ISSUE: December 2019

X-Capacitor Discharge Must Satisfy Both Safety And Energy Efficiency Rules

by Kevin Parmenter, Chair, and James Spangler, Co-chair, PSMA Safety and Compliance Committee

Many products including power supplies and household products are connected to the ac line. Within these products we find the so-called X capacitors used to provide line filtering. If no measures are taken to discharge these capacitors, they can retain a high-voltage charge even after ac power is removed from the product.

So, when the consumer removes the ac power cord plug of one of these products from the ac socket, there may be significant voltage remaining on the X capacitors. This high voltage may cause a shock to the consumer if their fingers touch the metal prongs of the ac plug during or shortly after its removal from the wall socket.

There are several regulations from the IEC/EN to prevent the consumer from being shocked if their fingers should touch the metal prongs of the ac power plug. These regulations are based on the IEC60335[1], IEC62368[2] , and IEC/EN/ UL 60950[3] standards.

IEC62368 applies to IT equipment and video and audio equipment, while the IEC60335 concerns appliances. Meanwhile, UL/EN/IEC 60950 is the harmonized standard for power supplies. UL has regulated the discharge of X capacitors for many years for TVs, where the X capacitor typically had a resistor value between a 1.0 MΩ and 2.2 MΩ to discharge them.

Satisfying the safety requirements for the discharge of X capacitors would be straightforward were it not for the energy efficiency standards, which are pervasive and over time are becoming more demanding. The simple act of using discharge resistors in a product's power supply can raise its power consumption under no-load or standby conditions to the point where it may exceed the mandated levels. This article discusses both the safety and energy efficiency requirements, looks at the different circuit approaches to discharging X capacitors and how well they do in terms of satisfying the energy efficiency regulations.

While the focus here is mainly on the X capacitors, note that there also Y capacitors. Nick Davis[4] describes these X and Y capacitors along with the IEC ratings in his article, "Safety Capacitors First: Class-X and Class-Y Capacitors".

The Y capacitor is connected from the mains to ground while the X capacitor is connected across the ac power mains. Fig. 1 shows both capacitor types. The Y capacitors are often ceramic and less than 0.0033 µF or 3.3 nF. The X capacitors cited in the standards are greater than 0.1 µF. These X capacitors are to be discharged to less than 34 V peak in 1 second after the power plug is removed from the socket. While it's only the X capacitors that pose the safety hazard, the Y capacitors are important to the discussion because they contribute to the ac leakage current. Therefore they also impact a product's ability to meet the energy efficiency rules.

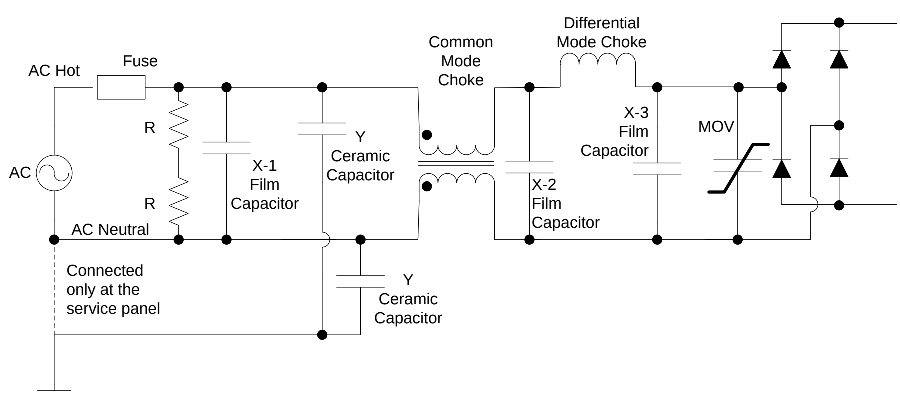

Fig. 1. Generic schematic showing the front end of a power supply including discharge resistors, R, common-mode choke, differential-mode choke, X film capacitors, and Y ceramic capacitors for a product. The X capacitors are for EMI control, and the Y capacitors are limited in value due to leakage current to ground.

© 2019 How2Power. All rights reserved.

Discharge Resistor Power Consumption

While a product is plugged in, any discharge resistors associated with X capacitors will be continuously dissipating power, contributing to the product's continuous power loss.

The power loss produced by an X capacitor discharge resistor is a function of the ac line voltage and the resistor value:

$$Power_{Loss} = {(Vac\ Line)^2}/{R}$$

In the U.S., Canada, and Mexico, Vac is 120 Vrms nominal and R is typically 1 MΩ, so

$P_{ower\ Loss}$ = 0.0144 W or 14.4 mW

In Europe, Vac is 230 Vrms nominal and R is typically 1 MΩ, so

$P_{ower\ Loss}$ = 0.0529 W or 52.9 mW

This wattage seems small until you take into account the standby power requirements for some products. The U.S. Department of Energy[5] and the California Energy Commission[6] have new requirements for standby energy consumption that are, in the most stringent case, less than 2X the loss imposed by the discharge resistor. The no-load mode power is given below in Table 1.[7]

Table 1. Efficiency requirements for single-voltage power supplies.

Nameplate Output Power (P_{no})[1]	No-Load Mode Power	Nameplate Output Power (P_{no})	Average Efficiency in Active Mode[2]
0 to ≤ 49 W	AC-DC: ≤ 0.100 AC-AC: ≤ 0.210	0 to ≤ 1 W	Basic Voltage: ≥ 0.5 * P_{no} + 0.16 Low Voltage[3]: ≥ 0.517 * P_{no} + 0.087
		> 1 to ≤ 49 W	Basic Voltage: ≥ 0.071 * ln(P_{no}) – 0.0014 * P_{no} + 0.67 Low Voltage[3]: ≥ 0.0834 * ln(P_{no}) – 0.0014 * P_{no} + 0.609
> 49 to ≤ 250 W	≤ 0.210	> 49 to ≤ 250 W	Basic Voltage: ≥ 0.880 Low Voltage[3]: ≥ 0.870
> 250 W	≤ 0.500	> 250 W	≥ 0.875

Discharge Time For X Capacitors

According to IEC 60335[1] and IEC 62368[2], the voltage across the X capacitors must be below 34 V, in less than 1 second. The X capacitors are part of the line-conducted EMI filter, and the values of these capacitors are determined at the time line-conducted EMI testing is performed. The design engineer should use place holders on the pc board so the different values can be tried.

Table 2 was created to show the value of the two resistors in series in Fig. 1 to discharge the total of X2 capacitors. The value of the X capacitors ranges from 0.1 μF to 5.6 μF. The voltage used for the calculation was 230 Vac. In addition, the power dissipation was calculated for the resistors in series. The value of the capacitance is the sum of the EMI capacitors including X-1, X-2, X-3 and the MOV capacitance.

© 2019 How2Power. All rights reserved.

Table 2. Discharge resistor values for power supply circuit in Fig. 1.

Capacitance value (µF)	Resistor value	Power dissipation (W)
0.10	4.43 MΩ	0.012
0.22	2.01 MΩ	0.026
0.33	1.34 MΩ	0.039
0.47	942 kΩ	0.056
0.68	651 kΩ	0.081
1.00	443 kΩ	0.119
2.20	201 kΩ	0.261
3.30	134 kΩ	0.394
4.70	94 kΩ	0.561
5.60	79 kΩ	0.668

The power dissipation shown exceeds the 0.1 W in the U.S. Department of Energy's standby power no-load regulations for some low-wattage power supplies and battery chargers of cell phones. To reduce the power dissipation in the standby mode, the semiconductor industry created X2 discharge ICs such as the Power Integrations CAPZero[8] family of parts. In a nutshell, these ICs disconnect the discharge resistors from the circuit when a product is plugged in, and reconnect these resistors at the time ac power is removed. In this way, the discharge resistors are not dissipating unnecessary power that contributes to the product's standby or no-load power consumption.

Other companies have similar parts such as the TEA1708[9] and HF81.[10] This approach is shown in Fig. 2, which is taken from the Power Integration Application Note AN-48.[15]

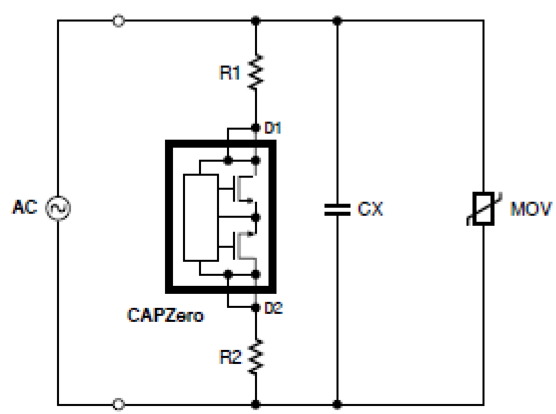

Fig. 2. CAPZero X-capacitor discharge IC approach. While the product is plugged in, the CAPZero IC disconnects the discharge resistors so that they are not dissipating power.

The semiconductor industry has found other ways to discharge the X capacitors and these methods have been implemented in pulse width modulation control ICs for the power supplies. This approach eliminates a separate X capacitor discharge control IC.

Some of these ICs were found via web search using "X capacitor discharge" as the search topic: FAN6756,[11] NCP12400,[12] TEA19363,[13] and BM1C102F.[14] This is not a complete list. The PWM control IC approach shown in Fig. 3 is taken from the NCP12400.

© 2019 How2Power. All rights reserved.

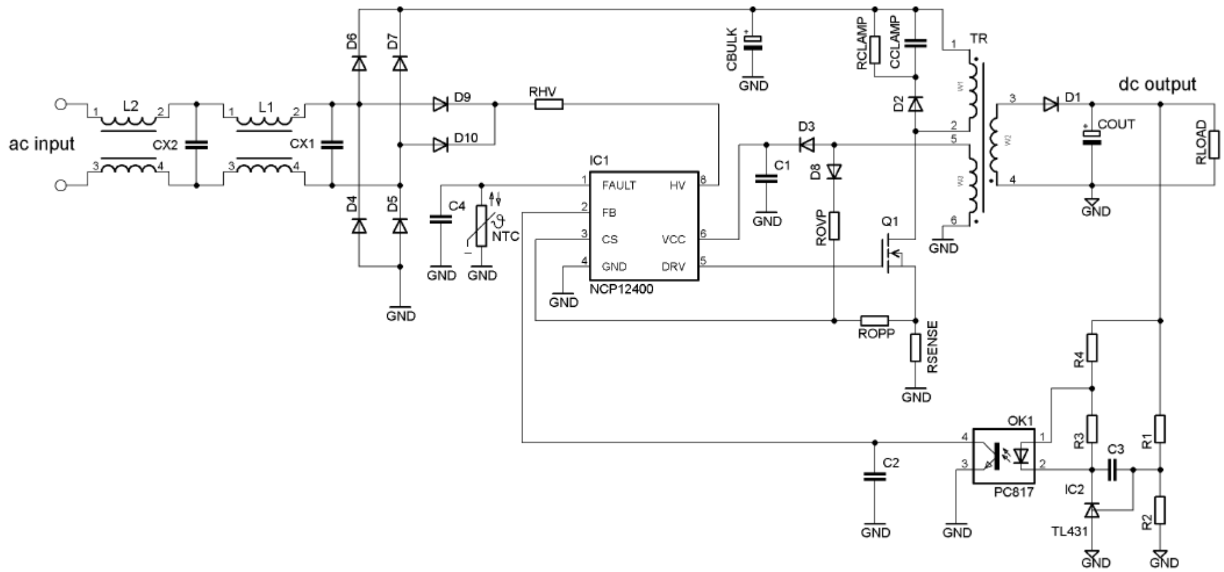

Fig. 3. The discharging of the X capacitors using the NCP12400.

The application note AN-48[15] from Power Integrations was helpful in determining the values of the discharge resistors and the time to discharge the X-capacitors. The X-capacitors used in the EMI or RFI filter capacitors can be classified as either X1 or X2 depending upon the construction of the capacitors; reference 4 explains the difference and uses of these capacitors.

Summary

This article explains why there are discharge resistors across the X capacitors of a product. The resistor is used to discharge the voltage left on the capacitor to a safe level so as not to cause an electrical shock to the consumer when the product in unplugged. The time allowed to discharge the capacitor is 1 sec.

However, whenever a product is plugged in, the discharge resistors are consuming power, unless there is a control IC used to eliminate the resistors' constant current draw. Without such a control IC, the power draw of the discharge resistors contributes to the product's power consumption in the standby or no-load mode and may exceed the power consumption mandated by regulatory agencies, including the U.S. Department of Energy and the California Energy Commission. Similar regulations apply in Europe.

References

1. IEC 60355.
2. IEC 62368.
3. UL 60950-1.
4. "Safety Capacitors First: Class-X and Class-Y Capacitors" by Nick Davis, All About Circuits, May 06, 2019.
5. U.S. Department of Energy.
6. California Energy Commission.
7. https://ac-dc.power.com/green-room/regulations-agency/us-doe-eisa2007-energy-independence-and-security-act/
8. CAPZero-3 and CAPZer0-2 product page.
9. TEA1708T data sheet.
10. HF81 data sheet.
11. FAN6756 product page.
12. NCP12400 product page.
13. TEA19363 data sheet.
14. BM1C102F data sheet.
15. "CAPZero Design Considerations," Power Integrations application note AN-48.

© 2019 How2Power. All rights reserved.

Acknowledgements

I would like to thank Edward Ong of Power Integration and Carl Walding of On Semiconductor for their input to this article.—Jim Spangler

About The Authors

Kevin Parmenter is an IEEE Senior Member and has over 20 years of experience in the electronics and semiconductor industry. Kevin is currently director of Field Applications Engineering North America for Taiwan Semiconductor. Previously he was vice president of applications engineering in the U.S.A. for Excelsys, an Advanced Energy company; director of Advanced Technical Marketing for Digital Power Products at Exar; and led global product applications engineering and new product definition for Freescale Semiconductors AMPD - Analog, Mixed Signal and Power Division.

Prior to that, Kevin worked for Fairchild Semiconductor in the Americas as senior director of field applications engineering and held various technical and management positions with increasing responsibility at ON Semiconductor and in the Motorola Semiconductor Products Sector. Kevin also led an applications engineering team for the start-up Primarion.

Kevin serves on he board of directors of the PSMA (Power Sources Manufacturers Association) and was the general chair of APEC 2009 (the IEEE Applied Power Electronics Conference.) Kevin has also had design engineering experience in the medical electronics and military electronics fields. He holds a BSEE and BS in Business Administration, is a member of the IEEE, and holds an Amateur Extra class FCC license (call sign KG5Q) as well as an FCC Commercial Radiotelephone License.

Jim Spangler is a Life Member of the IEEE with over 40 years of electronics design experience and is president of Spangler Prototype Inc. (SPI). His power electronics engineering consulting firm's priority is helping companies to place products into production, assisting them to pass government regulations and agency standards such as UL, FCC, ANSI, IES, and the IEC.

For many years, he worked as a field applications engineer (FAE) for Motorola Semiconductor, On Semiconductor, Cirrus Logic, and Active Semiconductor, assisting customers in using semiconductors. He published numerous application notes and conference papers at a variety of conferences: APEC, ECCE, IAS, and PCIM. Topics included power factor correction, lighting, and automotive applications. As an FAE, he traveled internationally giving switch-mode power supply seminars in Australia, Hong Kong, Taiwan, Korea, Japan, Mexico, and Canada.

Jim has a Master's Degree from Northern Illinois University (NIU), and was a PhD candidate at Illinois Institute of Technology (IIT). He taught senior and first-level graduate student classes: Survey of Power Electronics, Fields and Waves, and Electronic Engineering at IIT and Midwest College of Engineering.

Jim is a member of the IEEE: IAS, PELS, PES; the Illuminating Engineering Society (IES), and the Power Sources Manufacturers Association (PSMA) where he is co-chair of the Safety and Compliance Committee.

For further reading on power supply-related safety and compliance issues, see How2Power's special section on Power Supply Safety and Compliance.

© 2019 How2Power. All rights reserved.