LIGHTNING STRIKE SENSOR FOR POWER PRODUCING WIND TURBINES

T. Sorensen and M.H. Brask, DEFU[#]; P. Johansen, Jomitek; F.V. Jensen and N. Raben, SEAS;
J.T. Soerensen and H. Nielsen, Aalborg University; K. Olsen and M.L. Olsen; DTI.
[#]DEFU, P.O. Box 259, DK-2800 Lyngby (Denmark).
Tel: +45 4588 1400 – Fax: +45 4593 1288 – E-mail: info@defu.dk

INTRODUCTION

The paper presents a developed lightning sensor system for wind turbines. The sensor system registers lightning flashes striking the wind turbine regardless of the location of the attachment point on the wind turbine and gives an unambiguous signal to the wind turbine control system.

The lightning sensor system solves the problem of registering lightning striking wind turbines, which has become an increasing problem for Danish power companies who operate large numbers of wind turbines placed at locations long distances from the control and dispatch centres - and even off-shore.

KEY WORDS

Wind turbine, lightning, sensor, surveillance, control, safety.

BACKGROUND

Experiences from lightning strikes to wind turbines in Denmark have shown that interruptions and minor damages caused by lightning are difficult to identify. It is not uncommon that minor damages caused by lightning are not identified at first, and in some cases wind turbines with minor lightning damages have been operated for some time after the lightning strike until the damages were discovered more or less by chance. Obviously such unnoticed lightning damages represent a safety hazard both to the wind turbine itself and to people, livestock and equipment.

The need for a lightning sensor system for wind turbines was originally realised by the power company SEAS, who operate about 200 wind turbines including wind turbines placed off-shore.

The developed lightning sensor system described herein is designed for giving a highly reliable and unambiguous signal when lightning has struck the wind turbine. This signal may be used by the control system for automatic shut down after lightning strikes or relayed to the operator. The operator may then use the signal for deciding to instigate an inspection.

THE PROJECT ORGANISATION

The participating parties have different tasks in the project. DEFU came up with the basic ideas for the sensing principle and for the electronics, and DEFU is the project co-ordinator. The manufacturer of the lightning sensor system, Jomitek, who develops special sensing devices for power companies, was introduced to the project as a member of the DEFU Industry Co-operation. Aalborg University was involved in early investigations, and in the laboratory testing of the final system. DTI is involved in the project as specialists in product development. The power company SEAS, who originally realised the need for a lightning sensor for wind turbines, operates the 36 wind turbines on which the sensor system will be tested in 1999-2000.

SYSTEM DESCRIPTION

The sensor system is based on two magnetic loop antennae 10 cm by 20 cm in size that are mounted on opposite sides of the wind turbine tower at a height of approximately 3 m to be out of reach for people standing on the ground (fig. 1).

The magnetic signals picked up by the two loop antennae are fed via coax cables to a small converter box placed on the inside wall of the turbine at the height of the loops. In the converter box the signals from the loops are combined, filtered and converted into an optical signal. The lightning current itself provides the power necessary for generating the optical signal, hence no power supply is needed.

An optical fibre is used for transmitting the optical signal to a receiver box, which interfaces to the wind turbine control system. The receiver box may conveniently be placed in the wind turbine control cabinet. By using an optical fibre for transmitting the signal, complete galvanic separation and very good noise immunity is achieved. This means that lightning striking the wind turbine can be registered by the lightning sensor system without any risk of damaging the wind turbine power and control systems.

The electronics in the receiver box are powered by 230 V from the normal wind turbine power supply. Furthermore a battery is built in for backup power supply, as the most common type of lightning damage to modern wind turbines is damage to the control and communication systems (50 % of reported damages) followed by damages to the power system (20 %) [1]. The lightning sensor system is therefore able to detect lightning even when the wind turbine is without power. The electronics in the receiver box retains the lightning alarm signal until acknowledged by the wind turbine control system or manually reset. In the not unlikely event that a lightning stroke upsets the wind turbine power or control system the backup battery enables the electronics in the receiver box to retain the lightning alarm signal for several weeks. The alarm will then be given when power and control is restored, and furthermore a diode on the receiver box will give a signal indicating lightning strike, which is useful to personnel inspecting the wind turbine.

All parts of the lightning sensor system are made of high quality materials and components in order to ensure high system reliability, high mechanical strength and long lifetime even under the harsh environmental conditions off-shore. Thus the loop antennae are made of stainless steel and IP67 sealed, and all cables, connectors and boxes are RFI/EMI shielded, and IP55 sealed.

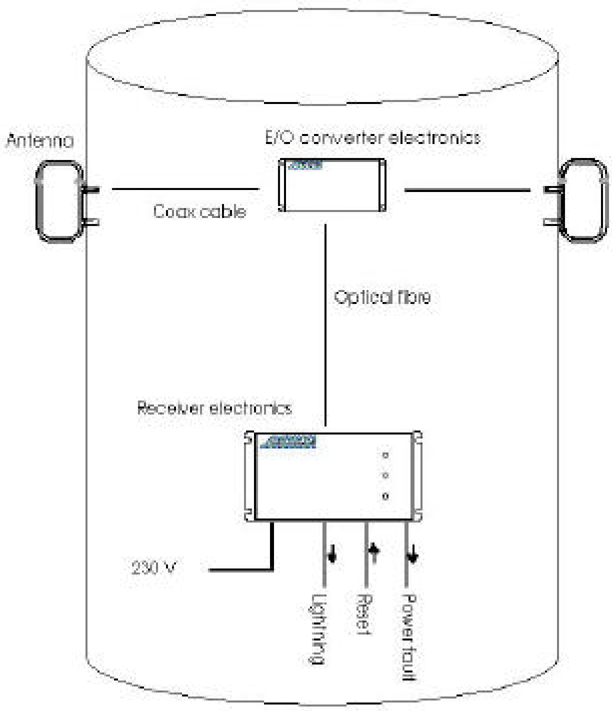

Figure 1: System overview showing the two loop antennae placed on opposite sides of the tower , the cabling and the electronics boxes – drawing not to scale.

SENSITIVITY

The lighting sensor system is designed to register lightning striking the wind turbine anywhere above the loop antennae, whereas lightning striking ground or e.g. another wind turbine nearby should not trigger the system. This is achieved by using two loop antennae placed on opposite sides of the wind turbine tower as described above.

The signals from the two loops are added when lightning current passes through the wind turbine tower on its way to ground, whereas the signals are subtracted when lightning strikes nearby. The trigger level of the sensor system for lightning flashes striking the wind turbine is adjustable, but normally set at 500 A peak current (8/20 μs).

The ability of the sensor system to distinguish between lightning striking the wind turbine and nearby lightning can be characterised by the peak lightning current needed for the system to be triggered by nearby lightning.

The signal picked up by one loop when lightning current passes through the wind turbine tower is proportional to the mutual coupling M_t, which can be approximated as:

$$M_t = k \cdot \ln\left(\frac{a + r}{r}\right)$$

where k is a constant , a is the loop width and r is the tower radius.

Likewise the signal picked up by the one loop antenna on the tower, when lightning strikes at a distance R from the tower is proportional to the mutual coupling M_d, which can be approximated as:

$$M_d = k \cdot \ln\left(\frac{(a \cdot \cos\alpha) + R}{R}\right)$$

where α is the angle between the loop plane and the direction towards the lightning channel, and R is the distance to the lightning channel.

Assuming a certain trigger threshold peak current and wave shape e.g. 500 A (8/20 μs) for a lightning current passing through the tower, then lightning striking at a distance R must have the ratio M_t / M_d times higher peak current, in order to give a signal strong enough to trigger the system.

This is illustrated in fig. 2, which gives a horizontal view of the area around a wind turbine. The vertical axis of the wind turbine tower is at (x,y)=(0,0), and only one loop antenna is placed on the side of the tower parallel to the x-axis (tower radius 1 m at the height of the antenna). It can be seen that a lightning flash with 50 kA peak current striking ground at 100 m from the wind turbine, would be able to trigger a system with only one loop (500 A trigger level). Even at 400 m very powerful lightning flashes with 200 kA peak current would be able to trigger a system with only one loop.

The advantage of using two loop antennae becomes clear, when looking at fig. 3, where the two loop antennae are placed on opposite sides of the tower parallel to the x-axis. The curves show how close nearby lightning flashes with 5 kA, 50 kA, 200 kA and 500 kA peak lightning current must be to the wind turbine to able to trigger the system. It can be seen that with a trigger level of 500 A for lightning currents through the wind turbine tower, lightning flashes with 50 kA

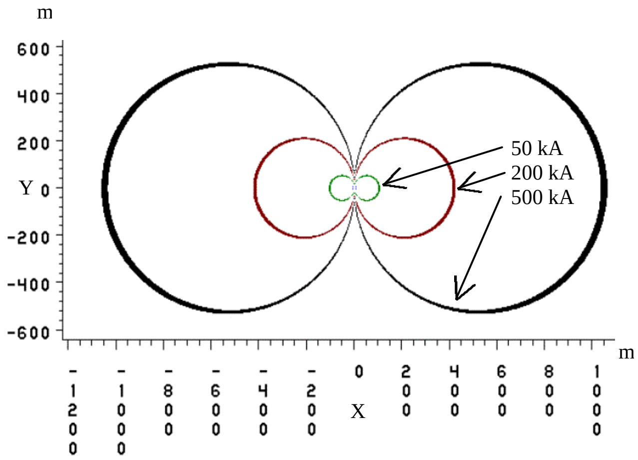

Figure 2: Horizontal view of positions at which nearby lightning with peak currents of 50 kA, 200 kA and 500 kA can trigger a lightning sensor system with only one loop antenna placed on the side of a wind turbine with tower radius 1 m. The vertical axis of the tower is at (x,y)=(0,0) and the plane of the loop antenna is parallel to the x-axis.

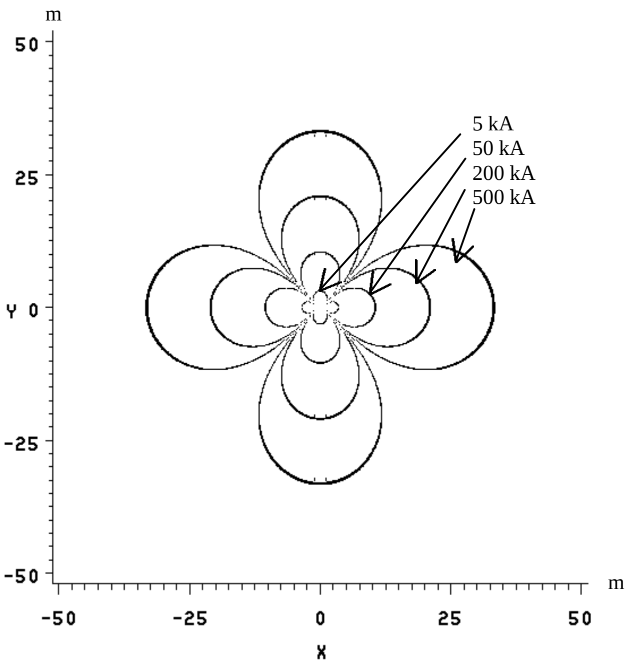

Figure 3: Horizontal view of positions at which nearby lightning flashes with peak currents of 5 kA, 50 kA, 200 kA and 500 kA can trigger the lightning sensor system with two loop antennae placed on opposite sides of a wind turbine with tower radius 1 m. The vertical axis of the tower is at (x,y)=(0,0) and the plane of the loop antennae are parallel to the x-axis.

peak current must be 10 m or closer to the wind turbine (tower radius 1 m) in order to trigger the system. Even a very powerful lightning flash with 200 kA peak current must be 20 m or closer to the tower.

Any lightning striking ground as close to a wind turbine as 20 m is highly unlikely, and thus considering the peak current levels and pulse shapes for natural lightning [2,3] the possibility of nearby lightning triggering the system is negligible.

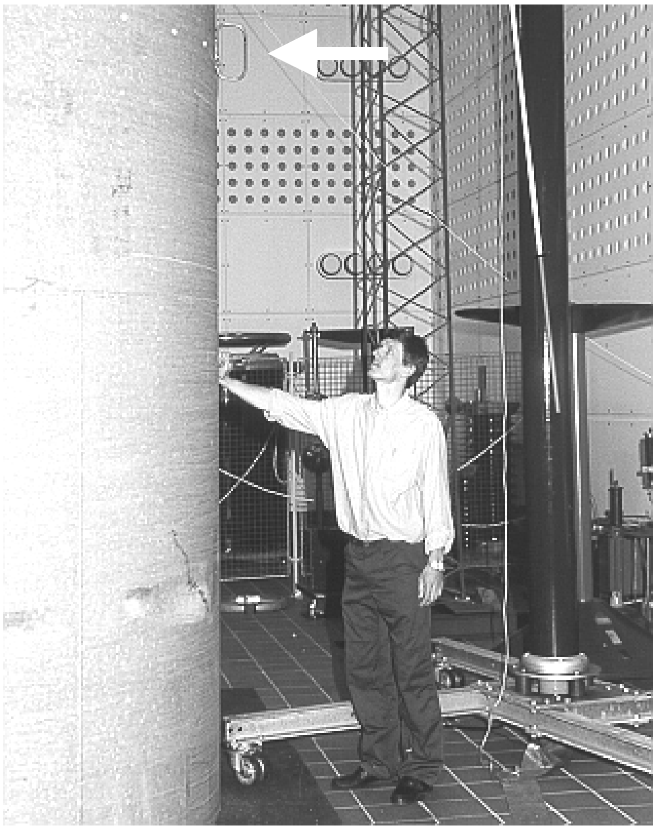

Figure 4: Laboratory testing of the sensor system. The loop antennae were mounted at a height of 3 m on opposite sides of a eight m high wind turbine tower section.

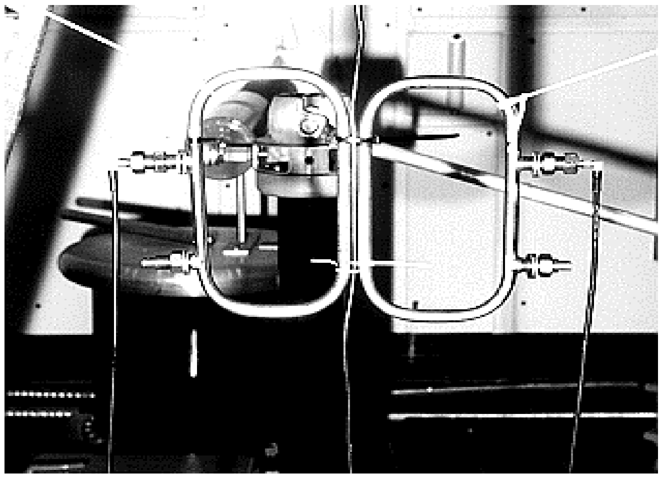

Figure 5: Scale test where the two loop antennae are brought closer together and subjected to a magnetic field corresponding to that of lightning flashes with high peak lightning current levels.

LABORATORY TESTING

The lightning sensor system has been tested in the high voltage laboratory at Aalborg University. For the tests the loop antennae were mounted on an 8 m high wind turbine tower section (fig. 4). As trigger level tests current pulses of different peak current levels up to 4 kA (approx. 8/20 µs pulse shape) were injected into the tower section at the top.

The tested system invariably triggered at peak current levels above a threshold of 500 A. Trigger tests with peak currents higher than 4 kA could not be made on the tower section due to the high inductance of the circuit and due to limitations of the surge current generator. Successful scale test were made, however, where the two loop antennae were brought closer together and subjected to a magnetic field corresponding to that of a peak lightning current of 200 kA in a wind turbine tower (fig. 5).

Further tests were made that confirmed that the lightning sensor system is not affected by other currents within the tower, such as short circuit currents between phase conductors and the tower.

FIELD TEST PROGRAM

A field test program of the sensor system is conducted in the years 1999-2000 with a total of 36 - 40 sensors. The first sensor system was placed on a 1 MW wind turbine in Copenhagen (fig. 6 and 7). This turbine has been struck by lightning at least two times in the past.

Also included in the field test program are the 11 Bonus 450 kW wind turbines in the off-shore wind park Vindeby, and the 24 DWT 400 kW wind turbines in the wind park Kappel. These wind turbines are operated by the power company SEAS.

The main objective of the field test program is to evaluate the lightning sensor system design when subjected to the influences of climate etc. A secondary objective is of course to register lightning striking the turbines. However, considering the low lightning density of on average 0.25 flashes per square km per year in Denmark, only a few lightning strikes can be expected within the two years.

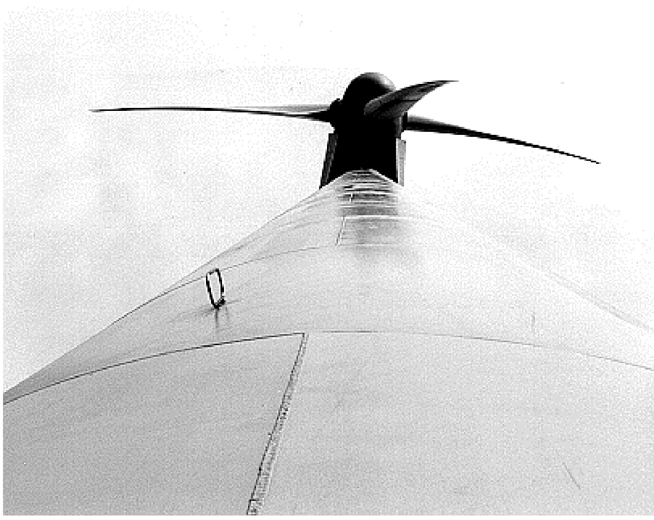

Figure 6: One of the loop antennae for the lightning sensor system placed on the tower of a 1 MW wind turbine at the power plant Avedøreværket in Copenhagen.

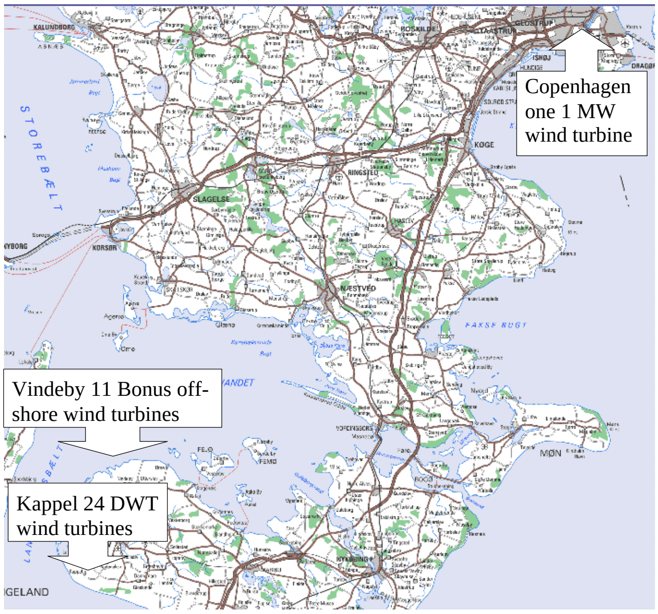

Figure 7: Locations of wind turbines used for the field test program.

ACKNOWLEDGEMENTS

Support by a grant from the Danish Energy Agency (J. No. 51171/97-0042) is gratefully acknowledged.

ADDRESSES OF AUTHORS

T. Sorensen, DEFU - Research Institute of Danish Electric Utilities, P.O. Box 259, DK-2800 Lyngby, Denmark.
Tel: +45 4588 1400, Fax: +45 4593 1288,
E-mail: trs@defu.dk

M.H. Brask, DEFU - Research Institute of Danish Electric Utilities, P.O. Box 259, DK-2800 Lyngby, Denmark.
Tel: +45 4588 1400, Fax: +45 4593 1288,
E-mail: mhb@defu.dk

P. Johansen, Jomitek, Skovlytoften 4, DK-2840 Holte, Denmark.
Tel: +45 4546 1415, Fax: +45 4546 1416,
E-mail: info@jomitek.dk

F.V. Jensen, SEAS, Slagterivej 25, DK-4690 Haslev, Denmark.
Tel: +45 5631 2700, Fax: +45 5631 5042,
E-mail: Flemming.Vagn.Jensen@seas.dk

N. Raben, SEAS, Slagterivej 25, DK-4690 Haslev, Denmark.
Tel: +45 5631 2700, Fax: +45 5631 5042,
E-mail: Niels.Raben@seas.dk

J.T. Sorensen, AAU - Aalborg University, Institute of Energy Technology, DK-9220 Aalborg Ø, Denmark.
Tel: +45 9814 1853, Fax: +45 9815 1411,
E-mail: jts@iet.auc.dk

H. Nielsen, AAU - Aalborg University, Institute of Energy Technology, DK-9220 Aalborg Ø, Denmark.
Tel: +45 9635 9276, Fax: +45 9815 1411,
E-mail: hn@iet.auc.dk

K. Olsen, K; DTI - Danish Technological Institute, Teknologiparken, DK-8000 Århus C, Denmark.
Tel: +45 8943 8446, Fax: +45 8943 8425,
E-mail: Kaj.Olsen@teknologisk.dk

M.L. Olsen, DTI - Danish Technological Institute, Teknologiparken, DK-8000 Århus C, Denmark.
Tel: +45 8943 8408, Fax: +45 8943 8425,
E-mail: Martin.L.Olsen@teknologisk.dk

REFERENCES

[1] Sorensen T. Brask, M.H.; Grabau, P.; Olsen, K.O.; Olsen, M.L.: *Lightning Damages to Power Generating Wind Turbines.* 24th ICLP Int. Conf. on Lightning Protection, Birmingham UK, September 14-18,1998.

[2] IEC 61024-1: *Protection of Structures against Lightning – Part 1: General Principles*, 1990.

[3] IEC 61024-1-1: *Protection of Structures against Lightning – Guide A – Selection of Protection Levels for Lightning Protection Systems*, 1993.