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Development of Gapless Surge Arresters and Application of Them to Power System Facilities

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***Abstract*—Technology of Metal Oxide Surge Arrester without gaps (MOSA) was first developed in Japan and improved. Original ZnO varistor discovery was made by Matsushita Electric Industry Co., Ltd. Meidensha Corporation applied it to high voltage systems in 1975 as a reliable lightning protection equipment. The product shifted to MOSAs from conventional gapped surge arresters (GSAs) 38 years ago, as GSAs had many gap-related problems. This paper shows the history of the development of MOSAs and also shows the author's involvement in development of various type and class gapless surge arresters and expanding them to domestic as well as overseas electric power systems through efforts of standardization.**

Keywords-component; lightning; lightning protection; surge arrester; MOSA; gapless

I. Ⅰ. INTRODUCTION

Lightning surge arresters had been made of silicon carbide valve elements and series gaps since around 1940. Meidensha Corporation (referred to as Meidensha, hereafter) has developed a new gapless surge arrester (referred to as MOSA, hereafter) [1, 2] which employs Zinc-oxide non-linear resistors and then gapless surge arresters are main stream of the surge arresters for lightning and switching surge protection of electric power systems. MOSAs have achieved a high reliability and a compact design because of their excellent non-linear and anti-pollution characteristics. The development of MOSAs is the most epoch-making one along with that of SF_6 insulation facilities. They have produced innovation in the field of electric power systems and now the stable power supply could not be realized without them.

In this paper, the author, who is one of key persons for developing the MOSAs, applying them to all voltage-level power systems and promoting JEC and IEC standardization, shows the development process of the MOSAs. Moreover the author shows the condition of technical development and promotion methods of MOSAs for electric power companies.

II. HISTORY OF SURGE ARRESTERS AND EXPECTATION FOR DEVELOPING MOSAS

In this chapter, the author shows the history of the development of various kinds (classes) of lightning surge arresters and the demand of gapless arresters (MOSAs) for electric power systems.

A. History of Surge Arresters

Figure 1 shows the history of development of various kinds (classes) of surge arresters.

From 1910s to 1930s, simple spark-gap type arresters of an aluminum cell type and an oxide film type were manufactured. After World War II, resist valve type surge arresters, which have SiC elements and series gaps, have been used widely. As a system voltage and a power transmission line length increased, protection from switching surges rather than lightning strikes became increasingly influential for surge arresters. A surge arrester of magnetic blowout type, which efficiently limited the AC-current ("follow current"), was developed. It was impossible, however, to eliminate the follow current as long as the SiC elements were used. Reliability for multiple lightning strikes was not resolved. In addition, the existence of series gaps affected the stable discharge characteristics.

In the 1970s, electric power companies required the development of compact, high-performance and high-reliability surge arresters, such as tank type surge arresters for a GIS and built-in type for composite equipment. They also required the development of super high-performance surge arresters (MOSAs) for UHV 1,100 kV system. The series connection of a complex current-limiting gap and a SiC element, in principle, was unable to satisfy these requirements. ZnO gapless surge arresters (MOSAs) had a possibility to satisfy the requirement.

B. Comparison of gapped surge arresters and gapless MOSAs

As newly developed MOSAs (Figure 2) have no gap and are not followed by a 50-60Hz frequency current (follow current), they have many advantages compared with conventional surge arresters as follows [2-6].

(1) Large current withstand capability.
(2) Excellent anti-pollution characteristics and live-washing type surge arresters.
(3) Parallel use of zinc-oxide surge arresters for high current duty [2]
(4) The most suitable surge arresters for SF_6 insulated switchgears and compact substation equipments.
(5) The most suitable surge arresters for UHV systems

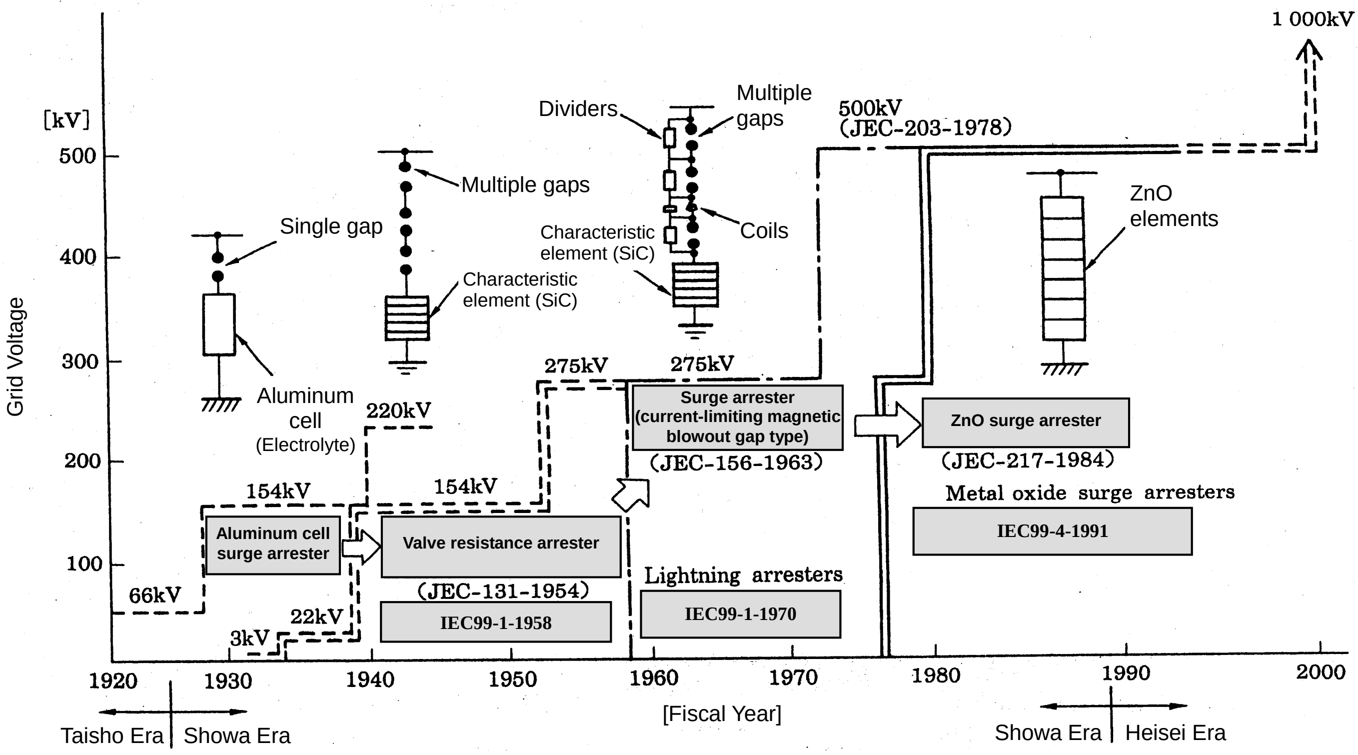

Figure 1. History of surge arresters

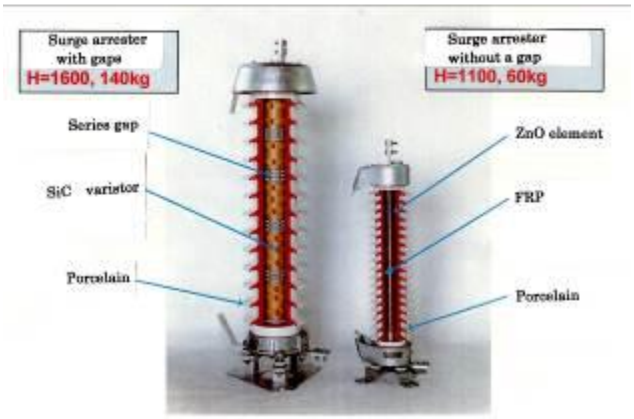

Figure 2. Surge arrester with gaps and without a gap

The configurations of a newly developed MOSA and a conventional surge arrester with SiC varistor and gaps are shown in Figure 3.

C. Requirements of Electric power industries for MOSAs

In the 1970s, as the consumers needed more reliability of electric power supply and total electric power rapidly increased, electric power companies were thirsty for the development of high-performance and high-reliability compact surge arresters, such as tank type surge arresters for GIS and built-in type for composite equipment. They also required the development of high-performance surge arresters for UHV 1,100 kV system as the new generation power transmission voltage. ZnO gapless surge arresters satisfied the requirements.

III. DEVELOPMENT PROCESS OF MOSAs FOR FACILITIES OF ELECTRIC POWER SYSTEMS

A. Cooperation with Matsushita for application of ZnO varistors to new surge arresters

In 1967 Matsushita Electric (present: Panasonic) discovered revolutionary ZnO Semiconductor and then developed a high–performance varistor. In 1970, Meidensha Corporation began to contact Matsushita Electric and the author participated in discussions with engineers of Matsushita Electric.

Through the discussions and the inspection of ZnO semiconductors the author recognized varistors had far more excellent voltage-current (V-I) nonlinearity than SiC elements.

Although the energy absorption capability of samples of those days was low, the author expected that improvement in a structure and a manufacturing process would be able to produce a dream solid-state (gapless) surge arrester. In the same year, Meidensha formally proposed cooperative research regarding the development of high-voltage surge arrester elements. Matsushita Electric accepted Meidensha's proposal because Meidensha was the earliest and the eagerest proposer, and because Meidensha products supplied to electric power companies and had a large market share.

Finally Meidensha and Matsushita Electric developed ZnO elements for facilities of electric power systems. Development of a surge arrester can get rid of gaps, which were installed to extinguish a following frequency current, in surge arresters. Surge arresters without a gap have a possibility to realize high reliability and to be made compact.

B. History of large-scale ZnO varistor (element) fabrication

When applying ZnO elements to actual electric power facilities, the technical problems were as follows:

- Can gapless arresters withstand a continuous AC voltage?
- Whether should newly developed surge arresters have gaps or no gap?
- Life estimation of surge arresters

The author and coworkers studied and discussed above items and finally have got answers for them. For example, “Life estimation of surge arresters” was solved by the equation of Arrhenius [2]. Then surge arresters began to be applied to power equipment. [4]

C. Adoption in Kyushu Electric Power Co. (1975)

In 1975, Meidensha delivered the world’s first gapless anti-pollution type surge arresters of 66kV for Hayato substation of Kyushu Electric Power Co., which was expected to be constructed in high pollution area (Figure 4).

In addition, Meidensha delivered a gapless arrester for a 500kV GIS substation (Figure 5), which was expected to be constructed in a narrow space of a hill foot. The Kyushu Electric Power Company was afraid that it cannot be designed with a large size surge arrester of a conventional SiC element and concluded that a gapless arrester was employed despite the absence of experience.

D. Adoption in Manitoba Hydro, Canada（1979）

Meidensha proposed gapless surge arresters for surge protection of Manitoba Hydro AC-DC converter stations as heavy operating duty surge arresters (Ferro-resonance measures) at circuit braking on an AC-DC converter station (Figure 6). Meidensha could join in the project. The author guessed that Manitoba Hydro understood Meidensha can make super-heavy duty type gapless arresters by parallel connection of ZnO elements. In this project the Manitoba Hydro estimated the energy absorbed in a gapless MOSA using “a simulation program of surge analysis” assisted by the author.

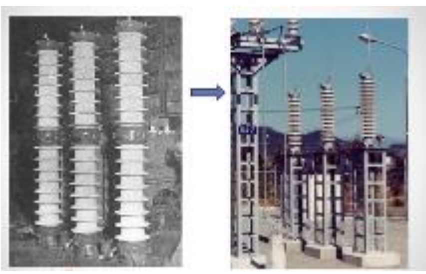

Figure 3. Surge arresters for66kV systems with SiC elements (left) and ones with ZnO elements (right)

Figure 4. MOSAs at Hayato SS of Kyushu Power Co.: 66kV heavy pollution type (0.12 mg/mm^2) (1975)

Figure 5. 500kV MOSAs for GIS of Kyushu Electric Power Co. (1975)

Figure 6. 500kV MOSAs at Manitoba Hydro AC-DC converter stations (1979)

E. Application of MOSAs to a power equipment

World record products of MOSAs (1975~1987) are as follows:

- In 1975 Kyushu Electric Power Company, Hayato SS: 66kV heavy pollution type (0.12 mg/mm^2) (Figure 4) -Certified as IEEE Milestone in 2014
- In1979 Manitoba Hydro AC-DC converter stations: 500kV super-heavy duty type (Figure 6)
- In 1979 Kyushu Electric Power Co. 500kV GIS for the line (tank type), Central SS (Hitachi GIS),Kita-Kyushu SS (Toshiba GIS) (Figure5)
- In 1979 Kitahon 250kV DC transmission submarine cable start-up point (Central Research Institute of Electric Power Industry and EPDC) (Figure 7)
- In 1980 KEPCO(Japan) 154kV reactor protection for oil-immersed MOSA / joint development
- In 1984 British side converter station of the English-French Channel DC transmission line, AC / DC various special arresters (Figure 8).
- In 1987 TEPCO(Japan) 6kV distribution transformers / lightning protection elements built-in oil / joint development (Figure 9)[6]

The purposes of the above development are as follows:

1) *For substations*
   - compact size
   - built-in type (composite type)
2) *For the distribution lines*
   - protection of pole transformers

For the first time, the engineers of the electric power company said that," It may be a dangerous to put it in high temperature oil." The author explained that the cooling effect in oil is larger than that in the air, and the engineers of the electric power company agreed with the author and coworkers [6].

IV. EFFORTS FOR THE WIDESPREAD USE OF PRACTICAL APPLICATION [4]

A. Efforts for expansion of gapless surge arresters

The author worked in the manufacturer and his final mission is not only to develop the MOSAs (gapless arresters) with excellent characteristics, but also to spread them to a number of power companies around the world. The author has paid the efforts of the following promotion for world users.

Electric power companies requested an evidence of stable experience for applying the newly developed gapless surge arresters to their electric facilities, but there was no experience of application. So the author proposed joint researches and a field test to a major user such as electric power companies. So he succeeded in getting customer confidence. Based on the above achievement, Meidensha made the bold decision to carry a joint type test according to the draft standard of Meidensha, getting excellent results.

In addition, the author joined dozens of times in various WGs /TFs of IEC /CIGRE, and finally the efforts were rewarded by the important standardization. (1977-1991)

Figure 7. MOSAs for DC cable of Kita-hon (1979)

Figure 8. MOSAs in Dover Channel converter station (1984)

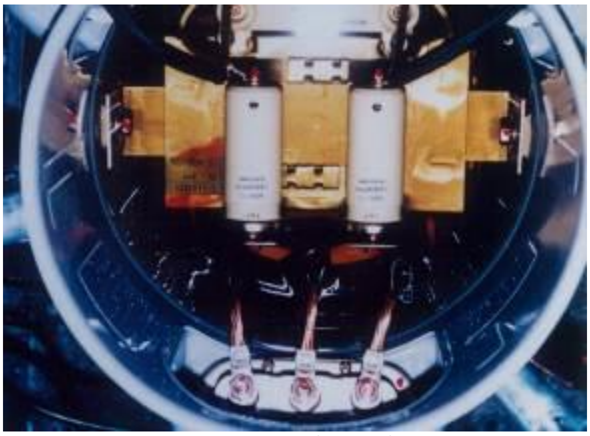

Figure 9. Liquid-immersed arrester for transformer (TEPCO, 1987)

B. Epoch-making presentation of papers on gapless surge arresters (MOSAs)

In the process of expansion for the application of MOSAs, timely paper presentation was essential. The author and collaborators presented the epoch-making papers at following conferences.

* In April, 1973, the Convention of IEEJ (The Institute of Electrical Engineers of Japan) Kanazawa, No.777 (in Japanese) [1]
* July, 1977 IEEE / SM (Mexico) F77-682-8 [2]
* August, 1978 CIGRE (Paris) 33-02 [3]

C. Efforts for standardization

It is virtually impossible that surge arresters were spread in the world without standardization. In a relatively early stage, the author and coworkers have succeeded in standardization in Japan, which is named as JEC. Meidensha could spread a lot of gapless surge arresters in Japan.

Since ANSI/IEEE standard for gapless surge arresters was enacted in 1987, Meidensha could spread gapless surge arresters in the United States of America and Canada.

The JEC / IEC standards were enacted as follows:

(1) The world's first JEC-217-1984 standard has been enacted. / Deliberations started in 1979
(2) After three years, ANSI / IEEE C62.11-1987 has been enacted in an incomplete form with some gaps.
(3) For the IEC standardization, deliberation was conducted since 1980 at the IEC WG37-04, and the final draft was established in 1985. As there were opinions from the other countries, IEC-60099-4-1991 was enacted as the international standard seven years later than JEC (Japan).

D. Establishments in relation to the standardization of gapless surge arresters (MOSAs)

In relation to the standardization of gapless surge arresters, the application for the individual electric power company and announcement of MOSAs are summarized as follows:

Domestic supply record (1975 Hayato SS, Kyushu Electric Power Company) ⇒ Success of the Joint format type test (1976) ⇒ Prospect for JEC standardization (1976) ⇒ The world's first IEEE paper (1977) ⇒ CIGRE paper in the Paris Session (1978) ⇒ Proposition of standardization of the gapless surge arresters (MOSAs) and approval of deliberating it, IEC TC37 Warsaw meeting (1979) ⇒IEC60099-4 (MOSA) -1991 enactment

As a result, Meidensha Corporation was able to export the MOSAs of Meiden <SORRESTER™> to several dozen countries.

V. AUTHOR AND COWORKER'S CONTRIBUTION TO THE DEVELOPMENT OF GAPLES ARRESTERS

(1) A key person of an electric power company in charge varies corresponding to each section such as substations, power distribution lines and power transmission lines in Japan. The author and coworkers tried to explain gapless surge arresters specifically and asked his cooperation for promotion of them.

(2) Since a demonstration test for each electric power company needed too much time, the author asked the key person of electric power companies to carry out the unified tests for Japanese power companies.

(3) The author explained the characteristics of gapless surge arresters to the committee members of IEC, CIGRE, and etc. and the person in charge of overseas electric power companies, leading to establish international standards.

Why could Meidensha Corporation, a medium-sized heavy electric manufacturing company, make such a great invention? The author thought about it and came to a personal conclusion as follows. As old Japanese saying goes," From the ancient period, there are three key factors for success (KFSs): Timing from Heaven, Advantage of the Land (being there), and Harmony among People (serendipity by the people's connections). His conclusion is "A miracle happens. The three KFSs were got at the same time by chance." Such a case happens very rarely. "We were very much blessed."

As the author has been working at multiple Societies and Technical Associations related to surge arresters for a long time, he was awarded for his efforts in development of MOSAs .The typical awards are shown as follows:

・M. Kobayashi, M. Matsuoka and M. Hayashi were 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.

・M. Kobayashi was awarded a Commendation by the Director of the Science and Technology agency in 1989.

・M. Kobayashi was awarded a National Medal of Honor with Blue Ribbon by the Prime Minister of Japan in 1992

・M. Kobayashi was awarded The IEC 1906 Prize in 2008.

VI. SUMMARY

This paper shows the history of the development of ZnO elements for facilities of electric power systems, and also shows the author and coworker's involvement in development of various type and class gapless surge arresters (MOSAs) and expanding them to domestic as well as overseas electric power companies through efforts of standardization.

The development of MOSAs has been made due to the rapid growth of an electricity demand, the request of the power equipment such as improved reliability and the request of the compactness of surge arresters.

A gapless surge arrester (MOSA) has become a major invention in the power systems together with GIS.

Meidensha was awarded by the president of IEEE, as Mile Stone for MOSA, in August, 2014.

Fortunately the author always has been concerned with the development of SiC arresters and MOSAs over 50 years.

The author put in mind always that the followings are important.

"Simple is best."

"Good things are sold well!"

ACKNOWLEDGMENT

The author has been working together with really a lot of people, who were guides, collaborators and coworkers for the development of MOSAs. In particular, for the development of initial ZnO element, Mr. Matsuoka and Wireless Institute of the Panasonic and for the development of gapless surge arresters, members of the engineers of electric power companies, gave the author much knowledge and convenience. For the creation of standards the late Professor Tsurumi and Professor Kawamura gave the author a great deal of guidance to the committee of the JEC. Also foreign members of the IEC TC37, including the Mr. Schei of Norway and the members of CIGRE WG took care of the author for publicity of the standardization.

Management team, including Mr. Hiraki, the president of Meidensha Corporation, adjusted external negotiations. In the company Project of MOSA "Z Pro", there were many people in Meidensha Corporation. They were valuable advisers or co-workers.

Finally, a long-term friend of the author, Dr. Yokoyama (Central Research Institute of Electric Power Industry), has always been a partner of the discussion about the application of the surge arresters to distribution lines [5], [6] and characteristics of winter lightning, and gave kind advice on summarizing this paper.

Especially, my wife, Yoshiko Kobayashi has supported me for more than 55 years. Without her support, I was not able to accomplish my success.

If it were not for them, it was impossible for the author to develop MOSAs. Here, again, the author represents the appreciation for them.

REFERENCES

[1] T. Nishikori, T. Masuyama, M. Matsuoka, S. Hieda, M. Kobayashi and M. Mizuno : " Zinc Oxide-based Gapless Surge Arrester for Electric Power Systems", Paper for National Convention, The Institute of Electrical Engineers of Japan (IEEJ), No. 777, 1973 (in Japanese)

[2] M. Kobayashi, M. Mizuno, T. Aizawa, M. Hayashi and M. Mitani : "Development of Zinc-Oxide Non-Linear Resistors and Their Applications to Gapless Surge Arresters", IEEE PAS, Summer Meeting, F77, 683-8(1977), IEEE, Transaction, Vol. Pas-97, No.4 (1978)

[3] Y. Ozaki, M. Takanashi, S. Tsurumi, K. Mitani and M. Kobayashi : "New Concept on Overvoltage Protection by Surge Arresters", CIGRE 1978 Session No. 33-02 (1978)

[4] Misao Kobayashi and Masao Hayashi ; "The Background and History of developing Gapless Metal Oxide Surge Arrester (MOSA) ", Papers of Research Conference, History of Electrical Engineering (HEE), IEEJ, HEE8-19 (2008) and HEE10-002 (2010) (Japanese and English-Translation)

[5] M. Kobayashi and S. Yokoyama : " Lightning Protection of Distribution System in Japan " CIGRE SC33.95(Coll.) IWD1, 22 1995

[6] S. Uchida, K. Mochizuki, K. Araki, I. Kaku, Y. Sakuraba, T. Takeshima, S. Shirakawa; "Relation of Insulation Resistance and Deteriorated Ratio of Reference Voltage of Oil-Immersed Surge Arrester Elements Enclosed in Pole Transformers", IEEE Transactions on Power Delivery, Vol.13, No.2, (1997)