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### **Extending the Life of Overhead Aging Assets with Focus on the Energized Portion of Transmission Line**

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#### **SUMMARY**

The 21<sup>st</sup> Century has been deemed “The Era of Rebuilding.” Infrastructure around the globe, much built in the early 20<sup>th</sup> century, including roads, bridges, pipelines, and not to be ignored, our electrical infrastructure! As it turns out, nothing lasts forever – because forever is a long time! The focus of this paper is “Extending the Life of Overhead Aging Assets” of the electric infrastructure, both transmission and distribution. Most particularly the transmission system, which is already overloaded beyond original design capacities, and the demand continues to increase. The concept of electric vehicles and the retirement of petroleum fueled vehicles is definitely a threat to the system, both generation and transmission.

Focusing on the Energized portion of the system basically includes anything below the insulators, including the conductor, deadends, splices/joints, terminals, and suspension clamps or systems. Most utilities are finding various problems on an increasingly frequent basis, and several have experienced “dropped conductors” for various reasons. Among those reasons are connector failures, predominantly those under tension. Over time, the electrical interface between the connector and the conductor degrades, increasing in electrical resistance, which in turn generates heat with the passage of current. If this is left unmitigated, the increasing resistance will eventually lead to thermal runaway and the connector will fail mechanically in a catastrophic fashion. The resulting electrical outage is a significant cost to the utility, and this is discounting the possibility of fire, obstruction of traffic, destruction of property and in the worst case scenario, loss of life.

Other factors resulting from age are damaged conductors, especially those having fatigued strands within suspension systems, as well as abrasion from loose spacers, dampers, or spacer-dampers, contact with vegetation, and on occasion, damage from a bullet.

This paper addresses these issues and introduces mitigation strategies to restore the damage to like-new or better than the original condition, both mechanically and electrically. These proven and well-established mitigation methods are fast, economical, and can be accomplished on energized lines without an outage. The integrity of the restoration will meet or exceed the original design parameters.

#### **KEYWORDS**

Aging Assets, Splices/Joints, Mitigation, Deadend Mitigation, Suspension Mitigation, Uprate, Upgrade, Engineered Electrical Mechanical Shunt, Electrical Shunts, Infrared thermography inspection, Classic Connectors, Resilience, Wildfire mitigation

## **ASSESSMENT**

When it comes to assessing the life extension of aging overhead assets, many factors must be considered. Obviously, the condition of the components is somewhat paramount, including everything from tower foundations, counterpoise, the structure itself, corrosion, attachment hardware, insulators, and of course the energized components being deadends, splices/joints, suspension clamps/systems, and the conductor itself.

It is necessary also to look at long range plans. Is this line scheduled for rebuild, possibly due to corrosive conditions of the core, which cannot be readily repaired? Is this line scheduled for a voltage uprate including substation equipment at both ends? Can additional right-of-way be obtained to complete a voltage upgrade? Is a thermal uprating required to comply with regulatory requirements? State and Local regulations and environmental concerns must be addressed during the planning process.

A further aspect is “hardening” the line, making it more resilient to the myriad of issues, which might render it inoperable, resulting in an outage. For the most part, most utilities have dealt with issues such as storms or overload conditions in a reactive manner – however taking a proactive approach to resilience – preventative maintenance – or “uprating/upgrading” to avoid the term “maintenance” has proven the most economical approach in almost every industry. Not really different than changing the oil in your vehicle, or replacing tires before they fail!

As stated in the summary, we will be focusing on the energized portion of the transmission line.

## **GENERAL INSPECTION**

A physical inspection of the line will be a prerequisite to making a determination on what must be addressed, and when the work must be done. A popular method in recent years has been the use of helicopters, and UAV’s (unmanned aerial vehicles) allowing personnel access to visibly inspect and photograph (visual, ultraviolet, and infrared), and assess the severity of wear on attachment hardware, insulators, and the conductor itself, checking for signs of abrasion from loose hardware such as spacers, dampers, or spacer-dampers, or from contact with vegetation, or even gunshot damage.

These methods answer several questions, which can be assessed visually for the entire system, and IR may give hints of thermal issues such as broken stranding within suspension systems and may locate some overheated connectors. However, a few things tend to mask IR readings, most particularly higher wind speeds of as little as 3-4 m/s when combined with a light electrical load.

The original method for making such assessments of steel core condition involves cutting out a few sections of conductor and making physical examinations. This of course requires new conductor to be spliced back in place of the section removed, and typically requires an outage. Some consideration should be given to the locations chosen as samples to assure they are “typical” for the line, and areas likely to be suspect, such as along coastal environments or other corrosive atmospheres should also be inspected.

A rather modern method for assessing the condition of the core involves the use of robotic line survey tools, such as LineVue® developed by Kinectrics. These devices can travel along a section of conductor and measure the remaining strength of the core and are reliable and very cost-efficient as this can typically be done on energized conductors. They are also capable of detecting broken strands which are not visible. From this information, a reasonable determination may be made regarding the remaining life of the conductor.

Once it is determined that the conductor has sufficient service life remaining, the remainder of the energized portion of the line must be assessed. If the conductor has several years of service life remaining, and the need to re-conductor is not required, a program to extend the life of the asset, and restore its full electrical and mechanical integrity by employing Engineered Electrical/Mechanical Shunts, may prove to be an economical option.

## **REVIEW OF SUSPENSION CLAMPS / SYSTEMS**

Many older lines were originally built without dampers. Following a few failures due to strand fatigue caused by Aeolian vibration, most lines were fitted with dampers to prevent further degradation. Nonetheless, vibration damage is still detected today. This is partially due to damage that occurred on older lines prior to being outfitted with vibration dampers. Fatigue failure due to bending stresses which exceed the endurance limit are cumulative, and the final failure or strand breakage may not occur for several years. While vibration-damping technology has made numerous improvements, dampers are not generally 100% effective.

Given sufficient time, abrasion, known as “fretting” will occur, and or fatigue of the strands resulting in a break. This occurs at fixed points, predominantly suspension clamps and deadends, and at semi-fixed points such as spacers on bundled conductors. Detecting these broken strands is difficult. Various methods employ techniques such as pulsed eddy currents, analysis of deviation from natural frequencies, and more commonly, X-Ray and IR. These methods have been employed but often with less than satisfactory or consistent results.

X-Ray will have some dependency on the resolution of the images, and the location of the equipment in relation to the strand breakage, which could be shielded in the image by the steel core of an ACSR conductor. IR may detect severe strand breakage due to current density in the remaining unbroken strands, provided the electrical load is sufficiently high and the wind speed is sufficiently low. The suspension systems which employ helical-formed rods have a tendency to mask this condition, but strand breakage under these rods has been found.

Should broken strands be detected, it will be necessary to mitigate these locations. This likely will not require mitigation of the entire line as wind velocities vary greatly based on terrain. Upon finding a few such instances, one must be cognizant of the cumulative effects mentioned earlier and recognize that these few represent the weakest and worst-case examples. However, it is likely that others are just short of the endurance limit and prone to failure soon.

## ASSESSMENT OF CONNECTORS

The connectors are typically considered the “weakest link in the chain” and are also commonly the principal reason for assessing the remaining service life. Both Splices/Joints and deadends must be assessed.

When Compression fittings were designed, the parameters considered by the designers were for “a 30-year life expectancy, operating on a conductor of a maximum continuous temperature of 75°C.” This evolved from the original copper standards of a maximum 30°C Rise over a 40°C ambient (i.e., 70°C) but with the allowance of conductor manufacturers, ACSR rated for 75°C, the target of the standard was bumped up to match the conductor. Then, as now, a connector was considered failed when it reached the temperature of the conductor on which it is mounted. Thus, there is no “normal” or lifetime connector operating temperature – it is dependent on the conductor temperature. For example, a connector operating at 60°C on a conductor which is operating at 75°C is perfectly acceptable (but it is getting on the high side) whereas the same connector operating at 60°C on the same conductor at 55°C is considered “failed” electrically. If not addressed, the continued rise in connector resistance will result in an increase in temperature in a condition known as “thermal runaway” and will result in a catastrophic mechanical failure.

Having 100 years of empirical evidence with aluminum in prominent use, it is generally accepted that a properly installed, utility class, overhead compression connector will serve 40-70 years provided it is operated within its design thermal limits. Apart from temperature limits, correct installation is paramount and results in connectors failing in less than 2 years or living to be 100 years old.

Connectors designed 80-100 years ago were generally heavier than their present-day (since the 1980’s) counterparts. If you have some old catalogs dating back to the 50’s or 60’s, just compare the same part number from that time frame with the modern connector bearing the same part number! The newer one will be shorter and weigh less than the original design. This is because in the late 80’s, actually July 2, 1987, was when the term “leveraged buyout” was coined, and the strategy of business changed dramatically. People with accounting backgrounds were moved into the management roles previously occupied more commonly by engineers. Many of the “accountants” looked at the bottom line and started cutting costs, charging engineering to pare back the product until it was just enough to pass the minimal performance standard! That is what we would call IEC 61284, ANSI C119.4, and all the other connector standards around the globe! Such Standards are the measure of performance for a connector to be accepted on the market – it must “at least” perform to the standard – no one complains if it performs better.

**Inhibitor** is a great concern. The general direction of electric utilities today is to operate lines as close to full capacity as possible, which brings additional heat into the equation. The original inhibitors utilized mineral oil as a base. With a maximum conductor temperature of 75°C and a properly installed connector operating in the 45-50°C range, this is perfectly acceptable.

However, mineral oil has a flash point of 168°C (335°F). This means that the volatility, or evaporation rate, is sufficiently intense at this temperature that enough concentration of outgassing vapor is being produced to ignite spontaneously with air. Mineral oil inhibitor has been found to have dried up in failed fittings and does not provide a barrier to water/electrolyte and oxygen ingress.

Temperature plays a major role in the evaporation rate of mineral oil and it is obvious that higher temperatures are a problem. High-temperature inhibitors utilize synthetic oils which have notably less volatility and higher flash points, and were developed for connectors operating above 93°C.

However, the connectors existing on aged transmission lines (those being addressed regarding the concept of Life Extension) were installed with mineral oil-based inhibitors. This includes connectors for ACSS, a conductor designed for continuous operation at 250°C. Suitable high-temperature inhibitors were not introduced until 2001. ACSS was introduced in the 1970's, and there has been a substantial amount of it installed prior to the advent of high-temperature inhibitors. Fortunately, very few utilities have operated anywhere near the 250°C limit for any substantial time, but those desiring to increase their load to match the conductor ratings need to take a really close look at the connectors utilized, especially those installed prior to 2001.

**Analyzing The Condition of Existing Connectors** is more complex than visual inspection. The concern is the degradation of the electrical interface between the connector and the conductor. This interface is not static. It degrades with time, and the rate of degradation is accelerated by temperature from load current and fault currents. This degradation, or breakdown of the microscopic asperities, i.e., contact points, is marked by increasing electrical resistance, which in turn increases temperature with the passage of current. The thermal energy serves to increase electrical resistance – the higher the temperature, the greater the resistance, and the more degradation. Left to a critical stage, this becomes an ever-defeating cycle which in turn leads to thermal and mechanical failure.

As stated above, an average useful service life of properly installed overhead compression connectors is accepted to be on the order of 40 to 70 years when operated within their design limits. Operating at higher currents and therefore higher temperatures will shorten this time frame.

A common inspection method (because it is fast and economical), is to scan the connectors with Infrared Thermography which is often accomplished during a routine line inspection with a helicopter. The shortcomings of this method, mentioned earlier, include combinations of wind, insufficient electrical loading, and reduced emissivity of the joint compared to the conductor, all of which mask the actual temperature of the joint. Furthermore, experts assess that by the time the temperature on the surface of the connector reaches a suitable magnitude that it reads a higher temperature than the conductor, upwards of 70% of the original interface may be compromised. "Thermal problems can be detected at any time during the failure cycle and thus, one can never be sure if the anomaly was found when it is just starting to rise in temperature."<sup>2</sup>

The most reliable assessment of the connector is a direct resistance reading of the interface. This can be accomplished on energized lines using a device marketed under the name OhmStik® manufactured by SensorLink Corporation [www.sensorlink.com](http://www.sensorlink.com) which provides a direct comparison of the resistance of the interface of the connector with an equivalent length of conductor. Resistance is a direct measure of the condition of the connection and is not related to load current at the time of measurement, as is the temperature which is directly related to load current. This measurement can be accomplished from an aerial platform using commercially available hotline tools.

A new technology coming to the market recently is Linebird® [www.linebird.net](http://www.linebird.net) which employs the use of a drone to position the OhmStik unit on the connector and then again on the conductor and provides a direct comparison of those measurements.

The resistance of the connection divided by the resistance of the conductor is called the Resistance Ratio (RR) and is a normalized figure of the condition. When the RR is less than one, the connection condition is in good health. When the RR is greater than one, the condition has deteriorated, the amount of the deterioration being related to how much greater the RR is than one. An example: If the RR is 3.0, the amount of heat generated in the fitting is three times the amount generated in the same length of conductor as is inside the fitting. This may be sufficient heat, under ideal conditions to allow IR to indicate a slight temperature increase compared to the adjacent conductor. Caution, an RR of 3.0 is already a significant amount of deterioration, which will continue to degrade at an increasing rate over time.

The drone, or UAV eliminates the need for an aerial platform, be it a bucket truck or helicopter, and a lineman to be in the energized conductor environment – a significantly safer option. The results obtained from this procedure will provide a true assessment of the electrical condition of the connector.

A review of the mechanical condition is a different issue. One cannot always assess the mechanical condition due to the unknown circumstances of installation. Inhibitor, mentioned earlier, plays a key role in

the longevity of the electrical interface and also resists corrosive attack on a metallic core wire. The principal purpose of inhibitor is to displace oxygen and prevent ingress of moisture and oxygen.

X-Ray reveals conditions of inhibitor. Sometimes we find connectors that never had inhibitor in them (often we find them on the ground)! When there is an insufficient amount of inhibitor found within, and as is often the case with aged connectors, the mineral oil has dissipated, leaving behind a clump of dried clay. Clay is the predominant thickener used in mineral oil-based inhibitors. This is usually assessed with X-Ray.

## **TIME and OUTAGE**

The old adage, “Time is of the Essence” certainly applies here. The difficulty of taking a line out of service for an extended period of time for rebuilding is extraordinarily expensive. The planning process itself is also expensive, considering the man-hours of work and engineering required. The assessment process just described can take many months of work and a great deal of money. Assessing the condition and remaining service life of the conductor is necessary, but a great portion of fitting assessment may be redundant. In the event, a few fitting failures have already occurred, and no particular installation errors were evident, similar fittings along the line are likely to fail at unknown intervals as well.

It is crucial to assess the condition of the conductor itself. Conductor is typically the greatest cost, and if it can be used for a few additional decades, the wisest choice is to proceed in that direction as opposed to reconductoring. Once that decision has been made, attention can be directed to the structures and insulators. From here forward, tremendous time and money can be saved by taking the steps to extend the life of the line. The time lost to extensive connector assessment can be minimized by shunting all the connectors on the line.

Engineered Electrical/Mechanical Shunts can be used to restore full mechanical integrity to both deadends and splices/joints, and where needed can do the same for suspension clamps/systems. Electrically, the line can be uprated to a higher ampacity, the limits of which rely almost exclusively on sag clearance. Sag clearance can often be addressed by raising a few towers in the spans with inadequate clearance, and systems have been developed to do this rather easily.

## **SHUNTING**

High Integrity Shunts have been developed, and implemented extensively, which will restore the energized system mechanically to full tension capacity and connectors to full electrical integrity. Shunts have been developed for every application on the energized portion of the system including connectors, both deadends and splices/joints, and of course jumper loop splices/joints, suspension clamps/systems, tee drops, and repair of in-span damaged conductor.

They have also been developed for all applications on overhead shield wire, including restoration of mechanical integrity to OPGW.

Engineered Electrical-Mechanical Shunts can easily be installed on energized lines, and are commonly applied with gloving techniques and hot line tools on distribution conductors. With hot line tools and barehand on transmission class conductors, there are no outages necessary. Thousands have been installed from helicopters, and the only tools required are a wire brush for cleaning, abrading, and de-oxidizing the conductor, and an impact driver with a 3/4” or 19mm socket to tighten the fasteners. All fasteners are torque-limiting shear-head units and no torque wrench is required.

No grips or come-alongs, hoists or jacks, or jumpers are needed. Typical EEMS over a splice/joint installation is done in less than 10 minutes, and deadends and suspensions are completed in about 20 minutes.

Engineered Electrical/Mechanical Shunts are designed for application on used-weathered conductors, with only dry brushing required to prepare the conductor. They are rated for applications on lines operating at 250°C on every aluminium-stranded conductor such as ACSR (including self-damping), ACSS, AAC, AAAC, and ACAR. They are electrically rated corona free at 765kV AC and 500kV DC.

There is also an option for use on copper, the components that feature nickel-plated components to prevent corrosion from copper salts.

## **Mitigating Connector Failures with Engineered Electrical-Mechanical Shunts**

It is important to note that EEMS are not temporary, nor an inferior means to restore a system, but are in fact, far superior in performance than the original connectors. They are especially designed for installation on aged and weathered conductor. This is important, because the conductor in service cannot be readily cleaned under the strands to a “like new” condition. Note, that the original connectors were designed, tested,



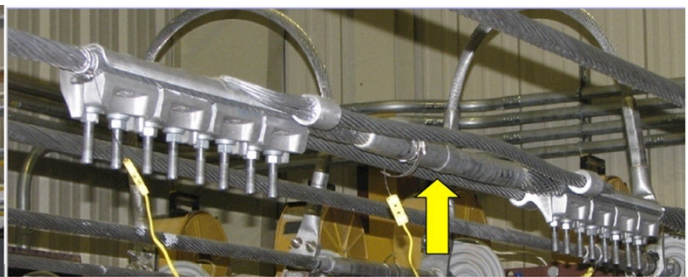
and intended for use on new, clean conductor, and numerous studies have shown their original performance parameters are severely degraded when applied on aged, weathered conductor. Properly applied EEMS restore full mechanical integrity to the system and increases the current capacity of the portion of conductor or connector over which they are installed. Thereby, many systems can be uprated in ampacity, provided the conductor capacity is suitable, and sufficient ground clearance is maintained.

Many utilities around the globe have chosen to extend the life of their aging assets and to uprate their systems to meet more stringent capacity demands. In most cases, the connectors are the limiting factor, but with the installation of EEMS, conductors may be operated as high as 250°C. EEMS are tested and proven to meet standard resistance stability on conductors operating during 500-cycle testing at 390°C, which is prescribed by the manufacturer to qualify them for use on conductors operating as high as 250°C. To illustrate the electrical integrity of EEMS compared to compression splices/joints, testing has been conducted, and infrared thermography photos are provided to show the performance.

The following photos were taken during testing of EEMS on new 795 Drake ACSR conductors and include the performance of an unprotected splice/joint. The test was conducted, with 2000 thermal cycles, maintaining the conductor in the test loop at 200°C and at a tension of 35.6kN (8000 lbf.) The splice shown was properly installed with proper conductor preparation of scratch brushing, and use of the manufacturer's specified inhibitor, press, dies, and instructions.

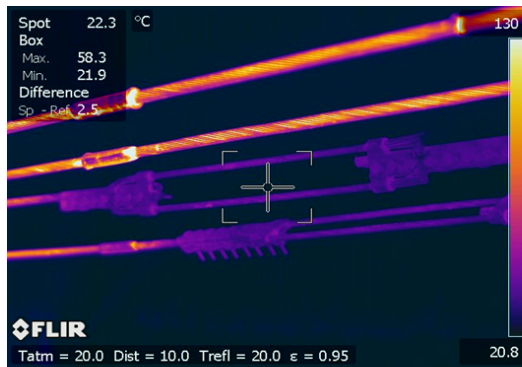


***EEMS Under Test – No Connector within***

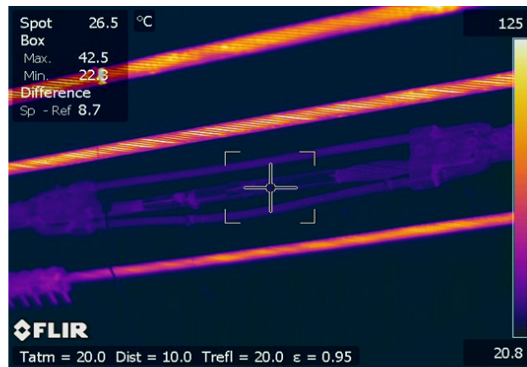


***EEMS installed over failed splice***

The splice/joint shown above did not have the EEMS applied until after it had reached the temperature of 332°C explained in the graph shown on the following page.



***EEMS Serving Full Mechanical & Electrical***



***EEMS Over Failed Mid-Span Joint / Splice***

Note the maximum temperature indicated in the box on the left compared to the right. The left is 58.3°C because the EEMS is carrying the full mechanical and electrical load, as evidenced by the conductor terminated in the ends of the EEMS. The one on the right is only 42.5°C because the old splice/joint is still in place and is carrying a portion of the current, albeit a very small percentage. The Spot temperature on the left is 22.3°C which is the ambient temperature on the back wall of the test lab, while the Spot on the right is on the original connector, now at only 26.5°C, barely above ambient.

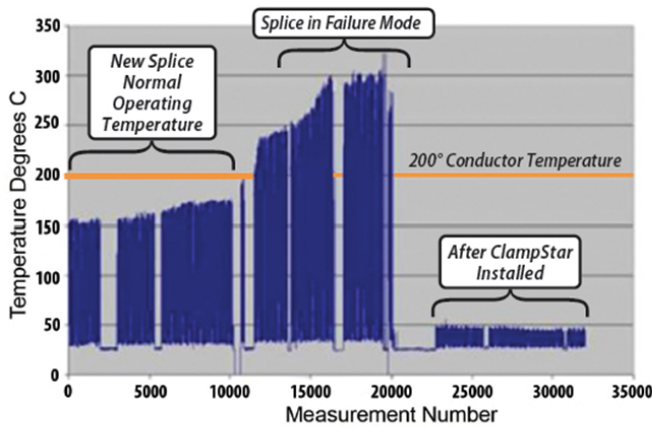
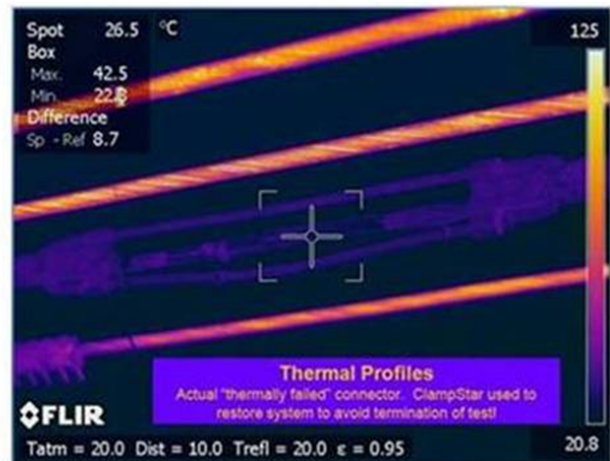


Figure 4.1: Shunt installed due to single-stage splice slipping.



Graph indicating thermal rise of splice, shown in photo to the right, total of 2000 thermal cycles.

The graph above depicts the thermal history of the Mid-Span Joint/Splice, which was properly installed, and as expected began operating at 150°C on a conductor operating at 200°C for a few hundred cycles. The rising slope depicted in the graph is the deterioration (increase in temperature) of the electrical interface. At approximately 1200 cycles, it reaches a peak of 332°C and it began to slip under tension. The EEMS was installed at this point to mitigate the failing connector. Note, that the connector does not just go back to the new condition of 150°C, – it drops to ONLY 42.5°C, and stays there throughout the remainder of the test, for another 800 cycles on a conductor operating at 200°C. Following this 2000 cycle test, after being subjected to these temperatures, this assembly was tested to and achieved full tension.

This clearly illustrates the superiority of the electrical integrity of the EEMS in comparison to replacing a connector. Had the connector been replaced, the replacement connector would have been back to 150°C as the original splice, but due to the conductor being aged through thermal cycling, the thermal escalation curve would have been much steeper than the original splice/joint installed on new conductor. There are several factors that cause the EEMS to operate much cooler. Among them is that they are designed to have lower resistance, which accounts for the lower temperature, however, the remarkable resistance/temperature stability is provided by a high force, resilient contact, with the actual electrical interface being substantially larger than that of a compression type connector.

#### Mitigation of Mid-Span Conductor Joints or Splices

The mid-span joint, also referred to as a splice, serves to hold the tension of the conductor and carry the current through itself via the electrical interfaces to the respective conductors on each end. Therefore, the EEMS units designed for mid-span applications are designed to provide both the full mechanical tension of the conductor as well as the rated current of the conductor.



*Transmission Class EEMS rated up to 800kV-AC and 500kV-DC and 250°C Conductor*

A very appealing aspect of the use of EEMS to mitigate Mid-Span Joints / Splices is installation time, which is approximately 4 minutes on the smallest units for distribution size conductors to 8-10 minutes for transmission class units for the largest conductors. The only tools required are an impact driver and socket, and a stainless-steel wire brush to brush the conductor. EEMS units come preloaded with a high-temperature inhibitor, allowing their use at a conductor temperature of 250°C. They are all provided with torque-limiting fasteners which eliminate the need for torque wrenches. All EEMS units are designed for easy installation on energized conductors, negating the need for a line to be taken out of service.

All in all, the EEMS approach is generally the easiest, fastest, and most economical solution to restore full mechanical and electrical integrity to the line.



### **Mitigation of Strand Damage and Broken Conductor Strands**

Conductor Damage and Broken Conductor Strands at suspension points are commonly related to Aeolian vibration. Fixed points are those components that are prone to reflect vibration, such as deadends, suspension clamps, and conductor spacers. Many photographs have been circulated in previous Cigre bulletins and other venues throughout the electrical transmission industry. The example photos below, illustrate wear and damage to conductor strands from dampers, spacer dampers, and of course, gunshots.

Rarely is there damage to the core wires of ACSR conductors, but it gets very close on occasion.



*Abraded Conductor*

*Gunshot Damage*

The resultant damage forces current constriction, driving current through the remaining unbroken strands, which of course results in localized heating and if left unattended will eventually result in local conductor annealing and potentially tensile failure.

Mitigation of this type of problem is easily addressed with EEMS devices known as Conductor Repair Units (CRUs), which serve to provide an alternate current path and restore full mechanical integrity.

The following illustrations depict the installation of a smaller size CRU installed to restore conductor damage on a distribution line. These are commonly installed on energized lines with hotline tools.



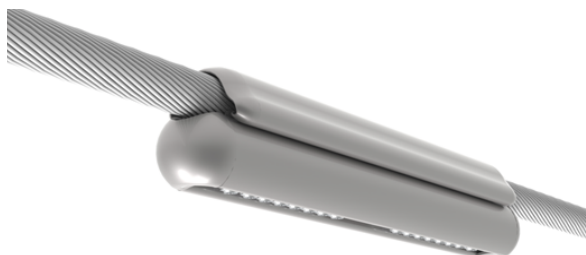
Depending on the length of damage and disturbed strands, a full-length EEMS unit normally used on splices/joints can be implemented, especially when no outage is available, or barehand crews are not available to better restore the lay of the damaged strands. The frame of the EEMS unit serves to expand the electrical field, reducing the surface gradient below critical values and shields the errant strands from corona.



*Gunshot damage restored using an EEMS designed for splice mitigation.*



The Transmission Class CRU is appropriately sized and shielded for corona up to 800kV AC and 500kV DC. Similar to other EEMS units, they are a two-piece design with captive fasteners. They are available in differing lengths and with a number of fasteners determined by conductor size and severity of damage.



*The body is centered over the damaged area, and the head is slid in place. Torque Limiting Fasteners are tightened until the head shears off, leaving the remaining portion within the corona shielding zone, restoring full mechanical and electrical integrity.*

As mentioned previously, it is rare that core wire damage occurs in these types of applications, but it is important to know the condition of the conductor such that the proper EEMS CRU may be selected and applied.

In the photo below, the CRU has been applied upside down. The orientation does not matter with these units, but as it was installed from a cart, it was easier in this fashion, however it would make crossing it later with a cart slightly more difficult.



***EEMS Mitigation of Strand Damage from Spacer-Damper before and after***

### **Electrical & Mechanical Restoration of Deadend Fittings**



*Photograph above on a tri-bundle 500kV installation*

Similar in design to the EEMS for use on splices/joints, the Deadend Transmission Class units are corona-free up to 800kV AC and 500kV DC and are easily installed on energized lines with bare-hand techniques. They are ampacity rated to operate continuously with conductors operating at 250°C and are suitable for use on any aluminum stranded conductor, including ACSS, ACSR, AAC, AAAC, ACAR, etc.

The unique feature for restoration of the mechanical integrity of the system is accomplished with stainless steel Tether and Bracket components. As can be seen above, these deadend units incorporate a

jumper conductor from the head mounted on the tension span to the original system jumper conductor. Because the EEMS unit, from end to end has upwards of 10-15% lower resistance than even an equivalent length of the system conductor, it will conduct the major portion of the current, bypassing the original deadend and terminal.

A mechanical failure of the original deadend would transfer the tensile load to the system jumper conductor, which could not support that load. For mechanical restoration of deadend connectors, the tether and bracket provide mechanical attachment to the original tension hardware, such as an eye attachment of a deadend connector.

The bracket is typically attached to the eye or clevis component of the deadend. There are several different styles of brackets to accommodate the wide variety of deadend attachments utilized on different systems.

Once the bracket is installed a tether made of all stainless-steel components connects the EEMS to the bracket. The unit provides up to 4 inches (100mm) of adjustment. Once everything is in place, this adjustment is used to apply approximately 1-2000 lbf. (4-9kN) of tension to assure there is no slack in the tether.

This system assures the utility that regardless of the condition of the deadend, the line will remain in the air and energized. Detailed and well-illustrated instructions are provided in the installation instructions with each EEMS unit.

### **Mitigation of Broken Strands in Suspension Clamps /Systems**

“A Slow and Steady Wind” may ignite fervor and zeal for the ancient mariner, or even for the more modern nautical enthusiast, but for overhead conductors, it is not the optimal environment.

Much has been written regarding the phenomenon of aeolian vibration, which can result in the catastrophic failure of overhead conductors. This high-frequency, low-amplitude oscillation of the overhead conductor is caused by low-velocity, laminar wind blowing across the conductor.

Vibration of the conductor, generated by the alternate shedding of vortices tends to occur between wind speeds of approximately 1-7 meters per second, or 2 to 15 mph, resulting in conductor vibration ranging from 3 to 150 cycles per second. The purpose of this article is not a scientific explanation of aeolian vibration, but rather mitigating the conductor damage once it has occurred, particularly related to components such as suspension clamps.

The problem is fatigue failure of conductor stranding. This failure occurs at points that are “fixed” in relation to the conductor, at suspension clamps, spacers, and deadends. The motion finds a resonant frequency in the conductor based on wind speed, direction, and conductor diameter. This gives rise to what is known as a standing wave, much like a particular note on a guitar string. The “fixed point” serves as a wave reflection, and can generate localized bending, which is known to lead to fretting fatigue of the conductor strands and, if not addressed, will result in conductor strand breakage.



Typical Strand damage Due To Aeolian Vibration



X-Ray of Broken Strand in a Suspension Clamp

The problem is exacerbated by the localized heating which occurs in the conductor stranding. The strands that break result in their share of the electrical current being transferred to the unbroken strands which in turn increases their temperature. This can lead to localized weakening and fracturing of the remaining strands. Sometimes broken stranding is found during a thermal scan with IR Imaging. If the breaks are within a clamp, or under helical rods, this heat will likely be masked by the mass of the clamp or helical rods.

There have been many designs of dampers or damping mechanisms to reduce the severity of aeolian vibration. The most common is the Stockbridge damper, of which many iterations of design exist. One



design goal for dampers is to accommodate a broad frequency range. At best, the state of the art presently addresses as many as four resonant frequencies.

It was the 1920's when George Stockbridge, an engineer for Southern California Edison, developed the original device, but it was into the 1960's and '70's before the application of dampers was widely used. Therefore, there are in existence many older lines, typically 50+ years old, that may not have been fitted with dampers originally and much damage occurred. Occasionally, older lines have been outfitted with dampers at a later date, for the purpose of mitigating the damage discovered.

This brings us forward to modern times, and due to the critically aging infrastructure we affectionately refer to as "the grid", there are notably more intense inspections and inspection techniques that have been developed and employed. The damage done by aeolian vibration for several decades past is being discovered as utilities work feverishly to extend the life of their aging assets. More and more utilities are discovering fretted and broken strands, particularly on tangent structures, where the heating effects have been masked by the relative mass of the suspension clamp.

The AGS type suspension system, employing the helical rods around an elastomeric cushion within the clamping structure has been considered by many as the "Cadillac" of the industry, and rightfully so, as they have performed admirably for decades. However, as earlier mentioned, these suspension systems are also being found with damage to strands underneath.



***Damage Strands found inside suspension unit and under rods***

While this should not be a surprise to anyone, we are discovering many flaws in our earlier designs, and finding that things we thought would last forever – we are learning, like with any product or material – nothing lasts forever because forever is a really, really, long, long, time!

The cost and time associated with reconductoring is generally considered a last resort. Utilities are finding it increasingly difficult to take lines out of service for even a few days, let alone the weeks required for such major restoration. Thus the need for a product that will restore the conductor system to full integrity, both electrical and mechanical is needed and is here.

The EEMS unit for suspension clamps/systems serves the purpose of restoring the full electrical and mechanical integrity to suspension systems. As with the other EEMS applications discussed thus far, they are designed with the installer in mind and are thus easy and fast to install on energized or de-energized lines – no outage necessary.

The fitting is easily retrofitted over the ball/socket joint on the bottom of the insulator, providing mechanical attachment points for the stainless-steel tether cables included in the kit. The EEMS body of the kit is designed to attach to locations on the conductor beyond any damaged areas, thus gripping the conductor mechanically, and simultaneously providing a superior electrical connection. A jumper conductor attached between the EEMS attachment heads provides an alternate electrical path, thus shunting the current around the damaged area of the system. This allows the damaged area to cool to within 3-4°C of ambient and assures that further degradation will be eliminated.



*Typical BallCap application, 115 kV 477 Hawk with armor rods – broken strands under rods*

Additional designs are available for conductors as small as 3/0 up to 1.912 inches (48.5mm) conductor diameter and include appropriate corona performance through 800 kV AC and 500kV DC.

## **BIBLIOGRAPHY**

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