Innovation on Power and Energy Technology
Developing the First Gapless Metal Oxide Surge Arrester (MOSA) in the World

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Introduction

In the present highly extended electric power systems, surge arresters protect important electric equipments against over voltages, such as in the case of a lightning surges or switching surges, and prevent a power outage. Design of insulation in the power transmission system is based on the protective characteristics of surge arresters. Improvement in protective characteristics remarkably reduces total construction costs of substation and transmission system.

ZnO surge arresters (MOSAs) have been improved in reliability, and reduced in size and weight. Development of practical MOSAs was an epoch-making event. There were no MOSAs thirty years ago, although nowadays they are naturally used. The development and increased use of MOSAs will be described below.

2. History of MOSAs

Figure 1 shows changes in surge arresters. The history of surge arresters started from a simple spark gap. Once the gap discharged a lightning surge to the ground, it also discharged AC operating voltage. A variety of surge arresters were devised in order to solve this problem. From 1900s to the beginning of 1930s, a simple surge arrester with a series resistor connected to the spark gap, an aluminum cell surge arrester and a valve-type arrester like an oxide film surge arrester were devised. When a silicon carbide (SiC) nonlinear resistor was developed, this was the start of a new age in which the valve resistance arrester used a spark gap and SiC sinter as a characteristic element. Even when a high current was repeatedly applied to the SiC elements, it was stable. Once the surge arrester discharged a lightning surge to the ground, it could not completely stop the follow current because of the inferior nonlinearity in the low current range. To interrupt the follow current, improvement in the series gap was regarded as a major part of surge arrester development. When a current-limiting magnetic blowout gap was developed in the 1960s, it was believed that the magnetic blowout type was the ultimate surge arrester. However, there was a need for small inexpensive surge arresters with improved reliability and resistance to multiple lightning strikes and contamination (pollution). There was also a need for surge arresters able to be installed in equipment. The series connection of a sophisticated current-limiting gap and a characteristic SiC element, in principle, was unable to satisfy such needs.

In 1975, the world's first ZnO (gapless) surge arrester was installed in the Kyushu Electric Power Company Hayato Substation (heavy anti-pollution type of 66 kV). Technological innovation then began. Figure 2 shows the world's first ZnO surge arresters installed in the actual substation.

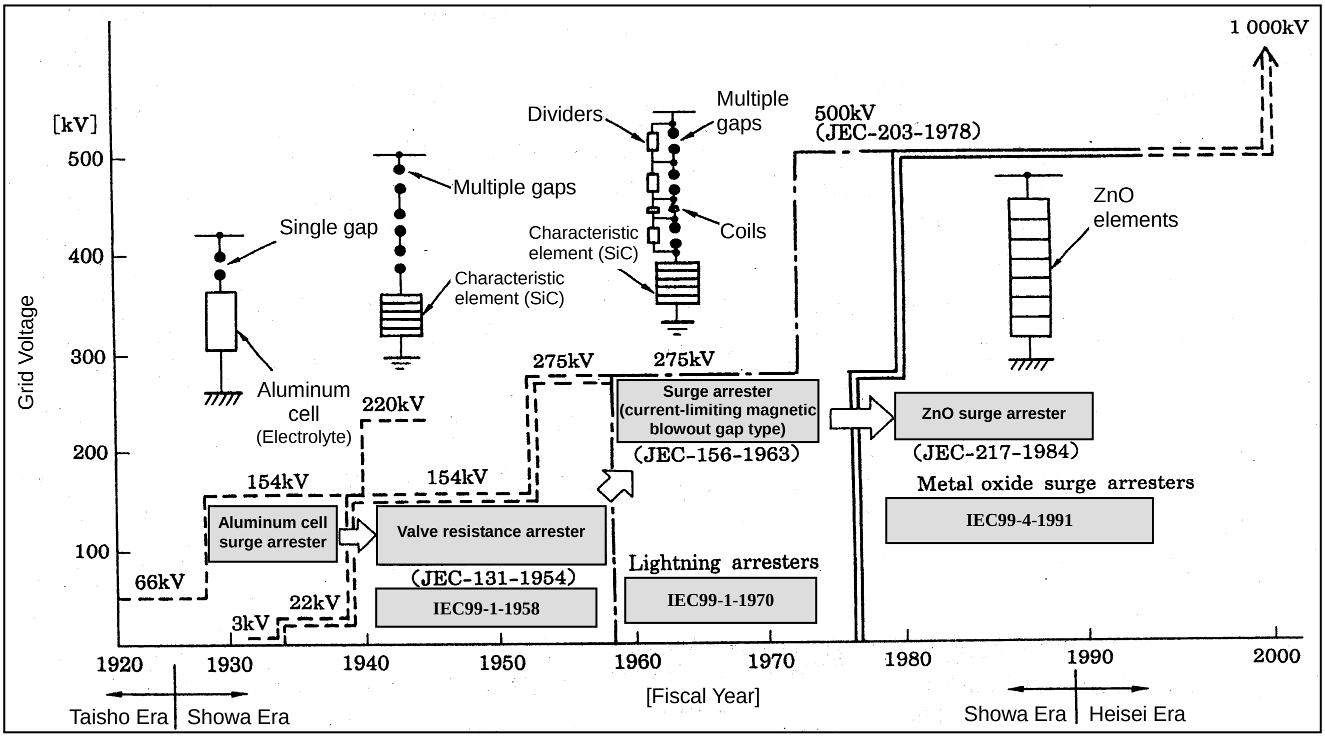

Figure 1 Graphic History of surge arresters

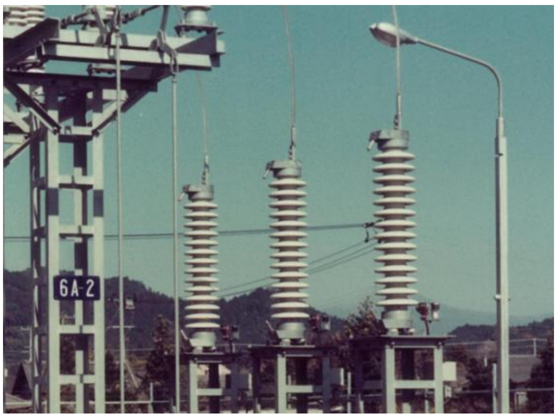

Figure 2 The first ZnO surge arrester (MOSA) in the world

3. Discovery of ZnO nonlinear resistor

In 1968, Matsushita Electric Industrial Co., Ltd. developed ZnO polycrystal sinter (ZnO varistor) [2] having Zener diode characteristics. Blending and sintering zinc oxide as a major component, and traces of additives produced a substance that had excellent nonlinearity from low current to high current, and an excellent energy absorption capability. Meidensha Corporation paid attention to this ZnO varistor for electronics, and expected it not only to replace the silicon carbide sinter (SiC resistor) as a characteristic element of the surge arrester, but also to eliminate the series gap, which was regarded as necessary for conventional surge arresters. In 1970, Meidensha started cooperative research with the Matsushita Electric Radio Laboratory in order to discuss applicability of the varistor for electronics to surge arresters. Material engineers and surge arrester engineers at Meidensha Research Laboratories formed a team, and aimed at creating new technology. With Matsushita Electric, the team continued the manufacture, verification and discussion of element prototypes. In 1973, in Kanazawa, Meidensha and Matsushita Electric engineers presented a paper[3] under joint signature regarding the world's first ZnO surge arrester

(MOSA) at the General Meeting of the Institute of Electrical Engineers of Japan. Figure 3 shows the overview and nonlinearity of a ZnO element.

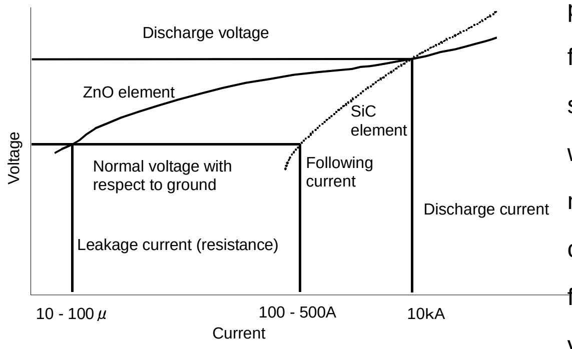

Figure 3 Voltage vs. current performance of ZnO element

4. Development of ZnO elements for high-voltage application

At first, it was doubtful whether varistors for electronics were applicable to the high-voltage grid (electric power systems). The engineers had the following difficulties in using varistors as gapless surge arresters for electric power systems. Figure 4 shows ZnO elements for high-voltage application.

① Improvement in voltage vs. current nonlinearity
② Improvement in energy absorption capability (side insulation coating that prevents side flashover)
③ Large size and mass production
④ Establishment of life estimation

(4・1) Current -voltage nonlinearity

for surge arresters. The engineers investigated the effects of various new additives and all possible interactions between two or more elements based on the periodic law. ZnO elements contained zinc oxide as the principal component and several additives. Wet blending and granulation of zinc oxide and traces of additives produced powder (granules) which were easy to form. The granules were formed into a disc, and sintered in a furnace to produce a ZnO element. It was known that blending of raw materials was a major factor in providing the required characteristics for ZnO elements. Although three or four basic additives provided nonlinearity for varistors, they did not provide enough nonlinearity Several additives were less than 10%. Chemical investigation into how zinc oxide and additives reacted with each other was a difficult and time-consuming process. The engineers used a method of preparing a great number of samples and electrically screening them. There were many cases in which solid-phase and liquid-phase sintering of multi-component samples provided unexpectedly inferior characteristics. Mass production by a selected blending method was a problem. Mass-produced samples containing industrial-grade raw materials had a lower performance than experimental samples containing reagent-grade raw materials in the laboratory. Industrial-grade raw material contained various impurities. It was found that traces of impurities, ranging from several ppm to several hundreds of ppm, affected performance. With the raw material manufacturer, the engineers inspected and verified the actual process for raw-material production. Establishment of production technology was based on this experience. Figure 5 shows the microstructure of ZnO elements.

Figure 4. ZnO elements for high voltage application

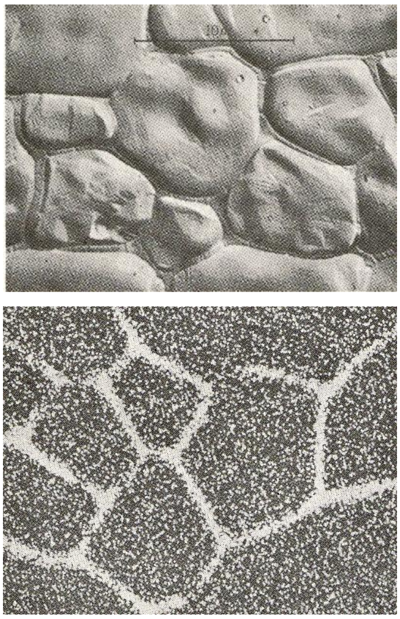

Figure 5 Microstructure of ZnO element

(4・2) Development of side insulator

For verification of current withstand capability, the high current of 4/10 μs was applied to surge arresters. Surfaces of ZnO elements had a lower resistance because they were less than the thickness of SiC elements used in series gapped surge arresters, because of ZnO crystals was electrically conductive. When a high current flowed, therefore, surfaces of ZnO elements were likely to cause flashover. It was essential to enhance side insulation strength of ZnO elements. Coating with an insulator after sintering was the simplest method but insufficient to satisfy performance requirements. Because ZnO crystals was electrically conductive, a newly developed method formed a side insulation layer so that there was no interface between the ZnO element and the side insulation layer, and electric conductivity gradually varied from the inside of the ZnO element toward the surface to the side insulation layer. This method comprised the steps of sintering, discontinuation of the sintering, coating with an insulator containing the same components as the ZnO elements, and baking the whole. This method also improved reliability of the life of a ZnO element as described below.

(4・3) Large-size ZnO elements

Experimental samples in the laboratory had a diameter of 10 mm to 30 mm and a thickness of 1 mm to 5 mm. When the method was developed, the target size of the surge arrester ZnO element was 48 mm in diameter and 22 mm in thickness. While being sintered, the ZnO element contracts to approximately one half of its original size. ZnO elements for high-voltage grids were required to be at least 15 times or more the volume of varistors for electronics. The engineers struggled to specify requirements for uniform contraction (reaction). They empirically knew that furnace temperature distribution, sintering speed and the furnace atmosphere were important factors in uniform contraction. In 1974, a new factory was built which had mass production equipment. The engineers at the new factory repeated mass production of prototypes, and established a mass production technique. They designed and manufactured an original furnace that had a high production capacity.

(4・4) Life estimation

Normal system voltage was continuously applied to ZnO elements because they had no series gaps. The engineers used the Arrhenius plot method to estimate the life of a ZnO element. They regarded degradation as a chemical reaction, and tested accelerated aging at various temperatures. They confidently estimated the life of a ZnO element at 30 years or more[(4)]. When the ZnO element was developed, electric power companies were very concerned about its longevity. (At present, very few people doubt the longevity of a ZnO element.) A foreign electric power company published a research paper that compared the lives of ZnO elements manufactured by two or more companies, the name of which was unreported. The author stated that our company's ZnO element had the best life characteristics probably because of the side insulator. We were pleased to hear that. After that, the engineers continued to improve ZnO elements. The life of a ZnO element has become extremely long and difficult to estimate. Applying 1.5 times the voltage stress to samples at 120 deg C, we tested accelerated aging for 20 years or more.

5. Wide use of MOSAs

In the late 1970s and early 1980s, many researchers in the world published basic research papers regarding the degradation of ZnO elements, the electric conduction mechanism and other basic subjects. Very few people carry out basic research regarding ZnO elements since high temperature superconductors were discovered in 1986. Those involved in the manufacture and use of MOSAs are disappointed at the lack of basic research.

Japanese electric companies showed a keen interest in MOSAs after a major electric power company carried out a field test in 1975. In October 1976, they carried out a joint experiment on MOSAs of 3.3 kV to 275 kV. In July 1978, improved ZnO elements were used to increase the range of surge arresters and provide a product for the 500-kV grid. Gapless MOSAs used in Japan include the heavy anti-pollution type with whole conductive glaze of 33 kV glaze porcelain insulator for the Kansai Electric Power Company Shirahama-Tsubaki Distribution Line, the oil tank type of 66 kV for the Tokyo Electric Power Company Kumegawa Substation (1976), the hot-line washing type of 154 kV for the Chubu Electric Power Company Shida Substation (1978), the SF6 gas tank type of 500 kV for the Kyushu Electric Power Company Central and Kitakyushu Substations (1979), the direct current type of 250 kV for J-Power Company Kita-hon Linked Equipment (1979) and the build-in reactor type of 154 kV for the Kansai Electric Power Company Shigi Substation (1980). New gapless MOSA products used in other countries include the ultra heavy duty type for protection of 500-kV transformer iron resonance at the AC/DC converter station for Manitoba Hydro Station (Canada) in 1979, various surge arresters of 500 kV with a pressure relief current of 100 kA for Ontario Hydro Station (Canada) in 1981 and various surge arresters for AC/DC converter station for the Central Electricity Generating Board Dover Strait DC Power Transmission (UK) in 1984.

After the field test in 1975, less than ten years passed until MOSAs were widely used in new projects throughout the world. The progress in transient phenomenon analysis (electromagnetic transients program, EMTP) enabled estimation of energy absorption to arresters. The increase in use of MOSAs was accelerated by demand, and by arrester energy estimation.

6. Promotion of JEC/IEC standards

When a MOSA was developed, all arresters had series gaps, and there were no standards for gapless arresters. While the JEC-203-1978 standard was being established, Sakuro Tsurumi, a professor at Tokyo University of Science, headed the surge arrester standardizing committee, and decided to describe the clause 7.1 type test as follows: "It is desirable that for the surge arresters with no series gaps, the user and the manufacturer should discuss the spirit of the standard, and carry out reference voltage tests and residual voltage tests instead of sparkover voltage tests." His wise decision enabled the standard to be applied to MOSAs. They waited for a standard exclusively for ZnO surge arresters until the JEC-217-1984 standard was published in 1984. In those days, Japanese manufacturers replaced series gap surge arresters with gapless MOSAs. Japan was a pioneer in the field of MOSAs.

The United States followed Japan. Considering the excellent protective characteristics of the conventional series gapped surge arresters, the U.S. manufacturers were unable to eliminate series gaps. Some U.S. products had series gaps that withstood only for normal line-to-ground voltage. Some U.S. products had parallel gaps. The standard (ANSI C62.11-1987) of such arresters was established three years after the JEC standard. On the other hand, Japan and several countries proposed the IEC standard for gapless surge arresters at the TC 37(Surge Arresters) Meeting in Warsaw (Poland) in March 1979. The WG37.04 (MOSA: Metal Oxide Surge Arrester) group was organized immediately. From 1980, meetings were held once or twice every year in eight countries including Japan. Except for the artificial pollution test, the IEC standard was substantially drafted at the Meeting in Stockholm in 1985. The IEC standard (IEC60099-4-1991) was published six years later in 1991, probably because European manufacturers took several years to develop products (MOSAs)

While making a special effort to establish the standard, the manufacturers sent papers to CIGRE and to IEEE. We presented papers at the 1977 IEEE Summer Meeting [5] (Mexico), and at the 1978 CIGRE Meeting (Paris) [6]. These opportunities led to the WG37.04 organization at the IEC TC37 Meeting in Warsaw. After that, we energetically presented papers, and provided topics for discussion regarding gapless surge arresters.

7. Postscript

MOSAs were discovered and developed in Japan, and are widely used not only in Japan but also throughout the world. This technological innovation was a great success. ZnO surge arresters solved the difficult problems of frequent sparkover and failure by multiple lightning and contamination (pollution). There was a need for much more reliable and compact surge arresters in order to establish the stabilization of grids, GIS and the UHV power transmission plan. MOSAs satisfied such needs. Meidensha Corporation has already exported products to 65 countries or more. A small newspaper article led to the cooperation of surge arrester engineers and material engineers who made a concerted effort to introduce MOSAs to the world. A surge arrester based on different principles has not yet appeared for thirty years since MOSAs were put into practical use. Recently, molded surge arresters have been increasingly used which have ZnO elements directly covered with silicone rubber without using porcelain insulator tubes as housings. This paper briefly describes the initial development of ZnO surge arresters.