Power Film versus Aluminum Electrolytic Capacitors

DC Link Capacitors for Inverter Applications

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Power Film Capacitors Versus Aluminum Electrolytic Capacitors for DC Link Applications

Replace Aluminum Electrolytic with Power Film?

- Film capacitors are not recommended as a one-for-one replacement of aluminum electrolytics.
- Considerations for new designs
  - Capacitance required for bulk storage
  - Ripple current requirements
  - Voltage requirements
  - Life and Reliability
  - Cost

Film capacitors are not recommended as one-for-one replacements of aluminum electrolytic capacitors. There are considerable mechanical and electrical differences. Switching from one technology to the other requires a new inverter topology. The design engineer must consider requirements for Capacitance, Ripple Current, Voltage, Life and Reliability, and Cost for new inverter designs.

DC LINK CAPACITORS

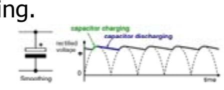
DC LINK CAPACITORS: Film Versus Aluminum

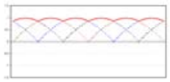
CHARACTERISTIC	ALUMINUM	FILM
Capacitance	High (3X Film)	
ESR mΩ	10X-15X ESR of Films	<2.0 mOhms typical
Operating Temp Rating (with full ripple)	105°C Max	85°C Max
Ripple Current @ 85C	1/2X Film	2X aluminum
Voltage	550 Vdc (max)	Up to 1500 Vdc. Eliminates the need for capacitors in series and balancing resistors.
Resistance to Overvoltage	50 V surge	1.5 X rated for 10 s
Failure Mode	rupture	fail open mode
Construction	Liquid Electrolyte	Dry, no liquid electrolyte
Polarity	Must observe polarity	Non Polar

This table compares aluminum and film capacitor electrical performance, energy density, failure modes and other considerations

DC Link Capacitance

- Aluminum Electrolytics have up to 2-3x the energy density of films.
- Applications such as UPS and Motor Drives generally require high capacitance for peak load requirements and voltage "ride through".
- Single phase versus three phase
  - Three phase requires less capacitance for smoothing.


Single Phase Rectification


Three-phase full wave rectification

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Some applications such as UPS and Motor Drives need high capacitance DC Link for bulk storage to handle peak loads or to prevent voltage sag at the output. Aluminum electrolytic capacitors have higher energy density and are generally used where high bulk storage is required. Wind and solar energy inverters typically don't require as much capacitance for the DC Link. More than 50% of wind energy inverters use film. Most new wind inverter designs are using film. Solar energy inverters , especially utility scale use films for the DC Link, while residential solar inverters use mostly aluminums.

DC Link Ripple Current

- Film capacitors have approximately 2x-3X the ripple current density of aluminum electrolytics <85°C
- Some applications use large banks of aluminum caps just to handle the ripple.
- If ripple current is the driver, film capacitors may be the best choice for the DC link.

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Aluminum Electrolytics have about 10x-15x the ESR of Film capacitors. Film capacitors have lower internal power loss for the same amount of ripple current. Some applications use large banks of aluminums just to handle the ripple current. Film capacitors are most economical where high ripple and low capacitance is needed.

DC Link Voltage

- Bus voltage exceeding 550 Vdc require at least two aluminum electrolytic capacitors in series.
  - Requires balancing resistors.
- Standard Film caps up to 1500 Vdc. No need to put them in series.
- Aluminum Caps can handle 50V surge above rated voltage. Film caps can handle 1.5x Vr for 10s

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Inverters with bus voltage exceeding 550 VDC need a series-parallel combination of aluminum caps to handle the voltage and ripple requirements. Balancing resistors are typically used to share the voltage equally across capacitors in series. Standard DC Link Film capacitors are available up to 1500 Vdc.

DC Link Life and Reliability

- Both film and aluminum electrolytic capacitors are highly reliable when manufactured properly and applied correctly.
- Lifetime for film and aluminum electrolytic can be estimated from life models.
- Film capacitors are self healing, some are protected.
- Use of fewer film capacitors for the DC Link can increase system reliability

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At the component level, both aluminum electrolytic and film DC Link capacitors are highly reliable and offer considerable life at rated conditions. Life models and calculators are available for both technologies. Life can be extended significantly through voltage derating and by keeping the capacitors cool. System reliability on the other hand can be greatly impacted when the DC Link is comprised of a large number of capacitors are banked together. Series-parallel banks of aluminum electrolytics are prone to failure if a single capacitor fails. Failure mode is an important consideration. Film caps generally fail open. Aluminum caps can fail short, explode and may cause significant damage to other components.

Cost for Energy vs Ripple Current ($/J vs $/A)

For rectified 440 Vac bus capacitors typical costs are

	Per Joule	Per Ampere
Film	20¢–50¢	$1
Electrolytic	5¢–10¢	$3

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Noteworthy fact: Most aluminum electrolytic applications use more capacitance than necessary, and many film applications use more ripple capability than needed. This is due to design requirements, the intrinsic relationship between stored energy and ESR of the capacitor dielectric, thermal conductivity, and economic constraints imposed by the above costs. In general, the lower cost per joule gives aluminum electrolytics the advantage in high-energy, high capacitance systems, and high ripple current gives power film the advantage.

Hidden costs

Other cost considerations are:

- Assembly time of multiple capacitors and resistors
  Films are simpler to connect, usually no need to insulate cans or use sharing resistors
- Voltage-sharing resistors for series-capacitor banks
  Electrolytics need to be connected in series and generally require divider resistors
- Cost of more complex bus structure for series designs
  Electrolytics need more elaborate and costly bus work
- Failure mode and incidental damage
  Electrolytics may cause concomitant damage when they fail
- Total size and weight of capacitor versus bank
  Films are smaller and lighter for a given amount of ripple handling at low ambient temperatures, while electrolytics are smaller and lighter for a given energy storage
- Power dissipation of capacitor
  Films generally produce less heating

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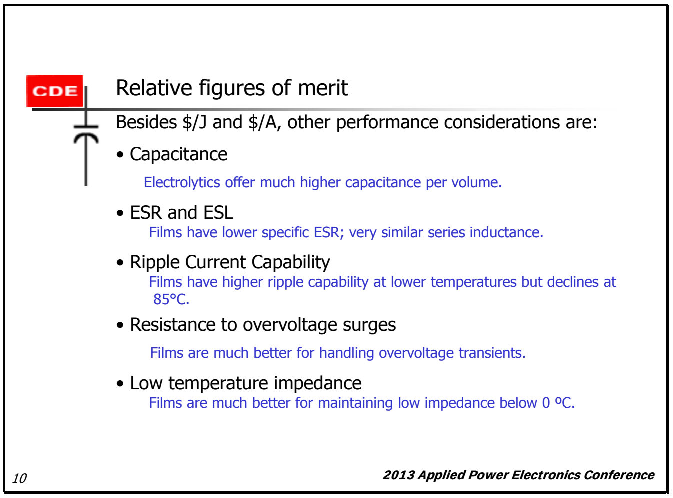
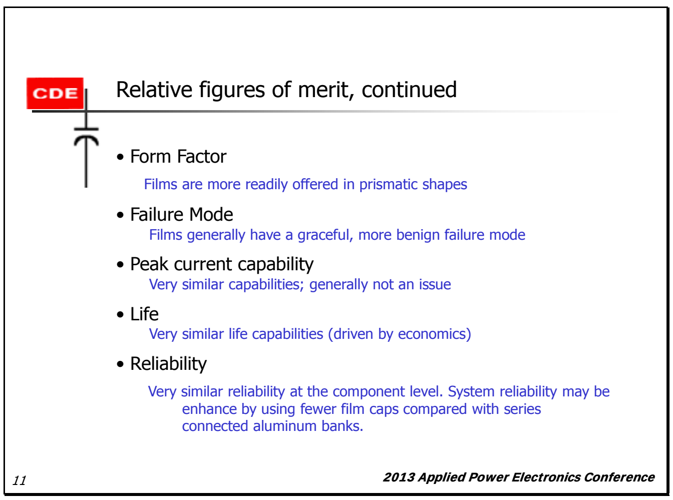
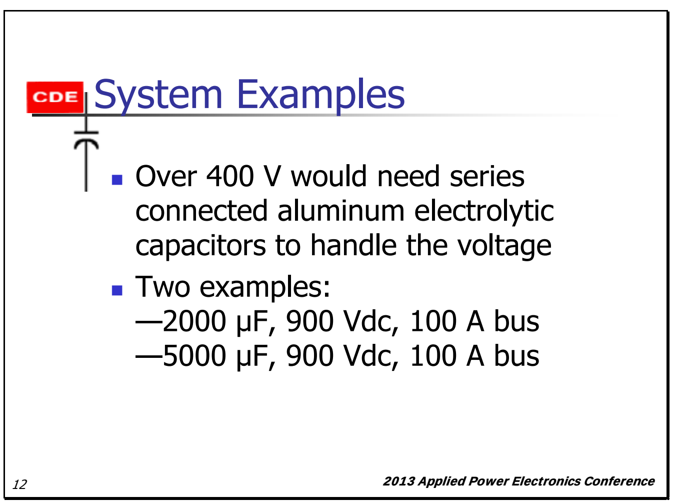
While film capacitors generally cost more per microfarad, assembly of aluminum electrolytic bus capacitors into capacitor banks counters the expense. Film capacitors are simpler to interconnect and don't need voltage-equalizing resistors, connected in parallel with series connected aluminum electrolytics. The higher voltage ratings of film capacitors avoids the need for series connections.



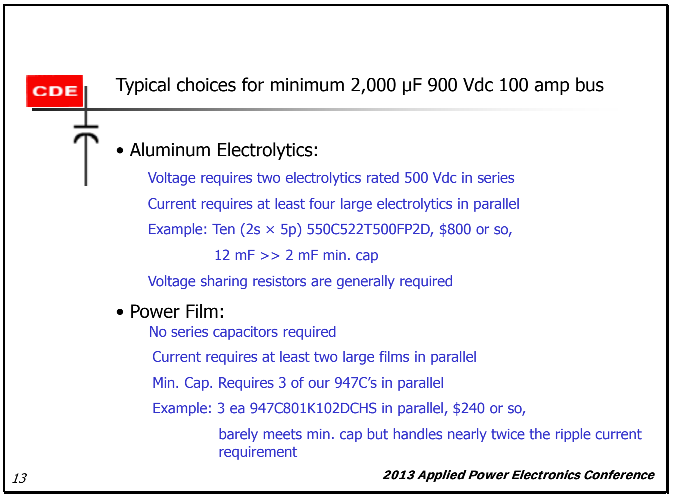
Aluminum electrolytics have much higher capacitance per volume. Film capacitors have lower ESRs and similar ESLs. Though films have lower specific ESR, the voltage withstanding capability of polypropylene dielectric is more severely limited at temperatures above 85 ºC than is the electrolytic dielectric. This can lead to an electrolytic being able to handle more high-frequency ripple current at 85 ºC than a film capacitor of the same size. Films are better with overvoltage transients and cold temperatures.



Advantages of film capacitors are that they are available in box shapes and fail benignly. Expected lifetime and reliability are the same as electrolytics.

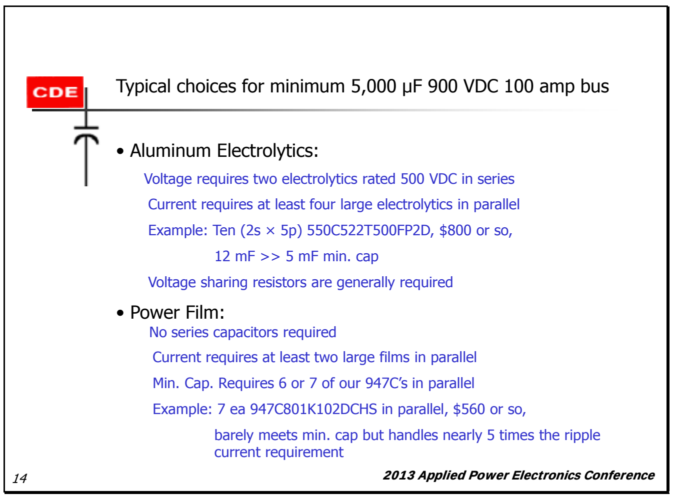


Capacitor banks in systems typically require series connection if aluminum electrolytics are used. Electrolytics are only available to a rated voltage of 550 Vdc. The next slide shows examples with 900 Vdc power buses.



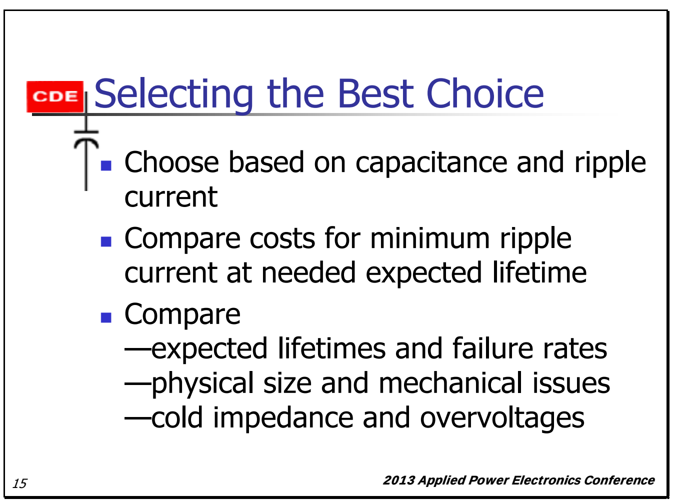
For the high 2000 µF capacitance, 900 Vdc, requires two sets of four or five large electrolytics connected in series. It could be constructed with ten 5200 µF, 500 V, Type 550C capacitors at a cost of about $800 with voltage equalizing resistors across each capacitor.

To do it with power film capacitors would require just three in parallel. It could be constructed with three 800 µF, 1000 V, Type 947C capacitors at a cost of about $240 and would have nearly twice the ripple current required.



The second example is with 2½ times the capacitance, 5000 µF instead of 2000 µF. While it has much higher capacitance, the electrolytic solution is the same because it had too much capacitance in order to handle the current.

Capacitance is the weak spot for the film capacitors, and the film capacitor solution requires six or seven units in parallel to supply the capacitance. It could be built with seven 800 µF, 1000 V, Type 947C in parallel for about $560. It barely meets the minimum capacitance but handles nearly 5 times the required ripple current.



The main determining factors in choosing between an aluminum electrolytic and a film capacitor are usually the minimum capacitance and ripple current ratings you need.

Compare the cost of a film capacitor to meet the minimum capacitance to the cost of electrolytics (including bus work and resistors) to meet the minimum ripple current.

Next, look at other design considerations such as life, reliability, cold impedance, physical size, possibility of overvoltage transients, etc.

Hopefully the rules of thumb outlined in this short presentation for the cost per joule and the cost per ripple ampere will be of some help in choosing the right capacitor. The technical staff at Cornell Dubilier is always eager to help you with any design exercises you may have.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Thank You!