

The Reconditioning of Vacuum Interrupters is Nearer Than You May Think

Finley Ledbetter, Group CBS, Inc.

OUTLINE

1. **Introduction - Slide 1**
2. **Foreword - Slide 2**
3. **MAG-R™ - Slide 3**
 - a. MAG-R™ Process Figure 1 - Slide 4
4. **VMAG-R™ – Slide 5**
 - a. VMAG-R™ Process Figure 2.a – Slide 6
 - b. VMAG-R™ Process Figure 2.b – Slide 6
5. **Case Study I. Pulse – High Pressure, VIs 20+ Years Old – Slide 7**
 - a. Figure 3 – Slide 8
6. **Case Study II. Pulse – High Presence Utility, VIs 20+ Years Old – Slide 9**
 - a. Image 1 – Saltwater Corrosion – Slide 10
 - b. Image 2 – Saltwater Corrosion – Slide 10
 - c. Figure 4 – East Coast Paper Plant, Hurricane Sandy-Affected – Slide 11
7. **A Better Vacuum Interrupter After Reconditioning – Slide 12**
8. **Summary – Slide 13**

VMAG-R™ and MAG-R™ Reconditioning Processes for Selected Vacuum Interrupters: A New Process to Recondition Certain Failed or Near Failure Vacuum Interrupters

INTRODUCTION

Vacuum interrupters (VI) are arguably the single most important component of medium-voltage equipment that is required to open, under both normal and electrical fault conditions, day in and day out; and doing so under many different environmental conditions and varied duty cycles. With literally millions of interrupters in service, assuring they continue to work reliably, safely, and within their original design limits is important to the owners and users of the interrupters.

A new, innovative reconditioning process will allow certain vacuum interrupters to be reconditioned and returned into service after they have reached their original life limits. If a VI has not outlived its wear limits or its contact structure has not experienced too much damage, it will likely be suitable for reconditioning. Most VIs have experienced minimal operation or use and need only to be reconditioned in order to go directly back into service. The real market disruption will start with the reuse of the original type certified vacuum interrupter design. This reconditioning process can be completed within three days at a vacuum interrupter reconditioning facility, or in some cases can be done in the field.

Some vacuum circuit breakers have been in service for forty plus years and there is no replacement for vacuum technology in sight. Thus, finding ways to keep old vacuum breakers in service is needed as the original manufacturers lose the capability to support these products. The innovative processes described in this paper are a significant step in extending the life of medium-voltage circuit breakers.

FOREWORD

The United States was at the forefront of vacuum interrupter development in the mid-1900s. Of course, every major industrial power was also on the hunt to develop and commercialize this revolutionary new product. It is indisputable that the influence Westinghouse, General Electric, and Jennings had on local acceptance and utilization in the 1970s quickly made all other interrupter technology obsolete in medium-voltage breakers.

The alarming fact is that most of this expertise in vacuum interrupter technology has retired or passed on. This, along with the ever-growing drive to build these products offshore to take advantage of low-cost labor and fewer EPA issues, has made the U.S. akin to a third world power in the vacuum interrupter field. Also, consider the importance of this small component to the U.S. infrastructure. Surely, we, the U.S., must reconsider and reenter the development and manufacture of these products here at home.

These small yet complex components are a key element of the U.S. industrial and utility machine; and they are all operating on a diminishing timeline. This timeline can be argued, but there is no doubt that all things wear out, time out or fail in time, furthering the question: how can we ensure that we can continue to support this aging equipment without a solution? Certainly, replacing all medium voltage switchgear in the U.S. as these components fail is not a viable scenario.

This problem was recognized over twenty years ago, and personnel have been developing testing techniques, replacement components, and buildout of a new, stand-alone vacuum interrupter manufacturing plant in the U.S. – the first in over fifty years. In this process, research and development has been on a parallel path to develop other ways, thinking outside the box, to extend the useful life of many existing interrupters until U.S.-made replacements are available or other solutions come from the major manufactures. The development of an interrupter reconditioning process, identified as VMAG-R™ and MAG-R™, is an example of an out-of-the-box program that has shown great promise. It is not a total solution; but it is a way to bridge the issue until it can be solved.

There are two separate processes for reconditioning aging, near failure, or high-pressure vacuum interrupters. Let's first categorize those which are stable, with low wear, and with pressures indicating at least five years of useful life remaining. The technology for these processes is complex; however, this paper will attempt to explain and demonstrate their utility and place them in the tool box of every field service and breaker repair company. We have conducted many tests whereby we have substantially lowered the internal pressure in existing, mid-life vacuum interrupters. These successful tests have been conducted under laboratory conditions and on various manufacturers and models of vacuum interrupters that have been taken from service and identified as failed or near failing. Again, these processes as identified as MAG-R™ and VMAG-R™.

MAG-R™ PROCESS

MAG-R™ process refers to magnetron, or magnetic, assisted gettering of gas molecules. This is achieved by creating field and energy flow that forces gas molecules to combine or adhere to the internal materials. Others in the industry call this the “getter-ion effect”. This process is in addition to the normal pumping effect from commonly added getters which adsorb or react with many types of gas molecules after manufacturing. In the MAG-R™ process, first, the surfaces inside are extremely clean since they've been heated in a deep vacuum to a point where any surface oxide is baked off and are therefore very reactive. Sealed vacuum interrupters, through residual gas analysis, have been found to contain N₂, H₂, CO₂, CO, Ar, and other trace gases. These molecules break down into ions (H⁺, O⁺, C⁺, etc.), which want to balance their charge by combining with molecules containing extra electrons in their outer shield but are trapped by the

electric field. The magnetic field then causes violent mixing of these charged particles; and when the high voltage is removed, they are released in all different trajectories. The ions hit a very clean metal surface which gives up a free electron to form an oxide, carbide, or other compound on that surface. This effectively removes the original gas molecule(s) from the vacuum.

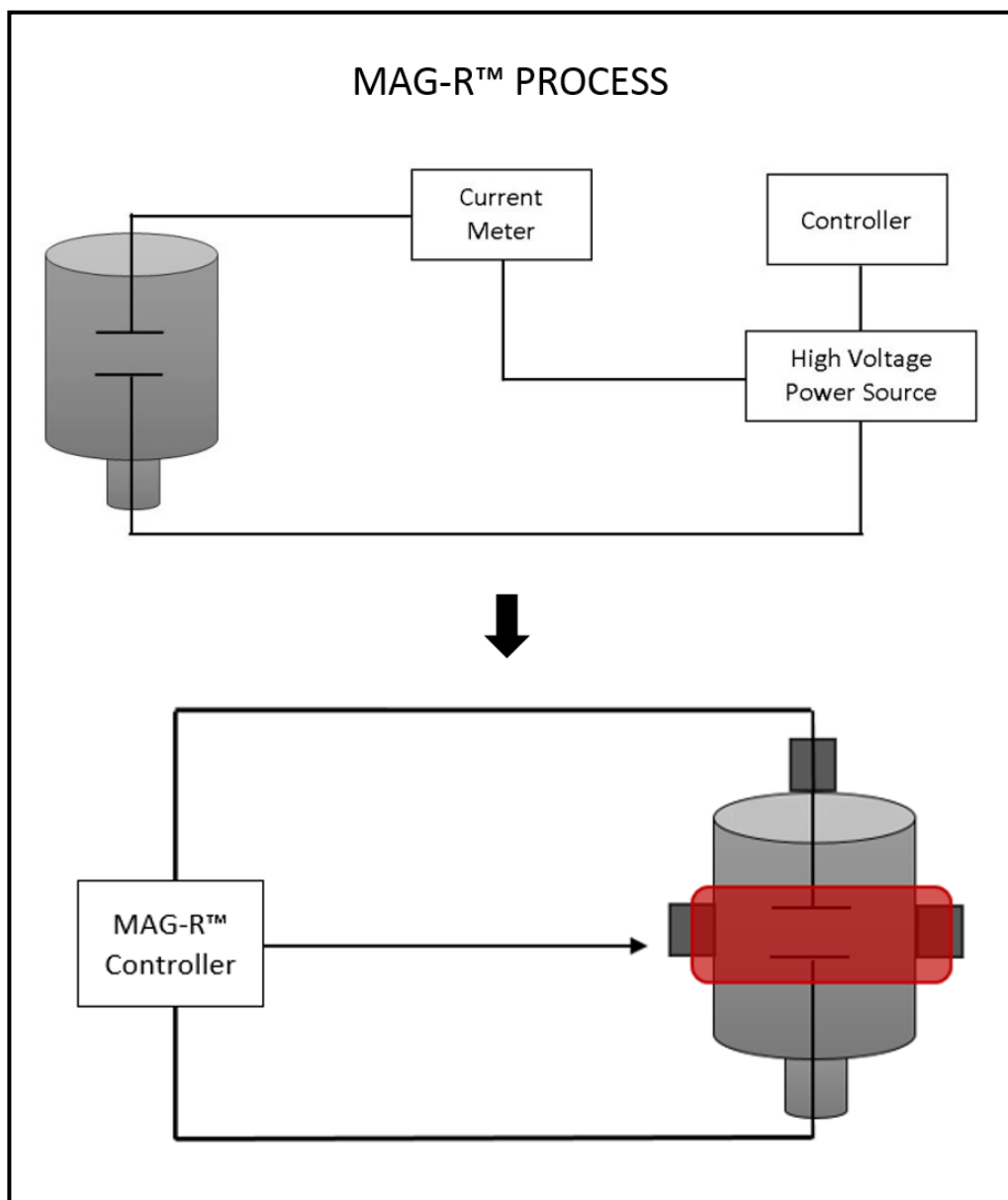


Figure 1 – Field-portable, quick, and easy-to-apply makes this a valuable tool to reprocess vacuum circuit breakers in service all over the world today.

VMAG-R™ PROCESS

VMAG-R™ process refers to the process by which, in conjunction with MAG-R™, the interrupter is punctured, cleaned, electro polished, existing contacts conditioned, and the envelope resealed with new getter material inserted at a pressure close to that at which it was manufactured. This process is required when the VI reaches an internal pressure that is too high for MAG-R™ reconditioning to be effective. VMAG-R™ will not be effective for all types of VI due to material science issues and of course wear and VI condition issues. This process requires several days and is subject to damaging the existing VI if strict thermal ramp rates and manufacturing routines are not developed for each VI.

A benefit to the VMAG-R™ technology is that the older VI designs can be improved by removing pinch-off tubes and installing better getter materials. The original type rated mechanical design can then be quickly installed back in the breaker instead of replacing the gear, which in some cases is cost-prohibitive or impossible to accomplish in the allowed time.

It should be noted that modifications are not permitted in ANSI-certified equipment. VIs which have undergone the VMAG-R™ process have also been tested under full power conditions; and new type certificates will be available if required. This process may also be used as a temporary solution to get the equipment back in service until new equipment can be designed, budgeted, purchased, and installed.

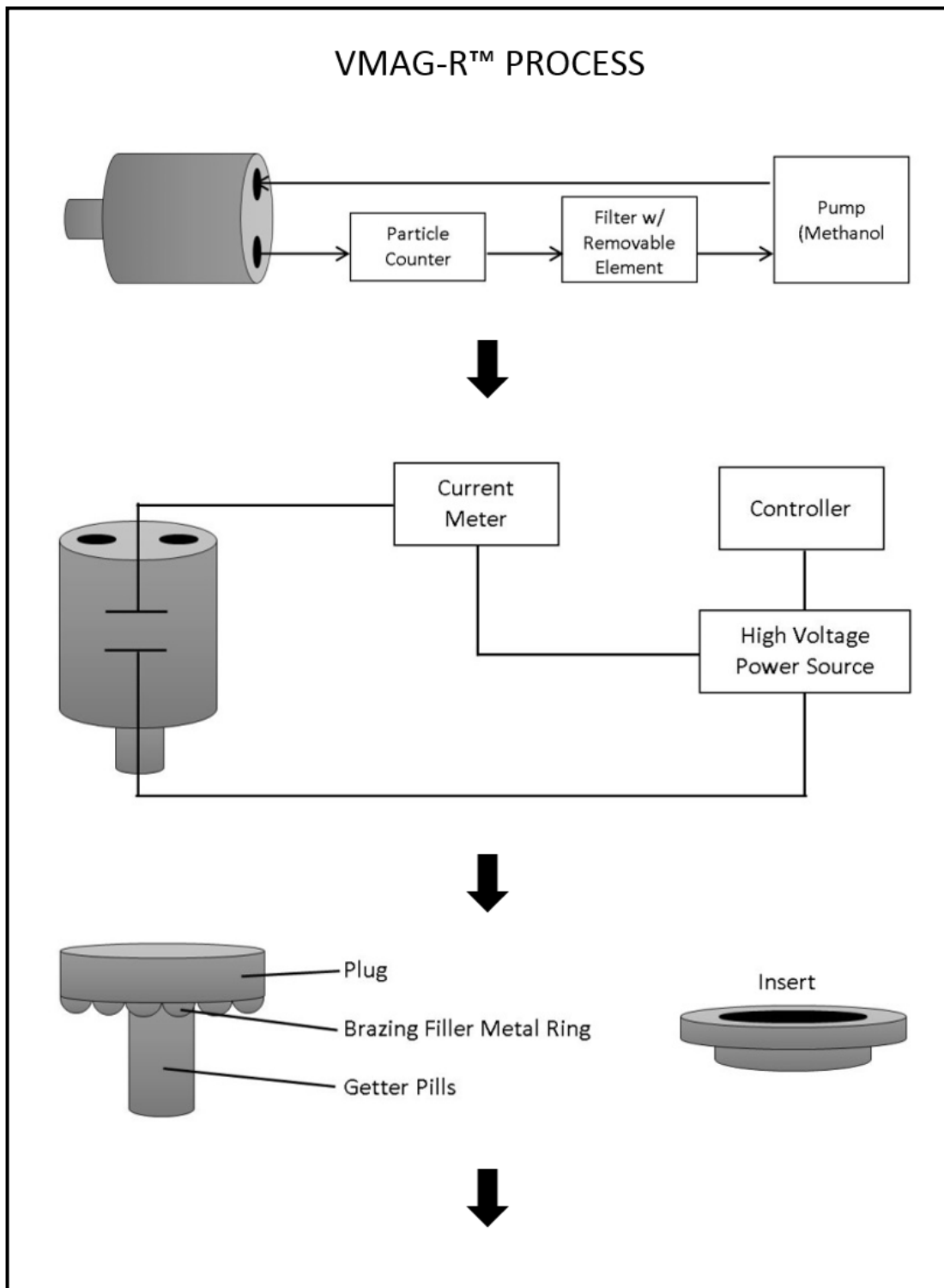


Figure 2.a – Only available for certain VIs and only possible in the workshop.

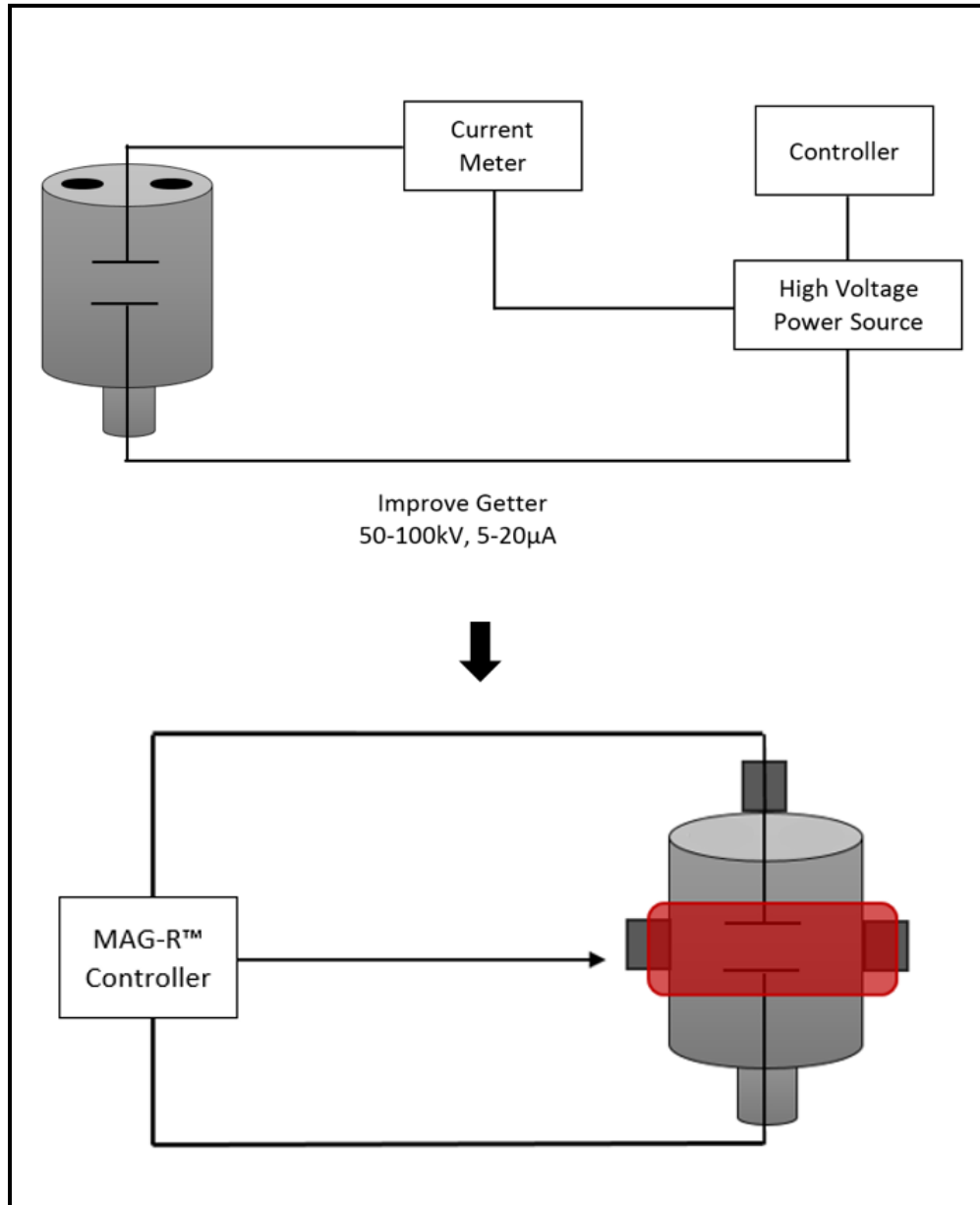
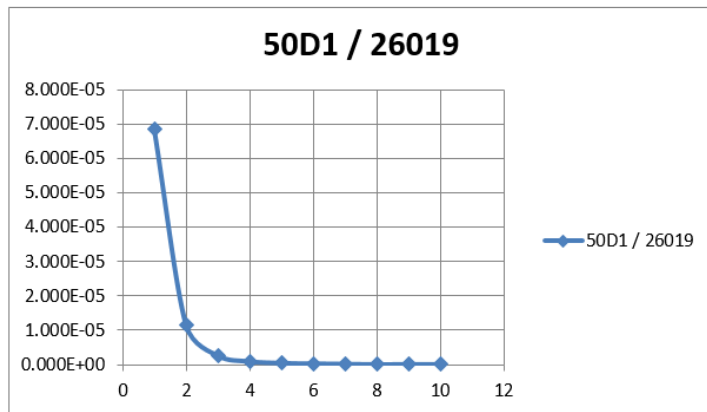


Figure 2.b – The final step is a full MAG-R™ conditioning routine.

CASE STUDY I. Pulse – High Pressure, VIs 20+ Years Old

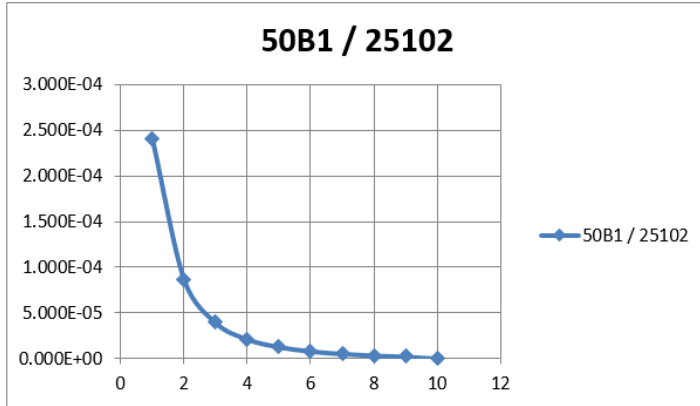
Outdoor Substation-Type Utility, Medium-Voltage Vacuum Circuit Breaker
 (Tested at 3-Minute Intervals and Rated Gap)

These two high-pressure VIs were removed from service and replacement VIs were installed in 2016. Vacuum Interrupters, Inc. tagged them for MAG-R™ reconditioning as the wear was negligible, the breakers had less than 1000 operations, and the VIs showed no signs of unusual service corrosion or misapplication. The original test data showed the pressures were in the -2 PA range -4 Amperes Ion Current. They were stored for a year and retested to verify that the leak rate was acceptable, and then subjected to a life pressure simulation protocol. The VIs were tested a third time to ensure integrity was acceptable. They were then subjected to MAG-R™ reconditioning protocol and the ten steps were recorded (shown in Tables 1 and 2). Next, they were subjected to accelerated life cycle gas testing to simulate being in service for five years, which showed no change in pressure. The subsequent testing phase was to administer 100 normal, open-close events under full-rated voltage at 15 kilojoules to simulate gas emissions from the metals during actual use. The results were favorable and are reflected in the two graphs below.



Ion Current vs. Pulse Count

VI Type	50D1	50B1
VI S/N	26019	25102
Pulse #1	6.850E-05	2.408E-04
Pulse #2	1.162E-05	8.678E-05
Pulse #3	2.721E-06	3.941E-05
Pulse #4	1.019E-06	2.127E-05
Pulse #5	5.441E-07	1.283E-05
Pulse #6	3.777E-07	8.112E-06
Pulse #7	2.839E-07	5.282E-06
Pulse #8	1.562E-07	3.365E-06
Pulse #9	1.902E-07	2.141E-06
Pulse #10	1.915E-07	1.024E-07



Ion Current vs. Pulse Count

Figure 3 – The graphs clearly show ion current reductions with each high energy MAG-R™ pulse.

CASE STUDY II. Pulse – High Presence, East Coast Paper Plant, VIs 20+ Years Old
(Tested at 3-Minute Intervals and Rated Gap)

Following Hurricane Sandy, we cleaned, re-lubricated, dried out, and placed thousands of circuit breakers back in service. Shortly afterwards, these breakers were systematically, as time would allow, taken out of service and ran through a service shop. The ion currents of the VIs were found to be very high, indicating high pressure; and consequently, new replacement vacuum interrupters were installed. Vacuum Interrupters, Inc. placed the removed VIs into a forensic study to determine the long-term effects of salt water contamination and determine mean-time to failure.



Image 1 - Saltwater corrosion.



Image 2 - Saltwater contamination on bellows.

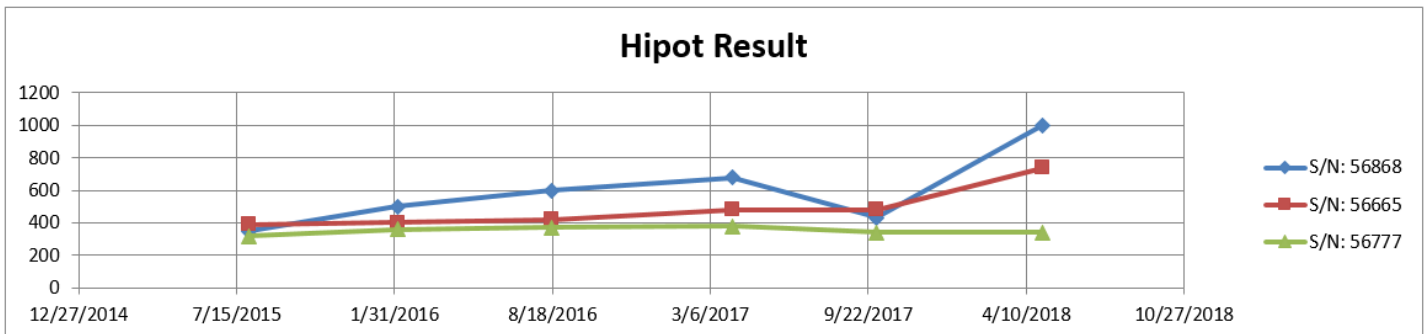
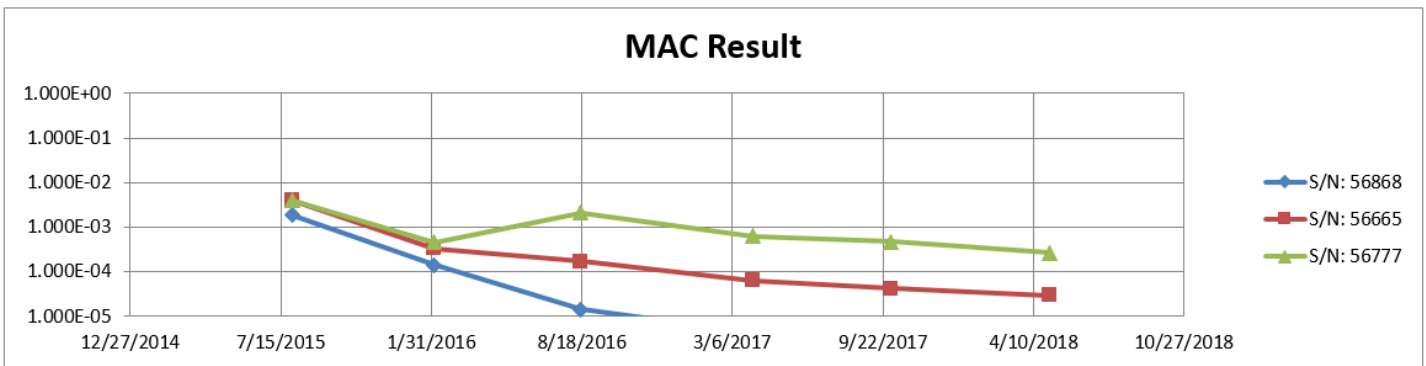
Three of the General Electric VIs in this case study were submerged in saltwater for a very short time. Two were left as control samples and one was treated with Corrosion X, an anti-corrosion inhibitor. We will see the results and report on this study over the next few years. For the purpose of this study, all three VIs are being tracked for ion current/internal pressure and have been systematically undergone MAG-R™ reconditioning on a regular basis. The results have been

favorable and are plotted in Figure 4 below. We expect a VI failure as the chlorides left behind by the saltwater slowly destroy the stainless-steel bellows. Our use of the corrosion inhibitor may slow or stop the corrosion; however, that is another topic to be discussed in a few years.

Type: 44B1 S/N: 56868			
Test Date	MAC Result [A]	Hipot Result [uA] @36kv	Resistance [uΩ]
7/31/2015	5.143E-05	350	83
2/4/2016	1.402E-05	500	15
8/17/2016	1.400E-05	600	23
4/3/2017	4.292E-06	680	19
10/3/2017	3.964E-06	430	23
5/1/2018	1.906E-06	1000	28

Type: 44B1 S/N: 56665			
Test Date	MAC Result [A]	Hipot Result [uA] @36kv	Resistance [uΩ]
7/31/2015	3.564E-04	390	83
2/4/2016	3.337E-05	400	34
8/17/2016	1.681E-04	420	17
4/3/2017	6.239E-05	480	17
10/3/2017	4.141E-05	480	14
5/1/2018	2.925E-05	740	14

Type: 44B1 S/N: 56777			
Test Date	MAC Result [A]	Hipot Result [uA] @36kv	Resistance [uΩ]
7/31/2015	2.032E-05	320	71
2/4/2016	4.605E-05	360	15
8/17/2016	2.130E-03	370	16
4/3/2017	6.262E-04	380	17
10/3/2017	4.726E-04	340	16
5/1/2018	2.657E-04	340	19



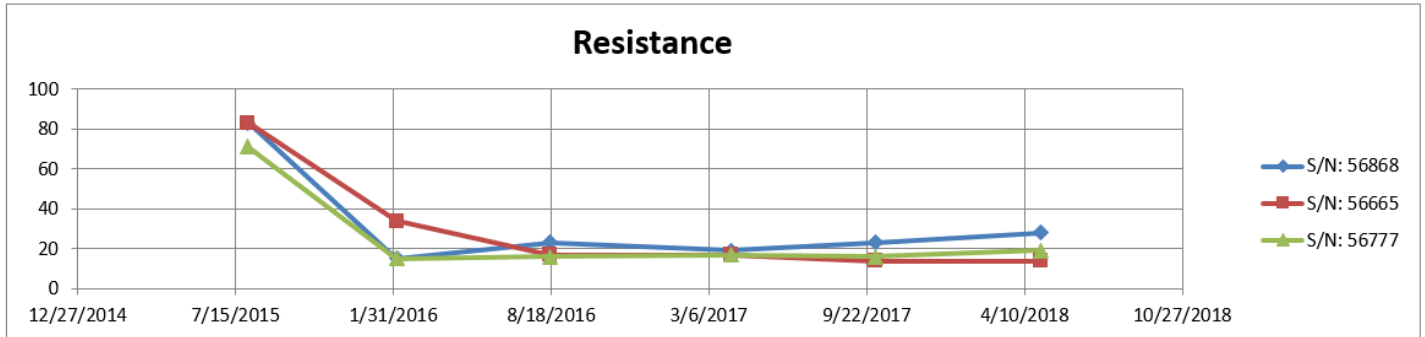


Figure 4 - East Coast Paper Plant, Hurricane Sandy-Affected

A BETTER VACUUM INTERRUPTER AFTER RECONDITIONING

Both the MAG-R™ and VMAG-R™ processes have been completed with success in our lab; and we are currently conducting tests to determine which materials are best and which VIs are best suited to these processes. Some positive things have come from this research. First, we can remove the pinch tube from the older pinch tube designs and install a new getter material. Additionally, the same opening can be resealed with modern brazing filler material far better-suited to this application than the original pinch tube that long has been a problematic seal off and point of failure in many VIs. Second, we can now add more and better getter material as the economic model has changed substantially from when they were originally manufactured. These processes have been patented in the U.S. and abroad and research is underway to improve and bring these, or at least one of these, processes into production this year.

The challenges are to identify which VIs warrant and will accept these processes and which process will each design best accept. Then, we must develop a way to take these processes from the lab to the field by developing field-portable, easily-applied conditioning equipment that can be used to extend the life of VIs. This will give us all a strong ally in the coming years in the battle to keep aging VIs in service. As service organizations, we already can test VIs, remanufacture the mechanisms in the shop and recondition, clean, lube, and adjust the mechanisms in the field. The MAG-R™ and VMAG-R™ processes very likely offers a way and means for testing and maintenance companies to bring real value to the client.

Understand, this is not theoretical speculation: this is real, here today, and a service that can be proven and provided as a value-added service. Our goal is to keep this equipment in service 100 years, until someone, somewhere, and that has not even started at a university yet, will develop a technology to replace it. In the meantime, old, clunky vacuum switchgear must stay in service; Group CBS and NETA will be at the forefront of this endeavor doing good things for the future.

SUMMARY

No viable replacement for vacuum circuit breaker technology is currently in the design stage, which means we need to consider alternate solutions. The ability to remanufacture, service, or maintain the mechanisms of medium voltage vacuum circuit breakers has been available for years. Now, there is a process and tool that will allow us to recondition and keep vacuum interrupters in service well beyond their original expected lifetime. A well-trained professional is needed to insure the VI is compatible and that the process is a well-suited option for each application; however, the VI reconditioning processes do give the industry a new tool to fight the issue of aging VIs reaching an end-of-life condition. The electrical industry, NETA, PEARL, and the overall electrical maintenance field will benefit from many possible uses of this technology going forward.

BIOGRAPHY

Finley Ledbetter is the Chief Scientist of Group CBS, Inc. with over 35 years of power systems engineering experience, a member of the IEEE, a past president of PEARL, is a certified NETA technician, and a well published author in the area of power engineering.