

MODERNIZING THE GRID: Don't Let Connectors Be the Failure Point

THE WEAK LINK:
Overlooked Connectors Under Extreme Load

THE SOLUTION:
ClampStar Reinforcement for Reliable Capacity & Safety

Increased Transmission Capacity

Splice

ClampStar Engineered Electrical/Mechanical Shunt

SECURE GRID & WILDFIRE MITIGATION

More Current. Old Connections. 21,000 Miles at Risk.

DOE just selected 31 projects expected to unlock more than 23 GW from existing transmission infrastructure. Every ampere behind those gigawatts still has to pass through a splice, a dead end, or another connection point.

We recently asked a question about DOE's SPARK program: With \$1.9 billion in federal transmission investment on the table, has anyone qualified the connectors?

On September 24, DOE provided clarity on the \$1.9 billion investment—but not on the connection point. The Office of Electricity announced 31 projects across 26 states, totaling \$5.25 billion: \$1.9 billion in federal funding and \$3.35 billion in recipient cost share. The projects are expected to reconnector or rebuild more than 1,500 miles of transmission lines while deploying grid-enhancing technologies across nearly 21,000 miles. DOE estimates this will add more than 23 GW of capacity and says the approach will bypass the multi-decade timelines typically required to build entirely new transmission corridors. The premise is sound. Increasing the capacity of existing corridors avoids much of the right-of-way and construction time that new lines require.

The SPARK selections reach far beyond the lines being rebuilt. For every mile of transmission line reconnector or rebuilt, roughly 14 more miles will gain capacity through grid-enhancing technologies (GETs). Across nearly 21,000 miles of existing lines, recipients are expected to deploy advanced line rating systems, power flow controls, and sensors to get more out of existing infrastructure.



This technology fundamentally alters the grid's duty cycle. It changes how heavily a line can be loaded, pushing more current through existing conductors. This adds significant thermal and mechanical duty onto all existing connectors, most of which have not been upgraded to handle the increased load.

This distinction matters. A reconductoring project generally replaces the connectors along with the conductor, though usually with the same compression technology. A GETs project typically leaves the existing connectors in place while asking them to carry more. By optimizing the 21,000 miles without reinforcing the physical connection points, we have not built a resilient grid—**we have simply engineered a massive network of unmitigated weak links.**

Much of today's reconductoring discussion centers on newer conductor designs. But ACSS is hardly new. As Paul Springer of Springer Power Consulting writes, "ACSS is the original high-temperature low-sag (HTLS) conductor." It remains an important option for high-temperature reconductoring, with a maximum continuous operating temperature (MCOT) of 250°C.

Springer's like-for-like assessment puts numbers around the choice. Composite core conductors offer real advantages in applications involving very long spans and severe clearance constraints. But in his reconductoring case, an ACSS/TW/MA5 conductor operated at its 250°C thermal rating, with modest structure modifications, delivered 1,990 A, 17% more than the maximum capacity of the composite core alternative evaluated. Steel core also has a substantially higher elastic modulus than composite core, and under heavy ice, the best steel core option sagged 2.3 feet less than the best composite core option. And as Springer notes, a composite core does not itself carry current.

The point is not that one conductor technology wins every application. Manufacturers rate conventional ACSR for 75°C continuous operation. Composite core conductors carry a maximum continuous operating temperature (MCOT) of 180°C. ACSS carries an MCOT of 250°C, and no rating exists above it. Utilities seldom run a line at its MCOT for long, because line losses rise steeply with temperature. The value of a high MCOT is the thermal headroom available for the relatively few hours when the grid needs it most, and ACSS provides the vital increased capacity to absorb critical grid contingencies. Those hours include contingencies, the condition planners call N-1, formalized in NERC Reliability Standard TPL-001-5.1 as planning event P1. When a parallel circuit is lost, the surviving line can be called on to carry roughly double the current, and that means four times the I^2R heating at every splice and dead end.

The conductor's thermal capability does not, by itself, establish the capability of the complete conductor-and-connector system. Along every line, current and mechanical load eventually reach a connection point, and each connection point fails in its own way. This paper works through the connection points one connection type at a time.

What actually holds a conductor together?

Compression splices and dead ends have no fasteners. Their mechanical grip and their electrical contact both depend on the residual clamping force left in the sleeve after the crimping dies are removed.

Research at Oak Ridge National Laboratory, sponsored jointly by DOE and EPRI, quantified how much of that force survives. During crimping, compressive stress at the sleeve-to-conductor interface reaches roughly 33,100 to 37,100 psi. Once the dies come off and the sleeve springs back elastically, it falls to 1,700 to 6,700 psi, only 5.13% to 18.05% of the peak. ORNL's simulations of the same splice under tension and thermal cycling then showed a further 92



to 95% reduction once cycling reached 100 to 125°C, temperatures high-temperature conductors reach in ordinary, non-emergency service.

ORNL's work used conventional ACSR with hard-drawn aluminum strands. ACSS uses fully annealed aluminum, which deforms and flows under compression rather than locking firmly within the sleeve, so a compression connector on ACSS starts with less residual clamping force. Thermal cycling further reduces that force over time. A line that normally runs cool but is pushed harder during peaks and contingency events can accumulate these cycles—the very operating pattern enabled by dynamic line rating and other grid-enhancing technologies.

Installation decides the starting point

A compression connector's performance depends heavily on a single step performed before the sleeve is crimped, and one that leaves no evidence once it is: wire-brushing the conductor to remove the aluminum oxide layer.

That step, along with applying inhibitor, is prescribed for virtually every connector installed on aluminum conductor. CIGRE Technical Brochure 905 documents what happens when those steps are skipped on compression fittings: the connector can overheat, distort, and allow moisture and corrosive pollutants in. The brochure attributes many compression fitting failures to inadequate surface preparation. Traditional mineral-oil-based inhibitor compounds also break down at about 162°C, well within the operating range of high-temperature conductors.

Furthermore, standard diagnostic measurements fall short of providing a complete answer. According to CIGRE Technical Brochure 905, neither resistance testing nor infrared thermography can identify hidden flaws that leave electrical resistance largely unaltered, such as a severed steel core or a misaligned sleeve. A spotless infrared scan merely reflects conditions at a single instant; it offers no guarantee regarding performance during the next demand peak.

That raises an uncomfortable qualification question. Industry mechanical qualification tests are performed on new connectors. A connector that passes its initial tensile test has shown it can hold the required load when new, not after years of high-temperature operation. EPRI's research reinforces this concern: above 100°C, hard-drawn aluminum strands lose tensile strength over time, faster as temperature rises, and EPRI notes knowledge gaps in the long-term performance and inspection of advanced conductors and “their associated hardware.” Connector heating follows I^2R , so a 30% increase in current raises the heat generated at a given resistance by about 69%. The question is whether the connectors can carry that added duty.

1. The splice: set on installation day, weakened every hot hour after

Field data shows the consequences. Avista's reliability modeling of 450 full-tension splices on its 230-kV system predicted that about 4% were in very poor condition and likely to fail within ten years, with another 25% questionable. Infrared inspections following earlier splice failures had not been able to predict which splices would fail next, so crews tested about 350 of those splices from a helicopter with a resistance-measuring instrument. One in five measured at least 1.5 times the conductor's resistance at the splice connection, and the worst read 31 times the conductor's resistance.

A large investor-owned utility X-rayed approximately 70 transmission compression splices and found that roughly 80% had not been installed correctly. Compression splicing uses the



same connectors, dies, and procedures industry-wide, often with the same contractors, so any utility X-raying its own splices would likely find similar results.

2. The dead end: tension and current meet at the structure

A dead end does two jobs at once. Mechanically, it transfers the conductor's full tension into the structure. Electrically, it carries the full line current: from the conductor strands, across the compressed interface, through the body of the dead end and out its terminal pad to the jumper. In a compression dead end, both jobs pass through the same compressed section of the sleeve, and both depend on the residual clamping force described above.

That shared dependence is what makes a failing dead end difficult to contain. As clamping force relaxes, contact resistance in the compressed section rises, and so does the heat generated there. Heat accelerates internal corrosion, which further raises resistance. CIGRE TB 905 documents where that cycle can end: a compression dead-end terminal pad that separated from the conductor after internal corrosion and high resistance in the compressed section caused it to overheat. A dead end that runs hot is no longer just a hot spot. It is a failing grip on the conductor, and when that grip fails, an energized conductor drops onto whatever lies below: a road, a field, a neighborhood, or dry brush in fire season.

3. The suspension clamp: the support point no one rates

The suspension clamp is the connection point that capacity studies are least likely to mention. Its case is mechanical, not electrical. At every tangent structure, the clamp holds the conductor's weight where the conductor bends, vibrates, and wears, and the industry knows less about that point than it should:

- **Fatigue concentrates there.** CIGRE TB 905 explains that cyclic conductor motion causes fretting fatigue of the strands where movement is restrained, mostly at suspension clamps. X-ray inspection has found broken aluminum strands inside suspension clamps.
- **The data stops at conventional conductors.** Safe vibration limits are available mainly for ACSR in metal-to-metal clamps. CIGRE TB 905 calls for more endurance data on conductors with annealed aluminum and trapezoidal strands, such as ACSS, the original HTLS conductor, and on clamps with elastomer inserts. The brochure itself is limited to ACSR, AAAC, and AACSR operating at no more than 95°C, and does not cover high-temperature, low-sag conductors.

In 2003, National Grid engineers wrote that high-temperature conductors require "special suspension clamps, high-temperature deadends, and high-temperature splices." Twenty-three years later, dynamic line rating makes that warning more relevant, not less. A line cleared to carry more current is not automatically a line whose existing connection points are qualified for the duty that comes with it.

Two standards, two very different questions

ANSI C119.4 is the industry's established connector standard, scoped for connectors designed for normal operation at or below 93°C. It also does not require any mechanical tension on the conductor during thermal cycling. A splice or dead end can pass C119.4 in the lab without carrying any of the tension it will hold every day in the air.

ANSI C119.7 is written specifically for connectors intended for normal operation above 93°C. EPRI's Advanced Conductor Specification Guide identifies C119.7 for this



application and notes that, until it is released, C119.4 and C119.0 should be applied with additional considerations above 93°C. The draft C119.7 protocol cycles the connector at high temperature while holding the conductor under sustained tension, so heat and load act on the connection together, as they do in service. That combination is what wears down the residual clamping force, and C119.4 never tests for it.

C119.7 remains unpublished. Manufacturers publish their own ratings above 93°C, but each rests on their own test protocol. So for any SPARK project, the qualification question comes down to four parts: which protocol, at what temperature, under how much tension, and for how many cycles?

What SPARK recipients should ask now

For the nearly 21,000 miles where existing conductor and connectors remain in service, here are the questions that need answers for splices, dead ends, and suspension clamps:

- ☐ When were they installed, and by whom?
- ☐ Is surface preparation documented?
- ☐ What inspection history exists?
- ☐ Which sit over road crossings, populated areas, or high fire-threat corridors?
- ☐ What evidence establishes the connectors' present condition?
- ☐ Was the proper design installed?
- ☐ Was it qualified only as a new component, or after thermal aging?
- ☐ Was mechanical tension present during thermal qualification?
- ☐ What temperature and duty cycle does the proposed uprating create?
- ☐ Were they selected for the conductor and operating conditions now proposed?
- ☐ Does qualification evidence cover the specific HTLS conductor construction and clamp design?

For the 1,500-plus miles being recondored or rebuilt, new connectors will be installed. Qualify the complete conductor-and-connector system at temperatures representative of the proposed MCOT, under representative mechanical tension, with appropriate margin. The objective is not a connector that survives the conductor's MCOT once. It is a system that stays mechanically and electrically stable across the service conditions the project is designed to create.

Wildfire resilience belongs in the connection discussion

DOE says the selected projects will also strengthen grid resilience by mitigating wildfire hazards. Connection points belong in that conversation. A degraded splice or dead end is not merely an efficiency problem. It can become a localized high-resistance point, generating intense heat exactly where the system depends on a reliable connection. More than one western utility already specifies splice shunting in its publicly filed wildfire mitigation plan.

Two solutions for SPARK's two pathways

Classic Connectors USA manufactures the products described below, and we have a commercial interest in this space. The engineering questions in this paper are broader



than any one product, but they're why we offer two approaches: one for the existing lines SPARK will push harder, and one for the lines being reconductored or rebuilt.

Pathway one: For existing lines, ClampStar® Engineered Electrical/Mechanical Shunts install over existing splices, dead ends, and suspension clamps on energized lines without an outage. They restore mechanical integrity and add a parallel, low-resistance current path where the mechanical load path and current path meet. In service since 2008, ClampStar shunts are now installed at 190 utilities across nine countries with no failures, and thousands of new units are being added every month. Leaving decades-old connectors in service without reinforcement is a decision to let the next peak, or the next contingency, find out whether they qualify for the new duty cycle. On an energized line over the public, that is not a test any utility should run.

Pathway two: For new and reconductored spans, the ClampStar Thermo-Lock full-tension splice and dead end has been tested to 390°C, well beyond the 250°C MCOT of ACSS. It installs faster than a traditional two-stage compression connector, using a 60-ton press, and includes an inspection port that confirms full core insertion.

The question the 23 GW leaves open

The industry has become very good at asking how many additional amps a conductor can carry. SPARK recipients should ask a second question: what happens to everything connected to it when those amps start flowing? The connection point is part of the current path and part of the mechanical load path, and the reliability of the new capacity depends on both.

While DOE tracks gigawatts along the line, true delivery depends on the integrity of every connection point.

Chris Costanzo & Trisha Crawford
Classic Connectors USA, LLC

Our technical white paper, The Limitations of Compression Connectors on HTLS Applications and the ClampStar Solution, co-authored with Carl Tamm, examines the limitations discussed here and the engineering basis for the ClampStar approach:

https://classicconnectors.com/downloads/The_Limitations_of_Compression_Connectors_on_HT_LS_Applications_and_the_ClampStar_Solution.pdf

#Transmission #SPARK #GridEnhancingTechnologies #Reconductoring #HTLS #ACSS
#WildfireMitigation #AssetManagement

Sources:

- DOE, SPARK selections announcement, Sept 24, 2026:
<https://www.energy.gov/articles/energy-department-announces-speed-power-investments-across-26-states-lower-electricity>
- DOE, SPARK selected applications:
<https://www.energy.gov/documents/selected-applications-de-foa-003580-spark>
- DOE, SPARK program overview:
<https://www.energy.gov/oe/speed-power-through-accelerated-reconductoring-and-other-key-advanced-transmission-technology>
- Springer Power Consulting, "An Objective Assessment of Conductor Technologies for Transmission Design and Planning":
https://www.springerpowerconsulting.com/_files/ugd/8472d0_a58062a55e8b422b96bac4ea59990fec.pdf
- Wang et al., ORNL/TM-2008/156, prepared for DOE and EPRI:
<https://info.ornl.gov/sites/publications/files/Pub12595.pdf>



- CIGRE Technical Brochure 905, Sustainability of Overhead Line Conductors and Fittings: Conductor Condition Assessment and Life Extension, Volume 1, WG B2.68, July 2023:
<https://www.e-cigre.org/publications/detail/905-sustainability-of-overhead-line-conductors-and-fittings-conductor-condition-assessment-and-life-extension-volume-1-state-of-the-art.html>
- D.R. Whicker (Avista), "Before the Lines Fall Down," T&D World, Jan. 2010:
https://classicconnectors.com/downloads/Before_Lines_Fall_Down.pdf
- C. Tamm, "Connectors — The Weak Link," Utility Products Magazine, Oct. 2019:
https://classicconnectors.com/downloads/Connectors_The_Weak_Link.pdf
- Peterson & Hoffmann (National Grid), "Transmission Line Conductor Design Comes of Age," T&D World, June 1, 2003:
<https://www.tdworld.com/overhead-transmission/article/20962828/transmission-line-conductor-design-comes-of-age>
- NERC Reliability Standard TPL-001-5.1:
<https://www.nerc.com/globalassets/standards/reliability-standards/tpl/tpl-001-5.1.pdf>
- EPRI, Advanced Conductor Specification Guide:
<https://www.epri.com/research/products/000000003002030304>
- EPRI, "Advanced Conductors Status, Applications and Opportunities: A GET SET White Paper," Product 3002031441, January 2025:
<https://www.epri.com/research/products/000000003002031441>

