

High power density solution for DC link on 48 V inverter application with Hybrid Aluminum Electrolytic Capacitors

[Aluminum Electrolytic Capacitors](#)[Axial Capacitors](#)[Hybrid Polymer Capacitors](#)[SMD Capacitors](#)[Capacitors](#)

High energy, reliable and volumetric efficient inverters are essential to reducing emissions of vehicles based on 48 V technology. DC-link capacitors can significantly contribute to this target by reducing parasitic losses and increasing thermal efficiency. High inverter powers can be theoretically achieved with multiple capacitor connections. However, a high number of parallel-connected parts also increase the complexity of the system stability. In the field of Aluminum Electrolytic Capacitors, the Hybrid Polymer technology offers higher ripple current densities by a factor of, e.g., 5x compared to standard Liquid Electrolyte technology. By applying the Hybrid Polymer technology to the large axial capacitor can sizes, with solid mechanical construction and special thermal dissipation feature, a compact DC-link solution with a reduced amount of capacitor and minimized thermal escalation risk through stable and efficient thermal design can be achieved.

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Introduction

The market tendency for DC-link capacitors bank for 48 V inverters is clearly toward smaller, more powerful and more efficient devices. Among the available capacitor technologies in the market, Hybrid Polymer Aluminum Electrolytic Capacitors stand out due to their high ripple current density. However, focusing even further on reducing the number of capacitors connected in parallel, TDK's axial capacitor, with hybrid polymer technology, addresses this matter by enabling streamlined, highly efficient, powerful capacitor bank designs.

Characteristics of TDK's Axial Capacitor with Hybrid Polymer Technology

The following distinctive design properties characterize TDK's axial capacitor with hybrid polymer technology:

- Hybrid polymer system
- Axial capacitor construction as an enabler

Understanding ESR and Self-heating

To properly distinguish the positive effect of the capacitor design properties on the ripple current capability of the component, the role of capacitor internal series resistance (ESR) and thermal resistance (R_{th}) has to be understood. The equation below is a simplified approach to describe the capacitor core temperature increase (ΔT) caused by a ripple current (i) applied.

$$\Delta T = i^2 \times ESR \times R_{th}$$

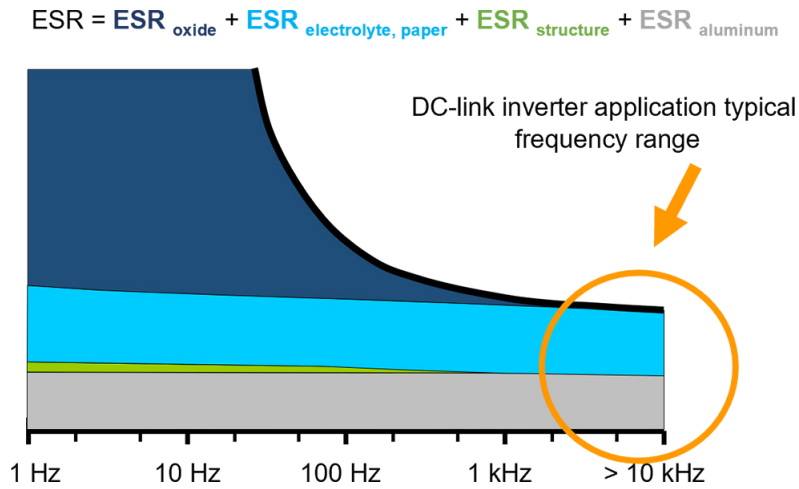
Where:
 ΔT = capacitor core temperature increase [K]
 i = applied ripple current [A]
 ESR = Equivalent Series Resistance of the capacitor [Ohm]
 R_{th} = thermal resistance [K/W]

Besides optimizing the thermal model of the component, thus lowering R_{th} , the ESR is the main parameter to be optimized in order to minimize the capacitor core temperature increase when it is operated with ripple current.

The ESR of a standard aluminum electrolytic capacitor results from the sum of several components as described in the simplified schema shown in Figure 1.

Considering that DC-link inverter applications have switching frequencies (f_{sw}) above 10 kHz, the components of “ESR electrolyte, paper” and “ESR aluminum” become a significant influence on the resulting ESR of the target capacitor; therefore, it is worth optimizing them.

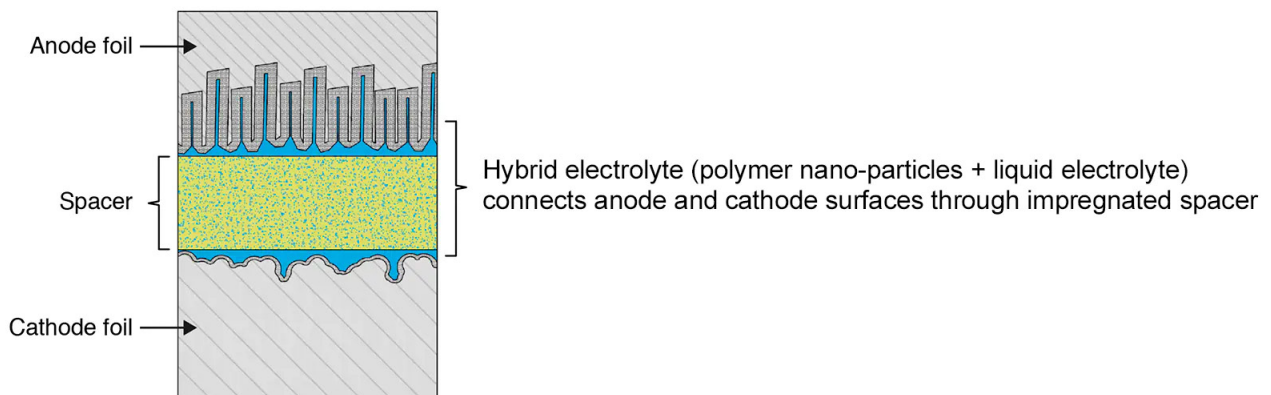
Figure 1 : ESR composition vs frequency



Hybrid Polymer System

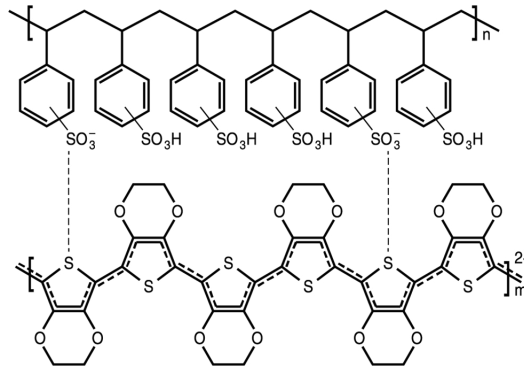
To optimize the contribution of “ $ESR_{electrolyte, paper}$ ” on the capacitor ESR, TDK employs a highly conductive polymer as cathode material in addition to a modified liquid electrolyte, replacing the liquid electrolyte commonly used in Aluminum Electrolytic Capacitors. Figure 2 shows the basic structure as a cross-section of the materials of TDK’s axial capacitor with hybrid polymer technology:

Figure 2 : Internal cross section



The conductive polymer used in these capacitors is based on PEDOT: PSS material (Figure 3). It achieves conductivities in the range of 1000 S/cm, while standard electrolytes are in the range of 0,01 S/cm.

Figure 3 : PEDOT:PSS polymer chain



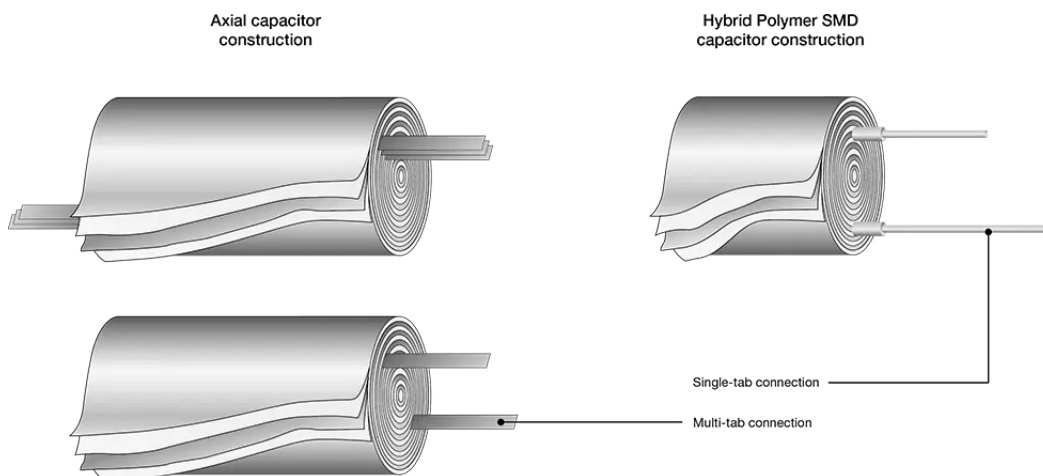
Despite its excellent conductivity properties, PEDOT: PSS is a material with challenging characteristics to process, and, the larger the capacitor is, the more complex the process gets. To realize the can size range of axial capacitors, TDK has developed a patented process to achieve good impregnation of the polymer in the foils and papers. Therefore, TDK's axial capacitors with hybrid polymer technology achieve larger sizes, thus remarkably more significant ripple current specifications than the existing parts in the market.

Additionally, to the conductive polymer, a modified electrolyte with reinforced structure, also patented by TDK, is used in the capacitor to protect the polymer layer and provide regeneration feature to the oxide during the capacitor lifetime.

Axial capacitor construction as an enabler

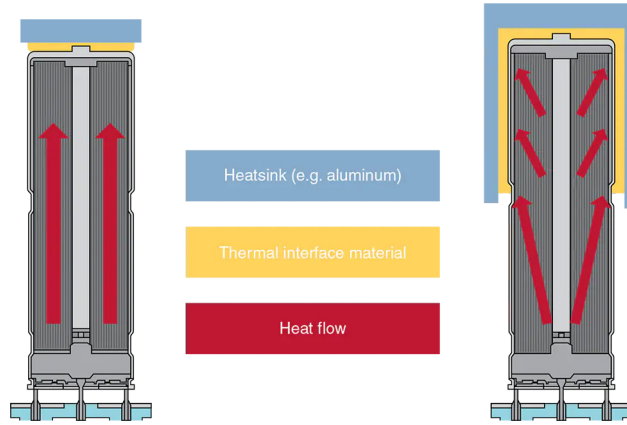
Due to the application of hybrid polymer technology, the ESR caused by "ESR_{electrolyte, paper}" is remarkably reduced. Therefore, the contribution of "ESR_{aluminum}" becomes dominant and shall be minimized to increase the component's overall ripple current capability. The axial capacitor construction provides an excellent platform for deploying multiple connections to anode and cathode foils, thus minimizing the ESR of a single component. Figure 4 shows a comparison between winding construction of hybrid polymer SMD capacitors and axial capacitors with hybrid polymer technology, pointing out how multiple connections (multi-tab) are applied to axial windings:

Figure 4 : Winding construction: multi-tab vs single tab



An additional advantage of axial capacitors is the thermal characteristics of the component. The winding element has a metal-to-metal connection to the aluminum housing providing a more efficient path to dissipate the internal heat to an outside heat sink attached to the capacitor's case. Due to its stable mechanical construction, axial capacitors with hybrid polymer technology also provide high internal vibration stability. This construction can achieve internal vibration stability up to 60 g, provided the case rigidly clamps the capacitor.

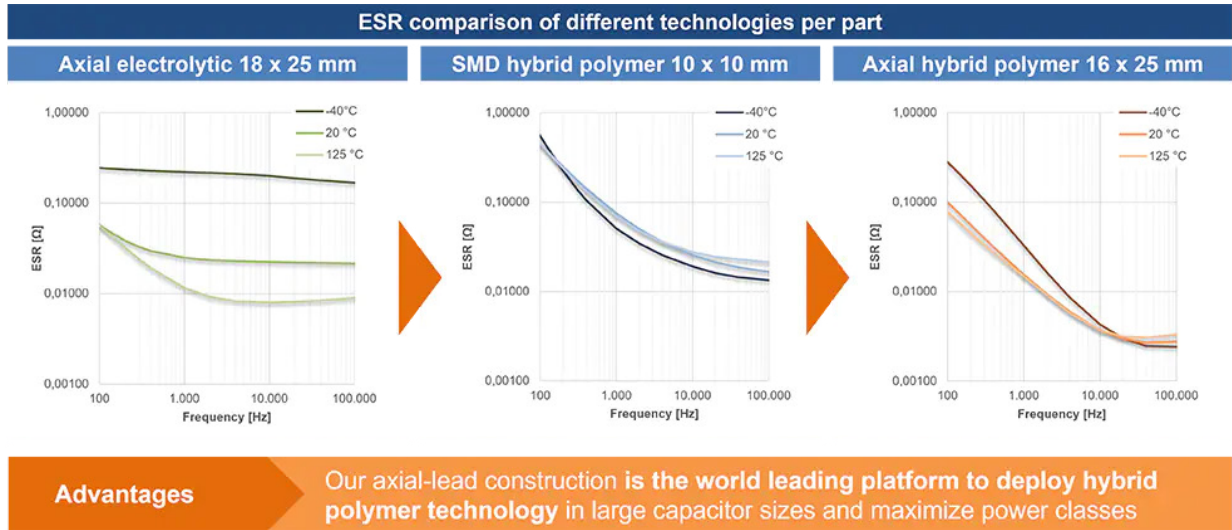
Figure 5 : Example of heatsink cooling



ESR comparison of relevant technologies

To verify the ESR performance of the hybrid polymer axial capacitors, measurements against relevant candidate capacitors [1,2,3] for DC-link position was performed and the results are presented in Figure 6. As a result, the remarkable advantage of Axial Hybrid Polymer Capacitors is verified by ESR measurements.

Figure 6 : ESR comparison between technologies



Conclusion

Axial Hybrid Polymer Capacitors are mainly targeted at higher power class 48 V inverters, for example, 15 kW and up, where the RMS ripple current for the DC-link capacitor bank is in the range of 150 Arms for continuous application and short periods can reach values of 300 Arms.

In such application scenarios, the DC-link capacitor bank is usually subject to a liquid cooling system to cope with the high capacitor self-heat due to ripple current requirements. Due to its excellent thermal and lower ESR characteristics, it is possible to design a DC-link capacitor bank with a minimized component count by applying Axial capacitors with hybrid polymer technology.






When designing such a capacitor bank, some factors must be considered as they can affect the size of the capacitor bank.

One factor is the switching frequency. Axial capacitors with hybrid polymer technology from TDK are specified for a frequency of 20 kHz. Other technologies have their ripple current specified for different frequency ranges. For example, SMD Hybrid Polymer Capacitors are set for 100 kHz, whereas standard Aluminum Electrolytic Capacitors are typically set for operation above 10 kHz.


The other important factor is useful life. Due to their robust construction, Axial Hybrid Electrolytic Capacitors can withstand higher internal temperatures for longer than standard Aluminum Electrolytic Capacitors and SMD Hybrid Polymer Capacitors. The ability to withstand higher internal temperatures for a more extended time is directly translated to higher ripple current handling capability.

Considering a reference lifetime of 4000 h with the case temperature held at 125°C, the comparison chart shown in Figure 7 can be made: Based on the comparison results, it is possible to observe that TDK's axial capacitors with hybrid polymer technology can reduce the component count in the DC-link capacitor bank.

Figure 7 : Component count in DC-Link vs technology

Technology comparison → No. of parts based on ripple current load			
Comparison on base of $I_{AC,max,TC} / 20 \text{ kHz} / 125 \text{ °C} / 4000 \text{ h}$			
Series	Axial hybrid polymer B40640 / B40740	Axial electrolytic B41687 / B41787	SMD hybrid polymer B40940
No. of parts	1	3	6
Parameter	  or  530 μF / 63 V / 16 x 25 mm PCB area ~ 240 mm^2 Volume ~ 6730 mm^3	 360 μF / 63 V / 16 x 25 mm PCB area ~ 720 mm^2 Volume ~ 20,200 mm^3	 120 μF / 63 V / 10 x 12.5 mm PCB area ~ 660 mm^2 Volume ~ 8470 mm^3

References

	Axial Hybrid Polymer Capacitors	SMD Hybrid Polymer Capacitors	Axial Electrolytic Capacitors
Series	B40640 / B40740 series 	B40940 series 	B41687 / B41787series 

Product Portal



Hybrid Polymer Capacitors Product Information

A comprehensive guide to information on Hybrid Polymer Capacitors from the TDK Group.



Axial Capacitors Product Information

A comprehensive guide to information on Axial Capacitors from the TDK Group.



SMD Capacitors Product Information

A comprehensive guide to information on SMD Capacitors from the TDK Group.

Selection Guide



Selection Guide

Aluminum Electrolytic Capacitors for Automotive