

Enhancing Safety Performance Through Improved Hazard Identification and Risk Assessment in Wind Farm Operations

Aditya Kumar Singh¹, Prof. Vishal Tiwari²

¹Research Scholar, Department of Fire Technology & Safety Engineering,

School of Engineering and Technology Vikrant University, Gwalior, (M.P.), India

²M.Tech Guide, Department of Fire Technology & Safety Engineering,

School of Engineering and Technology Vikrant University, Gwalior, (M.P.), India

Abstract

The rapid expansion of wind energy has increased the importance of occupational health and safety throughout wind farm operations. Although wind power is a low-carbon source of electricity, workers involved in turbine installation, operation, inspection, maintenance, electrical work, lifting activities, and emergency response can be exposed to significant hazards. These include falls from height, electrical shock and arc flash, fire, falling objects, mechanical hazards, confined spaces, adverse weather, lifting and transportation hazards, ergonomic stress, and psychosocial risks. Previous research has identified working at height and falling objects among important occupational risks, while electrical and mechanical maintenance activities can also present substantial risks. ScienceDirect+1

This paper examines how improved **Hazard Identification and Risk Assessment (HIRA)** can enhance safety performance in wind farm operations. The proposed approach combines systematic hazard identification, task-based risk assessment, risk prioritization, implementation of the hierarchy of controls, worker participation, permit-to-work and lockout/tagout systems, emergency preparedness, and continuous monitoring of safety performance. A practical HIRA framework is proposed for major wind farm activities, including turbine access, climbing, electrical maintenance, mechanical maintenance, crane operations, blade inspection, confined-space entry, and emergency rescue. The study argues that HIRA should be treated as a dynamic process rather than a one-time compliance exercise. Continuous review of hazards, near misses, changes in operating conditions, and worker feedback can strengthen preventive safety management.

Keywords: Wind farm, wind turbine, hazard identification, risk assessment, HIRA, occupational safety, safety performance, maintenance, renewable energy, risk control.

Introduction

Wind energy has become an important component of the global transition toward renewable electricity. The expansion of wind farms has created employment in turbine manufacturing, transportation, construction, installation, operation, maintenance, inspection, and decommissioning. However, the development of a renewable-energy industry does not eliminate occupational hazards. Wind technicians frequently work in elevated and confined areas, around electrical equipment and rotating machinery, and sometimes in remote locations and changing weather conditions.

Research on occupational risk at onshore wind farms has identified several significant hazards. A quantitative study of wind-farm occupational risk considered construction, operation, and maintenance activities and found that electrical and maintenance workers could have substantial occupational risk. Falls from elevation and being struck by falling objects were identified among important hazards requiring risk-reduction measures. ScienceDirect

The U.S. Occupational Safety and Health Administration (OSHA) identifies a range of wind-energy hazards, including electrical hazards, falls, fires, confined spaces, machine hazards, crane and hoist hazards, and lockout/tagout

requirements. OSHA+1 Similarly, an EU occupational-safety review identifies hazards associated with remote work, extreme weather, confined spaces, awkward postures, electrical risks, falls from height, musculoskeletal disorders, physical and psychosocial workloads, and exposure to hazardous substances. Publications Office of the EU

Therefore, effective safety management in wind farms requires more than responding to accidents after they occur. A systematic **Hazard Identification and Risk Assessment (HIRA)** process can help organizations identify hazards before incidents occur, determine the level of risk, select appropriate controls, and monitor whether those controls remain effective.

Problem Statement

Wind turbine operation and maintenance involve multiple simultaneous hazards. Technicians may climb towers, enter nacelles, work near energized electrical systems, handle heavy components, perform mechanical repairs, use lifting equipment, and work under changing environmental conditions.

A major challenge is that risk levels can change according to:

- Type and condition of the turbine.
- Nature of the maintenance activity.
- Worker competency and experience.
- Weather conditions.
- Availability and condition of safety equipment.
- Electrical and mechanical isolation arrangements.
- Lifting and access arrangements.
- Emergency-response capability.
- Communication between workers and supervisors.
- Changes to equipment, procedures, or work organization.

A conventional risk assessment performed only during initial planning may therefore become inadequate when working conditions change. Research has also highlighted the need for better understanding of occupational hazards across the entire wind-energy lifecycle and for further research into combined and emerging risks. ScienceDirect

Aim of the Study

The main aim of this research is to **develop an improved hazard identification and risk assessment framework for enhancing occupational safety performance in wind farm operations.**

Objectives

The specific objectives are:

1. To identify major occupational hazards associated with wind farm operation and maintenance.
2. To examine existing approaches to hazard identification and risk assessment in wind energy.
3. To assess the potential risks associated with major wind farm work activities.
4. To develop a practical HIRA methodology for wind farm operations.
5. To recommend suitable control measures using the hierarchy of controls.

Literature Review

Occupational hazards in wind energy

Wind farm workers can encounter both conventional industrial hazards and hazards specific to wind turbine environments. A review of occupational health hazards in the wind industry identified areas including noise, electromagnetic fields, physical stress, chemical exposures, weather conditions, vibration, welding fumes, and biological hazards, while noting gaps in research concerning some exposures and combinations of hazards. ScienceDirect

Major operational hazards can be grouped as follows:

Hazard category Examples

Working at height Tower climbing, nacelle work, blade inspection

Electrical Electric shock, arc flash, energized equipment

Mechanical Rotating machinery, stored energy, crushing and entanglement

Falling objects Tools, components, ice or materials falling from elevation

Lifting Crane operations, suspended loads, component handling

Fire Electrical faults, hydraulic systems, overheating

Confined spaces Tower/nacelle spaces and other restricted areas

Environmental High winds, lightning, extreme temperatures, poor visibility

Ergonomic Awkward postures, manual handling, repetitive tasks

Chemical Lubricants, resins, cleaning chemicals and other substances

Psychosocial Isolation, workload, fatigue, time pressure and remote work

Transportation Vehicle movement, site access and component transportation

OSHA specifically identifies electrical shock, arc-flash, falls and thermal burns as serious hazards associated with wind-energy electrical work. OSHA

Hazard Identification and Risk Assessment

Hazard identification involves systematically determining sources or situations that could cause injury, illness, equipment damage, environmental harm, or other unwanted consequences.

Risk assessment then evaluates the likelihood and severity associated with identified hazards.

A basic risk model can be represented as:

Risk = Likelihood × Consequence

For example, a five-level matrix may be used:

Likelihood Description

1	Rare
2	Unlikely
3	Possible
4	Likely
5	Almost certain

Severity Description

1	Insignificant
2	Minor injury
3	Moderate injury
4	Major injury
5	Fatality/catastrophic consequence

Thus:

$$\text{Risk Score} = \text{Likelihood} \times \text{Severity}$$

A score can subsequently be categorized according to the organization's approved risk matrix.

Importantly, numerical scores should support—not replace—professional assessment, site knowledge, applicable legal requirements, and consideration of reasonably foreseeable scenarios.

Major Hazards in Wind Farm Operations

Working at height

Wind turbine towers can require workers to operate at significant elevations. Falls can result from inadequate fall protection, incorrect use of access equipment, damaged equipment, poor work practices, or emergency situations.

Controls may include:

- Certified fall-arrest systems.
- Appropriate climbing equipment.
- Inspection of ladders and anchor points.
- Worker competency and rescue training.
- Two-person working arrangements where appropriate.
- Emergency evacuation and rescue plans.
- Weather restrictions for high-risk activities.

Falls from elevation have been identified as a significant wind-farm occupational hazard in previous research. ScienceDirect

Electrical hazards

Wind turbines contain electrical generation, transmission, control and distribution systems. Electrical maintenance can expose workers to shock, arc flash, burns and secondary falls.

Important controls include:

- Isolation of energy sources.
- Lockout/tagout.
- Verification of absence of voltage.
- Appropriate electrical PPE.
- Competent electrical personnel.
- Controlled access to electrical areas.
- Electrical inspection and maintenance.

Mechanical and stored-energy hazards

Rotating components, hydraulic systems, springs, braking systems and other equipment may retain energy even after a turbine has been stopped.

Controls include:

- Mechanical isolation.
- Lockout/tagout.
- Stored-energy release procedures.
- Machine guarding.
- Safe maintenance procedures.
- Verification before work begins.

Lifting and crane operations

Wind farm construction and maintenance frequently involve cranes, hoists and lifting equipment. Hazards include dropped loads, crane instability, suspended loads, poor communication, equipment failure and workers entering exclusion zones.

A safe lifting operation should include:

1. Lift planning.
2. Equipment inspection.
3. Verification of lifting capacity.
4. Competent operators and riggers.
5. Defined exclusion zones.
6. Weather assessment.
7. Communication arrangements.
8. Emergency procedures.

Confined spaces

Certain areas of wind turbine structures can meet confined-space criteria or present restricted-access hazards. OSHA notes that confined spaces can present risks such as limited entry/exit and hazardous atmospheres, including oxygen-deficient conditions. OSHA

Controls should include:

- Confined-space assessment.
- Atmospheric testing where applicable.
- Entry permits.
- Communication systems.
- Rescue arrangements.
- Competent personnel.

Sample HIRA for Wind Farm Operations

Activity	Hazard	Possible consequence	Initial risk	Control measures	Residual risk
Tower climbing	Fall from height	Serious injury/fatality	High	Fall protection, inspection, training, rescue plan	Medium/Low
Electrical maintenance	Electric shock/arc flash	Burns/fatality	High	Isolation, LOTO, testing, PPE	Low/Medium
Mechanical maintenance	Stored energy	Crushing/serious injury	High	Isolation, guarding, energy release	Low
Crane lifting	Dropped load	Fatality/equipment damage	High	Lift plan, certified equipment, exclusion zone	Medium
Blade inspection	Fall/falling objects	Serious injury	High	Fall protection, tool securing, exclusion zone	Medium
Confined-space work	Hazardous atmosphere	Asphyxiation	High	Permit, gas testing, ventilation, rescue	Medium/Low
Vehicle movement	Collision	Injury/fatality	Medium/High	Traffic plan, speed controls, trained drivers	Low
Severe weather	Lightning/high wind	Injury/fatality	High	Weather monitoring and work suspension	Low
Manual handling	Musculoskeletal injury	Injury/discomfort	Medium	Mechanical aids, team lifting, ergonomic training	Low

The risk categories in this illustrative table should be replaced by the organization's validated risk matrix and site-specific assessment before operational use.

Safety Performance Indicators

Improved HIRA should be connected to measurable safety-performance indicators.

Leading indicators

- Percentage of HIRA reviews completed on schedule.
- Percentage of workers trained in HIRA procedures.
- Number of safety observations.
- Number of near misses reported.
- Percentage of corrective actions closed on time.
- Percentage of lifting plans reviewed.
- Percentage of equipment inspections completed.
- Number of toolbox talks conducted.
- Percentage of emergency drills completed.

Lagging indicators

- Lost-time injuries.
- Recordable injuries.
- Fatalities.
- Lost workdays.
- Electrical incidents.
- Falls.
- Dropped-object incidents.
- Vehicle accidents.
- Equipment-related incidents.

Using both leading and lagging indicators provides a broader picture than relying solely on injury statistics.

Discussion

The literature indicates that wind farm safety involves a combination of conventional industrial hazards and risks arising from the unique operating environment of wind turbines. Previous research has quantified occupational risks across construction, operation and maintenance and identified maintenance-related activities as important areas for risk management. ScienceDirect

A risk assessment tool developed for onshore wind farms in Italy similarly emphasized proactive safety management and emergency preparedness and was applied across 56 Italian onshore wind farms. ScienceDirect

More recent research has also drawn attention to human and organizational factors. A 2025 scoping review identified individual, team, organizational, task and environmental factors as relevant dimensions of human factors in onshore and offshore wind work. Taylor & Francis Online This suggests that effective HIRA should not focus exclusively on physical hazards. Work organization, communication, fatigue, competence, supervision and decision-making can also affect safety performance.

Consequently, an improved HIRA system should combine **technical hazard assessment with human and organizational factors**.

Conclusion

Wind farm operations involve a wide range of occupational hazards, particularly during maintenance, electrical work, working at height, lifting operations, mechanical intervention, confined-space activities and adverse weather conditions. Published research and occupational-safety guidance demonstrate the importance of systematic risk assessment and preventive controls in managing these hazards. ScienceDirect+1

Improved HIRA can enhance safety performance by providing a structured process for identifying hazards, evaluating risks, implementing controls and monitoring their effectiveness. The effectiveness of this approach depends on worker participation, competent supervision, appropriate training, effective isolation procedures, emergency preparedness and continuous review.

The proposed framework therefore treats HIRA as a dynamic process integrated into daily wind farm operations. Combining conventional risk assessment with worker feedback, near-miss learning, human-factor considerations and leading safety indicators can provide a stronger basis for preventing incidents and improving occupational safety.

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