INVERTER OUTPUT AC FILTER CAPACITOR FOR TODAY'S DEMANDING APPLICATIONS

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Many of today's inverter circuits require highly reliable and rugged capacitors to filter out the rich harmonic content of their AC output waveforms. The current of the harmonics at the output of inverter circuits is often greater than the current at the fundamental frequency. Consequently, the harmonics can cause a significant increase in capacitor power dissipation. This condition affects both three-phase circuits (as illustrated) and single phase circuits. The harmonic currents are somewhat insignificant individually, however, in sum, they can become substantial.

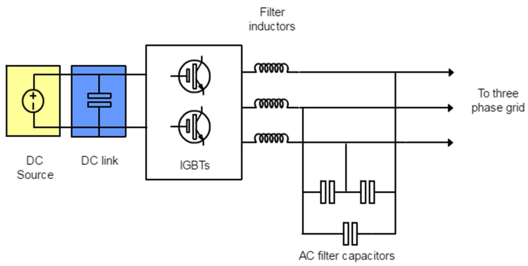

Figure 1: Typical Inverter Block Diagram with output filter capacitors

When specifying inverter output filter capacitors, the additional heating generated from the harmonic content of the system must be accounted for. If not, capacitor life will be shortened considerably. The filter capacitors selected should be designed to minimize losses in order to be able to dissipate the increased power generated by the harmonic currents. The increased peak voltage, caused by harmonic voltages superimposed on the fundamental waveform, should be examined as part of the design process. If the capacitor is not suitably sized, the dielectric can be damaged, causing premature failure.

CDE Power Conversion Type PC Series capacitors deliver a full 60,000 hour life at rated voltage, at a hot-spot temperature (area reaching the highest temperature) of 85°C. Type PC capacitors are wound using a high crystalline metallized polypropylene (HCPP) film, which possesses an extremely low dissipation factor. They are designed with materials and processes that keep the Ohmic series resistance (R_s) to a minimum, resulting in low loss across a wide frequency range. HCPP films also improve high voltage and temperature performance.

Figure 4: CDE Power Conversion Type PC

Power Conversion type capacitors feature extruded aluminum cases with steel or aluminum covers. Each is supplied with standard M6 X 1 threaded tin-plated brass terminals and a M12 mounting stud. Standard ratings include 300 Vac, 500 Vac, and 700 Vac. For more details vist CDE.com and enter the link below.

http://www.cde.com/resources/catalogs/PC.pdf

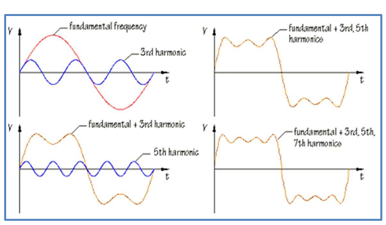

Figure 2: IGBT Switching causes distortion

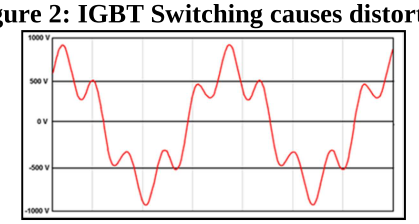

Figure 3: Harmonic rich waveform

Inverter IGBT switching circuits generate harmonics that are odd numbered multiples of the fundamental switching frequency (3rd, 5th, 7th, etc.) These harmonics combine with the fundamental frequency and cause distortion of the waveform. (Figure 2)

When harmonics are superimposed on the fundamental waveform, the peak voltage can be considerably higher. A typical 480 Vac sytem can have peak voltages approaching 1,000 Vac. This higher peak voltage must be considered when selecting the dielectric. (Figure 3)

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The CDE Type PC Series employs a dual protection system. First, the metalized film construction exhibits an inherent self-healing property, which allows the capacitor to clear away any imperfections or voids without reducing dielectric performance. This series also contains a built-in pressure interrupter (Figure 4) with fault current protection up to 10,000 Amps, to ensure a fail-open end of life. Although most applications require mounting the capacitors vertically, CDE PC Type capacitors have undergone testing by Underwriters Laboratories using three mounting options: vertical, horizontal, and inverted positions.

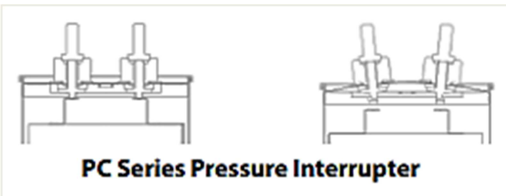

Figure 5
The safety pressure interrupter is designed to disconnect the capacitor section as the cover expands upwards due to internal gas build up. Care must be taken at installation to provide a minimum of 0.5 inch clearance to allow for this expansion.

CDE capacitors are vacuum impregnated with a specially treated environmentally safe dielectric fluid. This fluid serves to enhance the life of the capacitor by suppressing corona, increasing both dielectric strength and heat dissipation.

The following is an example that demonstrates the approach CDE engineers undertake while specifying or designing capacitors to meet inverter circuit harmonic filter applications:
CDE engineers require the following application input to properly specify or design the filter capacitor.

Table 1

Customer Application Input Required					
C (µF)	V_{rms}	V_{Peak} Waveform	$T_{ambient}$	Expected Life (h)	FFT (current/frequency)

With the required input data, the power generated by the fundamental and harmonic currents can be calculated and compared to the maximum power handling of the capacitors. The maximum power handling of the capacitor occurs when the hot spot temperature reaches 85°C.

The total power (P_t) is obtained by solving for the power generated at the fundamental and each individual harmonic and summing them,

$$P_{tt} =] \sum_{undamental}^{n^{th}harmoni}] \quad Power] \qquad (1)$$

The power is a combination of the power losses of the dielectric (P_d) itself and the Power losses due to the Ohmic resistances (P_r),

$$P = P_{dt} + P_{rt} \qquad (2)$$

$$P_{dt} =] \, {}^{2}_{rmst} * (X_{ct} * \delta_0)] \qquad (3)$$

$$\boldsymbol{P}] = \boldsymbol{I}^{2}_{]} \, {}_{st} * \boldsymbol{R}_{st} \qquad (4)$$

Where,

$$\delta_0 = Dielectric\ DF, fo \quad polypropylene: 0.0002 \qquad (5)$$

$$R_{st} =]Ohmic]Series]Resistance](\Omega)] \qquad (6)$$

$$X_c = \frac{1}{2*\pi*f*C} \qquad (7)$$

Solving for power,

$$P =] \, {}^{2}_{rmst}[R_{st} +](X_{ct} * \delta_0)] \qquad (8)$$

Example application input provided:

PCSX35T110K475S-0000

1. Capacitance: 110µF
2. Ambient Temperature: 70°C
3. FFT for the RMS currents
4. From CDE design rules or data table:
    a. $R_{tht} =]3.92°C/W]$
    b. $SA]=]71.5]in^{2t}$
    c. $R_{st} =]0.0036]\Omega]$

And,

$$P_{maxt} =] \frac{(85°C]-]T_a)}{R_{tht}} \qquad (9)$$

Where,

$$R_{tht} =]Thermal]Resistance]in] \, {}^{\circ}]\frac{Ct}{Wt} \qquad (10)$$

$$T_a = Ambien \quad empera\ ure\ near \quad he\ capaci\ or \qquad (11)$$

So that,

$$P_{maxt} =]\mathbf{3.83}]\boldsymbol{W}] \qquad (12)$$

The power at each frequency is then calculated and totaled:

Table 2

Input				
Frequency (Hz)	***I_{rms} (A)***	***P_r (Watts)***	***P_d (Watts)***	***P_t (Watts)***
60	*13.0*	*0.613*	*0.812*	*1.425*
880	*4.2*	*0.064*	*0.006*	*0.070*
2000	*11.6*	*0.488*	*0.019*	*0.507*
4000	*21.0*	*1.599*	*0.032*	*1.631*
6000	*5.4*	*0.106*	*0.001*	*0.107*
8000	*2.8*	*0.028*	*0.000*	*0.029*
10000	*1.6*	*0.009*	*0.000*	*0.009*
12000	*2.0*	*0.015*	*0.000*	*0.015*
14000	*1.0*	*0.004*	*0.000*	*0.004*
Total Power:				***3.80***

$$T_{hst} = T_{at} + \left(P * \frac{280}{SA}\right) \qquad (13)$$

$$T_{hst} = 70°C + \left(3.8 * \frac{280}{71.5}\right) = \mathbf{84.9°C} \qquad (14)$$

$SA = Surface\ area\ of\ capacitor, in^2 (from\ table)$ (15)

$T_{hs} = Capacitor's\ internal\ hot-spot\ temperature$ (16)

In this example the hot-spot temperature is just below the maximum allowable temperature of 85°C and the power dissipation is also just below the maximum power allowed as well. Therefore, the capacitor can be rated for full 60,000 hour life.

CDE PC Series capacitors are designed for an expected life of 60,000 hours of continuous service with a 94% survival rate at full-rated voltage and 85°C hot spot temperature. Life curves demonstrating projected life at other hot spot temperatures are shown below (figure 6) and can be estimated using the following formula.

(17)

$$Estimated\ Life = 60,000 * \left\{ 2^{\frac{(T_r - T_a)}{10}} * \left(\frac{V_{rt}}{V_{at}}\right)^{6.2} \right\}$$

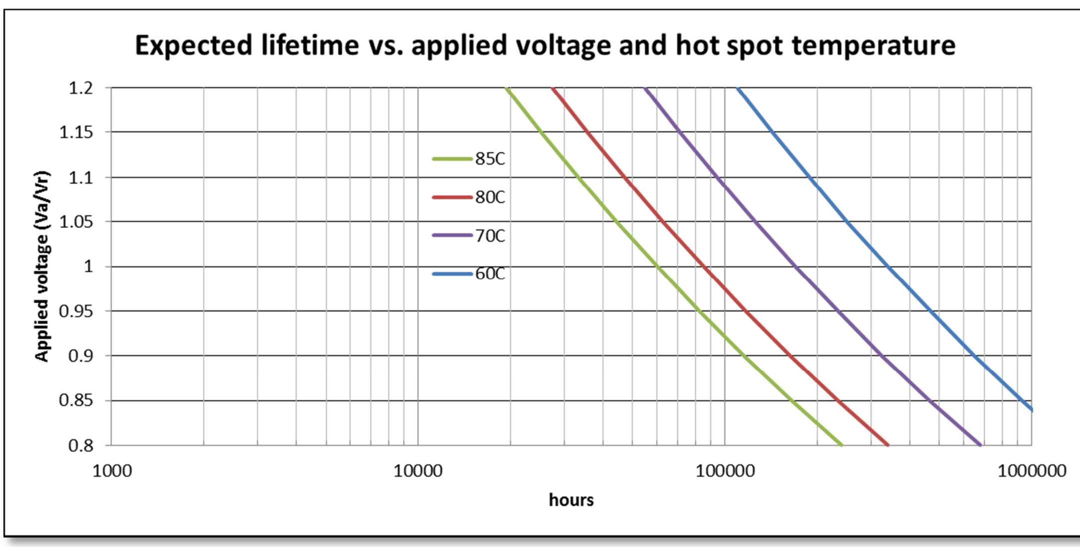

Figure 6

Where,

$$T_{rt} = 85°C, T_{at} = Application\ Temperature, V_r = Rated\ Voltage, V_{at} = Application\ Voltage$$