POWER ELECTRONICS TECHNOLOGY

Select Power Film Capacitor Terminations to Fit Application

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By Mark Gebbia, Illinois Capacitor, Lincolnwood, Ill.

Match the capacitor terminations with the requirements of the mating device.

You should limit thermal dissipation to a maximum of 15°C above ambient, and at no time should it exceed the maximum temperature rating of the capacitor.

Film capacitors have been rapidly evolving to satisfy a growing variety of applications. A hot area for development has been an ever-changing variety of terminations to accommodate the continuously changing requirements for mounting capacitors. Having a good match between terminations and the mating device is more than a convenience. It improves current handling, speeds assembly, saves space, improves mechanical reliability and can even improve heat dissipation.

The variety of film capacitor terminations to consider is especially apparent in snubber applications for IGBTs. Present day IGBT collector-to-emitter spacing now ranges from 20 mm to 65 mm, requiring the snubber capacitors to be able to connect to this wide range of spacing when mounted directly to the IGBT module. Other physical restraints add to the need for a large variety of terminations and body styles for direct mount, RCD (resistor-capacitor-diode) type snubber circuits. This includes p. c. board mount and mounting directly to bus bars.

For years, manufacturers have produced film capacitors in axial and radial lead configurations with two leads. More recently, manufacturers developed standard radial-leaded capacitors with four leads, solder lugs, spade and screw lug terminations along with numerous custom terminations. Although it's desirable to have a wide variety of termination and capacitor elements, this can complicate the process of selecting which capacitor termination style will best meet the design requirements. *Fig. 1* shows the broad range of available terminations.

Before selecting the termination style, the designer must first select the capacitor dielectric material. This is actually quite simple since there are only two commonly available film dielectrics — polyester and polypropylene. Capacitor manufacturers use polypropylene extensively in the majority of power capacitors applications. Polypropylene offers the best combination of characteristics needed in power applications.

- Low ESR over a wide frequency range
- Stability with temperature and frequency
- High pulse carrying capabilities

- High ripple current capabilities

You will find that although polyester is a more cost effective and volumetrically more efficient dielectric material its electrical characteristics are less than desirable in power applications, so it's only used in very special applications. Another area of confusion comes from the construction types available. Film capacitors for power applications come in one of two basic construction formats. They are noninductively wound film/foil construction and metallized film construction. A variety of combinations and variations of the two basic constructions are available for the ever-changing requirements these capacitors have to meet.

Metallized Dielectric

Manufacturers have made one variation that has grown in popularity by taking a metallized film and increasing the metallization edge thickness. Commonly called reinforced, this construction decreases the contact resistance between the end sprays and capacitor electrodes. This simple modification to the electrode construction allows the pulse current and ripple current-carrying capabilities of the capacitor to be increased while the physical size of the capacitor is minimized. You can use capacitors with this type of construction in high frequency filters as alternatives to aluminum electrolytic capacitors, which can't be used at frequencies above 100 kHz.

In power applications, the preferred construction type is a double-metallized electrode, with and/or without internal series connections. Double-metallized capacitors give the designer the best combination of properties offered by both film/foil and metallized film capacitors. Capacitors produced with double-metallized electrode construction are characterized by current capabilities and pulse current ratings similar to film/foil capacitors, but with the self-healing properties of metallized film capacitors. Although film/foil construction gives the best current carrying capabilities, it doesn't have the self-healing property of metallized film capacitors. The self-healing property of metallized films is fundamental in power applications. The lack of a self-healing property is a major drawback to using film/foil construction, because if the capacitor should fail, it will become a short circuit. In that situation, all the energy stored within the capacitor will discharge very quickly into the system, which in turn can cause severe damage to sensitive circuitry.

Lead Style

After dielectrics, engineers must choose the lead style that will optimize circuit performance, a critical decision in capacitor selection. While there are many variations, designers have five basic lead styles to choose from:

- Standard two-lead devices both axial and radial.
- Axial-lead lug terminals
- Four-leaded radial box capacitors (see *Photo 1*).
- Spade-lead box style capacitors (see *Photo 2*).
- Lug-leads for direct mounting (several styles are available) (see *Photo 3*, on page 20).

Each type has its own advantages and disadvantages, which can directly affect the capacitors performance. *Table 1*, on page 18, compares the characteristics of capacitors with different lead styles.

One of the limiting factors in each lead style is the current carrying limitation of its terminations. The size of the lead wires or lug terminals is the largest factor.

Two-leaded capacitors are generally limited to $12A_{rms}$ with lead wire diameters of 1.2 mm being the largest. Attempting to mount very large diameter wires to the capacitor element to increase the current carrying capability can lead to poor or weak connections to the end terminations or damage to the capacitor element from overheating during the lead mounting process. In either situation the capacitor will have reduced current carrying capabilities and higher ESRs.

Axial-leaded lug terminal capacitors allow increased current carrying capabilities and lower ESRs compared with their standard wire counterparts. Axial-lug terminal capacitors have current ratings as high as $30A_{rms}$ and typical ESRs as low as 6mΩ at 100 kHz. You can use these capacitors for mounting to bus bars when placing capacitors between the buses.

Two-leaded radial capacitors have the same limitations as their axial-leaded counterparts with box style capacitors having the benefit of additional vibration tolerance. To increase the capabilities of these capacitors, you could mount solder lug or screw lug terminations to these capacitors. Lug terminations that offer superior electrical characteristics come with a 40% or more cost premium.

A better and more cost-effective alternative is to mount a second lead wire to each end of the end terminations. This increases the current carrying capabilities of the capacitor and also helps to reduce its ESR and self-inductance. A four-leaded capacitor is more resistant to failure from vibration due to the second lead wire on each end adding strength to the solder connections as well as restricting capacitor movement.

Historically, capacitors with four leads (*Photo 1*) have had longer lead times and a higher rate of production failures. They were produced by hand and prone to overheating during lead connection, resulting in a large number of damaged capacitor elements during production. Advances in production technology have reversed this trend. Now, you can find four-leaded capacitors produced in large volumes with very low production failure rates. This is in part, a result of design standardization allowing manufacturers to produce four-lead capacitors on automated production lines. Four-leaded capacitors can reduce the ESR of a capacitor by 20% and increase the current carrying capability to as high as $22A_{rms}$, which is nearly double that of a two-leaded capacitor.

Lug-Mount

In applications where extremely high currents and low ESRs are required, screw-mount lug or circuit board mountable spade-lug terminals have been developed. Spade (*Photo 2*, on page 17) terminal capacitors have all the characteristics of screw lug terminal capacitors coupled with the solderability of leaded capacitors.

Screw-mount lug terminal capacitors (*Photo 3*, on page 20) offer the largest variety of terminations with each termination style allowing the designer flexibility in the characteristics and orientation of the capacitor. Screw-mount terminals are ideal for mounting to power modules where low contact inductance is critical. Depending on the type of lug termination selected, the designer can mount the capacitors where the space above the bus bars or power modules needs maximized or minimized. Screw lug styles allow the capacitors to mount directly to IGBTs or other power modules with terminal spacing as wide as 65 mm without the capabilities of the capacitors being reduced or compromised or the introduction of lead wires, which would add inductance to the circuit.

Besides the advantages described, capacitors with lug terminations deliver some of the best performance characteristics. These type of capacitors offer capacitance values ranging from 0.047 μF up to 60 μF in a single package, with voltage ratings as high as 3000Vdc/750Vac. Current carrying capabilities of $32A_{rms}$ per capacitor and pulse ratings up to 1600V/msec have been achieved.

Evaluate all power applications thermal dissipation within the capacitors. Too much internal heating causes capacitors to overheat and result in premature failure. You should limit thermal dissipation to a maximum of 15°C above ambient, and at no time should it exceed the maximum temperature rating of the capacitor.

By approaching the film capacitor selection process in a structured manner, it's certainly not overwhelming. Once the operational parameters that the capacitor must meet have been determined, selection of the right capacitor becomes a straightforward process of elimination. For example, if your design requires a single capacitor that can carry 25.5A_{rms}, eliminate two-leaded and four-leaded capacitors from further consideration. You are now limited to spade or screw-mount lugs terminal capacitors. For simplification, you can assume polypropylene dielectric and double-sided metallized electrodes.

Although we haven't addressed all electrical and environmental requirements a capacitor may need to comply with, you should evaluate these as you would when selecting any capacitor. If you have any doubts, you can always contact the capacitor manufacturer and ask for their advice. They should be able to simplify the selection process even faster and reduce the likelihood of the capacitor failures during prototyping and production cycles; and ultimately reduce the probability of field failures.

It should be apparent that designers of power systems utilizing power film capacitors have a larger-than-ever selection of capacitor body styles and terminations to choose from. When engineers remain informed to the options available and consider the merits of each, they have the opportunity to enhance the reliability of their products and speed the assembly process. While catalogs have been a time-tested way to tap into this knowledge base, the latest capacitor manufacturers' Web sites simplify this process even further. It's also the best way of gaining access to the most current product data.

References:

1. *Illinois Capacitor Catalog*

2. *Icel Catalog*

3. *Eric Motto, Powerex and Mark Gebbia, Illinois Capacitor Inc., "Snubber capacitor size and characteristics affect high power IGBT module performance," PCIM magazine, June 1994*.

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