Experience and Benefits of using High Temperature Low-Sag (HTLS) Overhead Conductors

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Some of the challenges facing Transmission and Distribution network operators

- Increased expectations on power supply reliability
- Growing demand for power causing increased line loadings
  - Potential issues with sag
- Financial and political pressures to reduce power losses
- Managing network congestion
- Need to reduce costs
- Difficulty in obtaining permissions for new line construction.
Traditional Overhead line conductor

- **ACSR** (Aluminum Conductor Steel Reinforced)
  - Over 100 years experience
  - As loads increase resistance increases causing increased losses
  - As loads increase conductor sag increases due to high Coefficient of Thermal expansion.
  - Expected life around 30 years – dependent upon loading, corrosive environment and quality
Aluminium

- Standard Aluminium and Aluminium Alloys can only operate continuously at temperatures up to 93°C.
- TAL and ZTAL aluminium have essentially the same conductivity and tensile strength as ordinary electrical conductor grade aluminium but can operate continuously at temperatures up to 150°C and 210°C, respectively.
- Fully annealed aluminium is chemically identical to ordinary hard drawn aluminium and can operate indefinitely at temperatures at 250°C (and higher) without any change in mechanical or electrical properties but has a much reduced tensile strength.

Annealed Aluminum is superior at high temperatures
Other Conductors

- AAC – All Aluminum Conductor
- AAAC – All Aluminum Alloy Conductor
- ACAR – Aluminum Conductor Aluminum Alloy reinforced
- ACSS – Aluminum Conductor Steel supported
- Invar – Aluminum Clad Invar (a special Fe–Ni alloy)
- Gap – Aluminum Zirconium with small gap filled with grease to steel core
- ACCR – Aluminum Conductor with fiber reinforced metal matrix.

**ACCC - Aluminum Conductor Composite Core**
Greater Strength 25% stronger than steel
Significantly improved sag
Twice the Capacity of AAC, ACSR and others
Increased Spans on fewer/shorter structures 60% lighter than steel
Reduced Line Losses by 25% to 40%
Lower Overall Lifecycle Costs
HTLS-Fiber Composite ACCC® Conductor

Aerospace grade carbon fiber composite core offers greater strength and line loss reductions

- ACCC® technology is based on replacing heavy steel core of traditional electrical transmission conductor with high strength, light weight carbon fiber composite core
- 28% More Aluminum = Greater Capacity, Reduced Losses, & Cooler Temps
- 25% stronger and 60% lighter than a traditional steel core = fewer or lower structures
- Lower Coefficient of Thermal Expansion = Less Sag at Higher Temperatures
- Longer spans, fewer structures, increased line capacity
- Applicable to all voltages
- Resists degradation from vibration, corrosion, ultraviolet radiation, corona, chemical and thermal oxidation and, most importantly, cyclic load fatigue
Carbon Fiber Composite Material Advantages

Lighter, Stronger, Dimensionally Stable & Corrosion Resistant

*Perfect attributes for a conductor’s structural core*
“Carbon fibers are not particularly susceptible to fatigue damage. A slight amount of alignment in the fiber microstructure takes place during fatigue, but fatigue lives - at stresses as high as 98% of the tensile strength - did not exhibit fatigue failure.”

F-35/Joint Strike Fighter (JSF)
Higher Capacity – Reduced Sag  Increased Spans
Benfits – Savings in reduced losses- an example
Line Loss savings translated into conductor value

<table>
<thead>
<tr>
<th></th>
<th>Peak Amps</th>
<th>Temperature at peak amps (°C)</th>
<th>Load Factor</th>
<th>MVA</th>
<th>Annual Line Losses (MWh)</th>
<th>Line Loss Reduction</th>
<th>Value of Reduction (at $50/MWh)</th>
<th>Value of Reduction per lineal conductor (meter)</th>
<th>Value of Reduction per lineal conductor (foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACSR</td>
<td>1,000</td>
<td>95</td>
<td>53%</td>
<td>398</td>
<td>76,917</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>ACCC</td>
<td>1,000</td>
<td>82</td>
<td>53%</td>
<td>398</td>
<td>56,588</td>
<td>20,329</td>
<td>$1,016,450</td>
<td>$3.39</td>
<td>$1.03</td>
</tr>
<tr>
<td>ACSS</td>
<td>1,600</td>
<td>194</td>
<td>53%</td>
<td>637</td>
<td>251,998</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>ACCC</td>
<td>1,600</td>
<td>156</td>
<td>53%</td>
<td>637</td>
<td>179,022</td>
<td>72,976</td>
<td>$3,648,800</td>
<td>$12.16</td>
<td>$3.71</td>
</tr>
</tbody>
</table>

Key Assumptions
- 100km AC three phase Line
- Load factor 53%
- Peak current 1600 amps

Benefits – Reduction in losses
- Saving of some $3.6M per year in losses
- $3.39 loss saving per meter compared to ACSR
- $12.16 loss saving per meter compared to ACSS
- Reduced CO₂ emissions

Investment in ACCC will significantly reduce losses and provide higher IRR for projects

CTC Global CCP Software can calculate savings for your specific project
ACCC Conductors combine efficiency and increased current carrying capacity to deliver more power with less losses based on equal conductor size and weight.
Moving on from benefits to experience
The Substantial Path to ACCC® Deployment

1. Developed & Tested the Composite Core
2. Tested Electrical Properties of the Conductor
3. Developed & Tested Ancillary Hardware
4. Assessed Environmental Exposure and Longevity
5. Evaluated Conventional Installation Procedures
7. Commercially Deployed in 2005
8. ISO Certified in 2006
9. 2013 over 22,000km’s installed worldwide
ACCC® is the Most Tested & Validated Conductor

Core Testing:

2.1.1 Tensile Testing
2.1.2 Flexural, Bending & Shear Tests
2.1.3 Sustained Load Tests
2.1.4 Tg Tests
2.1.5 CTE Measurements
2.1.6 Shear Testing
2.1.7 Impact and Crush Testing
2.1.8 Torsion Testing
2.1.9 Notched Degradation Testing
2.1.10 Moisture Resistance Testing
2.1.11 Long Term Thermal Testing
2.1.12 Sustained Load Thermal Testing
2.1.13 Cyclic Thermal Testing
2.1.14 Specific Heat Capacity Testing
2.1.15 High Temperature Short Duration
2.1.16 High Temperature Core Testing
2.1.17 Thermal Oxidation Testing
2.1.18 Brittle Fracture Testing
2.1.19 UV Testing
2.1.20 Salt Fog Exposure Tests
2.1.21 Creep Tests
2.1.22 Stress Strain Testing
2.1.23 Micrographic Analysis
2.1.24 Dye Penetrant Testing
2.1.26 High Temperature Shear Testing
2.1.27 Low Temperature Shear Testing

Mechanical Conductor Testing:

2.2.28 Stress Strain Testing
2.2.29 Creep Testing
2.2.30 Aeolian Vibration Testing
2.2.31 Galloping Tests
2.2.32 Self Damping Tests
2.2.33 Radial Impact and Crush Tests
2.2.34 Turning Angle Tests
2.2.35 Torsion Tests
2.2.36 High Temperature Sag Tests
2.2.37 High Temperature Sustained Load
2.2.38 High Temperature Cyclic Load Tests
2.2.39 Cyclic Ice Load Tests
2.2.40 Sheave Wheel Tests
2.2.41 Ultimate Strength Tests
2.2.42 Cyclic Thermo-Mechanical Testing
2.2.43 Combined Cyclic Load Testing
2.2.44 Conductor Comparison Testing

Systems & Hardware Testing:

2.4.55 Current Cycle Testing
2.4.56 Sustained Load Testing
2.4.57 Ultimate Assembly Strength Testing
2.4.58 Salt Fog Emersion Testing
2.4.60 Static Heat Tests
2.4.61 Suspension Clamp Testing
2.4.62 Thermo-Mechanical Testing
2.4.63 Cyclic Load Testing

Electrical Conductor Testing:

2.3.45 Resistivity Testing
2.3.46 Power Loss Comparison Testing
2.3.47 Amperage
2.3.48 EMF Measurements
2.3.49 Impedance Comparison Testing
2.3.50 Corona Testing
2.3.51 Radio Noise Testing
2.3.52 Short Circuit Testing
2.3.53 Lightning Strike Testing
2.3.54 Ultra High Voltage AC & DC Testing

Field Testing:

2.5.64 Ambient Temperature
2.5.65 Tension, Sag, and Clearance
2.5.66 Conductor Temperature
2.5.67 Electric Current
2.5.68 Wind Speed and Direction
2.5.69 Solar Radiation
2.5.70 Rainfall
2.5.71 Ice Buildup
2.5.72 Splice Resistance
2.5.73 Infrared Measurements
2.5.74 Corona Observations
2.5.75 Electric and Magnetic Fields
2.5.76 Wind and Ice Load Measurements
2.5.77 Vibration Monitoring
2.5.78 Typhoon Test

US / UK / France / Canada / Mexico / China / Brazil / Chile / Belgium / Indonesia / Germany
Installation Equipment

Conventional Bull-wheels, sheaves, and take-up reels are used in both transmission and distribution applications.
## Similar Installation Methodology and Equipment

<table>
<thead>
<tr>
<th>Installation Factors</th>
<th>ACCC</th>
<th>ACSR</th>
<th>ACSS</th>
<th>ACCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bull wheels</td>
<td>40 X diameter</td>
<td>40 X diameter</td>
<td>40 X diameter</td>
<td>72” Minimum</td>
</tr>
<tr>
<td>Sheaves Wheels</td>
<td>20 X diameter</td>
<td>20 X diameter</td>
<td>20 X diameter</td>
<td>28” Minimum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 units at first and last structure</td>
</tr>
<tr>
<td>Grips (Pulling)</td>
<td>Kellums</td>
<td>Kellums</td>
<td>Kellums</td>
<td>Special (PLP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DG grip</td>
</tr>
<tr>
<td>Grips (Sagging)</td>
<td>Chicago</td>
<td>Chicago</td>
<td>Pocketbooks, Chicago</td>
<td>Double blocks / roller arrays</td>
</tr>
<tr>
<td>Recommended Pulling Angles</td>
<td>30 degrees</td>
<td>unlimited</td>
<td>45 degrees</td>
<td>40 degrees</td>
</tr>
<tr>
<td>Extreme Angle Alternative</td>
<td>larger dia blocks / double blocks</td>
<td>n/a</td>
<td>larger dia blocks / double blocks</td>
<td>double blocks / roller arrays</td>
</tr>
<tr>
<td>Dead Ends</td>
<td>60 Ton w/ 1 set of dies</td>
<td>60 Ton w/ 2 set of dies</td>
<td>60 Ton w/ 2 sets of dies</td>
<td>100 Ton w/ 2 sets of dies</td>
</tr>
<tr>
<td></td>
<td>15 - 25 minutes</td>
<td>&gt; 30 minutes</td>
<td>&gt; 30 minutes</td>
<td>&gt; 30 minutes</td>
</tr>
<tr>
<td>Splices</td>
<td>1 set of dies</td>
<td>2 sets of dies</td>
<td>2 sets of dies</td>
<td>2 sets of dies</td>
</tr>
<tr>
<td></td>
<td>15 - 25 minutes</td>
<td>&gt; 30 minutes</td>
<td>&gt; 30 minutes</td>
<td>&gt; 30 minutes</td>
</tr>
<tr>
<td>Pre-Stress (Sagging)</td>
<td>Not needed but can further improve thermal sag performance</td>
<td>None</td>
<td>Recommended</td>
<td>None</td>
</tr>
</tbody>
</table>

*Data obtained from Companies' Installation Manuals*
Substantial Experience
over 22,000 km at 260 project sites

Countries:
- USA
- China
- France
- UK
- Poland
- Spain
- Portugal
- Mexico
- Chile
- Qatar
- Indonesia
- Belgium
- Brazil
- Germany
- South Africa
- South Korea
- Russia
- India
- Costa Rica*
- Columbia
- Congo
- Mozambique
- Netherlands*
- Nigeria*
- Vietnam

US Utilities:
- AEP
- APS
- PacifiCorp
- NV Energy
- Austin Energy
- Xcel Energy
- MI PUD
- KS PUD
- KAMO
- OG&E
- Ozark Electric
- WAPA
- STEC
- Entergy
- Riverside PUD
- Florida Power & Light
- Keys Energy
- Progress Energy
- Mohave Electric
- SCANA
- National Grid
- Alexandria (LA) PUD

Over 35,000 Dead-Ends & Splices in Service at over 260 Project Sites
New Line

Project Name: Kingman to Cunningham, Kansas
Project Goal: Install New Line
Conductor Size: Hawk
Conductor Length: 108 km
Voltage: 34.5 kV
Energized: 2006
Heavy Ice Application

Project Name: NV Energy Line 107 (Reno to Carson City)
Project Goal: Increase Ampacity (existing structures)
Conductor Size: Linnet
Conductor Length: 90 km
Voltage: 120 kV
Energized: 2009
Corrosive Marine Environment

Project Name: CFE Carmen to Noreste
Goal: Increase ampacity reduce line sag, avoid corrosion
Conductor Size: Hawk
Conductor Length: 32 km
Voltage: 230 kV
Energized: 2009
Long Span Application

Project Name: Chilectra El Salto to Torre 8 Line
Project Goal: Increase Ampacity – (existing structures)
Conductor Size: Linnet
Conductor Length: 28 km
Voltage: 110 kV
Energized: 2009
Wind Farm Link

Project Name: NEO Energia 80 turbine upgrade
Project Goal / Type: Increase Ampacity (existing structures)
Conductor Size: Amsterdam
Conductor Length: 57 km
Voltage: 66 kV
Energized: 2008
Extra High Voltage Application

Project Name: Amprion Gmbh
Project Goal / Type: Trial Line
Conductor Size: Oslo (bundled)
Length: 8.6 km
Voltage: 400 kV
Energized: 2009
Extreme Wind Survival

Project Name: NV Energy Line 107 (Reno to Carson City)  
Project Goal: Increase Ampacity (existing structures)  
Conductor Size: Linnet  
Conductor Length: 90 km  
Voltage: 120 kV  
Energized: 2009  
100+ mph Winds: 2010 Conductor Undamaged
Reconductor Project

Project Name: PacifiCorp 90 South to Oquirrh, Utah
Project Goal: Increase Ampacity (use existing structures)
Conductor Size: Drake
Conductor Length: 30 km
Voltage: 138 kV
Energized: 2005
Over 100 existing structures saved
Fire Storm Survival

Project Name: NV Energy Line 107 (Reno to Carson City)
Project Goal: Increase Ampacity (existing structures)
Conductor Size: Linnet
Conductor Length: 90 km
Voltage: 120 kV
Energized: 2009
Firestorm: 2012 – ACCC CONDUCTOR UNDAMAGED
River Crossing

Project Name: River Mondego
Project Goal: Increase Amps - Reduce Sag
Conductor Size: Amsterdam
Span Length: 475 Meters
Voltage: 60 kV
Energized: 2012
Tornado Toughness
ACCC® Hardware – Available Worldwide

- Unique patented splices and deadends help protect CTC’s ACCC intellectual property
- Splices and deadends currently available from 2 sources
- Hardware is easy to use with minimal training and effective
- Over 35,000 ACCC® Dead Ends and Splices currently in operation
ACCC Engineering Manual:

Helpful resource for understanding the unique attributes of ACCC Conductor
Conclusions on Experience and Benefits with HTLS Conductor

- Experience
  - Over 22,000 km’s installed worldwide in over 260 projects
  - Extensive testing and in-service experience.

- Benefits
  - Twice the Ampacity of ACSR
  - 25% stronger than steel and 60% lighter – less structures
  - Improved sag performance
  - Up to 40% savings in transmission losses
  - Lower overall lifecycle costs