TECHNICAL REPORT

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2002-07

Wind turbine generator systems –

**Part 24:
Lightning protection**

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WIND TURBINE GENERATOR SYSTEMS –

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FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.

IEC 61400-24, which is a technical report, has been prepared by IEC technical committee 88: Wind turbine systems.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
88/128/CDV	88/142/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

This document, which is purely informative, is not to be regarded as an International Standard.

The committee has decided that the contents of this publication will remain unchanged until 2007. At this date, the publication will be either

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

INTRODUCTION

During the last few years damage to wind turbines due to lightning strokes has been recognized as an increasing problem. The increasing number and height of installed turbines have resulted in an incidence of lightning damage greater than anticipated with repair costs beyond acceptable levels. The influence of lightning faults on operational reliability becomes a concern as the capacity of individual wind turbines increases and turbines move offshore. This is particularly the case when several large wind turbines are operated together in wind farm installations since the potential loss of multiple large production units due to one lightning flash is unacceptable.

Unlike other electrical installations, such as overhead lines, substations and power plants, where protective conductors can be arranged around or above the installation in question, wind turbines pose a different lightning protection problem due to their physical size and nature. Wind turbines typically have two or three blades with a diameter up to 100 m or more rotating 100 m above the ground. In addition, there is extensive use of insulating composite materials, such as glass fibre reinforced plastic, as load-carrying parts. The lightning protection system has to be fully integrated into the different parts of the wind turbines to ensure that all parts likely to be lightning attachment points are able to withstand the impact of the lightning and that the lightning current may be conducted safely from the attachment points to the ground without unacceptable damage or disturbances to the systems.

To that end this report was developed to inform designers, purchasers, operators, certification agencies and installers of wind turbines on the state-of-the-art of lightning protection of wind turbines.

WIND TURBINE GENERATOR SYSTEMS –

Part 24: Lightning protection

1 Scope

During the last few years, all major wind turbine manufacturers have made dedicated efforts towards developing adequate lightning protection systems, and the first experiences with these new designs are beginning to be seen. It is therefore reasonable at this time to consider and prepare for a standardization effort that will give both manufacturers and operators a common framework for appropriate lightning protection of wind turbines.

On the above background the following elements of work have formed the scope of a new working group with the specific aim of preparing a technical report on the subject prior to considering development of a full standard:

- identify the generic problems involved in lightning protection of wind turbines;
- collect and systematize existing experience with both older and new designs of wind turbines;
- describe appropriate methods for evaluating the risk of lightning damage to wind turbines, thereby making reliable cost-benefit evaluations of lightning protection efforts possible;
- describe and outline appropriate methods for lightning protection of wind turbine components, considering the special nature of wind turbines and the extensive use of composite materials;
- compile a technical report outlining problems and solutions as seen today. The working group should identify and quantify areas where further research and proper standardization efforts are needed.

This technical report is structured as follows:

- clause 3 gives the background on the current understanding on lightning phenomenology and its impact on wind turbines;
- clause 4 presents the lightning damage experience as extracted from the various national wind turbine databases;
- clause 5 describes risk evaluation;
- clauses 6 through 10 discuss appropriate methods for protection against lightning damage;
- clause 11 identifies areas for further research.

2 Definitions

For the purposes of this technical report, the following definitions apply.

2.1
accepted lightning flash frequency (N_c)
maximum accepted average annual frequency of lightning flashes which can cause damage to the structure

2.2
air-termination system
part of the external LPS which is intended to intercept lightning flashes

2.3
bonding conductor
conductor interconnecting separate installation parts to equalize potentials between them

2.4
bonding bar
bar on which metal installations, electric power and telecommunication lines, and other cables can be bonded to an LPS

2.5
dangerous sparking
unacceptable electrical discharges caused by lightning currents in the structure to be protected

2.6
direct lightning flash frequency to a structure (N_d)
expected average annual number of direct lightning flashes to the structure

2.7
down-conductor system
part of an external LPS which is intended to conduct lightning current from the air-termination system to the earth-termination system

2.8
downward flash
lightning flash initiated by a downward leader from cloud to earth. A downward flash consists of a first short stroke, which can be followed by subsequent short strokes and may include a long stroke

2.9
earth electrode
part or a group of parts of the earth-termination system which provides direct electrical contact with and disperses the lightning current to the earth

2.10
earth-termination system
part of an external LPS which is intended to conduct and disperse the lightning current to the earth

2.11
effective height (h)
effective height of a wind turbine is the highest point the blades reach, i.e. hub height plus rotor radius

2.12
efficiency of LPS (E)
ratio of the average annual number of direct lightning flashes which cannot cause damage to the structure to the direct lightning flash number to the structure. E can be expressed as the product of the interception efficiency (E_i) and sizing efficiency (E_s) expressing the probability with which the LPS protects the structure against direct lightning flashes

2.13
equivalent collection area (A_e)
equivalent collection area of a structure is defined as an area of ground surface which has the same annual frequency of direct lightning flashes as the structure

2.14
external lightning protection system
consists of an air-termination system, a down conduction system and an earth termination system

2.15
flash charge (Q_{flash})
time integral of the lightning current for the entire lightning flash duration

2.16
foundation earth electrode
reinforcement steel of foundation or additional conductor embedded in the concrete foundation of a structure and used as an earth electrode

2.17
frequency of damage by direct lightning flashes
average number of direct lighting flashes to the structure

2.18
ground flash density (N_g)
average annual ground flash density is the number of lightning flashes per square kilometre per year, concerning the region where the structure is located

2.19
interception efficiency (E_i)
probability with which the air-termination system of an LPS intercepts a lightning stroke

2.20
internal lightning protection system
all measures additional to those mentioned under external lightning protection system including the equipotential bonding, the compliance of the safety distance and the reduction of the electromagnetic effects of lightning current within the structure to be protected

2.21
lightning protection system (LPS)
the complete system used to protect a structure and its contents against the effects of lightning. Commonly it consists of both external and internal lightning protection systems

2.22
lightning current (i)
current flowing at the point of strike

2.23
“natural” components of LPS
component installed not specifically for lightning protection which can be used in addition to the LPS or in some cases could provide the function of one or more parts of the LPS

2.24
peak value (I)
maximum value of the lightning current

2.25
lightning equipotential bonding
bonding of separated conducting installation parts by means of direct conductors or SPD, involved into an internal LPS, to reduce potential differences between these parts caused by lightning current

2.26
lightning stroke
single discharge in a lightning flash to earth

2.27
lightning flash to earth
electric discharge of atmospheric origin between cloud and earth consisting of one or more strokes

2.28
lightning protection zone (LPZ)
zones where lightning electromagnetic environments are to be defined and controlled

2.29
long stroke
stroke with duration time T_{long} (time from the 10 % value on the front to the 10 % value on the tail) of the current typically more than 2 ms and less than 1 s (cf. IEC 61024-1)

2.30
metal installations
extended metal items in the structure to be protected which may form a path for the lightning current, such as the nacelle bed plate, the tower, ladders, elevator rails and wires and interconnected reinforcing steel

2.31
multiple strokes
lightning flash consisting in average of 3-4 strokes, with typical time interval between them of about 50 ms

2.32
point of strike
point where a lightning stroke contacts the earth, a structure or a lightning protection system

2.33
protection level
number denoting the classification of an LPS according to its efficiency

2.34
risk of damage
probable annual loss (human and goods) in a structure due to lightning

2.35
safety distance
minimum distance between two conductive parts within the structure to be protected between which no dangerous sparking can occur

2.36
short stroke
stroke with time to half value T_2 of the impulse current typically less than 2 ms (cf. IEC 61024-1)

2.37
sizing efficiency (E_s)
probability that the intercepted lightning stroke does not cause damage to the structure to be protected

2.38
specific energy (*W/R*)
time integral of the square of the lightning current for the flash duration; it represents the energy dissipated by the lightning current in a unit resistance

2.39
surge arrester
device designed to protect electrical apparatus from high transient voltage and to limit the duration and frequently the amplitude of follow-current. The term “surge arrester” includes any external series gap which is essential for the proper functioning of the device as installed for service, regardless of whether or not it is supplied as an integral part of the device

2.40
surge protective device (SPD)
device that is intended to limit transient overvoltages and divert surge currents

2.41
thunderstorm days (T_d)
number of thunderstorm days per year obtained from isoceraunic maps

2.42
upward flash
lightning flash initiated by an upward leader from an earthed structure to cloud. An upward flash consists of a first long stroke with or without multiple superimposed short strokes, which can be followed by subsequent short strokes possible including further long strokes

3 Lightning and wind turbines

3.1 The properties of lightning

A lightning stroke can be regarded as a current source. The maximum recorded value of lightning current produced by a single stroke is in the region of 300 kA. Similarly, the maximum recorded values of charge transfer and specific energy are 400 C and 20 MJ/Ω respectively.

These maximum values occur in only a small percentage of flashes worldwide. The median value of peak lightning current is approximately 30 kA with median values of charge transfer and specific energy of 5,2 C and 55 kJ/Ω, respectively. In addition, the electrical characteristics of a stroke vary with the type of lightning flash and the geographical location.

3.2 Lightning discharge formation and electrical parameters

Lightning strokes are produced following a separation of charge in thunderstorm clouds, a process detailed in a number of publications [1][1] [2] [3]. A lightning stroke is observed when this charge is discharged to the earth or to a neighbouring cloud. This chapter is concerned with the first of these discharges, the transfer of charge between a thundercloud and the earth.

A lightning discharge usually consists of several components. The whole event following the same ionized path is termed **flash** and may last more than 1 s. The individual components of a flash are called **strokes**.

Lightning discharges are one of two basic types, downward or upward initiated. A downward initiated discharge starts at the thundercloud and heads towards the earth. In contrast an upward initiated discharge starts at an exposed location of the earth (for example mountain top) or at the top of a tall earthed structure and heads towards a thundercloud. Commonly,

[1] Numbers in square brackets refer to the Bibliography.