

POWER CONVERSION CAPACITORS FOR HARSH ENVIRONMENTS

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Outdoor installations of power conversion systems are becoming more prevalent as the demand for EV charging, grid infrastructure and photovoltaic (PV) installations increases. According to the [U.S. Department of Energy](#), between 2015 and 2020, the number of electric vehicle supply equipment (EVSE) charging ports in the United States more than doubled, and strong growth continues (Figure 1). These projects require capacitors and other components to withstand a wide range of operating conditions, including temperatures upwards of 150 °C, high humidity and high vapor pressure.

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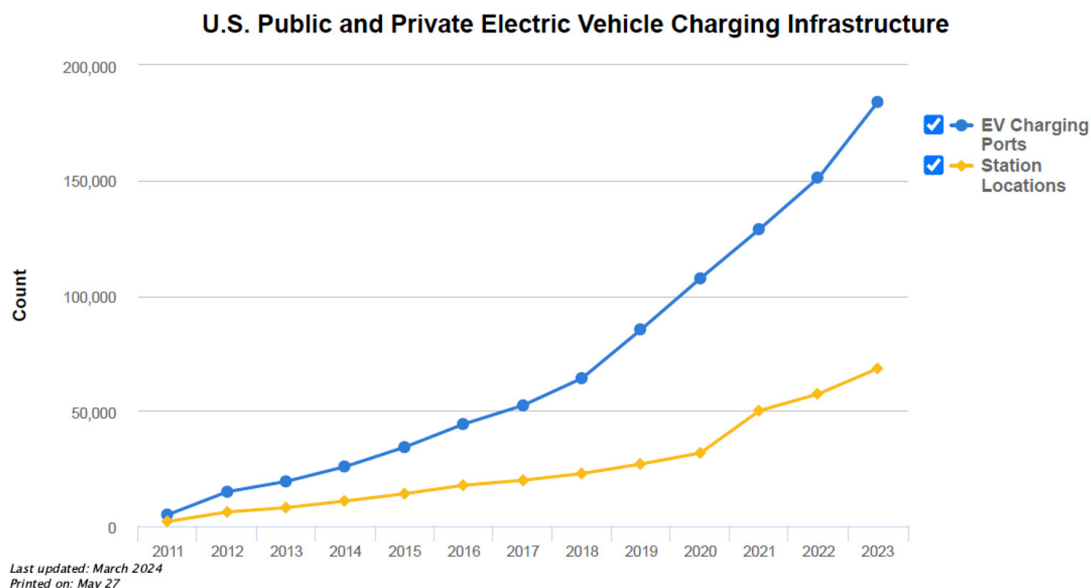


Figure 1. Chart showing the growth of public and private electric vehicle charging infrastructure in the United States starting in 2011. Source: [Alternate Fuels Data Center](#).

Here, we'll address the role of capacitors in power conversion circuitry, important characteristics for power conversion capacitors operating in harsh environments and trends in power conversion technology that result in greater stress on capacitors.

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Capacitors in Power Conversion Circuitry

Power conversion involves converting one type of electrical power into another (Figure 2). For example, converters convert AC to DC electrical power and inverters convert DC to AC electrical power.

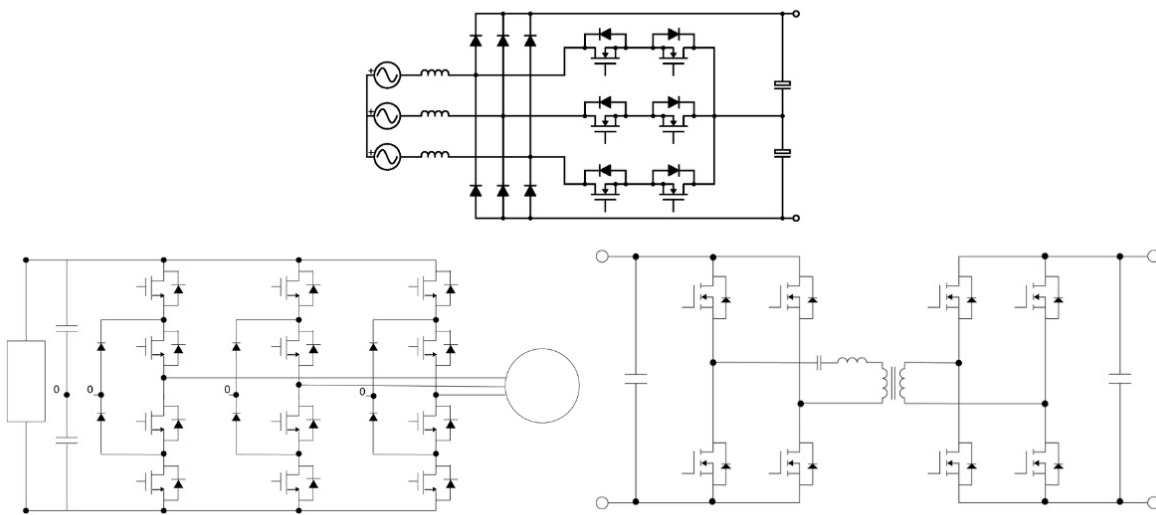


Figure 2. Power conversion is performed by a variety of converters that transform electrical energy from one form to another, including rectifiers (top), inverters (bottom left) and DC/DC converters (bottom right).

Capacitors serve a variety of critical functions in power conversion systems, but given their ability to store electric charge, they're essential for regulating and smoothing power flow.

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Here are four key capacitor types found in power conversion circuitry:

DC Link Capacitors

These capacitors, typically aluminum, electrolytic and film, function to smooth ripples during power conversion, store surplus energy and suppress voltage surges. DC link capacitors can be positioned between a rectifier and a DC/DC converter or between a DC/DC converter and an inverter, for example, to serve this balancing function on the DC voltage lines. They must be able to handle the high root mean square (rms) ripple that's associated with inverter switching and dissipate heat to prevent capacitor hotspots from destroying a switch.

AC Harmonic Filter Capacitors

High frequencies can cause harmonic distortion in AC power systems. Single and three-phase AC harmonic filter capacitors are designed to filter unwanted harmonics out of the inverter output, so the grid or load receives smooth, sinusoidal AC power. These capacitors have the effects of improving power quality, enhancing system efficiency and protecting electrical equipment.

Snubber Capacitors

Snubber capacitors (i.e., RC circuits, in conjunction with resistors) can be used to protect switching devices from overvoltage during switching functions. During switching, voltage spikes may exceed the switch's voltage rating, and snubber capacitors can absorb energy to reduce overshoot. When a switch opens and closes, the inductance opposes the rapid change in current. Higher inductance, or rapid changes in current, cause voltage spikes, so it's important to keep bus inductance low too.

In modern electronic systems with high-speed switching, snubber capacitors manage transients and reduce excessive ringing via damping. This function allows for faster and more efficient operation without compromising on reliability.

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AC and DC Input/Output Filter Capacitors

Input/output filter capacitors absorb energy and smooth voltage on the supply or load side. For example, in AC to DC conversions, AC filter capacitors can help smooth ripple voltage that appears after rectification by storing and releasing charge to even out the fluctuations. This results in a more stable DC output. They improve power quality, protect sensitive components and support more efficient power conversion.

Important Characteristics for Power Conversion Capacitors Operating in Harsh Environments

To best support power conversion systems that operate in harsh environments, capacitors must have the following characteristics:

- Higher operating temperatures
- Higher voltage ratings
- Lower inductance
- Higher temperature cycle life
- Small form factor
- Robust and stable operation over temperature, humidity and bias

When assessing your options, be sure to consider the following characteristics:

Thermal Management

Recent advancements in capacitor design have increased energy density, which reduces component footprint but increases heat. Exposure to high temperatures is a catalyst for capacitor aging. External capacitor cooling methods include convection, conduction and liquid cooling. Conduction is the main mechanism for removing heat from capacitors because of their material composition and compact design (i.e., large surface area relative to volume). However, liquid cooling is an active method of thermal management for reducing the internal temperature of a capacitor, which can be valuable in extreme heat.

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Packaging

By design, capacitor packaging offers various degrees of protection based on material selection. Standard metal- and plastic-cased components with epoxy fill offer moderate protection from moisture. Metal-cased capacitors with rolled seals are well-protected from moisture; however, metal-cased capacitors with glass-to-metal seals offer the highest level of protection due to the durability of metal casings and the impermeability, chemical stability and thermal stability of glass-to-metal seals. Material selection and processing is the biggest factor in determining whether packaging will enhance performance and withstand harsh environments or not.

Temperature, Humidity Bias (THB) Testing

THB testing exposes capacitors to real-world conditions and accelerates the aging process to understand potential failure mechanisms. They're subjected to high- and low-temperature cycles, moisture ingress and voltage bias to see how well they maintain their performance under electrical stress (Figure 3). Capacitors for power conversion in harsh environments are often subjected to IEC 60384 and/or AEC Q200 THB testing requirements.

	Temperature	Relative Humidity	Vr Bias Test?	Duration of Test
IEC-60384	85 °C	85%	Yes	1000 hours ¹
AEC-Q200	40 °C	93%	Yes	1000 hours

Figure 3. Temperature, Humidity Bias (TBH) testing conditions for two common standards for electrical equipment, IEC 60384 and AEC Q200.

¹ Varies according to grade: Parts are tested to 60384 Grade IIIB (1,000 hours), IIIB plus 500 hours (1,500 hours total) or IIIB plus 1000 hours (2,000 hours total)



Common Power Conversion Applications Employing Capacitors in Harsh Environments

As mentioned above, there are two notable applications that kick-started the proliferation of power conversion systems in harsh environments: the expanding networks of DC fast charging installations and the growing number of PV installations, both of which operate under challenging environmental conditions.

More Direct Current (DC) Fast Charging Installations

Electric vehicles (EVs) are designed with onboard chargers that convert AC power, the standard electricity distributed via power grids, to the appropriate DC power to charge the vehicle's battery. This typically involves an AC-DC converter (i.e., a rectifier) and a DC/DC converter.

DC fast chargers convert AC power to DC power before it even reaches the vehicle, bypassing the conversion steps performed by the onboard charger. In doing so, it charges the battery directly and significantly reduces the time it takes to charge the vehicle. The increasing availability of these chargers is expected to help increase EV adoption and decrease range anxiety.

DC fast charging requires higher power (i.e., up to 480 KW, in stacks of 40-50 KW modules) and higher voltage (i.e., 1000 Vdc). This is made possible in part by the faster switching speeds facilitated by the shift from silicon (Si) to switching devices with wide-band materials like silicon carbide (SiC). SiC devices have higher thermal conductivity and lower switching loss. Higher efficiency, increased power output and higher breakdown voltage make it possible to increase the efficiency and power density of inverters, on-board chargers and converters found in DC fast charging installations. The result is longer driving ranges and faster charging times.

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Growth in Photovoltaic (PV) Installations

PV systems include a series of solar panels, an inverter and accompanying electronics to convert sunlight into usable electricity. The inverter converts DC power to AC so it can be used for commercial and residential power.

Today, large solar plants are shifting their systems from a design that leverages one large central inverter (i.e., approximately 3.5MW) to multi-string configurations that rely on microinverters (i.e., approximately 250kW each). In traditional systems, solar panels are combined in parallel, so the inverter sees one combined DC voltage. Since each PV panel experiences different conditions and has a different optimal operating point, power can't be optimized panel-by-panel. Modular architectures are increasing reliability and uptime. This decentralized approach requires each inverter to have capacitors that manage power conversion and other inverter conditions, like DC link stabilization, at the local level. Capacitors in multi-string PV configurations are exposed to outdoor environments with thermal cycling, humidity and dust, which causes stress over time.

“In a PV system with a large central inverter, power can't be optimized panel-by-panel. Modular architectures offer a decentralized approach to increasing system reliability and uptime.”

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The Value of Extensive Capacitor Design and Manufacturing Experience

The support of an experienced capacitor design and manufacturing company with custom capabilities and extensive testing equipment is key to long-term success in outdoor power conversion systems. Every component selection makes a difference. At Knowles Precision Devices, our team of specialists covers the entire spectrum of AC to DC applications, and we're equipped for all forms of capacitor testing, including aerospace and medical.

★ MIL Certified Test Lab

★ Shock and Vibration

★ Thermal Cycling

★ Humidity Chambers

★ Solvent Resistance

★ 400 Hz Ripple Testing

★ Pulse Testing

★ Corona Testing

With decades of experience in high-reliability applications, we're uniquely qualified to support innovation and expansion in outdoor power conversion systems from a components perspective. For detailed specifications, review our [harsh environment capacitors page](#).