Lightning Protection of VAWT
Lightning protection of an experimental project of Vertical Axis Marine Wind turbine

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Abstract: The actual study presents the earthing and lightning protection of a marine vertical axis wind turbine (VAWT) and explains the most significant problems encountered during the conception.

Keywords—Lightning protection, VAWT, Wind turbine

I. INTRODUCTION
Considering the market potential for floating solutions, NENUPHAR, a French start-up, has developed an offshore floating VAWT (Vertical Axis Wind Turbine), based on a combination of several innovative components and manufacturing technologies and integrated with a semi-submersible floater. This technology aims at overcoming water depth limitation of fixed offshore wind turbines. A stall-regulated VAWT rotor is particularly adapted for floating applications, due to low center of gravity and reduced mechanical components (reduced maintenance).

Franklin France has been asked to collaborate on the lightning protection of such equipment which needs specific developments.

II. DESCRIPTION OF THE VAWT
The VAWT design is based on the following specifications:

The wind turbine architecture is optimized with no yaw, no pitch, and no gearbox. The EHS shall be friendly: No craning offshore shall be needed but only tug boats. Reduced complexity for installation and maintenance is a must.

Figure 1: VAWT global overview

Tilt tends to increase torque partly due to struts acting like blades.

III. ONSHORE TEST SITE
A first 35 kW onshore prototype has already been constructed and installed in the north of France. It is considered as a floating VAWT simulator, as the turbine can be tilted (offshore motion simulation).

The next step, currently being implemented, is the development of a 2 MW full-scale onshore...
prototype (called “Vertifloat”) in the south of France to validate VAWT rotor concept.

Extensive testing phase (power curve, loads, electrical behavior, lightning protection and wind flow) is planned for this prototype, before moving to the implementation of the full-scale offshore floating turbine. Testing of the onshore prototype involves validation of aerodynamic models and wind flow simulations for this innovative rotor concept.

Figure 2a: Phase 2 – Fos sur mer (France)

Figure 2b: Phase 2 – Fos sur mer (France)

IV. LIGHTNING PROTECTION AND EARTHING

A. Protection requests

Either during operation or at standstill, lightning strikes may occur and can critically damage the VAWT (mainly the blades or the struts), or basically may induce heavy electrical disturbances (or damage) to the Control & Safety Systems of the wind turbine by inducing a short term voltage potential elevation depending on the ground resistance of the site.

B. Earthing system description

The basic concept is to fulfill the NFC 17-102 standard [1] in use and the GL Wind recommendations [2].

The following Figure 1 shows a global overview of the items to be connected to the earth:

The earth potential is considered as the main voltage reference. The physical links to the earth allow a path for an electrical failure current to go back to its source and can be detected to trigger a protection system.

There are two structures that must be connected to the earth:

- The pylon of the VAWT in which all the electrical equipment is installed. The pylon is fully built in metallic material (steel).
- The substation in which auxiliary electrical equipment is also installed. The substation is made of concrete, with a lower section buried in the ground.

Between the pylon and the substation, flexible pipes are buried in the ground. Inside these pipes, power cables, communication cables, power supply lines are laid. One pipe is dedicated to cables that link together the pylon bonding bar and the substation bonding bar. This is the way the electrical main potential reference is achieved.

C. Pylon earthing system design

At the bottom of the pylon, a single bonding bar (which represents the electrical main potential reference) is connected to the pylon and to two buried structures:

- The first is a ring structure that can be compared to the substation buried structure. This ring structure is the lightning earth path which allows the lightning strike current to spread into the earth. The structure is linked with the substation buried structure in order to reduce the global resistance of the lightning earthing system.
- The second one is the metallic structure of the foundation. The steel bars are connected using special clamps to ensure a minimal contact resistance.

The previous structures are connected to the bonding bar using 3 connection points at 120°.

This structure permits a connection to the earth with a resistance value expected to be around 5 Ω maximum.
If this resistance value is not reached with the proposed structure, additional elements will be connected. This maximal resistance value of 5 Ω is expected to prevent any damage of the power electronic converters due to the transient voltage potential elevation.

V. LIGHTNING PROTECTION SYSTEM DESCRIPTION
The lightning protection system is based on:

✔ Lightning receptors placed on the blade winglets positioned at the top of the blade segments and conductors running through the blades and the struts (made of composite material) until the rotor mast (made in steel).
✔ An early streamer emission air terminal (ESEAT) device that is electronically triggered.
✔ A 4m high metallic additional mast where the streamer is installed at the top. At the bottom two straps are connected to the top hub structure.
✔ The steel structure of the main mast (where the struts are connected).
✔ The slewing bearing bypass made of 3 carbons brushes evenly spaced on the stationary ring of the slewing bearing every 120° and pressing against the rotating ring to ensure an electrical continuity between the rotor (rotating part) and the pylon (static part).
✔ The metallic pylon itself as a preferred path for the lightning strike current to join the earth.
✔ The earthing system previously described (substation and pylon interlinked buried structures).

In order to have an efficient lightning protection system, a preferred path (meaning lower electrical resistance) for the lightning strike current must be achieved along the structure.

A. Protection level
For offshore conditions, the protection level is 1, meaning that the diameter of the theoretical sphere to define the lightning system is 20 m.

B. Protection radius of an electronically triggered streamer
This radius can be calculated using the formula:

$$R_p = \sqrt{h (2D - h)} + \Delta L (2D + \Delta L) \text{ pour } h \geq 5 \text{ m}$$

Where:

✔ “h” is the height between the top of the streamer and the highest item to be protected (5m in our case).
✔ “D” is the diameter of the theoretical sphere for level 1 protection (20m in our case).

✔ “ΔL” is defined by the product of the speed v (m/µs) of the upgoing streamer and the ΔT value (pre-trigger time of the streamer) which is 60 µs in our case.

C. Structural elements used as natural conductors
It is possible according to [1] to use the structural elements as a natural path for the lightning current if the equivalent electrical resistance value is less or equal to 0,01 Ω. This means that steel elements can be part of the lightning earthing system.

D. The electronically triggered streamer
Retained early streamer (Ref. AFB 1762 2D):
A first device, named "impulse device" stores the electrostatic energy present in the atmosphere at the approach of a stormy cloud and releases the excitation of the ascending discharge at the right time.

![Figure 4: FRANKLIN Saint-Elme Active 2D® lightning conductor](image)

A second device, named "power device", collects and stores the wind and / or the solar energy in several strong power capacitors. The Saint-Elme lightning conductor is in this way permanently pre-loaded of an important energy which enables him to support the propagation of the ascendant tracer.

Close to the storm activity, an integrated sensor measuring the surrounding electric field value, releases the impulse device like most of usual Early Streamer Emission Air Terminals. Those lightning conductors almost immediately reverse the polarity of their head, creating a sudden amplification of the electrical field.

The innovation of Saint-Elme Active2D® lightning conductor comes from the use of a second integrated sensor which measures the intensity of the electric discharge current, which is formed on the lightning conductor’s head.

When the downward leader enters in the protection area of the lightning conductor, the measured current strongly increases. As soon as this current is higher than the characteristic threshold, the power capacitors discharge and release the necessary energy for the propagation of the leader.

In this last device, the lightning conductor’s head acts as a capture device. Therefore, the head is electrically insulated from the ground.

Main characteristics:
- Take in account the energetic information to choose the tracer which can become an ascending tracer
- Maintain the propagation of the tracer by discharge of the power device
- Source of energy autonomous and clean
- Solar (2) or wind (1) energy for the «power device»
- Atmospheric electrical field for the «impulse device» (3)
- Consider the cloud polarity
- Radius of curve of the head optimize to reduce the corona effect and guarantee the excitation device
- Protection of the electrical part against the rain with a dimensioned flange (4)
- Use of stainless steel to resist against corrosion

Figure 5: Zoomed view of the Saint-Elme Active 2D® lightning conductor

The early streamer will be installed with a “counter” that will allow to count the number of lightning strikes that have been captured by the early streamer.

It will be positioned on the highest hub cover at the top of a 4 m mast.

Another advantage is the height of this streamer. As it is much higher, the extending mast dimension will be reduced.

The protection radius of the ESEAT is:
- 31m at a height of 2m below the top of the ESE.
- 63m at a height of 4m below the top of the ESE.
- 79m at a height of 5m below the top of the ESE.

E. The rotating structure
The mast and the hubs are steel made, so they can be used as natural conductors (see chap. 5.3). To ensure electrical continuity all along the rotating structure, additional copper flexible straps will be used where greased bolting surfaces cannot ensure a resistance value of 0.01 Ω.

Figure 6 and Figure 7 below show the way the streamer will be installed:

F. Lightning protection of the blades
Blades are protected by installing the tip end receptors, connected to the main conductor (the main conductor passes through the blade and through the strut).

G. Lightning protection of the struts
Struts are protected by the “umbrella” of the lightning rod (streamer). Inside the struts, the conductor descending from the blade tip terminals is installed.

H. Lightning conductor in struts and blades
Copper conductor is embedded inside the blade and the struts to evacuate the lightning current.

I. Slewing bearing bypass
To prevent from any damage on the rolling elements of the slewing bearing, an electrical bypass must be achieved. To do
so, 3 brushes spaced 120° will be used, directly in contact with the top of the rotating ring of the bearing.

Figure 8 shows an equivalent type of brush and holder that will be used.

Connected to each brush, a rigid copper strap will go down to reach a screwed connection point at a level under the ring support.

This isolating part in epoxy has been designed so that it does not restrain the mechanic holding performance of the prototype.

A major point of the specification was that any data (parameters, test, etc…) of the lightning protection of the VAWT offshore wind farm must be available from NENUPHAR’s head office in Lille (France). If the experimentation proves that all the lightning strikes do not reach the blades, then the ESEAT efficiency and operationability will have been demonstrated. The ESEAT must therefore be “communicant”.

VII. CONCLUSIONS
The development of this very special system of lightning protection has been realized with a good cooperation between both teams.

The onshore project is at the time being in test phase. The offshore wind farm will be a very interesting in situ test for ESEAT if the test phase confirms the need of lightning protection on the tower.

VIII. ABBREVIATIONS AND ACRONYMS
VAWT: Vertical Axis Wind Turbine
HAWT: Horizontal Axis Wind Turbine
ESEAT: Early Streamer emission Air Terminals

IX. REFERENCES
[1]: NFC 17-102 (Release 2011): Lightning protection – Protection of structures and open areas against lightning using early streamer emission air terminals (French standard)
[3]: IEC61400-24 – Lightning Protection 2002