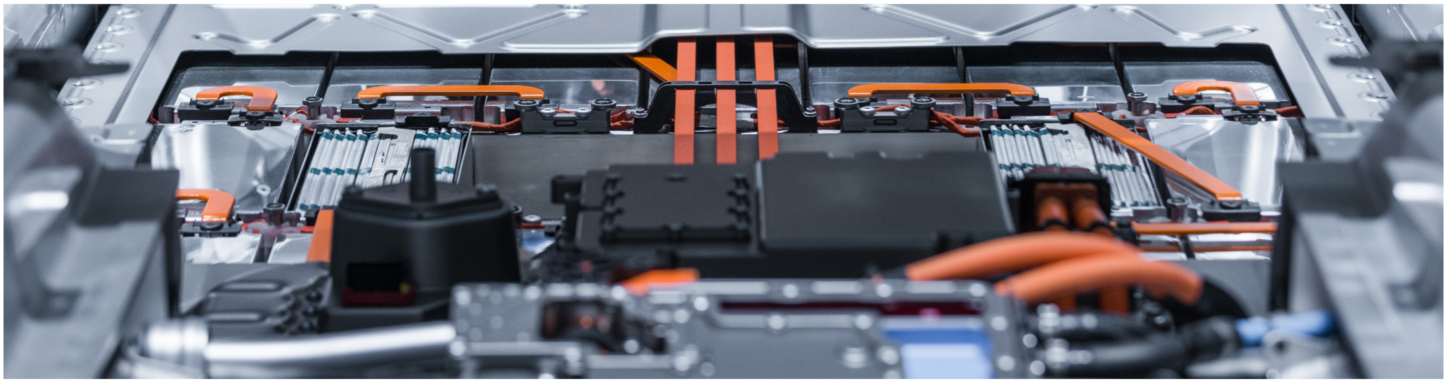
WHITEPAPER

Moving to Higher Voltages in Electric Vehicles: The Implications on Capacitor Selection



As countries around the world tighten emissions standards, the demand for fully electric vehicles (EVs) is increasing. However, for EVs to see mainstream adoption EV manufacturers must address the primary consumer concerns: longer driving ranges and faster charging. EV manufacturers are beginning to redesign their vehicles to make the switch from the 400V battery systems widely used today to 800V battery systems.

The 800V battery system offers twice the voltage and 2.7 times the power density compared to a 400V system, which translates to exactly what customers are looking for: the ability to drive further between charges and charge the batteries faster once required. And it's important to note that this move to higher voltage battery systems is happening fast. Currently, Hitachi Automotive Systems is starting mass production of its 800V battery system, while Porsche was recently the first manufacturer to include an 800V system in a production vehicle, the Taycan.

Just like engineers faced challenges when moving from the standard 12V batteries used in combustion vehicles to the higher voltage battery systems used in today's EVs, operating at 800V presents its own unique set of engineering challenges. This white paper offers a closer look at how operating at higher voltages is affecting the decisions EV designers and original equipment manufacturers (OEMs) must make to support the higher voltage systems. It also covers how component manufacturers down the supply chain are ensuring EV manufactures have the most reliable capacitor options available to meet the new challenges and regulations they face as operating voltages increase.

THE CHALLENGES PRESENTED BY HIGHER VOLTAGE EV BATTERY SYSTEMS

The higher the voltage, the more critical it is for EV OEMs to ensure they are using high-reliability components designed to withstand the higher voltages and temperatures sustained in these environments. Thus, OEMs need to prove they are designing well insulated, fail-safe systems that will contain electricity within the battery system under all circumstances. Since OEMs need to plan for worse-case scenarios, simply testing systems at or near the operating voltage of 800V is not enough. This results in one of the first major challenges both OEMs and suppliers face – components need to be subjected to testing at extremely high voltages, in some cases up to five times higher than the required operating voltage (Figure 1).

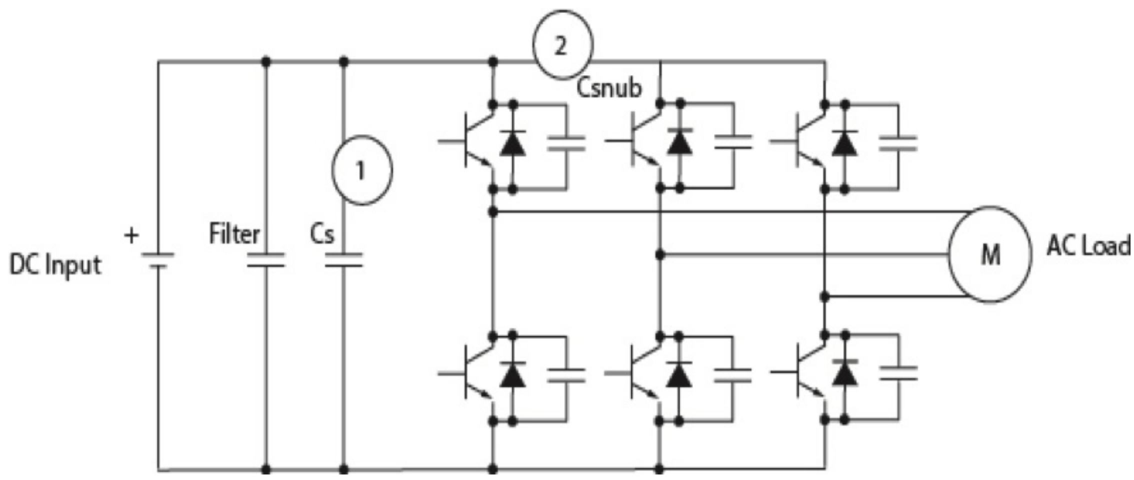


Figure 1. Circuits exposed to increased voltages, such as the DC-Link and snubber, need to be constructed with the voltage rating of the capacitors in mind.

Another challenge OEMs are faced with today is that the industry in general is moving toward making everything smaller and lighter to increase overall vehicle efficiency. However, operating at a high voltage requires physical space to avoid dangerous problems such as arcing. EV designers are facing competing demands to dramatically decrease the size and weight of systems while safely increasing voltages to address overall market demands and concerns. Other challenges, such as protecting against surge voltage and ensuring reliable and safe operation under high temperatures, also exist.

Let's further examine how these challenges are impacting the way OEMs select components, such as capacitors, and how suppliers are now needing to rethink the specifications of the capacitors they develop.

ENSURING EV SYSTEMS SAFETY AND RELIABILITY THROUGH HIGH-VOLTAGE INSULATION TESTING

To ensure safety, OEMs need components, including capacitors, rated to withstand much higher voltages than is required for normal operating conditions. Therefore, EV drivetrain reliability and safety testing is often conducted at voltages that far exceed what is needed for normal operation. For example, an OEM may require that a drivetrain running off an 800V battery system withstand tests of up to 4,000Vdc. In some cases, both the DC and AC voltage component ratings need to be considered closely and some OEMs may also demand testing of up to 2,000Vac 50Hz.

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One common test OEMs are required to perform is a high-voltage insulation test. The goal of this test is to ensure that if a failure occurs, all electricity will remain contained within the battery system and not affect other systems within the vehicle, or worse, cause a catastrophic consequence for drivers and passengers. The requirement of this high-voltage insulation test is one of the main factors driving the voltage ratings of capacitors up well in excess of the actual working voltage required.

In some instances, OEMs may choose to use a capacitor not rated for these higher voltages and "derate" the lifespan of the component to account for the higher voltage testing. However, the more reliable and better way to go about this is to never exceed the voltage rating of a capacitor, even for testing purposes, and use a capacitor that can withstand 4,000Vdc. As part of its mission to provide the most reliable capacitors available, Knowles Precision Devices is the first supplier to offer AEC-Q200 approved capacitors that support voltages up to 4,000Vdc.

MAINTAINING PROPER CREEPAGE DISTANCE FOR HIGH-VOLTAGE CAPACITORS

While the general trend in the automotive industry is to use components that are smaller and lighter to reduce the size and weight of vehicles, smaller is not always better when it comes to a capacitor. In general, there is a minimum distance that needs to be maintained between opposing polarities to avoid arcing that could result in dangerous sparking (Figure 2). There are also standards that require longer creepage distances with higher voltages.

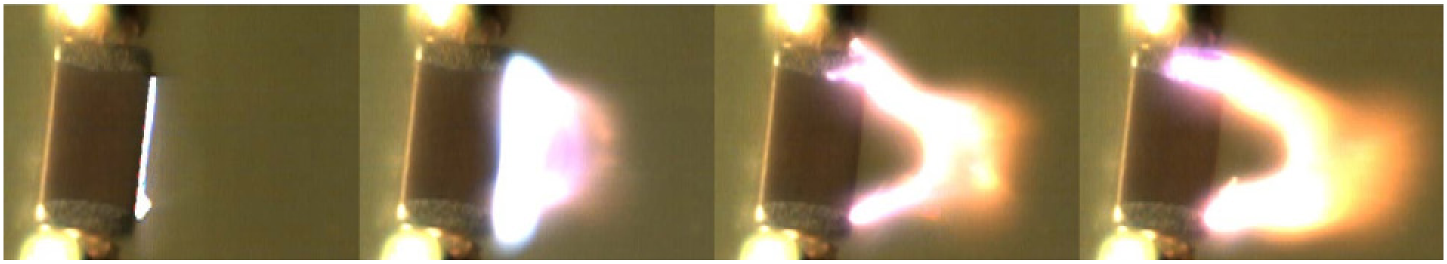

Figure 2. An example of an improper creepage distance that resulted in arcing.

To prevent issues with arcing, engineers need to consider the creepage, which is the distance across the capacitor surface between opposing terminations. As voltages increase, the creepage distance must also increase. A good rule to follow is that for every 1,000V, a minimum of 1mm of space should be provided. Thus, for 4,000V, the capacitor should be at least 4mm long, which is more than double the length of capacitors used today in traditional 12V systems.

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Voltage r.m.s. [1]	Minimum Creepage Distances								
	Printed Wiring Material								
	Pollution degree								
	1	2	1	2			3		
	All Material Groups	All Material Groups Except IIIb	All Material Groups	Material Group I	Material Group II	Material Group III	Material Group I	Material Group II	Material Group III [2]
V	mm	mm	mm	mm	mm	mm	mm	mm	mm
200	0,400	0,630	0,42	1,00	1,40	2,00	2,50	2,80	3,20
250	0,560	1,000	0,56	1,25	1,80	2,50	3,20	3,60	4,00
320	0,75	1,60	0,75	1,60	2,20	3,20	4,00	4,50	5,00
400	1,0	2,0	1,0	2,0	2,8	4,0	5,0	5,6	6,3
500	1,3	2,5	1,3	2,5	3,6	5,0	6,3	7,1	8,0
630	1,8	3,2	1,8	3,2	4,5	6,3	8,0	9,0	10,0

[1] This voltage is
- for functional insulation, the working voltage,
- for basic and supplementary insulation of the circuit energized directly from the supply mains (see 4.3.2.2.1), the voltage rationalized through Table F.3a or Table F.3b, based on the rated voltage of the equipment, or the rated insulation voltage,
- for basic and supplementary insulation of systems, equipment and internal circuits not energized directly from the mains (see 4.3.2.2.2), the highest r.m.s. voltage which can occur in the system, equipment or internal circuit when supplied at rated voltage and under the most onerous combination of conditions of operation within equipment rating.

[2] Material group IIIb is no not recommended for application in pollution degree 3 above 630 V.

Table 1. This table shows the creepage distance required by DIN EN 60664-1 to avoid arcing and failure.

When using a longer capacitor, a larger case is required to house these components. Unfortunately, as industry trends are moving toward using smaller and lighter components, many suppliers no longer supply larger cases. Knowles Precision Devices fully understands the importance of maintaining proper creepage distance in high voltage EVs and will continue to produce the larger case sizes that high-voltage EV OEMs need.

Addresssing Creepage Through Coating

There is a possible alternative to increasing the size of a capacitor to avoid issues with arcing at higher voltages. By using a coating, both creepage and arcing are changed since the terminations are no longer exposed. But this is not as easy as simply adding a layer of coating to an existing component. Since it is critical to ensure the coating material is under the chip as well, which is part of the requirements stated in IPC-610, this can change the entire design of a circuit. Between potential necessary design tweaks and the cost of coating in general, many OEMs do not consider this a practical option even though it would allow them to keep their designs smaller and lighter. However, if this is an option for you, Knowles Precision Devices is an expert in designing and coating circuit board assemblies.

PROTECTING CAPACITORS FROM SURGE VOLTAGE AND HIGH OPERATING TEMPERATURES

In EV subsystems, insulated-gate bipolar transistors (IGBTs) are three-terminal power semiconductors that are commonly used as fast and efficient switches for power electronics applications such as inverters, converters, and power supplies. When one of these switches is opened, it intrinsically induces a high voltage, or surge, across the device. EV design engineers need to consider the impact of this voltage surge on the system and take this voltage into account on top of any DC rating for a capacitor.

One way to reduce the effects of surge voltage is by using a snubber, which is an energy-absorbing circuit designed to protect electronics from voltage spikes and transients (Figure 3). The snubber provides an alternate flow path for the excess energy to be absorbed by the snubber capacitor and dissipated by a resister or other load.

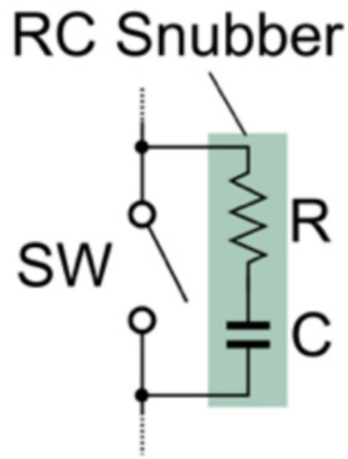

Figure 3. A depiction of a basic snubber circuit. (Source: Wikipedia)

Given that IGBTs and power modules are found everywhere in EVs, it's critical for designers to select the right high-voltage snubber capacitor that meets the application requirements and industry certifications such as AEC-Q200. Knowles Precision Devices recommends using the 600V-2kV nF-µF C0G or X7R capacitors to meet these requirements and provide the following benefits:

- High allowable voltage operating at high frequencies (100 kHz and above)
- Low equivalent series resistance (ESR)
- Low loss factor
- Low self-heating
- High allowable power capacity

Protection from High Temperatures

Traditional Class I and Class II piezo dielectric materials have temperature rating limitations that can lead to piezo-resistive cracking when limits are exceeded. Because of the high-temperature environment naturally found in high-voltage EV applications, Knowles Precision Devices' material scientists developed a proprietary non-piezo material known as Hiteca, which is a strontium bismuth ferrum titanate (SBFT) ceramic.

Compared to standard Class II materials like X7R, this low-loss, semi-stable Class II dielectric features high capacitance at the maximum operating voltage, improved capacitance stability, low ESR, low equivalent series inductance (ESI), and a 0 percent aging rate with no loss of capacitance over time. SBFT capacitors are made with 100pF to 2.2 μF capacitance range, 450 to 1000 VDC voltage ratings, and -55 to +125°F operating temperature. At 2.5 to 4 mm thickness, components made with Hiteca help enable the design of smaller, lighter power modules without the need for active cooling systems.

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MEETING ALL THE DEMANDS OF HIGH-VOLTAGE EV SYSTEMS WITH KNOWLES PRECISION DEVICES CAPACITORS

Knowles Precision Devices also offers larger case sizes to provide proper creepage distances and avoid possible safety hazards with arcing when higher voltages are used. Additionally, Knowles capacitors are safety rated, which means that if a failure does occur, the capacitors are guaranteed to fail in a way that is non-catastrophic for the system and users.

One more way Knowles Precisions Devices guarantees the reliability of their capacitors is by using FlexiCap terminations. FlexiCap is a proprietary flexible epoxy polymer termination material that is applied to the device under the usual nickel barrier finish. MLCCs built with a FlexiCap termination accommodate a greater degree of board bending than conventional capacitors, resulting in a higher resistance to mechanical cracking, and therefore are more reliable.

In the end, Knowles Precision Devices has the capacitors EV OEMs need to meet the growing demand for EVs to operate at higher voltages while still guaranteeing reliability and safety.

Use the Knowles Precision Devices' part builder to customize the perfect capacitor for your high-voltage EV application.

Use Part Builder

ABOUT KNOWLES

Knowles is a specialty components manufacturer, which means we choose to take on the complex challenges that come with high reliability, high temperature, high performance, and high frequency solutions. Our products can be found in every corner of the world, from 8,000 ft below the earth's surface to orbiting 254 miles above us on the ISS. Knowles Precision Devices is a premier global source for Capacitors, RF Filters, EMI Filters, Resonators, non-magnetic components and advanced dielectric materials. An umbrella for the brands of Compex, DLI, Johanson MFG, Novacap, Syfer and Voltronics, Knowles Precision Devices serves a variety of markets including military, aerospace/avionics, medical equipment, implantable devices, EMI and connector filtering, oil exploration, instrumentation, industrial electronics, automotive, telecoms and data networks.

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