Reference [9] (1)

The background and history of developing Gapless Metal Oxide Surge Arrester (MOSA) --(1) ～ From the discovery of the ZnO varistor for electronic circuit to the development of gapless MOSA for high voltage electric power systems ～

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Metal Oxide Surge Arrester (MOSA) technology was first developed in Japan and improved. Original discovery was made by Matsushita Electric Industry Co., Ltd by a finding of some diode phenomena. Meidensha Corporation applied it to high voltage system in Japan in 1975 as a reliable lightning protection equipment. Due to MOSA, the product shift to MOSA occurred from the conventional gapped type arresters (GTA) 35 years ago as GTA had many gap-related problems. Meidensha played a leading role to switch MOSA in the world with the surge arrester standardizing committee in Japan. The MOSA became a complete IEC standard (IEC60099-4-1991) taking 20 years from starting development. The MOSA now has a solid footprint in the world lightning protection space.

Keywords: Innovation, gapless, surge arrester, ZnO element, MOSA

1. Introduction

In the highly computerized society of today, surge arresters play an important role. In the case of a lightning surge or switching surge, they protect equipments from overvoltage, and prevent a power outage. In the 1950s, lightning frequently caused power outages. In the 1970s, however, Japan was one of the countries where few power outages occurred because of improvements in reliability of power transmission grids and equipments and improvements in performance of surge arresters. Electric power companies demanded compact surge arresters reliable for multiple lightning strikes and contamination. Surge arrester engineers, however, failed to satisfy the demand because a surge arrester, in principle, consisted of a series gap and a nonlinear resistor that contained silicon carbide (SiC element) as a major component.

Meidensha Corporation developed high-performance surge arresters based on the zinc oxide varistor (ZnO element) for electronics, which was accidentally discovered by Matsushita Electric Industry Co., Ltd (Panasonic Corporation). Meidensha succeeded in low-cost practical use of high-voltage gapless surge arresters that successfully solved all the above-mentioned problems. Development of practical gapless surge arresters was an epoch-making event, not merely an improvement in reliability of the surge arrester, or reduction in size and weight. Surge arrester manufacturers faced serious problems, such as the metallic tank type for GIS using SF6 gas, the built-in type for composite equipment, the high-performance type for UHV of 1100 kV and surge arresters for direct-current power transmission as well as reliability for multiple lightning strikes and contamination. Development of gapless surge arresters for high-voltage applications enabled all problems to be solved with high reliability, small size and low costs. At present, ZnO surge arresters are preferably used; however, they did not exist in the world until just over thirty years ago. The development and wide use of this product is described below.[1][2]

2. History of surge arresters and problems in the 1970s

Fig. 1 shows the history of surge arresters. From the Meiji Era (before 1910s) to the beginning of the Showa Era (after 1930s), simple spark gap and valve-type arresters of an aluminum cell type and an oxide film type were manufactured. After World War II, valve resistor type surge arresters were used which had SiC elements and series gaps. As multiple-gap type, the valve resistor type surge arresters were widely used. In 1954, the JEC-131-1954 standard exclusive for the lightning protection type was established. As system voltage rose and power transmission line length increased, protection from switching surges rather than lightning strikes became increasingly important for surge arresters. A surge arrester of magnetic blowout type was developed that stopped the after-current ("follow current") absolutely. The JEC-156-1963 standard was established for that purpose.

This ability to interrupt the follow current was extremely enhanced to develop a current-limiting type surge arrester. At first, it was believed that the current-limiting type was the ultimate surge arrester. It was impossible, however, to eliminate the follow current as long as the SiC element was used. Reliability for multiple lightning strikes and contamination was not resolved. There were demand for compact surge arresters, GIS surge arresters, and composite equipment including surge arresters. The series connection of a complex current-limiting gap and a SiC element, in principle, was unable to satisfy the demand. In the 1970s, electric power companies demanded the development of compact high-performance high-reliability surge arresters, such as tank type surge arresters for GIS and built-in type for composite equipment. They also demanded the development of super high-performance surge arresters for UHV 1,100 kV system as the new-age power transmission voltage. ZnO gapless surge arresters satisfied the demand.

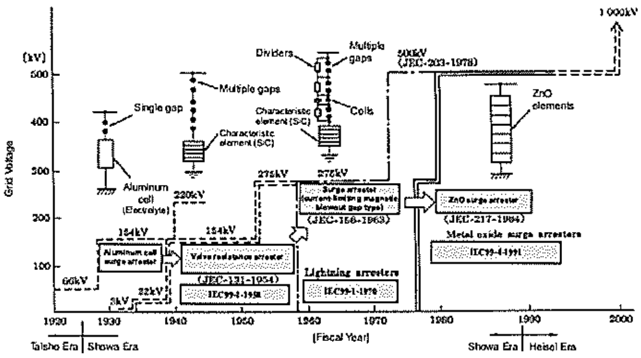

Fig. 1. History of surge arrester

3. Discovery of ZnO varistor for consumer electronics and development of high-voltage surge arrester elements

<3.1> Discovery of ZnO varistor [3]

In 1965, Matsushita Electric was developing a new low-cost high-performance varistor for stabilization of color TV. Yoshio Iida in charge of development at that time suggested research on a varistor that contained ZnO as a major component. In July 1967, an excessive temperature rise due to an electric furnace failure produced a defective example, which seemed to be an insulator.

Michio Matsuoka persistently researched this defective item. As a result, this proved to be a varistor of bulk type. The bulk nonlinear semiconductor device was very different from the aimed varistor. When researching a varistor of several volts, he discovered a new varistor of several hundred volts. A Copernican revolution took place. A new industrial field was founded by research and development of TV varistors and low-voltage surge absorbers based on the newly discovered varistor.

<3.2>Cooperative research regarding high-voltage surge arrester elements [1]

On May 16, 1970, Ken'ichiro Hiraki, president of Meidensha, noticed an article released from Matsushita Electric. The article described a new product (varistor), a ceramic semiconductor that contained zinc oxide as a major component. The president called Yoshio Murayama, director in charge of sales engineering, and asked him to research and determine whether Meidensha surge arresters had a close relationship with varistors or not. He promptly contacted Matsushita Electric. On June 2, along with Misao Kobayashi, chief engineer of the Surge Arrester Section, he visited Mr. Iida, deputy managing director of the Matsushita Electric Radio Laboratory.

Several business talks took place and samples were given. Varistors had far more excellent voltage-current (V-I) nonlinearity than SiC elements. Misao Kobayashi recognized this and expected that although the sample had a low energy capacity, improvement in structure and process would enable a dream solid-state (gapless) surge arrester. On September 4, Meidensha formally proposed cooperative research regarding the development of high-voltage surge arrester elements. In the following October, cooperative research started. It is said that at the same time, two or more Japanese companies proposed the same. Matsushita Electric accepted Meidensha's proposal because Meidensha was the earliest and the most eager proposer, and because Meidensha products supplied to electric power companies had a large market share.

To hold a monthly technological meeting in Osaka or Numazu, a memorandum was prepared between Matsushita Electric and Meidensha. On October 22, 1970, the first such meeting was held in the Meidensha Numazu Plant. Meidensha asked Matsushita Electric to provide a large-diameter element of 32 mm with metallic electrodes. In February 1971, the energy capacity test was conducted. As a result, it was shown that the large element had much larger energy capacity per unit area than the previous-year sample. The large element had at least the same energy capacity as the distribution line surge arrester SiC elements (40 mm in diameter). The large element had 1.5 times or more energy capacity per unit area of distribution line surge arrester SiC elements. After cooperative research started, both companies took four months to have a prospect for the development of high-voltage gapless surge arresters. Meidensha surge arrester engineers thus decided to attempt the development of gapless surge arresters.

<3.3> Licensing contracts and establishment of original technology

In 1971, Meidensha started to negotiate with Matsushita Electric for licenses, because during cooperative research, engineers took several months to provide success in high-voltage element development. In January 1971, Matsushita Electric gave GE (the U.S.) comprehensive licenses for varistors as communication/low-voltage surge absorbers. For high-voltage surge arrester elements, Matsushita Electric waited for the results of their cooperative research with Meidensha.

When engineers had a prospect for gapless surge arrester development, Matsushita Electric decided to make contracts with Meidensha for licensing and providing technological know-how, and to give licenses to Japanese and foreign major surge arrester manufacturers. In fact, Matsushita Electric made contracts with Meidensha on December 10, 1972 first. Then, Matsushita Electric made contracts with Japanese companies: Mitsubishi (1977), Hitachi (1978), Toshiba (1980), and foreign companies: GE, Westinghouse (1976), OhioBrass/Hubbel (1977) and Asea/ABB (1977) in this order.

Although Meidensha requested licenses for system of 3 kV or more, Matsushita Electric gave Meidensha licenses only for systems of 20 kV or more. In 1977, licenses for system of 3 kV to 20 kV were added. Matsushita Electric thought that (1) they could exclusively sell small distribution line ZnO elements to surge arrester manufacturers throughout the world, and that (2) the Matsushita Electric distribution line equipment division could exclusively sell distribution line ZnO surge arresters at least to Japanese companies. However, (1) because the surge arrester unit price was unexpectedly low, exclusive selling was not a highly profitable business; and (2) under the name of Matsushita Electric, it was difficult to expand exclusive selling of high-voltage surge arresters. These are probable reasons why Matsushita Electric adopted a new policy on collecting royalties from surge arrester manufacturers throughout the world.

4. Development of high-voltage gapless surge arresters [4]

<4.1> Idea of gapless surge arresters

Although magnetic blowout type surge arresters were positively used as improved multiple-gap type surge arresters, inferior performance for multiple lightning strikes and contamination was peculiar to the series gap type, and the problem remained unsolved. It was difficult to manufacture compact and reliable series gap type surge arresters. The conventional tank type for GIS needed nitrogen gas (N_2) in series gaps, and had a complex structure that separated N_2 from SF6 gas in the tank. Accordingly, the tank type was too large and inappropriate for satisfying the demand for compact surge arresters. To solve these problems, Meidensha was developing high-voltage ZnO elements. New surge arresters using ZnO elements were roughly divided into two types: type (1) produced by replacing conventional SiC elements with ZnO elements and gapless type (2) produced by eliminating series gaps and using ZnO elements only.

If a ZnO element was completed, type (1) was easier to develop. The ZnO element enabled the magnetic blowout gaps to be replaced with simple gaps. Despite the advantages, type (1) had difficulties in size and cost (for GIS and for integration in equipment), and its reliability for multiple lightning strikes and contamination would not improve in practical use. On the other hand, it was expected that development of type (2) would become an epoch-making event and solve all the problems. It was difficult, however, to associate Japanese and foreign standards and the customer's specifications with the estimated life span of ZnO elements. (How to specify the characteristics of the series gap for the gapless surge arrester ?) In other words, it was expected that even if a product was completed by the manufacturer, it would be difficult to sell the new product because the industry took a long period of time to establish the standard for the new product.

The Meidensha staff held thorough discussions. To follow convictions "Simple is best" and "Good things sell well" consistently, the management decided to develop gapless surge arresters of type (2) although difficulties in marketing were expected. According to the person in charge of Matsushita device research, at first, GE engineers aimed at type (1) and in 1971, they demanded a ZnO element with a low ratio of voltages at 10 kA and at 100 A (discharge voltage ratio). On the other hand, we completed a ZnO element with a low discharge voltage ratio at 10 kA and at 1 mA. In April 1973, Meidensha and Matsushita Electric presented a paper of the world's first gapless surge arrester prototype for 66-kV system to the national convention of the Institute of Electrical Engineers of Japan. [5] One month after that, GE adopted a new policy on demanding type (2). The Meidensha staff members were very satisfied with the corporate policy, and devoted themselves to the development of gapless surge arresters with confidence. Fig. 2 shows characteristics of ZnO elements of multiple-gap and gapless surge arresters. Table 1 shows comparison of the gapless type with the multiple-gap and magnetic blowout types.

<4.2>Development of 66-kV system ZnO surge arresters

Because there was a prospect for ZnO element development and Matsushita Electric made licensing contracts with Meidensha, the Meidensha factory started to manufacture and test a 66-kV system ZnO surge arrester-1 and requested the material laboratory for research and development to provide ZnO elements. Whereas the magnetic blowout type had a troublesome gap, the gapless type had a simple structure that included a ZnO element clamped only by FRP rods. It was possible to reduce such an internal structure significantly. In reality, it was possible to reduce the diameter; it was difficult, however, to reduce the overall length of the contamination type because of the external insulation length (effective length) of the insulator and the surface leakage distance (lower limit).

The gapless type (ZnO surge arrester) had an overall length of 1,000 mm and a mass of 50 kg. The gapless standard type (non-contamination type) was much smaller and much lighter than the conventional multiple-gap standard type of 2,400 mm and 300 kg and the magnetic blowout standard type of 1,600 mm and 150 kg. [5]

An airtight structure was very important for long-term reliability. Considering the significance of the world's first surge arrester, Meidensha adopted the rectangular sectional packing method, because Meidensha sold a great quantity of that type arresters over a long period of time, and had long experience in solving their problems. If a new reasonable method was adopted, and if a surge arrester problem occurred at an early stage, there might be a risk of affecting the worldwide use of gapless surge arresters. Meidensha gave priority to long experience. To ensure the worldwide use of the new product, Meidensha made a prudent decision and gave up the reduction of size and costs.

Instead of impulse sparkover voltage, residual (discharge) voltage was applied to gapless surge arresters. Instead of power frequency sparkover voltage, reference voltage (terminal voltage at a resistive leakage current of 1 mA) was used. Considering the spirit of the surge arrester standards, Meidensha released an alternative testing method and standard values as the Meidensha plan. [6]

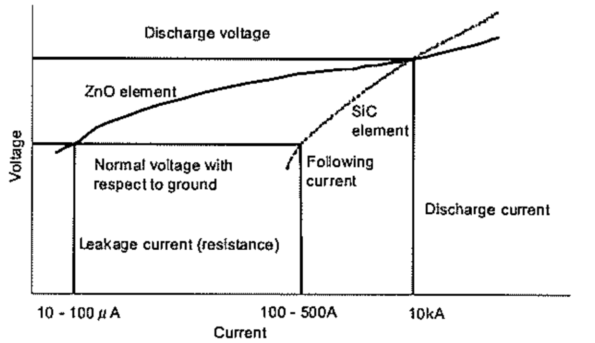

Fig.2. Voltage vs. current performance of ZnO element

Table 1 Comparison of conventional arrester and MOSA

Technical Problem	Conventional Problem	Solution by Gapless ZnO surge arrester
Improvement in reliability for multiple lightning strikes	Inferior insulation of series gaps against multiple lightning strikes may cause ground faults.	Because of the excellent voltage and current nonlinearity, the ZnO surge arrester will not cause the follow current at normal operating voltage after it discharged a lightning surge to the ground. (No ground faults will be caused by overheating or inferior insulation.)
Improvement in contamination resistance	Unstable insulation of series gaps may cause ground faults.	Because the ZnO surge arrester has no gap, it eliminates the gap insulation problem.
Improvement in switching surge energy absorption capability	Limited insulation stability is ascribed to switching surge energy absorption of series gaps.	Because the ZnO surge arrester has no gap, it eliminates the gap insulation problem. ZnO surge arresters connected in parallel can absorb high surge energy.
Manufacture of smaller composite products	It is difficult to manufacture smaller products that have series gaps.	It is easy to manufacture smaller ZnO gapless surge arresters, which have more stable performance and higher reliability.

5. Establishment of development and production facilities

<5.1> Construction of a new factory for ZnO surge arresters

Licensing contracts and the manufacture, tests and announcement [5] of 66-kV system prototype-1 made a favorable impression on electric power companies. At last, the management decided to produce and sell gapless surge arresters on a full scale. In May 1973, Meidensha started to build a new factory for gapless surge arresters in Meidensha Numazu Plant. Immediately after that, the first oil crisis occurred and Meidensha cut capital spending completely. Exceptionally, construction of the new factory was successfully promoted. Building materials became expensive and difficult to procure. Along with the building contractor, Misao Kobayashi, in charge of product development and new factory construction went to domestic cement companies, and made real efforts to procure cement. In January 1974, the new factory was successfully completed, and the engineers were really excited at the prospect of new products changing the course of surge arrester history.

Naturally, the Meidensha Production Division fully supported the new factory construction. Taking this opportunity, Meidensha installed its first 500-kV surge arrester production and testing equipment in the new factory. Meidensha expected to receive orders for 500-kV surge arresters and produce them.

<5.2> Corporate project named "Z-pro"

In October 1970, Meidensha started cooperative research with Matsushita Electric. Meidensha had a laboratory and a surge arrester factory. In April 1971, the laboratory Material Division and the factory Technology Division set up a cooperative research project named "Z-pro." Z implied both the Z-flag and ZnO. The Z-pro members were greatly encouraged by the catchphrase: "Changing the course of surge arrester history." They devoted themselves to the research. Regardless of the overtime work regulations, they worked hard night and day. The Meidensha Personnel Division pointed out their violation of the overtime work regulations. Misao Kobayashi (chief of the Technology Section) in charge of technology had to solve this problem as well as technical problems. He took advantage of his managerial position, and concentrated on the research project. Of the 365 days in 1974, he had only seven whole days of rest.

In October 1974, Meidensha conducted the type test on the heavy contamination type (0.12 mg/cm^2) for the 66-kV system. This type was a product recorded in the world history of surge arresters. Meidensha received an order for this type from Kyushu Electric Power Company. In July 1975, operation of this surge arrester was started at the Kyushu Electric Power Company Hayato Substation. The ZnO element used in this surge arrester was the first product sintered by the continuous electric furnace that had been installed in 1974.

Demonstration of type tests on the series of 3.3 kV to 275 kV was scheduled for October 1976. Preparation for the tests, however, made slow progress. The management (Shiro Seki, president) was deeply concerned about delays. In May 1975, the management decided to make all divisions support the Z-pro. All divisions sent members that formed a Z-pro organization. Shingo Shiotani, deputy general manager of electric power business and director, was designated as project leader. Shun'ichi Hieida, general manager of the Arrester Division, was designated as sub leader. Misao Kobayashi, chief of the Technology Section of the Arrester Division, was appointed to the secretariat. The Z-pro organization consisted of development, production, sales and purchase teams. The laboratory Material Division, the High-Voltage Laboratory and the Short-Circuit Laboratory were formally integrated into the development team. The Production Engineering Division was integrated into the production team. Misao Kobayashi acted both as leader of the development team and as leader of the technological team. As core members, Toru Aizawa (section chief), Kouhei Irie (engineer), Mitsuru Mizuno (chief) and Masahiko Hayashi (chief) led both teams to success. Masaki Haba, Misuzu Watanabe and Masao Hayashi were also active in the most advanced research regarding the basics and mass production of ZnO elements. Such efforts produced an acceleration in research and development, a balance between quality and cost, installation of mass production equipment, and other conditions of development, production, material procurement and selling. In 1976, demonstration of type tests was successfully conducted according to plan. As the Z-pro subleader and general manager of the Arrester Factory, Kazuo Mitani (who had been responsible for high-voltage technology at the initial stage of the Z-pro in April 1971) directed the members to conduct the demonstration of the type tests.

<5.3> Development of original ZnO elements

Although Meidensha obtained a set of technological data from Matsushita Electric based on the licensing and technological know-how contracts, and produced a ZnO element with the predetermined characteristics, the laboratory technological staff concentrated all their energies on producing Meidensha's original ZnO element that kept an ideal balance between performance, quality and cost. The high-voltage ZnO element development problems were roughly divided into three: (1) flattening the voltage-current nonlinear curve to a high current (of approximately 20 kA), (2) steadily producing large ZnO elements with a high energy absorption capability and (3) establishing a method of verifying that the gapless surge arrester could withstand the normal AC voltage for a long period of time.

For (1) flattening the voltage-current curve, the staff investigated many additive elements one by one. Industrial raw materials contained a variety of impurities. An impurity of several ppm to several hundred ppm proved to have an influence on performance. With the material manufacturer, the staff at Meidensha inspected the material production process. Some impurities of several parts per million to several dozen ppm affected the curve significantly. If a very small quantity of element is positively used, a great effort was made to mix it with accuracy. Fig. 3 shows the microstructure of the ZnO element.

For (2) steadily producing large ZnO elements, it was necessary to enhance the insulation of the ZnO element side surface. Meidensha completed a technique for forming a side insulation layer with no interface so that electric conductivity gradually varied from the inside of the ZnO element toward the surface to the side insulation layer. The Tokyo Metropolitan Government selected this technique as a remarkable patent. This technique comprised the steps of sintering, discontinuation of sintering, coating with an insulator containing the same components as the ZnO elements, and then baking the whole. This technique also improved the life of a ZnO element when the continuous voltage was applied to it.

As a long-term stable substance, the ZnO element made an impression on the staff; it was difficult, however, to (3) establish the durability-verifying method. Shinji Hirano (at the laboratory) made an effort to estimate the life of the ZnO element. He succeeded in an experiment using Arrhenius' law, which enabled a long ZnO element life (of 30 years or more) to be extrapolated for 6 months. 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.) Several years after ZnO surge arrester development, a foreign electric power company published a research paper comparing the life span of ZnO elements manufactured by two or more companies.[7]

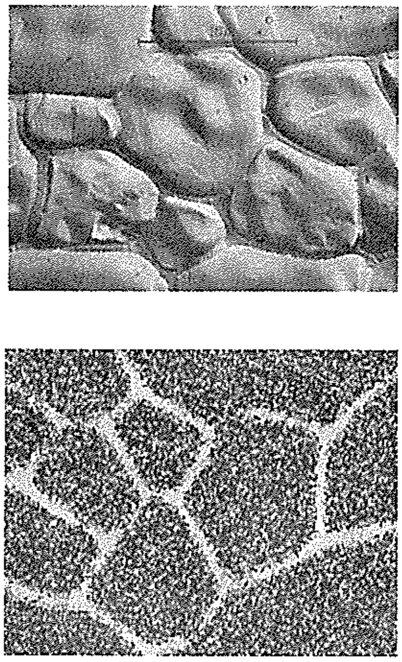

Fig. 3. Microstructure of ZnO element

The author stated that Meidensha ZnO element had the best long-life characteristics probably because of the side insulator. We were pleased to hear that. Afterwards, the engineers continued to improve ZnO elements. Applying 1.5 times the voltage stress to samples at 120°C, they tested accelerated aging for 20 years or more. Reliability was thereby verified.

The ZnO element based on the Matsushita Electric technological data, when continuous operating voltage was applied to it, increased leakage current, and was not applicable to 500 kV/UHV system or overseas systems that demanded high performance. From a tremendous number of experimental results, Meidensha obtained a composition that would not increase leakage current (but reduced it). In 1980, that composition was applied to a series for export. When there was demand for a ZnO element for UHV power transmission, three major manufacturers in Japan struggled to develop so-called "the C-characteristic element". The above-mentioned Meidensha export series had already equivalent life characteristics to the C-characteristic element.

<5.4>Installation of ZnO element production equipment

When the new factory was completed in Numazu Plant in 1974, equipment for research, development and production of ZnO element was installed. To operate this equipment and research production, several members were sent from the laboratory in Tokyo to Numazu. In cooperation with factory engineers, they promoted development of ZnO elements and products. In 1974, production equipment, such as the granulating machine and the sintering furnace-1, was installed in the new factory. In 1976, they designed and manufactured an original special electric furnace-2 for production research and mass production. This furnace-2 was designed to sinter the world's first high-voltage ZnO element. To prevent designers from leaking technical know-how, particular ZnO element research engineers drew detailed designs with the aid of a furnace manufacturer. With further experience in research and production by Furnace-2, Meidensha installed Furaces-3 and -4 for full-scale mass production. Fig. 4 shows ZnO elements for high-voltage application.

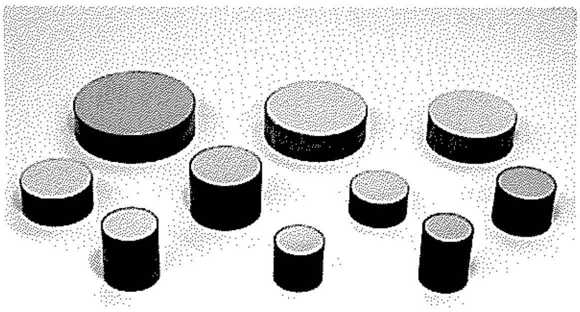

Fig. 4. ZnO elements for high voltage application

6. Demonstration of type tests, release and wide use in Japanese and foreign power systems

<6.1> Selling to Japanese electric power companies

Electric power companies were very interested in three or more repetitions of detailed descriptions of the new product and PR activities after its release [5] in 1973. Because these products were only supplied by Meidensha, we predicted that JEC standardization would take at least five years, and that IEC standardization would take ten years or more. To promote standardization, Meidensha proposed that electric power companies use the new products tentatively. Meidensha had a heated discussion with managers in charge of an electric power substation engineering. Although they were very interested in the new product, and admitted that development of ZnO surge arresters was an epoch-making event, electric power companies rejected the proposal for tentative use unless a quantity of products were used in principal for a period of time or unless standards were established. Meidensha argued that if they admitted that the product exhibited excellent performance, electric power companies should use the product tentatively, and that standardization would make slow progress unless a quantity of products were tentatively used over a period of time. Endless arguing was a problem.

To solve this, Meidensha made a plan for: (1) finding an urgent need for particular electric power companies, (2) persistently promoting standardization and including any formal description (in JEC) regarding prospects for standardization, (3) enlightening cooperative research members regarding the advantages of ZnO surge arresters, and (4) discussing issues with directors (executives) of Technology Divisions for particular electric power companies so that they could harmonize with Meidensha. The four items were implemented simultaneously.

As Meidensha 66/77-kV surge arresters had a large Japanese market share, Meidensha carried out several cooperative research projects with some electric power companies. Other electric power companies under special conditions had a problem to be solved only by gapless surge arresters. Meidensha persuasively negotiated with these electric power companies. In 1974, the type test on a heavy contamination type surge arrester for a 66-kV substation of the Kyushu Electric Power Company was conducted. In 1975, the world's first commercial product was put into operation in the Kyushu Electric Power Company Hayato Substation.

Technological innovation of surge arresters originated in this substation. Fig. 5 shows the world's first ZnO gapless surge arrester installed in the actual substation.

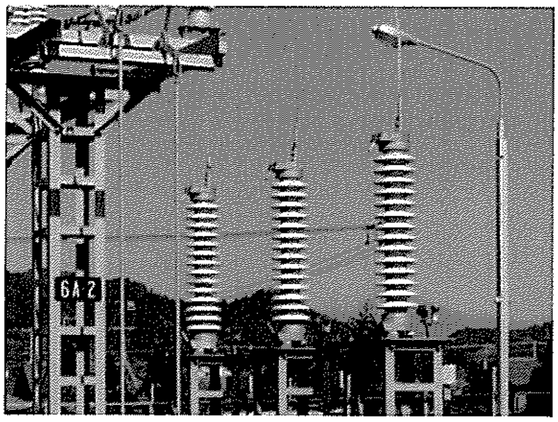

Fig. 5. The first ZnO surge arrester in the world (Hayato substation, Kyushu Electric Power Company)

Cooperative research with Kansai Electric Power Company regarding installation of 22/33-kV distribution lines in the cities used a high-performance compact gapless surge arrester for greatly reducing the insulation level. Tokyo Electric Power Company used a surge arrester of oil tank type for "The Superclad". Cooperative research with Chubu Electric Power Company and NGK Insulators, Ltd. used a 77-kV system surge arrester contained in the semi-conductive glaze porcelain insulator pipe. Meidensha recognized these facts, and persuaded not only the type approval divisions of the above-mentioned electric power companies but also for the other electric power companies asking them to use the new products tentatively.

Meidensha repeatedly requested that the surge arrester standard special committee, the Institute of Electrical Engineers of Japan, draft an item for gapless surge arresters. At the last stage of establishing the JEC-203-1978 standard, Sakuro Tsurumi, a professor at Tokyo University of Science, headed the special committee, decided to add Description (17) to Section 7.1 Type test items. His wise decision enabled gapless surge arresters to be used if the user negotiated with the manufacturer. In accordance with Description (17), Japan successfully collected more information regarding the actual use of gapless surge arresters than other countries. Professor Tsurumi had great foresight. Description (17) is as follows:

"If the standards are applied to surge arresters that do not have series gaps but do have elements with excellent nonlinearity, the spirit of the standards shall be considered. It is desirable, for example, that (1) the Reference voltage test (if DC or AC voltage is applied to the gapless surge arrester, the voltage shall be measured when an electric current of more than a some specified value starts to flow) instead of the power frequency sparkover voltage test, and the temporary overvoltage test (even when a specified voltage is applied to the gapless surge arrester for several seconds, it shall have no abnormal effects) be carried out, and that (2) the residual voltage test instead of the lightning and switching impulse sparkover voltage tests be carried out."

In 1976, the above-mentioned facts of use and Description (17) permitted the user to submit an application for type approval. In 1979, the committee started to deliberate the JEC-217-1984 standard exclusively for practical-use gapless surge arresters.

<6.2> Demonstration of type tests on series of 3.3 kV to 275 kV

Persistent efforts to promote standardization and to persuade electric power companies from 1973 to 1975 resulted in the prospect of type approval of gapless surge arresters. Type tests open to all Japanese electric power companies were scheduled for October 1976. The IEC/JEC standards specify that when a new series is developed, in accordance with the standards, the type test shall be conducted once. It was the custom in Japan, however, that when a major electric power company was in attendance, the type test was conducted separately. Repetitions of type tests were time-consuming and a heavy, expensive burden on manufacturers. Taking this opportunity, Meidensha intended to improve the plan for type tests to reduce times and costs, and to eliminate such a disadvantage to the development of new products.

Because a gapless surge arrester standard was not established, Meidensha and an electric power company took a long period of time to agree on a detailed plan for the discharge starting test and other items related to gapless surge arresters in accordance with Description (17). They needed a tremendous amount of type test expenses, and had to complete elaborate preparations for type tests. It was actually impossible for Meidensha and electric power companies to repeat similar type tests. Meidensha proposed a plan for type tests, and requested electric power companies to agree on the proposal. A slight modification produced a plan for joint type tests open to all electric power companies. With the conventional surge arrester, Meidensha would have failed in its attempt to improve the plan. All electric power companies understood that the product was the world's most advanced surge arrester, and that a gapless surge arrester standard was not established. Eventually, other Japanese manufacturers followed the plan.

On October 28 and 29, 1976, with all Japanese electric power companies in attendance, open type tests were conducted according to schedule. The type tests were successfully completed in the evening of October 29. Participants sent from electric power companies paid us a heartfelt compliment for our epoch-making development of new products. Most Z-pro members were overjoyed at success and too excited to sleep that night. In 1977, electric power companies replaced the conventional type with the new one probably because of favorable comments regarding the new surge arresters. In the last half of 1977, gapless surge arresters had a production share of 80%.

<6.3>Overseas release and CIGRE/IEC standardization promotion

When the open type tests were completed, there was a reasonable prospect that domestic sales of gapless surge arresters would increase. The management decided to sell them overseas. It was necessary to promote establishment of the IEC standards for gapless surge arresters. The International Council on Large Electric Systems (CIGRE) had to hold comprehensive discussions regarding the promotion of IEC standardization. To contribute a paper regarding the newly developed series to the Institute of Electrical and Electronics Engineers (IEEE), which was the most powerful authority of electricity in the world, Meidensha drafted the paper before the deadline of January 31, 1977 for the 1977 summer meeting. A drafter gave up his New Year holidays to work on this. Only with the IBM typewriter, he prepared a draft in English. Strenuous efforts were made to correct spelling because in those days, neither PC nor word processor was available, and because it was necessary to contact the typist who lived far from the office. [8]

A reading of the paper at the Mexico meeting was scheduled for July 21. At the end of June, the author brought it to Dublin, Ireland, and introduced gapless surge arresters to CIGRE SC33 WG06 (insulation coordination of AC systems). Participants at the Mexico and Dublin meeting were very interested in the new surge arresters. In 1978, at the Paris Session, Kazuo Mitani from Japan, director of Sorrester Factory, presented a paper entitled "New Concept on Overvoltage Protection by Surge Arresters" and introduced gapless surge arresters to CIGRE.[9] Sorrester is a registered trademark of a Meidensha new type surge arrester, and stands for a solid-state surge arrester.

In March 1979, at the IEC TC37 (surge arresters) Warsaw meeting, Japan formally proposed establishment of gapless surge arrester standards. Participants in the Warsaw meeting had fully recognized the new surge arresters at the Mexico, Dublin and Paris meeting. The participants decided to form a new WG37.04 promptly. Asle. Schei at the Electric Power Research Institute of Norway was designated as the convenor of WG37.04. They took 17 years to standardize gapless surge arresters probably because European manufacturers were developing new products. In 1991, the IEC-60099-4-1991 standard was established. On the other hand, gapless surge arresters were in practical use in Japan and the U.S. after the JEC-217-1984 standard and the IEEE C62.11-1987 standard were established.

7. Afterword

After a new varistor appeared in a newspaper in 1970, the author was devoted to the development, practical and worldwide use of gapless surge arresters for ten years until 1979. Twelve more years passed until the IEC standard was established. At this stage, presumably, the course of surge arrester history was determined.

After 1979, while Japanese and foreign manufacturers were still struggling to start production of ZnO gapless surge arresters (in particular, mass production of ZnO elements), Meidensha shipped products for all Japanese electric power companies and exported products to 65 foreign countries, and accordingly, production reached several times the initial amount. Misao Kobayashi was awarded the Progress Prize by the Institute of Electrical Engineers of Japan in 1978. Meidensha was awarded the Production Prize by the Okochi Memorial Foundation in 1979. Misao Kobayashi was awarded a Commendation by the Minister of State for Science and Technology in 1991, and was awarded National Medals of Honor with Blue Ribbon by the Prime Minister of Japan in 1994.

Meidensha supplied many products to Japanese and foreign electric power companies. The products recorded in the history of surge arresters include the oil tank type for the superclad of 66 kV for the Tokyo Electric Power Company Kumegawa Substation (1976), the SF6 gas tank type of 77 kV for the Kansai Electric Power Company Nishijima Substations (1977), the hot-line washing type of 154 kV for the Chubu Electric Power Company Shida Substation (1978), the SF6 gas tank type for 500-kV GIS for the Kyushu Electric Power Company Central and Kitakyushu Substations (1979), the superheavy-duty type for 250 kV DC for J-Power Company Kitahon Linked Equipment (1979), the superheavy-duty type for protection of 500-kV transformer ferro-resonance at the AC-to-DC converting station for Manitoba Hydro Station (Canada in 1979), the shunt reactor oil tank type of 168 kV for the Kansai Electric Power Company Shigi Substation (1980), the superheavy-duty high-performance type for protection of restriking of air circuit breaker of 242 kV for Ontario Hydro Station (Canada in 1981) and various surge arresters for the AC-to-DC converting station for the Central Electricity Generating Board Dover Strait DC Power Transmission (UK in 1984).

As Meidensha received a rapidly increasing number of orders for gapless surge arresters, equipment capacity for mass production of ZnO elements was enhanced (second phase installation). At the next opportunity, the authors will describe the facts in detail, including supplied and recorded products, further production equipment installation, the presentation of a paper at meetings and conferences in Japan and foreign countries, the promotion and progress of international standard establishment, composite equipment and other items.

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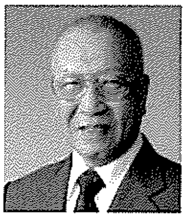

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