

# POLYPROPYLENE CAPACITORS FOR SNUBBER APPLICATIONS

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*Abstract*-- With so many types of capacitors available, circuit designers are faced with the challenge of selecting a capacitor that will be suitable for a specific snubber application. It is essential that the designer know the approximate conditions to which the capacitors will be exposed. The most important being peak voltage, temperature,  $dV/dt$ , and frequency. The designer may also be faced with constraints such as size, maximum allowable inductance, and cost. Once these conditions and constraints are identified the designer can begin the selection process.

## INTRODUCTION

Film capacitors are employed in a variety of applications where they may be used for filtering, energy discharge, power factor correction, snubbing and other power electronics applications. A number of film dielectrics are available, each having electrical and physical characteristics which may or may not make it ideal for a particular application. Polyester, polycarbonate and polypropylene are the most widely used film dielectrics in power electronics applications. Polycarbonate has fairly low loss and can be used at higher temperatures, but it is expensive relative to the other dielectrics. Polycarbonate caps are used mostly in military rather than commercial applications. Polyester is very lossy compared to polypropylene and polycarbonate. It is therefore used in light duty dc applications as well as some 60 Hz ac applications. Of the three dielectrics, polypropylene has the lowest losses over a broad frequency range making it suitable for high frequency power electronics applications where ambient temperatures don't exceed about 100 degrees centigrade [1 & 2].

## ELECTRODE TYPES

There are three major types of polypropylene film capacitors used in snubber circuits for power electronics applications. These are: *metallized*, *film/foil*, and *metallized/foil* - hybrid capacitors. Metallized capacitors use thin plastic films coated with vapor deposited metal, usually aluminum or zinc, as the conducting electrode as shown in figures 1 and 3. Film/foil caps employ a solid metal foil as the electrode system and film dielectric. See figure 2. Hybrid capacitors use a combination of foil and

metallized film as the electrode system as featured in figure 4.

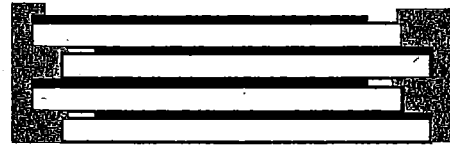


Fig. 1. Single sided metallized, nonseries winding

Single metallized capacitors are self healing and have the highest energy density of all the polypropylene capacitor types since the electrode, only angstroms thin, takes up very little space. Connection to the thin deposit is made with fine zinc or zinc alloy particles, a process known as schooping or endspraying. Over the schooped ends, there are many tiny connections made by endspray particles adhering to the thin electrode. Peak current handling depends on the amount of contact that is made to the film's metallic deposit. A thicker deposit provides more contact area but self healing is compromised since more deposit has to be evaporated during a fault condition [4]. Heavy Edge single metallized capacitors have graded metallization which is thicker at the capacitor's end where connection is made by the endspray. The body of the metallized layer is made thin enough to provide good self healing properties.

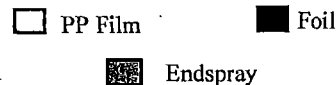
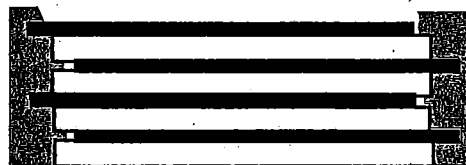


Fig. 2. Film / foil, nonseries winding

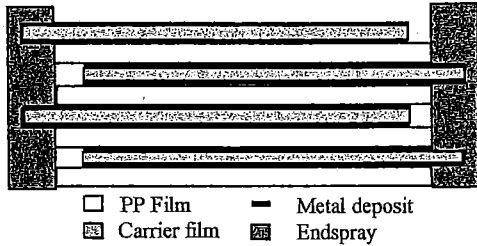


Fig. 3. Double metallized, nonseries winding

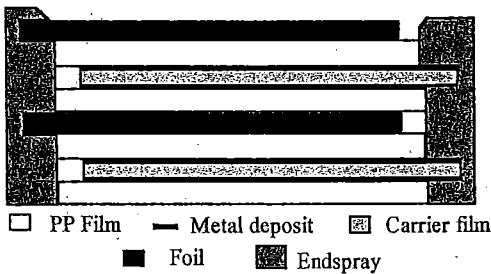


Fig. 4. Hybrid, nonseries winding

Film/ Foil capacitors use a solid metal foil, usually aluminum on the order of 0.22 mils thick, as the electrode. Connection to the capacitor's end is usually made using the scooping method, however swaging (connecting leads with solder to the foils) may be the preferred way if very high peak currents and high mechanical strength are imperative. Film/foil caps are rated for high peak and rms currents since the thick foils present a large area for making connections and serve to draw heat out toward the capacitor's leads. Some disadvantages of film/foil types as compared with metallized types are that they are not self healing, they have lower corona inception, lower peak voltage ratings for a given dielectric thickness, and lower energy density due to the foils taking up considerable volume relative to the dielectric.

Double metallized capacitors use a thin layer of film which is metallized on both sides. A plain polypropylene film is sandwiched between the double metallized layers. The double metallized film does not participate in the dielectric system. Polyester is typically used as the double metallized film which is commonly referred to as a carrier film. Double metallized capacitors provide at least twice the peak current rating of single metallized capacitors. Heavier metal deposits may be applied to achieve from four to eight times the peak current handling of single

metallized capacitors while maintaining good self healing characteristics. Typically 4 or 5 micron film is used as the double metallized electrode. Compared with the dielectric thickness used, the electrode takes up significant volume. Therefore, a double metallized cap will be significantly larger than a single metallized cap of the same CV rating.

Hybrid capacitors employ both metallized and solid foil electrodes. This construction is self healing and can be rated for high rms current ratings since foil is present to conduct heat out of the section. For nonseries wound hybrid capacitors there is no improvement in peak current capability over double metallized types because the weakest link is at the metallized/endspray interface. Series wound hybrids, however, have some advantages over double metallized and film/foil series wound capacitors. Series wound capacitors will be discussed later in this paper.

#### PEAK CURRENT, $dV/dt$ RATINGS

A capacitor's peak current rating depends on the integrity of the connection of the fine particles of endspray to the foils or metallized system. As pulses of high current pass through these many connections, some act as tiny fuses, thereby disconnecting. As more and more dislocate, fewer connections are available for sharing the current. Each remaining location is required to handle more current, disconnecting even more of the tiny connections, and so on. As the endspray connection deteriorates, ESR of the capacitor increases. This may cause significant heating which gets progressively worse as the end connection degrades even further. Thermal runaway is possible especially where the pulse rate is high or where significant ripple current is present. To avoid this undesirable effect it is necessary to select a capacitor which is rated for peak currents greater than those to which it will be subjected. It is desirable to select a capacitor that is large in diameter and short in length. This provides a greater cross section through which current can flow.

$dV/dt$  ratings for each type and CV rating are usually found in the manufacturer's literature. These ratings are determined by pulsing the capacitor with a given number of current pulses (usually 10,000) at

rated peak value and defined pulse duration. The capacitor's ESR must not increase by more than the change as prescribed by the reference standard. Most domestic and European manufacturers use the IEC-384-17 as the reference standard. Once peak current values are determined,  $dV/dt$  is calculated by dividing the peak current rating by the capacitance value.

#### SERIES WINDING FOR HIGH VOLTAGE AND HIGH $dV/dt$

Typical volts per mil stress for polypropylene is about 85Vdc per mil. A nonseries wound 1000 volt film capacitor requires at least 12 micron polypropylene film as the dielectric. This comes to 83.3 V/mil stress on the dielectric. Thicker films are available for higher voltage, however, they are seldom used in capacitors intended for snubber applications. The reason is that a series winding can be constructed to provide high voltage withstand, higher ac rms ripple voltage, and higher peak current ratings than can be achieved with a nonseries winding. The compromise is in size and cost of a series winding versus a non-series winding. The availability of series windings reduces the need for arranging capacitors in series which only addresses the voltage, but not the peak current requirements of many snubber applications.

The following example illustrates the advantage that series wound capacitors have over nonseries wound capacitors.

Figure 5 shows a simple capacitor with a rating of C1, V1.

The capacitance is given by

$$1) \quad C = \frac{lwk}{d}$$

where

- $C$  = capacitance
- $k$  = dielectric constant
- $d$  = dielectric thickness.
- $w$  = width of capacitor plates
- $l$  = length of capacitor plates

Next, we will look at the pad of a series wound capacitor of the same capacitance and voltage rating, as shown in figure 6.

The width of the capacitor winding is kept the same as the simple capacitor to illustrate how a series winding improves the peak current rating. One of the electrodes is split and separated by some distance called a margin. The margin must be of sufficient size to prevent arc-over when the cap is charged to full

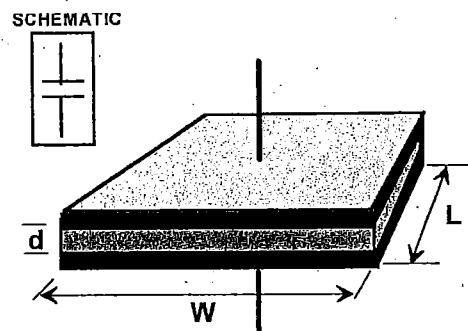


Fig. 5. Simple capacitor

voltage. The split electrodes are connected by endspray at the capacitor's ends. The other electrode is "free floating." That is, it just floats in the winding without

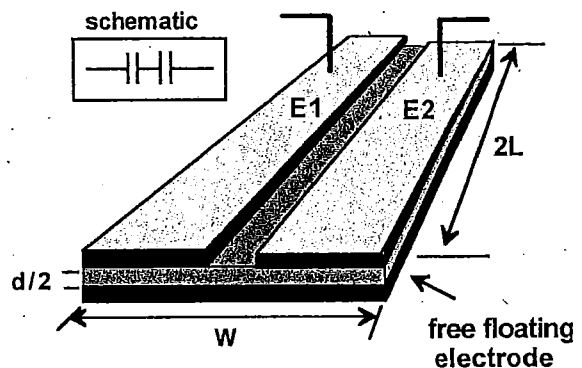


Fig. 6 Series wound capacitor

being connected to the terminations. The dielectric need only be half as thick since now there are effectively two capacitors in series to give the same voltage rating. If the winding length is kept the same, each capacitor segment would have a capacitance of

C1. But as measured from E1 to E2, the capacitance would be 1/2 C1. It is therefore necessary to wind the series capacitor to twice the length as a simple capacitor in order to get the same capacitance. Doubling the winding length gives the series wound capacitor twice the peak current capability as the nonseries wound cap of the same width since there is at least twice the exposed metal area available for endspray particle connection.

Series wound capacitors are manufactured in the single metallized, double metallized, film/foil and hybrid types as shown in figures 7,8,9 and 10.

Characteristics of series wound capacitors are similar to those for nonseries windings of the same electrode type. The most remarkable difference is the significant improvement in peak current ratings. Series windings also generally have higher corona inception than nonseries winding as the result of the reduced electric field strength in critical areas of the winding.

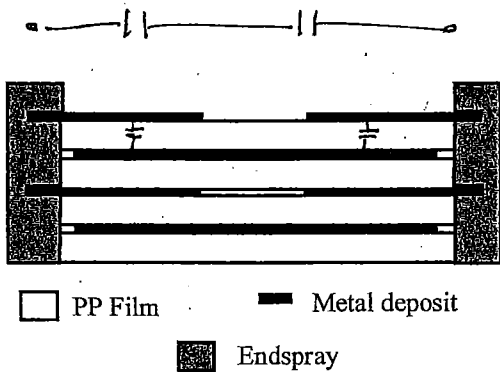


Fig. 7 Single metallized, series winding

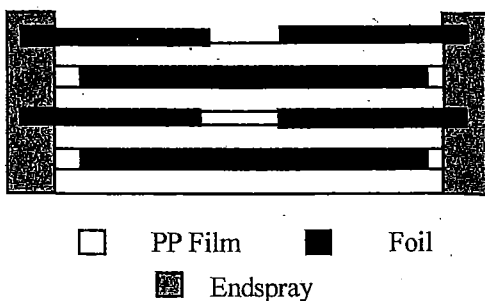


Fig. 8 Film / foil, series winding

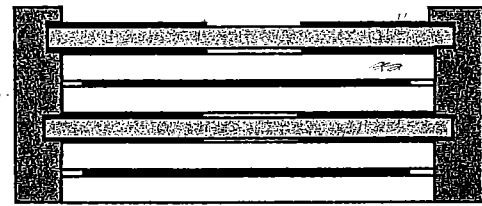


Fig. 9 Double metallized, series winding

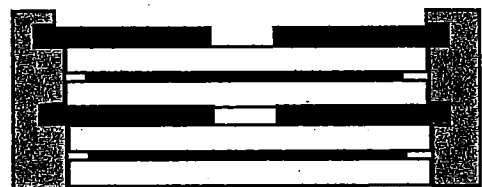


Fig. 10 Hybrid, series winding

Table 1 rates each of the capacitor types relative to the others on a variety of attributes. The table should prove to be useful in selecting the type of capacitor needed for a specific snubber application. It should be noted that the table does not show actual values for the attributes listed. The snubber designer is encouraged to consult with the manufacturer's application engineers or to obtain values from the manufacturer's literature.

Table 1

Relative performance of capacitor types (0-none, 1-poor, 2-fair, 3-good, 4-very good, 5-excellent)

Type	Peak Current	RMS Current	Size	Cost	Self Healing	Fail Open	Corona Inception
Nonseries single sided metallized	1	1	5	5	5	5	4
Non series film/foil	5	5	2	4	0	0	2
Nonseries double metallized	3	3	3	4	5	5	4
Nonseries hybrid	3	4	3	4	4	3	3
Series - single sided metallized	2	3	4	4	5	5	5
Series - film/foil	5	5	1	4	0	0	3
Series - double metallized	4	3	2	4	5	5	5
Series - hybrid	5	4	2	4	4	3	3

## PACKAGING AND TERMINATIONS

There are a variety of ways in which polypropylene snubber caps are packaged. Wrap and fill involves wrapping the capacitor winding with insulating tape and covering the section's ends with epoxy to protect it from the elements. Radial or axial leads are typically applied for PCB mounting or for soldering to other components. Some wrap and fills have copper lugs for higher rms current handling. Box style capacitors have their capacitor elements encapsulated within a resin filled case. Radial leads, multiple pin connections, or copper lugs may be applied. Figure 11 shows a box style cap which may be mounted directly to an IGBT switch or across the bus. Still there are more package styles, such as conformal epoxy coated and hermetically sealed types. The package style needed will depend on the application and on other constraints such as size and cost.

For most snubber applications it is essential to keep the inductance of the snubber as low as possible. The capacitor's terminations have much to do with its inductance. Axial wire and radial wire leaded capacitors typically have higher inductance than capacitors terminated with flat radial leads. Capacitor inductance is minimized by keeping the lead loop area and lead length as small as possible.

Packaging is also important in rating a capacitor for rms current. Heavy terminations conduct heat away from the capacitor element. RMS current ratings are also related to the size of the package since increased surface area will help radiate heat. RMS current ratings are typically estimated or calculated using some variation of the following formula:

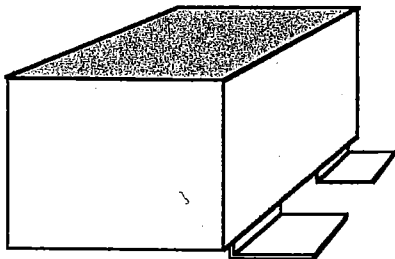


Fig. 11: Low inductance capacitor for direct mount to IGBT modules

$$2) \quad T_c = \frac{kI^2ESR}{Area}$$

where

$T_c$  = the maximum allowable case temperature rise that will result in a capacitor meeting its service life objective when operated at rated voltage and temperature

$k$  = emissivity constant

$ESR$  = equivalent series resistance

$I$  = rms current

$Area$  = total surface area over which heat is radiated.

The underlying idea is for the manufacturer to rate the capacitor such that the heat generated due to  $I^2$  ESR losses can be dissipated without causing excessive localized dielectric heating.

## SUMMARY

As the need for snubber capacitors for power applications continues to increase, so does the need for improved information regarding the important attributes of capacitors intended for these applications. This paper has discussed, in general, the most important of these attributes as well as the advantages and disadvantages of each of the major types of polypropylene film capacitors. Careful consideration of all of these characteristics leads to a good capacitor choice and ultimately a good snubber design.

## REFERENCES

- [1] Yoshinobu Tsujimoto, "Technological progress in materials application for electronic capacitors in Japan." IEEE Electrical Insulation Magazine, Vol.6, No.3. pp. 38-42, June 1990.
- [2] B. Lavene, "Careful capacitor selection optimizes switcher performance.", EDN, pp. 305 - 307, April 1984.