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**Energy Density of  
Film Capacitors for  
ETC Gun Applications**

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## Energy Density of Film Capacitors for ETC Gun Applications

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### Abstract:

In the late 1980s and early 1990s a significant effort was made to improve the energy density of capacitor for the ETC gun application where the pulse width is typically in the millisecond range. At that time, a relatively high energy density capacitor was developed using polyvinylidene fluoride (PVdF) as the dielectric. Relatively little work has been done on this type of capacitor since then. Significant progress has been made with in the use of other dielectric materials using new manufacturing techniques, some of which would most likely work with PVdF dielectric capacitors. This paper is a review of the basic properties of wound film capacitors applied to the ETC gun application along with projections of what would be expected from PVdF capacitors using today's manufacturing techniques.

### Electrical Properties of PVdF Capacitors

The primary concerns for capacitor used in the ETC gun application are energy density, performance in the application, and cost. The order of importance may vary but these are usually the top three concerns. PVdF has an advantage over other dielectric films in that it has a relatively high dielectric constant and a voltage withstand capability equal to polypropylene (PPL). The relative dielectric constant is about 8 for PVdF and 2.1 for PPL.

There are a number of disadvantages with the use of PVdF in other applications, not the least of which is the cost. A large capacitor built with PVdF film will cost about 5 times that of an equivalent capacitor built with PPL. This is the primary reason it is not popular in commercial products where it meets the other requirements of the application.

A second disadvantage associated with using PVdF is the nonlinear aspects of the material. The dielectric absorbs a significant charge when voltage is first applied. Under discharge conditions, the absorbed charge is released over time. Most of the charge is released in milliseconds with some of the absorbed charge remaining in the dielectric until forced out by reversing the voltage on the capacitor or by heating the capacitor until the charge is released. While these characteristics of PVdF dielectric capacitors make them unattractive for AC power applications where the voltage is continually reversed, or in fast discharge applications where the dielectric fails to release the absorbed charge, the material does have significant advantages in the ETC gun application.

Figure 1 shows some typical charging curves for PVdF capacitors using a constant current charging power supply. With a more linear capacitor, one would expect the charge curve to be a relatively straight ramp rather than the curves shown below. When charging PVdF capacitors, the beginning of the charge cycle and the end of the charge cycle are linear but the middle is different. Most of the charge absorption occurs about 1/3 of the maximum voltage stress levels used in the ETC gun application. This is evident in the swayback curve in the middle of the 3kV to 10kV range of Figure 1.

### Typical Charging Profile for PVdF Dielectric Capacitor Using a “Constant Current” Charging Power Supply

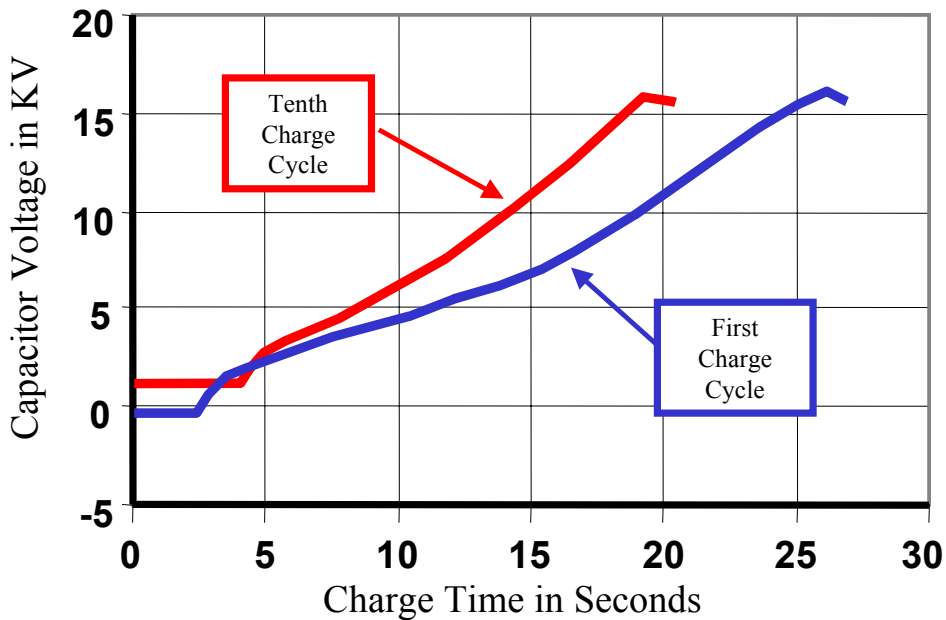


Figure 1

The charging profile of a PVdF capacitor is effected by the its charge history. As can be seen, the charge time for the first shot is about 21 seconds while the tenth shot 15 seconds. Also, note that the charge cycle does not start from zero volts on the tenth shot. After the capacitor has been discharged, that circuit is opened and absorbed charge is released by the dielectric resulting on a significant voltage appearing on the terminals of the capacitor.

The nonlinear characteristics of PVdF film result in relatively high energy loss during the charge discharge cycle. Figure 2 shows the distribution of the energy during a ten cycle charge discharge sequence. During this test, the capacitor has not been charged for several days before the sets was started. Most of the absorbed charge had drained off. The initial charge required significant about 170 kJ input to get about 82 kJ out on the discharge for a 45% efficiency. Much of the energy was dissipated in the form of

heat during the charging cycle. Later charge cycles required less energy and the output energy from the capacitor was improved to 79% on the tenth shot.

### Typical Energy Profile of a PVdF Capacitor During a 10 Shot Burst - Data From 1991

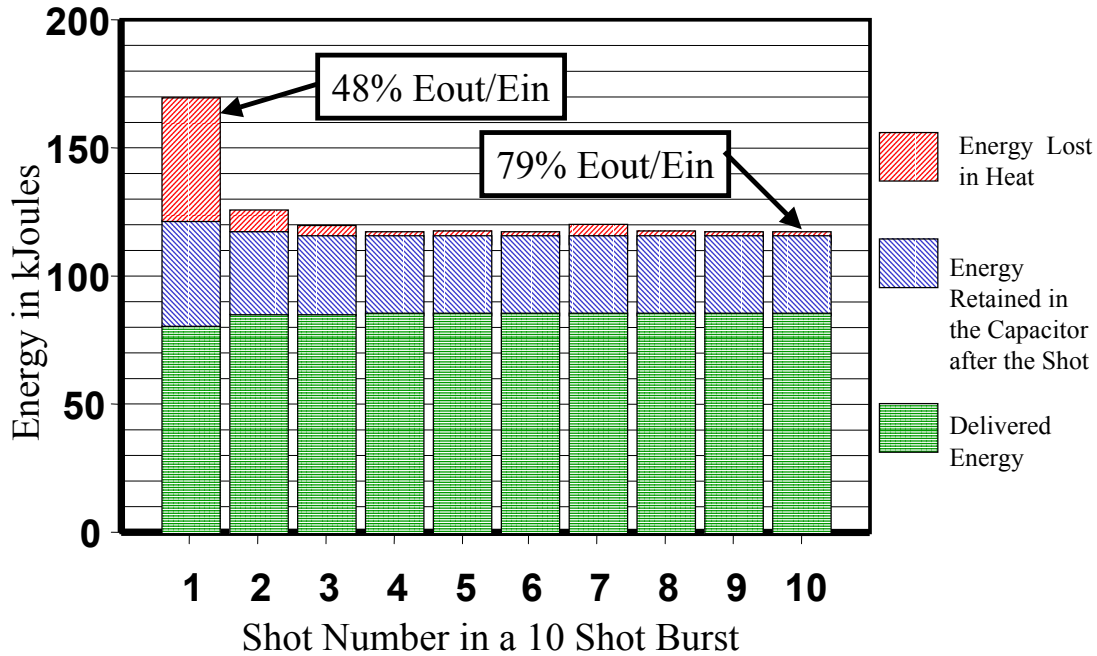


Figure 2

Thus far we have discussed the negative aspects of charge absorption. There is at least one positive aspect of this characteristic. Under fault conditions, PVdF dielectric capacitors dampen the circuit reversal and consume a significant fraction of the capacitors stored energy attempting to change polarity. Figure 3 compares the performance of PPL with that of PVdF dielectric capacitors.

With an ideal capacitor in a fault circuit the maximum reversal for the circuit can be calculated. If the capacitor is relatively efficient PPL dielectric capacitor, the actual reversal will be slightly below that of the calculated value of the ideal capacitor.

The PVdF capacitors respond much differently than PPL capacitors under fault conditions. Before the voltage can be reversed significantly, the absorbed charge must be overcome. After that has happened the dielectric will absorb charge in the opposite polarity. As shown in Figure 3, the PVdF capacitors do not reverse voltage in circuits where 30% voltage reversal is predicted given an ideal capacitor. The maximum voltage reversal that can be obtained is about 30% using PVdF capacitors.

## Comparative Voltage Reversal Under Fault Conditions

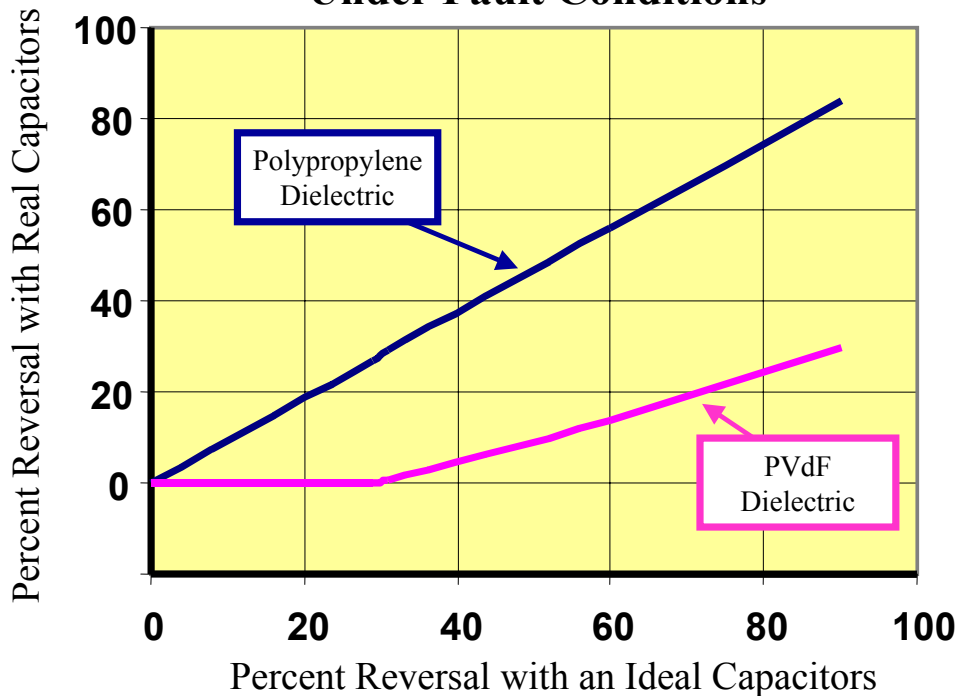


Figure 3

In comparing the performance of PVdF capacitors with the capability of today's film dielectric energy storage capacitors, the 1991 technology still compares favorably in terms of delivered energy per unit volume. If the development of PVdF capacitors would have kept up with that of more popular dielectric systems, the comparison would be even more favorable. Table 1 is such a comparison. The first column marked "PVdF Circa 1991" is just that. The performance achieved with PVdF capacitors in the ETC gun application ten years ago.

The column headed "Polypropylene" is what is commonly available for short lived capacitors in this application. The energy density for this type of capacitor has increased from about 0.7 J/cc to 1.1 J/cc over the last decade. The column headed "New Dielectric System" is a unique film capacitor design presently in production at General Atomics Energy Products. This type of capacitor is similar to PPL capacitors in many ways but the maximum energy density achieved is significantly higher.

The column headed "Estimate of PVdF Today" represents a realistic expectation for this type of capacitor if the capacitor technology developed over the last decade were applied this to PVdF capacitors.

<b>A Comparison of High Energy Density Wound Film Capacitors Operating In the ETC Gun Application</b>					
<b>Item</b>	<b>PVdF Circa 1991</b>	<b>Estimate of PVdF Today</b>	<b>Poly- propylene</b>	<b>New Dielectric System</b>	<b>Unit of Measure</b>
<b>Efficiency</b>					
First Shot	<b>&gt;45</b>	<b>&gt;45</b>	<b>&gt;90</b>	<b>&gt;91</b>	% Eout/Ein
10th Shot	<b>&gt;45</b>	<b>&gt;45</b>	<b>&gt;90</b>	<b>&gt;91</b>	% Eout/Ein
Rep Rate**	<b>&lt;4</b>	<b>&lt;4</b>	<b>&gt;100</b>	<b>&gt;100</b>	Hz
<b>Energy Density</b>					
1000 Shot Life	<b>2.4</b>	<b>4.3</b>	<b>1.1</b>	<b>1.6</b>	Joules/cc
<b>uSec Discharge Capability</b>	<b>No</b>	<b>No</b>	<b>Yes</b>	<b>Yes</b>	Y/N

Table 1

Today, PVdF film is not in production. The start up cost required to initiate production of capacitor grade PVdF film is in the \$200,000 range. The cost of the processed film used in the capacitors will be in the \$100 to \$200 per pound range or about 10 times the cost of PPL. These costs are the main reason why the development of PVdF capacitors have not kept pace with that of other dielectric systems.

### Conclusions:

There are a number of film dielectric capacitors that could be used for the relative long pulses associated with ETC gun applications. One of the more interesting options is the use of PVdF as a dielectric. A decade ago it was proven that this material yielded reliable high energy density capacitors. Applying today's manufacturing techniques to this dielectric material is expected to yield delivered energy densities of 4.3 joules per cc.

### References:

G. F. Greater, F. W. MacDougall, M. Hudis, X. H. Yang – Characterization of High Density Capacitors Under Projected U. S. Navy ETC Gun Operating Conditions – Presented at the 10<sup>th</sup> IEEE Pulsed Power Conference – Albuquerque NM, July 12 1995