Composite Conductor Field Trial Summary Report: Western Area Power Administration—FARGO

Installation Date	October, 2002
Field trial Location	Fargo, North Dakota, USA

Line Characteristics

Utility:	Western Area Power Administration (WAPA Great Plains)
Point of Contact at Utility	Ross Clark, Transmission Manager
Installation Date:	October 2002
Conductor Installed	ACCR 795 Kcmil *(467 mm^2)*
Length of line:	1 mile
Voltage	230 kV
Ruling span length	1,100 feet
Structure Type	Steel lattice towers

Data output,

(Time stamped every 10 minutes)

(1) Mechanical load cell
(2) MVA reading
(3) Ambient temperature,
(4) Net radiation sensor

Hardware

Suspension Hardware	Preformed Line Product, Thermolign™ Suspensions, TLS-0108-SE
Termination Hardware (1)	Alcoa high temperature compression dead ends and splice B9085-B (Dead End) and B9095-H (Splice)
Termination Hardware (2)	PLP Thermolign™ Dead Ends and Splice TLDE-795-N, TLSP-795
Insulator type	Ceramic
Dampers	Alcoa brand Stockbridge Dampers – 1706-10
Terminals	Alcoa brand Compression Terminal Connectors – B9102B

Results and Measurements

- Document installation procedure and video
- Behavior under extreme cold
- Response to high mechanical loads
- Response to aeolian vibration with and without dampers
- Performance under ice loading and strong wind
- Sag-temperature response from –35°C to + 50°C
- Monitor room temperature creep

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Photo Album

Overall view of the 230KV line

Installation of vibration recorders in the winter 2003

Alcoa brand Compression Splice

PLP Thermolign™ Suspension

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Installation process

Line installation began on Sept. 30, 2003, when three WAPA foremen and seven linemen gathered three manlifts and several other pieces of equipment in a soybean field just southwest of Fargo. Because this was a field test, representatives from the various equipment manufacturers were on hand to observe how their products would work in real-world conditions.

After ensuring that the line was de-energized, the crews used standard industry methods to install the conductor. They set up a pulling trailer at one end of the span to reel in the old cable and a tensioning trailer at the other end to load the new line. They also installed travelers on each tower. Then they disconnected the conductor from the insulator strings and lay it in the travelers. Using a sock, the crews pulled in the new cable by using the old conductor.

Finally, crews removed the travelers and hung the conductor on the insulator strings stretching from the three suspension towers between the two dead-end structures that mark the test segment.

The manufacturers also wanted to test different in-line and dead-end splice methods. Western used several different configurations on different phases of the line. Western crews installed two different types of dead-end splices so that project sponsors can compare performance. The first phase has Alcoa brand Compression Dead-Ends, the second has an Alcoa brand Dead-End on one tower and a Preformed Line Products' THERMOLIGN™ Dead-End on the other. The third phase has THERMOLIGN dead-ends at each end. Besides dead-ends, the crews also installed in-line tension splices by the same manufacturers to join two ends of the new conductor.

Other accessories evaluated in the field are PLP THERMOLIGN™ Suspensions and Alcoa brand stockbridge type vibration dampers. All accessories were designed and fully tested with 795-kcmil ACCR conductor in the laboratory prior to the field installation in Fargo.

The crews also installed monitoring equipment on two phases of the line, (CAT-1 system). The monitoring equipment is used to evaluate the sag of the conductor for a two year period; the measured sag is then compared with the predicted sag taking into account the loading history (creep) and temperature. The CAT-1 monitoring system includes two

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loads cells. One measures normal loading on one phase of the line. The second measures ice loading on a second phase

Response to Cold Temperatures

The conductor stretches over three suspension towers in between the two deadends, in an area with strong winds and severe weather such as frequent ice loading and sub-zero temperatures.

Measurement and calculation tracks the effect of changing temperatures on the conductor sag. The load data shows the variation in conductor tension from ambient temperature between -30^0C and $+30^0$C. Scatter is due to conditions such as wind, ice and thermal loading of conductor

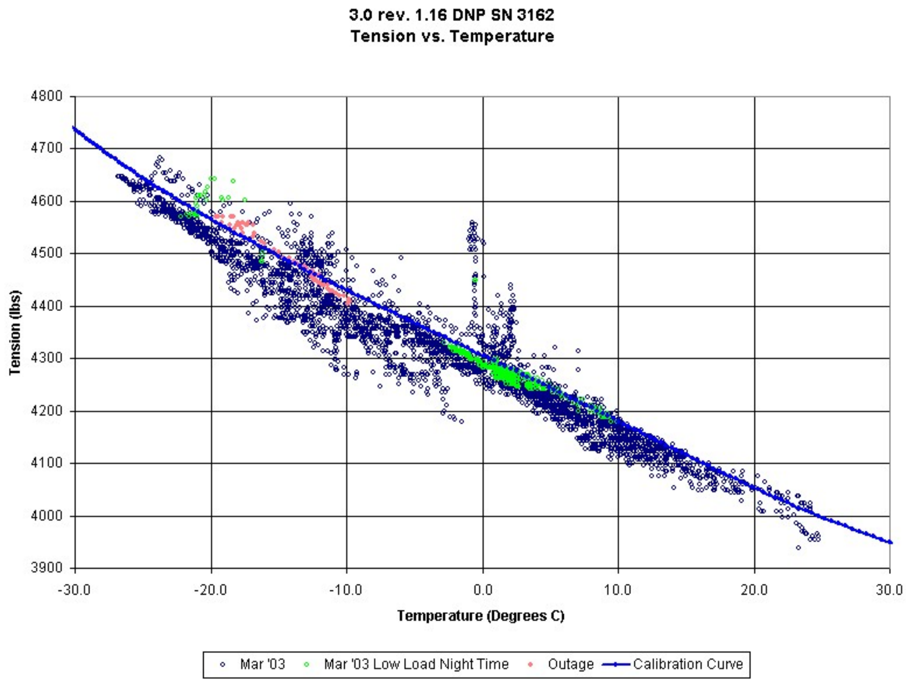

Figure 1: Load –temperature data on the 230kV ACCR line in Fargo, ND.

Overall, the low temperature tension follows the prediction from sag-tension models based on the conductor measured stress-stain response, coefficient of thermal expansion and creep.

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Measured and predicted sag

The sag was predicted with two methods: the Strain Summation Method to account for the full loading history, and the more commonly used Graphic Method, such as Alcoa SAG-10™ software.

The Strain Summation Method of Sag-Tension Calculation was used to model the sags and tensions, taking into account creep as a function of time. A conductor data file was created based on stress strain tests performed by NEETRAC on 795 kcmil ACCR. The Strain Summation Method accounts for creep and ice and wind loads on a daily basis because the method can examine any number of conductor states in sequence. This differs from the Graphic Method, which considers only two states: initial and final.

The model began with stringing the conductor on Oct. 3, 2002 matching the CAT-1 tension (cell 2 on phase 3) at the NRS temperature (Net Radiation Sensor) also provided by the CAT-1 System. CAT-1 load, NRS temperatures and times were used as input and the model provided sags and tensions as the corresponding output.

The calculated and measured tensions, both adjusted to 0°C, are shown in Fig. 1. The measured tensions are approximately 12 lb lower (about 0.2 percent of total load) than calculated in October 2002, but do not decrease quite as much as the calculated values thereafter. By the end of March 2003, the measured tensions are approximately 5 lb higher (0.1 percent of total load) than calculated.

In the first two months, the tension dropped by approximately 50 lb due to creep. In December 2002 and January 2003, the additional cause of permanent elongation was the high tension caused by the low temperatures, resulting in a further tension drop of 15 to 20 lb. In the second half of April 2003, tensions increased due to an electrical load drop from approximately 230 Amps to approximately 150 Amps.

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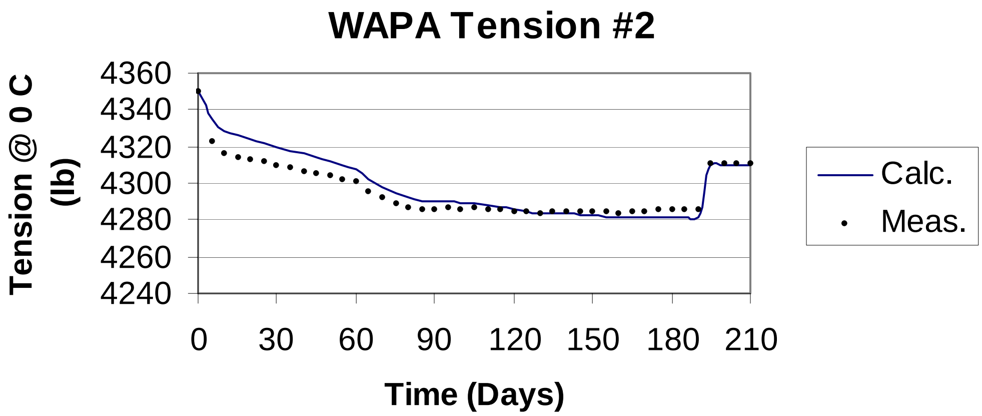

Figure 2: Calculated and Smoothed Measured Tensions adjusted to 0°C.

The predicted data matches the calculated data within a precision of 0.2 percent on tension when accounting the conductor stress-strain, thermal elongation, temperature, current and creep history. The corresponding measured SAG matches the predictions within +- 1 inch. The Strain Summation Method used above is able to predict the behavior with remarkable accuracy because it accounts for the actual loading history of the conductor.

It is also important to verify that the sag-temperature data is predicted by the "Graphical Method" (SAG-10™) software. Figure 4 shows the midnight data for October 2002 and April 2003. It is compared to the predicted "Initial," "10 Year Creep" and "Final Curve." The sags are computed from the CAT-1 tensions, taking into account that the difference between the measured maximum tension and the horizontal component of tension is significant. The measured data falls in between the predicted Initial and 10 Year Creep curves generated by the Graphic Method.

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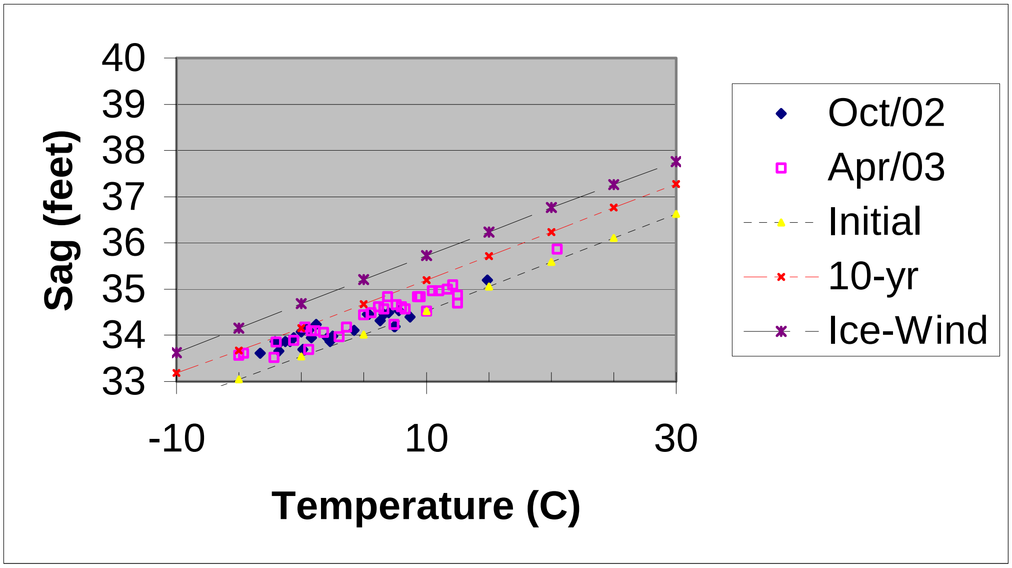

Figure 3: Midnight Ruling-Span Sags vs. NRS Temperature for October 2002 and April 2003.

The "Initial" line indicates the sag-temperature relation for a newly-strung conductor. This is based on stringing to 4,247 lb. maximum tension at 8.7 °C at approximately noon, Oct. 3, 2002.

The "10-Year Creep" line indicates the sag-temperature relationship after 10 years of creep at room temperature, which is typically considered as a "final" condition in the Graphic method.

The "Ice & Wind" line indicates the sag-temperature relationship after NESC heavy loading, which is 0°F (-17.8 °C), 0.5" ice with 4 lb/ft^2 wind and is another "final" condition typically considered by the Graphic method. North Dakota is in the NESC heavy loading zone.

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Field Vibration Study

The purpose of this study was to determine, in the field, the effectiveness of the PLP Thermolign Suspension and the Alcoa vibration dampers in controlling the bending stresses on the ACCR conductor when it is subjected to aeolian vibration.

The test line in Fargo for the 795 ACCR conductor was specifically chosen because this region is known to have the environmental conditions and flat terrain which can produce severe levels of vibration. A January (2003) study period was chosen because the conductor tensions would be the highest, due to extremely low ambient temperatures. It is well understood that conductor tension plays a major role in anticipated vibration levels. Generally speaking, the higher the tension, the more severe the vibration levels can become.

Over the years, the industry has done considerable work to attempt to determine "safe" tension levels for conductors to avoid serious vibration. One guideline that has been used is to limit the unloaded tension (without ice or wind) in cold weather (0° F, for example) to a percentage of the conductor's rated breaking strength (RBS). One limit that has been widely used, and confirmed by field experience and vibration studies, is 20 percent of the RBS.

The existing 954-kcmil 54/7 ACSR (Cardinal) on Western's line in Fargo has a published unloaded tension level of 5,787 lbs (17 percent RBS) at 0° F. The 795 ACCR conductor in the test section was installed to match the sag of the 954 ACSR. This resulted in an unloaded tension at 0° F of about 4,500 lbs (14.5 percent RBS).

To compare the levels of vibration on the 954 ACSR and the 795 ACCR, both with and without vibration dampers, a total of six vibration recorders were used for the study. The vibration recorders used in this study are the Ontario Hydro Mechanical Recorder . These recorders were used because of their ruggedness and overall reliability.

The six recorders were successfully installed on Thursday January 16, 2003 and left in place until February 5, 2003. The recorders were then removed and the vibration dampers were re-installed in the test area.

IEEE has established a standard method for the presentation of results for field vibration studies. This standard is a graph of mega-cycles per day (MC/Day) accumulated

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on the y-axis, and micro-strain on the x-axis. The mega-cycles per day is calculated from the total number of records at a specific amplitude. An assumption is made that the vibration activity that is recorded for the one second interval remains the same over the entire 15-minute period (until the next record is taken). Each record is multiplied by the frequency and than by 900 (seconds in 15 minutes) to get the total number of vibration cycles in the 15-minute period. All the records (multiplied by frequency than 900) for each amplitude level are accumulated and divided by 1,000,000 to get the MC/Day value. This is repeated for each amplitude level.

The micro-strain is the dynamic bending strain (inches/inch) on the outer strands of the conductor itself. The micro-strain is calculated from the measured amplitude and a “strain conversion factor” that had been developed in the 1950s by J. Poffenberger and R. Swart of PLP. The strain conversion factor was developed from extensive strain gauge measurements of conductors in the laboratory. Since the ACCR conductor is a unique design, a conservative strain conversion factor based on the theoretical properties of the conductor was used.

The graph in Figure 3 summarizes the study results. It is clear from this graph that the bending strain (micro-strain) on the 795 ACCR conductor is, for the worst case, 40 percent to 50 percent below that of the 954 ACSR for the same study period. This is mainly due to the protection provided by the PLP suspension on the 795 ACCR as compared to the suspension clamp with Armor Rods used on the 954 ACSR. The inner and outer rods of the PLP suspension take a large percentage of the bending stress, thus reducing the stress on the conductor by 40 percent or more.

The amount of bending strain on the 954 ACSR conductor, without dampers, is in the moderate range (280 micro-strain). This value is somewhat below the fatigue endurance limit for ACSR conductors. The fatigue endurance limit is a value (micro-strain) at which the conductor can handle, regardless of the accumulated number of cycles. Above the endurance limit, there is a finite number of cycles, after which the conductor will begin to experience fatigue failures in the outer strands. ACSR conductors in the field that have been subjected to micro-strain levels above 400 have been known to experience fatigue breaks in as little as one or two years.

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It is also clear from the results shown in Figure 3 that the vibration dampers are effective in reducing the levels of vibration on both the ACSR and ACCR conductors.

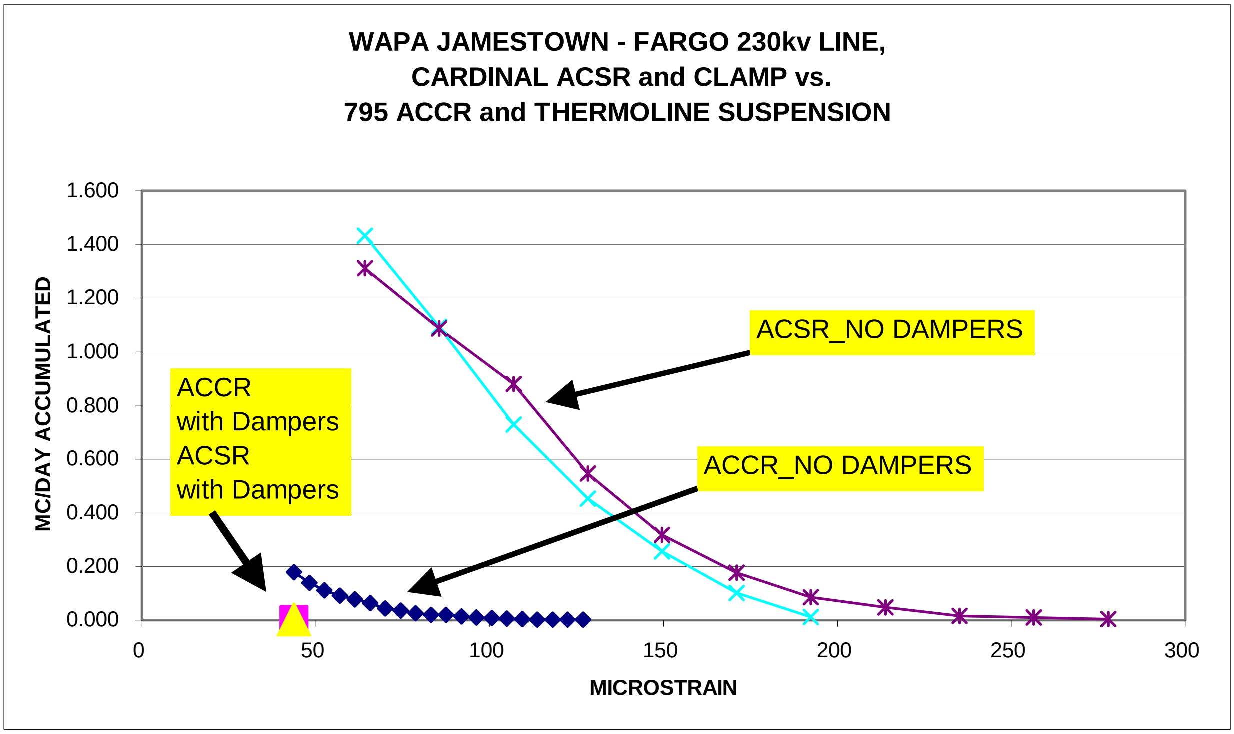

Figure 3: Results of vibration study in Fargo

Response to severe weather conditions

The conductor was subjected to cold temperature, frequent storms with winds in excess of 60 mph *(100 km/hour)* and temperatures as low as –28^{o}F, *(- 34^{o}C).* The conductor and accessories behaved as expected under such conditions.

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Severe Weather Log -- (Fargo, ND)

Date	Max Wind Speed (1)		Min. Temp	
	mph	*km/h*	*C*	F
January 17, 2003	39	*63*	*-23*	-9
February 7, 2003	38	*61*	*-22*	-8
March 1, 2003	39	*63*	*-24*	-11
June 25, 2003	47	*76*	*11*	52
June 26, 2003	46	*74*	*10*	51
November 30, 2003	47	*76*	*-3*	27
January 27, 2004	28	*45*	***-35***	**-31**
January 28, 2004	25	*40*	***-34***	**-29**
January 29, 2004	27	*44*	***-35***	**-31**
January 30, 2004	20	*32*	***-38***	**-36**
February 4, 2004	36	*58*	***-30***	**-22**
April 25, 2004	58	*94*	*5*	40
April 28, 2004	51	*82*	*2*	35
May 5, 2004	**63**	***102***	*11*	52
May 29, 2004	46	*74*	*21*	69

(1) Data from the National Weather Service in Fargo

795 ACCR Specification

			METRIC
Designation		795-T16	
Stranding		26/19	*26/19*
	kcmil	795	*467 mm^2*
Diameter	in	1.11	*28.1 mm*
Total Area	in^2	0.724	*467 mm^2*
Weight	lbs/linear ft	1.392	*1.333 kg/m*
Breaking Strength	lbs	31,134	*138.5 kN*
Modulus	msi	10.7	*74 GPa*
Thermal Elongation	ppm/C	16.3	*16.3 $10^{-6}/^{o}C$*

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