AC Film Capacitors in Connection With the Mains (≤ 60 Hz)

By Geert Stevens

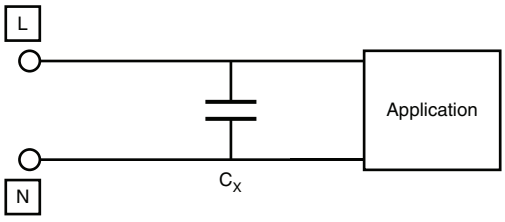
Because of the high energy availability and the severe environment of surge voltages and pulses, applications of capacitors in connection with the mains must be chosen carefully.

Two kinds of connections, and thus two kinds of applications, can be distinguished.

One is where the capacitor is directly connected in parallel with the mains without any other impedance or circuit protection, and another where the capacitor is connected to the mains in series with other circuitry.

CAPACITORS DIRECTLY CONNECTED IN PARALLEL WITH THE MAINS WITHOUT ANY OTHER IMPEDANCE OR CIRCUIT PROTECTION (ACROSS THE LINE OR X CLASS CAPACITORS)

To help reduce emissions and increase the immunity of radio interference, electromagnetic interference suppression film capacitors (EMI capacitors) are playing a major role in all kinds of applications. These capacitors are placed directly parallel over the mains at the input of the appliances.



Several functions are combined in these small components: excellent high frequency properties for short circuiting radio interference, the ability to withstand continuous stress from the AC mains voltage, and the ability to sustain transient voltages - caused, for example, by lightning strikes and switching - superimposed on the line.

For EMI capacitors, it is very difficult to fulfill the stringent requirements for safety, while at the same time miniaturizing the components to offer customers benefits in terms of costs, functionality, and mounting possibilities.

There are five main characteristics for EMI capacitors:

- Excellent capacitive filter: low inductance and equivalent series resistance are preferred
- Withstanding pulse loads: uncontrolled mains switching must be sustained
- Continuously biased by the mains voltage: a powerful energy supply is always available
- Withstanding surge voltages: high energy surge voltages could destroy the capacitors
- Safe end of life behavior

It has been noted by several national authorities that safety is the top priority for these components. Therefore, international safety standards have been developed, including IEC 60384-14 (world standard) and UL1414 (U.S. standard). National authorities prescribe that EMI capacitors connected directly in parallel with the mains must be proven to fulfill these standards. Approved products receive safety certificates and are identified with the following safety marks:

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COUNTRY	SAFETY STANDARD	APPROVAL MARK
U.S.A.	UL 60384-14	
Canada	CSA E384-14	
U.S.A. and Canada	Combination mark (UL 60384-14 + CSA E384-14)	
China	CQC	
Europe	EN 60384-14 and IEC 60384-14	(1)

Note

(1) ENEC10 or ENEC16 depending on approval office

When choosing an EMI capacitor, it is important to select a device with a higher rated voltage than the nominal mains voltage, to withstand mains instabilities and voltage tolerances. The **nominal voltage** is normally used in the connection of the mains (supply) voltage with an associated tolerance. It can be understood in a way to be "the name" of the voltage (e.g. 240 V_{AC}, ± 10 %). The **rated voltage** is the property of a component, device, or equipment, and defines the voltage that can be handled (e.g. for a nominal 240 V_{AC} supply voltage, the rated voltage must be a minimum of 264 V_{AC}).

Based on many years of experience, Vishay has introduced several EMI product series that fulfill these strong safety standards for across the line applications. Depending on the customer's application needs, the following product series are recommended:

CLASS	X2	X1 (4)	
NOMINAL (1) MAINS VOLTAGE (V_{AC})	**≤ 277**	**≤ 277**	**277 < ... ≤ 480**
Standard across the line applications, stability grade as per IEC 60384-14 (2)	MKP336 2 MKP338 2 MKP338 4 MKP339 F1778 F339X2 F340X2	F339X1 330VAC	MKP338 1 F339X1 480VAC F340X1
For continuous (3) across the line operation, higher stability grade than per IEC 60384-14 (2)	F340X2 F1772..2	F340X1 480VAC F340X1	

Notes

(1) The nominal voltage is the voltage of the mains supply without tolerances or instability

(2) IEC 60384-14 endurance test conditions require ± 10 % capacitance change after 1000 h of testing

(3) Continuous in the meaning of uninterrupted connection to the mains, 24 h a day for several years

(4) It is recommended to use only X1 capacitors in across the line 3-phase filter applications

APPLICATION NOTE

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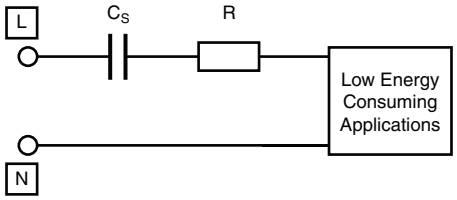
CAPACITORS CONNECTED TO THE MAINS IN SERIES WITH OTHER CIRCUITRY (SERIES IMPEDANCE APPLICATION)

In many appliances, a low voltage supply is needed for simple low energy consuming functions like sensing and phase detection. To reduce the voltage, reactive impedances like film capacitors are used.



In this application, capacitors are connected in series to the mains and the functions to be fulfilled are:

- Stable voltage dropper: a stable capacitance must be guaranteed over the total lifetime of the application
- An adjusted tolerance: to guarantee a well-defined current supply
- Continuously biased by almost the mains voltage: internal ionization must be avoided

But what about withstanding surge voltages? And what about safety?

As these capacitors are connected through other circuitry, the equivalent impedance of this circuit can protect them. A film capacitor could be destroyed when a high energy pulse is applied and its self-healing properties fail (self-healing is the ability to recover after a breakdown). As a general rule for standard capacitors that are not approved according to international standards for EMI devices, this can happen if surges occur higher than the guaranteed proof voltage. This is in general 1.6 times the rated DC voltage, or 4.3 times the rated AC voltage.

As it is generally accepted that surge voltage (1.2 µs rise time / 50 µs duration) can occur at the entrance of appliances rated to 2.5 kV for installation category II and 4 kV for installation category III (IEC 60664-1), the customer must verify that the impedance in series with the capacitor limits the overvoltage to these values. In general, this will be the case because it can easily be calculated that equivalent impedances will be in the range of 220 Ω to a few kΩ, depending on the low voltage application, and by this the surge will be topped off to a few hundred volts maximum.

In all other conditions an approved safety component must still be used, but here the extra functions of capacitance stabilization and tolerance adjustment must be fulfilled as well. This can only be guaranteed by a different capacitor construction, wherein two capacitor sections are internally connected in series.

For these series impedance applications, Vishay also offers a wide range of products to fulfill customers' needs and requirements:

CLASS	WITHOUT SAFETY APPROVALS [3]	WITH SAFETY APPROVALS	
NOMINAL [1] MAINS VOLTAGE (V_{AC})	**≤ 277**	**≤ 277**	**277 < ... ≤ 480**
Standard and continuous [2] in series with the mains operation	[4]	F1772..2	F339X1 480VAC F340X1 480VAC

Notes

[1] The nominal voltage is the voltage of the mains supply without tolerances or instability

[2] Continuous in the meaning of uninterrupted connection to the mains, 24 hours a day for several years

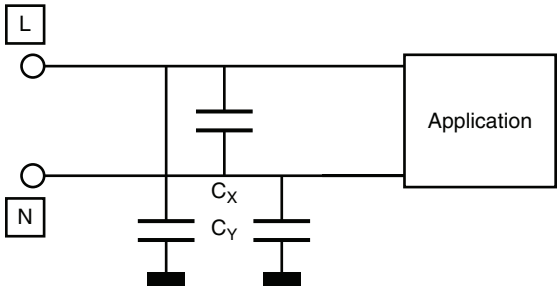
[3] The applicant must guarantee that the maximum continuous mains voltage is lower than the rated AC voltage and that maximum temporary overvoltages (< 2 s) are lower than 1.6 times the rated DC voltage or 4.3 times the AC rated voltage. Instructions can be found in the application notes and limiting conditions in the specifications

[4] For the right component choice, contact rfi@vishay.com

AC Film Capacitors in Connection With the Mains (≤ 60 Hz)

CAPACITORS DIRECTLY CONNECTED IN PARALLEL BETWEEN THE MAINS AND GROUND (LINE BYPASS OR Y CLASS CAPACITORS)

To help reduce common mode electromagnetic interference, capacitors are connected between the mains and ground. For these applications, only approved safety components are allowed. Different safety classes and standards are defined in the same IEC 60384-14 and UL 60384-14 standards.



Vishay has the following products in its film capacitor portfolio, adapted for customers' specific needs:

CLASS	Y2
NOMINAL (1) MAINS VOLTAGE (V_{AC})	**≤ 277**
Line bypass application for continuous (2) operation	MKP338 6 F1710 F340Y2

Notes

(1) The nominal voltage is the voltage of the mains supply without tolerances or instability

(2) Continuous in the meaning of uninterrupted connection to the mains, 24 h a day for several years

AC FILM CAPACITORS IN CONNECTION WITH A MAINS OF 400 Hz

In some special mains applications, the frequency is 400 Hz instead of the traditional 50 Hz or 60 Hz. Vishay EMI capacitors can be used for such applications, taking in account an additional de-rating of the product. This is needed because film capacitors are generally more sensitive to ionization damage at a higher frequency.

CLASS	X2	X2	X1
NOMINAL (1) MAINS VOLTAGE (V_{AC})	**≤ 240**	**240 < ... ≤ 277**	**... ≤ 480**
Standard across the line applications, stability grade as per IEC 60384-14 (2)	MKP338 4	Use F340X1 as X2 type	F340X1 480VAC (4)
For continuous (3) across the line operation, higher stability grade than per IEC 60384-14 (2)	F340X1 480VAC		

Notes

(1) The nominal voltage is the voltage of the mains supply without tolerances or instability

(2) IEC 60384-14 endurance test conditions require ± 10 % capacitance change after 1000 hours of testing

(3) Continuous in the meaning of uninterrupted connection to the mains, 24 hours a day for several years

(4) For capacitance values ≤ 1 µF, due to exceeded power dissipation at 400 Hz

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HUMIDITY ROBUSTNESS

EMI capacitors in general are subject to ionization phenomena, humidity, or a combination of both. These phenomena can result in a gradual capacitance decrease and ESR increase over the component's lifetime. As not all capacitors are used under the same circumstances, Vishay has defined three humidity robustness classes for its EMI series capacitors that surpass standard performance:

- Robustness under humidity grade (I)
- Robustness under high humidity grade (II)
- High robustness under high humidity grade (III)

For each application field, Vishay can offer the best solution for EMI capacitors:

ROBUSTNESS GRADE	PERFORMANCE TEST	FAMILY		
		X2	X1	Y2
Standard	40 °C / 93 % RH, duration of 56 days, no voltage	MKP339 MKP336 2 MKP338 2 MKP338 4 F1778 F1773 F1772..2	F339X1 330VAC F339X1 480VAC MKP338 1	MKP338 6 F1710
II	85 °C / 85 % RH, duration of 500 h, rated voltage applied	F339X2	-	-
III	85 °C / 85 % RH, duration of 1000 h, rated voltage applied	F340X2	F340X1	F340Y2