

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

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Abstract

The rapid expansion of wind energy has increased the importance of effective occupational health and safety management throughout wind farm operations. Wind turbines involve several safety-critical activities, including working at height, electrical work, lifting operations, confined-space entry, mechanical maintenance, transportation, and emergency response. These activities expose workers to potentially severe consequences when hazards are not adequately identified or controlled. This research examines how improved Hazard Identification and Risk Assessment (HIRA) can enhance safety performance in wind farm operations. The study proposes a systematic risk-management framework combining task-based hazard identification, risk assessment, hierarchy of controls, worker participation, Job Safety Analysis (JSA), Permit-to-Work (PTW), Lockout/Tagout (LOTO), dynamic risk assessment, and continual monitoring. International guidance emphasizes that hazards should be identified and assessed continuously, with controls prioritized from elimination and engineering measures through administrative controls and personal protective equipment. International Labour Organization+1 Wind-energy-specific guidance identifies working at height, remote locations, lifting operations, confined spaces, rotating machinery, falling objects, and electrical hazards among important occupational risks. The proposed framework can improve risk visibility, strengthen safety-critical controls, reduce unsafe acts and conditions, improve emergency preparedness, and support continual improvement of occupational safety performance.

Keywords: Wind Farm, Hazard Identification, Risk Assessment, HIRA, Occupational Safety, Wind Turbine, Risk Management, Safety Performance, JSA, LOTO

Introduction

The global transition toward renewable energy has resulted in rapid growth of wind power installations. Wind farms provide an important source of low-carbon electricity, but their operation and maintenance activities involve numerous occupational hazards. Workers may perform maintenance hundreds of feet above ground, enter confined spaces, work with high-voltage electrical systems, handle heavy components, operate lifting equipment, and perform tasks in remote locations.

The International Finance Corporation's Wind Energy Environmental, Health and Safety Guidelines identify several hazards associated with wind-energy facilities, including working at height, working over water, remote-location work, lifting operations, confined spaces, rotating machinery and falling objects. Working at height is particularly relevant during wind-turbine maintenance.

Consequently, effective Hazard Identification and Risk Assessment (HIRA) is essential for preventing incidents and maintaining safe operations. A risk assessment should not be regarded simply as a documentation exercise. The International Labour Organization recommends a systematic process involving hazard identification, identification of persons who may be harmed, evaluation of risk and controls, assignment of responsibility, and subsequent monitoring and review. International Labour Organization

Wind-turbine safety also needs to be considered across the equipment lifecycle. IEC 61400-1 establishes essential design requirements intended to provide protection against hazards over the planned lifetime of wind turbines and addresses systems including control and protection functions, electrical systems, mechanical systems and support structures. IEC Webstore

Therefore, improving HIRA in wind farms can provide a proactive mechanism for identifying hazards before accidents occur and for ensuring that safety controls remain effective during changing operational conditions.

Problem Statement

Although wind farms generally operate under established safety procedures, the effectiveness of risk assessment can be reduced by several factors:

- Inadequate identification of task-specific hazards.
- Generic risk assessments that do not reflect actual site conditions.
- Insufficient consideration of non-routine maintenance activities.
- Failure to recognize simultaneous or interacting hazards.
- Inadequate communication between operations, maintenance and contractors.
- Insufficient worker participation in risk assessment.
- Failure to update risk assessments after incidents or near misses.
- Over-reliance on administrative controls and PPE.
- Inadequate emergency planning for remote wind-turbine locations.
- Differences between planned work conditions and actual field conditions.

The ILO specifically recommends that hazard identification and risk assessment be conducted on an ongoing basis and before changes to work methods, materials, processes or machinery. It also emphasizes worker involvement in the assessment process. International Labour Organization

The central problem addressed by this research is therefore:

How can an improved Hazard Identification and Risk Assessment system enhance safety performance during critical operations and maintenance activities in wind farms?

Objectives of the Study

The specific objectives are:

1. To identify major hazards associated with wind farm operation and maintenance activities.
2. To evaluate existing HIRA practices used for safety-critical activities.
3. To assess the effectiveness of existing risk-control measures.
4. To identify gaps in hazard identification and risk assessment processes.
5. To develop an improved risk-assessment methodology for wind farm operations.
6. To strengthen the application of the hierarchy of controls.
7. To improve worker participation in hazard identification.
8. To integrate JSA, PTW, LOTO and dynamic risk assessment into safety-critical activities.
9. To develop safety-performance indicators for monitoring the effectiveness of HIRA.
10. To recommend measures for continual improvement of wind-farm safety performance.

Literature Review

Hazard Identification and Risk Assessment

Hazard identification is the process of recognizing sources or situations that have the potential to cause injury, ill health, property damage or other undesirable consequences.

Risk assessment involves evaluating the likelihood and severity of potential consequences and determining appropriate controls.

The ILO describes risk assessment as a key occupational-safety tool and recommends a five-step process:

1. Identify hazards.
2. Identify who may be harmed and how.
3. Evaluate risks and determine controls.
4. Assign responsibility and implementation timeframes.

5. Record, monitor, review and update the assessment. International Labour Organization

This approach is particularly relevant to wind farms because conditions can change rapidly during maintenance activities.

Wind Farm Safety Hazards

Wind-farm hazards can be grouped into several categories.

Hazard category Examples

Working at height Tower climbing, nacelle work, blade inspection

Electrical High voltage, stored energy, arc flash

Mechanical Rotating components, moving machinery, stored mechanical energy

Lifting Cranes, hoists, dropped loads

Confined space Tower/nacelle areas, restricted-access spaces

Falling objects Tools, components, ice, materials

Fire Electrical faults, hydraulic systems, hot work

Environmental Wind, lightning, extreme temperatures

Transportation Site roads, vehicles, remote locations

Ergonomic Manual handling, awkward postures

Chemical Oils, lubricants, cleaning agents

Emergency Rescue from height, fire, medical emergencies

Wind-energy EHS guidance specifically highlights working at height, lifting, remote locations, confined spaces, rotating machinery and falling objects as important risks.

Safety-Critical Operations

Some activities have a higher potential for fatality or serious injury and therefore require enhanced controls.

Examples include:

- Working at height.
- Electrical isolation.
- High-voltage switching.
- Blade maintenance.
- Major component replacement.
- Crane and lifting operations.
- Confined-space entry.
- Hot work.
- Mechanical isolation.
- Rescue operations.
- Work during adverse weather conditions.

For such activities, conventional risk assessment should be supported by task-specific procedures, competent personnel, verification of controls and emergency arrangements.

Research Methodology

Research Design

A **mixed-method research approach** can be adopted, combining quantitative and qualitative methods.

The study can include:

- Site observations.
- HIRA document review.
- Safety audits.
- Worker questionnaires.
- Interviews with supervisors and technicians.
- Incident and near-miss analysis.
- JSA review.
- Risk-matrix analysis.
- Comparison of pre- and post-improvement safety indicators.

Data Collection

Primary data

Primary data may be collected through:

- Questionnaires for technicians and supervisors.
- Interviews with HSE personnel.
- Workplace observations.
- Safety inspections.
- Task-based HIRA assessments.

Secondary data

Secondary information can include:

- Incident reports.
- Near-miss records.
- Previous HIRA documents.
- JSA documents.
- PTW records.
- LOTO records.
- Training records.
- Emergency-drill reports.
- Safety audit reports.
- Applicable standards and guidelines.

Proposed Improved HIRA Methodology

The proposed framework can follow the sequence below:

Activity identification → Hazard identification → Who may be harmed → Existing controls → Risk assessment → Additional controls → Residual risk → Responsible person → Verification → Monitoring → Review

Step 1: Identify the activity

Example:

Wind turbine gearbox maintenance.

Step 2: Break the activity into tasks

For example:

- Turbine isolation.
- Access to nacelle.
- Removal of guards.
- Component lifting.
- Component replacement.
- Testing.
- Re-energization.

Step 3: Identify hazards

Potential hazards include:

- Unexpected machine movement.
- Electrical energy.
- Falling objects.
- Working at height.
- Stored mechanical energy.
- Manual handling.
- Lifting equipment failure.

Step 4: Identify persons exposed

Potentially affected people include:

- Technicians.
- Supervisors.
- Crane operators.
- Contractors.
- Other workers.
- Visitors.

Step 5: Assess risk

A simple risk score can be calculated as:

Risk Score = Likelihood × Severity

For example:

Likelihood	Score
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Rare	1
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Unlikely	2
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Possible	3
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Likely	4
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Almost certain	5
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Severity	Score
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Insignificant	1
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Minor	2
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Likelihood Score

Moderate 3

Major 4

Catastrophic 5

Thus:

Risk Score = L × S

Example:

If likelihood = 4 and severity = 5:

Risk = 4 × 5 = 20

This would represent a very high risk requiring immediate additional controls, according to whatever risk-rating criteria the organization adopts.

Example HIRA for Wind Turbine Maintenance

Activity	Hazard	Possible consequence	Initial risk	Recommended control
Tower climbing	Fall from height	Fatality/serious injury	High	Certified fall-protection system, inspection, training
Electrical maintenance	Electric shock/arc flash	Fatality/burns	High	Isolation, LOTO, test-for-dead, electrical PPE
Blade maintenance	Fall/dropped objects	Serious injury/fatality	High	Fall protection, exclusion zone, tool tethering
Gearbox maintenance	Stored mechanical energy	Crush injury	High	Mechanical isolation and LOTO
Crane operation	Dropped load	Fatality/equipment damage	High	Lift plan, certified equipment, competent personnel
Confined-space work	Oxygen deficiency/toxic atmosphere	Asphyxiation	High	Gas testing, permit, ventilation, rescue plan
Hot work	Fire	Burns/property damage	Medium/High	Hot-work permit, fire watch, fire extinguishers
Remote-site work	Delayed response	emergency Increased severity	High	Communication and emergency-response plan

Proposed Safety Improvement Framework

The research proposes five major improvement areas.

Worker Participation

Technicians should actively participate in HIRA development because they have direct experience with actual work conditions.

Worker participation can identify hazards that may not be obvious during office-based risk assessments.

Learning from Near Misses

Near-miss reporting should be incorporated into HIRA reviews.

The ILO recommends reviewing accident, ill-health and near-miss information because such records can reveal less obvious hazards. International Labour Organization

Critical Control Verification

For high-risk activities, organizations should verify that critical controls are actually functioning.

For example:

Working at height → Harness inspected → Anchor verified → Rescue equipment available → Competent worker confirmed

This changes the approach from:

“Procedure exists”

to:

“Critical control is verified before work begins.”

Emergency Preparedness

Wind farms can be located in remote areas, making emergency response particularly important.

Emergency plans should address:

- Fall from height.
- Electrical shock.
- Fire.
- Medical emergency.
- Confined-space rescue.
- Severe weather.
- Crane/lifting incidents.
- Evacuation.

Continual Improvement

HIRA should not be a one-time exercise.

The cycle should be:

Plan → Implement → Check → Improve

This aligns with the Plan-Do-Check-Act approach used by ISO 45001. IISO

Safety Performance Indicators

To determine whether improved HIRA actually improves safety performance, the following indicators can be monitored.

Leading indicators

- Percentage of HIRAs reviewed on schedule.
- Percentage of safety-critical tasks with approved JSA.
- Percentage of workers participating in HIRA.
- Number of safety observations.
- Number of near-miss reports.
- Percentage of critical controls verified.
- Percentage of workers completing required training.
- PTW compliance rate.
- LOTO compliance rate.
- Emergency-drill performance.

Lagging indicators

10.5 Critical Control Verification

For example:

- Lost Time Injury Frequency Rate (LTIFR).
- Total Recordable Injury Frequency Rate (TRIFR).
- Number of serious incidents.
- Number of high-potential incidents.
- Number of property-damage incidents.
- Number of occupational illnesses.
- Severity rate.

A combination of leading and lagging indicators is preferable because accident statistics alone are retrospective.

Expected Results

Implementation of the proposed HIRA framework is expected to result in:

1. Better identification of safety-critical hazards.
2. Improved quality of risk assessments.
3. Greater worker participation.
4. Improved compliance with safe-work procedures.
5. Stronger control of high-risk activities.
6. Improved LOTO and PTW performance.
7. Better emergency preparedness.
8. Increased near-miss reporting.
9. Reduction in uncontrolled high-risk exposures.
10. Improved overall safety culture.

The expected outcome is not simply fewer accidents but a more proactive safety-management system in which hazards are identified and controlled before they result in incidents.

Discussion

The effectiveness of wind-farm safety management depends heavily on the quality of hazard identification and the reliability of risk controls. A major weakness of conventional HIRA systems can occur when assessments are developed as generic documents rather than as dynamic tools used by workers at the point of work.

For wind-farm operations, this is particularly important because maintenance activities can change rapidly. A task that is considered acceptable under normal conditions may become high risk because of weather, equipment condition, simultaneous work, personnel changes or unexpected technical problems.

Consequently, the proposed approach combines formal HIRA with field-level tools such as JSA, toolbox talks, PTW, LOTO and dynamic risk assessment.

The approach is also consistent with international occupational-safety principles that emphasize continuous hazard identification, worker participation, risk-control hierarchy and periodic review. International Labour Organization¹

The research therefore considers HIRA not merely as a compliance requirement but as an operational decision-making tool.

Conclusion

Wind-farm operations involve multiple high-risk and safety-critical activities. Working at height, electrical maintenance, lifting operations, mechanical hazards, confined spaces, falling objects and remote working conditions can expose workers to serious injury or fatality.

Improved Hazard Identification and Risk Assessment can significantly strengthen wind-farm safety performance when it is integrated with worker participation, task-based assessment, hierarchy of controls, JSA, PTW, LOTO, critical-control verification, emergency preparedness and continual improvement.

The proposed framework provides a structured method for moving from reactive safety management toward proactive risk prevention. Its effectiveness can be evaluated using leading and lagging safety-performance indicators.

Ultimately, successful implementation requires management commitment, competent workers, effective communication, reliable procedures and continuous monitoring. HIRA should therefore be treated as a dynamic safety-management process rather than a static document.

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