Topic XI: Lightning Protection of Wind Turbines Moderator's Report

Chairman: D. Agoris *University of Patras, Greece*
Moderator: T. Sorensen *DONG Energy, Denmark*

I. Introduction

An impressive number of high quality papers on different aspects of lightning interaction with wind turbines, and on lightning protection and testing methods of wind turbines have been submitted to the ICLP 2006. This clearly reflects that the importance of effective lightning protection for the exploitation of wind as a significant source of energy has been acknowledged by the wind turbine manufactures, the wind turbine owners, governmental energy agencies as well as the lightning research community.

Today Wind Turbines are the fastest growing energy source with an average annual growth rate of more than 26% since 1990. By the end of year 2005 the wind turbine generating capacity installed in the world was more than 59 GW [1]. In the same period 1990 – 2005 the typical size of new wind turbines has increased from about 400 kW to 2000 kW in generating capacity and 50 m to 120 m in total height. As a consequence of the increase in wind turbine size lightning striking wind turbines have even in regions with little or moderate lightning activity changed from a rare event, say on average once in the 20 year life time of a wind turbine, to an event reoccurring every few years. Hence for large wind turbines lightning is a condition of operation, to be designed and tested for, just as blades are designed and tested for high wind loads, fatigue, etc.. Fortunately the lightning current parameters relevant for protection of wind turbines are well known and described statistically in the lightning protection standards [2]. Lightning protection of wind turbines has become too critically important for the safety and economics of the large wind power systems erected today to allow lightning damages to wind turbines to be dismissed as natural disasters or semi-superstitiously as Act-of-God events.

The papers presented in Topic XI *Lightning Protection of Wind Turbines* of the ICLP 2006 and briefly summarized in the following, are important contributions to the accumulation of knowledge with regards to lightning interaction with wind turbines, assessment and protection.

II. Oral Session XI-A: Blade Damage and Protection

Paper XI-1, Nilesh J. Vase, Takehiro Naka, Shigeru Yokoyama, Atsushi Wada, Akira Asakawa, Shinji Arinaga, *"Experimental study on lightning attachment manner considering various types of lightning protection measures on wind turbine blades"*: Reports on high voltage laboratory lightning attachment testing of wind turbine blade tip sections in long air-gab rod electrode – blade tip section configurations, and with the tip section positioned in different angles. Unprotected blade tip sections and tip sections protected with conducting caps and with receptors are tested. Effects of surface pollution are investigated, as blades in operation are polluted with conductive deposits which will change the discharge conditions over time.

Paper XI-2, Takehiro Naka, Nilesh J Vasa, Shigeru Yokoyama, Atsushi Wada, Shinji Arinaga, *"Investigation between electrostatic field analysis and results of lightning discharge experiment with wind turbine blades"*: Reports on 3-dimensional finite element electrostatic field modelling analysis of long air-gab high voltage rod - wind turbine blade tip section arrangements. The FEM modelling includes blade tips with and without lightning protection, and the effects of pollution of the blade surface. Area of maximum field intensification are identified and compared

Contact Address:
Troels Sorensen
DONG Energy
A.C. Meyersvaenge 9, DK-2450 Copenhagen SV, Denmark
E-mail: slt@e2.dk

to experimental results.

Paper XI-3, Shinji Arinaga, Kazuhisa Tsutsumi, Naoto Murata, Takatoshi Matsushita, Masaaki Shibata, Kosuke Inoue, Yasuhiro Korematsu, Yoshinori Ueda, Yukio Suguro, Shigeru Yokoyama, *"Experimental study on lightning protection methods for wind turbine blades"*: Reports on high voltage laboratory lightning attachment testing of wind turbine blade tip sections in long air-gab rod electrode – blade tip section configurations, and with the tip section positioned in different angles, where the effects of different tip receptor configurations are investigated. Furthermore are described experiments with a real 29.5 m long blade suspended horizontally above an earth plane, where the blade down conductor was energized with a high voltage generator.

Paper XI-4, Soren F Madsen, Joachim Holboll, Mogens Henriksen, Kim Bertelsen, Hans V Erichsen, *"New test method for evaluating the lightning protection system on wind turbine blades"*: Reports on the development and experiences with an experimental procedure for high voltage testing of wind turbine blade tip sections based on the air craft industry lightning test standard SAE ARP 5416. The blade tip is suspended above an earth plane, and high voltage switching impulses shaped (50-250 us/ 2500 us) are applied to the blade tip down conductor. This procedure represents the conditions with natural lightning more realistic, as the long impulse allows time for development of leaders from the blade lightning protection receptors, whereas testing with high voltage rods pointed at the test object (as per the test procedure described in the US MIL 1757A) tend to give unrealistic results.

Paper XI-5, Joachim Holboll, Soren F Madsen, Mogens Henriksen, Kim Bertelsen, Hans V Erichsen, *"Discharge phenomena in the tip area of wind turbine blades and their dependency on material and environmental parameters"*: Reports on theoretical and experimental investigations of details in the electrical discharge processes, which are important for understanding how the lightning protection of wind turbine blades works, namely the formation of discharges in air and along surfaces, influences of space and surface charges, influences of surface pollution, and probably most important of all – the insulation breakdown strength of the blade composite materials. Graphics and UV-photographs are very instructive.

Paper XI-6, Masahiro Hanai, Hiroshi Koyama, Norio Kubo, Yoichi Hashimoto, Isamu Suzuki, Yoshinori Ueda, Haruo Sakamoto, *"Reproduction and Test Method of FRP Blade Failure for Wind Turbine Generators Caused by Lightning"*: Reports on experimental high voltage testing in long air-gab rod electrode – glass fibre reinforced plastic (GFRP) plate configurations. The GFRP plates investigated differed with regards to fibre orientation, aluminium coating, and inlayed copper mesh. Furthermore the paper reports on high current tests which demonstrate that surface discharges on cause a slight burn of the surface, while arcs penetrating to the inside of the blade cause the blade to be ripped open along the edges, and it is found that an 50 Hz alternating short circuit current cause damages similar to lightning damages.

Paper XI-7, Haruo Sakamoto, Norio Kubo, Youichi Hashimoto, Isamu Suzuki, Yoshinori Ueda, Masahiro Hanai, *"Lightning Failure Protection of FRP blade for Wind Power Generators"*: Reports on experimental high current tests on glass fibre reinforced plastic (GFRP) specimens of different types of fibre, aluminium coating and inlayed copper mesh. Details of resulting damages are presented, and compared to real lightning damages to blades. Furthermore results are presented from test of ½ and 1/1 blade tip models with and without aluminium coating.

III. Oral Session XI-B: Observation and Assessment

Paper XI-8, Hitoshi Sakurano, Minoru Hashimoto, Koichi Nakamura, *"Observation of Winter Lightning Striking a Wind Power Generation Tower and a Lightning Tower"*: Reports observations of lightning striking on a 100 m high wind turbine and on a 105 m high tower placed 45 m away. Lightning current measurements and photographic recordings were made. Peak current and total lightning charge statistics of lightning striking the wind turbines and striking the tower are presented. Influence of wind direction on whether lightning strikes the wind turbine or the tower is presented. Furthermore statistics of the position of the blade relative to vertical at time of lightning strike is presented.

Paper XI-9, Bastian Lewke, Florian Krug, Josef Kindersberger, *"Risk of Lightning Strike to Wind Turbines for Maintenance Personnel Inside the Hub"*: Reports on numerical Method-of-Moment simulation of magnetic fields inside the hub of a wind turbine when stuck by lightning in a blade. The purpose is to evaluate the levels of current induced in people working in the hub, and induced in wiring in the hub. The numerical modelling is verified with laboratory measurements of fields when injection a surge current into a hub. The investigation shows a significant influence of openings in the hub (i.e. man holes and openings towards the blades) on the field levels inside the hub.

Paper XI-10, Josef Birkl, Christian Frey, Peter Zahlmann, *"How to verify lightning protection efficiency for wind turbines? Testing procedures for lightning protection components"*: Reports on the status of lightning current testing on wind turbine components as has been made by Dehn + Soehne in the past several years in cooperation with numerous international manufactures of wind turbines. Tests procedures are described for bearings and brush protection systems, for blade tip samples, for electrical systems in nacelle and hub, and for low voltage power supply connection unit.

Paper XI-11, Masayuki Minowa, Masayasu Minami, Masayuki Yoda, *"Research into Lightning Damages and*

Protection Systems for Wind Power Plants in Japan": Reports on lightning damages and economical losses experienced in 8 wind turbine installations erected between 1994 and 2003 in the high winter lightning occurrence region of Japan facing the Japan Sea. The population of wind turbines, 12 in total, includes 6 turbines with lightning protected blades, one of which suffered damage despite the blade protection. Frequent damages are reported to unprotected blades as well as wind turbine control systems, sensors, and power systems. One wind turbine suffered 9 lightning damages in the period 1999-2004.

Paper XI-12, Kazuo Yamamoto, Taku Noda, Shigeru Yokoyama, Ametani Akihiro, *"A Study of Lightning Over voltages in Wind Turbine Generation Systems"*: Reports on experimental investigations with injection of impulse currents into blade tip and nacelle of a 3:100 scale model of a wind turbine. Voltage differences between wind turbine tower and an incoming conductor, between down conductor in tower and incoming conductor, and voltages induced in a loop inside the tower are reported as functions of injected current.

Paper XI-13, Yoh Yasuda, Takuma Yoshioka, Toshiaki Ueda, *"FDTD Analysis on Wind Turbine Earthing"*: Reports on Finite Difference Time Domain (FDTD) simulations of wind turbine earthing systems in different configurations of foundation earthing, ring electrode and depth electrodes. Resulting earth potential rise, earthing impedance is presented for different soil resistivity.

Paper XI-14, Yoh Yasuda, Naoki Uno, Hayato Kobayashi, Toshihisa Funabashi, *"Surge Analysis on Wind Farm at Winter Lightning Stroke"'*: Reports on transient simulations of a high voltage (6.6 kV) collection system connecting 10 wind turbines in a wind farm. The energy stress of HV arresters and corresponding risk of arrester failures is analyzed depending on which wind turbine in the wind farm is struck by lightning, depending on earthing resistance, and depending on whether the injected lightning current is characteristic of summer lightning or winter lightning.

IV. POSTER SESSION XI-P

Paper XI-15, Kosuke Inoue, Yasuhiro Korematsu, Nobuyasu Nakamura, Takatoshi Matsushita, Naoto Murata, Takao Kuroiwa, Masaaki Shibata, Yoshinori Ueda, Shinji Arinaga, Yukio Suguro, *"Study on damage-mechanism of wind turbine blades by lightning strike"*: Reports on experimental and analytical studies of pressure build up in closed cylinder and in wind turbine blade tips due to internal arc discharges. A proportional relationship is found between arc energy and pressure, and an inverse relationship between pressure and volume.

Paper XI-16, Shin Ichi Sumi, Hisashi Aichi, Kenji Horii, Masayuki Yoda, Masayasu Minami, Masayuki Minowa, *"Breakdown Tests of Wind Turbine Blade for Improved Lightning Protection"*: Reports on HV voltage tests performed on rod electrode – wind turbine blade section configurations, - on rod electrode – whole blade configurations. It is found that discharges inside the blade, voids in glued connections between blade sides, and electro conductive pollution may cause discharges through the blade material. Rocket triggered lightning experiments leading 'natural' lightning discharges to a 1.8 m long blade and resulting damage is reported.

Paper XI-17, Yasufumi Ishige, Nobuhiko Usui, Toru Tamagawa, Ryuichi Shimada, *"New lightning protection for wind turbine blade"*: Reports on investigations of the properties of a lightning protective paint developed for wind turbine blades. High voltage and impulse current experiments are presented which demonstrate that the paint prevents penetration of discharges into the interior of a 1.5 m long wind turbine blade sections.

Paper XI-18, Yasuhiro Shiraishi, Takahiro Otsuka, *"The Observation and a Study of Direct Lightning Stroke Current through the Wind Turbine Generator System"*: Reports on lightning current measurements performed on wind turbines on the Japan Sea coast. The current sensor used is a large Rogowski coil which is placed around the root of the wind turbine tower. 4 wind turbines are equipped with a peak current and total charge measuring device, one of which is also equipped with a device which records the current waveform. It is found that wind turbines placed higher and more exposed to the main wind direction experience more lightning strikes, as compared to wind turbines placed down wind. It is found that earthing leads inside a tower only conducts about 30% of the lightning current observed in the tower, and that the higher frequency components of the lightning current is not flowing into earthing leads inside the tower.

Paper XI-19, Mitsuru Furue, Ryuichi Maruyama, *"Activity Report on Study of Lightning Protection Measures for Wind Turbine Generators (WTG)"*: Reports on the Japanese 2004-2006 program for studying lightning in relation to wind turbines which includes the following activities: (1) Collection of lightning related information, (2) Measurement of winter time lightning currents using actual wind turbine generators, (3) Compilation of a lightning map by energy level, (4) Compilation of basic documents for lightning protection measures, (5) Establishment of a committee. The paper gives a survey of the activities in the program.

Paper XI-20, Masaru Ideno, Kazuichi Seki, *"Study of Improvement in a Performance of Wind Turbine Generation Systems and Lightning Damage"*: Reports statistical information on lightning damages to wind turbines in Japan, and it includes an analytical assessment of heating of wind turbine blade down conductors when conducting lightning current.

Paper XI-21, Kazunari Hanaya, Shigero Enomoto, Yoshio Watanabe, Shunichi Yanagawa, *"Measurement of Overvoltage generated in Equipments inside Wind Turbine"*: Reports on experimental investigations of voltage differences and current distributions in a real wind turbine injected with impulse current in the nacelle. Voltage differences between the core conductors and local earth are measured for cables placed inside the tower from the nacelle to ground level. Voltages are measured at top and bottom for cables without shield, for cables with shield earthed at one end, and with shield earthed at both ends. The current flowing in the cable shield is measured.

Paper XI-22, Yoh Yasuda, Toshiaki Fujii, *"FDTD Analysis on Ring-shaped Lightning Conductor for Wind Turbine"*: Reports on an innovative lightning protection system for wind turbines where the lightning current is diverted from the blades to earth via a system of double ring conductors around the hub and the top of the tower respectively and from the latter to earth via a down conductor separate from the tower. The system is analysed with Finite Difference Time Domain transient simulations to identify the positions of the rings where spark over to the nacelle and tower are avoided and the distances between the rings where spark-over between the rings occur. The simulation results are verified experimentally on a 1:100 scale model.

Paper XI-23, Kazuo Yamamoto, Masaki Morimoto, Keisuke Tamura, Nobutaka Mori, Akihiro Ametani, *"A Study of Lightning Overvoltages in a Pole-Mounted Transformer connected to a Small Wind Turbine Generation System"*: Reports on an experimental study of over voltages at the terminals of a pole mounted transformer connecting a small wind turbine system when injected with a lightning impulse current (1.2/50 us). The current is injected either on the low voltage phase conductor or on the transformer grounding wire. Over voltages are measured at the high voltage terminals, on the low voltage terminals and on transformer grounding wire. Measurement are performed for varying earthing resistances and for varying loads connected to the high voltage side.

V. Conclusions and Recommendations

Today it is quite clear that by applying standard earthing and lightning protection methods to the electric and electronic systems in wind power systems, it is possible to reduce lightning damages and interruptions for these systems to an operationally acceptable level [2], [3]. Several of the papers presented in Topic XI are significant contributions to understanding how to apply lightning protection for the electric and electronic systems in wind turbines effectively.

Effective methods for lightning protection of the large composite blades, which are the typical point of lightning strike, and the large bearings and gears which are in the down conduction path, are needed.

Many papers presented in Topic XI deal with lightning damages to blades, lightning protection of blades, and testing methods. Important findings are presented in the papers, but it is also reasonable to conclude, that there is definitely need for further work. For future work it is recommended to think of lightning protection systems for wind turbine blades as high voltage electrodes positioned in a rather inhomogeneous high voltage insulation system, where the actual blade construction, the material systems in the blades and the quality and homogeneity of the materials need to be considered carefully. Correspondingly high voltage and high currents tests needs to be developed which represent the lightning attachment to blades realistically and which can be standardised for qualification of lightning protection solutions particularly for blades and bearings.

Although it is obvious, that in many wind turbine constructions significant parts of the current from lightning attaching to the blades must pass through the large bearings and gears, very little information is available in the literature about damages and reductions of remaining lifetime for these important components. Effects of lightning current on bearings and gears and effective protection systems are therefore subjects which need further research.

The safety for people working in and on wind turbines during thunderstorms and lightning strikes are also important fields of further research.

VI. References

[1] Global Wind Energy Council, "Global Wind 2005 Report", [Online]. Available: http://www.gwec.net

[2] IEC TR 62305, "Lightning Protection", 2006, [Online]. Available: http://www.iec.ch

[3] IEC TR 61400-24, "Wind Turbine Generator Systems – Part 24: Lightning Protection", 2002, [Online]. Available: http://www.iec.ch