• What is lightning?
  Lightning is an electrical discharge in the atmosphere, very similar to a spark. It is the electrical breakdown of insulating air to provide a conductive path along which a current can run.

• An average bolt of lightning carries a current of 30 - 50kA, the highest reported to be 250kA.

• There are mainly two types of lightning, downward propagating and upward propagating. With more wind turbines moving offshore, upward initiated lightning will start to play a major role in assessing lightning damage.
Downward Propagating

- An initial path of ionised air, called “stepper Leader“, starts from negatively charged regions of the cloud (90%).
- The leader moves downwards in quick steps, sometimes 50mts long.
- Once the leader is closer to the ground, smaller discharges arise, usually from tall objects, due to the intense electric field of the approaching leader.
- The ckt is closed once these rising streamers meet the leader, thus giving rise to the main lightning stroke (return stroke) with a higher current.
Upward Propagating

- Similar to that of Downward propagating in the way the leader and streamer meet to form a conductive channel.
- Here the high electric field in the cloud attracts a leader from a tall object (tall buildings and Mountains).
- The leader again moves in steps towards the clouds and connects to a pocket of charge available, thus enabling a path for the return strike.
• What does a lightning strike require to form?
  1. A tall object capable of developing streamers or leaders
  2. Sharp edges where the field enhancement is high.

• ...Add these together, and a wind turbine, tall and its blades are the perfect set up for streamers that can attach themselves to incoming leaders.

• The blades are the most vulnerable parts to be damaged. Losses are incurred due to replacing these damaged blades and also due to downtime during replacement.

• All new blades are now protected with an inbuilt lightning protection system.
• Not all lightning strikes end up being intercepted by the receptor or the lightning protection points. Local damage to the area around receptors is still common.

• The main mechanism of damage is when the lightning current penetrates the blade and forms an arc inside.

• The pressure/shock wave could damage the blade, or cause cracks on the surface.

• Operators and manufacturers are trying to minimise damage on wind turbine blades as many of them move offshore and Offshore maintenance and repair is very expensive.
Data Analysis

- Two datasets analysed
- To sort data to assess the most vulnerable part of the wind turbine (e.g. blades, wind-vane, aircraft warning lights).
- Blades are the most vulnerable component and the most expensive component to repair.
- Data analysis reveals other components also have a high probability of lightning attachment (higher than that shown in papers by Madsen et al)
- It appears from this data that upward lightning is likely to be significant
- Expected for structures over 80m tall.
- Important knowledge in terms of modelling of lightning attachment
Lightning Current Probability

- Modelling of various combinations of upward / downward lightning has been carried out to assess likely current distributions that should be observed.
- Inclusion of around 75-80% of upward strikes gives correct probability distribution.
- Correlates well with the expected number of upward lightning strikes.
Data Analysis

- Higher than expected probability of strike to components other than blades
- Blades generally intercept higher peak currents
- A large number of strikes have low peak currents, indicating the probable presence of upward initiated lightning
- For the offshore windfarm, it can be seen that there are a larger number of strikes during winter as compared to that in other months
- The installation of the wind farms does increase the strike frequency of lightning as these tall structures do attract lightning. ( Strikes Recorded = 6 x Theoretical)
- Discrepancies in the PCS cards have been identified. The cards have been identified not to be as accurate as the manufacturer claims.
FEA Modelling Aims

• To create a wind turbine model in FEA software that can be used for upward lightning attachment modelling
• To determine the conditions required for successful leader inception and propagation.
• To determine the effect of cloud height on the lightning inception from a wind turbine, and to evaluate the ambient electric fields created due to a charged thunderstorm cloud
• To simulate the behaviour of a full scale wind turbine under a thunderstorm cloud
• To work with the radar side of the project and start to build FEA models with materials of stealth capability so as to find its effects on the existing lightning protection systems
FEA Modelling

Field Enhancement at Blades and Windvane
Stealth Blade Solution - RAM

- ATC and Marine radar have had problems with wind turbines, especially offshore wind turbines. Images show ghost targets, which are in reality not present.
- The model RCS Solution would consist of a 3 layers which would include a reflective surface and a high resistive layer in between the fiber glass layers.
- What impact would this have on lightning protection?
- The two main characteristics that have been analysed with the RCS solution are the Lightning Attachment and Lightning Current Conduction.
- FEA analysis performed for lightning attachment analysis.
- High Current Testing has been done on a Cu-Ni coated carbon fiber veil which could be used in the making of the stealth solution.
• Two lightning protection solutions exist – mesh and receptor
• Present model is based on the receptor lightning protection solution (mesh solution would only work in terms of radar should a specific dielectric layer be placed above it)
• Initial model shows a significant change in the field enhancement on the down conductor (i.e. the internal blade field). This is a positive result as the chances on streamers inside the blade are minimised.
• However, the field around the receptors is significantly distorted and reduced
• Once lightning attachment has been established, the lightning protection system will have to conduct the lightning current without damage, this is tested by high current tests.
A normal blade would show a high field intensification on the receptor.

The field is quite high on the surface of the down conductor as well.

The presence of a copper inner layer inside the fiber glass blade would decrease the blade internal field and, it seems, that around the receptor.

This would decrease the inception efficiency of the receptor.

An enhanced electric field inside the fiber glass also increases the risk of breakdown of this dielectric as well.
Impact on Lightning Current Conduction

- All lightning current carrying components needs to conduct and dissipate the energy without causing damage.
- Existing lightning protection systems rated to carry lightning current and are tested to confirm this.
- The new composite layer will have to carry part of the lightning current (IEC standards require current conduction of 200 kA).
- All conducting materials will have to be electrically bonded.
- High Current tests were performed on the new composite layer.
- Composite tested as itself and also as a sheet infused with epoxy.
High Current Tests

- Samples of different lengths and widths were tested.
- Ideally layers should distribute strike energy evenly thus avoiding damage to other layers.
- Unfortunately it does not, even at currents levels around 15kA.
Industrial Impact

• Data analysis brings about the importance of including upward initiated lightning into the standards. It highlights the risk of assessing lightning attachment on offshore wind farms, on the basis of historic data mostly consisting of downward initiated lightning.

• Data analysis shows the risk of increased lightning activity on offshore wind turbines. The analysis is the first of its kind and will help for future insight into this area.

• The analysis shows parts other than the blade at risk of lightning attachment as well. Though it cannot be confirmed that these are the only risk areas, due to absence of lightning registration systems at other areas.

• FEA modelling has confirmed other risk areas of lightning attachment other than the blades. These results match those of the data analysis.

• FEA Modelling can never replace full scale testing, but it will be a good start in assessing new prototype blades.

• With new materials being tested for both lightning protection and radar solutions, the present work shows the importance of trying to maintain the efficiency of the LPS whilst integrating new layers.