Reference
[7] in Japanese

論 文

電力技術のイノベーション(4)
酸化亜鉛形避雷器の開発

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Innovation on Power and Energy technology (4)
Developing the First Gapless ZnO Surge Arrester in the world

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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 phenomenon. Meidensha Corporation applied it to high voltage grid system in Japan in 1975 as a reliable lightning protection device. Japanese MOSA manufactures played a leading role in world MOSA innovations and developments. The BIL has been standardized based on arrester protective characteristics. Due to MOSA, the product shift to MOSA occurred from the gapped type arresters (GTA) since 35 years ago as GTA had many gap-related problems. 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.

キーワード：技術革新, 世界初, ギャップレス, 酸化亜鉛素子, 酸化亜鉛形避雷器
Keywords: Innovation, gapless, ZnO element, MOSA,

1. まえがき

現在のような高度に発達した電力系統において避雷器は系統への落雷による雷サージ、遮断器開閉サージ等の系統内に発生する過電圧から系統内の重要機器を保護し停電事故の発生を防ぐ使命を担っている。またその保護特性は系統の絶縁設計の基礎となり保護特性の向上は系統全体の建設費を著しく低減する経済効果も併せ持つ。

酸化亜鉛形避雷器の実用化は避雷器自体の信頼性向上、小形軽量化等の製品改良を超えた画期的なものであった。現在では当たり前のように使用されている酸化亜鉛避雷器だが30数年前は世の中に存在しなかった。この製品を如何に開発し広めていったかについて以下に紹介する。

2. 避雷器の歴史

避雷器の変遷を図 1 に示す。避雷器の歴史は単純な火花ギャップから始まった。しかしギャップが放電して雷サージを大地に導いても交流の運転電圧で放電が継続してしまう。この問題を避けるために様々な工夫がなされた。明治時代末期から昭和初期にかけて火花ギャップに直列抵抗を入れた角形避雷器、ギャップ抵抗形避雷器に続いてアルミニウムセル避雷器、オキサイドフィルム避雷器などの弁形避雷器が製作された。その後、炭化ケイ素非直線抵抗体が開発されるにおよんで火花ギャップと炭化ケイ素焼結体を特性要素として用いた弁抵抗形避雷器の時代となった。炭化ケイ素非直線抵抗体は多数回の大電流印加に対する安定性はあったが、小電流領域での非直線性能が悪かったため避雷器動作後の続流遮断能力が不十分であった。したがって直列ギャップの改良による続流遮断性能向上が避雷器技術開発の本流であった。この流れに沿って限流形磁気吹消ギャップ等が1960年代までに開発された。当時、磁気吹消形避雷器は究極の避雷器と考えられていたが、多重雷、汚損に対する信頼性を向上し、コンパクト化や機器内蔵が可能、経済性等の要求には複雑な限流形ギャップと炭化ケイ素特性要素の直列構成では原理的に対応できなかった。

1975 年世界で始めての酸化亜鉛形（ギャップレス）避雷器が九州電力隼人変電所（66kV重汚損形）に適用され避雷器技術革新の始まりとなった。図 2 に世界で始めて実系統

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に設置された酸化亜鉛形避雷器を示す。

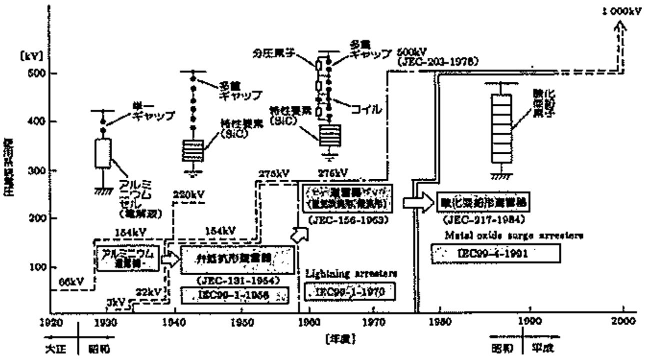

図１　避雷器の変遷[1]

Fig. 1.　History of surge arrester

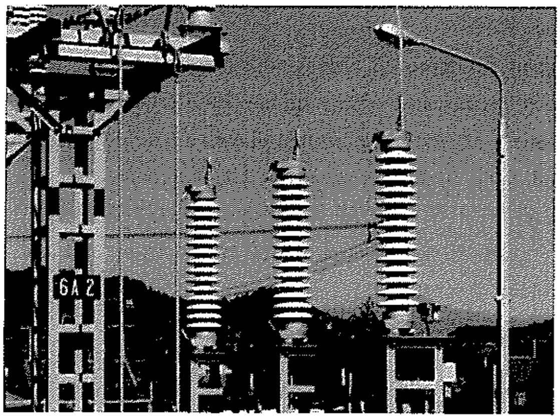

図２　世界初の酸化亜鉛形避雷器

Fig. 2.　The first ZnO surge arrester in the world

3. 酸化亜鉛非直線抵抗体の発見

1969 年松下電器産業よりツェナーダイオード特性を持つ酸化亜鉛多結晶焼結体（ZnO バリスタ）が発表された[2]。酸化亜鉛を主成分として様々な微量添加物を混合し焼結した物質が小電流領域から大電流領域までの優れた非直線特性を持つこと、またエネルギー吸収能力にも優れていることがわかった。明電舎はこの電子回路用 ZnO バリスタが、避雷器という高電圧機器の特性要素である炭化ケイ素焼結体に置き換わるだけでなく、避雷器に必要とされていたギャップをも取り去る可能性を持つものとして注目した。1970 年から電子回路用バリスタの避雷器への適用可能性検討のため松下電器産業無線研究所（当時）との共同研究を開始した。明電舎研究所の材料技術者と避雷器技術者がチームで新技術を夢見て松下電器産業と素子試作・検証・ディスカッションを継続して行った。そして 1973 年金沢市で開催された電気学会全国大会に世界初の酸化亜鉛形避雷器の論文[3]を松下電器産業との連名で発表した。酸化亜鉛素子の概観と非直線特性を図 3 示す。

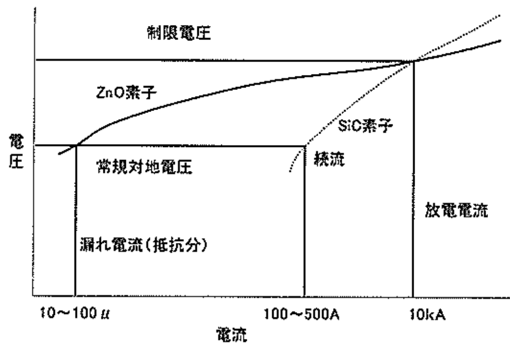

図３　酸化亜鉛素子の電圧電流特性

Fig.3.　Voltage vs. current performance of ZnO element

4. 電力用酸化亜鉛素子の開発

当初電子回路用バリスタが果たして電力用に使用できるのかという雰囲気があった。このバリスタ素子を電力用ギャップレス避雷器に適用するためには下記のような様々な困難があった。電力用酸化亜鉛素子を図 4 に示す。

①電流電圧非直線特性の改善

②エネルギー耐量の向上

（沿面フラッシオーバを防ぐ側面絶縁コーティング）

③大形化、量産化

④寿命推定法の確立

(4・1)　電圧電流非直線特性

酸化亜鉛素子は酸化亜鉛が主成分であり、数種類の添加物と呼ばれる微量添加物を加え湿式混合し造粒という工程を経て成形し易い顆粒状粉体（造粒粉）に加工される。造粒粉は円板状に成形後焼成されて酸化亜鉛素子となる。酸化亜鉛素子の特性発露の大きな要素は原料配合であることは既にわかっていたが、非直線性を発現する基本的な 3～4 種類の添加物のみでは避雷器に要求される非直線性特性が不足していたため、周期律表を基に様々な新添加物の効果および複数元素の相互作用をじゅうたん爆撃的に調査した。10%にも満たない複数の添加物がどのように酸化亜鉛や添加物同士反応していくのかを化学的に調査するのは時間的に困難であったので、多種類の試料を作成し電気的に選別する手法を取った。多成分系の固相。液相焼結反応なので予想通りの特性にならないことも多かった。選別した配合での量産時の問題としては、実験室レベルで試薬を原料として作成した試料に比べ工業原料を使用した量産試作品の性能が劣ることがあった。工業原料には様々な不純物があり、数 ppm～数百 ppm 程度の不純物が性能に影響を与えることもわかり、原料製造工程まで立ち入って原料メーカーと共に検証した。これらの経験が製造技術確立の基礎となった。酸化亜鉛素子の微細構造を図 5 に示す。

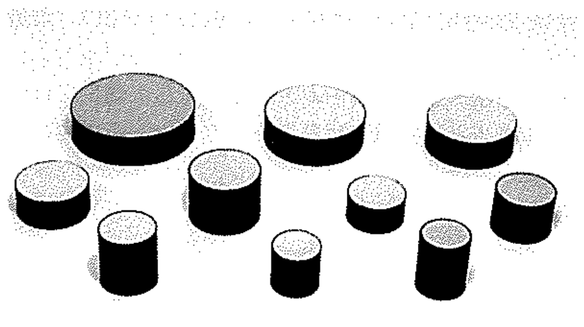

図４　電力用酸化亜鉛素子

Fig. 4.　ZnO elements for high voltage application

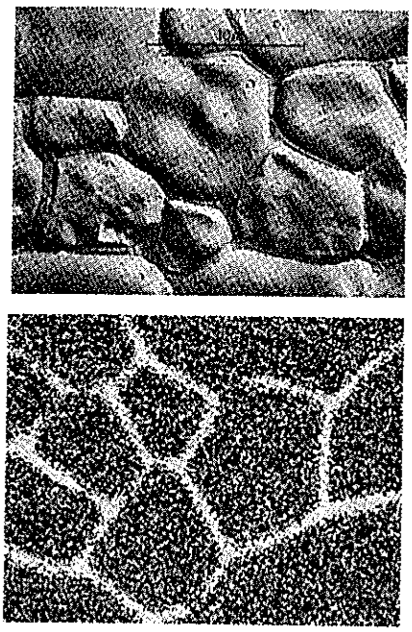

図５　酸化亜鉛素子の微細構造

Fig. 5.　Microstructure of ZnO element

(4·2)　側面絶縁材の開発

避雷器には放電耐量という 4/10μ s 波形での大電流印加試験がある。ギャップ付き避雷器に使用された炭化ケイ素素子に比べ酸化亜鉛素子は 1/3 以下に小形化されたため，また酸化亜鉛の結晶自体は導電性のため酸化亜鉛素子沿面の抵抗が大きくならない。そのために大電流通過時に素子側面をフラッシオーバする危険性があった。従って酸化亜鉛素子の側面絶縁強化は必須であった。焼成後の絶縁材コーティングがもっとも簡便な手法であったが性能的に不十分であった。そこで酸化亜鉛そのものは導電性であるので、酸化亜鉛素子内部から表面へ徐々に絶縁層へと変化する界面のない側面絶縁層を作る技術を完成させた。これは焼結反応を中途で止め、素子本体の成分を含んだ絶縁物質をコーティングした後、同時焼成するという方法である。この方法は後述する酸化亜鉛素子の寿命の点でも信頼性を向上させた。

(4·3)　酸化亜鉛素子の大形化

実験室でのサンプルは直径 10～30mm 厚さ１～5mm であった。当時の避雷器用酸化亜鉛素子のターゲットは 48mmφ-22mm t であった。酸化亜鉛素子は焼成中に体積が 1/2 程度まで収縮する。電子回路用素子に比べ 15 倍以上の体積が必要な電力用酸化亜鉛素子では均一な収縮（反応）を起こさせるための条件作りに苦労した。焼成炉の炉内温度分布、焼成速度のみでなく炉内雰囲気にも関係することも経験的に会得していった。1974 年には新工場を建設し量産設備を導入した。新工場で量産試作を重ね、量産技術を固めていった。更には量産性の高い自作焼成炉まで設計製造した。

(4·4)　寿命推定

酸化亜鉛形避雷器には直列ギャップがないため常時系統電圧が印加される。寿命推定にはアレニウスプロットといわれる方法を取り入れた。劣化を化学反応と捉え、様々な温度での加速劣化試験を実施し、30 年以上の寿命の確信を得た [4]。現在は酸化亜鉛形避雷器の寿命についてはほとんど問題にされないが開発当時は電力会社にとっては大きな心配事であった。酸化亜鉛形避雷器実用化の数年後、海外電力会社の研究論文で会社名は公表されなかったが複数社の酸化亜鉛素子寿命を比較した論文が報告された。論文著者から当社の酸化亜鉛素子が最も寿命特性が良いという結果とその理由が側面絶縁材によるものだろうとの話を聞き、喜んだ。その後も酸化亜鉛素子の改良を続け、現在では寿命推定が困難なほどとなった。結局 120℃で電圧ストレス 1.5 倍程度の加速劣化寿命試験を 20 年以上継続した。

酸化亜鉛素子の劣化、導電機構という基本事項の研究は 1980 年前後には基礎研究論文が数多く世界中で発表されたが 1986 年に高温超電導体が発見されてから酸化亜鉛素子の基礎研究がほとんどされなくなってしまった。酸化亜鉛形避雷器関係者としてはさびしい限りである。

5.　酸化亜鉛形避雷器の普及

1975 年の主要電力会社のフィールド試験以来、国内電力会社の関心は大いに高まり、1976 年 10 月に 3.3～275ｋV を対象に合同形式試験を実施した。1978 年 7 月には改良形酸化亜鉛素子を使用して 500kV 系統用まで製品系列を拡大した。ギャップレス MOSA の記録品として国内では関西電力白浜～椿配電線（33kV 全面導電釉重汚損形）、東京電力久米川変電所向け 66kV スーパークラッド用油タンク形(1976 年)、中部電力志太変電所向け 154kV 活線洗浄形(1978 年)、九州電力中央・北九州変電所向け 500kV SF6 ガスタンク形(1979 年)、電源開発北本連携設備所向け直流 250ｋV(1979 年)、関西電力信貴変電所向け 154kV リアクトル内蔵用（1980 年）。海外向けでは、マニトバハイドロ向け交直変換所 500kV 変圧器鉄共振保護用重責務形（1979 年カナダ）、オンタリオハイドロ向け 500kV 放圧電流 100kA 各種避雷器（1981 年カナダ）、英国電力庁ドーバー海峡直流送電向け交直変換用各種定格避雷器（1984 年）等へ新規適用が進んでいった。実系統適用から 10 年足らずで世界中で新規プロジ

ェクトに適用されたのは、世の中のニーズと過渡現象解析技術(EMTP)等の発達により避雷器へのエネルギー推定が可能になったことにも助けられた。

6. JEC/IEC 規格化の推進

当時、避雷器と言えばギャップ付き避雷器であったのでギャップレスに対応する規格は存在していなかった。たまたま JEC-203-1978 の規定作業中であったので、当時、避雷器標準特別委員会の委員長であった鶴見策郎東京理科大教授のご英断により、7.1 形式試験項目の説明に「直列ギャップを使用しない避雷器についても、ユーザーとメーカーの協議により、放電開始電圧試験の変わりに動作開始電圧・制限電圧試験を実施するなど、規格の趣旨を十分考慮して運用することが望ましい」という内容の文章を記述することにより、適用できるようになった。酸化亜鉛形避雷器専用の規格は1984年にJEC-217-1984として発行されるまで待たなければならなかった。この頃には国内各メーカーも酸化亜鉛形に切替えて、日本が酸化亜鉛形避雷器のパイオニアの地位を占めた。

一方、海外では米国が日本に追走したが、従来形の直列ギャップ付き避雷器の保護特性との絡みで完全なギャップレス化ができず常時の対地電圧に耐える程度の直列ギャップや一部の素子に並列にギャップを挿入した製品となり、それらを考慮した規格（ANSIC62.11-1987）が JEC より 3 年遅れて制定された。 IEC 規格に関しては比較的早い時点、1979 年 3 月の TC37 ワルシャワ会議で、日本他数カ国からギャップレス避雷器の規格化が提案され、直ちに WG37.04(MOSA: Metal Oxide Surge Arrester)が設置された。1980 年から日本を含む 8 カ国で年 1～2 回開催され、1985 年のストックホルム会議で汚損試験法を除いてほぼ成案ができたが、製品化が遅れていた欧州諸国の都合もあったのか、IEC 規格が発行されたのは 6 年後(IEC60099-4-1991)となってしまった。

規格成立への努力と平行してギャップレス避雷器を世界に普及させるため CIGRE、IEEE への論文発表にも力を入れた。1977 年 IEEE 夏季大会 [5]（メキシコ）、1978 年 CIGRE（パリ）で発表した [6]、これが IEC TC37 ワルシャワ会議での WG37.04 設立のきっかけになった。その後も精力的に発表を行いギャップレスアレスタに関する話題を提供した。

7. あとがき

日本で発見され日本で育てられた酸化亜鉛形避雷器は国内のみならず全世界に普及した。この技術革新は多重雷と耐汚損という宿命的課題と電力系統の安定化・GIS 化・UHV 送電計画というニーズの中で一気に花開いた。すでに明電舎だけでも 65 か国以上の輸出実績をもつ。小さな新聞記事がきっかけとなり、避雷器技術者と材料技術者で力を合わせて酸化亜鉛形避雷器を世の中に送り出すことができた。酸化亜鉛形避雷器実用化後すでに 30 年以上を経過しているが未だに原理的に異なる避雷器は出現していない。最近はハウジングとして磁器碍管を用いず、シリコーンゴムにより酸化亜鉛素子を直接モールドした避雷器が使用されるようになってきた。本稿では初期の酸化亜鉛形避雷器開発の一端について述べた。

（平成●●年●月●日受付，平成●●年●月●日再受付）

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小林　三佐夫　　（終身会員）1931 年 8 月 24 日生。1954 年 3 月東京工業大学卒業。同年 4 月㈱明電舎入社。以来、避雷器技術および高電圧・大電流試験・研究に従事。1988 年より生産総本部技師長。1996 年にサージプロテクト KK を設立し、パワーシステム代表として現在に至る。1978 年電気学会進歩賞、1989 年科学技術庁長官賞、1992 年藍綬褒章受賞。CIGRE 特別会員、IEEE Fellow、放電学会・大気電気学会・電気設備学会会員。

[7] In English

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Developing the First Gapless Metal Oxide Surge Arrester (MOSA) in the world

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1. Introduction

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

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

2. History of Surge Arresters

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

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

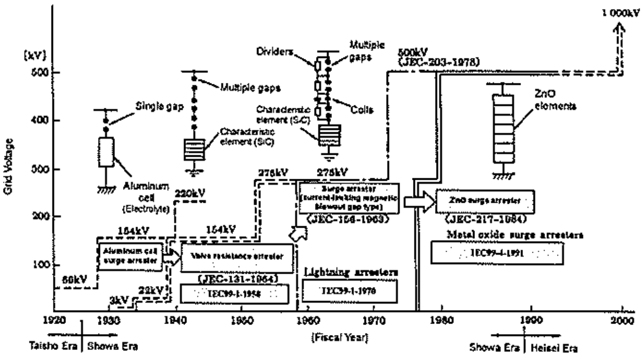

Fig. 1. History of surge arresters[1]

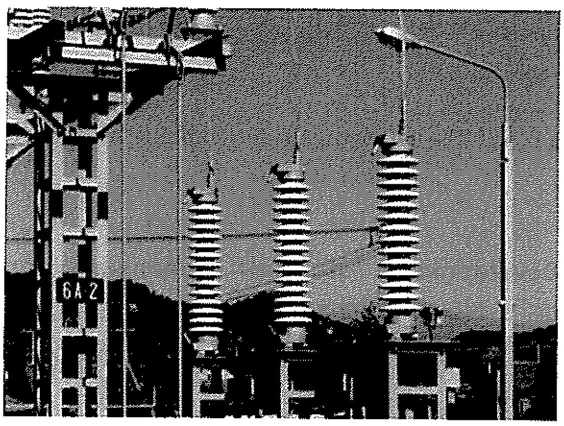

Fig. 2. The first ZnO surge arrester (MOSA) in the world

3. Discovery of ZnO nonlinear resistor

In 1968, Matsushita Electric Industrial Co., Ltd.

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

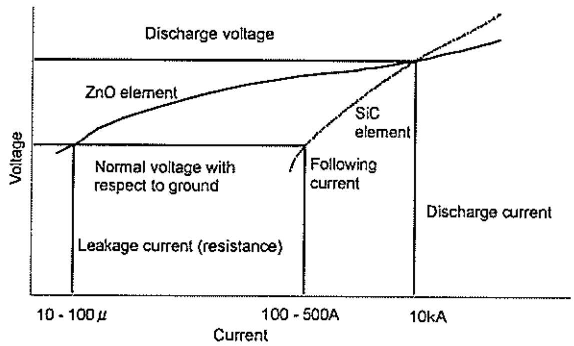

Fig.3. Voltage vs. current performance of ZnO element

4. Development of ZnO elements for high-voltage application

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

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

(4·1) Current -voltage nonlinearity

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

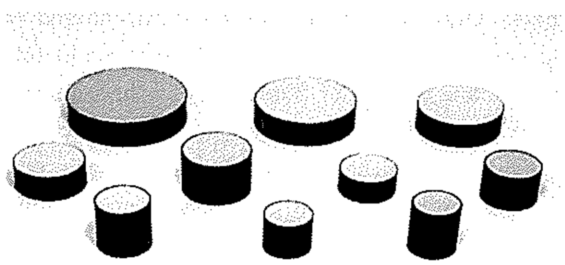

Fig. 4. ZnO elements for high voltage application

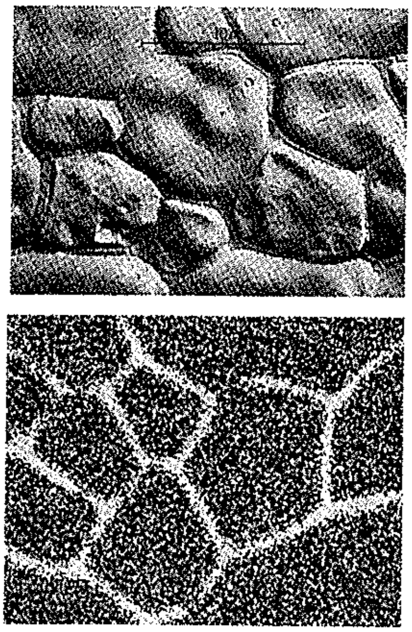

Fig. 5. Microstructure of ZnO element

(4·2) Development of side insulator

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

(4·3) Large-size ZnO elements

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

(4·4) Life estimation

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

5. Wide use of MOSAs

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

Japanese electric companies showed a keen interest in MOSAs after a major electric power company carried out a field test in 1975. In October 1976, they carried out a joint experiment on MOSAs of 3.3 kV to 275 kV. In July

1978, improved ZnO elements were used to increase the range of surge arresters and provide a product for the 500-kV grid. Gapless MOSAs used in Japan include the heavy anti-pollution type with whole conductive glaze of 33 kV glaze porcelain insulator for the Kansai Electric Power Company Shirahama-Tsubaki Distribution Line, the oil tank type of 66 kV for the Tokyo Electric Power Company Kumegawa Substation (1976), the hot-line washing type of 154 kV for the Chubu Electric Power Company Shida Substation (1978), the SF6 gas tank type of 500 kV for the Kyushu Electric Power Company Central and Kitakyushu Substations (1979), the direct current type of 250 kV for J-Power Company Kita-hon Linked Equipment (1979) and the build-in reactor type of 154 kV for the Kansai Electric Power Company Shigi Substation (1980). New gapless MOSA products used in other countries include the ultra heavy duty type for protection of 500-kV transformer iron resonance at the AC/DC converter station for Manitoba Hydro Station (Canada) in 1979, various surge arresters of 500 kV with a pressure relief current of 100 kA for Ontario Hydro Station (Canada) in 1981 and various surge arresters for AC/DC converter station for the Central Electricity Generating Board Dover Strait DC Power Transmission (UK) in 1984. After the field test in 1975, less than ten years passed until MOSAs were widely used in new projects throughout the world. The progress in transient phenomenon analysis (electromagnetic transients program, EMTP) enabled estimation of energy absorption to arresters. The increase in use of MOSAs was accelerated by demand, and by arrester energy estimation.

6. Promotion of JEC/IEC standards

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

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

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

7. Postscript

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

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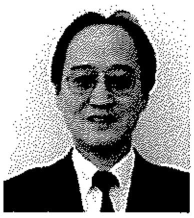

Masao Hayashi (regular member)

He was born in Japan on January 13, 1950. Received master's degree in Science and Technology from Sophia University in 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.

Misao Kobayashi (lifetime member)

He was born in Japan on 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 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.