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National Renewable Energy Laboratory Program on Lightning Risk and Wind Turbine Generator Protection

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NATIONAL RENEWABLE ENERGY LABORATORY PROGRAM ON LIGHTNING RISK AND WIND TURBINE GENERATOR PROTECTION

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1.0 INTRODUCTION

In the early development of wind turbine generators (WTG) in the United States, wind farms were primarily located in California where lightning activity is the lowest in the United States. As such, lightning protection for wind turbines was not considered to be a major issue for designers or wind farm operators. However, wind turbine installations are expanding into the Midwest, Southwest and other regions of the United States where lightning activity is significantly more intense and lightning damage to wind turbines is more common. There is a growing need, therefore, to better understand lightning activity on wind farms and to improve wind turbine lightning protection systems.

In support of the U.S. Department of Energy/Electric Power Research Institute (DOE/EPRI) Utility Wind Turbine Verification Program (TVP), the National Renewable Energy Laboratory (NREL) has recently begun to take steps to determine the extent of damage due to lightning and the effectiveness of various lightning protection techniques for wind power plants. Working through the TVP program, NREL will also perform outreach and education to

- help manufacturers to provide equipment that is adequately designed to survive lightning
- make sure that operators are aware of effective safety procedures
- help site designers and wind farm developers take the risk of lightning into account as effectively as possible.

This paper will describe the NREL program for addressing lightning protection for wind turbines. A test program will begin this summer at the Central and South West Services Inc. (CSW) wind farm near Fort Davis, Texas, to assess lightning risk, the frequency of lightning strikes on wind turbines compared to risk assessment predictions, and the effectiveness of some protection techniques. A Web page will be assembled to provide resources for designers and operators and feedback for issues as they arise. Also, a database of lightning events (and corresponding damage) will be collected to assist in maturing the understanding of wind turbine lightning protection.

2.0 DESCRIPTION OF PROBLEM

Wind turbines are tall structures, and they are often located atop hills in cleared or naturally open areas. Consequently, they are highly exposed to direct lightning strikes. Additionally, WTGs are controlled by sophisticated low voltage controllers, and they are usually connected by distributed monitoring systems. Such systems are at extreme risk of damage from indirect lightning effects due to the nature of the associated high current pulses.

Hundreds of damaging lightning events on WTGs have been reported throughout the U.S. and Europe. The damage has varied from direct strikes to blades and electrical generation/transmission systems to indirect damage in wind farm monitoring communications circuits. The downtime and repair costs from these events has been large, according to a 1994 survey and article in *Windstats* (1), an analysis of survey data by UMIST (2), and reports from some projects in Texas (3). In many cases, even minor damage can lead to extended downtime and loss of production due to the difficulty of identifying, repairing or replacing controller components. In fact, the UMIST report indicated that a lightning fault causes more loss in wind turbine availability and production per incident than most other faults.

2.1 DAMAGE MECHANISMS

Dodd et al. (4) indicate that there are two mechanisms by which lightning strokes affect wind turbine operation:

1. Loss of hardware
   - mechanical hardware such as blades, bearings, etc.
   - high-voltage equipment such as generators, transformers, contactors, and switch gear
   - low-voltage circuits such as data acquisition, communication lines, and controller boards.
2. Loss of operation
   - damage on any hardware component listed above may cause loss of operation, which eventually translates to higher cost of wind-generated energy.

Mechanical hardware damage is usually caused by directly conducted lightning currents. Damage is minimized by installing lightning protection on each individual component. Heat related damage is caused by I^2R losses caused by the lightning current flowing through highly resistive material, e.g., blade FRP material. Thus, in this case, components prone to direct lightning current conduction should be protected by providing an alternate current path to deflect the majority of the lightning current from flowing through the component.

Electrical hardware damage can be caused by voltage surges due to inductive or capacitive coupling, so-called indirect effects of the lightning currents. Voltage surges can also be conducted through wires from inside or outside the wind farm. Surge protection and proper shielding can increase the immunity of electrical hardware against such disturbance, thereby minimizing the damage on the electrical side.

2.2 CURRENT STANDARDS AND RESEARCH

As is common in the wind industry, current IEEE standards (5, 6) and other structural protection standards (7) fall short in comprehensively covering the wind turbine application. Essentially, a WTG is a power plant atop a lightning rod with a low voltage controller between it and the path to ground. There is also a (usually) non-conductive, expensive component as the highest point, the blades. The problem is compounded by the stochastic nature of lightning. It is difficult to make judgments on patterns of damage when the nature of the event (and the protection system) can vary significantly.

International interest to improve WTG lightning protection was strongly displayed at well-attended experts meetings in 1994 in Milan, Italy (8) and recently in Germany. These were sponsored by the International Energy Agency (IEA) under their Annex XI Cooperation of Wind Turbine R&D. A great deal of interesting research on lightning protection in Europe was reported, including evaluating lightning connection points, testing blade and turbine protection techniques, and damage forensics. During the first meeting, it was decided that the IEA should develop recommended lightning safety practices to protect a wind turbine and make them available to the wind industry. NREL engineers attended both meetings and are currently participate in the development of the IEA recommended practices.

3.0 NREL LIGHTNING PROTECTION PROGRAM

In response to these issues, NREL has instituted a program to address the gaps in lightning protection practices in the wind industry. The goals of this effort are as follows:

- assist U.S. wind industry (utilities, turbine manufacturers, developers, O&M organizations) in protecting the wind turbines and wind farm equipment from lightning and its impacts
- maximize the safety of wind farm personnel
- minimize downtime of wind turbine operations due to lightning
- minimize wind turbine component damage that may occur due to lightning strikes
- identify reliable diagnostic procedures for accurately identifying that observed damage was caused by lightning.

NREL hosted a wind turbine lightning protection meeting at the National Wind Technology Center (NWTC) in January 1997 as part of its role to provide technical support to the Utility Wind Turbine Verification Program, a collaborative effort between the Department of Energy and the Electric Power Research Institute. Meeting participants included representatives from EPRI, utilities, wind turbine manufacturers, wind farm operators, and consultants specializing in wind energy and lightning protection. Information was shared about operational experiences with wind turbines in high lightning risk areas, recommended lightning protection techniques and design practices, and other related issues. At the close of the meeting, the participants recommended that NREL pursue the following lightning research activities:

- survey the existing lightning protection systems at a selected wind farm, monitor the lightning activity, and document the resulting damage
- develop a Web page for WTG lightning protection to inform the wind industry about lightning-related issues and experiences
- publish a technical report and present technical papers at industry conferences and workshops to disseminate lightning information gathered
- develop guidelines for WTG and wind plant lightning protection that complement the IEA recommended practices.

These and other steps are being taken to further the understanding of lightning protection of wind turbines.

3.1 SITE LIGHTNING RISK EVALUATION

The first item to be addressed is the assessment of lightning risk for specific WTGs at a potential wind farm site. We will utilize various methods that predict this risk level, and in-field monitoring data will be used to evaluate these techniques. Additionally, site personnel safety will be assessed using advanced lightning warning systems that provide sufficient notice to allow personnel to move to safety in advance of a lightning storm with minimal false alarms.

The National Lightning Detection Network (NLDN) will be used to perform site evaluations for existing wind farms. This will be matched against the standard approach and information from the in-field test. Although the NLDN has a smaller data history (8 years) than the isokeraunic map approach (100 years), it may prove to be more useful due to its accurate and localized nature.

Advanced warning of lightning is very useful for wind farm operations and maintenance (O&M). It allows operators to have warning of incoming storm activity with sufficient time to evacuate technicians from the usually exposed wind farm areas and the dangerous proximity of the turbines (due to the risk of deadly step voltages). Such devices range from the extremely sophisticated optical and potential gradient devices to simple hand held units that sense characteristic electromagnetic pulses from lightning strokes. This hardware will be deployed on-site and exercised and evaluated by O&M personnel and the test engineers.

3.2 FIELD TEST

A test is currently being instituted by NREL to determine the effectiveness of various lightning protection techniques for wind power plants. Analysis will be carried out to assess site specific lightning risk, the frequency of lightning strikes on wind turbines compared to risk assessment predictions, and the effectiveness of some protection techniques.

Additionally, the test includes evaluation of site lightning risk assessment tools and on-site lightning alert equipment to provide for operator safety. Such equipment provides a warning when a lightning storm or high-risk conditions are incoming so that operations and maintenance personnel or visitors can suspend activity and move to safety. It may also prove possible to use information from these devices to disconnect selected electrical or communications circuits during the time that lightning is in the area of the wind farm.

All twelve of the Zond Z-40 wind turbines at the CSW site and the point of common coupling (PCC) with the 25 kV distribution line will be instrumented to determine the source of lightning strikes. Sensors on each turbine will be set to monitor the lightning strikes. The lightning current will be detected with inductive shunts and current sensors (items 1 and 2 in Figure 1), and the communication lines will be monitored for voltage surges. These sensors and a pair of lightning-activated video cameras will be used to identify strike locations (i.e., what turbine, where on the turbine, or where on the ground nearby a turbine) and time stamp any lightning events. The point of common coupling (PCC) at the junction between the wind farm and the utility will also be monitored to capture and identify surges from either inside the wind farm or from the external power distribution network.

The National Lightning Detection Network will be utilized to evaluate the strength and the nature of strikes to WTGs and the wind farm site using the collected time stamped data. It is expected that we can measure the level of disturbance captured by the sensors on the wind turbines and the PCC and correlate the data from NLDN to gauge the level of lightning damage immunity of the wind turbine system.

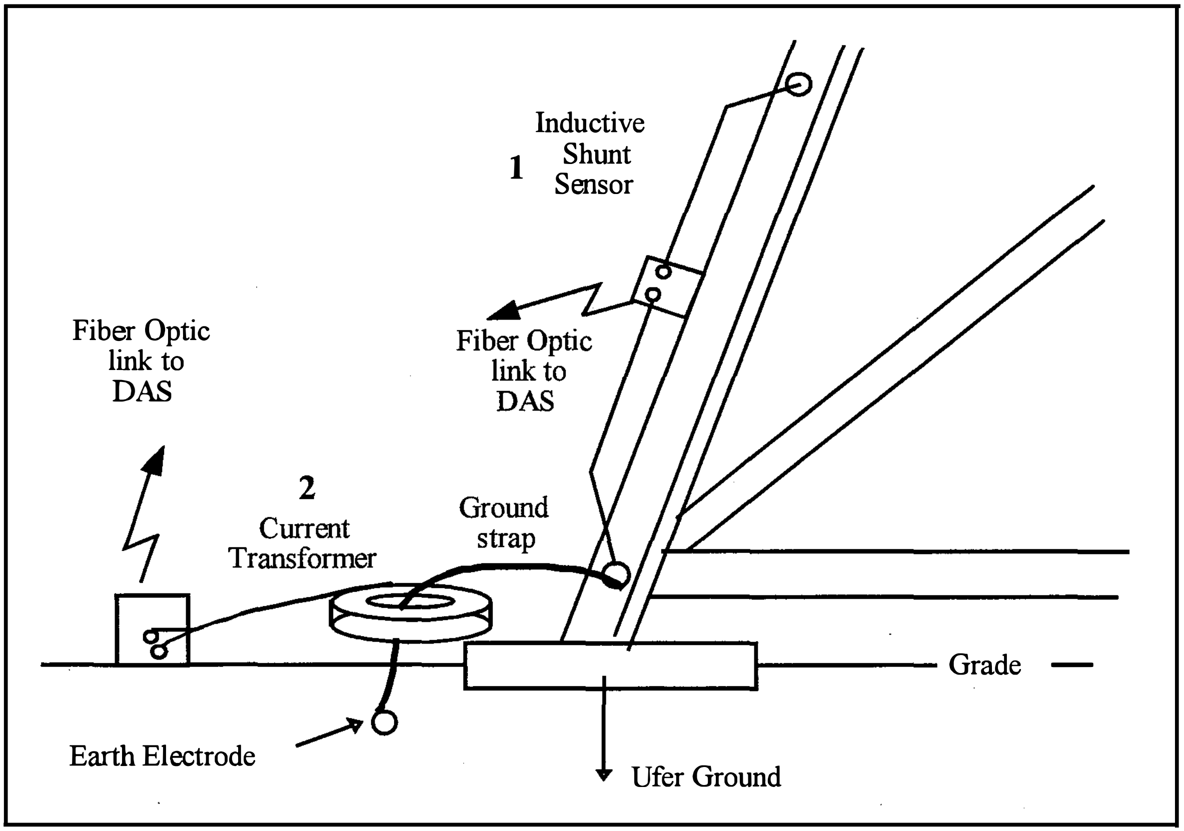

FIGURE 1 TOWER LEG LIGHTNING CURRENT SENSORS

3.3 INFORMATION DISSEMINATION

The Web page will be the primary vehicle for distributing information gathered from testing and monitoring other research. We expect to keep abreast of international research and recommendations through participation in the IEA program and basic literature searches. Additionally, several lightning consultants will be included to advise on proper protection techniques as reflected by research in complementary fields such as utility systems, aircraft, and the like.

The proposed contents of the Web page follows:

- NREL background on lightning protection for WTG & bibliography
- technical papers and reports on lightning relevant standards and recommended practices from IEA, IEEE , or NEC
- NREL lightning research activities—current status & future plans
- lightning damage survey for wind farm operators (i.e., forms, database statistics and results)
- lightning protection project results and recommendations (as they become available)
- wind turbine lightning safety guidelines for site personnel.

It should be noted that the information available and the survey data presented in the Web page will be masked in order to provide anonymity to the manufacturer and/or operator. This data will be gathered into a database and analyzed for the purpose of furthering our understanding of the impact of lightning damage to better protect wind turbine operation.

4.0 SUMMARY

In support of the DOE/EPRI TVP, NREL has begun to take steps to determine the extent of damage due to lightning and the effectiveness of various lightning protection techniques for wind power plants. Working through the TVP program, NREL will also perform outreach and education to

- help manufacturers to provide equipment that is adequately designed to survive lightning
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