Electric Power Systems Research 80 (2010) 489–494

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Transient EMF induced in LV cables due to wind turbine direct lightning strike

Petar Sarajčev*, Ivan Sarajčev, Ranko Goić

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Ruđera Boškovića bb, HR-21000 Split, Croatia

ARTICLE INFO

Article history:
Received 18 December 2008
Received in revised form 15 July 2009
Accepted 24 October 2009

Keywords:
Cables
Earthing
Electromotive force
Lightning
Travelling waves
Wind turbine

ABSTRACT

This paper presents a novel, easy to use, engineering method for determining the transient electromotive force (EMF) induced in low-voltage (LV) cables, connecting the wind turbine with a near-by transformer, in the event of direct lightning strike into the top of the wind turbine tower. Proposed method is based on the application of the travelling wave analysis onto the system consisted of wind turbine tower, earthing system of wind turbine, earthing system of near-by transformer station and LV cables connecting the wind turbine with associated transformer. Hence, this design gives rise to a complex, mutually connected, earthing system. Direct lightning strike to the wind turbine initiates a travelling wave process in the system consisted of lightning channel, wind turbine tower and earthing system of the wind turbine. Due to the transient nature of the observed phenomenon, current and voltage states at the earthing system as well as in the associated low-voltage cables are formed through the propagation and reflection of the accompanying travelling waves. Transient EMF induced in LV cables could endanger cable main insulation and insulation of the associated transformer LV winding. Developed theory is subsequently applied on the concrete wind turbine example.

1. Introduction

Wind turbines regularly present tall, isolated objects. Typical modern wind turbines have a rated power in the range of 1–2.5 MW with typical tower height 50–100 m. Length of one blade can reach 60 m. The large size, distinctive shape and the fact that they are open-air structures placed in often isolated, mountainous conditions means that they are vulnerable to lightning strikes. Areas of favourable locations for wind turbines usually coincide with areas of thunderstorm activity, which has been confirmed, amid others, by NASA report [1]. This report shows that in most areas where wind density is high, there are 30 or more thunderstorm days per year [1,2]. Wind turbine blades are by far the most likely points of direct lightning strike. However, almost any part of the turbine is susceptible to direct lightning strike. In a study completed in 2002, the National Renewable Energy Association statistics showed that up to 8 out of 100 wind turbines could be expected to receive one direct lightning strike every year [2,3]. Between 1992 and 1995, Germany alone reported 393 incidents of lightning damage to wind turbines, of which a 124 direct lightning strikes to the wind turbine [2,4].

Apart from serious damage to blades, breakdown of low-voltage and control circuits have frequently occurred in many wind farms throughout the world. According to IEC TR61400-24 [5], the most frequent failures, more than 50%, in wind turbine equipment are those occurring in low-voltage (LV), control, and communication circuits. Currently, available statistics reveal that between 4% and 8% of European wind turbines are damaged by lightning every year [6]. This situation is even worse in southern parts of Europe, due to the increased thunderstorm activity. Should lightning damage a wind turbine, production will be lost and expensive repairs may have to be carried out.

Typical wind turbine design, from the point of view of LV/MV transformer housing, can be divided in two categories: wind turbines with transformer housed at the base of the tower and wind turbines with transformer housed in a near-by object. This object (transformer station) provides a space for the transformer itself and other electrical equipment (MV switchgear and low-voltage installations). Hence, transformer station is connected with cables to the near-by wind turbine. This situation is graphically shown in Fig. 1.

Direct lightning strike to the wind turbine tower results with a complicated transient phenomenon, whose numerical solution procedures tend to be rather involved. Several sophisticated numerical procedures have been developed in recent years, which could account for the various phenomena that accompany such a lightning stroke occurrences. An excellent overview of the available numerical methods for the solution of the mentioned problems could be found in [7]. Treatment of the phenomena associated with direct lightning stroke, adopted in this paper, is confined to the basic engineering model. More advanced treatments could be found in e.g. [8,9]. Direct lightning strike to the wind turbine

* Corresponding author. Tel.: +385 21 305 806/725/736; fax: +385 21 463 877.
E-mail addresses: petar.sarajcev@fesb.hr (P. Sarajčev), ivan.sarajcev@fesb.hr (I. Sarajčev), rango.goic@fesb.hr (R. Goić).

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doi:10.1016/j.epsr.2009.10.032