DEVELOPMENT OF ZINC OXIDE VARISTORS: THE AFRICAN EXPERIENCE

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ABSTRACT

Zinc oxide varistors are functional ceramic based semiconductor devices with highly nonlinear current-voltage characteristics similar to back-to-back zener diodes. Its development and implementation in protecting electronic, electrical and power distribution and transmission circuits from the destructive voltage due to lightning and switching surges has been on for almost forty years. The raw materials for the mass production of these protective devices are available in Nigeria. This work is aimed at revealing some of the indigenous approaches adopted by the authors while developing these components under the local content development strategy. The area of experience includes powder preparation, pellets production, sintering, electroding and encapsulations. Other important areas were mechanical and electrical property measurements. The indigenous research and development initiatives revealed that varistors can be mass produced in Nigeria at a very cost effective rate when compared with the imported ones. Adoption of appropriate indigenous technology in all facets of our economy would go along way in transforming African nations from consumers to producer nations.

Keywords: Varistors, Development Initiative, Indigenous Technology, Experience, Raw Materials, Benefits.

INTRODUCTION

The protection of electrical appliances, installations and personnel against surge voltages resulting from lightning and switching of reactive loads is not new. Benjamin Franklin is a pioneer scientist in the study of lightning (Gupta, 2007). After his famous experiment of flying kite in thunder cloud in 1745, he proved then that lighting stroke is caused by the discharge of electricity. He invented lightning rods for fixation on tall building and grounding it for protection against lightning strokes.

(Goedbloed, 1987) stated that voltage surges are common, He monitored low voltage mains power supply for a total of 3,400 hours, on the average, approximately one transient occurs every eight minutes. That is a total of nearly 28,000 transient voltages. Fortunately most of these transient are of very low level and are unlikely to disturb electronic equipment. About 240 transient overvoltages likely to cause disturbance were recorded. That is one disturbance occurs every 14 hours. Most of these will cause disruption, general nuisance and known degradation of components. In general the larger the transient overvoltages the worst are the effects (Furse,1996; Holle and Lopez,1998; Furse,1999).

The first commercially available lightning arrester was developed in the late 1890's by the Stanley Electric Manufacturing Company in Massachusetts. This arrester was rated 1,200 V and consisted of a simple rod –gap design. Series of development and improvement in the raw material selection, process technology for improved performance led to the discovery of zinc oxide varistors. Detailed historical developments of lightning arrester technology are available in the literature (Brass, 2004).

Since, the discovery of zinc oxide varistors by Masuka in 1970, significant work has been done and many are still on going in the field of zinc oxide varistors technology for optimal performances. (Levinson and Philipp,1986; Lagrange, 1991). The actual microstructure structure of ZnO varistor is complex as shown in Figure 1, while Figure 2 is a typical current-voltage characteristic of ZnO varistors.

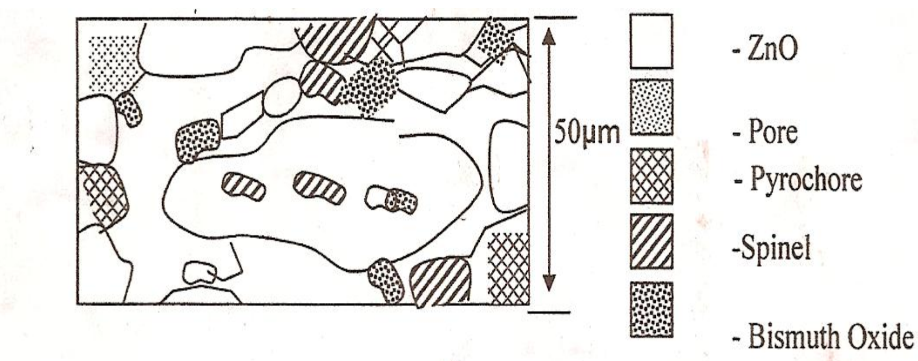


Figure 1: Actual Structure of ZnO Varistor (Lagrange, 1991).

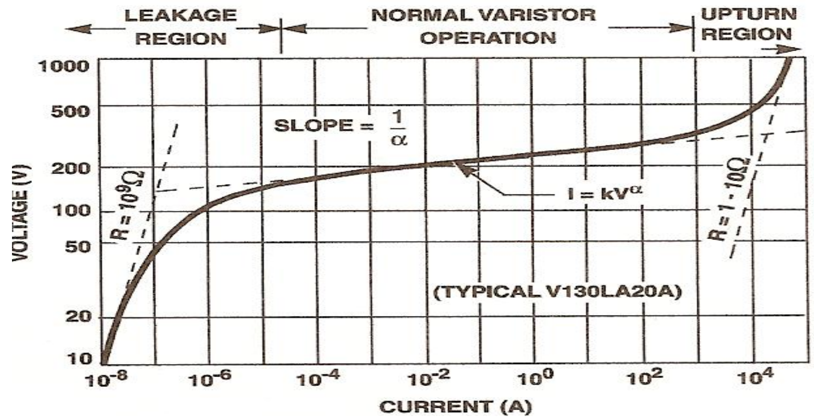


Figure 2: Typical Varistor V – 1Curve Plotted On Log - Log Scale: (Harris, 1999)

(a):Variation Of Nonlinear Coefficient α With Peak Current

(b): Plot Of β Versus α

Figure 3: Non – Linear Coefficients Curves For ZnO Varistors (Lagrange, 1991; Kyocera Group

The varistor effect is represented by equation 1,

$$I = KV\alpha \qquad (1)$$

where   α is the nonlinear coefficient (>1) and K is a constant depending on geometry and manufacturing process. The higher value of the α , the better the protection α is not a constant, but varies with voltage, α achieves its maximum near 1m A/ cm2 as shown Figure 3(a), while Figure 3(b) shows that as α approaches maximum, β reduces to minimum value.(Lagrange, 1991; Kyocera, 2007).

Pioneering works in the production of lightning arresters using locally available materials in Nigeria were done by Oria Usifo and Edeko F.O. (Usifo and Edeko, 1998; Usifo, 2001). These erudite scholars used the Oriaghe compound which is a mixture of haematite and calcium carbonate to achieve these great feats. A further work on these materials by Oria Usifo in 2001 resulted in the present day Oriaghe lightning arresters, which have the same characteristics with that of the silicon carbide based lightning arrester. It would be interesting to note that these lightning arresters were the spark gap types, while that proposed by Evbogbai in the year 2007 were gapless and advance ceramic materials based (Evbogbai, 2011a).

After over four decades of the existence of zinc oxide varistor technology, the successful development of these function semiconductor devices has been done by Evbogbai, Edeko and Ajuwa,(2011a). The nonlinear coefficients of the locally developed varistors have been reported (Evbogbai, Edeko and Ajuwa, 2011b). The prospects and challenges (Evbogbai, Ajuwa and Edeko, 2011a) and the optimal composition (Evbogbai, Edeko and Ajuwa, 2011b) of varistor developed in Nigeria has been established. Other investigations on the varistors developed in Nigeria includes, the effect of geometry(Evbogbai, Anyasi and Momoh,2011), the effect of frequency (Evbogbai, Yeboah and Iyere, 2011), computation of the electrical parameters(Evbogbai,2011b) and the commercialization(Evbogbai, 2011c) has been reported.

This work therefore, is to give an overview of the experience of the authors in the development of zinc oxide varistors in Nigeria.

MATERIALS AND METHOD

Materials

Chemical substances used for the experiment were zinc oxide bismuth oxide (Bi_2O_3), cobalt oxide (CoO), deionized water and organic binder (Starch). The detailed apparatus used for the varistors produced in Nigeria can be found elsewhere(Evbogbai Edeko and Ajuwa, 2011a).

Experimental Procedures

The ZnO and additive oxide (Bi_2O_3 and CoO) powders were weighed in grams, which gave the corresponding %mol. The zinc oxide and additive oxide weighed were poured into a polyethylene container. The oxides were thoroughly mixed using zirconia balls and 20 grams of starch and 20 milliliretres of deionised water were used for ball milling.

The paste formed was dried at room temperature for forty-eight (48) hours, after which it was pressed in steel ring moulds of different diameters to produced disc of different diameter and thickness. Some of the pellets samples are shown in Plate 1. It should be noted that from the processes of powder mixing, milling and pellets production were manually done due to lack of equipment. The ZnO pellets were sintered in an electric furnace at a 1260^{O}C for three hours. The furnace is allowed to cool down to room temperature and the sintered ceramics produced were removed as shown in Plate 2.

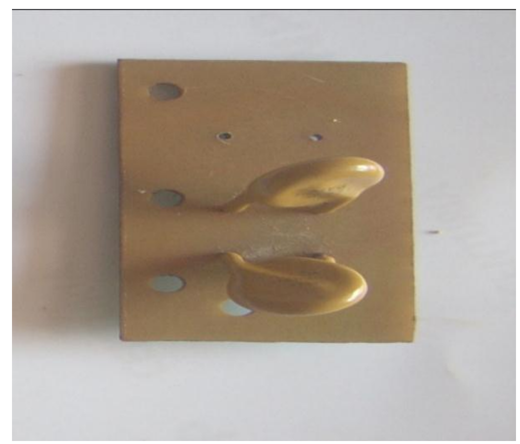
Plate 1: Samples Of ZnO Varistors Disc Pellet Ready For Sintering.

Plate 2: ZnO varistor samples cooling down to room temperature after sintering.

Electroding And Encapsulation

The samples produced were polished using P60D and P220C waterproof silicon carbide paper. The thickness and diameters were measured using micrometer screw gauge and venier calipers respectively. These data were used to compute the surface areas and volumes of the disc. 18KT Gold spray paints (ABRO Products) was sprayed on the top and bottom side of the discs to form electrodes for ohmic contact before soldering. After fifteen minutes, the first spray dries; a second spray was applied to get a better and thicker electrodes coating. 1.5mm copper conductors of about 5cm in length were soldered to both sides of the electrodes to serve as lead for external connection.

ABRO Epoxy steel resin and hardener were thoroughly mixed to encapsulate the prepared samples, which dries in less than twenty minutes. There after, the developed ZnO varistors were properly labeled. Plate 3 shows the photograph of the developed ZnO varistor samples and their foreign made counterpart. It should be noted also that the polishing, electroding and encapsulation processes were manually carried out.



(a) :Developed Zinc Oxide Varistors. (b) :Foreign Made Varistors.

Plate 3

Electrical Measurement

The detailed electrical properties measurements such as current-voltage data, capacitance, various mathematical computations and analysis of the locally developed ZnO varistors has been reported by Evbogbai, etal(2011).

RESULTS AND DISCUSSION

Dimensions of the zinc oxide varistor samples has been reported by Evbogbai, Anyasi and Momoh(2011). A comparative analysis of these I-V characteristics of the developed ZnO varistors shown in Figure 4 with that in Figure 2 and other literatures (Lagrange, 1991; Harris, 1999; Brass, 2004) shows similar behaviour confirming that the developed samples had varistor properties similar to the foreign ones.

Plots of the nonlinear coefficients α against the peak current shows that α is not a constant but varies with voltage and it achieved its maximum value near 1mA for all the ZnO varistors samples as indicated in Figure 5. Comparatively it is analogous to that in Figure 3a.. The higher, the values of α, the better the protection.

The nonlinearities could equally be represented by β. Plots of nonlinear coefficients α against β for the developed ZnO varistor sample shown in Figure 6, revealed that the curves decay exponentially, depicting the degree of nonlinearity, which is similar to those in Figure 3b.

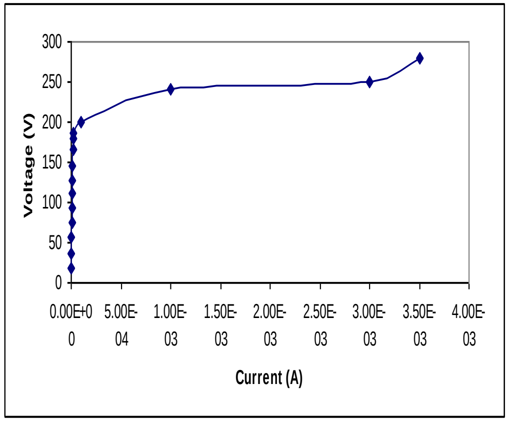


Figure 4: Current-Voltage Characteristics Of the developed ZnO Varistor

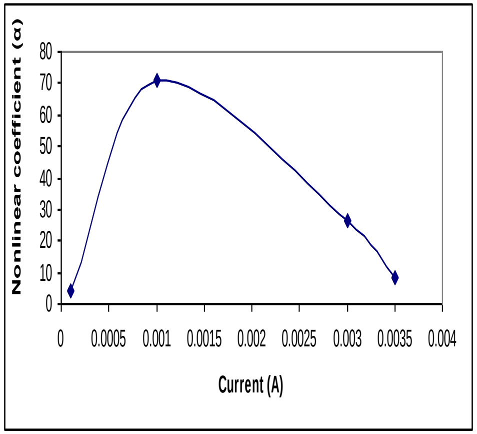


Figure 5: Variation Of Nonlinear Coefficient α With Peak Current Of The ZnO Varistor

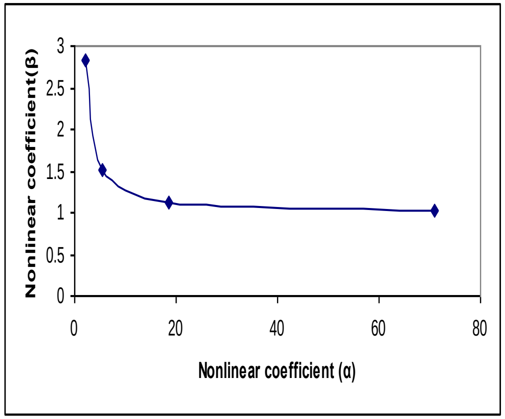


Figure 6: Plot Of β Versus α For ZnO Varistor.

The better the homogeneity of barrier distribution, the better is the performance of the ZnO varistors. However, this could not be achieved under the prevailing conditions of powder preparation by conventional steps of mixing and milling the elements. To improve homogeneity of the barrier distribution and grain growth control, powder preparation by a chemical method have been recommended. Several chemical methods had been reported in the literatures. The zinc oxide grains used in all the developed ZnO samples were assumed to be of the same size. Bi_2O_3 and CoO were the only additives available for these experiments. During processing (mixing and milling) these additives were located in the intergranular layer between ZnO-ZnO grain boundaries. As a result of varistors processing, the ZnO in the ZnO varistors were semi conducting, while the intergranular layer offered potential barriers. The addition of additive oxides in the compositions improves the nonlinear characteristics to certain limits (Evbogbai, Ajuwa and Edeko, 2011b).

Comparison of the current-voltage characteristics, nonlinear coefficients and effect of supply frequency on the capacitance for both the developed zinc oxide varistors and the imported ones exhibit analogues behaviour. The proof tests and destructive test conducted on the zinc oxide varistors developed in Nigeria gave a satisfactory result. It is worthy of mentioning, that despite the developed reasonable precise theoretical model for varistor conduction, commercial improvements proceed mainly by educated trial-and-error activity in mix selection and processing schedule development (Buchanan, 1991). It should be emphasized that the raw materials (Raw Materials Research and Development Council, 2003; 2004) and human resources for the mass production of Zinc oxide varistors are abundant in Nigeria.

The successful commercialization (Evbogbai, 2011c) of these functional, protective semiconductor devices would create employment opportunity, income and wealth. The financial analysis revealed that the investment is a profitable venture with a profit ratio of 61.71% and a high rate of return of 61.61%. The investment will pay back in less than two years.

CONCLUSION

The major challenges encountered during the development and analysis of the varistors made in Nigeria, were lack of equipment, inadequate funding, epileptic electric power supply and poor policy implementation in the solid mineral development and utilizations in Nigeria. The benefits and recommendations resulting from these experiences have been reported (Evbogbai, Ajuwa and 10Edeko, 2011).

The major contributions to knowledge from these research experiences include:

(i) For the first time in the history of Nigeria, varistors has been fabricated using locally available materials.

(ii) The technology behind the production of zinc oxide varistors, such as sintering, electroding and encapsulation has been revealed.

(ii) An optimum composition of 98 percent zinc oxide, 1 percent bismuth and cobalt oxides respectively has been established.

(iv) An easy and simple method of obtaining the current-voltage characteristics of the fabricated zinc oxide varistors has been demonstrated.

(v) It has been shown that for the fabricated varistors, when α is maximum, β is minimum.

(vi) Characterization of the nonlinear coefficient (α) against the peak current revealed that the value of α is maximum near 1mA for all zinc oxide varistor samples under study.

(vii) Local content development of our solid minerals has been demonstrated.

(viii) Maintenance facilitation and replacement has been demonstrated.

(ix) Capital flight issue and conservation of foreign exchange will be enhanced.

(x) It has been demonstrated that the production of ZnO varistors in Nigeria will create employment opportunities and entrepreneurship, which will serve as a roadmap for small and medium scale enterprises.

Conclusively, the indigenous research and development initiative in Nigerian, experienced in the development of zinc oxide using locally available materials in Nigeria is capable of transforming African nations as a major manufacturer of semiconductor components and devices if given the necessary attention.

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