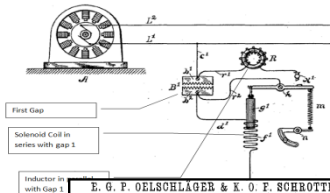
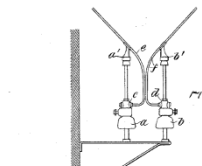


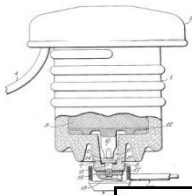
(No Model.)
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LIGHTNING ARRESTER.
No. 433,430. Patented July 29, 1890.



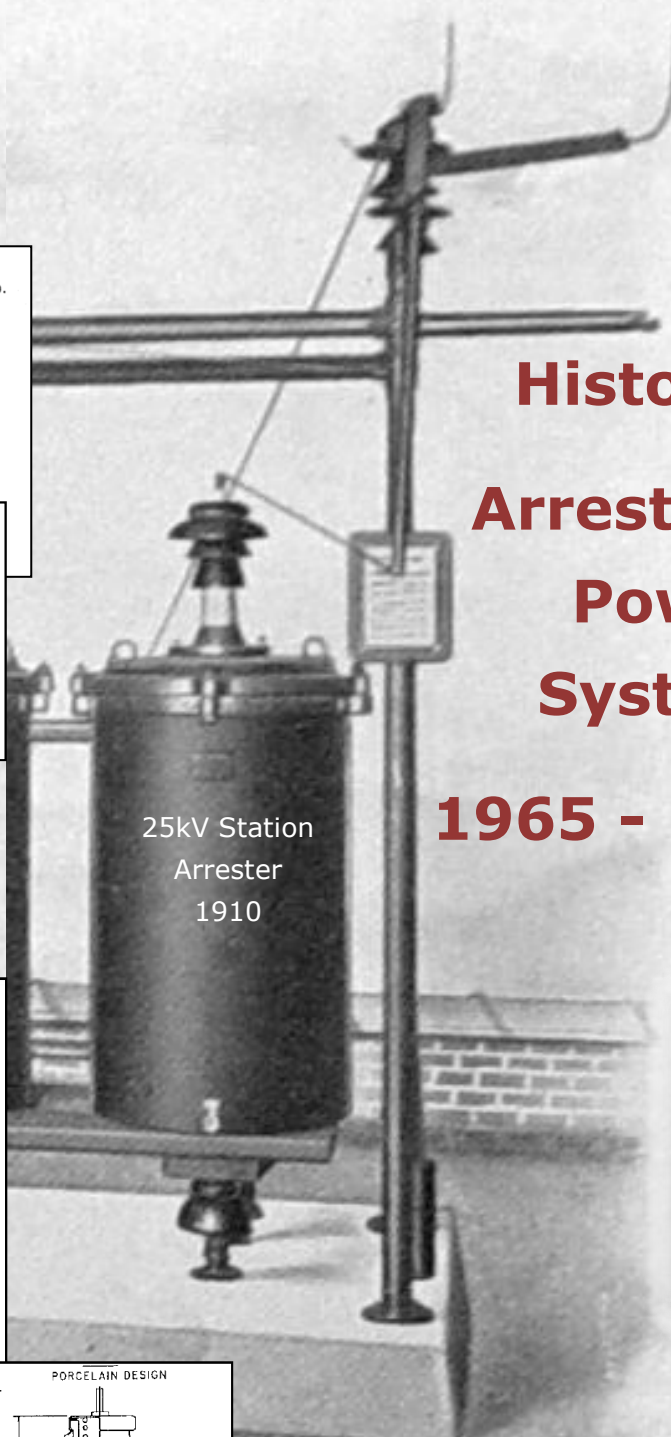
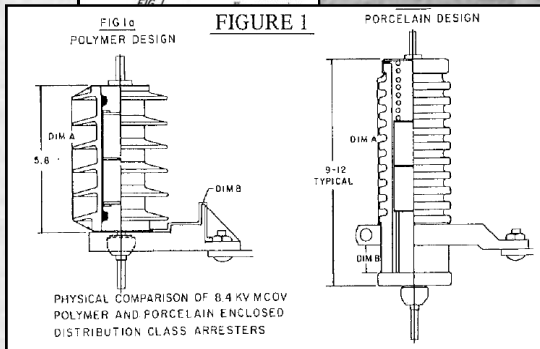
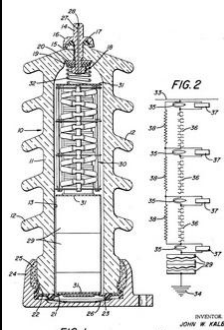
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25kV Station
Arrester
1910

History of Arresters on Power Systems

1965 - Present



25kV Station
Arrester
2010

1965 – Present

By Jonathan Woodworth ArresterWorks

It is hard to imagine, but the transistor radio of the 1950's and the high power surge arresters in common use today are intimately tied together technically and developmentally. Let me explain.

The development of the Metal Oxide Varistor (MOV), which is the heart of the modern surge arrester, did not happen overnight. There were many characters and many breakthroughs that made it possible. The MOV arrester was also the beginning of the end for the two giants in surge protection: GE and Westinghouse.

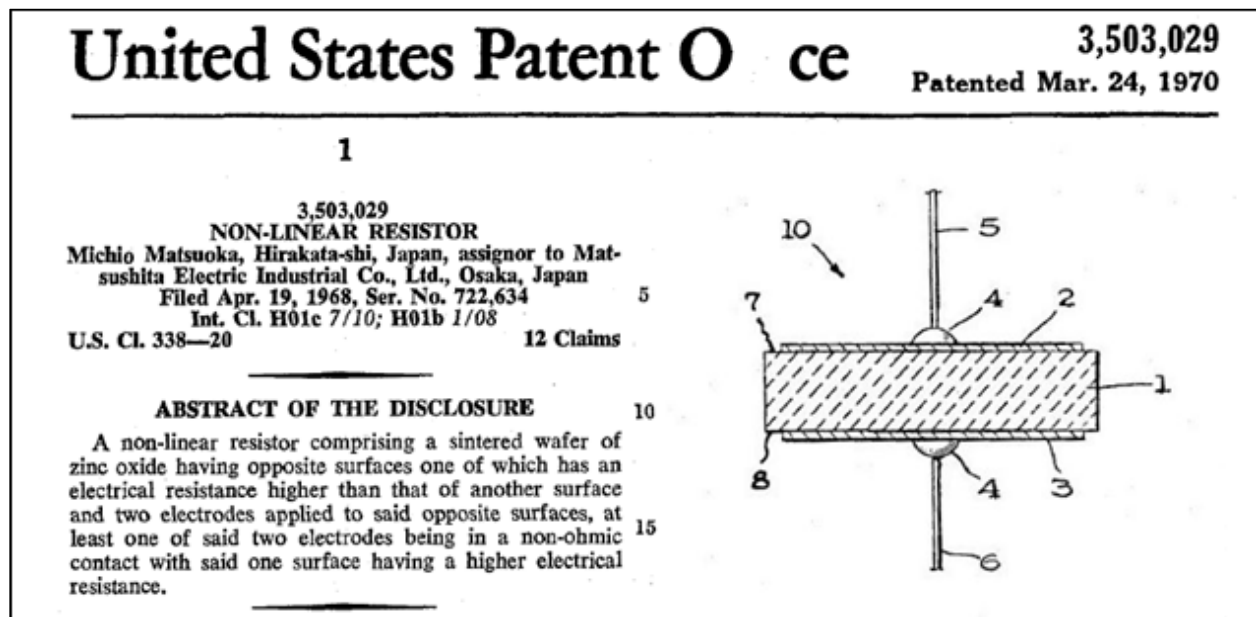


Figure 1 First Zinc Oxide Varistor Patent by Matsushita Electric Co Japan

To better understand this subject, we need to take a quick trip back to 1947. The U.S. was at the beginning of its post WWII technology explosion. In December of that year, Bell Laboratories, led by the famous William Shockley, demonstrated the first transistor. The next year they demonstrated the first transistor radio prototype. A few short years later in 1952, the Japanese Ministry of International Trade and Industry licensed semiconductor technology from Bell Labs and introduced the semiconductor industry to the Japanese industry.

Soon after that in Japan, the Matsushita Electric Company, which later became known as Panasonic, introduced their first transistor radio to the industry. By the end of 1965, they had become a significant competitor in the semiconductor industry and had their own R&D group. Also by 1965 it had become obvious to those involved in surge protection of the semiconductor components that Silicon Carbide Varistors were no longer capable of protecting the sensitive low voltage Shockley type junctions. The SiC technology that had successfully been used to protect vacuum tubes just could not take care of this emerging technology. In November of that year, one of Matsushita's young scientists named Michio Matsuoka, was assigned the task of improving surge protection of semiconductors. Thus the start of the development of a new varistor.

Research for a new varistor proceeded along a path that they were familiar with, which was to create a nonlinear junction using a ceramic and non-ohmic electrode. It was anticipated that the interface between the ceramic and electrode would result in a Shockley junction that was non conductive at lower voltages, but when a voltage threshold was met, it would become conductive. Based on numerous experiments between 1965 and 1967, the material choice was Zinc Oxide for the ceramic and Silver Oxide along with a glass frit for the electrodes. By March 1967, they had achieved the goal of producing a Shockley barrier type varistor, but the threshold voltage was much too low to be useful. They knew they had to increase the turn-on voltage level of the device to use it as a surge protector. They then proceeded to run a series of experiments to discover a means of producing a higher voltage device.

In July 1967, one of the sintering ovens used in the experiments failed to control the temperature properly and an oven thermal runaway occurred. The samples were sintered at a much higher temperature than desired resulting in material that was heated past its useful state. Dr. Matsuoka decided to measure characteristics of the overheated sample anyway: the test results were a complete surprise. Much to their amazement, the overheated sample exhibited a higher turn on threshold voltage than they had ever seen before. Additionally, the typical asymmetrical conductivity (one direction only) was not evident. The accidentally overheated semiconductor

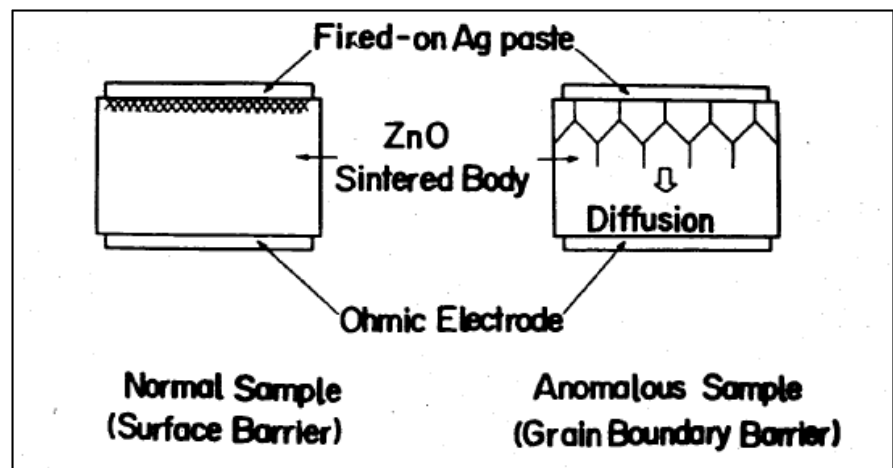


Figure 2 Contrast of Surface and Grain Boundaries Barriers

conducted symmetrically with a high threshold voltage at both positive and negative polarities. The results were unbelievable.

It is easy to imagine the excitement in the lab at that moment. Further examination of the sample showed that the silver paste and glass frit that was meant to be an electrode had diffused into the ZnO ceramic and formed junctions between the ZnO grains. This resulted in the formation of numerous Shockley type junctions which in turn created an increased turn-on threshold voltage. Instead of creating a simple “Surface Barrier”, they had discovered the “Grain Boundary Barrier” phenomena.

Detailed analysis of the new material showed that it was the bismuth oxide in particular and other impurities found in the glass frit that created the voltage sensitive grain boundary with the zinc oxide grains. This Zinc Oxide material doped with bismuth and other minor heavy metals is the exact material used in all modern surge arresters manufactured today.

The Matsuoka team went on to convert the information discovered in the experimental accident and immediately applied for US and World patents. After three years of fruitful research, on April 19, 1968, Dr. Matsuoka applied for a US patent that was granted in March 1970. The Metal Oxide Era of surge protection had begun.

Within a few months, the scientists at the GE R&D center, who had been actively evaluating other semiconductor type varistors, were on their way to Japan to learn more about this new varistor material. They were very impressed with what they learned and GE immediately signed an agreement with Matsushita Electric Co. to work with them in further development of this material in the US. In 1972, Harnden, Martzloff, Morris, and Golden published their first paper on their newly developed Super Alpha Varistor, announcing that GE was about to produce the first GE-MOV. The applications for this new varistor were at voltages below 500 volts and the material was still not yet ready for the high voltage world.

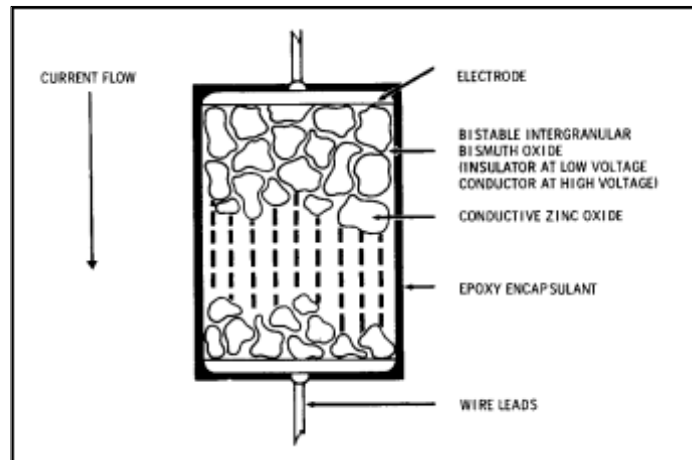


Figure 3 Explanation of New Varistor Material by GE Scientist

At the same time, the high voltage surge arrester design team at GE, led by Eugene Sakshaug, was keeping a close watch on the new varistor. The team was intrigued by the concept but knew that a varistor for high voltage applications would have to pass a more severe criterion than it did for lower voltages.

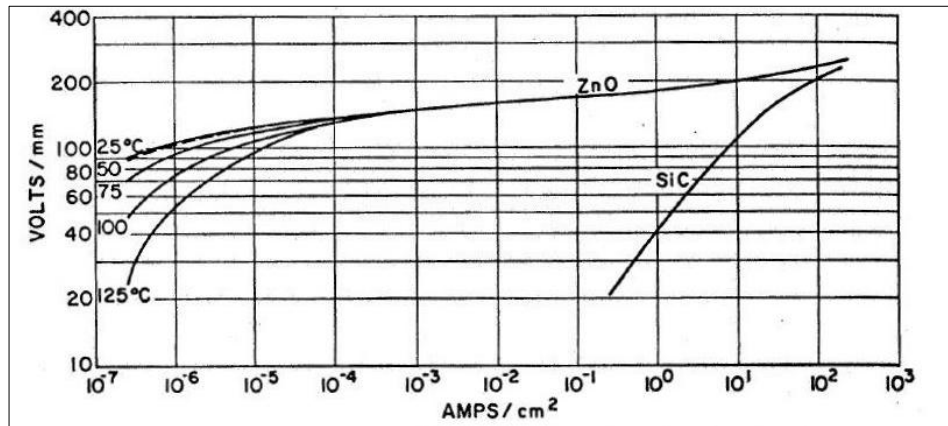


Figure 4 Early VI Curve showing the difference between Zinc Oxide characteristics and Silicon Carbide characteristics

They embarked on their own development of this new Zinc based varistor material. After many months of experiments and tests, the GE high voltage arrester team produced the first power system type MOV arrester in 1976. Sakshaug, Kresge, and Miske published their seminal paper, “A New Concept in Station Arrester Design”, in March 1977.

Because of the incredible nonlinear characteristics of the new MOV material, series gaps were no longer needed by the varistor when energized at system voltages. The age old issue of gap instability had been overcome. For the first time in the history of surge suppression, no gaps were needed to assist the series resistors. Not only was the gap gone; their removal allowed for significant height and weight reduction of arresters. The gapless arrester era had started and GE was at the head of the game.

The SiC to MOV Technology Transition

The transition from gapped silicon carbide arresters to MOV type gapless arresters was rapid. All the US manufacturers of surge arrester could see that the future of the business lay in investment in zinc oxide technology and production of this new semi-conductor. The transition was positive for some and not so for others. McGraw Edison chose the development path, and in the late 1970’s they developed their own zinc oxide formula. They were the first in the US to produce a MOV type arrester for the distribution systems. The Kearney Co. attempted to produce their own version of the MOV arrester, but by 1990, they had failed and were out of the surge

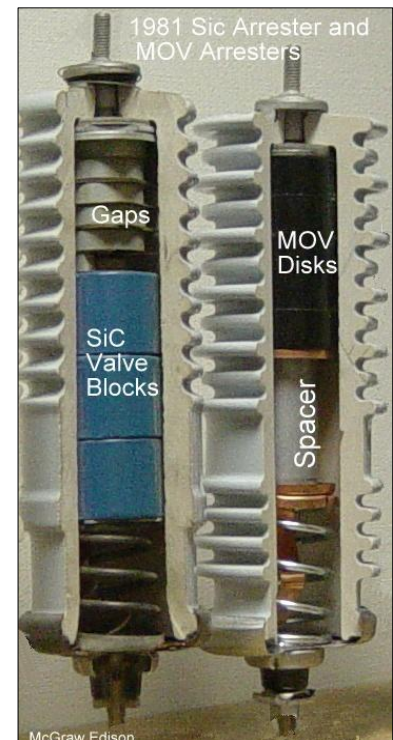


Figure 5 Silicon Carbide Varistor and Zinc Oxide Varistor based Arrester Comparison

arrester business. The Ohio Brass company licensed the technology from Toshiba in the early 1980's and their strong station arrester market presence carried them through to the next paradigm shift. The Joslyn manufacturing company held strong and with some technology licensing, they made the transition from SiC to MOV.

Westinghouse, once a supreme giant in the surge arrester industry, hit a solid wall in this technology transition. Their development efforts in MOV did not yield a manufacturable product. Coupling their technical difficulties with the strategic corporate decision to divest manufacturing assets resulted in the end of a long history of surge arrester design and production. The arrester design and production engineers found homes at other manufacturers.

Even though GE led the way into the MOV era in the US for the surge protection industry, they too hit a solid wall in this transition. The turn of events came from within GE with the strategic announcement by Jack Welch in 1988 that the industry giant was exiting the manufacturing business. By the early to mid 1990's all of GE surge arrester designers and manufacturing professionals had left the business. The Ohio Brass (Hubbell) company had purchased all the manufacturing assets of GE and became their sole supplier of arresters. GE remains a distributor of surge arresters, but no longer leads technological advances in this industry, as they had for the last 100 years.

GE and Westinghouse, once dueling giants in the surge protection industry, were no longer in the race. Today in this industry three manufactures stand alone: Hubbell Power Systems (Ohio Brass), Cooper Power Systems (Line Material-McGraw Edison) and MacLean Power Systems (Joslyn Mfg), along with a couple much smaller players.

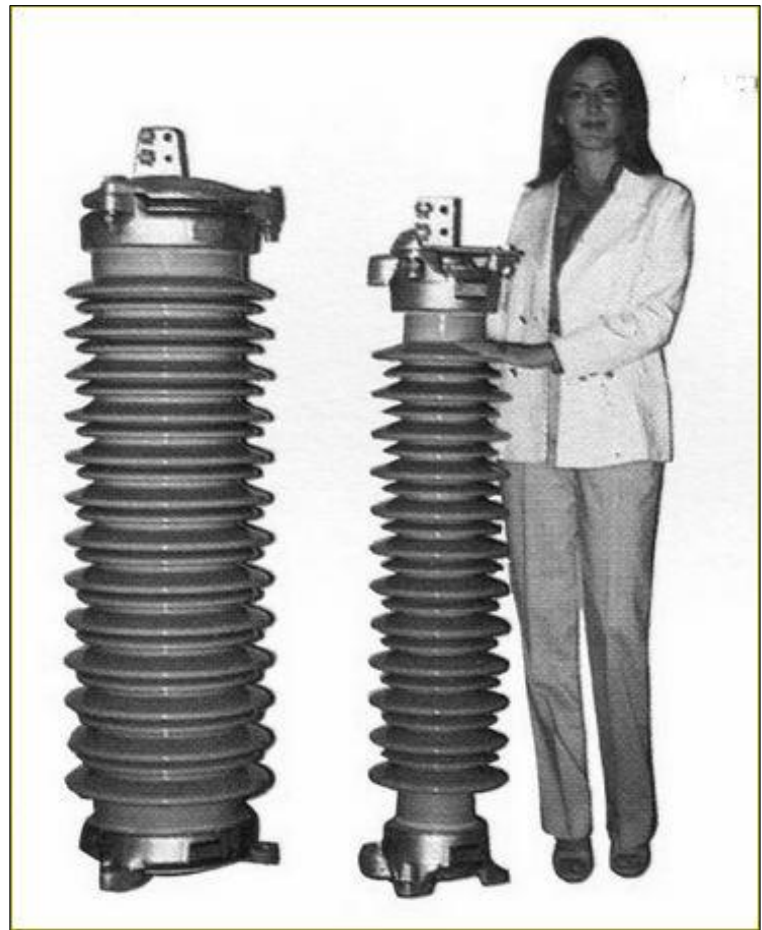


Figure 6 Silicon Carbide Arrester on the left and MOV Arrester on the right. For 115kV systems. 400 vs 200 lbs. Dynagap and Dynavar Arresters from Ohio Brass Co

The Polymer Housed Surge Arrester

On December 14, 1984, Donald E Raudabaugh submitted a patent application to the US patent office that would change the surge arrester industry once again. While still in the early parts of the transition to MOV, this Ohio Brass engineer realized that with the advent of solid state arresters, there was another technology that could be used to make the arrester a much safer device.

Raudabaugh had spent much of his career working with insulators, which were in the process of a technology change as well with the transition from porcelain housings to polymer sheds with fiberglass rod cores. Using a tool that had been used in this industry many times, he transferred knowledge from one product line to another. In this case, he conceived how to wrap a stack of MOV disks in a cost effective manner that would hold the disks together not only for its life time, but also during a most onerous failure mode. His wrapping idea was a game changer when used in conjunction with rubber housing. Patent application

681,800 – 1984 became patent 4656555 – 1987 and is titled “Filament Wrapped Electrical Assemblies and Method of Making Same.”

In 1987, Ohio Brass produced the world’s first polymer housed surge arrester;

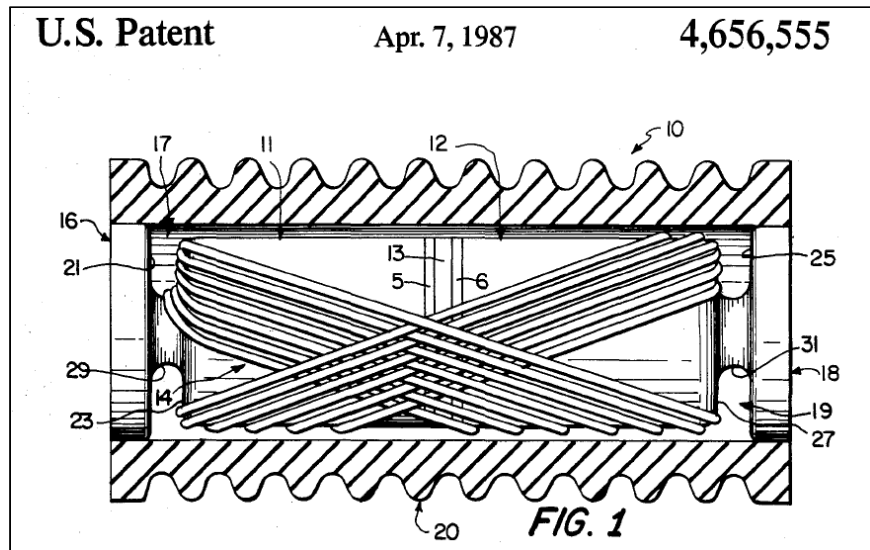


Figure 7 First Polymer Housed Arrester Patent Raudabaugh 1987

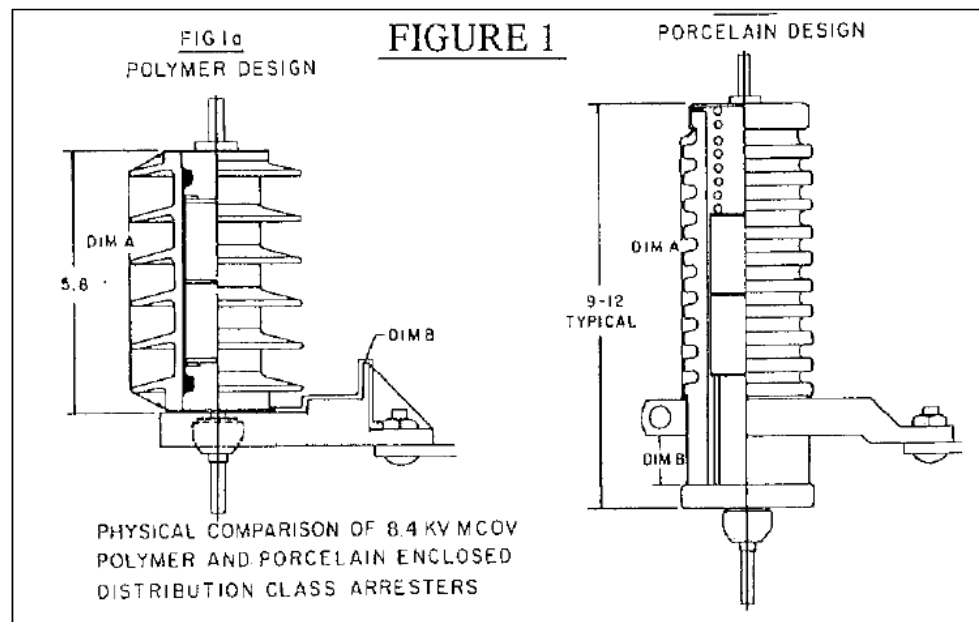


Figure 8 Polymer Housed Arrester and Porcelain Housed Arrester Comparison

thus the polymer housed surge arrester era began. Dennis Lenk, also of Ohio Brass, published his seminal IEEE paper the following year, titled “A New Approach to Distribution Arrester Design”, which outlined in detail the testing and concept of this new arrester type.

Within a few short years, all US manufacturers were producing this new type of arrester. The driving force for this new design was safety. Since the beginning of this product history, failure modes were often associated with explosions and scattering of shards of porcelain. With this new design, the arrester no longer exhibited such significant failure modes. Safety has a tendency to push new concepts along faster in this modern era. Within a few short years, Hubbell had introduced the same concept in the station class arrester family. By 1995, all distribution arresters being installed in the US were polymer housed.

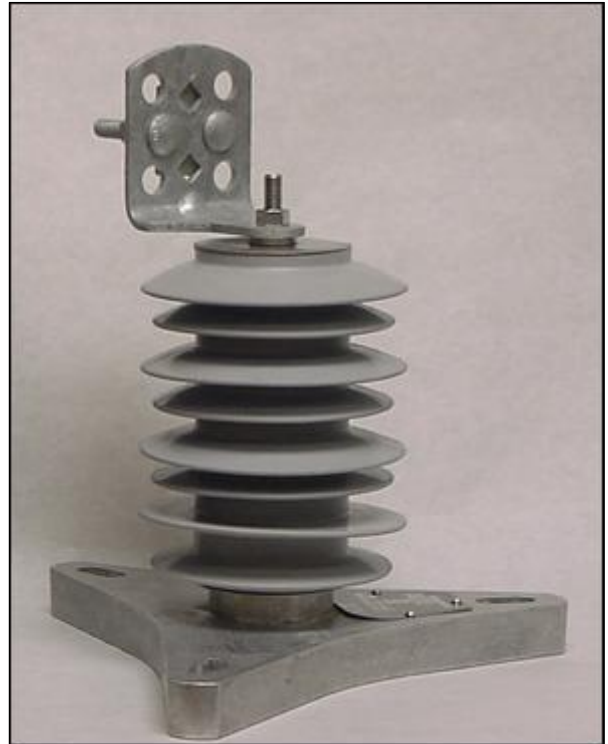


Figure 9 2010 25kV Polymer housed MOV Type Station Class Arrester

Where Next

Surge Arresters have been in use for over 150 years. In that time they have gone through numerous major technological advancements. As we have seen in these four history articles, some of the changes were just variations of an earlier theme, while some were very different and unpredictable. One has to wonder what will come next and where this industry will be in another 150 years. One thing is certain; it will be different and most likely much better in many ways. Another certainty is that as long as there are power systems, there will be a need for surge protection. Most importantly, the improvements will not happen by themselves. It will take ingenious engineers that love to solve problems to forge ahead. Carry on engineers of the future, we are depending on you.

Note from the Author:

Many thanks to Waymon Goch for his encouragement to write this history and for his numerous contributions. Also much credit goes to my critical but excellent editors Deborah Limburg and Megan Gerrity. The content of this series comes from years of exploration and enjoyment in the surge protection world and I take full responsibilities for any errors (I hope there are only a few). Thank you Stan Kershaw for hiring me into this exciting industry in 1979.

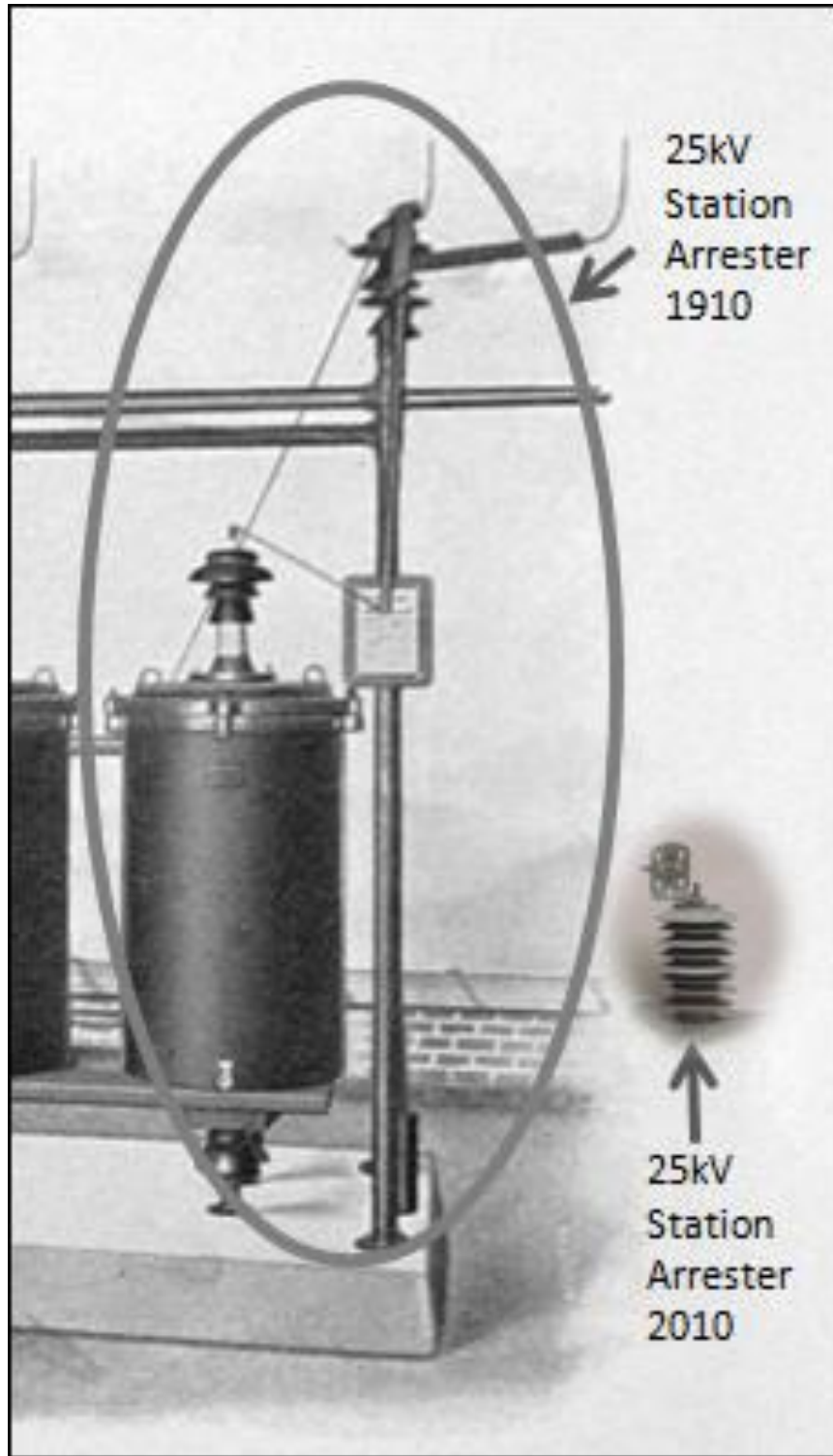


Figure 10 Lightning Protection Then and Now on the same scale