CABLE DESIGNS TO MEET WIND TURBINE INDUSTRY STANDARDS

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Over the last several decades, wind turbine installations have dramatically increased. As their use has become more widespread, they have evolved in both efficiency and complexity. Today's wind turbines are comprised of a vast array of sophisticated components that are subject to damage from the harsh environments in which they operate. Among the most critical and overlooked components in turbine systems are the cables that handle the power and data transmission.

Because they can fail when exposed to the temperature extremes, chemicals and electromagnetic interference (EMI) found on wind turbines, cables for the wind energy applications must be selected very carefully. They must also be tested rigorously to make sure they meet industry standards.

Here's an update on the current state of standards for wind turbines in North America, as well as a more in-depth look at the factors design engineers should consider when selecting cabling for wind turbine applications.

INDUSTRY CODE CHANGES IN NORTH AMERICA

As the use of wind turbines in industry and commercial applications becomes more prevalent, there is a growing need to ensure their proper installation and safe operation, which has prompted mandates to provide clearly written safety standards. While utility companies are monitored by government agencies, non-utility applications are guided by the National Electrical Code (NEC). In 2011, a new section called Article 694 was added to the NEC to ensure installation safety of small wind electric systems. NEC Article 694 covers small wind power single turbines that are rated for 100 Kilowatts (0.1KW). There is no limit to the number of wind turbines that can be installed in a given location. When several of these machines populate the same location, it is referred to as a "wind turbine farm" which can cover an area of several hundred square miles.

To establish consistency and to prevent confusion, UL has drafted several subjects corresponding to wind turbine generating systems: UL Subject 6141: Large Wind Turbine Systems (WT) and Electrical Subassemblies, and UL Subject 6142: Small Wind Turbine Systems (WT) and Electrical Subassemblies. Wind turbines with entrance access are defined as "large" per UL 6141. They are grid-connected and are used for "utility" applications. Wind turbines without entrance access are defined as "small" per UL 6142. They are not connected to the grid and are considered "non-utility." As the industry grows and the emphasis towards revision of standards continues, UL 6141 and 6142 will be upgraded to include new requirements.

In addition, there are corresponding UL Standards that focus on specific internal components within the wind turbine. For example, Rotating Electrical Machines must meet UL Standard 1004–1. Electric Generators have to meet UL Standard 1004–4, and so forth. In UL Standard 1004–1 AWM, cables are permitted, but only with exceptions. Section 20.2 allows the use of either standard building wire or appliance wiring material (AWM). Section 20.4 permits AWM, provided it has an insulation thickness appropriate for the insulation material type and meets stringent cable construction requirements. As UL Standard 1004–1 allows for the AWM option, building wire is a “listed” product, automatically qualifying it as an NEC compliant wiring method. It’s worth noting, however, that AWM is not an NEC acceptable wiring method, so it may be subject to potential acceptance issues during an inspection.

Within the construction of the wind turbine, cable trays or raceways route and support cables to accommodate power for the various operating systems. To address safety concerns about performance of these cables under operating conditions inside the wind turbine, UL released an outline of investigation for “Flexible Motor Supply Cable and Wind Turbine Tray Cable.” This Outline, referred to as UL 2277, permits a 1,000 Volt rating and specifies safety and performance requirements for cable intended to be installed within a tray or raceway in the wind turbine. UL 2277 mandates that cables used in a cable tray or raceway in the wind turbine must also meet all performance criteria of UL 1277, known as the “Tray Cable” standard.

DESIGN CONSIDERATIONS

In addition to the guidelines set forth by these standards, there are other physical factors to consider when specifying cables for wind turbine applications.

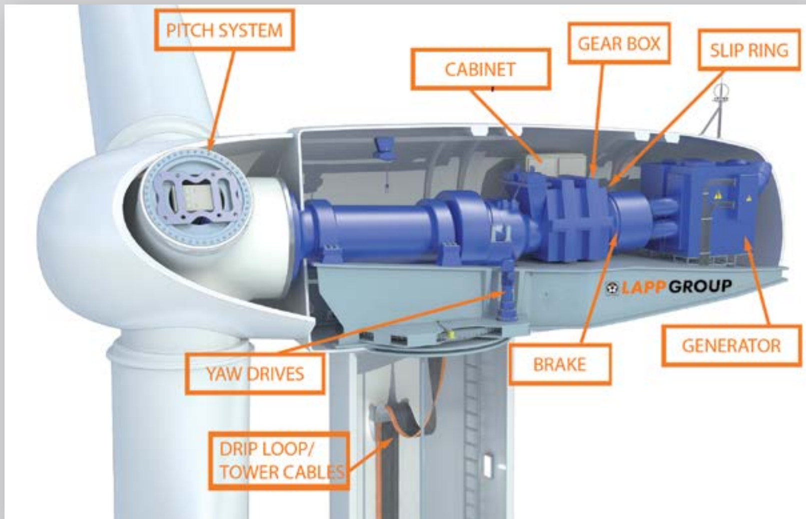
Grease, Oil, and Hydraulic Fluids. Many components within the wind turbine itself require grease, oil or hydraulic fluid to function correctly. Oils and grease are used to prevent premature wear and avoid potential breakdown, and hydraulic fluid is necessary for brake systems to perform. However, these media can attack and degrade certain cable jacket compounds. There are several areas in the wind turbine where accidental contact is considered routine, so cables can be exposed to them for long periods of time. Oils, grease and hydraulic fluid can attack a cable jacket through different mechanisms: 1) absorption by the compound, which results in swelling where the jacket weakens and falls apart, and 2) extraction of the softening components from the compound, which causes the jacket to eventually harden, shrink and crack. The jacket is the first line of defense for the cable; once it is compromised, the chemical will migrate through and begin to attack the insulation. To avoid these problems, you’ll want to make sure that the cables you select are resistant to

these types of chemicals and are compliant with UL standards Oil Res I and Oil Res II requirements.

Low Temperature Exposure. Depending on its geographical location, the wind turbine’s operating environment can quickly become very cold and remain that way for extended periods. This makes it critical to consider whether the cables you select can withstand cold conditions. Once the jacket - the cable’s first line of defense - has been compromised, the insulated conductors are exposed, and are then subject to the surrounding environment. This can create a potentially hazardous condition. To avoid these issues, look for cables that maintain their handling performance even at the lowest temperature extremes. Certain cables designed for use in wind turbines are available that pass the –40°C cold impact test per UL and CSA standards.

Flame Resistance. If a fire occurs in the wind turbine, vertically exposed groups of cables can act as flame conduits from section to section, so it is critical to incorporate cables with high flammability resistance. You can verify a cable’s flammability resistance by making sure that it has been tested to the stringent requirements of the CSA FT4 flame test. This test requires groups of cables to be loaded within a vertical tray ladder and then exposed to an extreme, intense, angled, horizontal flame for a period of twenty minutes. Certain criteria must be met regarding flame spread, cable charring and damage, self-extinguishing characteristics etc,. The FT4 flame test provides assurance that flames will only progress vertically to a certain point and then self-extinguish. In Europe, the majority of cables offered for wind turbines only comply with the UL VW–1, CSA FT1 or the IEC 60332–1.

WIND TURBINE PRINCIPLE OF OPERATION & DESCRIPTION



Wind turbines convert wind energy into rotational energy to generate electricity. In their most basic form, they are comprised of a tower nacelle and three rotor blades, which connect to rod and gear mechanisms. Yet modern designs are actually much more sophisticated. What's more, wind turbines with different features tailored for specific applications are available from several manufacturers. These can include superior variable speed technology to maximize wind energy capture and minimize drive train loads, blade designs for increased efficiency and more.

Applications & Descriptions

Component	Definition/Description/Function	Maintenance/Repair/Failure
Pitch System	Drive system which controls the exact positioning of the rotor blades to adjust the rotation speed and power generation.	Moving parts require heavy duty grease suitable for long term use to provide protection. Parts may wear requiring replacement to maintain efficiency.
Cabinet	The main control unit of the wind turbine which determines its operation. Cabinet is for all control electronics, wire & cable, connections, switches, relays, etc.	Clean and dry environment, oils, grease, will be not be present under normal conditions, lubricant is for door hinges/locks. Failure of any components will effect turbine performance or prevent operation.
Gear Box	A gear box converts the low speed and high torque of the rotor into the nominal speed of the generator. The gear box contains a reservoir for the gear oil used (approximately 80 gallons) that is dispersed to the gears at set intervals.	Mechanical gear system where a constant dispersion of gear oil is required to insure lubrication. Gears may wear, distort, teeth wear, or break. Replacements of worn, distorted or broken gears are required to insure efficiency and proper operation.
Slip Ring	The slip ring provides for an electrical connection through a rotating assembly. Serves as a rotary type of electrical switch that reverses current direction.	Electrical contact points must be kept clean and corrosion free. Moving parts require heavy duty long term grease for lubrication. Damage of any electrical/ moving parts must be replaced.
Brake	Electro mechanical type of braking system using hydraulic control mechanisms to function is used to shut down the system for maintenance.	Seals must be checked for any signs of swelling or cracking. Requires hydraulic oil that provides good anti wear protection and minimal deposits.
Generator	Generator converts the rotation of the blades caused by the wind into electricity. Internal bearings are in continuous rotary movement.	Bearings require treatment of wide temperature range extreme pressure grease that provides long term lubrication. Bearings may wear hampering generator performance and must be replaced.
Yaw Drive	The wind turbine is automatically positioned in relation to the wind to maximize the amount of electrical energy produced. This is accomplished through using a system of planetary gears combined with motors and brakes. Wind direction is determined using a sensor (anemometer).	Gear system requires a high performance bearing grease that provides optimum wear protection under the extremes of varying speeds, vibration, shock loads, or pressure. Gears may distort, experience teeth wear, or break. Replacements of worn, distorted or broken gears are required to insure efficiency and proper operation.
Drip Loop/ Tower Cables	Defines the transition from the rotating nacelle to the static tower area. Cables used in the drip loop are susceptible to continued strain due to the axial rotation.	Cables are inspected for any signs of damage; repair generally requires replacement of the damaged length. Can be subjected to cycles of continuous torsional movement, abrasive conditions, severe low temperatures, and a variety of lubricating oils, hydraulic fluids, and grease.

LAPP GROUP WIND TORSION ATTRIBUTES AND TEST STANDARDS

The Wind Turbine's drip loop tower cables are subjected to a severe degree of strain, so it is critical to use cables that can withstand it. This strain, in the form of vertical torsion, is created when the turbine nacelle turns to fully utilize wind direction. When selecting a cable for this application, look for cables that have been designed specifically to accommodate the torsional stresses caused by repeated turning motions within the turbine.

Torsion Test Method

Test Parameters	Test Values
Temperature	Ambient
Angle of Torsion	± 150° / meter
Test Length	2.5 meters
Test angle depending on the test length	± 375°
Rotational Speed	1 RPM
Tensile Load	Simulated to satisfy field application length
Cycles	5,000

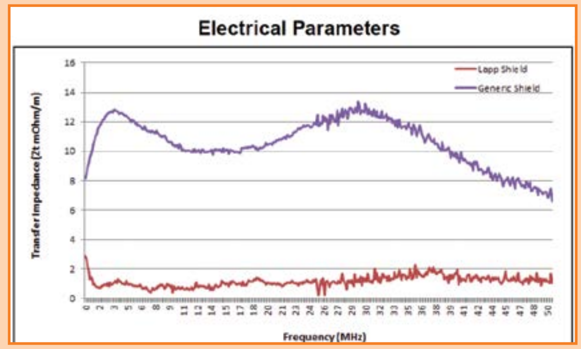
Lapp has developed a torsion and bending test system to ensure that its cables will continue to perform under these extreme conditions. During the test, cables are set up in a vertical formation, connected to a current source and subjected to the required cycles of torsional twisting at the specified test angle. A computer monitors the number of test cycles continuously for twenty-four hours per day, seven days per week and records the data. Once the required test cycle intervals have been achieved, testing is complete.* Because of this stringent testing, Lapp established industry-standard cable attributes WT-01 and WT-02 to evaluate torsional cable performance. WT-01 passes the minimum UL 1277 Cold Bend Test @ –20°C. WT–02 passes the –40°C Cold Bend Test. Some of the products pass the UL 1277 Cold Impact Test @ –40°C.

*Note, however, that the number of completed cycles does not indicate a cable failure has occurred.

LAPP Rating	Test Angle (± °/m)	Cycles	Temperature (°C)
WT-01	150	5,000	-20
WT-02	150	2,000	-40
WT-03	150	2,000	-50

ELECTRICAL CONSIDERATIONS

Electromagnetic Interference and Shielded Cables. Because wind turbines are comprised of many electrical systems, electromagnetic interference (EMI) is a common concern, and cables are highly susceptible to it. Since transfer impedance is a key parameter in determining the shield's performance of a cable, you'll want to select a cable with low transfer impedance. It's also worth noting that the type and quality of the cable shield and how it is terminated can improve noise immunity.



The test Equipment Lapp USA uses are a network analyzer and a precision tube to measure the transfer impedance of a shielded cable. The transfer Impedance test is performed per EN 50289–1–6 / IEC 62153–4–3 Ed2 Surface Transfer Impedance – Triaxial Method. The test setup consists of a network analyzer and a precision tube with terminations to the cable screen and the network analyzer.

Electromagnetic Interference and Shielded Cables. Because wind turbines are comprised of many electrical systems, electromagnetic interference (EMI) is a common concern, and cables are highly susceptible to it. This is especially true in models with space constraints, where a noise source is often located near sensitive equipment, increasing the likelihood of failure from EMI. Shielded cables help provide protection against sudden high electrical current surges that may occur on a cable that is connected to sensitive equipment, such as the CPU of the wind turbine. Protection against current surges is one of the primary reasons shielded cables are required in certain areas of the wind turbine. To provide the best protection, look for a product that incorporates the correct shielding design into the cable construction. Since transfer impedance is a key parameter in determining the shield's performance of a cable, you'll want to select a cable with low transfer impedance. It's also worth noting that the type and quality of the cable shield and how it is terminated can improve noise immunity.

Specifying the proper cabling is one of the simplest ways to keep wind turbines up and running. By adhering to industry standards and paying attention to the type of physical exposure the cable will see in use, design engineers can pick cables that will provide long uninterrupted service life even in the severe environment found on turbines.

LAPP GROUP PRODUCTS

Component Type	ÖLFLEX® 190	ÖLFLEX® TRAY II	ÖLFLEX® CONTROL TM	ÖLFLEX® FORTIS	UNITRONIC® 300 CY	UNITRONIC® BUS CAN	ETHERLINE® 2pr CAT.5/ CAT.5e	ETHERLINE® TORSION	H07BN4-F	SKINTOP®	EPIC®
Pitch System	X	X	X		X		X			X	X
Cabinet	X	X	X	X		X	X			X	X
Gear Box	X	X	X	X						X	
Slip Ring	X	X	X		X	X	X			X	X
Brake	X	X	X		X		X			X	X
Generator	X	X	X	X						X	
Yaw Drive	X	X	X							X	X
Drip Loop / Tower Cables		X	X	X				X	X		

Approvals	ÖLFLEX® 190	ÖLFLEX® TRAY II	ÖLFLEX® CONTROL TM	ÖLFLEX® FORTIS	UNITRONIC® 300 CY	UNITRONIC® BUS CAN	ETHERLINE® 2pr CAT.5/ CAT.5e	ETHERLINE® TORSION	H07BN4-F	Standards
UL WTTC 1000V		X	X	X						UL
UL TC-ER		X	X	X						UL
UL MTW	X	X	X	X						UL
UL PLTC		X			X					UL
UL CMG					X					UL
UL Oil Res I	X	X	X	X	X					UL
UL Oil Res II	X	X	X	X						UL
-40°C Cold Bend	X	X	X	X						LAPP
-25°C Cold Impact		X	X	X	X*					CSA
-40°C Cold Impact				X						UL/CSA
CSA CIC/TC		X	X	X						CSA
FT4 Flame		X	X	X	X		X			CSA
Torsion	WT-01	WT-02	WT-02	WT-03	WT-02	WT-01	WT-01	WT-01	WT-01	LAPP

** Material components comply with CSA test requirements*

WIND TURBINE STANDARDS

UL Subject 6141 – Large Wind Turbine Systems. These requirements cover large wind turbine systems (WT) and electrical subassemblies. With respect to this standard, large WT are wind turbines where a user or service person may, or is intended to, enter the turbine to operate it or perform maintenance. These WT are for use in utility-interactive, grid-tied applications that operate in parallel with an electric power system (EPS) to supply power to common or stand-alone loads. This standard includes requirements for WT intended for EPS grid connections at transmission, sub-transmission and distribution levels, depending on the specifications of the specific WT.

UL Subject 6142 – Wind Turbine Generating Systems, Small. These requirements cover small wind turbine systems (WT) and electrical subassemblies. With respect to this standard, small WT are wind turbines where a user or service person is not intended or required to enter the turbine to operate or to perform maintenance. These units are for use in stand-alone (not grid-connected) or utility-interactive applications. Utility-interactive, grid-tied WT are operated in parallel with an electric power system (EPS) to supply power to common loads.

UL Subject 2277 – Outline of Investigation for Flexible Motor Supply Cable and Wind Turbine Tray Cable. This outline covers the requirements for Wind Turbine Tray Cable (WTTC) rated 1000 volts, 90 to 200°C dry and optionally rated 90°C wet. It also covers the requirements for Flexible Motor Supply Cable rated 1000 or 2000 volts and 90°C dry.

UL 1004–1 - Standard for Rotating Electrical Machines – General Requirements. This Standard applies to rotating electrical machines and linear motors both ac and dc, rated 7,200 volts or less and is used to evaluate both motors intended for field and factory installation. The requirements of this Standard that address the risk of fire do not apply to a motor provided with a metal enclosure where there are no openings in the enclosure through which molten metal, burning insulation, flaming particles or other ignited material could fall onto flammable material, or through which a flame could be projected.

UL 1004–4 – Standard for Electric Generators. This Standard is intended to be read together with the general requirements of UL 1004–1. The requirements in this Standard supplement or amend the requirements in UL 1004–1. The requirements of UL 1004–1 apply unless modified by this Standard. This Standard covers electric generators, that, when coupled with prime movers, such as engines or electric motors, are used to produce electricity. Both generators (dc machines) and alternators (ac machines) rated 7,200 volts or less, are covered.

CSA C61400–1–08 - Wind Turbines - Part 1: Design Requirements. This part of IEC 61400 specifies essential design requirements to ensure the engineering integrity of wind turbines. Its purpose is to provide an appropriate level of protection against damage from all hazards during the planned lifetime. This standard is concerned with all subsystems of wind turbines such as control and protection mechanisms, internal electrical systems, mechanical systems and support structures. This standard applies to wind turbines of all sizes. For small wind turbines, IEC 61400–2 may be applied.