Jurnal
Teknologi

Full paper

Effect of Ambient Temperature on Leakage Current of Gapless Metal Oxide Surge Arrester

C. L. Wooi[a], Zulkurnain Abdul-Malek[a*], Saeed Vahabi Mashak[a]

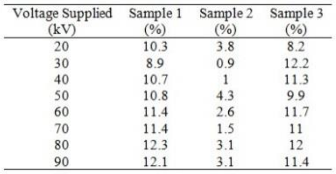
[a]*Institute of High Voltage and High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*

*Corresponding author: zulkurnain@utm.my

Article history

Received :15 February 2013
Received in revised form :
10 June 2013
Accepted :16 July 2013

Graphical abstract



Voltage Supplied (kV)	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)
20	10.3	3.8	8.2
30	8.9	0.9	12.2
40	10.7	1	11.3
50	10.8	4.3	9.9
60	11.4	2.6	11.7
70	11.4	1.5	11
80	12.3	3.1	12
90	12.1	3.1	11.4

TABLE I: Percentage difference in leakage current of three samples for temperature 30°C compare with 40°C.

Abstract

Zinc oxide (ZnO) gapless surge arresters are used for lightning and overvoltage protection in electrical power system. The leakage current monitoring is one of the well known method for the ZnO surge arrester ageing level determination. However, the ZnO leakage current is known to be dependent on the ambient temperature. This paper aims to study the effects of temperature variation due to ambient conditions on the leakage current of ZnO surge arrester. The effect of a significant increment of leakage current with an increase in temperature may result in a wrong assesment of the ageing level of the arrester. The leakage current of three 120kV rated polymeric housed ZnO surge arresters were measured in a custom made thermally insulated enclosures at varying temperatures. Up to 20% increase in the leakage current was observed with a 20°C increment above the ambient temperature. For a typical variation of ambient temperature in Malaysia in the range of between 30°C and 40°C, the corresponding changes in the leakage current can be up to 11%. The temperature does significantly affect the leakage current measurements used for monitoring of zinc oxide surge arresters. This significant change in the leakage current due to ambient temperature variation can affect the decision in assessing the condition of surge arresters during routine monitoring.

Keywords: Surge arrester; leakage current; aging level; temperature effects

Abstrak

Penangkap kilat zink oksida (ZnO) tanpa sela digunakan bagi perlindungan dari voltan lampau dan kilat dalam sistem kuasa. Pemantauan arus bocor merupakan satu kaedah penentuan tahap penuaan penangkap pusuan ZnO yang diketahui ramai. Walau bagaimanapun, arus bocor ZnO diketahui bergantung kepada suhu persekitaran. Kertas kerja ini bertujuan untuk mengkaji kesan perubahan suhu disebabkan oleh keadaan persekitaran terhadap arus bocor penangkap pusuan ZnO. Kesan penambahan ketara arus bocor disebabkan oleh penambahan suhu boleh menyebabkan penilaian yang salah terhadap tahap penuaan penangkap pusuan. Arus bocor tiga penangkap pusuan dengan penebatan polimer dan kadaran 120kV diukur dalam kebuk kedap suhu pada suhu yang berbeza. Penambahan arus bocor sehingga 20% dikesan apabila suhu dinaikkan sebanyak 20°C melebihi suhu persekitaran. Untuk perubahan suhu tipikal di antara 30°C and 40°C di Malaysia, perubahan arus bocor adalah sehingga 11%. Suhu boleh memberi kesan yang ketara kepada pengukuran arus bocor penangkap pusuan zink oksida. Perubahan arus bocor yang ketara disebabkan oleh perubahan suhu persekitaran boleh memberi kesan kepada penilaian tahap penuaan penangkap pusuan semasa pemantauan berkala.

Kata kunci: Penangkap pusuan; arus bocor; tahap penuaan; kesan suhu

■1.0 INTRODUCTION

Surge arresters have been playing an important role on power systems since the beginning of ac transmission. Overvoltages usually occur in a power system due to lightning, fault and switching operation. Surge arresters are often used to protect power and electronic from the destructive transient overvoltage. In order to protect system equipment and to guarantee an economic and reliable operation, surge arresters are installed in almost all types of electrical network [1]. These protective devices are used to limit the overvoltage to a level which is sufficiently safe for the equipment being protected by diverting the overvoltage to ground[2, 3].

The measurement of leakage current in a zinc oxide surge arrester under normal operating voltage is possible due to its gapless configuration [4]. It is known that the leakage current, in particular the third harmonic component of the resistive leakage current, can be used for monitoring the ageing condition of the surge arrester [5, 6]. The degradation of metal oxide arrester can be related to the change in voltage-current characteristic of the arrester.

Due to the leakage current which consists of both resistive and capacitive components, the zinc oxide blocks within the arrester heat up. As the zinc oxide blocks age, the blocks effective resistance during normal operating voltage decreases, and consequently the resistive current increases. In short, the heat generation in the surge arrester body increases as a result of degradation in metal oxide surge arrester [7].

The impedance of metal oxide arresters at voltages below the rated voltage is so high that the resulting current is in the milliampere range. During overvoltage events the metal oxide surge arrester limits the voltage to an almost constant value, even if the discharge current increases extremely. The direct consequence of this extreme nonlinearity is the possibility of constructing surge arresters with no series gaps [8, 9].

However, since these arresters contain no gaps, a leakage current flows through the material at working voltages, which causes power losses and heating of the ZnO elements. This can be dangerous to the stability of the arrester, particularly in the low conduction regime (0-0.001 A) where the voltage-current characteristic of ZnO material is very sensitive to temperature[7]. The thermal stability of ZnO surge arresters is affected by ambient temperature, heat dissipation capability, impulse degradation, and ageing [10, 11].

If the temperature exceeds a certain temperature for a particular arrester, the arrester may fall into the thermal runaway condition. Therefore, surge arrester must operate properly in both normal operating voltage and fast transient conditions [12].

Since leakage current has been widely used for ageing monitoring of surge arrester, any mechanism or environmental effect on the leakage current should be seriously considered. Several experiments had been previously carried out to show the thermal characteristic of a complete surge arrester as well as of a zinc oxide element. However, the correlation between the arrester temperature and the total leakage current is yet to be developed [13, 14]. This paper aims to show that there is a significant effect of temperature on the leakage current measurements of zinc oxide surge arresters.

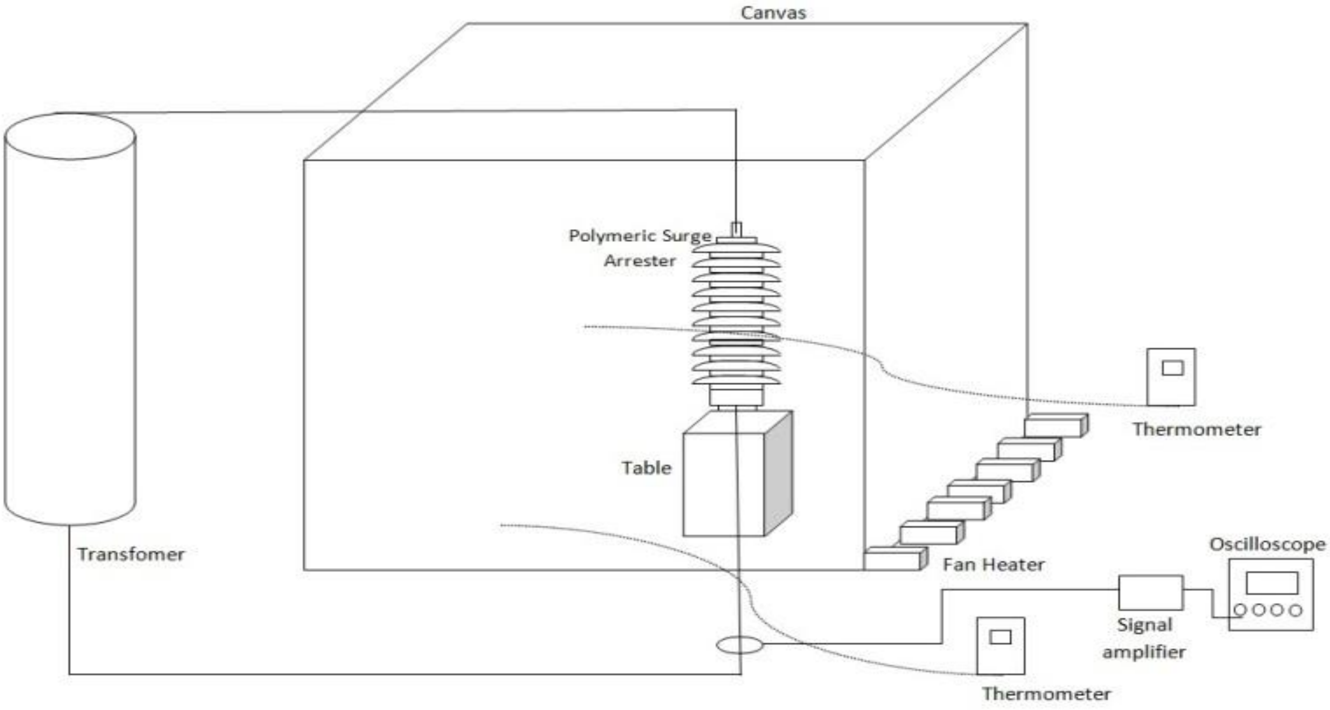


Figure 1 Schematic diagram of the leakage current detection using current probe and temperature detection using the k-type thermometers

■2.0 METHODOLOGY

Due to the high sensitivity of the voltage-current characteristic to temperature in the low conduction regime, the surrounding temperature of the arrester should be careful observed and maintained to guarantee the accuracy of measurements. Three 120 kV rated polymeric housed arrester samples were provided by the power utility. The arresters were manufactured in 2003 and installed in 132 kV high voltage transmission system.

In this work, the leakage current of three 120kV rated polymeric housed ZnO surge arresters were measured in a custom made thermally insulated enclosures at temperatures raising from 30°C to 50°C. The chamber was specially designed for temperature insulation with a dimension of 3m x 3m x 3m. The chamber was designed in such a way that enough clearances prevent any unnecessary discharges to the ground structure.

A digital storage oscilloscope, a current probe (ZCT-80H Clamp), and a purposely designed signal amplifier were used to measure the leakage current. The experimental set up is as shown in Figures 1 and 2. The minimum measureable leakage current value by the current probe was 100 mA. An amplifier as well as a filter is therefore needed. The chamber temperature was controlled by using eight units of 3 kW rated Dimplex DXFF30TS fan heater. The chamber temperature was measured using two k-type Lutron TM-902C thermometers. Only two units of thermometers were used to measure the temperature since thermocouple cannot work properly under high electric field due to the possible occurrence of discharges at the tips of the thermocouple.

The schematic diagram in Figure 3 shows the current probe and the signal amplifier were previously calibrated using three Tekronix AFG 3021B signal generators, two Fluke 8845A ammeters, and a LeCroy Waverunner 44xi digital oscilloscope.

The temperature of the chamber was slowly raised from room temperature to about 50°C. A sufficient time was allowed to pass at each temperature level to ensure an even temperature distribution within the chamber before the leakage current measurement was taken.

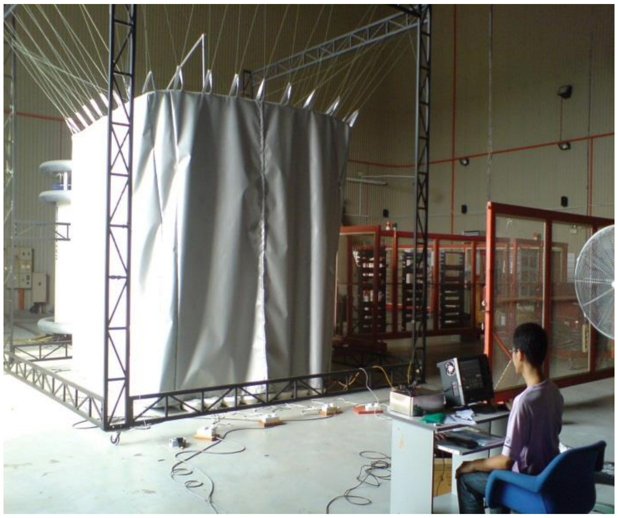


Figure 2 Image of the experimental setup where the arrester was positioned within an enclousure

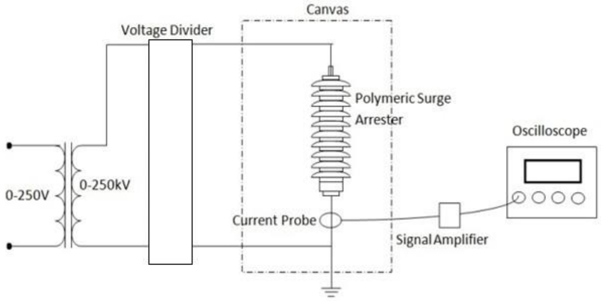


Figure 3 Schematic diagram of the power supply and leakage current and detection

■3.0 RESULTS AND DISCUSSION

Three samples of arresters had been tested with the enclosure temperature varied from 30°C until 50°C. At each temperature, the applied voltage across the arrester was slowly increased from 20 kV to 90 kV.

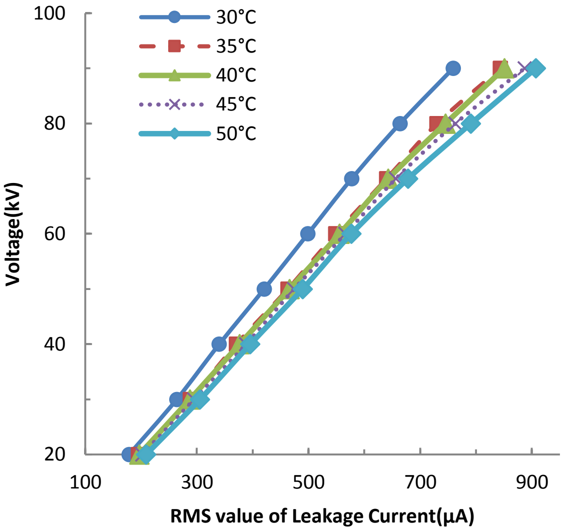


Figure 4 Voltage-current characteristic for sample 1 at varying temperature

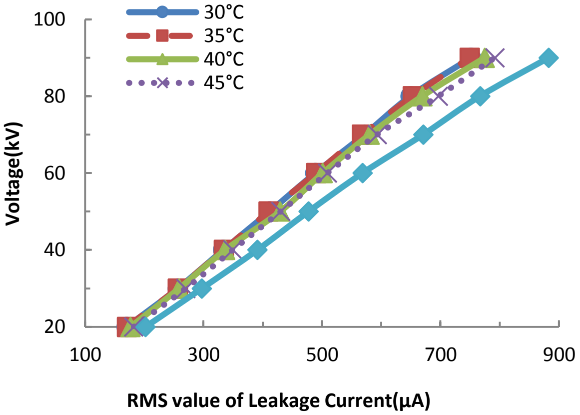


Figure 5 Voltage-current characteristic for sample 2 at varying temperature

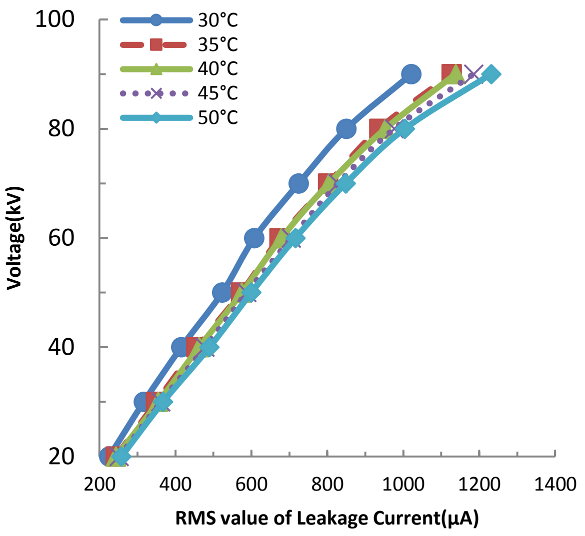


Figure 6 Voltage-current characteristic for sample 3 at varying temperature

Figures 4 to 6 show the voltage-current characteristics for various temperatures for samples 1 to 3 respectively. It can be observed that the leakage current of the arrester increases as the applied voltage increases. It can also be observed that the effect of a temperature increase is to increase the leakage current for the same applied voltage. In other words, as the temperature increases, the voltage-current curves shifted to the right. An example of the increase is as for sample 1 in Figure 4. The arrester’s leakage current for 30°C surrounding temperature and 90 kV applied voltage is 759 µA; the current increases to 907µA for 50°C chamber temperature and the same applied voltage. This in equivalent to an increase in the leakage current by 148µA which can be attributed to the increase in the resisitive leakage current since the temperature is known not to affect the capacitive leakage current.

Although the manufactured year of the surge arrester is almost the same but there is some leakage current differences. This shown that all three samples have different aging levels.

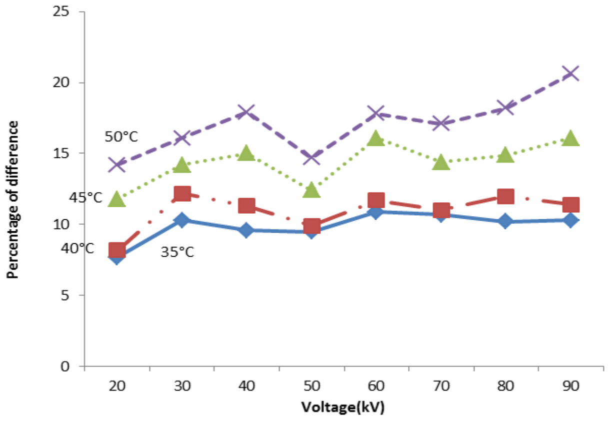


Figure 7 The increase in total leakage current due to temperature increase for sample 1 (shown as percentage increase above that for 30°C)

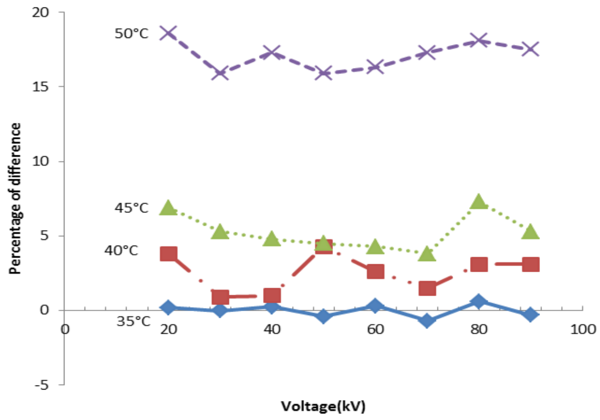


Figure 8 The increase in total leakage current due to temperature increase for sample 2 (shown as percentage increase above that for 30°C)

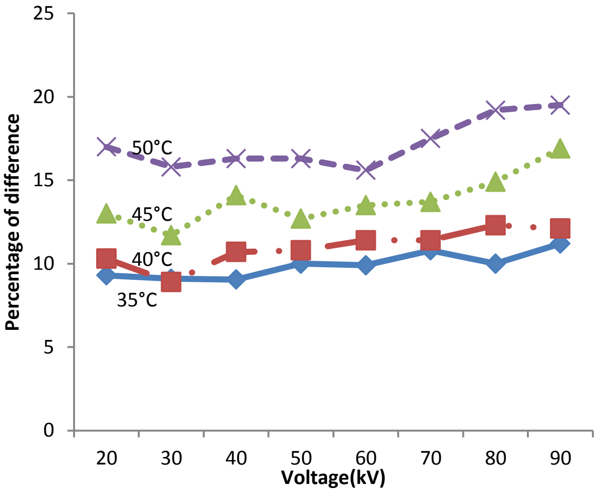


Figure 9 The increase in total leakage current due to temperature increase for sample 3 (shown as percentage increase above that for 30°C)

Figures 7 to 9 show the percentage difference in the leakage current as a function of applied voltage for various temperatures compared to the leakage current at the reference temperature (30°C). As high as 20% difference is observed as the temperature changes from 30°C to 50°C.

Further analyses on the effect of temperature increases are shown in Tables 1 and 2. Table 1 shows the percentage increase in the leakage current due to 10°C temperature increase above 30°C for all three samples. Sample 2 seems to be least affected by the 10°C temperature increase with an average corresponding percentage increase in leakage current of 2.5%. Samples 1 and 3 have a larger average of percentage leakage current increase of 11%.

Table 2 shows the percentage increase in the leakage current due to 20°C temperature increase above 30°C for all three samples. All three samples now have an average percentage increase in the leakage current of about 17%.

Generally, for a typical variation of ambient temperature in Malaysia which is in the range between 30°C and 40°C, the corresponding changes in the leakage current is observed to be up to 11% (as can be seen in Figure 7 to 9, and Table 1). From the results obtained, it is noted that the temperature does significantly affect the leakage current measurements used for monitoring of zinc oxide surge arresters. This significant change in the leakage current due to ambient temperature variation can affect the decision in assessing the condition of surge arresters during routine monitoring.

Table 1 The percentage increase in the leakage current due to 10 °C temperature increment (from 30°C) for all three samples

Voltage Supplied (kV)	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)
20	10.3	3.8	8.2
30	8.9	0.9	12.2
40	10.7	1	11.3
50	10.8	4.3	9.9
60	11.4	2.6	11.7
70	11.4	1.5	11
80	12.3	3.1	12
90	12.1	3.1	11.4

Table 2 The percentage increase in total leakage current due to 20 °C temperature increment (from 30°C) for all three samples

Voltage Supplied (kV)	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)
20	16.9	18.6	14.2
30	15.7	15.9	16.0
40	16.3	17.2	17.9
50	16.3	15.9	14.6
60	15.5	16.3	17.7
70	17.4	17.3	17.1
80	19.1	18.1	18.1
90	19.5	17.4	20.6

■4.0 CONCLUSION

Any leakage current measurement technique has to take into account of temperature effect before determining the surge arrester aging level. There is the possibility of temperatures affecting the leakage current results and analyses in several extremely hot or extremely cold weather countries. From the results of this study, a leakage current difference of up to 20% can occur as the temperature changes from 30°C to 50°C. For a typical variation of ambient temperature in Malaysia in the range of between 30°C and 40°C, the corresponding changes in the leakage current can be up to 11%. Even though the percentage increase in the total leakage current was computed instead of that of the resistive component of the leakage current, the percentage increase can be mainly attributed to the increase in the resistive component of the leakage current. This is because there is minimal direct effect of the temperature increase on the capacitive component of the leakage current. The effect of temperature on the third harmonic component of the resistive current is being studied and is to be reported in a future publication.

Acknowledgement

The author would like to thank Ministry of Science, Technology and Innovation (MOSTI), and the Research Management Centre (RMC), Universiti Teknologi Malaysia for the financial and management support provided under Votes 4S004 and 00H41.

References

[1] Z. A.-M. Novizon, Nouruddeen Bashir and Aulia. 2011. *Condition Monitoring of Zinc Oxide Surge Arresters*.

[2] Z. Abdul-Malek, *et al.* 2008. A New Method to Extract the Resistive Component of the Metal Oxide Surge Arrester Leakage Current. In Power and Energy Conference, 2008. PECon 2008. IEEE 2nd International. 399–402.

[3] Abdul-Malek Z., Ahmad-Noorden Z, Novizon. 2010. Assessment Of Zinc Oxide Varistor Degradation Using Return Voltage Measurement Method', CMD 2010, Tokyo, 6-11 Sept.

[4] Z. Abdul-Malek, *et al.* 2010. Performance Analysis of Modified Shifted Current Method for Surge Arrester Condition Monitoring. In High Voltage Engineering and Application (ICHVE), 2010 International Conference on. 649–652.

[5] Z. Abdul-Malek, *et al.* 2010. Field experience on Surge Arrester Condition Monitoring-Modified Shifted Current Method. In Universities Power Engineering Conference (UPEC), 2010 45th International. 1–5.

[6] S. K. BH Lee, H. S. Choi, Y. H. Baek. 2004. A New On-Line Monitoring Device of ZinC Oxide Surge Arresters.

[7] A. H. a. D. Warne. 2007. Advances in High Voltage Engineering: The institution of Engineering and Technology.

[8] E. C. Sakshaug, *et al.* 1977. A New Concept In Station Arrester Design. *Power Apparatus and Systems, IEEE Transactions on.* 96: 647–656.

[9] M. Kobayashi, *et al.* 1978. Development of Zinc-Oxide Non-Linear Resistors and Their Applications to Gapless Surge Arresters. Power Apparatus and Systems, IEEE Transactions on, vol. PAS-97. 1149–1158.

[10] A. Vicaud, A. C. 1986. Voltage Ageing of Zinc-Oxide Ceramics. *Power Delivery, IEEE Transactions on*. 1: 49–58.

[11] P. Kirkby, *et al.* 1988. Long-term Stability and Energy Discharge Capacity of Metal Oxide Valve Elements. *Power Delivery, IEEE Transactions on.* 3: 1656–1665.

[12] E. T. W. Neto, *et al.* 2009. Artificial Neural Networks Used for ZnO Arresters Diagnosis. *Power Delivery, IEEE Transactions on*. 24: 1390–1395.

[13] Y. Miyakawa, *et al.* 2008. Influence of Temperature Variation On Characteristics of ZnO Elements. In Electrical Insulating Materials, 2008. (ISEIM 2008). International Symposium on. 119–122.

[14] H. Jinliang, *et al*. 2003. Thermal characteristics of high voltage whole-solid-insulated polymeric ZnO surge arrester. *Power Delivery, IEEE Transactions on*. 18: 1221–1227.