Calculating and Interpreting Power Dissipation for Polypropylene Film DC-Link Capacitors

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Vishay MKP1848 series datasheets display important information for the preliminary calculation of power dissipation, and the consequent temperature rise as a function of the ripple current flowing through the capacitor.

Film capacitors can deliver high power density due to their low ESR and high ripple current capabilities, and offer the highest ampere per µF ratio of capacitor technologies. This feature, combined with their high reliability and long lifespan, make the film DC-link capacitor a central component for power inverters in industrial and automotive applications.

Despite these benefits, when designing in the MKP1848 DC-link capacitor, power dissipation must be taken into consideration, as well as the influence of the expected ambient temperature on the application. Therefore, for a selected capacitor it is important to establish the expected power dissipation and component temperature for a given ripple current.

CASE STUDY

An engineer is designing a solar inverter and selects an MKP1848650704Y5 capacitor, which will have to comply with the operating conditions below:

- V_{DC} = 630 V_{DC}
- V_{DC} (max.) = 750 V_{DC}
- I_{RMS} (max.) = 19 A
- f_{sw} = 20 000 Hz
- T_{amb} = 70 °C

The engineer wants to know if these conditions are acceptable for the MKP1848650704Y5, and their level of power dissipation and temperature rise.

ELECTRICAL DATA AND ORDERING CODE

U_{NDC} AT 85 °C (V)	CAP. (8) (µF)	DIMENSION (5) (mm)			P1 (mm)	P2 (mm)	dV/dt (V/µs)	I_{PEAK} (A)	I_{RMS} (2) (A)		ESR (3) (mΩ)		tan δ 10 kHz (< 10^{-4}) (4)		ORDERING CODE (1)
		w	h	l					2 PINS	4 PINS	2 PINS	4 PINS	2 PINS	4 PINS	
700	U_{OPDC} AT 70 °C = 800 V, U_{OPDC} AT 105 °C = 500 V														
	50	30	45	57.5	52.5	20.3	20	1000	15	15.5	5.5	5	270	240	MKP1848650704Y*

From the above information retrieved from the MKP1848 datasheet, and knowing that the MKP1848650704Y5 is a 4-pin device, the specified ripple current for the part is 15.5 A. However, the values specified are at nominal conditions, including a nominal temperature of 85 °C. To understand what can be admissible at 70 °C, the engineer will then consult the “Maximum I_{RMS} Current in Function of Ambient Temperature” graph, which is also available on Vishay MKP1848 series datasheets for the benefit of the designer.

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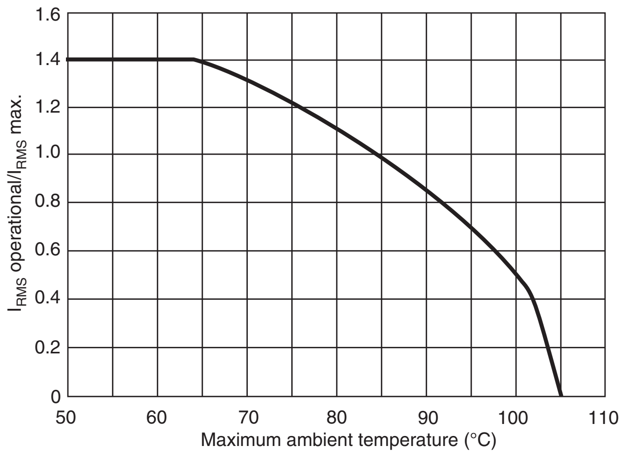

Maximum I_{RMS} current in function of the ambient temperature

From the graph, we can determine that at 70 °C a factor of 1.3 can be multiplied by the maximum ripple current specified on the “Electrical Data and Ordering Code” table displayed above. Consequently, the operational I_{RMS} current at 70 °C is 20.15 A, which means the capacitor is able to withstand the maximum I_{RMS} current specified by the engineer for the inverter’s DC-link capacitor.

The next step is to estimate how the capacitor will be and determine the power dissipation by ohmic losses. The “Electrical Data and Ordering Code” table shows that the MKP1848650704Y5 has an equivalent series resistance (ESR) of 5 mΩ. It is widely known that ESR changes with frequency. Vishay's MKP1848 datasheet specifies the frequency range applicable to the given typical ESR value:

- Capacitors with 27.5 mm lead spacing: from 10 kHz up to 100 kHz
- Capacitors with 37.5 mm lead spacing: from 10 kHz up to 70 kHz
- Capacitors with 52.5 mm lead spacing: from 10 kHz up to 50 kHz

The switching frequency utilized by the inverter under design is 20 kHz, which means that the typical ESR value specified in the “Electrical Data and Ordering Code” table is applicable up to 50 kHz, since the MKP1848650704Y5 features lead spacing of 52.5 mm. To estimate the power dissipation:

$$P_d = ESR \times I_{RMS}^2 = 5 \times 10^{-3} \times 19^2 = 1805 \text{ mW}$$

With a simple mathematical operation, using only data provided the datasheet, an estimation of the power dissipation can be calculated. But how can this be related to temperature rise, as these are Joule effect losses? Once again, the DC-link datasheet provides the necessary data to make this estimation.

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HEAT CONDUCTIVITY			
DIMENSIONS (mm)			HEAT CONDUCTIVITY (mW/°C)
w	h	l	
9.0	19.0	32.0	24
11.0	21.0	32.0	28
13.0	23.0	32.0	32
15.0	25.0	32.0	36
18.0	28.0	32.0	44
21.0	31.0	32.0	51
21.0	35.0	32.0	56
18.5	35.5	43.0	54
21.5	38.5	43.0	61
24.0	44.0	42.0	70
30.0	45.0	42.0	81
25.0	45.0	57.5	77
30.0	45.0	57.5	85
35.0	50.0	57.5	100
45.0	45.0	57.5	94
70.0	65.0	57.5	152
130.0	65.0	57.5	243

The table above specifies the heat conductivity (G) for each of the catalog's standard dimensions. The MKP1848650704Y5's dimensions are 30 mm x 45 mm x 57.5 mm, corresponding to a heat conductivity of 85 mW/°C. For 20 kHz at a 19 A ripple current, the temperature rise (ΔT) is:

$$\Delta T = \frac{P_d}{G} = \frac{1805}{85} = 21.2\ °C$$

At an ambient temperature of 70 °C, the capacitor temperature (T_C) is:

$$T_C = T_{amb} + \Delta T = 70 + 21.2 = 91.2\ °C$$

Based on the fact that the maximum rated voltage is 700 V_{DC} at 85 °C and 500 V_{DC} at 105 °C, it can be linearly derived that at 91.2 °C the maximum allowed voltage is 638 V. So there is no problem with 630 V_{DC} in this application.

Having estimated the power dissipation and component temperature for their application, the engineer has a final concern. During startup of the solar inverter, at dawn and sundown, there is no load on the inverter, causing the DC-link voltage to rise up to 750 V_{DC}. Since the MKP1848650704Y5 has a rated voltage of 700 V_{DC}, can this represent a hazard for the capacitor?

The answer is no. The MKP1848 DC-link series specifies nominal DC voltage at 85 °C, but at lower temperatures the operating voltages may be higher, as can be seen in the "DC Voltage Ratings" table in the datasheets:

DC VOLTAGE RATINGS						
U_{NDC} at 85 °C	450 V	700 V	800 V	900 V	1100 V	1200 V
U_{OPDC} at 70 °C	500 V	800 V	900 V	1100 V	1350 V	1500 V
U_{OPDC} at 105 °C	300 V	500 V	570 V	650 V	800 V	850 V

So, for the MKP1848650704Y5, operating at 70 °C allows for an operating voltage of 800 V_{DC}. With a maximum DC-link voltage, during inverter initialization 750 V_{DC} is well within the operating range of the DC-link capacitor.

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CONCLUSION

With the aid of the detailed information in Vishay's MKP1848 series datasheets, it is simple to estimate a component's performance and adequacy to a given mission profile. This information is available on the AEC-Q200 automotive grade MKP1848, the compact industrial grade MKP1848C, and also on the slim, low profile MKP1848S.

Power dissipation and the consequent temperature rise in components are major design aspects to consider when designing a capacitor into an inverter's DC-link. Film capacitors offer the lowest ESR, and as high power density devices, offer higher ripple current capabilities. However, these benefits have limits and need to be accounted for.

For more precise calculations, please contact Vishay Intertechnology, Inc.

Datasheets:

MKP1848 - www.vishay.com/doc?28164

MKP1848C - www.vishay.com/doc?26015

MKP1848S - www.vishay.com/doc?26010