

Lightning Protection of Power Systems - Then and Now - Part 2

1890 - 1930

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Introduction

The earliest roots of lightning protection of power systems dates back to the middle of the 18th century as discussed in part one of this article. The era from ~1890 to ~1930 will be covered in this part of the history of lightning protection of power systems. During this era, lightning protection of electrical equipment divides into many subcategories, such as communications, electronics, radio towers, railroad (DC), and the one discussed herein, power systems. I like to joke with my fellow power system engineers that we seem to think that the electrical world started with us, but in reality, the communication branch of electrical engineering was already several decades old when our branch of engineering was born. As discussed in Part 1 of this history, protection of the telegraph gave birth to the gapped device first called an arrester. It

wasn't until the 1890's that power lines were added to the utility poles crisscrossing the country and immediately needed arresters that could protect them from lightning also. The fundamental difference however is that telegraph lines were not energized 100% of the time as are power lines and the designs of the pre 1890 arrester used to protect the telegraph lines just did not meet the needs of power systems.

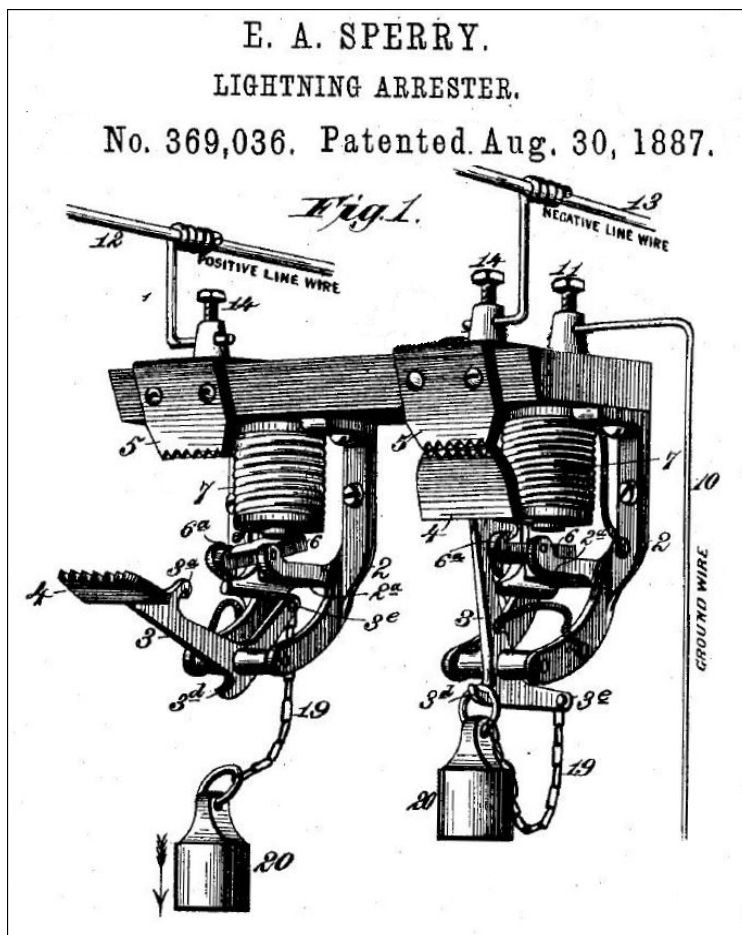


Figure 1 Early Power System Lightning Arrester. Gap between plates 4 and 5 opens up when follow current from the system activates the solenoid 7 allowing weight 20 to pull down and effectively increasing gap resistance.

AC Lightning Arrester Issue

Power system engineers interested in lightning protection soon learned that the gap, what was sufficient for telegraph protection, was not of sufficient separation distance to interrupt the current from the 60hz power arc after the lightning surge was over. This current flowing off the power system from the AC source



became known as *power follow current* and it remained a significant challenge to the arrester designers for this entire era. They quickly learned that the only way to interrupt this power follow current once it flashed over was to turn off the AC power or insert a resistance into the circuit. The early means of inserting resistance in series with the gap was to change the size of the gap. In Figure 1, the arrester inventor, Sperry, ran the ground lead of the arrester through a magnetic solenoid. If the gap sparked over from lightning and was followed by power system current, it would pulse the solenoid, which in turn would allow the gap to snap open. The added distance in the gap increased the length of the arc, which is a common means of increasing the arc resistance. This increase in resistance resulted in interruption of the arc when the voltage crossed zero. It would appear that the Sperry arrester would be a maintenance issue in that it needed to be reset after a strike: something more was needed.

The second method of increasing the series resistance of the gap was to use a linear resistor; however, as the system voltages increased this also became a problem.

A third design that can still be seen protecting insulators today was the Horned Gapped Arrester. Figure 2 shows an 1896 version of this arrester type. The principal behind this type of arrester is that as the arc burns, the magnetic field pushes the arc out toward the ends of the electrodes. Since the gap size increases from the bottom to the top, the length of the arc increases, which in turn increases its resistance. This action limits the current to levels that can lead to extinguishment at voltage zero.

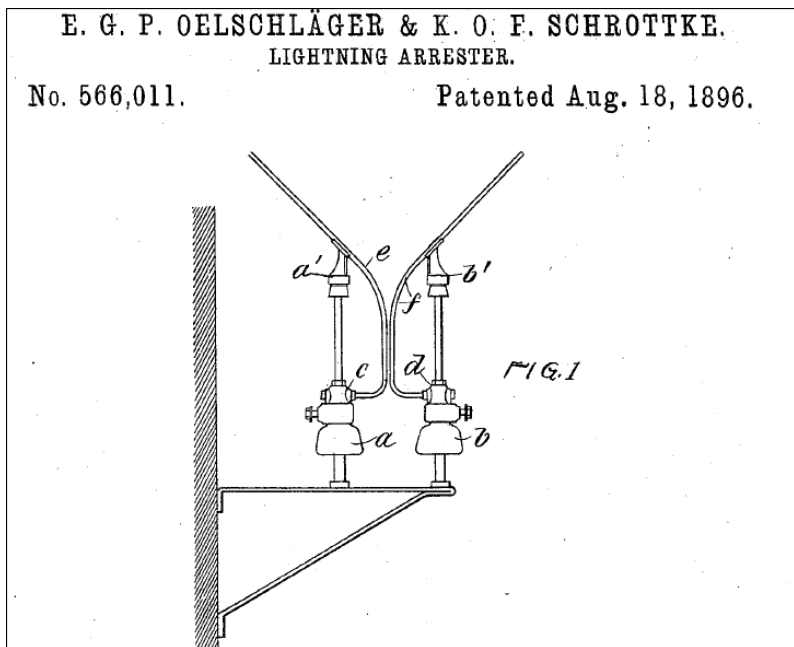


Figure 2 Horned Gapped Arrester 1896 Vintage

The Electrolytic Arrester to the Rescue

For the higher voltage systems, the chemical arrester, as it was known, had the answer to the series resistance issue. Arrester designers had learned that the perfect arrester would have a resistance in series with the gap that had non-linear characteristics. This means that at higher voltages and currents it would have lower resistance. This variable resistance made it possible for the arrester to conduct high lightning currents, and after the event it was also able to assist the gap to interrupt the follow current.



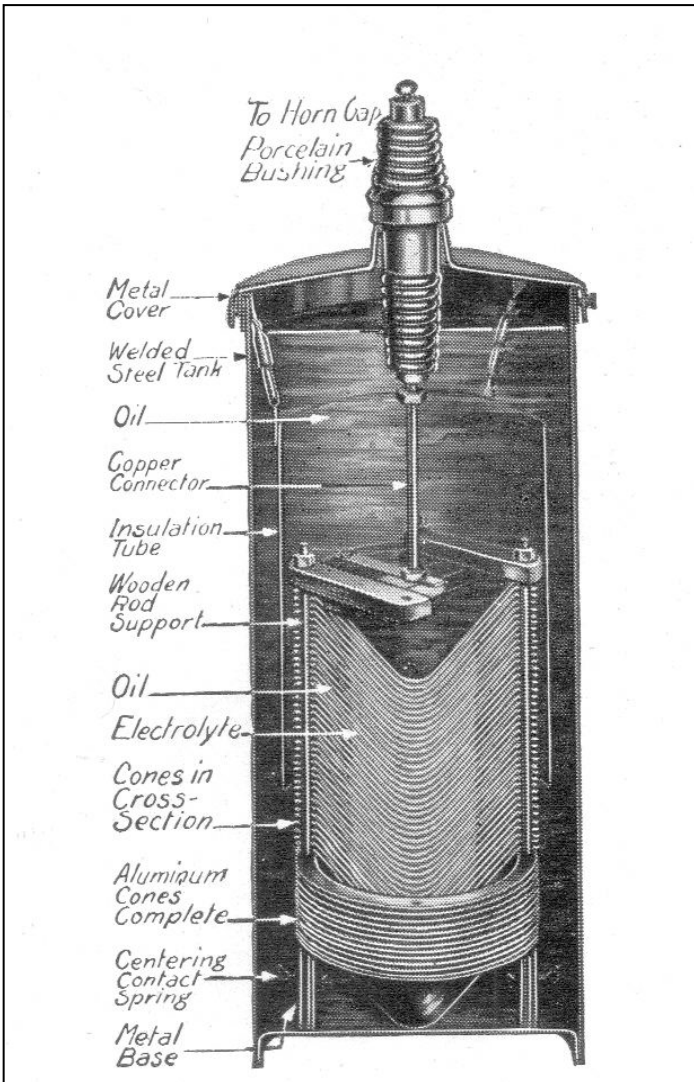


Figure 3 Electrolyte Arrester.
Also known as the Aluminum Cell Arrester

During the winter of 1906/1907, the battle for dominance in the arrester world was waging at full pace. Charles Steinmetz, the august leader of the team at GE, had just completed construction of his famous high voltage laboratory in Schenectady, New York. He could for the first time simulate lightning with a capacitor bank for testing arresters. At the same time at Westinghouse Electric, 265 miles to the southwest in Pittsburgh Pennsylvania, a formidable team was making progress on their concepts. Both teams had been developing arresters for power systems for almost two decades. Unfortunately, since early 1905 there had been little activity in the high voltage arrester patent arena. Both teams were in need of something new to take the technology to the next level.

Back in New York, on those short, cold days of a Schenectady winter, the recently hired engineer Elmer Ellsworth Farmer Creighton believed he had the answer. Creighton had been added to the GE team two years earlier with the acquisition of the Stanley Electric

Company. For this new position, he had moved to the GE Schenectady complex from Pittsfield Massachusetts where he had worked for Stanley the prior three years.

On February 7th 1907, Creighton filed the first application for an altogether new type of high voltage arrester: a design that he had been working on behind closed doors since joining GE. The patent application described an Aluminum Cell Electrolytic Arrester and became patent 992,744 in 1911. By the time the patent was issued, product had already been introduced to the surge protection market.



Public Disclosure

A month and a half after the patent application, Creighton presented a paper titled “New Principles in the Design of Lightning Arresters” to the American Institute of Electrical Engineers

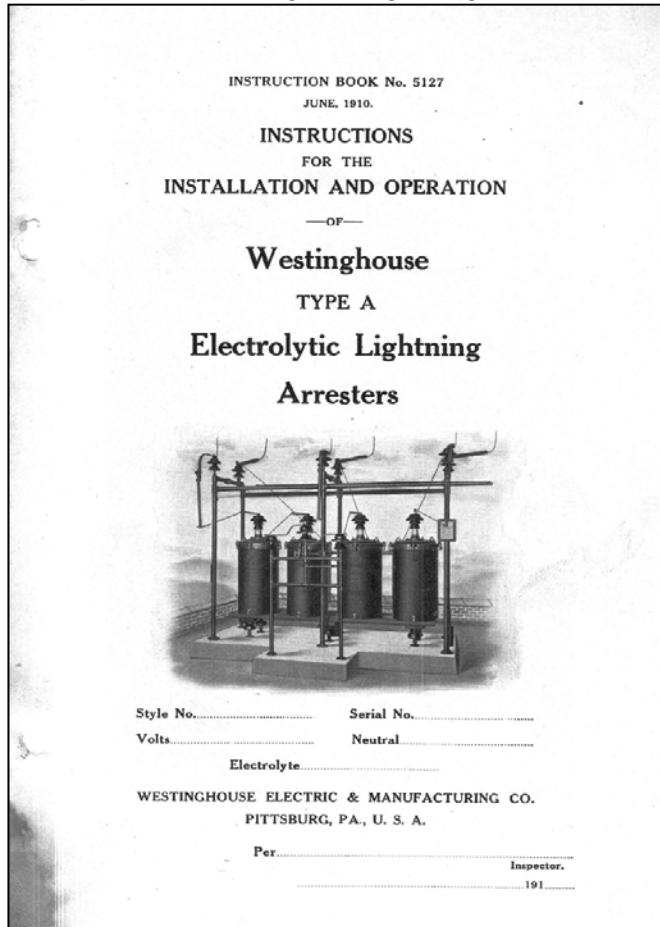


Figure 4 1910 Westinghouse Electric Instruction Manual on Type A Electrolytic Arrester

electrolytic arresters despite the fact that GE had been granted patent rights. Figure 4 is the cover of a 1910 installation instruction brochure that shows that Westinghouse had product to the market before the 1911 GE patent was issued. Westinghouse did finally receive a patent on this type of arrester in 1919 with inventor Joseph Slepian (1,456,941). So the battle raged on with no clear winner in this arrester type.

Electrolyte Arrester Theory of Operations

The theory of the Electrolytic Arrester (also known later as the Aluminum Arrester) can best be understood by considering a single aluminum cell. The cell consisting of an electrolyte into which extends two aluminum plates (Figure 5) with a microscopically thin film of aluminum hydroxide. The electrolyte was the same as that used in the formation of the film. When the voltage was applied to the cell and gradually increased, the current through the cell was very small until a critical voltage was reached. At that point, the current flowed freely being limited

(AIEE) at the annual winter meeting in New York City. At that meeting he presented and defended his new invention. Proceedings of the meeting give excellent details of the written discussion that resulted from the presentation. I'm sure that Westinghouse engineers were not pleased to see this turn of events. Several contributors in the written discussions gave RP Jackson, a recognized expert in the area of surge protection from Westinghouse, credit for the actual introduction of the concept a few months earlier. However, if Jackson was the first to introduce the concept, he was outflanked in the patent battle by Creighton and GE since there are no patents in his name.

The February 1907 patent application was just the first of many that Creighton filed over the next eighteen years. GE had won the patent campaign, but that was all they won. Over the next twenty years, GE and Westinghouse both marketed and sold



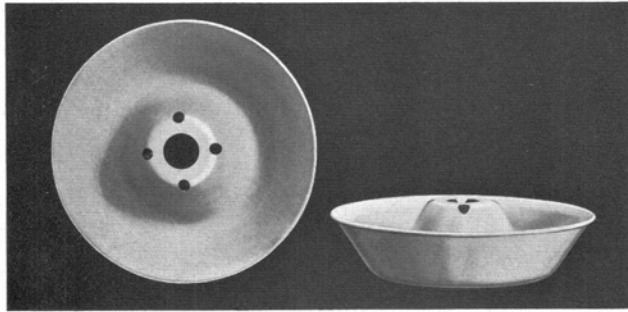


FIG. 2—DETAIL VIEWS OF ALUMINUM TRAYS USED IN THE ELECTROLYTIC ARRESTER

Figure 5 Aluminum Plates of the Electrolytic Arrester

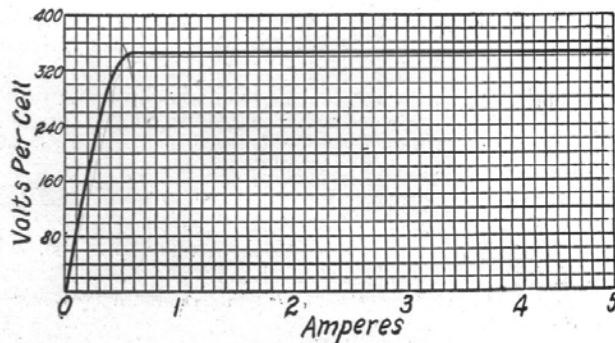


Fig. 2

Volt-ampere Characteristic Curve of an Aluminum Cell

Figure 6 VI Curve of Electrolytic Arrester showing significant change in resistance after the knee of the curve.

Expulsion Arrester

In parallel with the development of the electrolyte arrester, a far simpler arrester was taking shape. It was referred to as an expulsion arrester. This arrester also used a gap as the means of holding off standard voltage during steady state. However after flashover by a lightning surge a blast of air was directed onto the gap. This air blast was the means of increasing the resistance of the gap, which allowed it to interrupt the current at voltage zero. It appears that the earliest version of this arrester came out of a small, well established company in Philadelphia named Electric Service Supply Company (ESSCO).

only by the internal resistance of the cell, which was very low. The Figure 6 VI Curve illustrates this *turn on point*.

The current which flowed above the critical voltage was equal to the excess voltage (voltage above the critical voltage) divided by the resistance, not the total voltage applied across the arrester.

The vital characteristic of the Electrolytic Arrester was due to the thin film of hydroxide of aluminum. When the critical voltage was reached, a myriad of minute punctures were created in the oxide layer that allowed the current to flow. When the excess voltage was removed, the minute punctures sealed up at once. The original resistance reasserted itself and no discharge of dynamic (power frequency) current followed. This was a major step forward in overvoltage protection because breakers were not needed to terminate the surge event.

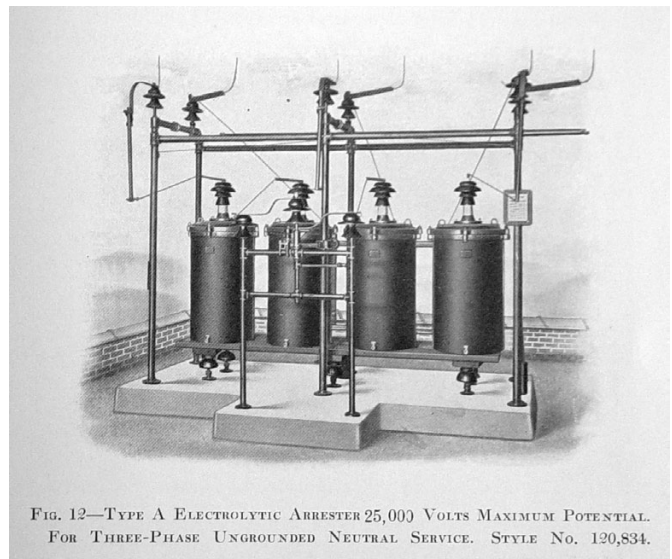


FIG. 12—TYPE A ELECTROLYTIC ARRESTER 25,000 VOLTS MAXIMUM POTENTIAL FOR THREE-PHASE UNGROUNDED NEUTRAL SERVICE. STYLE NO. 120,834.

Figure 7 25kV Arresters of the Electrolytic Type by Westinghouse



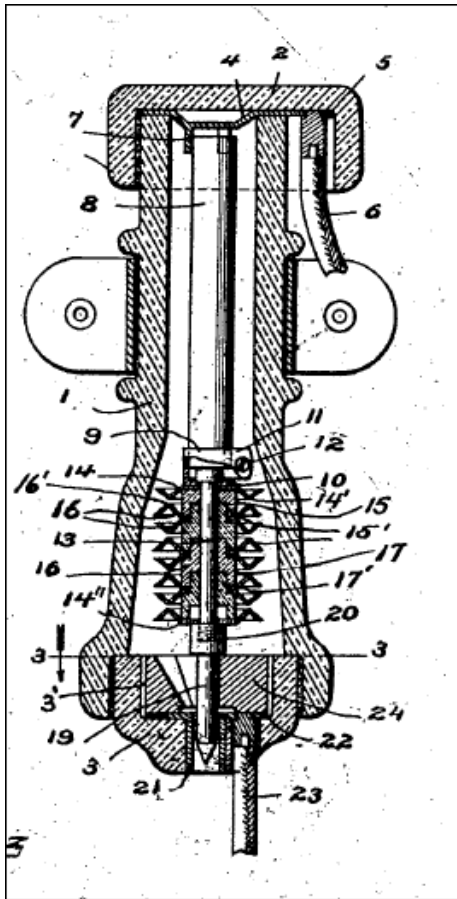


Figure 8 Early Expulsion Arrester from 1918 McFarlin Patent using hot moving air through the gap section to increase the arc length and resistance.

In 1918, John Robert McFarlin, a young engineer from the University of Delaware was granted his first of many patents in arresters over a long and fruitful career. As seen in Figure 8, component 8 was a low ohmic resistor made of carborundum, a high temperature low ohmic material commonly used in arresters in this era. When the follow current started to flow after the surge, the resistor rapidly heated the air inside the unit and expelled it out the bottom of the unit after passing through the series stacked gap plates. This fast moving air increased the arc length and arc resistance necessary to interrupt the event. No external fuse or breaker was necessary to end the surge event. It appears that this design was not acceptable for higher voltages since it does not show up in higher voltage designs.

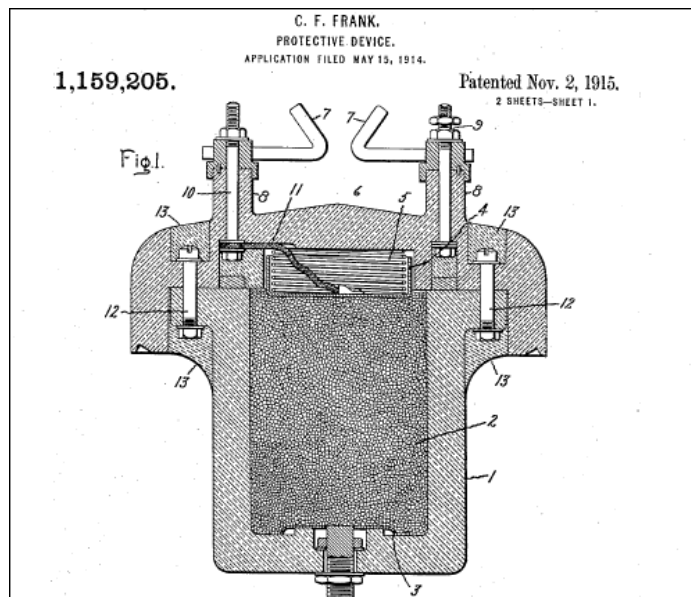


Figure 9 Pellet Type Arrester 1915 CF Frank GE. Item 2 represents the pellets with oxide film coatings. Note that the Horned Gaps are used in series with the resistance of the pellets.

Pellet Type Oxide Film Arrester

Competing head to head with the first expulsion arrester was the new Pellet Type Oxide Film Arrester. This new design was a product of arrester titan, GE. From the patents and other literature, it is clear that GE had numerous engineers designing arresters in this era. This new pellet type arrester had the excellent voltage current characteristics of the Aluminum Cell arrester, but without a liquid dielectric. Patent 1,159,205 was granted to CF Frank for this design in 1915. In 1921 NA Lougee, also of GE applied for an improved version of this arrester using peroxide lead pellets. This design had an additional advantage of lower cost and was better suited for line protection. However, there were still lingering issues with this type of arrester. It appeared to have a limited lifetime due to damage to the oxide film during each surge. This damage was not repairable as in the liquid oxide film arrester. Clearly more work was needed in the industry.



The First Gapped Silicon Carbide Arrester

In 1926 John Robert McFarlin, who was still working for ESSCO, filed for a patent using a new material that he referred to as: “infusible refractory materials of limited conductivity and comparatively low specific resistance in the silicon carbide family.” He goes on to state that “these properties greatly enhance the effectiveness, durability, stability and simplicity of surge arresters.” Thus began the long history of the Silicon Carbide (SiC) family of arresters. This type of arrester remained in production into the 1990’s in the US and is still in production in other parts of the world. As design engineering manager of the surge arrester business at Cooper Power Systems; this author personally shut down the last US based production line of this product in 1994.

It seems surprising that the introduction of the first SiC arrester didn’t come from GE or Westinghouse, the titans as they were in the area of overvoltage protection. Silicon carbide resistance material quickly earned the number one position in arrester designs for all voltage levels.

In 1930, J Slepian the lead arrester designer at Westinghouse at the time published an extensive article on his invention the Autovalve Arrester (patented in 1924). Although there were numerous material improvements over the years, this arrester remained in production until the 1980’s. It was very similar to the SiC arrester resistance material but used carbon and fillers as the nonlinear section. The term Valve Block was first used in this era.

At GE in Pittsfield, Massachusetts, the design team lead by highly regarded Karl B McEachron was very close behind McFarlin in developing a silicon carbide based resistance material. They patented what came to be known as their Thyrite material in 1931. They had filed for their patent in June of 1927, only 14 months after McFarlin at ESSCO. It is interesting to note that McEachron published his extensive paper on the Thyrite material in the same American Institute of Electrical Engineers (AIEE) journal in 1930 that contained Slepian’s Autovalve paper. The titans in lightning arrester were still going at it some 20 years after the last battle over the electrolyte arrester. The Thyrite arrester remained in production for many years and was removed from production only when the metal oxide generation of arresters started.

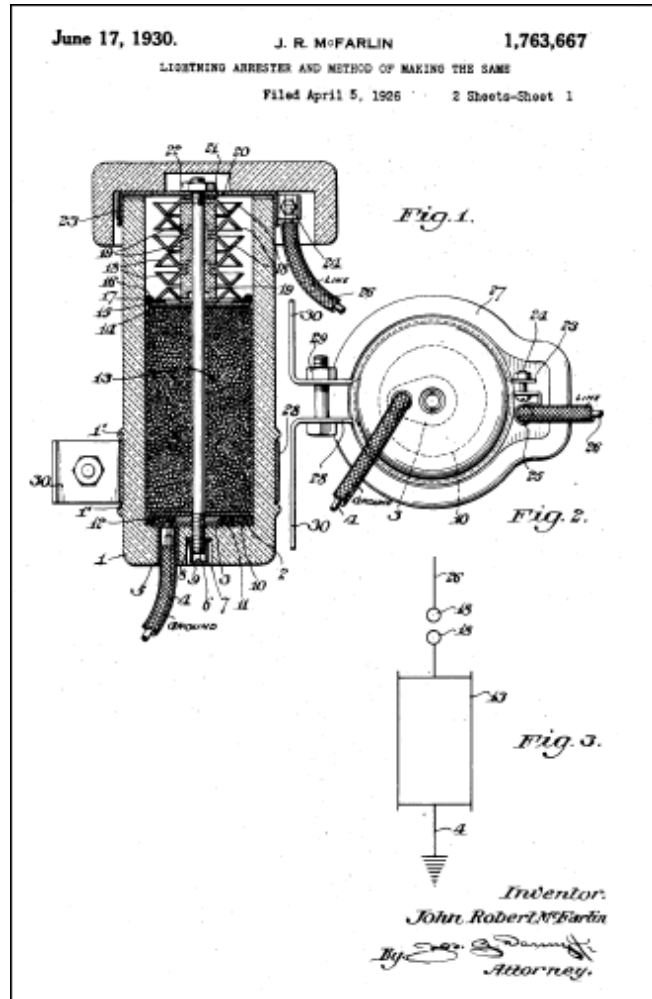


Figure 8 First Silicon Carbide Arrester Patent Filed in 1926 and Issued in 1930



As the 1930's unfolded, there were several other arrester manufacturers that entered the scene. The Line Material Company under the guidance of engineer AG Steinmayer, filed for their first arrester patent in 1928 and was issued as patent 1,758,181. This arrester was of the expulsion type and it actually generated gas from an arc similar to the 1918 McFarlin arrester, however in this design, the gas actually moved the gap plates apart to create a second series gap to assist in breaking the follow current. The Joslyn Manufacturing Company (Chicago, Illinois), and the Kearney Co (Arkansas) were two more manufacturers during the SiC era that started producing arresters.

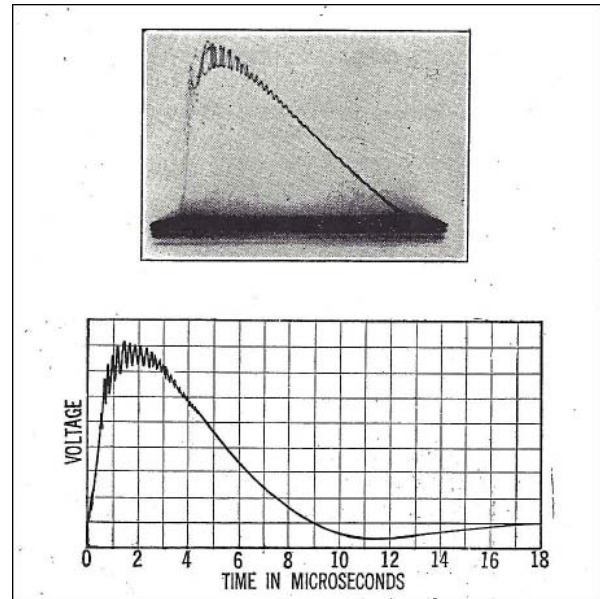


Figure 9 Ocullographic recordings as shown in the 1927 AIEE paper "The measurement of Surge Voltages on Transmission Lines Due to Lighting

Arrester Standards

By 1928, the American Institute of Electrical Engineers (AIEE) was involved in the authoring, maintaining and developing standards throughout the power system industry. Meetings were held routinely to discuss standards development. The Lightning Arrester subcommittee of the AIEE Committee on Protective Devices was lead by JA Johnson of the Niagara Falls Power Company. In 1928 they published a second edition of "Proposed Standard for Lightning Arresters No. 28". This draft standard later became the first AIEE standard on arresters. Herman Halperin, of the Commonwealth Edison Company, wrote in his 1929 committee report that the development of the klydonograph and cathode ray scope were critical to the development of these standards; without these instruments they could not have standardized on a wave shape. He indicated that in previous years, they could measure amplitude with sphere gaps, but did not have a good idea of the rate of rise and fall of a lightning surge.

Summary

The years 1890-1930 saw many changes in the quality and capability of surge arresters. As the systems grew in voltage, so did the lightning protection requirements. Engineers' ingenuity saves the day again. In the next segment of this history, we will examine the station class arresters, current limiting gaps, revisit the next generation of expulsion arrester, explore the transmission line protective gaps, and the arrester sentinel, the disconnecter.

Comments are welcome

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