Lightning strikes: Challenges and mitigation

– N Karunamoorthy and A S Isverya

In India, wind sector is expanding rapidly – with the installed capacity being 53.12 GW as of September 2025. To achieve the government's target of 140 GW by 2030, hub height and rotor diameter of the wind turbines are increased, enabled by technological development. But this also makes the turbine blades more prone to lightning strikes.

Lightning is the discharge of electrical energy caused by imbalances between the cloud and the ground. This may create a surge in the electrical circuit which can be extremely destructive to the electrical equipment.

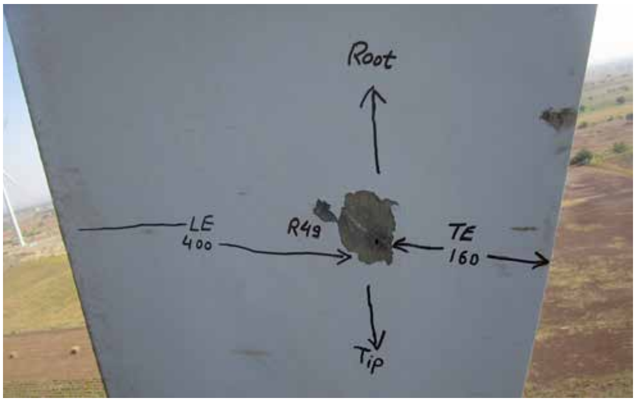
Lightning strikes on wind turbines are the most frequent and costly cause of damage which leads to unplanned downtime and major component failures in India as it is one of the most lightning prone countries in the world. In India, the coastal, hilly and high wind regions like Tamil Nadu, Gujarat, Maharashtra and Karnataka experience a combination of monsoon storms and high thunderstorm density which intensifies the lightning risk.

Challenges due to lightning in wind turbines

One lightning flash can discharge a current of about 200 kiloampere at a temperature of around 30,000°C. As India lies in a high lightning density zone, it experiences 15–20 flashes per sq.km annually. As hub height increases beyond 120–130m, the turbine blade becomes more susceptible to lightning.

There are three types of lightning impacts on wind turbine blades.

1. Direct strike: When lightning strikes the tip or middle of the blade, the heat due to lightning can burn a hole or shatter the laminate in the blade.



Lightning strikes can burn a hole in the blade (Photo: Windplus)

2. Surface flashover: While lightning current travels along the blade, it erodes the blade surface and receptors.
3. Secondary effect: Induced current from nearby strikes may cause control failure by damaging the sensors, pitch systems or communication cables.

These may also allow moisture ingress which significantly reduces the aerodynamic efficiency, and affects the annual energy production and structural life.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Lightning causes cracks on the blades (Photo: Windplus)

Several operational aspects also increase susceptibilities:

1. Old wind turbines: Turbines which were installed in the initial period of wind energy development and were not upgraded to the latest International Electrotechnical Commission (IEC) lightning standards.
2. High resistive soils: These types of soils are found in the hilly / rocky regions which cause poor grounding.
3. Inadequate inspection: The lightning receptors installed in the blade and the grounding pits are to be inspected on a regular basis. When these inspections are not performed at regular intervals, it may lead to the damage of blades.
4. Monsoon pattern: Monsoon triggers frequent thunderstorms.
5. Improper bonding: The improper bonding between the receptor systems and down conductor in blades may cause damage.
6. Degradation of lightning protection system (LPS) over time: Frequent exposure to lightning strike, corrosion, loose connectors or resin covering over the receptors degrades the LPS over a period.

Operational challenges

Lightning damage affects both the technical performance and financial viability of a project.

1. Extended downtime: When wind turbine blades are damaged, it may take a minimum of six months to dismantle the blades and replace the new blades depending on crane availability and OEM schedule.
2. Generation loss: As the downtime increases, it affects the generation. Since the turnaround period is six months, the generation loss will be enormous, ranging from 10–15 lakh units, if the downtime happens during the wind season.

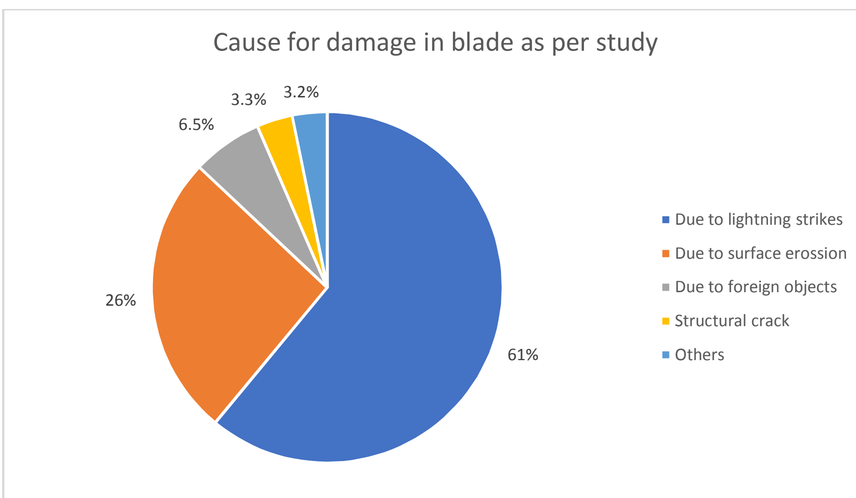
Technicians attending to lightning damages to reduce turbine downtime (Photo: Windplus)

3. Reduced profitability: The prolonged turnaround time could potentially result in a revenue loss of Rs 30–50 lakh. The long downtime not only stops energy production right away, but it also impacts the project's cash flow and yearly yield goals.

4. Cost of blade and other components: The cost of repairing or replacing the wind turbine blades and other components such as transformers and pitch control system is extremely high, as it requires specialised equipment, skilled resources and extended downtime. Although all turbine components have insurance, the expense for replacing or repairing the blade is too high which cannot be covered completely through the insurance amount. In many cases, the insurance claim dispute arises due to the classification of latent defects and force majeure. Some insurance classifies the failure as latent defect in design or material and rejects the claim or settles partially.

Case studies on lightning incidents in Indian wind projects

India's wind power generation is mainly concentrated in five states namely, Tamil Nadu, Gujarat, Karnataka, Maharashtra and Rajasthan. These states account for 80–85% of the total installed wind capacity and are considered to be the lightning prone zones in India. The major damages caused in blades are represented in the pie chart.



Blade damages caused due to lightning are classified as catastrophic, severe, normal and minor depending on the physical characteristics of the damage. Types of damages and their category are as follows:

Type of damage	Sub category	Level of severity
Tip detachment	a) Blade rupturing	Catastrophic damage
	b) Blade getting burnt	
	c) Wire melting	
Debonding and shell detachment	a) Surface cracking	Severe damage
	b) Surface tearing	
Debonding	a) Surface stripping	Normal damage
	b) Receptor loss	
Delamination	a) Receptor vaporisation	Minor damage
	b) Surface scorching and blotching	

Some of the recent incidents that occurred due to lightning are studied and mentioned in as per the severity.

Date of incident	Incident summary	Location	Operational impact	Cause	Level of severity
May 2024	Wind turbine caught fire	Jaisalmer, Rajasthan	Turbine nacelle and blade were burnt completely, which also had a long turnaround time.	It was caused due to heat wave and lightning.	Severe
October 2023	Wind turbine caught fire after a lightning strike during a sudden shower.	Kethanur, Palladam, Tamil Nadu	Turbine nacelle and blades were damaged completely and downtime/ repair or replacement time was too long.	It is suspected that the lightning conductor might have been damaged, due to which the turbine caught fire when there was a lightning during the monsoon storm.	Severe
July 2020	Wind turbine caught fire due to the lightning strike during peak monsoon time.	Nakhatrana, Kachchh, Gujarat	Turbine fire and visual destruction in blade and nacelle leading to long turnaround time.	It was caused due to the heavy lightning.	Severe

How turbines are protected?

Nowadays all modern wind turbines include lightning protection systems that provide a conductive path from the turbine blades to the ground, to ensure safe current dissipation. The key components present in modern wind turbines are:

1. Blade protection: Blade is protected by tip receptors, down conductors and lightning bands which channel the energy away from the composite materials.
2. Light current transfer unit (LCTU): Transfers the current from blade to nacelle safely by bypassing the bearings and gearbox.
3. Tower and foundation earthing: The current flows through the bronze yaw-ring connectors, and earthing bars into the concrete foundation.
4. Surge protection: Collectors, transformers and grid connections are safeguarded with overvoltage arrestors.

Protection type	Areas covered	Standard	Effectiveness
Standard LPS	Entire turbine (Top to ground)	IEC 62305/61400 - 24	Baseline Protection
Copper cap	Blade tip electric field control	IEC 61400 - 24:2010	80% fewer lightning incidences
Copper strips	Blade spar structural core	Field tested	Superior protection for high density sites.

Mitigation

Lightning related losses can be reduced by a combination of better design, preventive maintenance and real-time monitoring. Following approaches are effective in Indian wind farms:

1. Blade and receptor design improvements

   - Blade design can be improved by using integrated LPS with multiple receptors that are connected to the continuous conductive path to the root.
   - OEMs should ensure full electrical continuity of carbon fibre connectivity and tests should be conducted according to IEC 64100-24:2019 during manufacturing and after repairs.
   - Carbon fibre continuity checks must be carried even after repairs.

2. Site-specific lightning risk assessment

   Lightning risk assessment should be conducted by using

   - India Meteorological Department (IMD) or satellite-based lightning data.
   - Isokeraunic map and records of seasonal thunderstorm patterns.

   This helps in designing the blade.

3. Effective grounding and earthing

   - Earth resistance to be maintained at 1 ohm for each WTG. Grounding values to be tested and recorded regularly during every monsoon season and post-maintenance.
   - Ring electrodes and counterpoise systems should be used in rocky terrains to achieve effective grounding and earthing.

4. Routine inspection and monitoring

   - Periodic drone or thermal inspections should be carried out for degradation or delamination of receptors.
   - Lightning event counters should be installed and integrated with SCADA system to monitor and record the number of lightning strikes on the wind turbine blades.

5. Retrofitting older fleets

   - Install LPS, copper cap and strips in the old wind turbine blades which were installed before 2015, especially in the coastal and hilly regions where the lightning strikes are frequently experienced.
   - Grounding and surge protection of control panels should follow IEC 62305 standards.

6. Advantages

   Doing the above improves the turbine availability by 1–2% and strengthens the project bankability and long-term asset value.

Conclusion

Lightning still remains the most persistent operational challenge in India's wind power sector.

As India is moving towards 3–4 MW turbines with larger hub height and rotor diameter, lightning protection is not just a design element it also ensures the continuous operation. Due to unpredictable climate change, proactive lightning mitigation is possible using robust lightning protection for sustainable operation.

Developers, OEMs and O&M service providers must work together to:

1. Design turbines with Class I protection defined in the IEC 61400-24 standard that is suitable for India.
2. Maintain robust grounding and lightning protection systems and perform testing.
3. Integrate lightning monitoring system in SCADA to monitor the number, intensity and frequency of the lightning strikes.

By integrating these practices, India's wind sector can reduce lightning-related downtime, safeguard expensive assets and ensure sustainable power generation to achieve India's net zero target. In India's mission for a greener grid, lightning protection is not just related to safety, it's about resilience, reliability and future readiness.

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