TRANSMISSION & DISTRIBUTION WORLD

Before Lines Fall Down

Jan 1, 2010 12:00 PM
By Daniel R. Whicker, Avista Utilities

Resistance measurements enable Avista to detect and remove failing splices.

It's all in the numbers. And since Avista Utilities (Spokane, Washington) clocks in at a century old, it is not surprising that many of the numbers concern aging infrastructure. Just as with other utilities across the country, much of Avista's infrastructure was built right after World War II, when the ubiquitous baby boom was taking off. In the 1990s, full-tension splices on transmission lines started to fail. At first, it was just a sporadic few, but in time, the numbers became significant. Avista opted to investigate the situation with an eye toward prevention and applied some ingenuity.

Overhead Transmission

Major Brazilian Electric Utility Installs ACCR, Boosting Power to S�o Paulo Without Larger Towers
Montana-Dakota Utilities Power Line Route Approved by North Dakota PSC
TVA Transmission Lines Returned to Service from April Tornadoes
ITC Great Plains Receives Siting Approval for the Kansas V-Plan Transmission Line Project
National Grid, Bangor Hydro Seek FERC Approval on Funding Approach for Proposed New Transmission Line
»More from this section

Aging Splices

The splices are aluminum-alloy cylinders that are hydraulically compressed onto the conductor to splice ends together. They must perform for decades under full line tension, which varies from 2000 lb (907 kg) to as much as 6000 lb (2722 kg). These splices or sleeves are part of the aging infrastructure.

Analysis Methods

Most of Avista's 230-kV system uses aluminum conductor steel reinforced (ACSR). Some lines were built using all-aluminum conductor (AAC). The conductor and ancillary hardware performed dependably for 40 years. In 1998, a series of full-tension splice failures began occurring on the AAC. There was an average of one splice failure per year from 1998 to 2007. Avista's statistical analysis predicted the number of failures would rise to almost two per year on the AAC lines during the coming decade and become even worse later. There have been no failures on the ACSR lines.

In 2005, Avista formally established a group dedicated to asset management. One primary asset management effort has been the study of existing infrastructure components to verify and quantify the perceived increasing risk associated with aging utility equipment. In this effort, an indispensable study tool is risk-analysis software. Avista chose a product by Isograph of the United Kingdom. Two modules of the Isograph software have been used extensively, RCM Cost and AvSIM+. These software packages model component and system performance over time using statistical analysis and Monte Carlo simulation.

An invaluable component of the software is the ability to use hardware-failure age data and surviving-population age data for the system under study to generate Weibull probability distribution curves to estimate future system performance. The Weibull distribution is used extensively in reliability engineering to analyze the projected life-cycle failure-rate changes of hardware.

The formula underlying the Weibull distribution incorporates two main parameters: shape and scale. The Weibull can be configured to use age or a value such as the number of cycles to indicate usage of the object. Shape describes how the failure rate changes with use or time; for example, does the failure rate stay constant, increase or decrease (infant mortality) with age? The scale indicates the age at which about two-thirds of the population is predicted to fail; a larger-scale number indicates a longer-lived component.

The Isograph RCM Cost software package was used to analyze the possible effectiveness of an inspection and testing program. To be conservative in analysis, the inspection effectiveness was set at 50% (i.e., inspection would only find half of the splices in poor condition). The cost of a repair operation after splice failure was set to an average value based on past repair information. Inspection costs assumed a helicopter could be used to test components located over remote terrain. The cost of reinforcing splices found during inspection prior to failure was estimated.

A second crucial software input is the ability to define consequences that may happen if a failure does occur. For example, the energized conductor falling to the ground may be in an area with a significant probability of sparking a brush fire. Transmission outage records were consulted to estimate the possibility of a splice failure causing a wildfire.

The transmission splices were modeled with documented cases of splice failure since 1998, using good information for installation dates of the lines being studied. Quantities of the original splices still in service (the surviving population) were estimated based on survey work performed by operations personnel. The estimates were accurate to within 10% of the actual number of installed splices.

Analysis Results

Two levels of results were extracted from the RCM studies: the number of splices predicted to fail during the next 10 years and the number of questionable splices that might be headed toward failure further into the future. Out of a population of 450 splices, 17 were predicted to be in very poor condition and 115 were predicted to be questionable.

Life-cycle-cost calculations were then computed using methods accepted by state utility commissions with inputs based on the RCM study results. This showed the internal rate of return of inspection exceeded 10% compared to the base case of only responding to failures. Avista's neutral point of the internal rate of return, the point above which it is advantageous for the rate payer to have the project done, is 7.4%. With this information, Avista informed state regulators that splice inspection was a viable and valuable project, and requested it be included in the expanded operations and maintenance expenditures it was proposing because of other asset management studies.

Inspection and Testing

Avista has used infrared inspection within substations for several years with excellent success. Only a few attempts have been made to use infrared on the transmission system. About 25 years ago, some bad splice components were found using infrared on a 115-kV line. The bad 115-kV splices were a style where the conductor is contained in a heavy sheet-metal cylinder, and the cylinder and conductor are then twisted to form a mechanical bond. Other attempts at infrared inspection in the last several years, following failures on the 230-kV system, have not been successful in predicting future splice failures. The physical distances involved in the use of a handheld infrared device on a transmission line, not to mention the unlikelihood of having the tests coincide with good ambient conditions and sufficiently heavy line loading, make it difficult to see a bad splice.

While researching inspection methods for splices, Avista discovered the Ohmstik Plus, manufactured by Sensor Link. It simultaneously measures the current flow and voltage drop on an energized conductor and calculates the resistance of the 12-inch (305-mm) section spanned by the device. It is a direct-reading instrument that has to be brought into contact with the energized conductor.

After consulting with others who had used the Ohmstik and potential helicopter contractors, Avista elected to request quotes for helicopter service to include the pilot, ground support and a lineman to handle the Ohmstik, to be supplied by Avista. An Avista representative would fly with the pilot and lineman to record the test results. The successful contractor was AIR2.

Testing using the Ohmstik began in June 2009. The program appears to be a success in finding deteriorated splices. Test readings were consistent without an excessive number of outliers. The resistance readings were fed into an Excel spreadsheet to compute the parameters of a basic normal distribution to determine the average value and standard deviation. Splices with very poor test results stood out starkly from the majority of the population.

Almost 350 splices were physically tested using the Ohmstik. Line-clearance concerns for the helicopter to operate between energized conductors and shield wires prohibited testing of the remaining 100 splices of the original estimated population. Of the 350 tested, 70 results are in a questionable category, where the resistance at the conductor-splice junction was at least 1.5 times the conductor resistance. Of that 70, 19 tested badly enough to be scheduled for work as soon as possible. The worst of those read a resistance of 31 times the conductor resistance, and about half of those were five to six times the conductor resistance.

The testing method for each splice involved three steps:

1. Measure the wire resistance immediately adjacent to the splice.
2. Measure the resistance of the junction between the wire and one end of the splice.
3. Measure the resistance between the wire and the other end of the splice.

Follow Up

Granted, it could be argued that measuring the wire resistance at every splice is redundant, but the person performing the test can establish a rhythm, and once positioned, the test instrument only stays in place for 5 to 10 seconds before it is moved a short distance to test the conductor-splice junction.

Three people were in the helicopter: the pilot, the lineman performing the test and the utility representative recording the results. Often, three pairs of eyes were very useful in spotting the splices as the line was flown. The testing project was not without difficulty. Testing of the center phase in the horizontal configuration required vertical deployment of a hotstick from the helicopter. The stick would then have to be pulled back into the helicopter to view and record the test readings. In a few instances, the longer hotstick also had to be used on outer phases where tree tops were uncomfortably close.

The plan for going forward is to schedule line outages and install a reinforcing product over the existing splice or, in some cases due to dimensional constraints, cut in new replacement splices and conductor. Avista plans to use two devices: an item manufactured by Preformed Line Products called a Splice Shunt and an item by Classic Connectors Inc. called the ClampStar. When splices in other phases are located close to a splice that tested so poorly, the bad splice is scheduled for work as soon as possible, and the adjacent splices also will be reinforced.

At this point, the consistency of the test results is pleasing, as the poor test results clearly stood out from the rest of the population. The relatively low number of very bad test result numbers for what should be a long-lived component of the transmission system is consistent with many experienced opinions. However, it was also eye-opening to see that, across the board, the resistance of splices is higher than it should be; a progressive aging process is thought to be taking place.

Without a doubt, Avista's no-stone-unturned technique for preventing transmission splice failures delivers on the numbers: the testing of hundreds of splices, with dozens identified for repair.

Acknowledgements

But significant and impressive statistics only begin to tell this story. The asset management group remained ever-mindful of those affected by their work, most notably preserving worker and public safety. The group's carefully constructed assessment and repair process allows for accurate capital budgets for years to come. What's more, forward-thinking environmental stewardship and increasingly reliable service promotes good customer relations.

All that from a helicopter hovering over a 3000-ft (914-m) canyon.

The author would like to thank Joe Renowden (JDR Engineering Inc.) for his assistance in helping the project team understand the subject and the interpretation of the Ohmstick results. He also would like to thank the personnel of AIR2, especially Yonaton Shapira, Robert Pritko, Tim Galeotti, Pete van der Lugt and Dwayne Moquett. Finally, this project could not have happened without Avista operations personnel support, dedication and continued hard work, sometimes under very adverse conditions.

Avista Corp.

Daniel R. Whicker (dan.whicker@avistacorp.com) is a 1971 graduate of the U.S. Coast Guard Academy and holds a master's of engineering management degree from Washington State University, earned in 1995. He is currently employed by Avista Utilities as a project engineer within the electrical engineering group, supporting work for transmission, substation design and asset management.

Avista Corp., formerly Washington Water Power, is a 120-year-old utility with roots in serving residential, agricultural, mining and timber industries. Avista operates two voltage levels of transmission: 115 kV and 230 kV. A significant portion of Avista's 115-kV transmission structures are wood poles more than 60 years old; some structures are more than 85 years old. The 230-kV system is also predominately wood-pole structures, with 90 miles (145 km) out of 950 miles (1529 km) having been rebuilt during the last five years using steel structures. However, the majority of the 230-kV system is the original structure construction from the 1950s and early 1960s.

Companies mentioned in this article:

Measured and Calculated Resistance Values

Conductor	**Average measured resistance/standard deviation**	**Calculated resistance at 20�C (68�F)**	**Calculated resistance at 50�C (122�F)**
954 MCM, Magnolia	24.12/6.00	18.78 �Ω	20.92 �Ω
1272 MCM, Strafe	17.81/6.87	14.42 �Ω	15.99 �Ω
954 splice, one end	29.00, with a standard deviation of 21.35		
1272 splice, one end	26.19, with a standard deviation of 52.29. Ignoring the worst test value only gives a standard deviation of 13.02.		

Note: The current on each of the two types of conductor was approximately 450 A at the time of the test, and ambient conditions were partly cloudy weather with about 80�F (27�C) and a light breeze.
Source of calculated resistance: *Kaiser Aluminum Electrical Conductor Technical Manual*, 1954.

AIR2 www.air2.com

Avista www.avistautilities.com

Classic Connectors Inc. classicconnectors.com

Isograph Ltd. www.isograph-software.com

Preformed Line Products www.preformed.com

Sensor Link www.sensorlink.com