Electronic Components KEMET CHARGED.

Power Conversion with Film Capacitors

INTRODUCTION

Film capacitors have been around for a long time, but new technologies and processes have enabled big leaps forward in the capabilities of these tried and true devices. Higher capacitance densities, frequencies, environmental ratings, and life expectancies are all being realized. Today's power film capacitors are the ideal solution for power conversion in sustainable energy, energy storage, industrial, or automotive applications.

POWER CONVERSION EXPLAINED

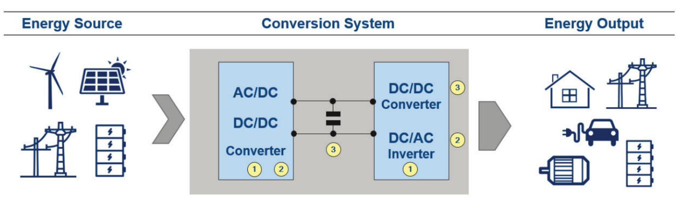


Figure 1: Energy Conversion Model

Power conversion circuitry takes energy from a power source and converts it into an output format usable by end devices. Energy sources could be the traditional power grid, renewable energy generators like solar or wind, or stored energy in batteries or capacitor banks. Those sources provide energy that is not conditioned for end devices, but rather it is conditioned for transmission or the raw output from the source.

Power conversion systems have an input stage, where the power is converted from AC or DC to the desired DC level, and then an output stage where the DC voltage is converted to the AC or DC level required by the end devices. These systems also include an intermediate stage where the DC-link capacitor, or capacitors, reside. The DC-link capacitor is responsible for filtering the voltage to provide a clean, consistent energy source to the output stage.

In each stage, input and output, pulse snubber capacitors (1, in Figure 1) are used to suppress undesirable voltage pulses. In either the input or output stage, if AC voltage is coming in or going out, you will find AC filter capacitors (2, in Figure 1). And in all power conversion circuits you will find DC filter or DC-link capacitors (3, in Figure 1) in the input or intermediate stages. DC filter capacitors may also be found in the output stage, if it is a DC/DC converter stage.

DESIGNING PARTS IN SPECIFIC APPLICATIONS

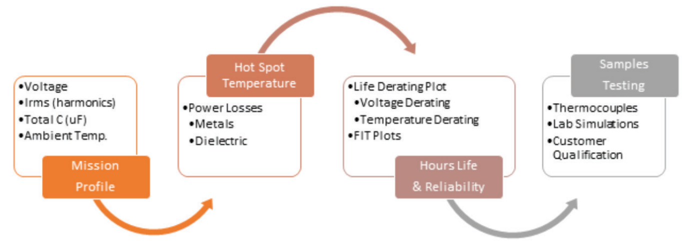


Figure 2: The design process for a DC-Link or AC filter capacitor

The first step of the design process is selecting the right part that meets the design needs. Once the part that meets the voltage, current, capacitance and temperature requirements is identified, the next step is to analyze the design for the capacitor's hot spot temperature. Next, the designer should calculate the necessary deratings and the expected lifetime and reliability. And finally, the parts should be tested and qualified in the application.

DC-LINK CAPACITORS

Capacitors in the DC circuits at the output of either the input or output stages of a converter are called DC-link capacitors. These serve as filters on the DC voltage, as well as energy storage capacitance to provide instantaneous current to all downstream circuits. They can also be used in certain applications to store energy for failsafe power loss operations.

DC-link capacitors need to be able to withstand high power, high ripple currents, and many charge/discharge cycles.
They need to do this reliably and safely in extreme conditions, since a lot of these power converters are found in windmills, solar farms, and other renewable energy source circuits.

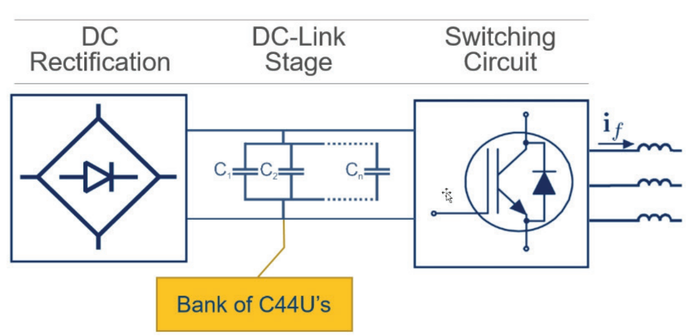


Figure 3: KEMET's C44U-M capacitors in a DC-link application

Traditionally, electrolytic capacitors have been the choice for power conversion applications due to their low cost per capacitance. But because of the increasing needs of higher ripple current and higher voltages, film products are becoming more attractive in this application. More power conversion systems in green energy are now managing voltage ranges up to 1,500 VDC in their DC-Link bus stage and 600 VAC outputs. This trend is forcing the designers to consider more and more film technology because of the advantages that bring to their design, including:

- Lower DF = lower ESR = low losses; higher current ripple current capability
- Dry Construction = no concern for evaporation and C and DF degradation in time = Extended life without needing replacement or continual maintenance and monitoring.
- Higher voltage = Reduce the need for capacitors in series; no need for balancing resistances (less losses and control); more cost-space efficient.

APPLICATION EXAMPLE FOR DC-LINK FILM CAPACITORS IN POWER CONVERTERS

For this application, we will assume the designer of the circuit has selected a 320uF capacitor (KEMET part number C44UQGT6320M83K). We will also assume an application ripple frequency of 10kHz, and an Irms application current of 46A, and an ambient temperature maximum of 40°C.

To calculate the life expectancy, we must first calculate the hot spot temperature.

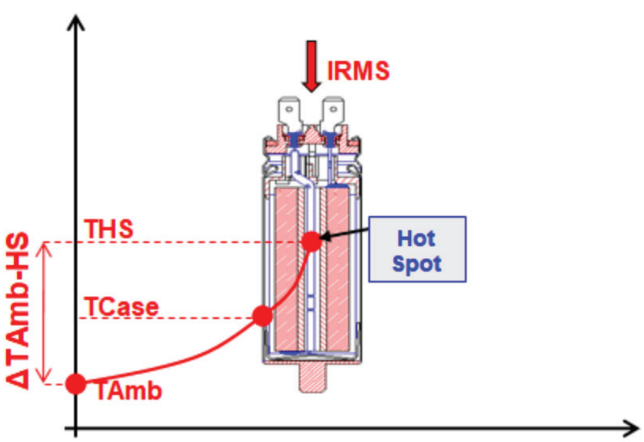


Figure 4: Hot Spot Calculation

The hot spot temperature calculation is given by the following equation:

$$T_{HS} = T_{amb} + R_{th} * (I_{rms}\text{^}2) * ESR$$

$$T_{HS} = 40°C + 5.8\ °C/W * (46\text{^}2) * 2.4m\Omega = 69.5°C$$

Because the hot spot temperature is below the maximum reference temperature of 70°C, this application is acceptable. And from the datasheet, we can see that the expected life at a hot spot temperature of 70°C is 100,000 hours.

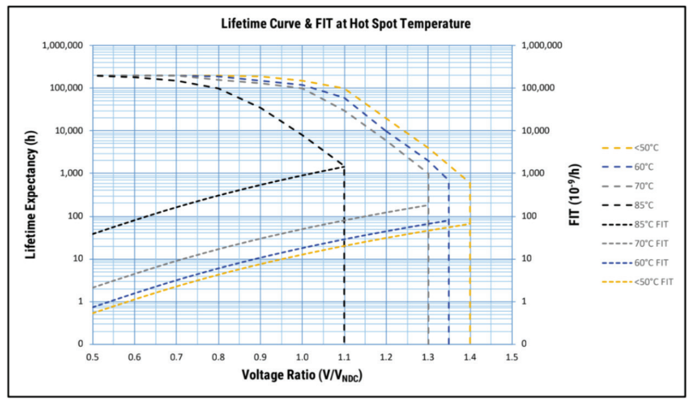


Figure 5:C44U-M Lifetime Curve at Hot Spot Temperatures

AC FILTER CAPACITORS

Capacitors placed on AC voltage lines to filter them are called AC filter capacitors. On three phase AC power lines, these capacitors can be placed in either a delta or wye configuration. In a delta configuration, the capacitors are connected between the different phases, but in a wye configuration the capacitors are connected between each phase and a central point. This neutral point is sometimes connected to ground or sometimes left as a floating neutral, depending on the system design.

These capacitors provide filtering for the AC voltage lines. Because these are large devices that can be found on high power lines, one of the most important requirements for these types of devices is safety. They need to be highly reliable and completely safe.

PART NUMBER	C µF	U_{NDC} Vdc	dV/dt V/µs	Ipkr Apk	ESL nH	ESR @10kHz mΩ	Irms* 40°C@10kH z Arms	Rth hs/amb °C/W	DIMENSIONS (mm)			SPQ pcs	W kg
									Ø	H	H1		
C44UQGT6320M83K	320	1100	9	2835	50	2.4	46	5.8	85	124.5	126	5	5.1

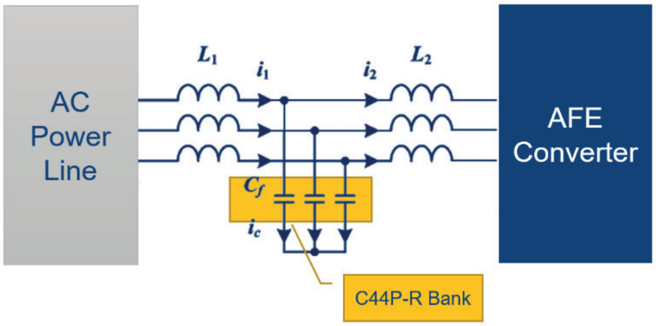


Figure 6: KEMET's C44P-R capacitors in an AC filter (wye config) application

KEMET's new C44P-R series AC filter capacitors represent a step forward in technology. They have a high current capability and a long life expectancy. They are metalized film capacitors that are self-healing - in the case of a dielectric breakdown, the arc energy is enough to close the channel, resulting in a self-healed device at the cost of just a small capacitance drop. These capacitors are also constructed with an overpressure safety mechanism. When the internal oil in the capacitor can expands due to heating, the can elongates and disconnects the terminals. When the temperature decreases, the contacts are reconnected.

APPLICATION EXAMPLE FOR AC FILTER FILM CAPACITORS IN POWER CONVERTERS

For this application, we will assume the designer of the circuit has selected a 100uF capacitor (KEMET part number C44PK-GR6100RASJ). We will also assume the following:

Fundamental frequency, F_1 = 50Hz
Application ripple frequency, F_2 = 7kHz
RMS application current, I_{RMS} = 30A
Ripple current, I_2 = 27A
Ambient temperature maximum, T = 39°C

Again, to calculate expected life, we must first find the hot spot temperature. For AC applications, the hot spot calculations are a little more complicated because we need to sum all of the dielectric power losses with all of the joule power losses to find the impact of the power dissipation on the hot spot. Dielectric and Joule power losses are given by the following equations.

1. Dielectric Power Losses

$$P_D(f_i) = 2 * \pi * f_i * C * V(f_i)^2 * tg\delta_0$$

which can be alternatively calculated as

$$P_D(f_i) = \frac{I(f_i)^2}{2 * \pi * f_i * C} * tg\delta_0$$

where: $tg\delta_0 = 2 * 10^{-4}$

2. Joule Power Losses:

$$P_J(f_i) = Rs * I(f_i)^2$$

And then the total power is the sum of all individual dielectric and joule power losses, as follows:

$$P_T = \sum_i [P_D(f_i) + P_J(f_i)]$$

Once the total power (P_T) is determined, the hot spot is calculated by adding the delta temperature contributed by the power dissipation to the ambient temperature, as given by the following equation:

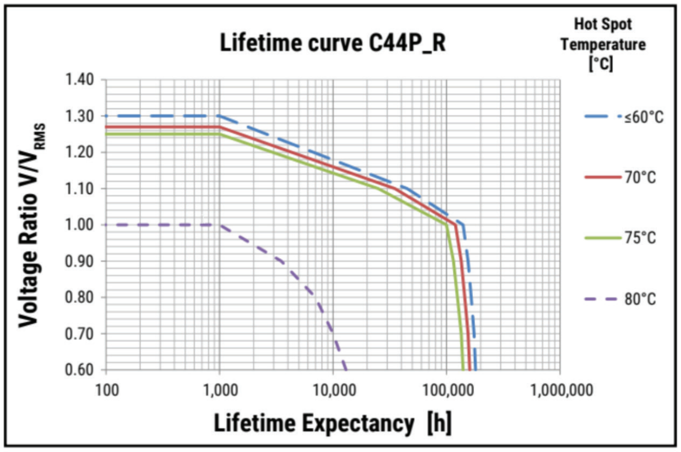
$$T_{HS} = T_a + P_T * R_{th}$$

Applying these equations to our application as defined above, and utilizing the numbers found in the datasheet for the selected component, we get the following results:

P_D(50Hz) = 2 * π * 50 * 100 * 10-6 * 4402 * 2 * 10−4 = 1.22 [W]
P_D(7,000Hz) = [272/(2 * π * 7,000 * 100 * 10−6)] * 2 * 10−4 = 0.03 [W]
P_J(50Hz) = 2.7 * 10−3 * [(2 *π * 50 * 100 * 10−6 * 440)2] = 0.52 [W]
P_J(7,000Hz) = 2.7 * 10−3 * 272 = 1.97 [W]
P_T = 1.22 + 0.03 + 0.52 + 1.97 = 3.74 [W]
T_{HS} = 39 + 5.7 * 3.74 = 60 [°C]

Expected Life at T_{HS} = 75°C → 100,000 hours (see lifetime curve)
Expected Life at T_{HS} = 60°C → 140,000 hours (see lifetime curve)

Cap Value (µF)	V_{rms}	Rated Voltage	Surge Voltage	Maximum Dimensions (mm)		I_{rms} at 10 kHz, 40°C	R_s	ESL	Thermal Resistance	dV/dt (V/µs)	Part Number
	VAC	VDC	VDC	D	H	(A)[1]	(mΩ)	(nH)	(°C/W)		
100	440	1,000	1,500	75	147	30	2.7	145	5.7	20	C44PKGR6100RASJ



KEMET'S POWER CONVERSION CAPACITOR SOLUTIONS

KEMET's new film capacitors for power conversion meet the needs of today's most demanding applications. The whole package of the R75H pulse snubbers, the C44P-R AC filters, and the C44U-M DC link capacitors provide the full capacitance solution for power converters in any environment.

To learn more, visit KEMET's website at https://www.kemet.com/en/us/applications/power-conversion.html

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