

## The background and history of developing Gapless Metal Oxide Surge Arrester (MOSA) --(2)

### — Practical application and widespread use of Metal-Oxide Surge Arrester (MOSA) —

Misao Kobayashi (Surge Protect K.K./Original MOSA key development member at Meidensha Corporation),  
Masao Hayashi (MSA Co., Ltd.)

Metal Oxide Surge Arrester (MOSA) technology became a well-known signature "Made in Japan" technology in the power apparatus. This technology is being used in the world as a lightning and switching surge protection device and it is unique one as a standard originated in Japan. In going IEC Standard (IEC60099-4:1991) in 1991, it took about 20 years from the initial joint development stage of two companies (Matsushita Electric Industry Co., Ltd (current Panasonic Corporation) and Meidensha Corporation.)

The adoption of MOSA accelerated in the advanced nations including Japan after it became a JEC Standard in Japan as JEC-217-1984. The previous issue Part I discussed the early days of MOSA development, field testing, etc. in 1970s. This Part II discusses the period of practical application and the widespread use in the latter half of 1970s and the former half of 1980s.

Keywords: Innovation, gapless, ZnO element, MOSA

## 1. Introduction

Zinc oxide (ZnO) surge arresters are well known as a signature case of Japan originated technology in power apparatus field. At present, ZnO surge arresters, called "Metal-Oxide Surge Arrester (MOSA)," were originated in Japan and are being used throughout the world, and regarded as the de facto standard in power system. It took approximately 20 years to become the IEC standard (IEC 60099-4:1991) from the 1970 start of the joint development research project on high-voltage ZnO elements between Meidensha Corporation ("MEIDEN") and Matsushita Electric Industry Co., Ltd (current Panasonic Corporation) ("Matsushita Electric").

In the Japan Market and the world market, there had been an increasing demand for surge arrester to have high reliability and protection against multiple lightning strikes and contamination. There were demands for a variety of applications (for GIS, UHV power transmission, insulation level reduction, built-in type in the power apparatus). With Gapless ZnO surge arrester's compact design, high performance, high reliability and economical, it became widely accepted in Japan and the western nations around the time the JEC 217-1984 became an official standard in Japan. In the previous paper [1], the authors described the early development and testing method of ZnO surge arresters mainly in the 1970s. This paper describes the widespread practical use of ZnO surge arresters in the latter half of

the 1970s and the early 1980s.

## 2. Overview of gapless surge arrester development

### <2.1> Limitations of gapped type surge arresters

After World War II, valve resistor type surge arresters were used which had SiC elements and series gaps. Multiple-gap valve resistor type surge arresters were widely used. In 1954, the JEC 131-1954 which mainly covers the lightning protection in power apparatus became an official standard in Japan. As system voltage rose and power transmission line length increased, protection from switching surges rather than lightning strikes became increasingly important engineering challenge for surge arresters then. A magnetic blowout type surge arrester was developed that stopped the after-current ("follow current") completely. JEC 156-1963 and IEC 60099-1-1970 standards were adopted for such products..

This ability to interrupt the follow current was significantly enhanced by the emergence of 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 completely as long as the SiC element was used. Reliability for multiple lightning strikes and contamination was not assured. SiC-based arrester could

not meet the requirement of the time: high reliability and compact design and fit for GIS application and for the built-in System. This is because of the limitation created by its complex current-limiting gap and series connection configuration of SiC element.

In the 1970s, electric power companies demanded the development of compact high-performance high-reliability surge arresters to be used in the application for a system equipment and for GIS (tank type arrester). They also demanded the development of ultra high-performance surge arresters for UHV 1,100 kV systems which was then next-generation power transmission voltage. Gapless surge arresters of zinc oxide satisfied these requirements. Table 1 shows the requirements for surge arresters. Table 2 shows the advantages of MOSA.

Table 1 Requirement for arrester

Item	Requirement
Insulation	Surge arresters shall withstand normal power-frequency voltage.
Protection	Overvoltage due to lightning strikes and circuit switching shall be reduced to a predetermined value (discharge voltage). Thus, surge arresters shall protect the insulation of important equipment.
Duty	Immediately after overvoltage disappears, surge arresters shall recover (return to insulator) without disturbing the normal state of the system.

Table 2 Comparison of conventional arrester and MOSA

Technological Issue	Problem	Solution by ZnO Type
Improving protection against multiple lightning strikes	Multiple lightning strikes may reduce insulation of the series gap, leading to a ground fault.	MOSA will not cause follow current after absorption of lightning due to excellent the voltage-current nonlinearity. (No heat up and no ground fault)
Improving performance against contamination	Unstable insulation of the series gap may cause a ground fault.	Because the ZnO type has no gap, it will not cause such a problem.
Improving the ability to absorb switching surge energy	When the series gap absorbs switching surge energy, it should maintain insulation; however, this effect is limited.	Because the ZnO type has no gap, it will not cause such a problem. The use of ZnO elements in parallel enables absorption of high-energy surges.
To reduce the size and to integrate surge arresters into composite equipment	The series gap makes it impossible to reduce the size.	Because the ZnO type has no gap, it is easy to reduce the size. The gapless ZnO type has stable performance and higher reliability than the gapped type.

## <2.2> History from development to widespread use (approximately 15 years)

### <2.2.1> Commencement of high-voltage ZnO element development and conviction for success[1][3][4][5][6]

Responding to a newspaper article which appeared on May 16, 1970, MEIDEN people visited Matsushita Electric Radio Laboratory in Kadoma City ("MERL") to meet with the laboratory head and the chief engineer and proposed the joint research project which included testing, evaluation, improvement of ZnO element

samples. Matsushita Electric accepted MEIDEN's proposal. On October 22, the first technological meeting was held at Meiden Numazu Works in Numazu City, Shizuoka Prefecture, Japan. This was a major event in MEIDEN's history. For three years or more, monthly technological meetings were held alternately in Kadoma and Numazu. Major participants (note: all shown titles were then) included from MERL: Mr. Masuyama, Chief of the Material Development Section-2 and Mr. Matsuoka, senior engineer; from MEIDEN: Mr. Hieda, Manager of Surge Arrester Section; Mr. Kobayashi, Senior Engineer; and Mr. Mizuno, Staff Engineer. Mr. Naoki Kondo, Chief Researcher of the Engineering Division in Tokyo, and Mr. Masahiko Hayashi, Staff Engineer. Basic required performance for the element of a high-voltage surge arrester were a flat voltage-current curve in the range 1 mA to 10 kA, and sufficient energy capacity per unit volume for 2-ms rectangular wave current. The ZnO element had much better voltage-current characteristics than the SiC element. With our experience in developing SiC elements, we expected that an element with excellent voltage-current characteristics would have insufficient energy capacity. MEIDEN requested that Matsushita Electric manufacture and provide a sample 34 mm in diameter and 6 mm thick. In early February 1971, MEIDEN tested it at Meiden Numazu Works. Unexpectedly, it had a far superior energy capacity than the SiC element. On that day, we became convinced that the ZnO elements had ideal characteristics for surge arrester devices. Fortunately, we were able to devote ourselves to development of the necessary large-element production technology and a study of ZnO element potential for the gapless surge arrester. In April 1973, MEIDEN and Matsushita Electric presented a paper on the world's first gapless surge arrester prototype for 66 kV systems to the national convention of the Institute of Electrical Engineers of Japan[2].

### <2.2.2> Decision to develop a gapless surge arrester

MEIDEN continued basic research based on the SiC element for many years from 1954 and at one occasion, it gave up the dream of developing an ideal gapless surge arrester. In early February 1971, at the sight of the unexpectedly excellent results of the 2 ms energy capacity test, we were overjoyed with the finding. It seemed the possibility of producing a "dream-like" ideal gapless surge arrester became suddenly real in front of our eyes.

The arrester related people in the Company soon gathered and had heated discussions on the advantages and technical challenges of gapless surge arresters for several weeks. They concluded that only gapless surge arresters could eliminate the defects inherent in conventional series gap type surge arresters, and that there was a high chance to produce gapless surge arresters.

In those days, relating to the SiC element performance improvement project, the Surge Arrester Section of System Equipment Factory in Numazu Work, had a relation with the Material Research Section (Naoki

Kondo and Masahiko Hayashi) of the Engineering Division in Tokyo (renamed "Core Technology Research & Development Center" or "R & D Center" later). When carrying out daily research and testing on surge arresters, the Surge Arrester Section had a close relationship with the High-Voltage Laboratory (Mr. Toru Aizawa) and the Short-Circuit Laboratory. In cooperation with the Material Research Section, the High-Voltage Laboratory and the Short-Circuit Laboratory, the Surge Arrester Section started the section-level development project in April 1971 as its most important development theme. Before that, Matsushita Electric only manufactured and provided ZnO elements, and MEIDEN evaluated their characteristics, and proposed improvements. The R & D Center in Tokyo installed manufacturing and testing facility so that MEIDEN could also manufacture ZnO elements and carry out research and development of the original ZnO element in parallel with the joint research with Matsushita Electric. In 1975, Mr. Shiro Seki, then President of MEIDEN, ordered to upgrade this research project into All Meiden Level development project which involved the production engineering department, sales department and the procurement department. Mr. Shingo Shiotani, Director and Deputy General Manager, Heavy Electric Business Unit, was assigned as project leader. Mr. Shunichi Hieda, General Manager of the Arrester Division, was designated as sub-leader. Mr. Misao Kobayashi, Manager of the Engineering Section, Arrester Division, was appointed to the secretariat. As another sub-leader, Mr. Kazuo Mitani, Deputy General Manager of the Transformer Factory joined the group later. This All Meiden level program was a key factor in bringing the success of the product development of a gapless surge arrester.

### <2.2.3> Development of high-voltage zinc oxide element from varistor

Among heavy electric system manufacturers, the common perception was it would be quite challenging to use varistor which was originally for electronics circuit for the power apparatus protection device. To apply the varistors to high-voltage gapless surge arresters, we had the various issues shown below:

- (1) Improving voltage-current nonlinearity
- (2) Improving energy capacity (coating the side with an insulator in order to prevent flashover outside)
- (3) Enlarging and mass-producing the ZnO element
- (4) Assuring the life of the ZnO element if continuous voltage is applied to it over a long period of time (establishing a life estimation method)

Typically, the R & D Center undertook the task of finding solutions to these problems. (1) To improve voltage-current nonlinearity, in 1974, MEIDEN established its own production method, and started to operate a mass production line. In 1976, MEIDEN completed an improved type of ZnO element. For several years, Mr. Masaki Haba, Ms. Misuzu Watanabe, Mr. Masao Hayashi, etc. stationed in Numazu City for this research project. The project leader was Mr. Masahiko Hayashi (the R & D Center). They actively researched on the mass production of ZnO elements. Mass production consisted mainly of a multicomponent liquid-solid

sintering reaction, and used raw material that contained some impurities. It was very hard, therefore, to reach laboratory quality level. The raw material contained a variety of impurities. Impurities of several ppms to several hundred ppm proved to have an influence on performance. With the material suppliers, the staff members from MEIDEN inspected the material production process. MEIDEN established production technology based on these experiences. In the 1980s, MEIDEN completed comparative testing on the raw material of zinc oxide produced by manufacturers: four Japanese companies and five foreign companies. MEIDEN found subtle differences in characteristics among the sintered ZnO elements that contained some impurities. Because other raw materials were used in small quantities, MEIDEN limited raw material manufacturers to one or two companies without demanding control over impurities. MEIDEN used six or seven types of mixed raw materials, and analyzed the quantity of each impurity in each supplied lot. MEIDEN thus established a method of adjusting the quantity of an influential impurity.

Figure 1 shows the voltage-current characteristics of elements for surge arresters.

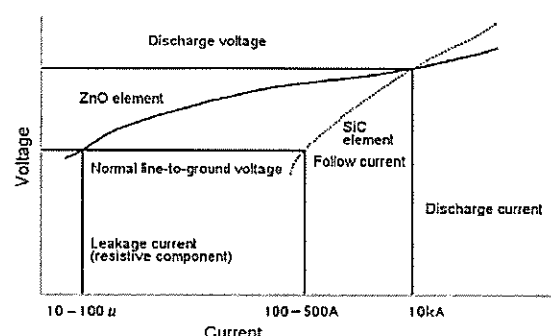


Fig. 1 Voltage vs. current performance of ZnO element

(2) To improve energy capacity, it took a long period of time to devise a scheme to prevent flashovers on the side of the zinc oxide element. The zinc oxide element was made compact, and had less than one-third of the volume of the silicon carbide element used in the gapped surge arrester. Because the crystal of zinc oxide is electrically conductive, resistance cannot be high on the surface of the zinc oxide element. When a large current passed through the ZnO element, therefore, there was risk of a flashover occurring on the surface of the ZnO element. Meidensha developed 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. 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. The Tokyo Metropolitan Government selected this technique as a remarkable patent. This technique also improved the life of a ZnO element when a continuous voltage was applied to it. (3) To enlarge and mass produce the ZnO element, Mr. Kohei Irie, Manager, Engineering Section of the SORESTER Factory built a continuous production

system which covered the various steps -- mixing raw materials, granulating, molding, calcining, coating with insulator, sintering, polishing, adding electrodes and inspecting -- with the support from Production Engineering Department (Mr. Hideo Ishigami, General Manager) which was in charge of All Meiden Level production engineering and it provided key idea and human resources to this research project. The continuous production equipment contributed greatly to reduction of characteristic dispersion and costs.

(4) MEIDEN succeeded in devising a method of estimating the ZnO element life at 30 years by applying the Arrhenius law. It took only six months to estimate such a long life of the ZnO element by this method. Mr. Shinji Hirano at the R & D Center used a large number of thermostatic chambers to collect data. As a result, he successfully produced an Arrhenius plot. Many electric power companies were deeply concerned about the life (and possible degradation) of the gapless ZnO element when continuous voltage was applied to it. An explanation based on the Arrhenius plot was very effective in convincing various electric power companies of the ZnO element's long life. Further investigation revealed that the balance between heat dissipation from the surge arrester enclosure (porcelain housing) heating of the built-in surge arrester element was more important[7] than the static degradation and life of the ZnO element. Discussions focused on measurement of heat dissipation from the surge arrester housing and the heating characteristic of the built-in element. After completing its duty, the zinc oxide element heats up. The leakage current characteristics of the zinc oxide element have such a temperature coefficient that if the ZnO element heats, leakage current increases, and the temperature rises further. If the ZnO element overheats, thermal runaway eventually occurs. Discussions clarified that heat dissipation was an important factor in designing a ZnO surge arrester. It should be noted that the current standard reflects the idea of thermal stability.

#### <2.2.4> Effects of cooperative research with Matsushita Electric[6]

With the special supports from Matsushita Electric such as its research organizational power, human resources and the financial support, it could accelerate the product development at the enhanced and accelerated fashion which would have been impossible just by the limited resources of Surge Arrester Section. We could succeed the big development project in a short period. .

When GE (the U.S.) requested licensing, Matsushita Electric limited the scope of licensing to low voltage (in 1971). When there was a prospect of the real product development under the joint research project with MEIDEN, Matsushita Electric made a licensing agreement only for a high-voltage range of 20 kV or more with MEIDEN (in 1972). Matsushita Electric extended the license range upto 3 kV or more (in 1976) probably at the request of Power Distribution Business Division at Matsushita Electric for 6kV Level Power Distribution.

For a high-voltage range (20 kV or more), MEIDEN was licensed more than four years ahead of the

competitions. Fortunately, MEIDEN could enjoy the "founder's profit" for a certain period.

### 3. Increasing domestic demand

We continued our PR activities so that electric power companies would place orders for gapless surge arresters. On July 24, 1975, the world's first 66 kV heavy contamination type surge arrester ( $0.12 \text{ mg/cm}^2$ ) started operating at the Kyushu Electric Power Company Hayato Substation. In July 1975, gapless surge arresters for 77 kV systems were operated at the Kansai Electric Power Company Konan Substation and at the Chubu Electric Power Company Chikko Substation. At the same time, the 33 kV distribution line surge arrester of heavy contamination type contained in semi-conductive glaze porcelain housing was supplied to Kansai Electric Power Company. In 1976, Nissin Electric Co., Ltd supplied a tank type surge arrester for SF6 GIS to Kansai Electric Power Company. Tokyo Electric Power Company employed and tested a surge arrester to be used in oil tank for "The SuperClad." These various surge arresters were remarkable achievements for MEIDEN. In October 1976, with all electric power companies, MEIDEN conducted joint type testing on A-series gapless surge arresters for high-voltage systems of 3.3 kV to 275 kV as described in the previously published paper[1]. In July 1978, we carried out the type test on B-series gapless surge arresters using the improved ZnO elements for high-voltage systems of up to 500 kV.

The persons in charge on substation engineering at electric power companies in Japan admitted that this gapless surge arrester was an epoch-making and excellent surge arrester. Although they showed a strong interest, the absence of the applicable standard specific to the gapless surge arrester was a challenge for the acceptance. To promote the process of making new standard, MEIDEN asked to use it on a trial basis as long as they admitted that the gapless surge arrester had a higher performance. MEIDEN insisted that unless they used gapless surge arresters, even tentatively, they would not be able to build a supply record and such supply record is an important step in the standard-making process. This was a state of so-called "Chicken and Egg Debate." Fortunately, in 1978, MEIDEN supplied the hot-line washing type surge arrester for 154 kV to Chubu Electric Power Company. In 1979, Meidensha supplied the 500-kV SF6 gas tank type surge arrester to Kyushu Electric Power Company, and the gapless surge arrester for 250 kV DC to J-Power Hokkaido-Honshu HVDC link Equipment. In 1980, MEIDEN supplied the oil immersion type surge arrester (with a built-in reactor) for 154 kV to the Kansai Electric Power Company Shigi Substation. They steadily increased their supply records. From 1975 to 1979, MEIDEN discussed the requirement specification of the 500-kV SF6 tank type surge arrester with Kyushu Electric Power Company. Its structure was small in terms of height, and used an insulator capsule in which ZnO elements were placed in parallel, but electrically connected in series. In those days, GIS technology study meetings were held at Meiden Numazu Works where engineers from Switchgear Factory and Transformer Factory joined. We learned about GIS and

tank structure technologies. The R & D Center gave us the full technical support and we could complete the product development of the insulator capsule. With a strong recommendation by Kyushu Electric Power Company (Mr. Koichi Yamaguchi, Manager, Central Electric Power Transmission Line and Substation Construction Project) we could receive a cooperation from Hitachi Ltd. (Mr. Seizo Nakano, Senior Engineer at Hitachi Kokubu Works) relating to the installation of the 500 kV tank type surge arrester at the GIS substation. While developing the 500 kV tank type surge arrester, we were developing a 250 kV DC surge arrester for the Hokkaido-Honshu HVDC Link Equipment. We took a very long time to make them understand the benefits of the ZnO element surge arrester. The cooperative research with Central Research Institute of Electric Power Industry (CRIEPI) greatly helped them in employing the ZnO element surge arrester. To lower the protective level, and to avoid great DC stress on ZnO elements, we used the bypass gap method (in which a gap is provided in parallel with some elements). Although current-limiting gap technology was researched for conventional surge arresters, it was useful for developing the 250 kV DC surge arrester. In those days, some people doubted if the ZnO element would have a long DC life. Mr. Mitsugu Takanashi of CRIEPI advised us that after ten years, we should replace the surge arrester if the degraded ZnO elements were observed after 10 years. This advice was very encouraging to us. Although more than 25 years have passed since his advice, this surge arrester is still providing the sound performance. At present, these DC 250 kV surge arresters were all pure gapless surge arrester. Electric power company engineers, CRIEPI, etc. gave the vital supports in bringing new technology for the practical use and we could commercialize the various gapless surge arresters. Regarding an oil tank built-in type surge arrester for the distribution line transformer, MEIDEN proposed the gapless surge arrester immersed directly in oil which has the excellent total reliability and economics as the research subject of joint research project involving the three surge arrester suppliers (MEIDEN included) and Tokyo Electric Power Company.

At first, other surge arrester suppliers's responses were negative; however, MEIDEN strongly persuaded them and received the accord and we could complete the development (in 1985). Although MEIDEN has supplied several million of these surge arresters, so far actually we have near zero accident on such installed units. Our products contribute to improvement in the reliability of high-voltage power distribution systems. (Tadao Aoki and Yukiya Sakuraba at the SORESTER Factory were in charge of this research project.)

#### 4. Developing the Overseas Market

While continuing PR activities in Japan, MEIDEN introduced gapless surge arresters to CIGRE WG33.06 (Insulation Coordination of AC systems) at the Dublin Meeting. In July 1977, engineers from Japan presented a paper[8] at the IEEE Summer Meeting (Mexico), starting PR activities in overseas countries. It was very difficult

to increase the use of gapless surge arresters in overseas countries because there were no IEC or ANSI standards. Mr. Kobayashi, Mr. Mizuno and Mr. Sasaki were well versed in the gapless surge arrester technology, and were assigned to visit overseas customers. Making a team by one such expert engineer and one sales person (those area Mr. Chiba, Mr. Imoto, Mr. Ito or another sales person at International Business Unit in charge of overseas sales of surge arresters) such teams visited a great number of overseas countries. It often took a month for each team to complete an overseas business trip.

##### <4.1> The Americas

To increase overseas demand, in 1977, Mr. Kobayashi, Deputy General Manager of the Engineering Division, went on a business trip to the U.S. first. He attended the CIGRE and IEEE meetings and communicated with three major surge arrester manufacturers. Although only two papers on surge arrester were presented in IEEE meeting: one paper on Meiden gapless surge arrester and the other paper on GE bypass gap surge arrester. Such paper submittal was irregular as these discussed the application aspect. U.S. surge arrester manufacturers had already recognized that gapless surge arresters were vastly superior to conventional gapped type surge arresters. They expected that the IEEE and ANSI standards would soon cover gapless surge arresters. They immediately requested field test samples and exclusive sales rights from MEIDEN. After that, in North America, we energetically carried out market research and sales activities for four to five years.

In 1978, the Manitoba Hydro in Canada made an inquiry regarding a specially specified surge arrester of 500 kV. In 1979, Mr. Kobayashi researched the Canadian surge arrester market. Manitoba Hydro engineers understood the excellent feature of gapless surge arresters, and they changed their surge arrester specifications from gapped to gapless. Mr. Kobayashi succeeded in receiving an order for a superheavy-duty gapless surge arrester. Instead of Mr. Kobayashi, Mr. Sasaki and Mr. Mizuno at the Engineering Division took turns to go on business trips to North America in order to carry out market research and acquire information. They visited several companies, including the BC Hydro and the Ontario Hydro. The visitors were surprised at their hosts' eagerness to use better products immediately, although only two years had passed since MEIDEN had commercialized the gapless surge arresters. Since then, MEIDEN has supplied more than 1,000 station class gapless surge arresters for the Ontario Hydro including a great number of 500 kV gapless surge arresters. In 1979, MEIDEN started to research the Mexican and Brazilian surge arrester markets.

##### <4.2> Europe

In April 1978, at the Hannover Messe, MEIDEN exhibited its gapless surge arresters. As a result, suddenly an increasing number of Europeans knew about Meiden gapless surge arresters (trademark: SORESTER). MEIDEN representatives visited Merlin Gerin, Alstom, and other electric power equipment manufacturers; and EDF (a European energy company based in France) and

ENEL (an Italian energy provider). In those days, in France, surge arrester failure occurred frequently, and EDF had minimized the number of surge arresters. EDF had a large experimental station at which EDF could conduct the type test on products supplied to EDF. Before employing gapless surge arresters, EDF conducted various tests on samples at the experimental station. Meidensha is still supplying products to EDF.

#### <4.3> Other regions

MEIDEN energetically undertook PR activities in other regions than the Americas and Europe, and MEIDEN representatives have visited Australian, South African and Asian companies many times. Accordingly, the Company has received an increasing number of orders for gapless surge arresters.

As a result, for the ten years from 1977, MEIDEN sold gapless surge arresters to 53 countries or more. Figures 2 through 7 show products recorded in world history.

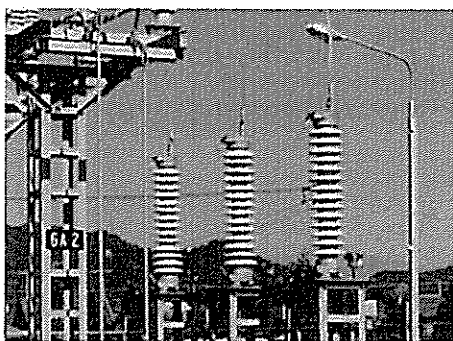


Fig. 2 The first ZnO surge arrester in the world (1975)

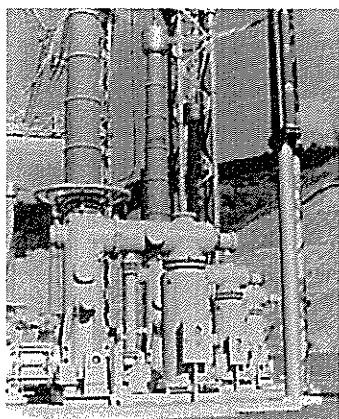


Fig. 3 500kV GIS tank type surge arrester (1979)

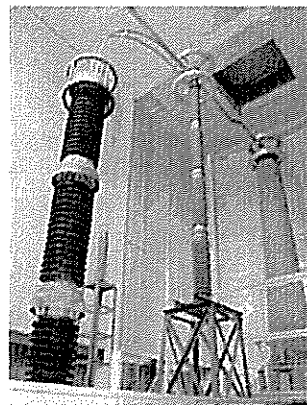


Fig.4 250kV HVDC arrester for Hokkaido-honshu submarine cable protection (1979)

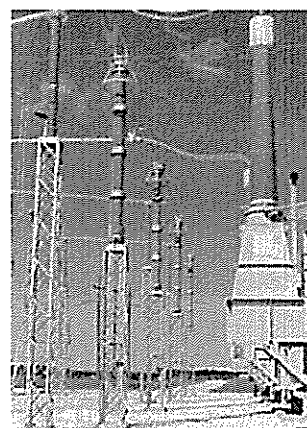


Fig. 5 500 kV heavy duty arrester for Ferro-resonance protection of transformer (1979)

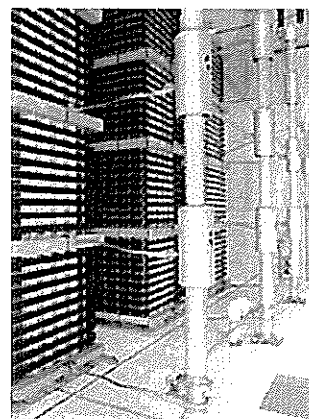


Fig.6 250kV HVDC arrester for thyristor valve protection (1984)

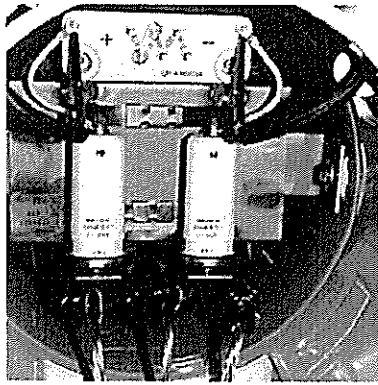


Fig. 7 6 kV Built-in type surge arrester for pole transformer (1985)

## 5. Promoting Japanese and international standardization

### <5.1> JEC standard

In the early stage of development (from 1970 to 1975), the JEC 156-1963 standard applied to gapless surge arresters. This standard specified protection against switching surges and contamination, and was a more improved standard than the early JEC 131-1954 standard that specified protection against lightning and overvoltage only. However, the JEC 156-1963 standard did not adequately specify performance requirements or protection characteristics. The committee was improving the standard and drafting a new standard (JEC 203-1978) in order to ensure consistency with the IEC 60099-1-1970 standard, which also specified switching surge protection. A few years before application, the committee had decided substantially all of the JEC 203-1978 standard. Obeying the spirit of the new standard, the manufacturer and the user were required to negotiate with each other regarding a method of testing gapless surge arresters, and thereby allowed the open type test as described above to be conducted. Negotiating with the user and testing and supplying products remained time-consuming and expensive until the JEC 217-1984 standard was established exclusively for gapless surge arresters.

In 1975, the world's first ZnO surge arrester (66 kV heavy contamination type for Kyushu Electric Power Company) was put into practical use. In 1976, the open type test on the 3.3 kV to 275 kV series was conducted successfully. Many Japanese electric power companies as well as Meidensha requested that the committee establish the JEC standard exclusively for gapless surge arresters. In 1979, the surge arrester standard special committee (Mr. Tsurumi, a professor at Tokyo University of Science) started drafting the standard. Six working groups, WG1 through WG6, drafted it over five years. In 1984, the world's first gapless surge arrester standard, JEC 217-1984, was finally established and applied. When the committee started the standardization process in 1979, Japan (at the IEC/TC37 Warsaw meeting in March 1979) requested that IEC standardize gapless surge arresters. WG37.04 was organized and drafted the standard over six years. After six more years, the IEC 60099-4-1991 Metal-Oxide Surge Arrester standard was

established (for details, see the next section). Meidensha has developed the second and third types of high-performance ZnO elements. Accordingly, for high-performance surge arresters and for GIS tank type surge arresters, the committee has established standards: JEC 2371-2003, JEC 2372-1995, JEC 2373-1998 and JEC-TR23002-2008.

The UHV committee expected future development of a characteristic element (the so-called "C-characteristic element") and made a report (in 1985). In reality, Meidensha developed it in 1978. Since 1979, Meidensha has supplied a great number of C-characteristic elements to foreign countries where performance requirements were strict. (In those days, for systems of 500 kV or less, Japan did not have stricter performance requirements than foreign countries.)

### <5.2> IEC standard

IEC standards for surge arresters included the IEC 60099-1-1958 for lightning and overvoltage protection only, and its improved version, IEC 60099-1-1970 that specified switching surge protection. Both standards were established for the so-called "gapped valve resistor type surge arrester" that consisted mainly of a silicon carbide (SiC) element and a series gap. It was expected that IEC standardization of gapless surge arresters would be very difficult because they were based not on the SiC element but on the ZnO element discovered in Japan, and because gapless surge arrester development in Japan was an epoch-making event. We thought it was essential (1) to supply products to major electric power companies in the world, (2) to have an international discussion at the CIGRE meeting and (3) to submit a paper to IEEE and discuss gapless surge arrester standardization.

Immediately after MEIDENs succeeded in the open type test in October 1976, we started to discuss the chapters of a paper. In 1977, a drafter gave up his New Year holidays to draft and submit the paper to IEEE/PAS1977 SM[8]. A presentation of the paper was scheduled for July 21, 1977. From June 20 to June 24, the author brought it to Dublin, and introduced gapless surge arresters to CIGRE WG33. 01/33.06 Participants at the Dublin meeting had an interesting discussion. In 1978, at the CIGRE Paris Session, Mitani[9], Professor Tsurumi (SC33 domestic committee member) and Mr. Ozaki of CRIEPI presented a paper to CIGRE, and it was highly appreciated around the world. Japanese experts continued to present papers regarding gapless surge arresters[10][11][12][13][14].

Our papers were of benefit to IEC members. In March 1979, at the IEC/TC37 (surge arrester) Warsaw meeting, Japan requested that IEC standardize gapless surge arresters. IEC promptly decided to organize WG37.04 (Metal Oxide Surge Arrester). Asle Schei (former manager of the ASEA Surge Arrester Design Section) at Norway EFI (Electric Power Research Institute of Norway) was designated as convener of WG37.04. Eight WG meetings were held around the world over six years from 1980. The second WG meeting, for example, was held in Tokyo, Japan. In June 1985, at the eighth meeting in Stockholm, WG04 issued its final report. Standardization, however, was delayed because



European countries and the U.S. proposed numerous amendments. In 1988, at the Gettysburg meeting (in the U.S.), TC37 had its final discussion and made a great number of amendments. In particular, France, Italy and the U.S. expressed strong opinions, and proposed amendments. In 1989, TC37 issued its final draft. The six-month rule further applied to it. The IEC 60099-4-1991 was finally established and applied in 1991, six years after WG04 issued its final report. I have recently inferred that the U.S. strongly proposed amendments because the IEEE C62.11-1987 standard was established at almost the same time. The delayed standardization was not a practical problem because after 1985, major manufacturers in the world were producing and selling surge arresters in accordance with the final WG report. With this experience, however, we learned that it was difficult to establish a new IEC standard. Because it was difficult to reach an international consensus regarding the contamination test only, it was kept under consideration. CIGRE and IEC organized a joint working group (CIGRE/IEC JWG06/04), which discussed the contamination test for several years. As a result, Amendment 1 (Annex F)-1998 was established. The IEC 60099-4 Ed.2-2001 was further established which specified GIS, oil immersion and polymer types.

#### <5.3> IEEE/ANSI and other standards

The United States was drafting the IEEE standard in the period from 1984 to 1985, when the JEC 217-1984 standard was established and the final IEC WG37.04 report was issued. In 1987, the IEEE/ANSI C62.11-1987 standard was established. It should be noted that this standard was based on the U.S. power transmission grid conditions and on the performance of ZnO elements in those days. This standard specified the partial series/parallel gapped type and the gapless type, and was complex and difficult to understand. As a guide to application of this standard, the IEEE/ANSI C62.22-1991 standard was established in 1991. Both standards are reviewed every six years. European countries have established the CENELEC (European Committee for Electrotechnical Standardization) standard that resembles the IEC standard. Canada, Australia and other countries have established domestic standards based on the IEC or IEEE standard. In October 1976, all electric power companies successfully conducted the joint open type test<sup>(3)</sup> based on Meiden testing method because in discussions held around 1975, the JEC 203-1978 standard was supposed to allow the manufacturer and the user to conduct the type test on gapless surge arresters if they negotiated with each other regarding an appropriate testing method. The open type test had a great influence on electric power companies. In 1977, MEIDEN supplied a large number of gapless surge arresters (of 66 kV or more) to several electric power companies. The success of the open type test enabled Japanese experts to present a paper[8] regarding the world's first gapless surge arrester series at the IEEE Summer meeting (Mexico) scheduled for July 21, 1977.

## 6. Afterward

Japan has led electric power companies around the world since the Japanese discovery and development of a zinc oxide varistor of bulk type in 1967. A high-voltage gapless surge arrester was developed in Japan in 1975, and the JEC 217-1984 standard was established in 1984. In other words, the zinc oxide surge arrester originated in Japan, and has become a world standard. There seems to be technological and strategic factors in converting the zinc oxide varistor for electronics into a world standard high-voltage surge arrester. The technological factors include (1) the energy capacity and life span of the product increased by sintering the side insulator and the zinc oxide element simultaneously; and (2) the long-term reliability of the product being verified by applying the Arrhenius law. The strategic factors include (1) satisfying a particular user's demands, and carrying out cooperative research (during which executives gain confidence in the product); and (2) presenting papers and promoting standardization.

In those days, no surge arresters in the world satisfied the technological requirements (multiple-lightning and contamination protection, GIS, built-in type for composite equipment, UHV power transmission). Reading the newspaper, MEIDEN management noticed an article released from Matsushita Electric, which led to commencement of gapless surge arrester development. It started with a simple and flexible idea wondering if an electronics product could be used in the power apparatus. It evolved into a section level project in a factory and later became All Meiden Level project. This led to a realization of an epoch-making product – gapless surge arrester. The surge arrester business unit was very small even at MEIDEN but have many close contacts inside MEIDEN in the field of material research, production engineering, high voltage and short circuit laboratory. .

Such close relationships enabled them to share the same vision of spreading the innovative technology to the world. We also learned that the reason why we could realize the joint development with Matsushita Electric were: MEIDEN is a member of Sumitomo Group companies and its founder, Mr. Konosuke Matsushita had a very good relation with The Sumitomo Bank, Limited. (then President Mr. Shozo Hotta). The Sumitomo Bank (current Sumitomo Mitsui Banking Corporation) is a key bank in Sumitomo Group companies.

In product development of this special product, we are feeling there were a series of luck and relation (beyond the power of our engineers at former surge arrester business unit): "Right Timing, Right Place and Right People". It was like the harmony of Heaven, Earth and People. Three factors were established almost at the same time and drove us to the successful journey of this special product development.

## Acknowledgments

Without the support of Mr. Matsuoka of Matsushita



Electric and the joint development project with Matsushita Electric Radio Laboratory, it will not be possible to complete the product development of gapless surge arrester which contribute the system safety of the world power network systems. Back then our section, Surge Arrester Section at MEIDEN was very small and had limited resources. We would like to express our great appreciation to Panasonic Group. Further, we would like to express our special appreciation to the late Mr. Hiraki, former President of MEIDEN; the late Mr. Seki, former President; the late Mr. Shiotani, former Director; the late Mr. Hieda, former General Manager; and ever project members at the Z-pro and then SORESTER Factory people and MSA people.

### References

- [1] M. Kobayashi and M. Hayashi : "The background and history of developing Gapless Metal Oxide Surge Arrester(MOSA)-(1)", HEE-08-19, IEE Japan
- [2] T. Nishikori, T. Masuyama, M. Matsuoka, M. Kobayashi, M. Mizuno : "Gapless Power Arrester by Zinc Oxide Nonlinear Resistors" National Convention Report of IEE of Japan, No. 777, 1973
- [3] K. Mitani : "Records of Development of Gapless Metal Oxide Surge Arrester (MOSA) for Electric Power Systems " Serial Story by News Paper "Denki Shimbun" Nov 30, 1979(1) to Jan 21, 1980 (8)
- [4] M. Hayashi and M. Kobayashi : "Developing the First Gapless Metal Oxide(ZnO) Surge Arrester(MOSA) in the World ", IEE of Japan Trans. PE, Vol. 128 No.3 (2008)
- [5] K. Uchihashi : "A Stone Breathes Lightning ", Era of Craftmanship, Pocketbook by Koudansya Vol.1, No.3 (1985)  
Evening News Paper "Fuji ", Serial Story 16 times ( Sept 15~Oct.5, 1979)
- [6] M. Kobayashi : "Craftmanship and Originality on Surge Arrester Development" OHM (Electrical Magazine in Japan) No 3, 1993
- [7] M. Mizuno, M. Hayashi, M. Mitani : "Thermal stability and life of the gapless arrester", IEEE PAS-100, No.5, May 1981
- [8] M. Kobayashi, M. Mizuno, M. Hayashi, K. Mitani : "Development of Zinc-Oxide Non-Linear Resistors and Their Applications to Gapless Surge Arresters" , IEEE PAS, Summer Meeting, F77, 682-8(1977), IEEE Transavtions, vol. pas-97, No.4(1978)
- [9] Y. Ozaki, M. Takanashi, S. Tsurumi, K. Mitani, and M. Kobayashi: "New Concept on Overvoltage Protection by Surge Arresters", CIGRE No.33-02(1978)
- [10] S. Tsurumi, M. Kunishima, M. Mitani, K. Naito : "Performance under Polluted Washing and Field Test of Metal Oxide Surge Arresters", CIGRE No. 33-03, 1980
- [11] M. Hayashi, M. Haba, S. Hirano, M. Okamoto, M. Watanabe : "Degradation mechanism of ZnO varistor under dc bias ", J. Appl. Phys. Vol. 53, No.8, Aug. 1982
- [12] M. Kobayashi, M. Mizuno, M. Hayashi, Y. Sugita : " Metal Oxide Surge Arrester" IEEE Trans EI21 No 6 1986
- [13] Y. Harumoto, Y. Tsuda, M. Kobayashi, M. Mizuno, T. Aoki : " Evaluation for Application of Built-In Type Zinc Oxide Surge Arresters for Power System Equipments " IEEE Trans PWRD-2, No.3 1987
- [14] M. Kobayashi, S. Yokoyama : " Lightning Protection of Distribution System in Japan " CIGRE SC33.95 (Coll ) IWD 1.22 1995



Misao Kobayashi (lifetime member)

Born August 24, 1931. Graduated from Tokyo Institute of Technology in March 1954. Joined Meidensha Corporation in April 1954. Engaged in surge arrester technology, high-voltage high-current tests and research. Appointed chief engineer of Production Division in 1988.

Founded Surge Protect KK in 1996. Currently representative of power systems. Awarded Progress Prize by IEE of Japan in 1978. Awarded Commendation by the Minister of State for Science and Technology in 1989. Awarded National Medal of Honor with Blue Ribbon by the Prime Minister of Japan in 1992. CIGRE Distinguished member. IEEE fellow. Member of Institute of Engineers on Electrical Discharges in Japan. Member of Society of Atmospheric Electricity of Japan. Member of Institute of Electrical Installation Engineers of Japan.

Member of Institute of Electrical Engineers of Japan



Masao Hayashi (regular member)

Born January 13, 1950. Finished master's degree program at Graduate Division of Science and Technology, Sophia University in March 1974. Joined Meidensha Corporation in April 1974. Researched and developed surge arresters. Became general manager of

Sorester Factory in 1999. Founded MSA Co., Ltd. in March 2004. Currently manufactures and sells surge arresters.

Member of Institute of Electrical Engineers of Japan