POWER ELECTRONICS CAPACITORS
SELECTION GUIDE

- UL Certified
- IEC 61071 compliant

Selecting the right
power electronics capacitor

JUST A FEW STEPS TO SELECTING THE RIGHT POWER ELECTRONICS CAPACITOR!

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JUST A FEW STEPS TO SELECTING THE RIGHT POWER ELECTRONICS CAPACITOR!

1. VOLTAGE AT THE CAPACITOR

(i.e. the specified voltage withstand rating)

When selecting a power electronics capacitor for AC applications, the nominal voltage rating of the capacitor must be greater than the peak value of the AC voltage.

Example:
Peak voltage = 420 V;
capacitor nominal voltage rating V_N = 450 V

Always choose the higher voltage level because of safety and lifetime.

AT PWM filter applications, the peak voltage can be higher ≥ than inverter DC bus voltage. Please consider that.

2. SELECTING THE CAPACITANCE OF THE CAPACITOR

The desired capacitance must be selected based on the voltage and the connection type according to the FRAKO brochure Power Electronics Capacitors with tables.

Example:
V_N = 450 V ; $C_{desired}$ = 50 µF

Type List 3-phase capacitors with fast-wiring screwless terminals

	V_N = 450 V V_{rms} = 320 V V_s = 970 V									
	Article-No.	Type	Capacitance in µF	I_{max} in A	Î in kA	R_{th} in K/W	R_S in mΩ	Diameter in mm	Height in mm	Weight in kg
320 V_{rms}	31-13000	LKT-F-020.0-3-450-BC	3 × 20	22	0.7	≤ 4.2	1.36	60	150	0.590
	31-13001	LKT-F-030.0-3-450-BC	3 × 30	22	1.0	≤ 4.2	1.10	60	150	0.590
	31-13002	LKT-F-040.0-3-450-BF	3 × 40	28	1.4	≤ 3.5	1.79	70	223	1.090
450 V_{pk}	31-13003	LKT-F-050.0-3-450-BF	3 × 50	28	1.7	≤ 3.5	1.66	70	223	1.090
450 V_{dc}	31-13004	LKT-F-075.0-3-450-BF	3 × 75	28	2.6	≤ 3.5	1.49	70	223	1.090
	31-13011	LKT-F-100.0-3-450-BJ	3 × 100	45	3.5	≤ 2.9	0.57	85	215	1.550
	31-13012	LKT-F-135.0-3-450-BK	3 × 135	50	4.7	≤ 2.6	0.80	85	278	1.900
	31-13013	LKT-F-150.0-3-450-BK	3 × 150	50	5.2	≤ 2.6	0.77	85	278	1.900

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3. SELECTING THE CURRENT WITHSTAND RATING OF THE CAPACITOR

(taking its peak current and RMS current into consideration)

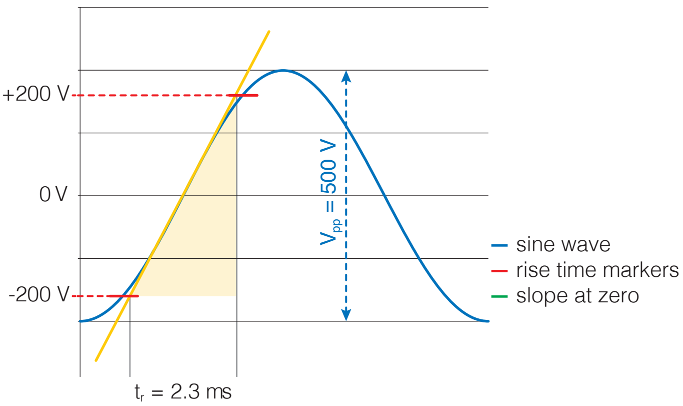
Typical calculation for an AC application – a numerical example:

Given parameters for the calculation example:

peak-to-peak voltage	V_{pp}	= 500 V
frequency	f	= 100 Hz
rise time	t_r	= 2.3 ms
capacitance	C	= 150 µF

3.1. Calculation of rising edge slope

Here is an example of an rising edge with its given values.



V_{pp} = peak-peak voltage
t_r = risetime of a value (typically considered as time from 10 % to 90 % of peak voltage)

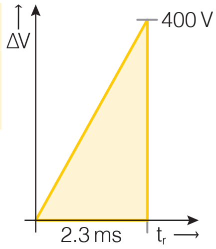
Determined values:

Here is t_r = 2.3 ms (10 % to 90 % of the peak voltage)
ΔV = +400 V during the time of t_r

The slope can also be much larger or faster, in this case the highest rise must be considered in the calculation.

Formula of a rising edge slope:

$$\frac{dv}{dt} = \frac{\Delta V}{tr} = \frac{400\,V}{2.3\,ms} = 173.91\frac{V}{ms} = 0.174\frac{V}{\mu s}$$



ΔV = voltage increment in V
dt = time increment

3.2. Calculation of the peak current

The periodically recurring peak current I_p is given by

$$I_p = C \times \frac{dv}{dt} = 150\,\mu F \times \frac{0.174\,V}{\mu s} = 26.09\,A$$

C = capacitance in F
I_p = peak current in the application
dv = voltage increment in V
dt = time increment

3.3. Calculation of the Root-mean-square current

$$I_{RMS} = I_p \times \sqrt{2 \times f \times t_r}$$

I_{RMS} = Root-mean-square value (I_{RMS}) of the capacitor current
I_p = peak current in the application
f = AC frequency in Hz
t_r = rise time in s

$$I_{RMS} = I_p \times \sqrt{2 \times f \times t_r} = 26.09\,A \times \sqrt{2 \times 100 \times 2.3 \times 10^{-3}}$$
$$= 17.7\,A \text{ (at } f = 100\,Hz)$$

Type List 3-phase capacitors with fast-wiring screwless terminals

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4. POWER LOSSES AND TEMPERATURE RISE OF A CAPACITOR

Overall power loss:

The overall power loss (P_{loss}) in a capacitor consists of the ohmic losses due to the flow of current plus the dielectric losses inside the capacitor.

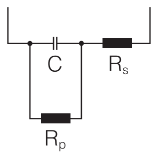
$$P_{loss} = P_{ohmic\ loss} + P_{dielectric\ loss}$$

The loss factor is the tangent of a capacitor's loss angle δ and is calculated as follows:

$$\tan \delta = \frac{P}{Q}$$

This is the ratio of the (notional) equivalent resistance in series with the capacitor to its capacitive reactance for a given AC voltage and frequency.

Equivalent circuit



The tangent of a capacitor's loss angle (tan δ) is thus given by:

$$\tan \delta = \tan \delta_0 + 2\pi \times f_0 \times C \times R_s + \frac{1}{2\pi \times f_0 \times C \times R_p}$$

This latter term is very small for AC applications and can be neglected.

f_0 = frequency of the AC component in the application
C = capacitance of the capacitor
R_s = effective ohmic resistance of the conductors and metallic coating in the capacitor (value stated on the data sheet)
$\tan \delta_0$ = loss factor of the coiled dielectric film used (e.g. $\tan \delta_0$ at Polypropylene = 2×10^{-4})
R_P = resistance in parallel – Represents the insulation resistance of the dielectric with respect to the residual current (This value is very small and can therefore be neglected)

Equivalent Series Resistance (ESR)

The equivalent series resistance (ESR) indicates the effective ohmic resistance which exists between the terminals of the capacitor. All ohmic components are combined (lead wires, contact resistances and the electrodes). ESR values are not mentioned in the respective data sheets of the individual series. Values for specific capacitances can be calculated using the following formula:

$$ESR = \frac{\tan \delta}{2 \times \pi \times f \times C}$$

ESR = Equivalent Series Resistance
tan δ = dissipation factor
f = frequency of the AC voltage component in the application
C = nominal capacitance of the capacitor

It is important to note that the ESR is frequency dependent and this can only be calculated for given sizes. R_s is the effective ohmic resistance of the conductors and metallic coating in the capacitor. It is better to use the R_s with the formulas below, because it is not frequency dependent. But for the sake of completeness ESR is mentioned here.

JUST A FEW STEPS TO SELECTING THE RIGHT POWER ELECTRONICS CAPACITOR!

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4. POWER LOSSES AND TEMPERATURES IN THE CAPACITOR

4.1. Calculation of the total losses of a capacitor

$P_{loss} = P_{ohmic\ losses} + P_{dielectric\ losses}$

Calculation of the ohmic losses:

$P_{ohmic\ losses} = (I_{RMS})^2 \times R_s$

In this example:
$P_{ohmic\ losses} = (I_{RMS})^2 \times R_s = (17.7\ A)^2 \times 0.77\ m\Omega = 241\ mW$

where

$P_{ohmic\ losses}$ = ohmic losses in the capacitor
I_{RMS} = root-mean-square current in the capacitor
R_s = effective ohmic resistance of the conductors and metallic coating in the capacitor (value stated on the data sheet)

4.2. Calculation of the dielectric losses

$P_{dielectric\ losses} = (V_{pp})^2 \times \pi \times f_0 \times C_N \times \tan\delta_0$

In this example:
$P_{dielectric\ losses} = (V_{pp})^2 \times \pi \times f_0 \times C_N \times \tan\delta_0$
$= (500\ V)^2 \times 3.141 \times 100\ Hz \times 150\ \mu F \times 2 \times 10^{-4}$
$= 2.36\ W$

where

$P_{dielectric\ losses}$ = dielectric losses of a capacitor
V_{pp} = peak-to-peak voltage in V between the highest and lowest points of the sine wave
f_0 = AC frequency
C_N = capacitance of the capacitor
$\tan\delta_0$ = loss factor (data sheet);
for polypropylene $\tan\delta_0 = 2 \times 10^{-4}$

4.3. Calculation of the total power losses

Total power losses:

$P_{loss} = P_{ohmic\ losses} + P_{dielectric\ losses}$

In this example:
$P_{loss} = P_{ohmic\ losses} + P_{dielectric\ losses} = 0.241\ W + 2.36\ W = 2.601\ W$

4.4. Calculation of the increase in temperature

Increase in temperature (ΔT) over ambient temperature (self-heating)

$\Delta T = R_{th} \times P_{loss}$

ΔT = temperature increase in kelvin
R_{th} = thermal resistance (on capacitor data sheet)
P_{loss} = total power loss in the capacitor

In this example:

$$\Delta T = R_{th} \times P_{loss} = 2.6\ \frac{K}{W} \times 2.601\ W = 6.76\ K$$

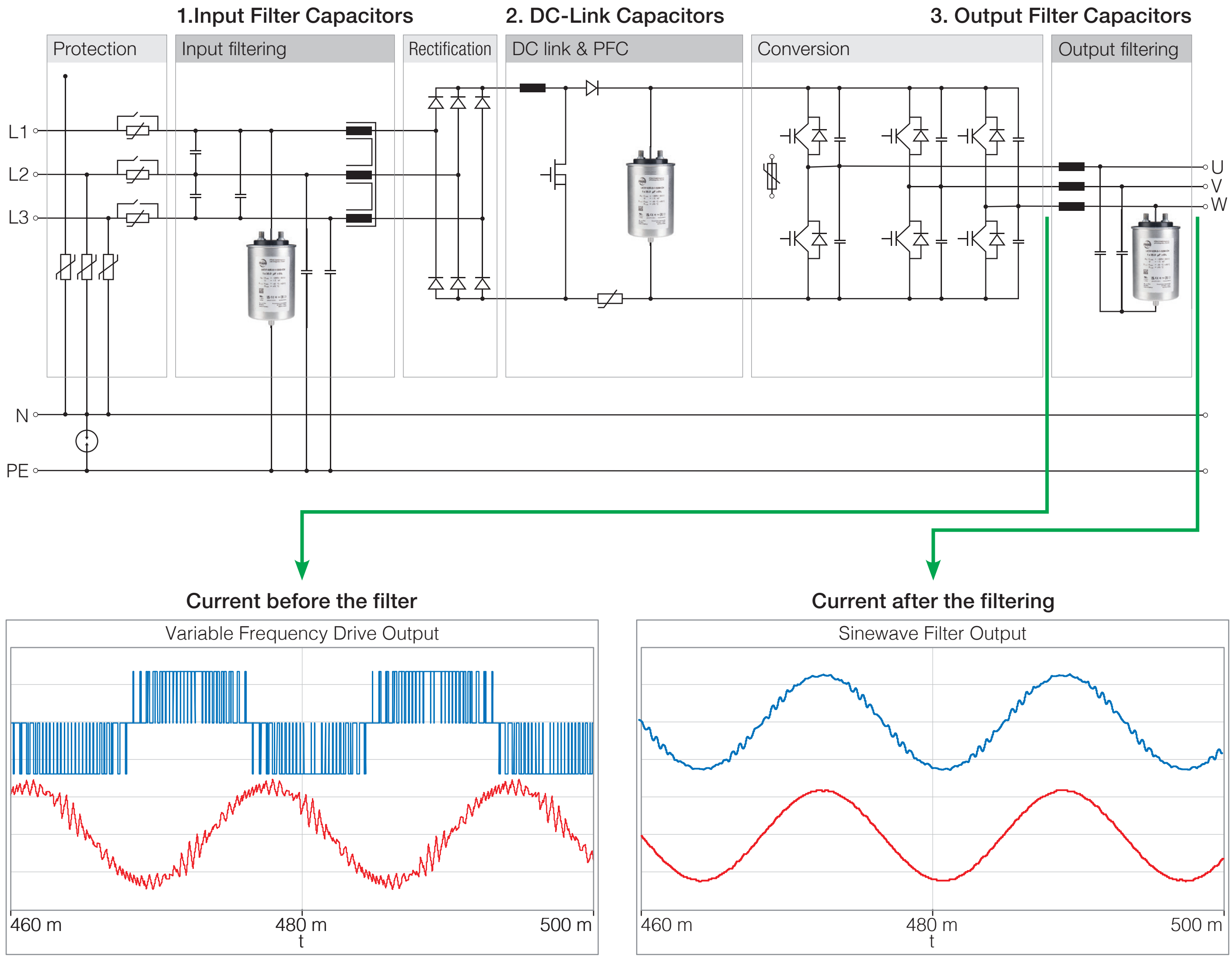
In the case of the AC application in this example, the hottest spot temperature of the capacitor would thus increase by 6.76 Kelvin above ambient temperature.

TEMPERATURE

APPLICATIONS FOR POWER ELECTRONICS CAPACITORS

TYPICAL APPLICATIONS FOR POWER ELECTRONICS CAPACITORS IN FREQUENCY CONVERTERS

A typical use of a capacitor is, for example, a filter for drive technology. The structure of such a drive is shown below. At the end of the converter the filtering of the output signal for the motor takes place. This is exactly where power electronics capacitors from **FRAKO** are used.

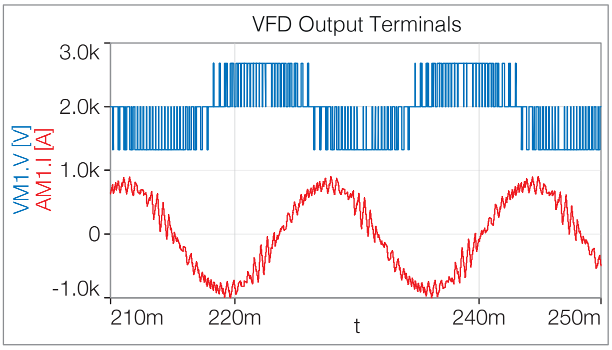


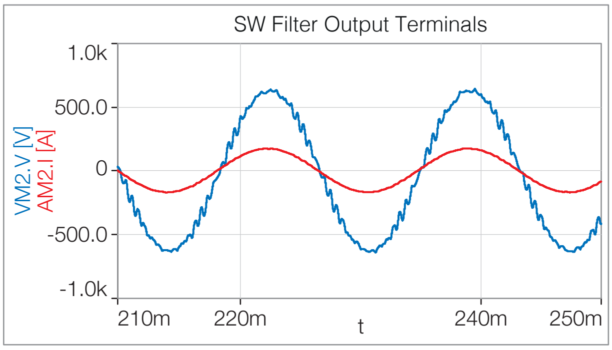
At the output of an inverter the current is not sinusoidal (left). By using a filter capacitor the current is sinusoidal again (right).

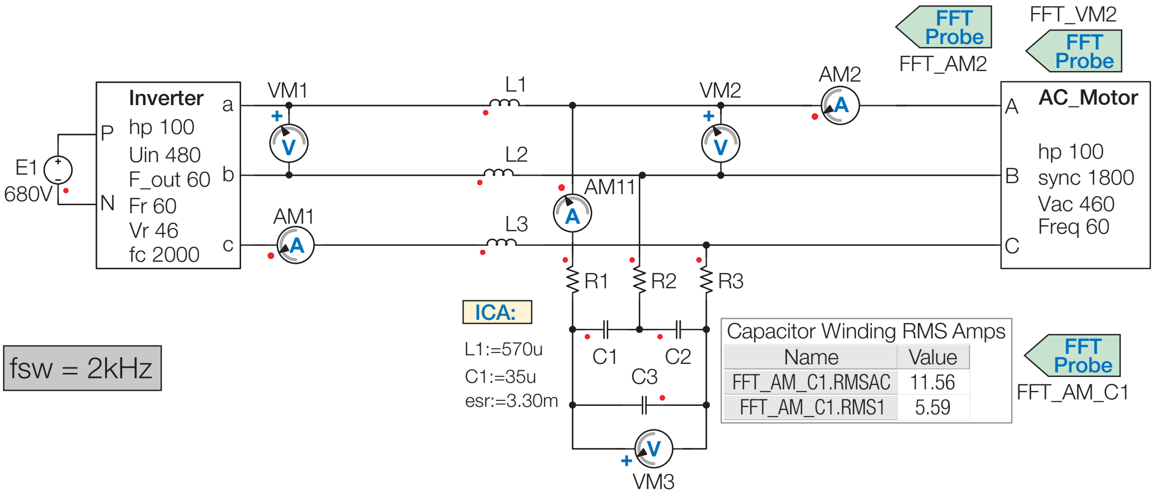
APPLICATION OF A SINE WAVE FILTER

Analysis by a simulation

Simulation of a sinewave filter in a motor application:







Motor Amps & Volts	
Name	Value
FFT_AM2.THD [%]	1.30
FFT_AM2.RMSAC	120.86
FFT_AM2.RMS1	120.85
FFT_VM2.THD [%]	5.25
FFT_VM2.RMSAC	444.82
FFT_VM2.RMS1	444.21

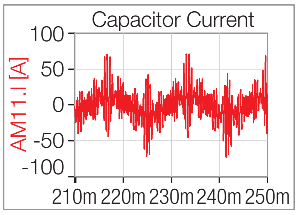
Capacitor Winding RMS Amps	
Name	Value
FFT_AM_C1.RMSAC	11.56
FFT_AM_C1.RMS1	5.59

FFT Probe

FFT_AM11_Fs w

Capacitor PEAK Amps (Fsw)	
Name	Value
FFT_AM11_Fsw.A1	44.10
FFT_AM11_Fsw.A2	6.75
FFT_AM11_Fsw.A3	3.45
FFT_AM11_Fsw.A4	1.93
FFT_AM11_Fsw.A5	235.26
FFT_AM11_Fsw.RMSAC	31.69

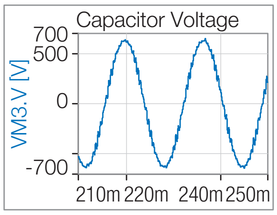
Capacitor RMS Amps (Fsw)	
Name	Value
FFT_AM11_Fsw.RMSAC	31.69
FFT_AM11_Fsw.RMS1	31.18



FFT Probe FFT Probe

FFT_AM11 FFT_VM3

Capacitor LINE Amps & Volts	
Name	Value
FFT_AM11.RMSAC	19.89
FFT_AM11.RMS1	9.43
FFT_VM3.RMSAC	444.79
FFT_VM3.RMS1	444.18



The waveforms show in blue the voltage of the sinewave filter application. The waveforms in red show the current.

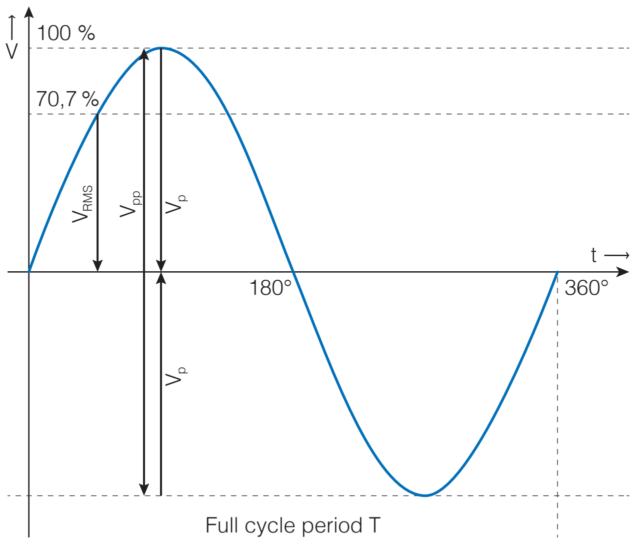
Before filtering:
The waveform on the left side above shows the output voltage and output current of an inverter. The current is not sinusoidal and not suitable for feeding a motor.

During the filtering:
The two waveforms above show in red the filter current and the voltage of the sinewave filter at the capacitor.

After the filtering:
The waveform on the right side shows the voltage and current after the sinewave filter (voltage and current for the motor). Now the current is sinusoidal and suitable to drive a motor.

DEFINITIONS OF TERMS IN AC APPLICATIONS

SINE WAVE PARAMETERS



Symbol	Description	Formulas
V_{pp}	Peak-to-peak voltage between the highest and lowest points of the sine wave	$V_{pp} = 2 \times V_p$ $V_p = 2 \times V_{RMS} \times \sqrt{2}$ $\sqrt{2} = 1.414$
V_p	Peak voltage between the highest or lowest point of the sine wave and the horizontal (zero) axis	$V_p = V_{RMS} \times \sqrt{2}$ $\sqrt{2} = 1.414$
V_{RMS}	Root-mean-square (RMS) voltage, about 70.7 % of the peak voltage V_p AC voltages are as a rule specified by their RMS values. An AC current of 1 A (RMS value) generates the same amount of heat as a DC current of 1 A. The RMS voltage is an effective mean value and is therefore used as the nominal voltage of an AC supply.	$V_{RMS} = V_p \times \frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}} = 0.707$
T	Full cycle period: the time taken for the voltage sine wave to complete one cycle	$T = \frac{1}{f}$
f	Frequency: the number of cycles per second	$f = \frac{1}{T}$

DEFINITIONS OF TERMS IN AC APPLICATIONS

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USEFUL CALCULATION FORMULAS FOR POWER ELECTRONICS CAPACITORS

Capacitance [C] = µF

$$C = \frac{Q_C\,[\text{kvar}] \times 1000}{(V_{\text{phase voltage}})^2 \times 2\pi f}$$

Relationship [CΔ] - [C_Y] = F

$$C_\Delta = 3 \times C_Y \qquad C_Y = \frac{1}{3} \times C_\Delta$$

Reactive power [Q_C] = kvar

$$Q_C\,[\text{kvar}] = \frac{2\pi f \times C \times (V_{\text{phase voltage}})^2}{1000}$$

Current [I] = A

$$I = \frac{Q_C\,[\text{kvar}] \times 1000}{V_{\text{phase voltage}} \times \sqrt{3}}$$

Capacitive reactance [X_C] = Ω

$$X_C = \frac{1}{2\pi f \times C_Y}$$

Resonant frequency [f_r] = Hz

$$f_r = \frac{1}{2\pi f \times \sqrt{L \times C_Y}}$$

Peak current [I_p] = A

$$I_p = C \times \frac{dv}{dt}$$

Total power loss [P_{loss}] = W

$$P_{\text{loss}} = P_{\text{ohmic losses}} + P_{\text{dielectric losses}}$$

Ohmic losses in AC applications
[$P_{\text{ohmic losses}}$] = W

$$P_{\text{ohmic losses}} = (I_{\text{RMS}})^2 \times R_s$$

Dielectric losses in AC applications
[$P_{\text{dieelectric losses}}$] = W

$$P_{\text{dielectric losses}} = (V_{pp})^2 \times \pi \times f_0 \times C \times \tan \delta_0$$

Temperature increase (ΔT) above ambient temperature [ΔT] = K

$$\Delta T = R_{th} \times P_{\text{loss}}$$

DEFINITIONS

NOTES

POWER ELECTRONICS CAPACITORS SELECTION GUIDE

Ideal for filter applications

KEY TO SYMBOLS

C_N	Nominal capacitance
V_N	Maximum operating peak recurrent voltage of either polarity of a reversing type waveform for which the capacitor has been designed
V_{RMS}	Root-mean-square value of the maximum recurrent operating voltage
V_S	Peak voltage induced by switching or any other disturbance of the system which is allowed for a limited number of times and for durations shorter than the fundamental cycle period
V_I	Root-mean-square value of the sine wave voltage for which the insulation between the terminals of the capacitors to the casing or earth is designed
$V_{M/M}$	Voltage metallic coating / metallic coating
$V_{M/C}$	Voltage metallic coating / housing
V_I	Isolation voltage
V_{pp}	Peak-to-peak voltage in V between the highest and lowest points of the sine wave
I_{max}	Root-mean-square value of the maximum current in continuous operation
I	Maximum repetitive peak current that can occur for a short duration in continuous operation
I_p	Peak non-repetitive current induced by switching or any other disturbance of the system which is allowed for a limited number of times, for durations shorter than the fundamental cycle period
L_{self}	Self-inductance
R_{th}	Thermal resistance (on capacitor data sheet)
R_S	Effective ohmic resistance of a capacitor's conductors and metallic coating under specified operating conditions
P_{loss}	Maximum power loss at which the capacitor may be operated at the maximum casing temperature
$P_{ohmic\ losses}$	Ohmic losses in the capacitor
$P_{dielectric\ losses}$	Dielectric losses in the capacitor
f_0	AC frequency
f_1	Frequency at which the power loss of the capacitor is maximum at the nominal voltage
f_2	Maximum frequency at which the maximum current produces the maximum power loss in the capacitor
θ_{min}	Lowest temperature at which the capacitor may be energized
θ_{max}	Highest temperature of the casing at which the capacitor may be operated
ΔT	Temperature increase in kelvin
$\tan \delta_0$	Loss factor of the coiled dielectric film used (**$\tan \delta_0 = 2 \times 10^{-4}$** at **FRAKO** capacitors)

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