonly called "voltage sense" that regulates or maintains the dc output voltages within a predetermined range. The voltage sense lines do not carry any current but are rather used by the server power supply's controller to monitor the various output voltages. In some server power supplies the voltage sense feature is optional while in others it is mandatory for the proper function of the device. In such server power supplies where voltage sense functionality is required, the output voltages will fall out of range if the voltage sense lines are not connected to the corresponding output voltage busses. This can lead to inaccurate efficiency measurements. Therefore, any server power supply with output voltage sensing lines must be tested with those output voltage sensors connected to their respective output voltage busses to ensure accurate results.

6. Loading Criteria For Efficiency Testing

6.1 General Provisions

Loading criteria for ac-dc power supplies shall be based on rated dc output current and not on rated dc output power. For example, consider the 50% loading condition for a 50 W, +5 V single-output power supply with a rated dc output current of 10 A. The load condition is achieved by adjusting the dc load (using a rheostat or electronic load bank) connected to the 5 V bus output so that 5 A of current is flowing on the bus. This is *not* equivalent to adjusting the load bank until the load on that bus dissipates 25 W of power, because voltage regulation may not remain constant under a range of loading conditions.

For power supplies with multiple output voltage busses, defining a consistent loading criteria is much more difficult, because each bus has a rated dc output current. The sum of the power dissipated from each bus loaded to these rated currents may exceed the overall rated dc output power of the power supply. A proportional allocation method is recommended for providing consistent loading guidelines for multiple-output ac-dc power supplies. This method is described in detail in Section 6.1.1.

6.1.1 Proportional allocation method for loading multiple output ac-dc server power supplies

This section shows a procedure for developing loading guidelines based on a proportional allocation method. Measurements shall be taken at the following load points: 0% (standby), 5%, 10%, 20%, 50% and 100% of rated output power. The UUT's nameplate specifies the maximum rated dc output current on each output voltage bus, and care should be taken not to exceed those values. However, loading the busses to their *individual* current maximums often will exceed the *overall* rated dc output power of the power supply. In some cases, ratings are established for a subgroup of the output voltage busses. These *subgroup* ratings can also be exceeded if the busses are loaded to their *individual* current maximums. The following sections provide procedures for loading multiple output ac-dc power supplies by using a calculated derating factor (*D*) to ensure that neither the individual busses nor bus subgroups are not overloaded..

6.1.1.1 Method of Proportional Allocation Based on Overall Power Supply Rated Dc Output Current With No Sub-group Ratings

The manufacturer has provided rated dc output current limits for each bus and an overall rated dc output power for the power supply. The approach for loading criteria is as follows:

Assume a power supply with four output voltage busses. A sample output specification of this power supply is shown in Table 6-1.

Table 6-1: Labels for Output Variables

Rated Dc Output Voltage of Each Bus	Rated Dc Output Current of Each Bus	Rated Overall Dc Output Power
V_1	I_1	P
V_2	I_2	
V_3	I_3	
V_4	I_4	

Step 1: Calculate the derating factor D using the procedure outlined in Eq. 6-1.

$$D = \frac{P}{(V_1 * I_1) + (V_2 * I_2) + (V_3 * I_3) + (V_4 * I_4)}$$ ***Eq. 6-1***

Step 2: If $D \geq 1$, then it is clear that loading the power supply to the rated dc output current for every bus does not exceed the overall rated dc output power for the power supply. For this case, the required output dc current on each bus for X% loading can be determined by

$$I_{bus} = I_n * \frac{X}{100}$$ ***Eq. 6-2***

where I_{bus} is the required output dc current for that bus at X percent load and I_n is the rated dc output current for that bus. For example, Table 6-2 shows the guideline for 50% loading of the power supply based on $D \geq 1$.

Table 6-2: 50% Loading Guideline for **D ≥ 1**

Output Voltage of Each Bus	50% Loading Guideline
V_1	$0.5*I_1$
V_2	$0.5*I_2$
V_3	$0.5*I_3$
V_4	$0.5*I_4$

Step 3: If, however, $D < 1$, it is an indication that loading each bus to its rated dc output current will exceed the overall rated dc output power for the power supply. In this case, the following loading criteria using the derating factor can be adopted:

$$I_{bus} = \frac{D * X * I_n}{100}$$ ***Eq. 6-3***

This effectively derates the output dc current of each output voltage bus such that at 100% load, the overall load will equal the rated dc output power of the power supply. It also derates other load levels. For example, Table 6-3 shows the guideline for 50% loading of the power supply based on $D < 1$.

Table 6-3: 50% Loading Guideline for* D *< 1

Output Voltage of Each Bus	50% Loading Guideline
V_1	$D*0.5*I_1$
V_2	$D*0.5*I_2$
V_3	$D*0.5*I_3$
V_4	$D*0.5*I_4$

6.1.1.2 Method of Proportional Allocation Based on Overall Power Supply Rated Dc Output Current with Sub-group Ratings

In some cases, the power supply manufacturer specifies the rated dc output power for a subgroup of busses in addition to the overall rated dc output power of the power supply. An example of this type of power supply is a power supply with an overall rated dc output power of 330 W and a rated dc output power of 150 W for the +5 V and +3.3 V busses combined. Loading each bus to its individual rated dc output current may now exceed both the overall power supply's rated dc output power and the subgroup's rated dc output power. This section outlines a procedure for ensuring that both the subgroup and overall current ratings are not exceeded.

Assume a power supply with six output voltage busses with an overall rated dc output power P_T. Let the rated dc output power for subgroup busses 1 and 2 be P_{S1-2} and a rated power for subgroup busses 3 and 4 be P_{S3-4} and the ratings for bus 5 and 6 be simply equal to the product of their individual voltages and currents. A sample output specification of this power supply is shown in Table 6-4.

Table 6-4 Output Variable Labels for Maximum Rating of Subgroup Output Voltage Bus

<table>
<tr><th>Output Voltage of Each Output Bus</th><th>Maximum Rated Output Current of Each Bus</th><th>Maximum Rated Output Wattage for Subgroups V_1, V_2 and V_3, V_4</th><th>Maximum Power Supply Total Rating</th></tr>
<tr><td>V_1</td><td>I_1</td><td rowspan="2">P_{S1-2}</td><td rowspan="6">P_T</td></tr>
<tr><td>V_2</td><td>I_2</td></tr>
<tr><td>V_3</td><td>I_3</td><td rowspan="2">P_{S3-4}</td></tr>
<tr><td>V_4</td><td>I_4</td></tr>
<tr><td>V_5</td><td>I_5</td><td>P_{S5}</td></tr>
<tr><td>V_6</td><td>I_6</td><td>P_{S6}</td></tr>
</table>

Step 1: Calculate derating factors D_{S1} to D_{S6} for each of the subgroups as shown in Eq. 6-4.

$$D_{S1-2} = \frac{P_{S1-2}}{(V_1 * I_1 + V_2 * I_2)}$$

$$D_{S3-4} = \frac{P_{S3-4}}{(V_3 * I_3 + V_4 * I_4)}$$

$$D_{S5} = \frac{P_{S5}}{(V_5 * I_5)}$$

$$D_{S6} = \frac{P_{S6}}{(V_6 * I_6)}$$

Eq. 6-4

If the derating factor $D_S \geq 1$, then it is clear that when the subgroup is loaded to the rated dc output currents, the subgroup rated output powers will not be exceeded and there is no need for derating.

However, if one or more D_S factors are less than 1 then the subgroup power will be exceeded if the outputs are loaded to their full output currents and there is a need for derating.

Step 2:

There is also a need to check whether the sum of the subgroup maximum rated powers is greater than the total maximum power rating of the power supply (P_T). If the sum of the subgroup maximum rated powers is greater than the overall power rating of the power supply then a second derating factor D_T must be applied. This factor is calculated as shown below:

$$D_T = \frac{P_T}{P_{S1-2} + P_{S3-4} + P_5 + P_{S6}}$$

Eq. 6-5

If $D_T \geq 1$ then no derating is needed.

If $D_T < 1$ then the derating for each of the outputs has to be applied and is shown below.

For example, Table 6-5 shows the guideline for X% loading of the power supply based on $D_S < 1$ and $D_T < 1$.

Table 6-5 Output Loading Current Calculation for Each Individual and Sub-group Bus Voltages

Output Voltage	Output Current Rating	Subgroup	Output Loading Current
V_1	I_1	1-2	$D_T * D_{S1-2} * I_1 * \frac{X}{100}$
V_2	I_2		$D_T * D_{S1-2} * I_2 * \frac{X}{100}$
V_3	I_3	3-4	$D_T * D_{S3-4} * I_3 * \frac{X}{100}$
V_4	I_4		$D_T * D_{S3-4} * I_4 * \frac{X}{100}$
V_5	I_5	5	$D_T * D_{S5} * I_5 * \frac{X}{100}$
V_6	I_6	6	$D_T * D_{S6} * I_6 * \frac{X}{100}$

6.1.2 Method of Current Allocation for Measuring the Ac Power Consumption of a Server Power Supply in the Standby Mode Condition

Measurement of the ac power consumption of server power supplies operated in the standby mode condition shall be conducted as follows:

1. Determine the *minimum* standby load that the server power supply will support. The minimum standby load is defined as the minimum current load that can be supplied by the server's standby voltage rail.
2. Allow the power supply to operate at this load for a period of 15 minutes.
3. Measure and record the ac input power.
4. Repeat steps 2 and 3 at 50% and 100% of the standby voltage rail's rated current output.

6.1.3 Method of Current Allocation for Measuring the Ac Power Consumption of a Server Power Supply in the No Load Condition

Measurement of the ac power consumption of server power supplies operated at the 0% load point or no load shall be conducted by connecting the power supply to an ac voltage source through its ac input and measuring the ac input power consumed under no load. In some redundant server power supply configurations, one or more of the power supply units may stay in a low load condition all the time, ready to assume the full server load in case if there is a failure in one of the primary power supply units.

7. Measurement Procedures

1. Record all the input and output specifications of the ac-dc power supply provided by the manufacturer in the power supply specification sheet. These may include one or more of the following specifications:
    - Rated input ac voltage
    - Rated input ac voltage range
    - Rated input ac current
    - Rated input ac current range
    - Rated input frequency
    - Rated input frequency range
    - Rated output dc power
    - Rated output dc current
    - Rated output dc current range
    - Rated output dc voltage
    - Rated output dc voltage range
2. Record the ambient environmental conditions at the site of the test, including:
    - Ambient temperature
    - Elevation of test location
    - Barometric pressure
3. Calculate the loading criteria for each output voltage bus for each loading level defined by the loading guidelines used for the UUT, as described in section 6.
4. Complete the test setup with the source, UUT, load, and measurement instrumentation. Given that no universal standard exists for the dc output connector of server power supplies, a mating connector (either supplied by the manufacturer or fabricated in-house) will be required to connect the server power supply to the load. Furthermore, server power supplies may require output voltage sensing/feedback connections for accurate regulation of dc output voltage. Connect all necessary output voltage sensing control lines as stated in the user manual of the power supply. Refer to IEEE 1515 Annex B, General Test Practices, for general guidelines and recommended practices for measurement and instrumentation setup for testing power supplies.
5. Set the power source input voltage and frequency (if programmable) as per the test requirement.
6. Load the output voltage busses (using either a rheostat or an electronic dc load bank) based on the loading criteria established for the UUT within the tolerance levels specified in this protocol.

7. If the fan turns on intermittently, then follow the procedure outlined in section 4.4 for taking an averaged measurement of power supply efficiency.
8. Measure and record the following at each load condition. For dc values, record separate values for each dc output voltage bus:
    - Rms ac input power
    - Rms ac input voltage
    - Rms ac input current
    - Power factor
    - Total harmonic distortion of input current
    - Dc output voltage
    - Dc output current
    - Dc output power
9. Calculate the efficiency of the power supply for the loading condition using the equation:

$$\eta = \frac{\sum_i P_{o,i}}{P_{in}} \times 100 \qquad \textbf{\textit{Eq. 7-1}}$$

Where, P_{in} is the true rms input power and $P_{o,i}$ is the output power of the i^{th} bus.

10. Repeat this procedure for other loading conditions.
11. Measure and record the ac power consumption of the UUT in standby mode and no load mode as specified in Sections 6.1.2 and 6.1.3 of this document, respectively.

7.1. Test Report

In the test report, graphically display the key data (measured and calculated) from the test along with a description of the power supply that includes the manufacturer's model name and model number, specifications, and loading criteria. Appendix A provides an example test report for a server power supply and a graphical representation of power supply efficiency under different loading conditions. For additional information on power supply test reports and other relevant information, refer to the website *www.EfficientPowerSupplies.org* .

8. Appendix A: Example Efficiency Report for a Server Power Supply

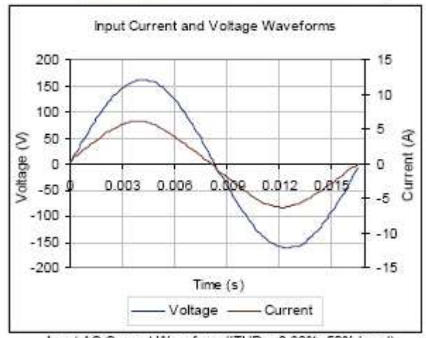
Server Power Supply Efficiency Test Report

TYPICAL EFFICIENCY (50% Load): **88.42%**
AVERAGE EFFICIENCY : **66.16%**

Specimen Number	yy
Manufacturer	xxxx
Model Number	
Serial Number	N/A
Year	2006
Type	1U
Test Date	xx/xx/xxxx

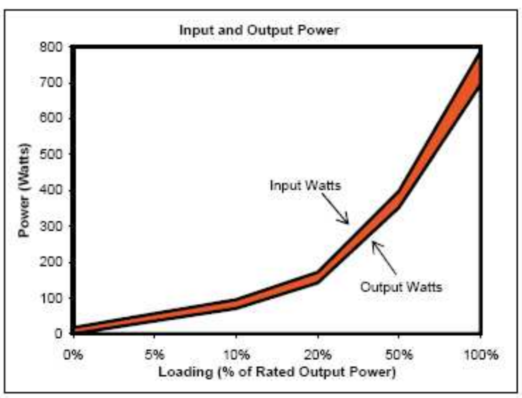
Rated Specifications	Value	Units
Input Voltage	115-230	Volts
Input Current	6-8	Amps
Input Frequency	50/60	Hz
Rated Output Power	**700**	**Watts**

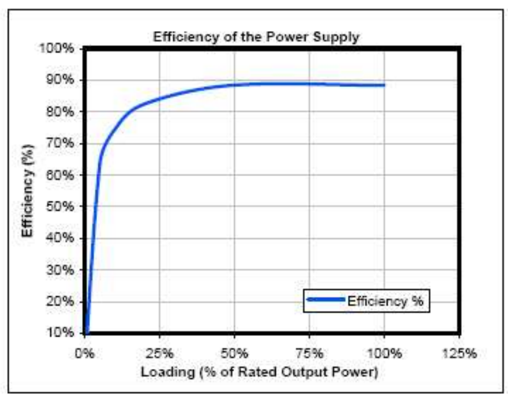
Note: All measurements were taken with input voltage at 230 V nominal and 60 Hz.



Input AC Current Waveform (ITHD = 3.66%, 50% Load)

I_{RMS} A	PF	I_{THD} (%)	Load (%)	Fraction of Load	Input Watts	DC Terminal Voltage (V)/ DC Load Current (A)		Output Watts	Efficiency %
						12V	5V*		
0.32	0.23	18.3%	0%	Standby	17	12.2/0	5.0/0	0	0.00%
0.43	0.56	10.7%	5%		56	12.2/2.84	5.0/0.2	36	63.42%
0.56	0.74	7.4%	10%		96	12.2/5.67	5.0/0.4	71	74.31%
0.84	0.89	5.3%	20%		172	12.1/11.34	5.0/0.8	142	82.47%
1.77	0.98	3.7%	50%		398	12.1/28.35	4.9/2.0	352	88.42%
3.45	0.99	1.8%	100%	Full	788	12.1/56.72	4.7/3.9	696	88.32%





Tested by Electric Power Research Institute, Knoxville, TN.

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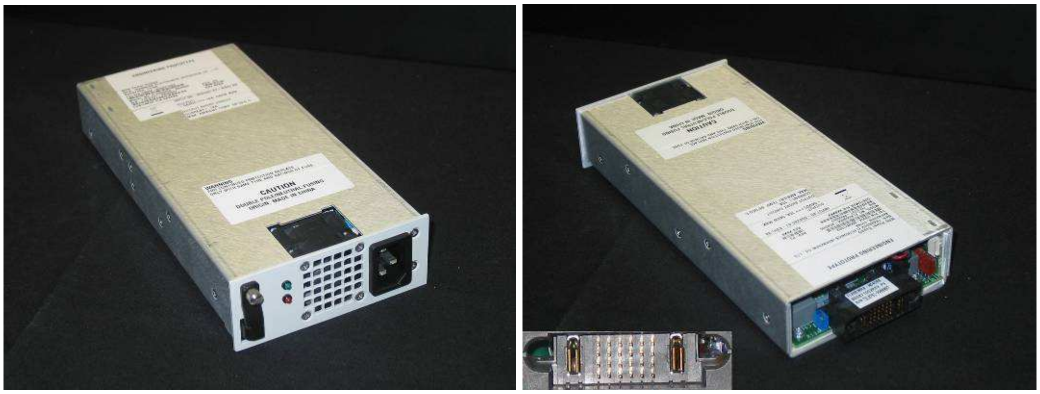
9. Appendix B: Server Power Supply Discussion

The common housing structures for server power supplies considered in this test procedure are rack-mountable units as shown in Figure B-1.



(a) Single Output Server Power Supply: -54VDC

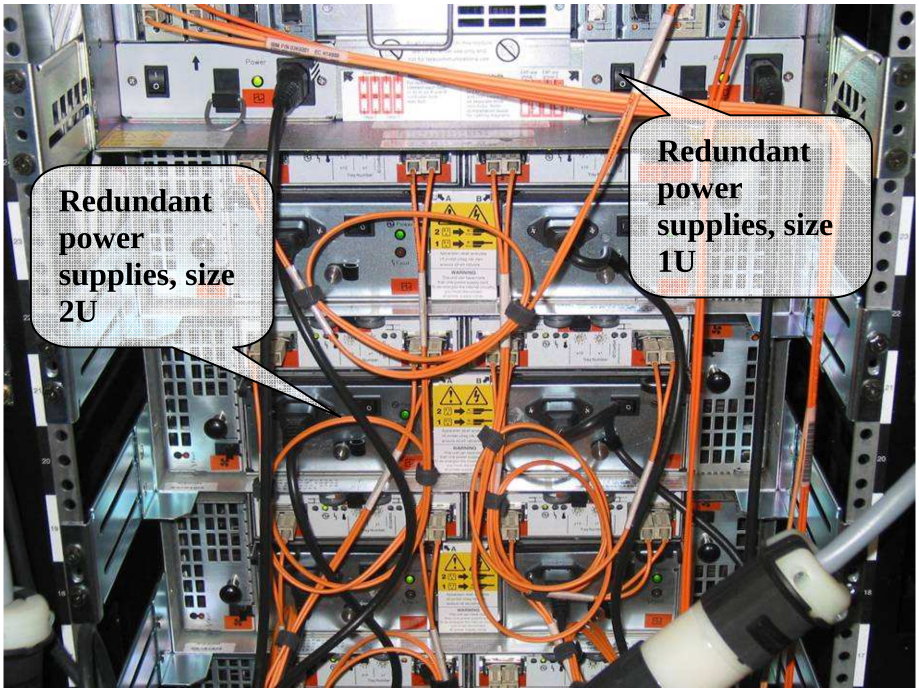
(b) Dual Output Server Power Supply: 48VDC and 5VDC

(c) Single Output Server Power Supply with Standby Rail: 12VDC, 3.3VDC Standby

Figure B-1. Examples of rack-mountable server power supplies that have (a) single output (TDI), (b) dual outputs (C & D Technologies), and (c) multiple outputs (Delta Electronics)

Each of the three server power supplies shown in Figure B-1 has a unique output connector interface, resulting in an additional step necessary to measure their efficiencies.

Examples of server power supplies operating in a data center are shown in Figure B-2. Notice how power supplies are configured redundantly such that two individual power supplies power one single server or server bank. If one of the power supplies fails, the other will assume the entire load. This scheme protects data center operators from unnecessary downtime.



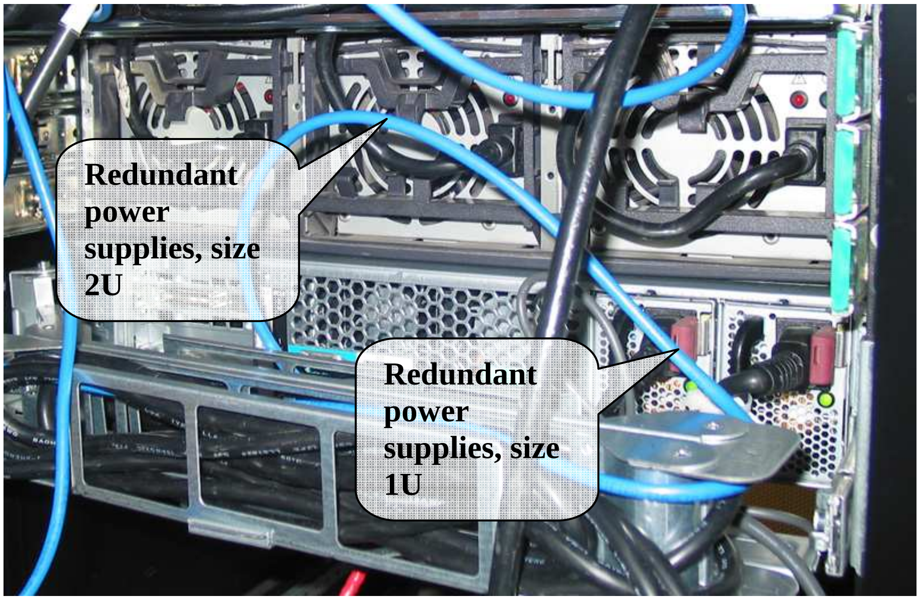


Figure B-2. Examples of redundant server power supplies in a data center (courtesy of Electric Power Research Institute)

Server power supplies vary widely in their nameplate characteristics, such as output power and voltage. A representative sample of one-unit (1U) rack-mountable server power supplies and their nameplate ratings are listed in Table B-1.

Table B-1: Specifications of a sample of server power supplies

Manufacturer	Rated Output Power (W)	Size	Category	Voltage Outputs (V dc)
A	1625	1U	Dual Output	12V, 3.3Vstby
B	1900	3U	Single Output	48V
C	540	1U	Single Output	-54V
D	500	1U	Multiple Output	12V, 5V, 3.3V, -12V, 5Vsb
E	750	2U	Multiple Output	12V, 5V, 3.3V, -12V, 5Vsb
F	2000	1U	Dual Output	48V, 5V