2000년도 대한전기학회 하계학술대회 논문집 2000.7.17-20

에너지저장 커패시터용 MPPF의 셀프힐링 특성

정종욱* 곽희로 *박하용 **박중신 ***김영찬
숭실대 *삼척대 **한국전력 중앙교육원 ***기술표준원

The Self Healing Characteristics of MPPF for Energy Storage Capacitors

Jong-Wook Jung* Hee-Ro Kwak *Ha-Yong Park **Jung-Shin Park ***Young-Chan Kim
Soongsil Univ. *Samchok Univ. **Central Institute of Education, KEPCO ***Agency for Technology and Standards

Abstract - This paper describes the self healing characteristics of a metalized polypropylene film(MPPF) used for energy storage capacitors.

In the experiment, a d.c. voltage was applied to the MPPF, and the partial discharge inception voltages(PDIVs), the applied voltages at self healing, the burn out area and the current in the grounding conductor were measured and recorded.

As a result, it was found that no PDs were found till the first pre-self healing occurred, and the applied voltage at self healing was increased with PPF thickness. Self healing was much more dependant on the shape of the air void than its diameter, and the burn out area and the current in the grounding conductor at self healing was also increased with the applied voltage at self healing.

1. Introduction

The term 'self healing' was first used by Klein from Germany during the second World War to express that the vapor deposited metal changes into an oxidized thin membrane through its burn out, in the process of the breakdown test of inorganic paper and polymer film with metalized surface. Self healing is the phenomenon that the thin polymer film with metalized electrode recovers the insulation ability as soon as it meets a breakdown, when defects exists on or in the polymer film with metalization or the voltage is over the critical breakdown voltage of the polymer with defects. Fig. 1 shows the schematic of self healing mechanism[1][2][3].

Fig. 1 Schematic of self healing mechanism

As shown in Fig. 1, when the dielectric with the defect reaches a breakdown, the short current flows across the dielectric. This current generates the local heat about 3,700~4,200[℃] at the failure point. Consequently, the dielectric is punctured with very small hall approximately 1~100[㎛] in diameter, and the vapor deposited metal around the hall is oxidized and evaporated[3]. The site where self healing occurs is electrically isolated because conductive metalization is burnt out and the burn out spot becomes an insulation material or a semiconductor. This action prevents the local failure due to the defects from spreading out larger failure of a capacitor unit[3][4]. In this paper, the various characteristics of self healing which plays important role of improving the performance of capacitors are studied.

2. MPPF capacitor

Out of the manufacturing processes of a capacitor element, an air void can be generated, if the winding tension is not constant or the impregnant is not permeated completely between the MPPF layers, in the winding and impregnating process, which can result in a local breakdown of the MPPF[2][5]. Fig. 2 shows the air void between the MPPF layers, generated in the manufacturing processes.

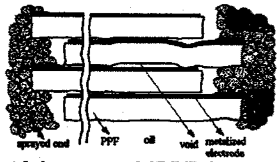


Fig. 2 Air void between MPPF layers generated in manufacturing processes

As shown in Fig. 2, the thickness of the air void between the PPF and the deposited electrode is almost constant all over the area except only the edge of the air void, by the winding tension determined as PPF thickness×PPF breadth×(1~1.5)[5].

3. Experiment

3.1 Experimental setup

Fig. 3 shows the experimental setup to investigate the self healing characteristics of the MPPF under d.c. condition.

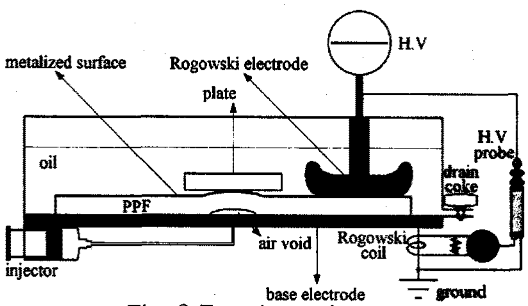


Fig. 3 Experimental setup

As shown in Fig. 3, to imitate the air void between the MPPF layers in a capacitor, an injector was attached, by which the diameter of the air void could be adjusted.

The metalization resistance is generally determined by 3~9[Ω], and it plays an important role in oxidization and burning out the vapor deposited metal at self healing event. Higher resistance of metalization can be more effective in that the insulation ability of the burn out area is excellent because the higher the vapor deposited metal resistance is, the broader the burn out area becomes. However, the loss in capacitance is getting increased. The heat due to the loss leads to the reduction in capacitance, and the performance of the capacitor will be worse[4][6]. Table 1 shows the specification of the MPPF used in this experiment.

Table 1 Specification of MPPF used

PPF thickness	Deposited metal / thichness	metalization resistance
5, 6, 10, 12[㎛]	Al / 300[Å]	7[Ω]

The impregnant can be contaminated by the metallic oxide and the hydrocarbon gas formed at self healing, which makes insulation performance of the impregnant worse[1]. And thus, the impregnant was refilled with new one through the drain coke and the entrance every time the MPPF was changed. The insulation oil(SUN OHM C) manufactured for impregnating the PPF was used as an the impregnant. Table 2 shows the electrical and physical properties of the impregnant.

Table 2 Electrical and physical properties of impregnant(@80[℃])

specific weight	viscosity[cSt]	ε'	$\tan\delta$	dielectric strength[kV/2.5㎜]
0.916	12.3	2.8	0.03	72

3.2 Experimental procedure

First of all, a sheet of the MPPF was put on the base electrode, and it was covered by the acryl plate with a scale. The case was filled with impregnant. Second of all, the air void diameter was measured by the scale on the acryl plate after inserting the air void with an arbitrary diameter ranging 1~3[cm], by an injector, since it is very difficult to accurately adjust the diameter of the air void. D.C voltage was applied to the MPPF, and the PDIVs, the applied voltages at self healing, the burn out area of vapor deposited metal at self healing and the current waveforms in the grounding conductor at self healing were measured and recorded. This procedure was repeated every time the MPPFs were changed, so 60~70 self healing data by each MPPF thickness were acquired.

4. Results and discussion

The MPPF suffered several pre-self healing events, due to the defects sparsely locating between the MPPF and the base electrode, which occurred at lower voltages than the breakdown voltage of the PPF[1][3]. In addition, when the applied voltage was continuously increased, self healing events took place all over the MPPF area as soon as the applied voltage was near the breakdown voltage of the PPF.

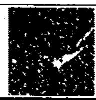
4.1 PDIV characteristics under d.c. condition

In this experiment, the PD was not observed until several pre-self healing events occurred, and this is considered because the leakage current path bridges between the edge of the burn out spot due to self healing and the base electrode. The number of pre-self healing that PD began to be observed was increased with PPF thickness: equal or more than 2~3 pre-self healing events in case of 5[㎛] PPF, and equal or more than 4~5 pre-self healing events in case of 12[㎛] PPF. Comparing both cases, the PD magnitude between them was far different. From this result, it can be assumed that the PD is closely related to the insulation ability due to burn out area at self healing.

4.2 Effect of air void diameter and PPF thickness on self healing

Table 3 shows the self healing(S.H) characteristics by the air void shape.

Table 3 Self healing characteristics by air void shape

	circular void	pin void	wrinkle void	X or Y void
S.H event probability	very low	○	○	○
S.H position	·edge	·pin tip	·wrinkle side ·wrinkle tip	·wrinkle side ·wrinkle edge ·wrinkle cross point
feature	·Subsequent self healing at the edge of burn out spot due to self healing observed ·gas generated at self healing → removed when voltage applied and increased			
shape				

·pin void : void equal or less than 1[cm] in length
·wrinkle void : void more than 1[cm] in length
·X or Y void : void with cross point

As shown in Table 3, self healing mainly took place in case of a pin void equal or less than 1[cm] in length, a wrinkle void shaped very long pin void and X or Y voids with cross point of wrinkle. In this case, self healing was found at pin tips, wrinkle sides, cross points of the wrinkles, respectively. Moreover, several subsequent self healing events were observed at the edge of the burn out spot at or after self healing, as shown in Table 3.

The breakdown voltages of the PPF has been somewhat differently reported depending on the testing condition and the various factors: the PPF manufacturing type, the film stretching and its surface treatment, etc. In this country, about 0.4~0.5[kV_{dc}/㎛] is usually considered the breakdown voltage of the PPF itself, and about 0.2[kV_{dc}/㎛] lesser is taken into account in manufacturing capacitors[5]. In this experiment, the initial applied voltage belonging to the voltage group whose self healing frequency was most was taken as the applied voltage at self healing at PPF thickness, and Fig. 4 shows the result.

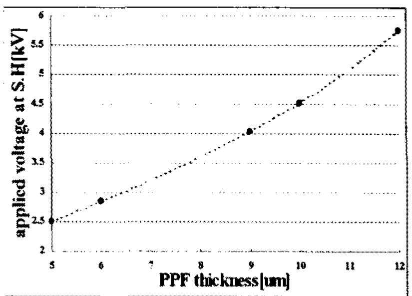


Fig. 4 Applied voltage at self healing with PPF thickness

As shown in Fig. 4, the applied voltage at self healing was increased at the rate of about 0.4[kV/㎛] with PPF thickness.

4.3 Burn out area of vapor deposited metal at self healing

Photo. 1 shows the burn out spot of the vapor deposited metal at self healing.

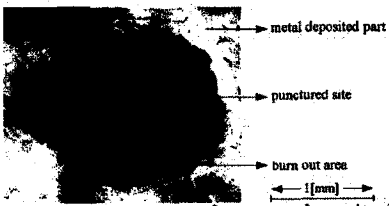


Photo. 1 Burn out spot of vapor deposited metal at self healing : 5[㎛] PPF

As shown in Photo. 1, the MPPF was punctured due to self healing, and the vapor deposited metal around the very small hall was oxidized and evaporated. In most of self healing events, gas was generated. According to early reports, it consists of hydrocarbon with the molecular structure of C_mH_n in case of the PPF[1]. This gas was getting disappeared with the applied voltage. Fig. 5 shows the burn out area of the vapor deposited metal at self healing, with the applied voltage at self healing and PPF thickness.

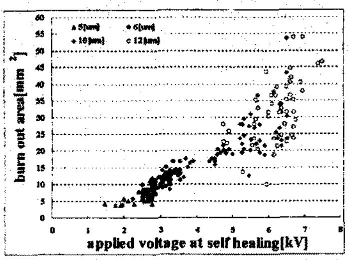


Fig. 5 Burn out area of vapor deposited metal at self healing with applied voltage at self healing and PPF thickness.

As shown in Fig. 5, the burn out area at self healing was getting broader with the applied voltage at self healing. It is considered because the applied voltage at self healing is increased with PPF thickness. In case of a.c. voltage, the burn out area at self healing is exponentially dependant on the applied voltage at self healing[1]. In this experiment, however, the burn out area at self healing was linearly increased with the applied voltage at self healing in case of thinner PPF, and there was no increasing patterns, in case of thicker PPF, because the burn out area was widely varied due to the frequently occurred pre-self healing.

4.4 Current in grounding conductor at self healing

Fig. 6 shows the peak current, at self healing, in the grounding conductor connected the base electrode.

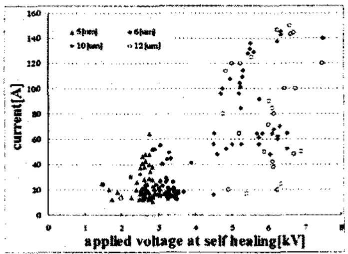
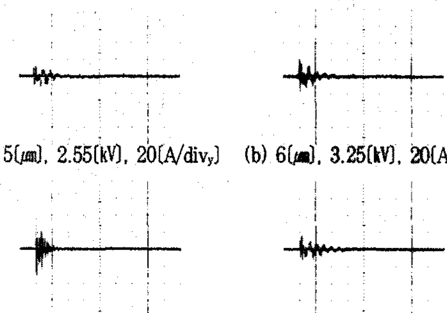


Fig. 6 Current at self healing

As shown in Fig. 6, the peak current in the grounding conductor was increased with the applied voltage at self healing. In case of 10[㎛] and 12[㎛] PPFs, it was widely varied.

Fig. 7 shows the typical waveforms of the current in the grounding conductor at self healing, by PPF thickness.



(a) 5[㎛], 2.55[kV], 20[A/div$_y$] (b) 6[㎛], 3.25[kV], 20[A/div$_y$]

(c) 10[㎛], 4.5[kV], 40[A/div$_y$] (d) 12[㎛], 6.15[kV], 100[A/div$_y$]

Fig. 7 Current waveforms at self healing(1[㎲/div$_x$])

As shown in Fig. 7, the current in grounding conductor was oscillated and damped, and mostly tended to be zero within 5[㎲].

5. Conclusion

As a result to investigate the self healing characteristics of the MPPF employed as the dielectric in energy storage capacitors, this paper concludes as follows;

(1) Pre-self healing frequently took place, and it was abruptly reduced with time.
(2) No PDs had been found till the first pre-self healing occurred, and they could be observed after several pre-self healing events occurred.
(3) The applied voltage was increased with PPF thickness.
(4) Self healing mainly took place at the edge of a pin void, a wrinkle void and X or Y voids, and self healing at the circular void hardly occurred. Even though self healing occurred at the circular air void, it was limited to the edge of the circular air void.
(5) The burn out area of the vapor deposited metal at self healing was linearly increased with the applied voltage in case of thinner PPF.
(6) The peak current in the grounding conductor at self healing was increased with the applied voltage, and the current in the grounding conductor was oscillated and damped. After all, it was mostly to be zero within 5[㎲].

[Referenes]

[1] C. W. Reed and S. W. Cichanowski, "The Fundamentals of Aging in HV Polymer-film Capacitors," *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 1, No. 5, pp. 904-922, October 1994.
[2] "Technical Trend of Capacitor Films," OHM, pp. 36-40, October 1998.
[3] R. Bartnikas and R.M. Eichhorn, Engineering Dielectrics-Electrical Properties of Solid Insulating Materials : Molecular Structure and Electrical Behavior, ASTM Special Technical Publication, Vol. IIA, pp. 505-509, 1983.
[4] D.G. Shaw, S.W. Cichanowski and A. Yializis, "A Changing Capacitor Technology-Failure Mechanisms and Design Innovations," *IEEE Transactions on Electrical Insulation*, Vol. EI-16, No. 5, pp. 399-412, October 1981.
[5] K.S. Kim, "The Manufacture Technology in Power Condenser," Monthly of Electrical Technology, pp. 65-69, November 1999.
[6] Yasunobu Yoshida and Takashi Muraoka, "The Development of High Voltage Power Capacitor Technology in Japan," *IEEE Electrical Insulation Magazine*, Vol. 11, No.1, pp. 32-45, January/February 1995.

이 연구는 민군겸용 기술개발사업의 일환으로 한국전기연구소의 연구비 지원을 받아 수행되었음.