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Computational Analysis of Thermal Degradation in Wind Turbine Spars' Equipotential Bonding Subjected to Lightning Strikes

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Abstract : Rotor blades of large, modern wind turbines are highly susceptible to downward lightning strikes, as well as to triggering upward lightning; consequently, it is necessary to equip them with an effective lightning protection system (LPS) in order to avoid any damage. The performance of existing LPSs is affected by carbon fibre reinforced polymer (CFRP) structures, which lead to lightning-induced damage in the blades, e.g. via electrical sparks. A solution to prevent internal arcing would be to electrically bond the LPS and the composite structures such that to obtain the same electric potential. Nevertheless, elevated temperatures are achieved at the joint interfaces because of high contact resistance, which melts and vaporises some of the epoxy resin matrix around the bonding. The produced high-pressure gasses open up the bonding and can ignite thermal sparks. The objective of this paper is to predict the current density distribution and the temperature field in the adhesive joint cross-section, in order to check whether the resin pyrolysis temperature is achieved and any damage is expected. The finite element method has been employed to solve both the current and heat transfer problems, which are considered weakly coupled. The mathematical model for electric current includes Maxwell-Ampere equation for induced electric field solved together with current conservation, while the thermal field is found from heat diffusion equation. In this way, the current sub-model calculates Joule heat release for a chosen bonding configuration, whereas the thermal analysis allows to determining threshold values of voltage and current density not to be exceeded in order to maintain the temperature across the joint below the pyrolysis temperature, therefore preventing the occurrence of outgassing. In addition, it provides an indication of the minimal number of bonding points. It is worth to mention that the numerical procedures presented in this study can be tailored and applied to any type of joints other than adhesive ones for wind turbine blades. For instance, they can be applied for lightning protection of aerospace bolted joints. Furthermore, they can even be customized to predict the electromagnetic response under lightning strikes of other wind turbine systems, such as nacelle and hub components.

Keywords : carbon fibre reinforced polymer, equipotential bonding, finite element method, FEM, lightning protection system, LPS, wind turbine blades
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