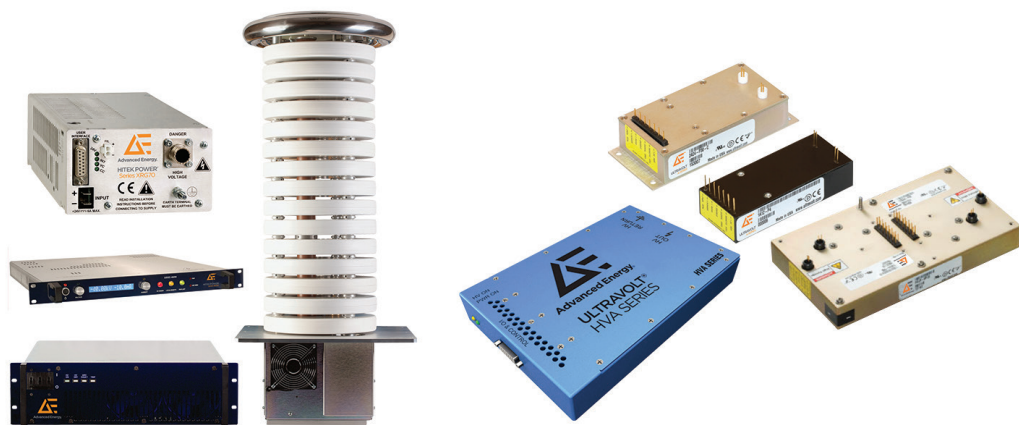


# Selecting the Right Standard High-Voltage Power Supply

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High-voltage power supplies drive a broad range of applications across diverse segments, including semiconductor, scientific, medical, industrial, and more. Designed to deliver stable supply voltages at 50 V and up, the power supplies, comprised of sophisticated components and specialized materials, must carefully manage the high voltages and associated effects, for example, corona and arcing. For systems developers choosing standard high-voltage power supplies, the specialized nature of high-voltage power calls for a power supply selection process that reflects the unique characteristics of the high-voltage power supply and its operation.

## Low-voltage versus high-voltage power supplies

Standard high-voltage power supplies bear only a faint resemblance to familiar low-voltage supplies designed for consumer devices and office products. Advances in power component functionality and integration have enabled designers to deliver more efficient low-voltage power supplies in smaller, lower-cost packages. Indeed, these supplies meet growing demand for size reduction across most consumer and business applications. For these applications, fluctuations in output that lie within a few percentage points of the target output level generally remain well within required performance parameters. In fact, product designers are typically more concerned about size and cost of low-voltage supplies than about high precision and tight stability. Consequently, characteristics like supply footprint, watt/in<sup>3</sup>, and cost/watt rise in importance in this domain, closely behind basic characteristics, including input voltage, output voltage, and output current.

For applications with high-voltage demands, however, the specialized requirements of each application present unique challenges to supply designers. In fact, designers sometimes must build custom high-voltage supplies to meet the unique requirements of customer applications. Nevertheless, with the availability of advanced power semiconductors and novel materials, manufacturers can now provide standard high-voltage power supplies capable of meeting nearly any combination of specialized requirements.

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**Figure 1: High-voltage power supplies rely on highly robust components such as this high-voltage resistor. Image credit: EBG**

Common Requirements	Low-Voltage Considerations	High-Voltage Considerations
<ul style="list-style-type: none"> <li>• Input voltage</li> <li>• Output voltage</li> <li>• Output current</li> </ul>	<ul style="list-style-type: none"> <li>• Watt/in<sup>3</sup></li> <li>• cost/Watt</li> </ul>	<ul style="list-style-type: none"> <li>• Unit size dimensions (power and voltage density)</li> <li>• Ripple and noise</li> <li>• Accuracy and stability performance</li> <li>• Specialized features/functions (ARC protection, temperature compensation, slew rate limits, low stored energy)</li> </ul>

**Table 1: Low- and high-voltage power considerations**

**Unique high-voltage design considerations**

High-voltage supplies remain fundamentally different from their low-voltage counterparts because of the nature of high-voltage operation itself. Designers cannot simply scale low-voltage designs to operate at high-voltage levels. Characteristics that designers can overlook in low-voltage supplies become critical in the face of high voltage and current levels. Likewise, power supply users must take a more methodical approach in selection criteria to determine which standard, high-voltage power supply capabilities meet their application requirements.

Specification/Characteristic	Low-Voltage Power Supply	High-Voltage Power Supply	High-Performance High-Voltage Power Supply
Regulation	1%	0.1%	down to 10 ppm
Control range	± 10%	10-110%	0-110%
Control gain	1	100:1	1000:1 to 10,000:1
Ripple	0.1-1.0%	0.1%	1-2 ppm

**Table 2: Differences in sample specifications for low-voltage power supplies versus nominal high-voltage power supplies and high-performance HVPSs**

Low- and high-voltage supplies share a basic architecture, where high-frequency AC waveforms applied to the primary coil of a transformer result in stable output voltage after filtering and regulation by associated control circuits. The nature of the implementation of that basic architecture differs

significantly as supply designers cope with effects that have little impact on low-voltage supplies. For example, switching losses in low-voltage supplies might increase temperature levels and can be safely ignored with little impact if occurring in the safe operating area. In fact, a 5 VDC low-voltage supply has nominal control and regulation error with a 5 VDC control system since errors as little as 10 mV manifest as only a 10 mV output error. At high-voltage levels, however, even low-percentage switching losses will significantly degrade efficiency and performance and complicate thermal management in these designs. So, a 5000 VDC high-voltage supply with 5 VDC control has a gain of 1000:1. In this case, a control error, ground shift, or noise element of 10 mV causes a 10 VDC output error.

Similarly, the transformer configurations used to boost output in high-voltage supplies present designers with another challenge rarely encountered in low-voltage supplies. The combination of high-switching frequency and high-turn ratios in transformer secondary windings results in reflected parasitic capacitance on the primary side, further affecting the performance of the driving circuit. Beyond these phenomena, high-voltage operation presents designers of these systems with multiple additional challenges in managing characteristics, such as noise, ripple, and stability.

To counter these challenges, high-voltage power supply designers employ unique materials and devices. For example, novel magnetic materials are used to help reduce losses in transformer cores, while advanced power semiconductors deliver the very fast switching and reduced forward-drop characteristics needed in these designs. Even the performance requirements for basic passive components become tighter as designers look to reduce output error and long-term drift.

Designers combine these materials and components in proprietary designs built on sophisticated converter topologies needed to maintain low noise levels, reduce switching loss, and reduce reflected capacitance. At the same time, effective solutions for addressing those requirements often bring increased design complexity and cost. Thus, designers turn to approaches, such as resonant converter topologies, that add significant complexity but also provide vital features, such as zero-current switching.

In parallel with the power path, the control subsystem regulates the output and manages each stage of the power path to ensure that faults, sudden load changes, or even short circuits will not lead to catastrophic failures. Power supply designers have employed a variety of feedback methods that use primary-side sensing or secondary-side sensing across the isolation boundary.

As with the power circuits themselves, high-voltage operation presents some unique demands on control-circuit design. For example, in high-voltage supplies, stored energy levels can be substantial, resulting in high-energy arcing—even in properly insulated designs. Although control circuits are designed to monitor voltage or current and suppress arcs when they arise,

the nature of the most suitable suppression method can vary significantly. If the arc-suppression response is too rapid, for example, additional arc events can occur in some cases. Consequently, high-voltage supplies might employ a variety of suppression profiles and automatically tailor the response as needed.



Figure 2: Large differences in electrical potential can suddenly discharge through ionized gas in the atmosphere or through paths to ground in circuits, resulting in electric arcs in nature and in high-voltage applications. Image credit: [pixabay.com](http://pixabay.com)

### High-voltage selection priorities

The significant differences in design between high-voltage and low-voltage supplies reflect the need to account for the variety of effects that uniquely arise in high-voltage circuits. In turn, these differences significantly shift the nature and relative importance of the characteristics commonly used to specify power supplies. Consequently, users can often find themselves reprioritizing characteristics, such as efficiency, size, and even cost, that can dominate the decision process in low-voltage supply selection.

To address high-voltage effects, designers rely on design methods that inevitably translate into larger, heavier power supplies and increased size and cost:

- isolation, insulation, and encapsulation techniques
- more robust filters for arc management and reducing energy storage
- enhanced thermal management methods
- high-performance, high-accuracy components

Furthermore, the need for more specialized devices and more precise components leads to essential features but also means higher cost. The nature of these designs also impacts final efficiency. Even with low-loss components and highly efficient design techniques, operation at high voltage and current levels contributes to increased power consumption in the final design. Although these supplies typically operate with reasonably high efficiency ratings, they are simply not able to reach the level found in more advanced designs for low-voltage supplies. The net effect of higher cost and

lower efficiency means that these supplies typically fall into much higher ranges for cost/watt than found in low-voltage supplies.

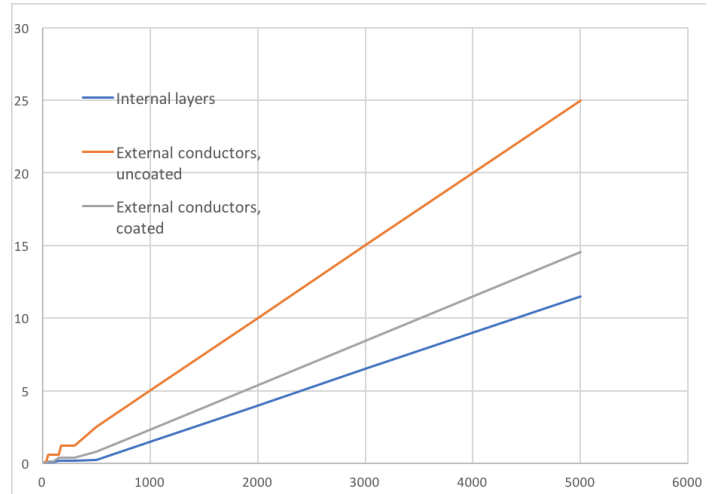


Figure 3: To reduce the chance of discharge between components as voltage increases, standard bodies specify increasing spacing requirements such as these for internal layers and external components. Image credit: IPC 2221B via [smppowersupply.com](http://smppowersupply.com)

Again, the broad implications of high-voltage operations and their associated design requirements mean that engineers cannot simply scale designs to higher output levels. Similarly, users cannot simply apply criteria considered acceptable in low-voltage supply selection to high-voltage systems. For example, one percent output ripple might be considered exceptional performance for a consumer power supply. Yet, for supplies intended to deliver output levels rated at tens of kV, one percent output ripple could compromise equipment with supply variations in the hundreds of volts. Similarly, relative noise levels that can be ignored in low-voltage supplies can significantly erode performance in high-voltage applications or compromise results in instrumentation systems.

### Key characteristics

Ultimately, the key characteristics of a high-voltage supply revolve around its output stability and reliability. Users are most interested in application-specific requirements that include:

- process stability
- output precision
- tunable performance functions

In the face of fluctuations in the input source, output loading, and temperature, advanced high-voltage supplies are able to maintain the required output level within a specified range of error. Even here, the unique nature of high-voltage supplies emerges: Because output can drift due to self-heating effects in components immediately following power up, manufacturers typically quote stability levels after a 30-minute warm-up period for this class of supply.

In an environment where even seemingly minor variations in performance can mean large changes in output, high-voltage supplies often distinguish themselves in their ability to maintain output despite load variation or temperature changes. In advanced supplies, control mechanisms maintain the specified output level despite changes in the load or in the input supply itself.

As with many aspects of high-voltage design, engineers can tune regulation to meet specific requirements for characteristics such as output variation and response time. Similarly, designers can adjust characteristics such as output error, temperature dependency, and long-term drift by incorporating components that feature greater accuracy, lower-temperature coefficients, and minimal drift—trading these performance characteristics for higher cost.

### Conclusion

Recognizing the unique effects of high-voltage operation—and the specialized nature of high-voltage supplies designed to address those effects—is of paramount concern for the user selecting the right standard high-voltage power supply. Basic performance criteria considered suitable for low-voltage supplies typically scale poorly, if at all, to high-voltage systems. In high-voltage circuits, even small percentage changes in performance characteristics can translate to unacceptable changes in output level. In this environment, high-voltage supply selection starts with matching application requirements with fundamental performance characteristics, including output level, stability, regulation, and protection. By focusing on these primary performance characteristics, users can find standard high-voltage power supplies that best match their unique applications.

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