Aerial Spacer Cable for Utility Scale Wind Energy Sites

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Introduction

Aerial Covered Conductor Systems, including both Spacer Cable and Tree Wire, have been used for distribution and transmission for over 72 years. Standard applications include improved reliability, reduced tree trimming, storm hardening, multiple circuit construction, environmental stewardship, and wildfire mitigation, to name a few. This paper describes how and why covered conductor systems are practicable for use as collection systems in utility-scale wind energy facilities.

Background

Windmills have been around for thousands of years for food production, irrigation, agriculture, sawmills and more. As such, it is surprising that the first utility-scale wind farm was built as recently as 1980. Harnessing wind to produce electric power has seen a steady increase in application here in the US as well as abroad. Wind power generation has increased approximately 11% per year from 2010 to 2022, at which point wind generation accounted for about 10.2% of the total generation capacity in the US. This trend is anticipated to continue, with wind energy supplying 20% of the nation's energy needs by 2030, and 35% by 2050. How best to site those facilities and get their generation onto the grid is an important issue for power planners and clean energy advocates.

Aerial Covered Conductor – Spacer Cable and Tree Wire Systems

It is helpful to first describe what is meant by covered conductor systems. Spacer Cable Systems consist of three heavily covered, but unshielded, phase conductors. The conductors are usually AAC when in a spacer configuration, since there is no tension on the phase conductors, but are usually ACSR or AAAC when installed in a self-supported or "Tree Wire" configuration.

In Spacer Cable construction, the phase conductors are attached to a messenger by spacers, installed every 30 ft. (10m.) along the messenger. The messenger is a high strength, alumoweld (AW) or alumoweld-aluminum (AWA) conductor which has several functions. The first is that the messenger is the mechanical strength member, holding the phase conductors up. The messenger can also be used as a system neutral, is a lightning shield, and provides a mechanical protection function by protecting the phase conductors from any items (leaves, branches, trees) which can fall onto the bundle from above. The spacers are made of High Density Polyethylene (HDPE), as are the pin or line post insulators used on the angles, to ensure dielectric compatibility with the phase conductors.

Tree Wire systems, on the other hand, look more like bare wire construction. They utilize the same 3-layer covered conductor design, but the phase conductors are usually either ACSR or AAAC (since it is self-supported and fully tensioned). Tree Wire systems are strung in an open wire configuration on crossarms with polyethylene insulators. The photo below on the left shows a spacer cable system, while the photo on the right shows a tree wire configuration.

Tree wire is seldom, if ever, used for wind farms collection systems, which are normally either underground, bare wire or Spacer Cable Systems. This is because the compactness of the Tree Wire system is not as efficient as the compactness of a Spacer Cable System. While tree wire performs well in high wind conditions, it is cumbersome when building multiple circuits beyond two per pole line.

Impetus for Spacer Cable at Wind Facilities

Not all wind farm layouts are alike. Some are massive arrays of turbines stretched out on flat land for miles, with appropriate separation to avoid wind perturbations from one turbine affecting an adjacent turbine. Many wind farms, however, are what are known as "ridgeline" wind farms, with turbines located on mountain tops and along mountain ridges. This creates challenges for designers. The "strings" (lines from the individual turbines to the 34.5 kV collection system) and "homeruns" (34.5 kV lines from the wind farm strings to the transmission substation) have to take into account the terrain, which may be hostile to bare wire, as well as underground cable.

When/Where Spacer Cable is Viable for Wind Facilities

If wind farms are spread out on flat land with little or no complexities (no boulders, granite, hilltops, etc.), it is likely that the turbines will be optimally spaced, with distances between turbines depending on the turbine size (rotor diameter), wind speeds, and land cost, with turbine wind interference factored in. The strings will likely be underground, go from the wind turbine to the inverter and 0.6/34.5 kV transformer, then to a connection point with the collection circuit. The collection circuit brings power from multiple strings/turbines back to the substation sited adjacent to the transmission grid.

Once the turbines are optimally sited, the planner has to determine how to get the collection circuits back to the transmission substation. Options include bare wire, underground cable, and spacer cable. Let's look at the challenges the circuit designer must face and how each construction choice solves (or creates problems) with respect to those issues.

Conductor Clashing

The phenomenon of conductor clashing, or "conductor slap" as it is sometimes called, is usually due to conductors swinging wildly in high winds resulting in unintended contact. The result is vaporization of aluminum, ejection of superheated metal particles, possible ignition of a wildfire scenario, and an extended outage. Unfortunately, the outage is not confined to a single turbine. A collection circuit will have numerous turbines and carry up to 30/40/50 MW. The conductor clashing incident then leaves a major block of generation off-line for the time it takes to locate and repair the fault, which can be days or even weeks, depending on the location and repair requirements.

When the collection circuit is constructed with Spacer Cable, the conductors themselves are attached to spacers every 30 feet in close spacing (approximately 12 inches) and are thus held in place and unable to contact one another. However, should a wind event take place which results in conductor-to-conductor contact, there will be no damage. The covered conductor's insulation will limit the leakage current to a fraction of a milliamp and avoid a flashover and any attendant damage that would otherwise be experienced with a bare wire line.

Because wind farms are sited in locations with high wind speed, it is not surprising that the major cause of outages (at least in early wind farm experiences) was conductor clashing. Financial and wind farm availability impacts of such outages are magnified since the occurrence generally takes place during a high wind event, when the system is expected to be pumping power back into the grid at maximum capacity.

Strings (lines from the turbine to the collection circuit) are usually underground, since areas close to the turbine itself are subject to concerns for toppling, as well as wake effects which might disturb an overhead powerline. It is the wake effect that is a primary concern for conductor clashing close to the turbine itself, although high winds can produce this phenomenon as well.

Harsh Weather

Many utility scale wind farms are located in harsh weather environments, meaning they regularly see high winds, snowstorms, and ice storms throughout the year. While the turbines themselves can be designed to withstand the harsh conditions, consideration must be given to the design of the collection system to avoid outages during harsh or extreme weather conditions. Bare wire systems are inherently susceptible to conductor clashing and failures from ice and wind. Covered conductor systems, however, fare much better in wind, ice, and snow, as has been demonstrated in real world field testing.[1] Spacer cable systems, specifically, perform much better and are more storm hardened than bare wire systems under these conditions.

Right-of-Way (ROW) Issues

Ridgeline wind farms are often in locations where the forest is abundant. A standard ROW is cleared prior to construction, but the tree trimming may be neglected, especially with respect to trees left at the edge of the ROW which have the potential to fall inward at some point in the future and negatively impact a collection circuit. The photo below on the top shows a bare wire wind farm collection circuit taken off-line by a fallen tree. Use of spacer cable would have resulted in the tree being supported by the messenger without harming the circuit or knocking it off-line. The photo below on the bottom shows a similar ridgeline wind farm collection circuit built with spacer cable construction.

1. Wareing, Dr. B., Chetwood, Pat, and Ward, Alan, "Erection and Testing of Hendrix Spacer system at Deadwater Fell Test Site," EA Technology Service Report, 2001.

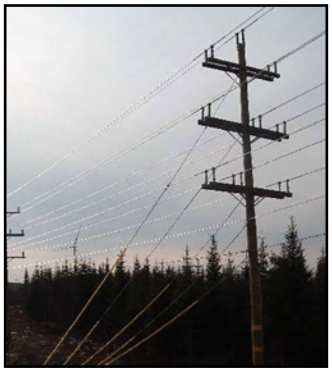
Topography and Soil Conditions

With ridgeline wind farms, it is not uncommon to find granite or other rock formations. The use of underground cable thus requires extensive blasting of rock to lay the cable. While this is cost prohibitive in many cases, the blasted rock also creates abrasion hazards for the cable jacketing. So topography and ground surface composition also play a role in selecting whether to use bare wire, underground cable, or spacer cable.

Multiple Circuit Construction

As noted previously, wind farm layouts differ widely from one installation to the next. Turbines are sited perpendicular to the prevailing wind direction at the site. Collection circuits then run past each turbine location and pick up the string from that turbine, combining generation from a number of turbines. If the turbines are 1.5 KW each, and the collection circuit picks up ten strings, then the collection circuit will be loaded to 15 MW. This is relatively easy to design, and the limiting factors in selecting a conductor size would be voltage drop (usually kept to a target of 2%) and losses (1% goal). While a smaller conductor can be selected to satisfy the ampacity needs, it is often a requirement to use a larger conductor to bring the losses and voltage drop back to acceptable limits.

When the number of collection circuits per pole is one or two, it is easy to use bare wire (although care must be taken to avoid conductor clashing). However, as the number of collection circuits reaches three or more, bare wire is neither a viable nor reliable choice. Conductor clashing is a threat. Maintenance is also difficult without de-energizing, as closely spaced bare wire of multiple circuits poses a significant hazard for maintenance work. Maintenance is unwieldy, takes more time, more danger is involved (exposing line workers to undesirable threat elevation), the circuit must de-energized, and all of this significantly impacts availability, as generation will be off-line for large blocks of time.



The photo above left shows a wind farm with three collection circuits on a single pole line. At this site, the first winter experienced an ice storm, which knocked many of the bare wire lines to the ground, a scenario that could have been avoided if the wind farm had employed spacer cable for the collection system. The photo above right shows a wind farm using spacer cable with three circuits per pole line.

Spacer Cable Voltage Regulation Gives Rise to Savings

A less recognized benefit of spacer cable is that by bringing the phase conductors close together, the mutual inductance is mostly cancelled out. This reduces the total inductance and thus system impedance by 15% or more. This then provides a circuit with 15% less voltage drop. For long collection systems required in remote areas, this often allows the designer to choose a smaller conductor size, which translates to significant savings in aluminum purchases for phase conductors.

OPMW – Optical Messenger Wire

Another benefit of using spacer cable for the collection system is that the fiber optics can be put into the messenger. The photo below left shows a wind farm whereby the fiber is strung as ADSS above the power space on the pole. This creates the need for a pole which is at least five feet taller. The photo below right shows where the fiber has been put into the messenger. This alleviates the need for a taller pole, a second messenger (ADSS self-support), makes for a lower profile installation, and would be expected to reduce project cost.

Entering the Substation

A fairly common method of bringing powerlines into the substation is to terminate the aerial cable on a pole just outside the substation fence, transition to a riser and underground cable, run under the substation fence and then connect to the substation bus. These connections are unwieldy, and have elevated costs both for materials (cables, switches, cabinets, etc.) and labor. Using spacer cable provides the opportunity to simply deadend the collection circuit on a pole outside the substation fence, then run a slack span from the last pole directly to the substation bus.

The photo above left shows circuits turning a ninety degree angle off the last pole outside the substation fence, then running as a slack span (no messenger) into the substation. The photo above right shows the phase conductors deadending on the substation bus.

Summary and Conclusions

Experience has shown that Spacer Cable Systems are a technically viable and economic choice for the collection systems of many utility-scale wind farm sites. Savings can be attributed to improvements in reliability and availability (storm hardening and elimination of conductor clashing), ease of multiple circuit construction, improvements in power quality, increase in safety, and cost reductions made possible by utilizing design strategies afforded by this technology (such as reduced voltage drop leading to smaller cable sizes, using shorter poles, and putting the fiber in the messenger).