Surge Arrester Faults and Their Causes at EThekwini Electricity

M. Gumede and G. Frederick d'Almaine
Durban University of Technology/Power Engineering, Durban, South Africa
Email: makhosonke.gumede@yahoo.com, dalmaine@dut.ac.za

***Abstract*—Failures in polymeric housed surge arresters have recently increased. This has resulted in a number of studies being done in order to establish the condition of surge arresters whilst in service, the aim being to remove them from service before they failed. This paper utilizes a thermovision technique to predict potential faults allied to a visual inspection of arresters placed in eThekwini outdoor substations. Infrared analysis was valuable in obtaining sufficient information on arrester failures by detecting hotspots within the arresters while still connected to the system and comparing these test results with those performed on failed units. During the visual internal inspection of arresters evidence of punctures, treeing, tracking and moisture masks were noted on ZnO blocks and seals.**

***Index Terms*—polymer housed surge arrester, moisture ingress, infrared scanning and visual inspection**

I. Introduction

Polymeric housed surge arresters are widely applied to power transmission systems in order to protect the systems from overvoltages. Their advantage over porcelain or ceramic surge arrester is that they perform well in polluted with the polymeric silicone rubber arresters excelling [1]. Apart from electrical stresses caused by AC voltage impulses or switching operations, the degradation of polymeric housed surge arrester can also be influenced by other environmental factors, such as moisture ingress into the sealing or housing and salt contamination [1]-[6]. These factors could cause problems for the surge arrester in service. As a result, it is very important to measure the condition of arresters in service. Moisture ingress, exacerbated by pollution, plays an important role in the degradation of a surge arrester. It has been reported that moisture ingress in high voltage apparatus is the most important source of degradation [2] and [5]. The moisture absorption in an arrester results in slightly increased leakage current, which is typically in the range of mA [7] and [8]. Hence, this can lead to overheating of the zinc-oxide varistor (ZnO) elements causing the temperature of an arrester to increases until it bursts [9].

Krystain Chrzan reported in the last century that moisture ingress was responsible for 80 per cent of outages in arresters [10]. The same problem is being experienced today (see Fig. 1) [6].

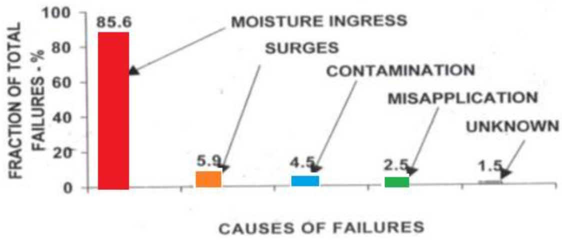


Figure 1. Total failure surge arresters in percentage [11].

As a result of this, it is imperative to do in service condition monitoring of surge arresters in order to check their condition before they fail. This paper presents various methods used to detect faults in surge arresters and their causes at eThekwini electricity.

The thermovision technique was utilized as a tool for data acquisition to detect thermal heat in the arrester and a visual inspection was also done at the electrical workshop to check the condition of the failed arresters. The measurements were applied for diagnosis of 120kV/65kA surge arresters of different makes. The author recommends infrared scanning as the preferred tool to be used for faults detection in arrester because of the validity of the results.

II. Description of Polymer Housed Arresters

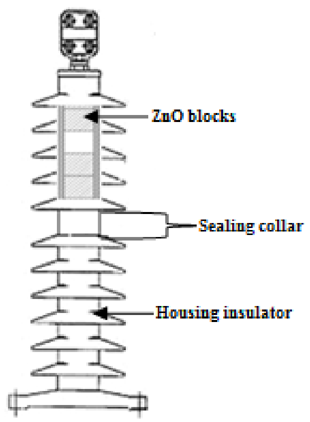


Figure 2. The cross-section drawing view of a polymer housed surge arrester.

Manuscript received July 12, 2013; revised September 13, 2013.

doi: 10.12720/ijoee.2.1.39-44

The insulated housing is directly molded on to ZnO varistor blocks and Fiber-glass reinforced plastic (FRP) to ensure total enclosure of all components and high mechanical strength of the entire structure of the surge arrester. The surge arresters housings have traditionally have been made of polymeric insulating material for arresters for both distribution systems and for medium voltage systems and recently even for power substations system voltages (see Fig. 2).

The heart of an arrester comprises individual ZnO resistor blocks stacked on top of each other to provide the desired nonlinear voltage-current or V-I characteristics and to present a strong relationship with temperature. The secret to the arresters success in diverting lightning or high electrical surges is the ZnO varistor; this is the heart of an arrester. ZnO varistor blocks are semiconductors that are highly sensitive to voltage. Hence, any degradation in the varistor blocks can lead to arrester failure in service. To avoid this problem, selecting a good monitoring techniques can help to minimize these failures.

III. Degradation of ZnO Surge Arresters

As discussed earlier, moisture or humidity inside surge arresters plays a significant role in the degradation process of varistor elements. This moisture increases thermal heating, leakage current [8] and causes discharges. These phenomena are directly responsible for tracking and erosion in a ZnO varistor block of an arrester (see Fig. 3).

Figure 3. Internal partial discharge [10].

The formation of sparking discharge is closely related to the variation trends of the total leakage current and creates high temperature spots leading to bond scissions and other chemical changes on the surface insulation [4]. Leading to permanent failure of the varistor elements. ZnO varistor degradation is used to describe the electrical condition of a varistor relative to its past or future state when under the influence of external stresses [10] and [12]. The amount of degradation is a good quality indication of varistor reliability and is usually used for foreseeing the life span of a ZnO varistor [10].

A. Sealing Defect

A defective arrester may not be able to work in a satisfactory way when an electrical surge occurs [9]. Hence, it could allow moisture to penetrate to a surge arrester housing or sealing (see Fig. 4 and Fig. 5). A consequence of this effect is the reduction of the level of security in the performance of the apparatus. As it has a continuous leakage of gases, the system of protection against explosion becomes inefficient, being no longer capable of performing on extreme heating [5].

Moisture can also penetrate into the interior through the housing material by diffusion [6]. Reference [13] also confirmed effective and proper tests for this family of arrester. For proper design, a thorough knowledge of arrester behavior during different moisture diffusion processes is required [6].

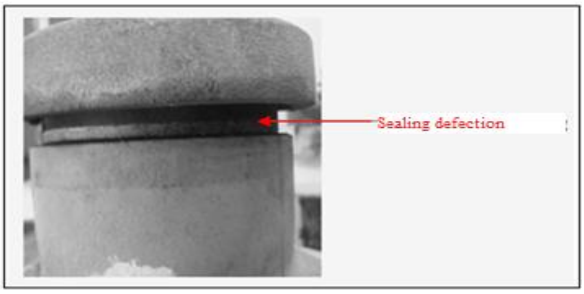


Figure 4. Upper sealing defection.

Figure 5. Sealing collar defective [14].

B. Moisture Ingress

Moisture ingress in high voltage apparatus is the primary source of degradation [2] and [5], because of this situation several studies and research have been done in order to improve sealing material of arresters [10]. Earlier publications have showed that multistress aging testing is an important design test to prevent polymer housed surge arresters having improper design of the insulation [15]. Moisture ingress may result in moisture condensation, changing the protection level and the energy dissipation capability. Frequently, the surge arrester aging may present a gradual rising in the resistive component of the current loss that contributes to thermal instability and finally leads to complete fault (see Fig. 6).

Figure 6. Moisture ingress on the sealing interior [16].

C. Influence of Moisture in ZnO Arrester

The looseness of the insulation from the end sealing as represented in Fig. 4 [2], where for a surge arrester in-service the humidity inside can increase due to deterioration of sealing. Humidity has been shown to increase up to 40-50%. However, at very high humidity levels, about 95%, there is the possibility of condensation at temperature changes [10].

The moisture layer on the internal wall of the housing or on the varistor column can initiate internal flashover [10]. Conversely, moisture absorption into the sealing can also leads to electrical discharge activity, such as tracking, cracking and water trees; trees are the source of aging [5].

IV. Failure Modes of ZnO Surge Arrester

The arrester with polymer housing may burn open the external insulation; such failed arresters are shown in Fig. 7.

Figure 7. Metal oxide surge arresters with polymer housing that failed during in service condition.

Various studies, as in [3] and [7] have been done and show that polymer housed surge arresters are exposed to various stresses such as temporary overvoltages (TOV), switching overvoltages and lightning overvoltages. Thus, due to different factors affecting them their failure may appear in different ways;

- Damage of sealing due to thermal heating produced inside varistor (see Fig. 8)

Figure 8. Defective sealing increase high rate of moisture ingress.

- Localized losses and discharges caused by poor inter-disc contact
- Housing deterioration or pollution changing the voltage distribution along the stack (see Fig. 9)

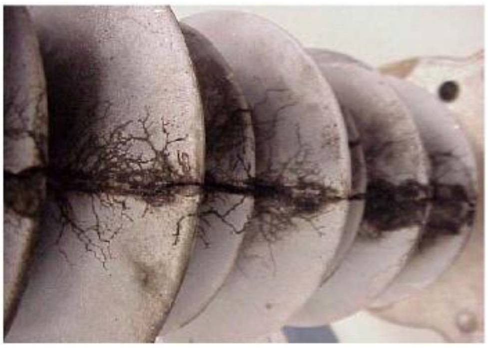


Figure 9. Deterioration on insulation housing [17].

- Mechanical fractures in ZnO varistor due to thermal runaway after a high current surge (see Fig. 10)

Figure 10. Mechanical cracks in varistor elements.

- Damage due to surge current concentration at the edge of the electrode resulting in failure
- Resultant damage to the disc created by previous multiple-stroke lightning surges.

V. Evaluation Methodology

To attain good results for fault detection and diagnosis, it is extremely important to select a set of inputs whose information is capable of allow the fault identification in the surge arrester. Hence, the research methodology applied for evaluating the failure of the family of surge arresters was established. Thermo vision technique was used as a tool for a data acquisition.

Infrared scanning was selected to be used on this study after review of the appropriate literature studies concerning failure of arresters in service condition. The use of infrared thermography is a very convenient approach since the measurement device operates with no physical contact with the tested equipment.

Fig. 11 presents the diagnostic flow chart utilized for data acquisition using thermovision in addition to visual inspection.

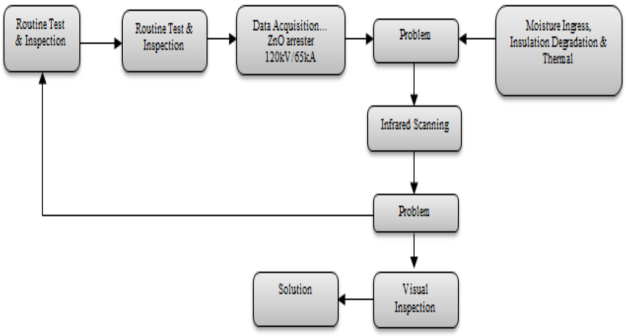


Figure 11. Evaluation flow chart.

The testing covered not only the surge arrester condition but also their major active parts, for instance zinc oxide varistor (ZnO) and insulation of arresters.

VI. Test Results

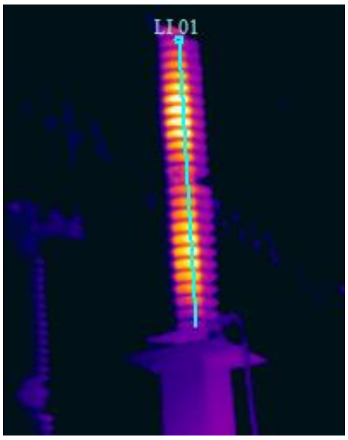
The infrared (IR) analysis was conducted while the surge arresters were energized and under full load. The surge arresters that were tested are of different manufactures (see Table I).

TABLE I. Surge Arrester Types Tested

Arrester manufacture	Housing material	Uc [kV]	Moulded housing	Number of sheds
A	polymer	98	X	24
B	polymer	98	X	24
C	polymer	98	X	24

Uc Max. Continuous operating voltage (IEC 60099-4)*

During the field trail analysis the results of failing arresters were obtained. Images of surge arresters showed the high rate of thermal heat. Results showed the thermal image and temperature profile of surge arresters tested, (see Fig. 12-Fig. 14). Note that the yellow in center of the image is a hot spot. This designates that instant de-energization and replacement must be undertaken before they failure.



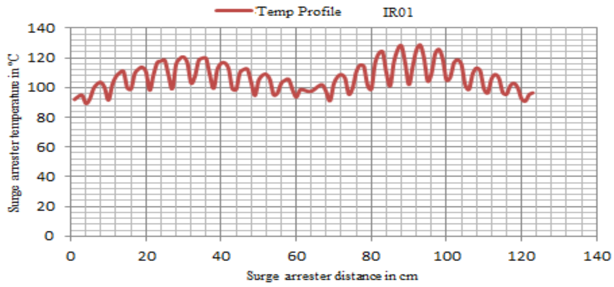
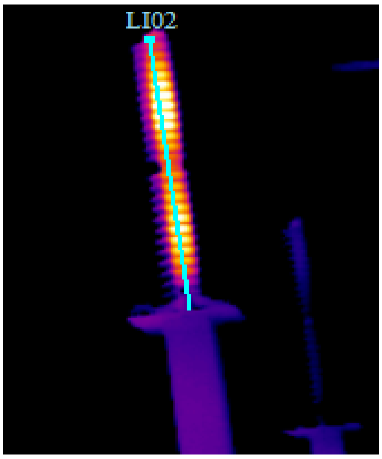


Figure 12. Thermal image of arrester and temperature profile along the arrester.



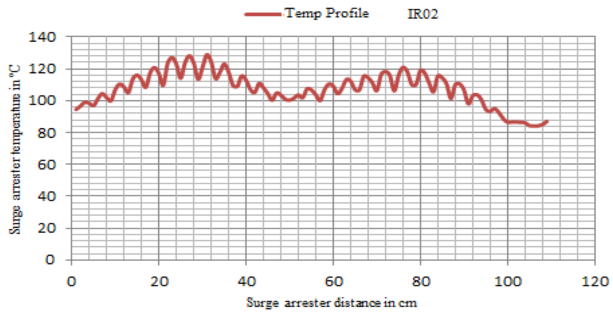
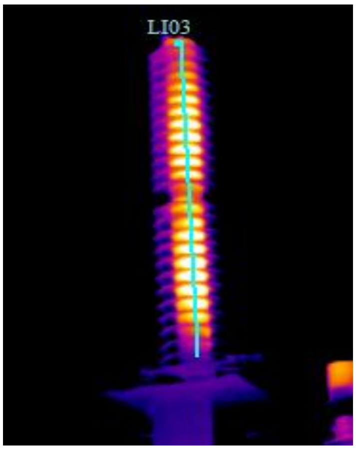


Figure 13. Thermal image of arrester and temperature profile along the arrester.



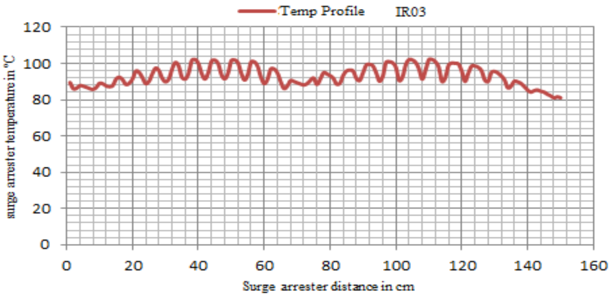


Figure 14. Thermal image of arrester and temperature profile along the arrester.

VII. Images Obtained during Visual Analysis

The results obtained during the visual inspection of the surge arresters of manufacturer A, (see Fig. 15-Fig. 18). The moisture ingress through the sealing collar causes serious problems such as surface discharges. These factors can eventually end with a full breakdown over the insulation system. Water treeing inside the sealing collar was noted as were cracks on the zinc oxide blocks closest to the sealing, this indicates that that the failing started here.

Figure 15. Treeing inside the sealing collar.

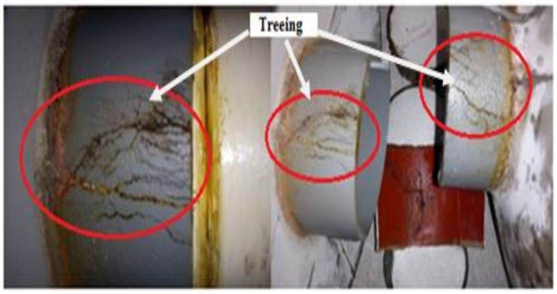


Figure 16. Water treeing on the sealing collar.

Figure 17. Cracks and damp on zinc oxide blocks.

Figure 18. Damp on zinc oxide varistors.

VIII. Conclusion

During thermovision analysis exciting results were obtained. The surge arresters that were measured in outdoors substations showed high thermal temperature inside the zinc oxide varistor. This proves that there was moisture ingress in the sealing collars of arresters whilst in service.

This determines that the heat was generated there because with this family of arresters the sealing of the surge arrester was defected, so it allowed humidity or moisture to penetrate. Throughout visual inspection on the arresters in the eThekwini electrical workshop, evidence of water trees, punctures on sealing collar was found. The images taken during arresters analysis clearly indicated failure of surge arresters caused by moisture ingress leading to degradation on varistor blocks.

Acknowledgements

The authors gratefully acknowledge the contributions of senior engineer in high voltage substation at eThekwini electricity Mr. R Mkhize.

References

[1] I. A. D. Girianntari and T. R. Blackburn, "Surface discharge characteristic of silicone rubber surface arrester housings with high humidity and pollution," in *Proc. 2000 Australasian Universities Power Engineering Conference,* September 2000, pp. 325-330.

[2] M. Clark, *Insulating Materials for Designer and Engineering Practice*, New York: Wiley, 1962.

[3] G.-S. Kil *et al.*, "Measurement method of the resistive leakage current for lightning arrester diagnostic," *Transactions on Electrical and Electronic Materials*, vol. 6, no. 2, pp. 63-66, 18 April 2005.

[4] H. G. Cho, U. Y. Lee, S. W. Han, J. U. Cheon, and K. J. Lim, "The performance of tracking aging and surface in polymer insulator," in *Proc. 2002 International Conference on Electrical Engineering,* 2002, pp. 1-4.

[5] J. Kim, C. Park, Y. Jung, and I. Song, "An investigation of aging characteristics of polymer housed distribution surge arresters by accelerated aging test," presented at the IEEE, Annual Report Conference on Electrical Insulation Dielectric Phenomena, Qu ébec City, Canada, Oct. 26-29 2008.

[6] K. Lahti, K. Kannus, and K. Nousiainen, "Behavior of the dc leakage currents of polymeric metal oxide surge arresters in water penetration tests," *IEEE Trans. Power Delivery*, vol. 13, no. 2, pp. 459-464, April 1998.

[7] V. Larsen and K. Lien, "In-service testing and diagnosis of gapless metal oxide surge arresters," in *Proc Conf. International Symposium on Lightning Protection*, November 2007, pp. 1-6.

[8] D. A. Silva, E. C. Costa, J. L. Franco, S. R. Abreu, R. C. Jesus, M. Antonionni, and J. Pissolato, "Polymer surge arresters:

Degradation versus electrical performance," present at the IEEE, Electrical Power and Energy Conference, London, Ontario, Canada, October 10-12, 2012.
[9] E. T. W. Neto, E. G. da Costa, T. V. Ferreira, and M. J. A. Maia, "Failure analysis in ZnO arresters using thermal images," presented at the IEEE PES Transmission and Distribution Conference and Exposition Latin America, Caracas, Venezuela, 15-18 August 2006.
[10] K. L. Chrzan, "Influence of moisture and partial discharges on the degradation of high-voltage surge arresters," *European Trans, on Electrical Power*, vol. 14, no. 3, pp. 175-184, 2004.
[11] USAID. Presentation on surge arresters. *The American*. [Oline]. pp. 62, Available: http://www.sarienergy.org/PageFiles/What_We_Do/activities/Training.
[12] H. R. P. Oliveira, M. L. B. Martinez, I. G. Campos, R. G. Oliveira, C. Salles, and C. Lefort, "New techniques for field inspection of medium voltage surge arresters," presented at the IEEE Lausanne, Power Tech, Lausanne, Switzerland, 1-5 July 2007.
[13] V. Hinrichsen. (1997). Monitoring of High Voltage Metal Oxide Surge Arresters. [Online]. Available: http://www.energy.siemens.com/us/pool/hq/power-transmission/high-voltage-products/surge-arresters-and-limiters/publications/monitoring-1400180.pdf
[14] M. Gumede and G. Frederick d'almaine, "In-service condition monitoring of surge arresters within eThekwini electricity," in *Proc. Power Engineering Conf*, 2013, pp. 62-63.
[15] K. Lahti, K. Kannus, and K. Nousiainen, "Diagnostic methods in revealing internal moisture in polymer housed metal oxide surge arresters," *IEEE Transaction of Power Delivery*, vol. 17, no. 4, pp. 951-956, October 2002.
[16] D. Silva and E. Costa, "Reliability of directly-molded polymer surge arresters: Degradation by immersion test versus electrical performance," *International Journal of Electrical Power & Energy Systems*, vol. 53, pp. 488-498, December 2013.
[17] J. P. Holtzhausen and W. L. Vosloo, *High Voltage Engineering Practice and Theory*, Netherlands, August 2003, pp. 69-70.

Makhosonke Gumede was born in Durban, South Africa on December 25, 1987. He graduates with a BTech Degree in Electrical Engineering from Durban University of Technology, Durban, South Africa in 2011. Since January 2012 is a student at Durban University of Technology pursuing Master's in Electrical Engineering. He is currently working for Durban Municipality under Electricity Department. His main interests are in the area of high voltage engineering, especially surge arresters and diagnostics. He has published a paper: In-service condition monitoring of surge arresters within eThekwini Electricity in North West University, South Africa, SAUPEC in February 2013. Mr. Gumede is registered as candidate technologies.

G. Frederick d'Almaine is a Senior Director in the Department of Power Engineering at the Durban University of Technology. He specializes in power systems both on grid and off grid and is a director of the Real Time Power System Simulator at the university.