Capacitor in New Energy Market
KEMET Capacitors
98% of Dielectric Solutions

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Main Market Segments

Market: Solar Inverter

Application: DC-Link, Snubber, Output Filtering

Customers: Elett. Santerno, Fronius, Ingeteam, Kaco, Kostal, PowerOne, Siemens, SMA, SolarMax Sputnik, Sunpower

Areas: EU, Asia

<table>
<thead>
<tr>
<th>Application</th>
<th>Shape</th>
<th>Power / config.</th>
<th>Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output harmonics filtering</td>
<td>Box type</td>
<td>low power</td>
<td>C4AT</td>
</tr>
<tr>
<td>Output harmonics filtering</td>
<td>Cylindrical can</td>
<td>medium power</td>
<td>C44P-C20A : mono-phase</td>
</tr>
<tr>
<td>Snubber for IGBT protection</td>
<td>Box type</td>
<td>lug terminals</td>
<td>C4BS</td>
</tr>
<tr>
<td>DC-link</td>
<td>Box type</td>
<td>low power</td>
<td>C4AE</td>
</tr>
<tr>
<td>DC-link</td>
<td>Cylindrical can</td>
<td>medium power</td>
<td>C44U</td>
</tr>
<tr>
<td>DC-link</td>
<td>Brick type</td>
<td>medium-high power</td>
<td>C4EE</td>
</tr>
</tbody>
</table>
## Market: Windmill Generator

### Application: DC-Link, Output Filtering

### Customers: Semikron, Coverteam, Danfoss, Ingeteam, Enerkon, Vestas, Sedecal, SEG, Emerson, Vacon, ABB

### Areas: EU, Asia

<table>
<thead>
<tr>
<th>Application</th>
<th>Shape</th>
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<tbody>
<tr>
<td>Output harmonics filtering</td>
<td>Cylindrical can</td>
<td>medium power</td>
<td>C20 : mono-phase</td>
</tr>
<tr>
<td>Output harmonics filtering</td>
<td>Cylindrical can</td>
<td>medium power</td>
<td>C9T: 3-phase</td>
</tr>
<tr>
<td>DC-link</td>
<td>Cylindrical can</td>
<td>medium power</td>
<td>C44U (high capacitance)</td>
</tr>
<tr>
<td>DC-link</td>
<td>Brick type</td>
<td>medium-high power</td>
<td>C4EE (high capacitance)</td>
</tr>
</tbody>
</table>
Solar Power Inverter Grid Systems Solutions

Capacitor Functions:
- a) filter out / smoothen DC-bus voltage variation
- b) prevent ripple from interfering back to DC source

1. AC Harmonic Filtering (Film)
   - C4A (Box type / wire term. - low power)
   - C44 / C20 (Alu-can - high power / high voltage)

2. Snubber (Film)
   - C4BS (Box / wire or lug terminal)

3. DC-link (Film)
   - C4AE (Box / wire term. - PCB mount-low power)
   - C44U (Alu-can - busbar/cable - medium power)
   - C4DE (Flat type - busbar/cable - high Irms current)
   - C4E (Brick type - PCB/busbar - high power)

3. DC-Link (Electrolytic) Snap-In
   - ALC10/12, PEH506 (85°C)
   - ALC40/42, PEH532/4/6 (105°C)

3. DC-Link (Electrolytic) Screw Terminal
   - ALS30/32/34, PEH169/PEH200 (85°C)
   - ALS40/42, PEH169 (105°C)

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AC Harmonic Filter

Snubber

DC Link

One world. One KEMET.
Power Converter
AC Harmonic Filter Capacitors

AC Filtering
To reduce the harmonic components overlapped to the fundamental frequency

Typical rated voltages:
- 330 Vac - Output / Star Connection
- 440 Vac - Output / Delta Connection
- 525 - 640 Vac - Input
- > 690 Vac - Wind Generators

Demanded Life Expectancy:
- >10 years (100k hours)
AC Filters
Main products

C4AT
- Suitable to PCB installation
- 4 wires for a better Irms capability
- Mainly requested for small power equipment
- 160Vac ÷ 350Vac application range

C44A/E
- Old technology with solid polyur. resin filling + aluminum metallization
- Suitable to high current applications
- Not provided with FPU (Overpressure Device)
- Available in faston or screw terminals execution

C44P/C20
- New technology with castor oil vacuum filling + slope zinc metallization
- High capacitance density and high performance
- Provided with FPU
- Plastic isolators for high compliance with busbar mounting

C9T/C93
- Series coming from PFC technology and then with medium performances
- C93 → faston terminals + polyureth. Liquid resin + FPU
- C9T (3-phase) → terminal block + oil filling + slope
New special AC box series can grant a high ratio \( \text{Irms} / \text{Capacitance} \) by granting at the same time a better capacitance density per volume if compared to the Alu Can.

- Alu Can types can cover also the range 450Vac up to 1000Vac while the box types can do that only with old technology that misses all the above points.
- Alu Can types can be provided with Fuse Protection Unit (mechanical overpressure device) while box types can be protected only through film segmentation - generally less reliable.
Links for added safety

Aluminum/Zinc “Plate”
Distributed links

Termination links

Aluminum/Zinc “Plate”

Film

Electrode

Electrode

Electrode

Electrode

Electrode

Electrode
Three-phase capacitors are popular in some AC Filter applications because of their compactness (only one can instead of three) and the lower price.

Three-phase are suitable only for cable mounting while single-phase can be also mounted on busbar connections.

Three-phase cannot be paralleled due to the limitation on the terminal block. This requires often a “daisy-chain” configuration (every cap connected through cables to a common point).

The Irms/Capacitance ratio is much higher in the single-phase types. The tough AC Harmonic Filters cannot be fulfilled by three-phase types.
Dry technology vs Impregnated technology

→ Dry alu can capacitors can generally work at higher temperature than impregnated ones
→ Dry technology doesn’t fit completely the new advanced metallisations that perform better with oil impregnation. The result is a general lower capacitance density (thicker dielectric needed) for the dry vs the impregnated
→ Dry capacitors cannot be properly protected with the Overpressure device which needs liquid filling to let the pressure generated by the short circuit propagate through the can
→ MESSAGE: if you don’t need high working temperatures, the impregnated technology is the most performing for AC

Dry Series ➔ C44A - C44B - C44E
Imp Series ➔ C44P - C20A - C9T
Snubber Capacitors

Snubber
Connected in parallel with semiconductor components to damp dangerous voltage spikes on semiconductor switches

Typical rated voltages:
- 1200 Vdc
- 1600 Vdc
- 3000 Vdc

Demanded Life Expectancy:
- >10 years (100k hours)

Most important parameter in snubbers is the dv/dt or peak current. All Kemet Arco snubbers are designed with “heavy edge” metallization and polyestere carrier so to give the best performances in current.

\[ C = \frac{L \times I^2}{\Delta V^2} \]
### Snubbers

**Main products**

<table>
<thead>
<tr>
<th>Product</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C4BS</strong></td>
<td><em>Suitable to be installed directly on IGBT terminals or to busbars thanks to Tab terminals</em>&lt;br&gt;<em>Available with different tab mechanical styles so to fit the majority of IGBT brands</em></td>
</tr>
<tr>
<td><strong>C4AS</strong></td>
<td><em>Same internal layout of C4BS but with wire terminations for PCB mounting</em>&lt;br&gt;<em>Available in P 27.5 - 37.5 - 52.5mm</em>&lt;br&gt;<em>2 Wires / 4 Wires</em></td>
</tr>
<tr>
<td><strong>C44B</strong></td>
<td><em>Cylindrical version suitable to be used in old designs where no PCB, no busbar, no IGBT were used</em>&lt;br&gt;<em>Available with both faston and M6 screw terminal</em></td>
</tr>
</tbody>
</table>

---

*One world. One KEMET.*
The Tab Style

C4BSNBX4200ZBLJ

<table>
<thead>
<tr>
<th>Style</th>
<th>L</th>
<th>P</th>
<th>a</th>
<th>b</th>
<th>P1</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>41.5</td>
<td>22</td>
<td>16</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>42</td>
<td>22</td>
<td>16</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>42.5</td>
<td>22</td>
<td>16</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>57.5</td>
<td>37</td>
<td>31</td>
<td>43</td>
<td>21</td>
</tr>
</tbody>
</table>
Industrial
IGBT Snubber Function

Without snubber capacitor
spikes can damage IGBT
With snubber capacitor
spikes reduced to safe level

The severity of the spikes depends on the total
inductance of the system, including unintended stray
inductance from cabling, etc.
### DC-Link

To support a DC network by supplying periodically high currents

#### Typical rated voltages for film DC-Link:
- 700 Vdc - welders
- 900 Vdc - solar converters
- 1100 Vdc - wind converters
- 1300 Vdc – wind converters

#### Demanded Life Expectancy:
- >10 years (100k hours)

Typically the DC-Link capacitors must withstand higher operating temperatures than the AC Filters due to the proximity to the IGBT’s
DC-Link
Main Products

**C4AE**
- Box type / 4 wires
- Up to 100μF

**C44U**
- Cylindrical type
- Up to 2000μF

**C4E / JSP / PHZ**
- Brick type
- Up to 10000μF
C4AE series – MKP - Radial case

- High Temperature use
- High Ripple Currents
- Expected life of 150,000 hours

<table>
<thead>
<tr>
<th>Value (μF)</th>
<th>Voltage (Vdc)</th>
<th>Current (Arms)</th>
<th>Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>450</td>
<td>22</td>
<td>70</td>
</tr>
<tr>
<td>75</td>
<td>600</td>
<td>20.5</td>
<td>70</td>
</tr>
<tr>
<td>60</td>
<td>700</td>
<td>19.5</td>
<td>70</td>
</tr>
<tr>
<td>40</td>
<td>900</td>
<td>18</td>
<td>70</td>
</tr>
<tr>
<td>27</td>
<td>1100</td>
<td>16.5</td>
<td>70</td>
</tr>
</tbody>
</table>

NEWS

- Introduction of pitch 27.5mm.
- Extension of data sheet parameters
  - Temp till 105° C with Voltage Derating;
  - Lifetime and FIT curves.
DC-Link film capacitors in Alu-can

C44U - High Capacitance Density
MKP Capacitors for DC Link and High Energy applications

Up to 2000μF / 900Vdc
Other Voltages: 1100 – 1300 Vdc, range to be defined.
Male and female screw terminals available

NEWS
- New mechanical design: CAP introduction and SLEEVE elimination.
- Extension to 116mm diameter.
- Capacitance density increase on 1100Vdc/1300Vdc
- Extension to 1800Vdc rated voltage
- Extension to 600Vdc rated voltage
- 100% UL approved construction (Sept 2012).
- Data sheet with lifetime and FIT curves (Feb 2012).
3 General Construction

Typologies: Snap-ins for low power drives/inverters/UPS, PCB mounting

- ALC10, ALC40 (European manufacture)
- PEH506, PEH536 (Chinese manufacture)

Screw Terminals for medium to high power drives/inverters/UPS

- ALS30/31, ALS40/41, PEH200/169 (European manufacture)
- ALS32/33, ALS42/43 (Chinese manufacture)

KEMET electrolytic capacitors use extended cathode construction for enhanced thermal dissipation.
# Dc Link - comparison Film / Lytic

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Film</th>
<th>Electrolytic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life</td>
<td><strong>Up to 100,000 hours</strong></td>
<td><strong>2,000 to 50,000 hours</strong> <em>(with high C derating)</em></td>
</tr>
<tr>
<td>Voltage</td>
<td><strong>Up to 1,300Vdc (C44U series)</strong></td>
<td><strong>450Vdc</strong></td>
</tr>
<tr>
<td>ESR</td>
<td><strong>Low</strong></td>
<td><strong>High</strong></td>
</tr>
<tr>
<td>Ripple Current</td>
<td><strong>High</strong></td>
<td><strong>Low</strong></td>
</tr>
<tr>
<td>Capacitance</td>
<td><strong>Low</strong></td>
<td><strong>High</strong></td>
</tr>
<tr>
<td>Energy Density</td>
<td><strong>0.16 J/cm³ (C44U series)</strong></td>
<td><strong>0.8 J/cm³</strong></td>
</tr>
</tbody>
</table>
Design Example: DC-Link Film and Electrolytic Trade Offs

### 3 Phase AC Generator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output V</td>
<td>690Vac</td>
</tr>
<tr>
<td>Vdc Link</td>
<td>1000Vdc</td>
</tr>
<tr>
<td>V ripple max</td>
<td>100V</td>
</tr>
<tr>
<td>Frequency</td>
<td>50Hz</td>
</tr>
<tr>
<td>Capacitance</td>
<td>500uF</td>
</tr>
<tr>
<td>Ripple Current</td>
<td>30A</td>
</tr>
<tr>
<td>Freq DcLink</td>
<td>300Hz</td>
</tr>
<tr>
<td>Temp</td>
<td>75 °C</td>
</tr>
</tbody>
</table>

### Electrolytic Solution

<table>
<thead>
<tr>
<th></th>
<th>ALS30</th>
<th>Film C44U</th>
</tr>
</thead>
<tbody>
<tr>
<td>C uF</td>
<td>1500</td>
<td>500</td>
</tr>
<tr>
<td>V dc</td>
<td>500</td>
<td>1100</td>
</tr>
<tr>
<td>DxL mm</td>
<td>77x105</td>
<td>85x174</td>
</tr>
<tr>
<td>Volume cm³</td>
<td>622.5</td>
<td>1257.2</td>
</tr>
<tr>
<td>I ripple (A)</td>
<td>10.6</td>
<td>30</td>
</tr>
<tr>
<td>Tot. Vol.</td>
<td>5602.5</td>
<td>1257.2</td>
</tr>
<tr>
<td>Tot. C uF</td>
<td>1500</td>
<td>500</td>
</tr>
</tbody>
</table>
### Comparison of Film and Electrolytic Technologies

<table>
<thead>
<tr>
<th>Electrolytic (ALS30)</th>
<th>Film (C44U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Volume</td>
<td>5602.5</td>
</tr>
<tr>
<td>30A</td>
<td>30A</td>
</tr>
<tr>
<td>10A</td>
<td>10A</td>
</tr>
<tr>
<td>10A</td>
<td>10A</td>
</tr>
<tr>
<td>30A</td>
<td>30A</td>
</tr>
<tr>
<td>1500 Vdc</td>
<td>1100 Vdc</td>
</tr>
<tr>
<td>1500 uF</td>
<td>500 uF</td>
</tr>
<tr>
<td>3 times required capacitance</td>
<td>(stable over years)</td>
</tr>
</tbody>
</table>

But how long will these last?
Main Market Segments

Market: Automotive

Application: DC-Link, DC-filtering

Customers: Caterpillar, Robert Bosch, Magneti Marelli

Areas: EU, Asia

<table>
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<th>Application</th>
<th>Shape</th>
<th>Power / config.</th>
<th>Series</th>
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<tbody>
<tr>
<td>DC filtering</td>
<td>Axial</td>
<td>low power</td>
<td>A50</td>
</tr>
<tr>
<td>DC-link</td>
<td>Box type</td>
<td>Low / modular</td>
<td>C4AE</td>
</tr>
<tr>
<td>DC-link</td>
<td>Brick type</td>
<td>Medium / compact</td>
<td>C4EE</td>
</tr>
</tbody>
</table>
EV / HEV Power Train
DC-Link Capacitors

DC-Link Functions
- Protect the battery
- Reduce ripple noise on the inverter input stage
- Decouple / supply during motor load changes

High Torque asynchronous or synchronous
- PMSM
- BLDC

Hybrid Vehicles include an ICE (Internal Combustion Engine) requiring higher temperature capacitors than Full Electric vehicles
EV / HEV Power Train
DC-Link Capacitors

**Advantages:**
- High ripple life 20 khours
- High voltage
- Large capacitance / Brick
- High operating temperature
- High switching frequencies
- Low ESR, Low ESL

**Typical Designs:**
- Cap: 100 to 2000 uF
- Voltage: 450 to 1300Vdc
HEV Automotive DC-Link Brick

KEMET - DC-Link 150uF/600Vdc

One world. One KEMET.
Infineon Hybrid Pack II IGBT Module
EV / HEV Automotive DC-Link Brick
IGBT Specials

3-phase IGBT inverter
IGBT SKAI2
- 600 V up to 150 kVA
- 1200 V up to 230 kVA.
automotive qualification
EMI filters
Liquid cooling
DC link capacitor

Capacitor Solution: C4E Brick
- Capacitance: 1000uF / 900V
Automotive DC-Link Capacitors
Heat Dissipators, Soft Winding

DC-Link Capacitor for Hybrid Vehicle
Design questions for a DC Link capacitor:
- What is the Capacitance and Voltage profile
- What is the AC Spectrum Frequency and Ripple Current
- What is the Ambient Temperature and possible Cooling
- What is the Inductance needed
- What are the Mechanical Stresses / Vibration and Shock
- What is the Mechanical Shape/Dimensions/Connections

Hybrid Vehicles’ Internal Combustion Engine requires generally higher temperature capacitors than Full Electric vehicles
Charging Stations

Market Drivers
EV & PHEV growth
Europe driven by OEM strategies, federal governments and energy generation.
North America driven by legislation, OEM strategies and energy security.

Issues
Standardization
Charging time
Charging method
Billing

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Charging Stations</th>
<th>Key Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>Above 500</td>
<td>Coulomb Tech, Eaton, EVOasis and others</td>
</tr>
<tr>
<td>Germany</td>
<td>Approx. 380</td>
<td>Park &amp; Charge</td>
</tr>
<tr>
<td>France</td>
<td>Approx. 260</td>
<td>DBT, STGE, Circutor and others</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Approx. 190</td>
<td>Elektromotive and Park &amp; Power</td>
</tr>
<tr>
<td>Spain</td>
<td>Less than 10</td>
<td>N/A</td>
</tr>
<tr>
<td>Norway</td>
<td>Approx. 40</td>
<td>N/A</td>
</tr>
<tr>
<td>Portugal</td>
<td>Approx. 20</td>
<td>EDP</td>
</tr>
<tr>
<td>Italy</td>
<td>Approx 121</td>
<td>ACI Informatica</td>
</tr>
<tr>
<td>Austria</td>
<td>Approx. 80</td>
<td>Park &amp; Charge</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Approx. 200</td>
<td>Park &amp; Charge</td>
</tr>
<tr>
<td>Denmark</td>
<td>Approx. 40</td>
<td>N/A</td>
</tr>
<tr>
<td>Sweden</td>
<td>Approx. 150</td>
<td>N/A</td>
</tr>
<tr>
<td>Japan</td>
<td>Above 75</td>
<td>N/A</td>
</tr>
<tr>
<td>China</td>
<td>Above 100</td>
<td>N/A</td>
</tr>
<tr>
<td>Monaco</td>
<td>Approx. 176</td>
<td>N/A</td>
</tr>
<tr>
<td>Australia</td>
<td>Approx. 20</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Battery Charger Solutions for EV, Plug-in HEV

AC Harmonic Filtering (Film)
- **C4A** (box type / wire term. - low power)
- **C44 / C20** (alu-can - high power / high voltage)

DC-link (Film)
- **C4AE** (box / wire term. - PCB mount-low power)
- **C44U** (alu-can - busbar/cable - medium power)
- **C4DE** (flat type - busbar/cable - high Irms current)
- **C4E** (brick type - PCB/busbar - high power)

Snubber (Film)
- **C4BS** (box / wire or lug terminal)

DC-Link (Electrolytic) Snap-In
- **ALC10/12, PEH506** (85°C)
- **ALC40/42, PEH532/4/6** (105°C)

DC-Link (Electrolytic) Screw Terminal
- **ALS30/32/34, PEH169/PEH200** (85°C)
- **ALS40/42, PEH169** (105°C)
Thank You!