Case Study of Lightning Damage to Wind Turbine Blade

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1.0 Summary

We examine a lightning event at a wind farm in south central Texas USA. The region has an approximate flash density of five to six strikes per sq. km. per year. Over a three-year period, about five percent of wind turbines at this facility have experienced some lightning damage to blades.

Figure 1: Characteristic lightning signature to blade tip

Lightning to Blade No. 4608 at Turbine No. 155 was the proximate cause of its subsequent failure. The National Lightning Detection Network at 08:30.36 on March 6, 2008 reported a 10kA strike in close proximity to the location of this turbine. Subsequent events are described. Our conclusions are based upon May 7-8, 2008 site observations, known lightning behavior, code references and studies by others.

2.0 Review of Lightning Physics

Tall towers may launch upwards lightning. Not withstanding its stochastic behavior, most lightning leaders seek out elevated grounded objects and impose electric fields upon them. These objects may respond with upwards streamers. When leaders and streamers connect, a high-energy electric circuit (flash) is completed.

In addition to electrical and magnetic properties, lightning contains X-Rays, light, an acoustic shock wave (thunder), which can approach some 10 atmospheres and heat where temperatures approach 55,000 F. Each flash may contain, on average, three to four strokes some 50 ms apart. The known consequences of lightning to wind turbine components are well described in the literature.

Lightning current parameter	Relevant component of the lightning strike	Effect	Endangered Components
peak current ***I***	first impulse current	potential rise of the wind power plant, voltage drop across cable shields	nacelle & power plant building, SCADA
specific energy ***W/R***	first impulse current	electromechanics, heating, evaporation	blades and bearings stressed by ***I***
charge ***Q***	long duration currents, first impulse current	melting	blades and bearings
average current steepness ***I/T1***	subsequent and super-imposed impulse currents	magnetic induction	SCADA
number of impulse currents ***n***	subsequent and super-imposed impulse currents	repeated H-field impulses	SCADA

Table 1: Lightning Effects to Components of Wind Turbines (Ref. 7.1)

Investigations into effects of thermal expansion of internal blade moisture was considered in this study. Ohmic heating to water vapor can cause a 2.1 X 10-4 increase in unit volume per degree Centigrade**.** This topic is further described in section 5.0, below.

3.0 Composition of the Turbine Blade with Lightning Protection

3.1 Construction of these 1.5MW turbine generator blades are fibreglas epoxy resin with an exterior gel coat. The blade interior structure is spar-reinforced with rigid polyurethane foam encased in fiberglass. Further interior strength is via "sandwich sheets" of urethane/fibreglas/urethane/fibreglas in built-up layers. It is not within the scope of this study to examine the cellular nature, sheer strength or other physical characteristics of urethane foam. However, crude experiments at the wind farm showed water was absorbed into urethane samples.

3.2 Lightning protection consists of several exterior copper “receptor” air termination discs, which are fastened to interior aluminum conductors running the length of the blade. Conductors are fastened to the blade and to one another with steel bolts. Near the blade root a portion of the conductor is imbedded into the fibreglas. The conductor transitions from the blade root area via bonding to the hub and thence to a ground reference.

Other components of the lightning protection systems were examined briefly. The manufacturer provided satisfactory surge protection for sensitive electronics. Grounding requirements were completed “per manufacturer’s specifications” by the installation contractor.

Figure 2: Damaged blade showing internal spars and lightning conductors

4.0 Codes and Standards Compliance

4.1 Compliance with information contained in ***NFPA-780 Standard for the Installation of Lightning Protection Systems, v. 2008.***

4.1.1 Section 4.5 - Aluminum is acceptable in place of copper as a conductor.

4.1.2 Section 4.5.3 - "An aluminum conductor shall not be… installed in a location subject to excessive moisture." The presence of moisture promotes corrosion on aluminum.

4.1.3 Section 4.10.2 - "No combination of materials shall be used that will form an electrolytic couple of such a nature that, in the presence of moisture, corrosion will be accelerated." The aluminum conductors are secured to the blade using steel bolts. Steel is not compatible with aluminum. Copper "receptors" are fastened to the aluminum conductor. Copper is not compatible with aluminum. Aluminum is the anode. Steel and copper are the cathodes.

4.2 Compliance with ***IEC 61400-24 (2008), Wind Turbine Generator Systems, Lightning Protection***. This document is in draft document stage and has not been distributed in final form. It was not consulted for this study.

5.0 Problem of Moisture Inside Blades

5.1 Condensation processes are dependant upon humidity, pressure and temperature. Changes in ambient conditions create differentials in water vapor pressure from outside-to-inside materials. Water vapor can condense on blade interior surfaces. Polyurethane foams used as structural spars and as honeycombed sandwich layers between fibreglas sheets may have varying degrees of absorption and permeability.

5.2 Moisture penetrating different locations of the blade interior may cause imbalances.

5.3 Moisture can penetrate blades via previous structural cracking or as a result of surface damage caused from previous lightnings.

5.4 Blade repairs that result in surface porosity may lead to future water ingress.

5.5 The combination of lightning's high temperatures (50,000 F) and residual internal moisture can lead to energetic events where accumulated moisture suddenly is phased into steam pressure expansion. Consequential damage can be some or all of: de-lamination; burst bonding; residue compromise; trailing edge cracking; detached blade pieces; de-bonding; longitudinal cracks; spar separation; fires due to presence of hydraulic fluids/lubricants; or partial or complete blade destruction.

5.6 Wind turbine blade failures create expensive repairs and loss of electric power production.

Figure 3: Removal of damaged blade root by crane

6.0 Conclusion

The lightning conductor did not conduct as designed. Lightning created an internal shock wave from air or moisture expansion, or both. Lightning temperatures may have caused interior moisture to transition to an expansive state (steam). In turn, over-pressures stressed the blade to subsequent failure. Further research into wind turbine blade interior air/moisture expansion issues is needed.

7.0 References

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7.6 NFPA-780 (2008), Standard for the Installation of Lightning Protection Systems, NFPA Quincy MA.