About Increase of the Specific Energy Characteristics and Lifetime of High-voltage Pulse Capacitors

I.S. Shvets, I.Yu. Grebennikov, V.I. Gunko, A.Ya. Dmitrishin, L.I. Onishchenko

Institute of Pulse Research and Engineering of the National Academy of Sciences of Ukraine
43a Zhovtnevy Ave., 54018 Mykolayiv, Ukraine
Phone: +38-0152-22-41-13, Fax: +38-0512-22-61-40
E-mail: ipre@iipt.aip.mk.ua

Abstract – IPRE of the National Academy of Sciences of Ukraine carries out research on the increase of energy characteristics and lifetime of high-voltage pulse capacitors owing to the use of capacitor sections with purely film insulation in the capacity of main electric insulator, which are impregnated with non-polar liquid dielectric with high gas stability and stability to partial discharge, with low loss factor.

Various structures of a purely film dielectric were investigated: polypropylene, polyethylene terephthalate, combined polypropylene-polyethylene terephthalate, that were impregnated with phenylxylylethane and insulating oil.

Graphic charts of specific stocked energy of capacitor from the lifetime of a purely film dielectric for selected structures impregnated with phenylxylylethane and insulating oil, were curved in comparison with paper-film dielectric, impregnated castor oil.

Carried out researches have shown that the use of a purely film dielectric in comparison with paper-film one, allows to increase specific stocked energy of capacitor more than twice at the same lifetime or to increase fairly the capacitor lifetime at the same specific stocked energy depending on the structure of a film dielectric and the type of impregnant.

It should be noted that when using a purely film dielectric the impregnant must be compatible with used film and the mode of thermal vacuum dehydration and capacitor impregnation must be correctly selected to eliminate the formation of ply blisters.

The use of purely film dielectric in constructions of high-voltage capacitors in comparison with paper-film dielectric will also allow to shorten thermal vacuum turnaround time, to reduce inputs on production and, therefore, to reduce their cost.

The growing level of high-voltage pulse engineering requires the creation of new types of high-voltage pulse capacitors with heightened values of specific stocked energy and lifetime. Such capacitors are indispensable for many areas of science and engineering (laser technology, petroleum production and others), where specially problems of a decrease of weight-dimension factors, increase of the specific energy characteristics, reliability and service life of the equipment, electrophysical plants acutely cost.

Carried out researches in IPRE NAS of Ukraine have shown, that the increase of the specific energy characteristics and lifetime of high-voltage pulse capacitors can be reached by use as working dielectric of sections of capacitors of purely film insulation, impregnated non-polar liquid dielectric with high gas stability and stability to partial discharges, with low with low loss factor.

The specific stocked energy of capacitors on volume basis (specific energy output $W_{уд}$ of purely film impregnated capacitor dielectric disregarding of characteristics of a material of plates) can be determined under the known formula:

$$W_{sp} = \frac{\varepsilon_f \cdot E_w^2 \cdot \left[d_f + \left(\frac{\varepsilon_f}{\varepsilon_{lq}} \right) \cdot d_{lq} \right]}{2 \cdot \left(\rho_f \cdot d_f + \rho_{lq} \cdot d_{lq} \right)}, \qquad (1)$$

where ε_f, ε_{lq} – relative dielectric permabilities of a polymer film and impregnating liquid accordingly; E_w – working electric field strength in dielectric; d_f, d_{lq} – common thickness of a film and impregnating liquid accordingly; ρ_f, ρ_{lq} – densities of a film and impregnating liquid accordingly.

Earlier problems of increase of specific energy output of capacitors with purely film working dielectric were attended in the works [1] and [2]. In [1] the problem of the increase of specific stocked energy of the capacitor in concordance with the given formula was decided at the expense of increase of relative inductivity of film dielectric by means of application of polyvinylidenfluoride film (PVDF). However film PVDF with ε_f from 10 up to 14 owing to high dielectric losses (at frequency of 10^3 Hz and temperature 20 ºC $\mathrm{tg}\delta = 0.015$, and at higher frequency of 10^6 Hz – $\mathrm{tg}\delta = 0.22$) can be applied only in capacitors exploited in a monopulse mode, and already at frequency of following charge-discharge 1–2 Hz in structure of working dielectric of the capacitor places of a local overheating appear, that leads to its fast mortality.

In [2] with taking into account [1] was considered not the PVDF film, but composition film PET-KE with thickness $d_f = 20$ microns and $\varepsilon_{f1} = 3.2$ and

applied on it layer of the PVDF film with thickness $d_{f2} = 2$ microns and $\varepsilon_{f2} = 10$, i.e. common thickness of $d_f = 22$ microns. For comparison the PP polypropylene film with $\varepsilon_f = 2.2$ was considered. Equivalent relative dielectric permability ε_f of composition of a PET-KE – PVDF can be determined from the known formula:

$$\varepsilon_f = \frac{d_f}{\frac{d_{f1}}{\varepsilon_{f1}} + \frac{d_{f2}}{\varepsilon_{f2}}}. \quad (2)$$

The value of equivalent relative dielectric permability of composition of a PET-KE – PVDF amounts $\varepsilon_f = 3.41$, i.e. in comparison with the PET-KE film it increases unsignificantly, but as shown in [2] the long-term electric strength of this composition is higher than that of the PVDF film. However in this composition places of a local overheating also are observed.

To problem of increase of specific stocked energy of capacitors at the expense of use of purely film dielectric is attended also in [3]. But in this work the purely film dielectric was esteemed with reference to increase of an operational frequency of following charges-discharges of capacitors and the correlation of the mean lifetime of capacitors with their specific stocked energy was not reflected in case of the use of a purely film dielectric.

The purpose of the given article – estimation of accessible specific energy output of high-voltage pulse capacitors on the basis of impregnated purely film dielectrics with allowance for of lifetime of capacitors.

As objects of research the following structures of three-layered purely film dielectric were used:

– polypropylene with thickness of 36 micron, on the basis of the polypropylene film PP-KSSh;

– polyethylene terephthalate with thickness of 35 micron, on the basis of the polyethylene terephthalate film PET-KE;

– combined polypropylene-polyethylene terephthalate with thickness of 34 micron, on the basis of two layers of a polypropylene film PP-KSSh and layer, arranged between them, polyethylene terephthalate film PET-KE.

As impregnating liquid dielectrics were investigated phenylxylylethane (PXE) and insulating oil T-1500.

The experimental researches of short-term and long-term electric strength of selected structures of purely film dielectric were carried out on the models of sections of the high-voltage pulse capacitor.

In the Table 1 the experimental data on the short-term electric strength determination of different structures of purely film dielectric are adduced.

The criterion of selection of structures of purely film dielectric for realization of experimental researches on determination of their long-term electric strength was the values of their short-term electric strength. Therefore for realization of further researches the structures with the largest electric strength were selected – polypropylene dielectric, impregnated phenylxylylethane; polyethylene terephthalate, impregnated insulating oil T-1500 and combined polypropylene-polyethylene terephthalate, impregnated PXE and insulating oil T-1500.

The researches on determination of long-term electric strength of different structures of purely film dielectric on the models of sections were carried out in a mode of an oscillatory discharge with a reverse of discharge current 0.3, frequency of following charges-discharges 1.5 Hz at high values of a working electric field strength in dielectric.

In the Table 2 the experimental data on the determination of long-term electric strength are adduced.

Table 1. Data on determination of short-term electric strength

Film dielectric	Permeating dielectric	d_f, micron	tgδ	R_{ins}, MOhm	E_{brk}, kV/mm
Polypropylene	phenylxylylethane	36	0.0015	12500	424.6
	insulating oil T-1500		0.0009	23000	334.3
Polyethylene terephthalate	phenylxylylethane	35	0.0079	17500	325.7
	insulating oil T-1500		0.0077	25000	437.1
Polypropylene-polyethylene terephthalate	phenylxylylethane	34	0.0027	13000	407.8
	insulating oil T-1500		0.0024	25000	453.0

Table 2. Data on definition of long-term electric strength

Film dielectric	Permeating dielectric	d_f, micron	E_w, kV/mm	$N_{average}$, charges-discharges
Polypropylene	phenylxylylethane	36	173.6	$5.96 \cdot 10^5$
Polyethylene terephthalate	insulating oil T-1500	35	178.6	$4.83 \cdot 10^5$
Polypropylene-polyethylene terephthalate	phenylxylylethane	34	183.8	$6.27 \cdot 10^5$
	insulating oil T-1500		183.8	$5.3 \cdot 10^5$

By results of tests with usage of the empirical formulas the graphs of specific stocked energy of the high-voltage pulse capacitor against its lifetime are obtained at working strength of electrical field in dielectric up to 183.8 kV/mm.

In Fig. 1 and 2 the curves of relation of specific stocked energy of the capacitor from average lifetime for different structures of purely film dielectric, impregnated PXE and insulating oil T-1500 in comparison with paper-film dielectric, impregnated castor oil are shown.

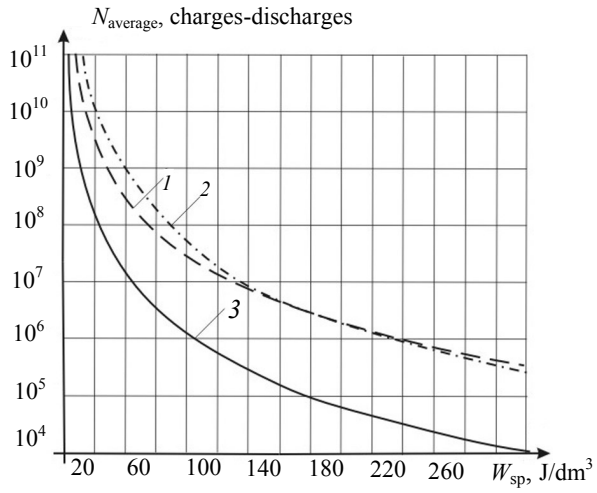

Fig. 1. Specific stocked energy dependence of the average lifetime of capacitors at the phenylxylylethane impregnation of film dielectric in comparison with paper-film dielectric, impregnated with castor oil. *1* – polypropylene dielectric; *2* – combined polypropylene-polyethylene terephthalate dielectric; *3* – combined paper-film dielectric

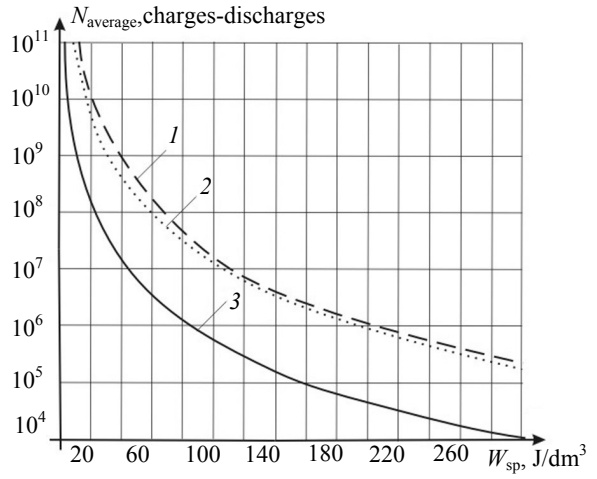

Fig. 2. Specific stocked energy dependence of the average lifetime of capacitors at the T-1500 insulating oil impregnation of film dielectric in comparison with paper-film dielectric, impregnated with castor oil. *1* – polyethylene terephthalate dielectric; *2* – combined polypropylene-polyethylene terephthalate dielectric; *3* – combined paper-film dielectric

Analyzing graphs, shown in Fig. 1, we can see, that at specific stocked energy 180 J/dm^3 lifetime of capacitors with polypropylene and combined polypropylene-polyethylene terephthalate dielectric, impregnated PXE, are peer. With further increase of the value of specific stocked energy up to 300 J/dm^3 the lifetime of capacitors with combined dielectric is slightly reduced. It can be explained by the following causes - smaller electric strength of combined dielectric and larger dielectric loss in comparison with polypropylene dielectric.

At a decrease of specific stocked energy of capacitors from 160 J/dm^3 up to 20 J/dm^3 at equal lifetime the capacitors with combined polypropylene-polyethylene terephthalate dielectric have larger specific stocked energy in comparison with polypropylene owing to the larger relative dielectric permability of combined dielectric. It is necessary to allow at that, that at a decrease of specific stocked energy of the capacitor up to 20 J/dm^3 the value of a working electric field strength was reduced also, and at values from 100 up to 120 kV/mm these dielectrics have approximately equal long-term electric strength.

Analyzing graphs, shown in Fig. 2, we can see, that polyethylene terephthalate and combined polypropylene-polyethylene terephthalate dielectrics, impregnated insulating oil T-1500, have approximately equal lifetime dependence of specific stocked energy of capacitor. Thus the specific stocked energy of the capacitor with polyethylene terephthalate dielectric is a slightly higher owing to the lager relative dielectric permability.

Comparing the graphs with each other, shown in Figs. 1 and 2, we can see that in the area of high values of specific stocked energy, since 140 J/dm^3 and is higher, i.e. at high strength of an electrical field in dielectric, the impregnation phenylxylylethane, in comparison with insulating oil T-1500, provides higher lifetime of capacitor. It is explained by higher gas stability and higher intensity began of partial charges in PXE as comparison with insulating oil T-1500.

Analyzing lifetime dependence of specific stocked energy of capacitors for different structures of purely film dielectric, impregnated PXE and insulating oil T-1500 in comparison with paper-film dielectric, impregnated castor oil, we can see, that the use of a purely film dielectric allows to increase specific stocked energy of the capacitor at equal lifetime more than twice or to increase a fair amount the lifetime of capacitor at equal specific stocked energy depending on structure of film dielectric and type of impregnating liquid.

It should be noted, that at usage of a purely film dielectric the impregnating liquid should be compatible with a used film, and the mode thermal vacuum dehydration and impregnation should be correctly selected, which provides high electric strength of working dielectric of the capacitor, having eliminated formation of ply blisters. At the same time it should be noted, that the duration of a cycle thermal vacuum

processing of capacitors with purely film dielectric, and accordingly the power inputs, is considerably lower as compared with analogous capacitors, in a design which one the purely paper or combined paper-film dielectric is used.

On the grounds of stated material we can conclude that the use of purely film dielectric in designs of high-voltage pulse capacitors will allow, as compared with paper-film dielectric, to increase specific stocked energy of capacitors more than in twice or to increase a fair amount their lifetime, and also to decrease power inputs on their manufacturing and, therefore, to lower their cost.

References

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