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Hazard Identification and Risk Assessment (HIRA) in the Construction of Large-Scale Solar Power Plants in India

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Abstract: *The rapid transition towards renewable energy in India, driven by ambitious national targets and the need for sustainable development, has catalyzed a massive surge in the construction of utility-scale solar power plants. While these mega-projects are indispensable for achieving energy independence and reducing the national carbon footprint, their extensive and fast-paced construction phases introduce highly complex occupational health and safety challenges. This research presents a comprehensive investigation into Hazard Identification and Risk Assessment (HIRA) meticulously tailored for the unique environment of large-scale solar project sites across India*

Renewable power plants are booming these days. Constructions of renewable power plants pose serious risks to workers safety and health. To ensure its success we need to make sure that it remains safe, reliable and sustainable throughout its construction and operation phase. This can be achieved by effectively evaluating a power plant's health and safety, associated hazards and risks and implementing necessary control measures. In this study, we have used a HIRARC (Hazard Identification, Risk assessment & Risk control) model to identify all the hazards and associated risk to the worker's safety and health on a 350MW Solar Power plant unit-I and Unit-II. Hazard identification is carried out by critically analyzing existing risk assessments, interviewing personnel and conducting walkthroughs. Risk assessment is carried out using qualitative analysis of hazard's likelihood and its consequence severity. Quantitative analysis is used to divide the risk in high, medium and low categories using simple 5X5 risk matrix. The findings were then used to identify and recommend necessary control measures to deal with high risk activities and bring down its risk level to an acceptable range. The aim of this study is to make solar power projects much safer and accident free by identifying significant hazards, evaluating the associated risks and determining the necessary control measures based on the basic risk control hierarchy. These measures will help in making solar power projects a safer project sites, reducing accident rates at site, reducing staff turnover rates, improving safety culture and increasing worker's satisfaction in terms of safety.

The study systematically evaluates the entire construction lifecycle—ranging from initial site clearing, heavy earthmoving, and foundation piling, to the erection of Module Mounting Structures (MMS), Photovoltaic (PV) panel installation, deep trenching, and the critical commissioning of high-voltage electrical infrastructure such as inverters and transformers. Through a robust methodology combining rigorous site observations, historical incident analysis, and structured questionnaire surveys distributed among site engineers, safety officers, and project managers, a wide spectrum of unsafe acts and environmental conditions was documented. The research highlights critical occupational hazards, including high-voltage electrical risks (arc flashes and shocks), mechanical entrapments during heavy material lifting, ergonomic strains from repetitive module handling, and fall hazards during structural erection, and extreme thermal stress due to prolonged exposure to harsh Indian weather conditions.

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Utilizing both quantitative and qualitative risk assessment tools, including the Relative Importance Index (RII) and standardized Risk Matrices, the identified hazards are systematically ranked based on their probability of occurrence and potential severity. The analysis isolates the most acute safety vulnerabilities that demand immediate managerial intervention. Consequently, this study proposes a site-specific framework of mitigation strategies, integrating engineering controls, stringent administrative protocols, and the mandate of specialized Personal Protective Equipment (PPE). Ultimately, this research provides a pivotal safety management blueprint for industry stakeholders, aiming to eliminate workplace accidents, ensure strict regulatory compliance, minimize costly project delays, and foster a sustainable safety culture within India's booming solar infrastructure sector.

Keywords: Solar Power Plants, HIRRAC, Risk Assessment, Hazard Identification, Hazard Identification and Risk Assessment (HIRA), Construction Safety Management, Large-Scale Solar Power Plants, Occupational Health and Safety (OHS), Relative Importance Index (RII), Renewable Energy Infrastructure, Risk Mitigation and Control Measures, Photovoltaic (PV) Plant Construction etc

I. INTRODUCTION

Renewable energy has started playing an increasingly important role for augmentation of grid power, providing energy access, reducing consumption of fossil fuels and helping India pursue its low carbon development path. Our emissions intensity has since reduced by 36% during 2005 to 2020, and the target has now been enhanced to 47% to be achieved by 2035. Towards the updated NDC's goal on enhancing share of non-fossil fuel energy resources in installed electric power capacity, the country has achieved 52.57 % non-fossil capacity (February 2026), successfully meeting the target five years ahead of the timeline and now the ambition has been further raised to 60% share of non-fossil fuel-based energy resources in installed electric power capacity to be achieved by 2035. Further on the NDC goal of creating additional carbon sink through forest and tree cover, India has already created 2.29 billion tonnes of CO_2 equivalent by 2021 Afforestation and ecosystem restoration efforts continue to contribute towards India's carbon sink targets while supporting rural livelihoods. Our afforestation efforts have been duly acknowledged by independent agencies such as Food and Agriculture Organization (FAO) which has ranked India as third in terms of net gain in forest area and ninth in terms of area under forest. This progress is a testimony to the fact that India has maintained a balance between economy and ecology even as it maintains a high GDP growth rate. Now, we have further enhanced the ambition of creating carbon sink through forest and tree cover to 3.5-4.0 billion tonnes of CO_2 equivalent by 2035 from 2005 level.

Figure1.1 Solar Plant Project view

In this paper, the hazard identification, risk assessment and risk control techniques are discussed in a 350 MW solar power plant project unit-1 and unit-2, the various activates are being taken into consideration and found many hazards in all Departments which should be considered deeply for the reduction of the risks by implementing various Risk Assessment Techniques such as HIRA, Risk Matrix, Hierarchy of Control etc.

To translate the safety policy into standard practices with "ZERO INCIDENTS" outcome, a need was felt for identification of possible hazards, assessment of associated risks and their mitigation measures. Company renewables

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covers solar, wind, hydrogen and Hydrogen derived chemicals. All these domain pose specific hazards and therefore requires appropriate mitigation measures.

This HIRA document is being prepared to serve as a reference document for RE-sites. This will guide for identification of hazards, assessment of associated risks and their control measures to execute the jobs SAFELY. The Operation Control Procedures (OCPs) for working with ladders, scaffoldings, Hydra, Welding, etc. have been indicated for ready reference

While India has traditionally been dependent on the supply of solar cells from China, recent efforts by the government have attempted to shift this balance towards the country's manufacturing capabilities. While the government considered providing capital subsidies to India's solar cell manufacturers, it eventually settled on imposing safeguard duties on imported cells and tried to push local developers to procure from Indian manufacturers to ensure they have enough incentive to keep producing. These safeguard duties have had a counterproductive effect in recent quarters as developers simply chose to defer increasing their capacity against high solar cell prices, but the situation is set to improve with Indian manufacturers showing significant signs of growth. Solar systems can mainly be divided into On-grid systems, Off-grid systems and Hybrid systems

On-grid systems: are connected to the public electricity grid using solar inverters or micro converters. They do not have storage capabilities and return the excess power generated to the grid, this process is called exporting and the user gets paid a feed-in-tariff for that amount of power.

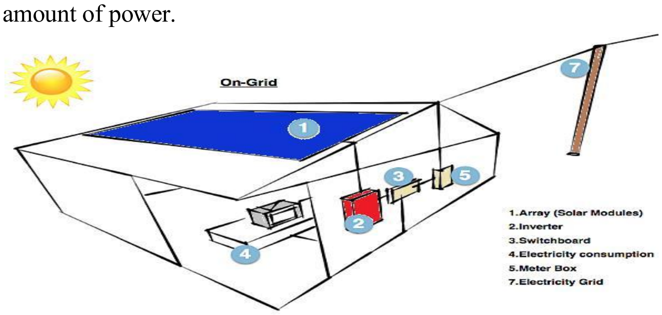

Figure1.2 On-grid system

They cannot operate during a power failure due to safety reasons. Because they feed the excess power produced directly back into the public grid, and if this happens during a power failure while there might be technicians working on the grid to remedy the issue, they could get electrocuted. This kind of system is popular with individual users and businesses and as of now, are by far the most common systems.

Figure1.3 The meter and electricity grid

Off-grid systems: While these systems have the ability to store excess power they produce, they are much more expensive because of the added cost of the batteries. These systems are not connected to the grid and are preferred at remote locations where the grid connection is difficult to obtain. Because there is no grid connection, these systems must be made in such a way that they are able to generate and store enough power to meet demands throughout the year, even during spells of low sunlight like the winters. However, the cost of batteries is showing a sharp decline and while also

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showcasing improved performance. Making this option more attractive for even consumers who are not in remote locations.

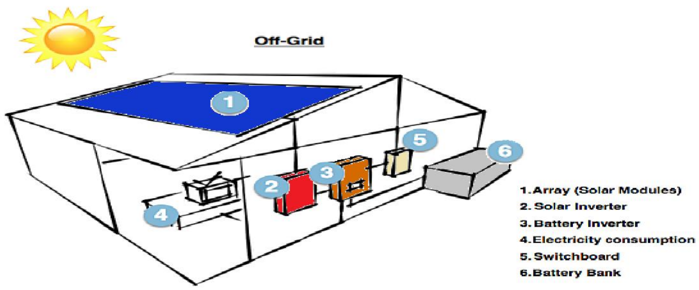

Figure1.4 Off-grid system

Hybrid systems: Are systems that have both grid connection and battery to store energy. Many consumers who initially used On-grid systems added batteries to make their system hybrid, due to the reduction in battery cost. In such systems, the extra power produced is stored in the battery, and when the battery backup also runs out, the consumer can take power from the grid, making this option ideal in the long run. Additionally, when solar power is insufficient, these systems are also able to charge the batteries from 12 am to 6 am, when power from the grid is cheaper.

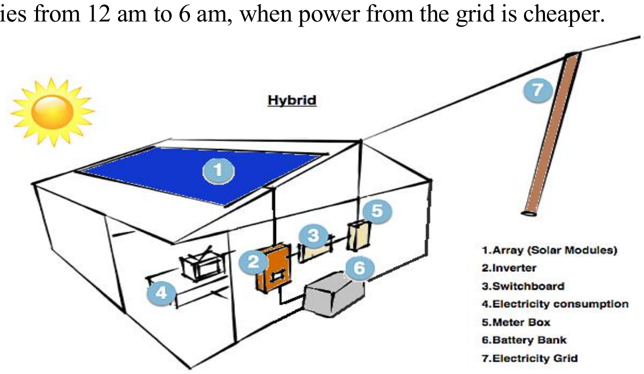

Figure1.5 Hybrid-grid system

Background of the research

The construction industry is historically known for its high accident rates due to dynamic and constantly changing work environments. Solar power plant construction sites present unique safety challenges compared to conventional building construction. These sites are often located in remote, arid, or desert regions characterized by extreme weather conditions, high temperatures, and high wind speeds.

Furthermore, the workforce employed is largely unorganized, migratory, and often lacks formal safety training. The combination of heavy machinery, electrical systems, working at heights (on rooftops or MMS structures), and harsh environmental conditions creates a high-risk matrix. Traditional reactive safety measures (responding after an accident occurs) are no longer sufficient. Therefore, a proactive safety management system driven by HIRA (Hazard Identification and Risk Assessment) is required. HIRA systematically breaks down every construction activity, identifies what could go wrong, evaluates the severity and probability of the risk, and establishes control measures based on the Hierarchy of Controls (Elimination, Substitution, Engineering Controls, Administrative Controls, and PPEs)

Scope of the research

The scope of this thesis is strictly confined to the construction and commissioning phases of large-scale solar power projects. It does not cover the manufacturing of solar panels or the long-term Operation and Maintenance (O&M) of the plant.

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Specifically, the study encompasses:

Civil Works: Hazard identification during site clearing, leveling, excavation, and foundation/pile driving.

Mechanical Erection: Risk assessment of material handling, unloading of heavy transformers, MMS (Module Mounting Structure) assembly, and PV module installation.

Electrical & Commissioning: Safety analysis during DC/AC cable laying, stringing, inverter installation, transformer charging, and LOTO (Lockout/ Tagout) implementation.

Geographical/Environmental Context: Addressing occupational hazards like heat stress, dust exposure, and ergonomic risks prevalent in Indian climatic conditions.

Objectives of the research

The primary aim of this research is to enhance occupational safety in solar plant construction by systematically analyzing risks. The specific objectives are:

- To identify potential hazards associated with various civil, mechanical, and electrical activities during the construction of a solar power plant.
- To perform a quantitative Risk Assessment using a standard 5 X 5 Risk Matrix to evaluate the probability and severity of the identified hazards.
- To propose effective mitigation strategies and control measures based on the Hierarchy of Hazard Controls to reduce the risk to an ALARP (As Low as Reasonably Practicable) level.
- To develop a standardized safety framework and checklist that can be utilized by safety engineers and site managers on future solar construction sites in India.

Research structure

This dissertation is organized into six comprehensive chapters to systematically present the research work:

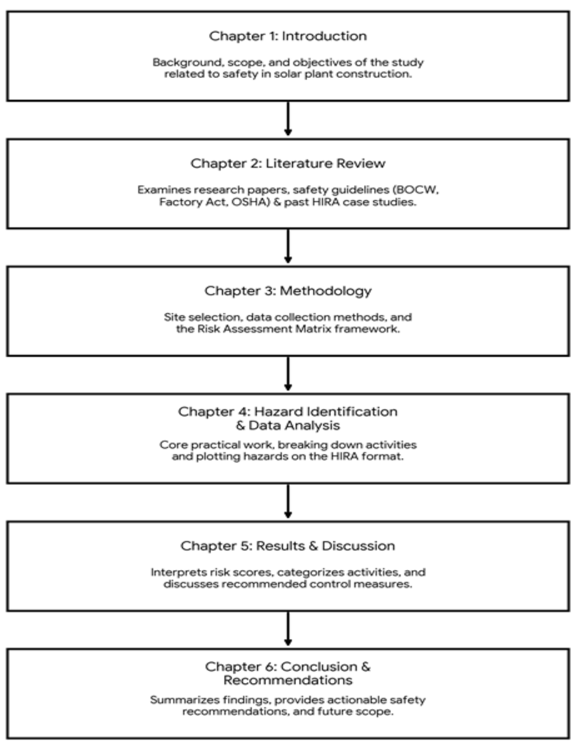

Figure1.6 Flow diagram of Research work

II. LITERATURE REVIEW

This part examines existing research, safety guidelines, and case studies related to occupational health and safety (OHS) in the construction industry, with a specific focus on renewable energy and solar plant projects. The review explores the foundational methodologies of Hazard Identification and Risk Assessment (HIRA) and their practical application in mitigating site-specific hazards.

2.1 General Construction Safety and HIRA Methodologies

The necessity of transitioning the construction industry from qualitative guesswork to empirical risk estimation models has been heavily emphasized in recent academic literature. Hallowell and Gambatese (2009) established that utilizing a structured HIRA matrix can reduce high-severity accidents by over 60% through proactive identification of root causes prior to the execution of high-risk activities. This is supported by Jannadi and Almishari (2003), who introduced a computerized Risk Assessment Model (RAM) demonstrating that standardizing risk scores—calculated as Risk = Probability x Severity allows project managers to dynamically prioritize and allocate safety budgets to critical activities.

Integrating these assessments early in the project lifecycle is crucial. Rozenfeld et al. (2010) concluded that incorporating hazard identification into the project scheduling phase minimizes unexpected cascading delays across subsequent mechanical and electrical stages. When evaluating heavy civil projects, Pinto et al. (2011) highlighted that manual material handling and working at heights are the primary drivers of fatal injuries—risks that directly parallel the Module Mounting Structure (MMS) erection processes in solar plants.

The effectiveness of safety frameworks heavily relies on human factors and the hierarchy of controls. Zhou et al. (2015) identified that over 80% of safety incidents on dynamic sites result from human error, cognitive fatigue, and improper Personal Protective Equipment (PPE) usage, necessitating continuous administrative controls. In the Indian context, Patel and Jha (2016) observed that unskilled migratory labor forces often lack hazard perception, making daily Tool Box Talks (TBT) an essential requirement. While administrative controls are necessary, Amin et al. (2017) validated that engineering controls (e.g., using mechanical cranes) yield a 75% higher risk reduction rate than administrative reliance. However, implementing these controls faces financial hurdles; Buniya et al. (2021) highlighted that budget constraints and poor regulatory enforcement in developing nations often lead to failed safety plans, underscoring the need for a practical, low-cost HIRA framework.

Furthermore, specific operational hazards require distinct protocols. Zhao et al. (2016) found that over 30% of electrical accidents occur during temporary power setups due to improper grounding, requiring strict Lockout/Tagout (LOTO) procedures. Similarly, Subramaniam et al. (2018) established a direct correlation between continuous heavy manual lifting and acute musculoskeletal disorders (MSDs), providing a critical reference point for the repetitive nature of solar panel installation.

2.2 Occupational Hazards in Solar and Renewable Energy Projects

While earlier studies like Fthenakis et al. (2008) focused on the life cycle of photovoltaic (PV) systems—noting that chemical hazards dominate manufacturing while physical and structural hazards dominate field installations—recent research specifically targets utility-scale construction. Franca et al. (2020) identified that large-scale solar construction creates a unique overlapping hazard zone characterized by extensive linear trenching, simultaneous multi-point panel installation, and high-voltage grid connections.

Site preparation and environmental factors introduce severe early-stage risks. Turney and Fthenakis (2011) noted that massive dust generation during land clearing severely impairs worker visibility and induces respiratory distress. In desert and semi-arid regions, Al-Badi et al. (2020) highlighted that loose sand and soil liquefaction lead to outrigger sinkage, significantly increasing the risk of catastrophic crane tip-overs during heavy transformer unloading. Furthermore, extreme climatic conditions pose a direct threat to workers. Kumar and Kumar (2019) documented that

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sustained ambient temperatures exceeding 40°C in Indian states like Rajasthan lead to heat exhaustion, reduced cognitive alertness, and a 35% increase in operational accidents during the afternoon.

The mechanical and electrical phases of solar construction present distinct occupational health risks. Bakhiyi et al. (2014) observed that field workers face primary threats from lacerations caused by sharp structural edges, electrical burns, and heat stroke. Addressing ergonomic strain, Zhang et al. (2017) demonstrated that single-person manual lifting of glass-metal panels causes extreme spinal shear stress, whereas adopting a two-person team approach reduces spinal loads by 45%. System type also dictates hazard profiles; Ali et al. (2021) established that ground-mounted utility-scale plants carry higher risks of machinery-related accidents and trench cave-ins, unlike rooftop installations which are dominated by fall hazards.

Fast-track project execution further exacerbates these risks. Jackson et al. (2018) emphasized that rapid completion targets often lead to skipped safety inductions, causing a disproportionate surge in preventable hand injuries. During the final stages, Jones and Smith (2022) proved that uncontrolled stored energy in DC strings presents catastrophic arc flash hazards during inverter synchronization, necessitating specialized Arc Flash PPE and isolation protocols.

2.3 Application of HIRA and Specific Mitigation Strategies

The practical implementation of HIRA has proven highly effective in mitigating solar construction risks. Silva and Perez (2019) successfully utilized a 5 risk matrix for utility-scale solar projects, categorizing inverter commissioning and high-voltage grid connections as "Extreme Risk" activities requiring mandatory Permit-to-Work (PTW) controls. Validating this approach in India, Sharma et al. (2021) demonstrated that implementing continuous, activity-based HIRA inspections on a 250 MW solar site reduced near-miss incidents by 40% and resulted in zero fatal accidents over 2 million safe man-hours.

Addressing structural assembly risks, Reddy and Singh (2020) identified pinch points and sharp galvanized steel edges as high-frequency hazards causing maximum lost-time injuries (LTIs), justifying mandatory cut-resistant PPE. For tracking systems, Chaurasia et al. (2022) combined Failure Mode and Effects Analysis (FMEA) with traditional HIRA to map out severe mechanical binding hazards in drive-shaft installations.

Strategic administrative and engineering controls are critical for site safety. Gupta and Raj (2018) found that modifying work-rest cycles and shifting heavy manual labor to morning hours (06:00 AM – 11:00 AM) reduced heat-induced medical consultations by 60%. To prevent severe earthwork accidents, Mishra and Tiwari (2020) established that un-shored trenches deeper than 1.2 meters in sandy soils present extreme cave-in risks, dictating strict shoring and flagging requirements for underground DC cabling. On the engineering side, Wang et al. (2021) highlighted that substituting manual labor with vacuum lifting machines for solar panels reduces ergonomic back strain by 70% while simultaneously lowering breakage costs.

Worker well-being and regulatory compliance represent the broader scope of project safety. Deshmukh and Patil (2019) documented that poor sanitation and a lack of clean drinking water in temporary labor camps severely affect worker stamina, indirectly driving up on-site accident rates. Ensuring compliance requires robust monitoring; Nair et al. (2023) suggested deploying drone technology to identify safety violations in vast solar farms, proving them to be five times faster than manual inspections. Finally, Das et al. (2022) reviewed the regulatory frameworks in India, identifying a significant gap in the enforcement of the BOCW Act (1996) for renewable mega-projects, thereby emphasizing the urgent need for contractors to adopt self-regulated and robust HIRA frameworks.

2.4 Summary of Identified Hazard Severities

Based on the synthesis of field observations and structural assembly studies, the severity of common site hazards can be categorized to inform standard risk matrices

Identified Hazard	Probability Level	Severity Score
Handling of cement bags	Most likely	5

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Shifting column post	Possible	4
Dehydration	Possible	4
Falling into bore holes	Conceivable	3
Drill bits of DTH operation	Conceivable	3
Cement mixers operation	Conceivable	3
Handling of structural templates	Conceivable	3
Handling bolts and sharp tools	Conceivable	3
DTH Vehicle movement	Remote	2

Table 2.1: Probability and Severity of Identified Early-Stage Hazards

2.5 Research gap

<table>
<tr><th>Literature Review Section</th><th>Focus of Existing Literature</th><th>Identified Research Gap</th><th>Proposed Contribution of Current Study</th></tr>
<tr><td rowspan="3">2.1 General Construction Safety and HIRA Methodologies</td><td>* Evaluates general safety frameworks (e.g., ISO 45001/OHSAS 18001).</td><td>* Conventional HIRA models do not account for the vast horizontal sprawl, high-speed modular assembly, and non-stationary nature of utility-scale solar projects.</td><td rowspan="3">* Adapts traditional HIRA methodologies and statistical techniques (RII) specifically for the fast-paced, sprawling layout of large-scale solar site construction.</td></tr>
<tr><td>* Focuses on conventional civil infrastructure (high-rise buildings, dams, bridges).</td><td rowspan="2">* Lack of tailored quantitative hazard ranking models specific to fast-track renewable projects.</td></tr>
<tr><td>* Uses standard 5x5 risk matrices and Relative Importance Index (RII) for static, high-rise site hazards.</td></tr>
<tr><td rowspan="3">2.2 Occupational Hazards in Solar and Renewable Energy Projects</td><td>* Primarily examines Operational & Maintenance (O&M) safety or rooftop solar installations.</td><td>* Scarcity of empirical research on construction-phase hazards in utility-scale ground-mounted solar plants within developing nations.</td><td rowspan="3">* Systematically identifies and quantifies construction-phase hazards (civil piling, module mounting, trenching, DC stringing) under real-world Indian environmental and labor conditions.</td></tr>
<tr><td>* Relies heavily on safety standards and hazard data from developed Western countries.</td><td rowspan="2">* Insufficient data on the impact of extreme Indian climatic conditions (heatwaves, dust storms) combined with large-scale migrant labor dynamics.</td></tr>
<tr><td>* Focuses mainly on fatal electrical shock risks during operation.</td></tr>
</table>

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2.3 Application of HIRA and Specific Mitigation Strategies	* Proposes broad, theoretical risk control recommendations.	* Absence of task-specific, phase-wise hierarchy of controls tailored for Solar EPC (Engineering, Procurement, and Construction) contractors.	* Formulates a practical, phase-specific mitigation framework integrating engineering controls, ergonomic tools, site-level administrative protocols, and technological monitoring tailored for Indian solar sites.
	* Focuses heavily on generic Personal Protective Equipment (PPE) compliance and standard safety checklists.	* Limited focus on mitigating chronic ergonomic strains from repetitive manual panel lifting and specialized DC electrical risks during commissioning.	

Table 2.2 Research Gap Analysis Based on Literature Review

III. ARIA OF STUDY

The geographical and operational context of this research is a 325 MW segment of a 450 MW utility-grade solar power park located in Madhya Pradesh, India. The site was strategically selected for its favorable solar insolation, expansive barren land, and grid proximity. The scope of the study is confined to the Balance of System (BOS) package during the construction and commissioning phases. The research evaluates the Hazard Identification and Risk Assessment (HIRA) framework within a complex, multi-tiered organizational structure comprising a state-owned Principal Developer, an EPC Contractor, and numerous sub-contractors.

The occupational hazards and risk determinants of the study area are shaped by several critical factors:

Geographical and Topographical Risks: The site features undulating terrain with a mix of loose topsoil and hard subsurface strata. This topography introduces severe hazards during foundational activities, including trench engulfment risks, severe noise and vibration (Hand-Arm Vibration Syndrome) during piling, and heavy machinery accidents during site grading.

Climatic and Meteorological Stressors: Operating as an open-sky project, the workforce is exposed to severe micro-climatic shifts. Summer temperatures frequently exceeding 42°C result in high-probability thermal stress and dehydration. Additionally, high-velocity wind gusts create significant aerodynamic hazards during heavy lifting operations and working at heights.

Technical Phasing and Concurrency: The project follows a phased commissioning model (Unit I: 105 MW, Unit II: 220 MW, Unit III: 125 MW pending). This segmented execution causes civil, mechanical, and high-voltage electrical activities to occur simultaneously across zones, creating complex and overlapping hazard intersections.

Workforce Demographics: With approximately 596,295 cumulative man-hours recorded, the project relies on a massive, transient, and fragmented multi-contractor labor force. The heavy reliance on unskilled and semi-skilled migrant workers across decentralized agencies results in a disparate safety culture and challenges in standardized hazard communication.

Baseline EHS Framework: The site's existing Environment, Health, and Safety (EHS) infrastructure provides the baseline data for evaluating risk control efficacy. This includes proactive indicators like massive Toolbox Talks (TBTs), inductions, and safety drives, alongside reactive metrics such as Lost Time Injury (LTI) tracking and scheduled emergency response drills.

IV. PROBLEM IDENTIFICATION

By going through literature and site visit a preliminary problem identification can be drawn with three objective which will be the basic aim of this paper to be fulfilled. As 350 MW solar power plant project is quite big it has major operational challenges during entire project implementation phase. The three objectives which are framed are as follows:

To identify major activities under a solar power plant project.

To analyze and assess risk and its control for each activity.

To give control measure for each activity individually.

To systematically mitigate these risks, a Master Hazard Identification and Risk Assessment (HIRA) framework is required for the most high-risk site operations. The 22 critical activities identified for mandatory HIRA tracking include

Civil & Earthworks	Mechanical & Structural	High-Risk & Specialized Tasks
Excavation	Bar Bending & Cutting	Working at Height
Road Work-Widening	Scaffolding	Lifting of Material
Under Ground Tunnel Work	Formwork & Shuttering	Confined Space Entry
Working Over/Adjacent to Water	Batching Plant Operation	Welding, Gas Cutting & Grinding
Working near IR Track	Concreting	Sand/Abrasive Blasting
Blasting Activity	Tower Erection & Stringing	Radiography
Roof Works	Movement of Machineries	Portable Electric Power Tools

Table 4.1 Critical Activities Scope

V. METHOODOLGY

This procedure is established, documented, implemented and maintained to help an organization for ongoing identification of OH and S hazards, assessment of risk and determination of necessary controls. This shall focus its resources on those areas that is most important to achievement of its goals.

An effective OH&S Management System begins with identification of hazards in the process & understanding how an organization can control the hazards by assessing risks involved. The source, situation, or act with a potential for harm in terms of human ill health or injury or both can be a hazard.

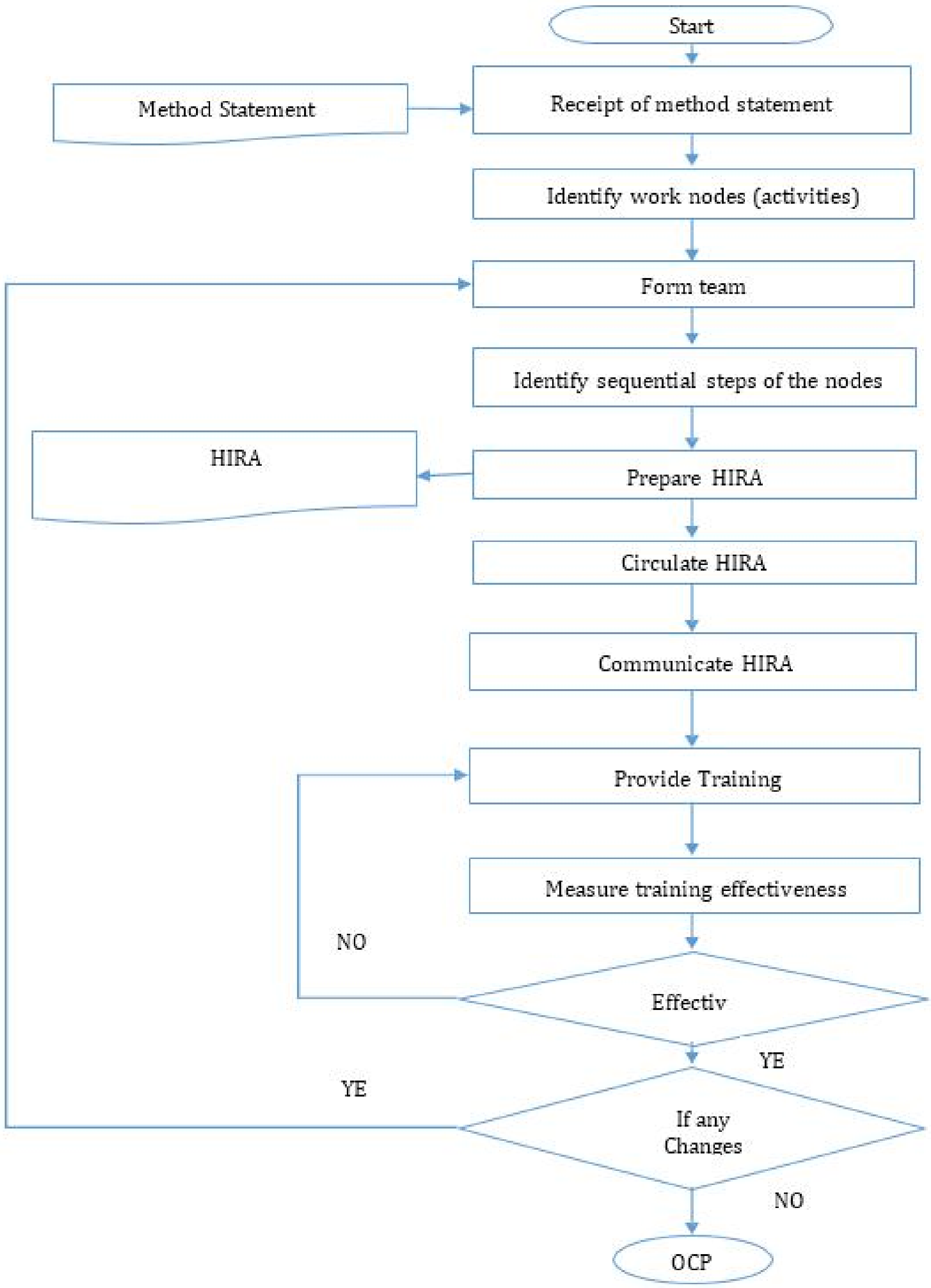

Figure 5.1 HIRA Flowchart

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Steps for HIRA

Renewables construction and operation workers are exposed to risk when they do a job. To minimize this, they should be more informed about various risk resulting from different hazards. A simplified five-step hazard and risk assessment along with control measures is given below.

- Identification of a Hazard.
- Identification of associated Risk.
- Control of the risk, which Includes:
- Elimination / Substitution.
- Engineering barrier.
- Administration controls.
- Personal protection equipment.
- Documentation of the HIRA process.
- Monitoring and review of the HIRA process

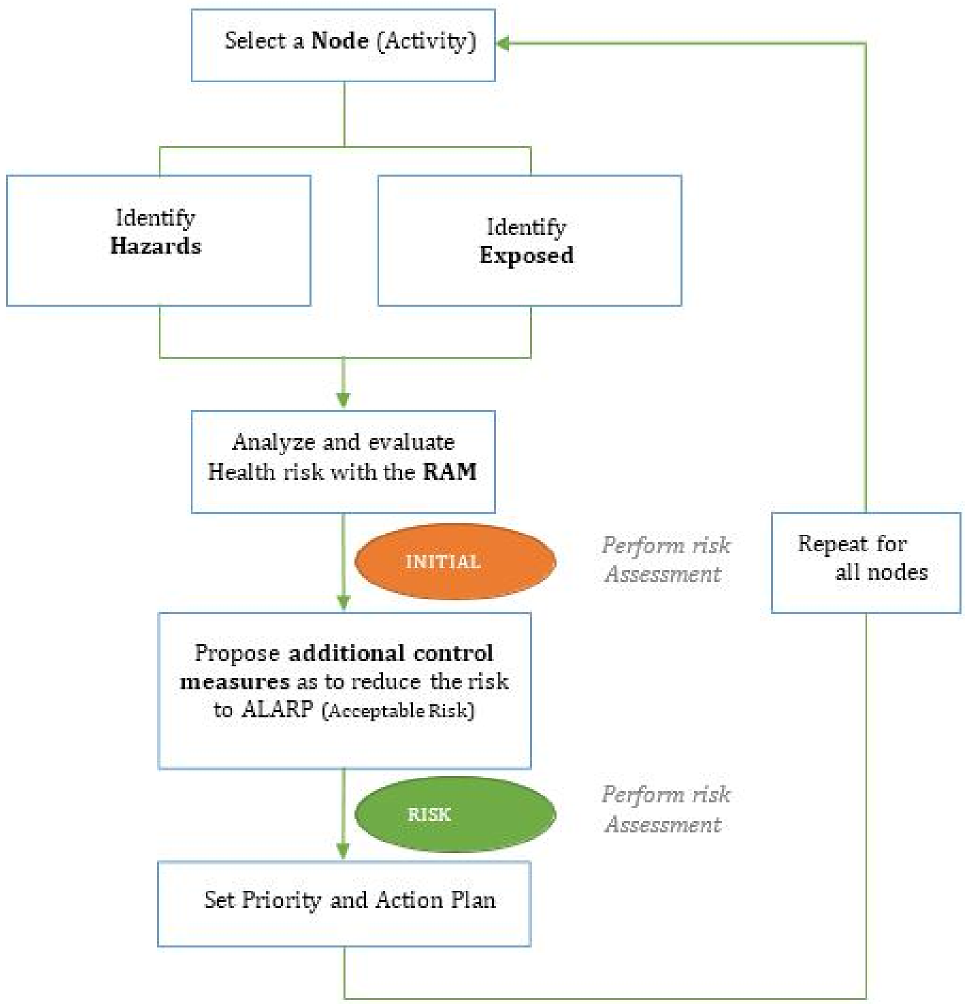

Figure 5.2 Overview of HIRA Methodology

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Risk Index Matrix:							
Risk Level			Probability of Accident(O)				
			1	2	3	4	5
			Rare	Remote	Occasional	Frequent	Almost Certain
Severity of Accident(S)	5	Catastrophic	M	M	H	H	H
	4	Major	M	M	M	H	H
	3	Moderate	L	M	M	M	H
	2	Minor	L	M	M	M	M
	1	Negligible	L	L	L	M	M
Low Risk OxS ≤ 3 Green colour	Acceptable		No additional risk control measures may be needed. However, frequent review may be needed to ensure that the risk level assigned is accurate and does not increase over time.				
Medium Risk 4 ≥ OxS≤ 12 Yellow colour	Moderately acceptable		A careful evaluation of the hazards should be carried out to ensure that the risk level is reduced to as low as reasonably practicable within a defined time period. Interim risk control measures, such as administrative controls, may be implemented. Management attention is required.				
High Risk 15 ≥OxS≤ 25 Red colour	Not acceptable		Alternate arrangements to be made.				

Table 5.1 Risk Index matrix

Probability/Likelihood of Accident		
Probability/ Likelihood	**Rating**	**Description**
Rare	**1**	**Not expected to occur but still possible**
Remote	**2**	**Not likely to occur under normal circumstances**
Occasional	**3**	**Possible or known to occur**
Frequent	**4**	**Common occurrence**
Almost Certain	**5**	**Continual or repeating experience**

Table 5.2 Probability/Likelihood of Accident

Severity of Accident/injury		
Consequence	**Rating**	**Description**
Catastrophic	**5**	**Fatality, fatal diseases or multiple major injuries**
Major	**4**	Serious injuries or life-threatening occupational disease (includes amputations, major fractures, multiple injuries, occupational cancer, acute poisoning)
Moderate	**3**	Injury requiring medical treatment or ill-health leading to disability (includes lacerations, burns, sprains, minor fractures, dermatitis, deafness and work-related upper
Minor	**2**	Injury or ill-health requiring first-aid only (includes minor cuts and bruises, irritation, ill-health with temporary discomfort)
Negligible	**1**	Not likely to cause injury or ill-health.

Table 5.3 Severity of Accident/injury

VI. RESULT

This chapter synthesizes the empirical data gathered during the construction of the large-scale 325 MW Balance of System (BOS) solar project in district, Madhya Pradesh. By applying the Hazard Identification and Risk Assessment (HIRA) framework established in Chapter 3, this section systematically categorizes the identified occupational hazards, quantifies their baseline and residual risk scores using the Risk = Probability \times Severity$ matrix, and evaluates the efficacy of the site's environmental, health, and safety (EHS) performance. The analysis is strongly grounded in continuous project monitoring data spanning the final quarter of the fiscal year, specifically drawing upon tracking logs and EHS reports from January through March 2026. The primary objective of these results is to transition theoretical safety constructs into actionable intelligence for the Indian renewable energy sector.

Hazard Identification and Risk Matrix Outcomes

Before counter measure			**After counter measure**		
HAZARD	LIKELIHOOD	LEVEL	HAZARD	LIKELIHOOD	LEVEL
Extreme temperature	Most likely	5	Extreme temperature	Minor	2
Dust	Possible	4	Dust	Minor	2
Mental stress	Remote	2	Mental stress	Negligible	1
Vibration	Remote	2	Vibration	Negligible	1
Ergonomics	Conceivable	3	Ergonomics	Negligible	1
Falling into the bore holes	Conceivable	3	Falling into the bore holes	Minor	2
DTH Vehicle	Remote	2	DTH Vehicle	Fatal	4
Drill bits of DTH	Conceivable	3	Drill bits of DTH	Serious	3
Cement mixers	Conceivable	3	Cement mixers	Fatal	4
Shifting column post	Possible	4	Shifting column post	Negligible	1
Handling of cement bags	Most likely	5	Handling of cement bags	Serious	3
Handling of templates	Conceivable	3	Handling of templates	Minor	2
Handling bolts, other tools	Conceivable	3	Handling bolts, other tools	Negligible	1
Dehydration	Possible	4	Dehydration	Serious	3

Table 6.1 Likelihood of identified hazards before and after counter measures

During the inspection of the Solar power plant, several hazards were found on the site, and the details of the hazards has been kept in the records and will be informed to the plant EOHS Department.

The hazards identification and risk assessment and its control are carried out for all hazards in the concerned division and will be reported to the company and also recommendations will be given to the company for elimination of the hazards and reduction of the risk.

During the site visit & site inspection, many hazards found on the site which may harm and may cause any incident/accident in coming future are mentioned below in their respective head along with control measure:

Risk Control, elimination and reduction:

Extreme temperature: Risk can be controlled by providing training to the workers on how to be protected from heat strokes, providing glucose water, Suggesting increase water consumption by the body, wear light color clothes.

Dust: Risk can be controlled by sprinkling water and by using respirator masks.

Mental Stress: suggesting work in shifts or take rest while lunch in resting shelters.

Vibration: Risk is tolerable.

Ergonomics: Risk is tolerable and could carry out work in shifts.

Falling into bore holes: Risk can be controlled by Barricading the area and assigning work permit.

DTH vehicle: Risk can be control by ensuring that the vehicle has competent driver and having back horn all lights and signals are working appropriately or by using red flag when in operation and by providing vehicle permit.

Drill bits of DTH: Risk could be control by not allowing any other work by providing work permit and by providing specific training.

Cement mixers: Risk can be control by ensuring that the vehicle has competent driver and having back horn all lights and signals are working appropriately or by using red flag when in operation and by providing vehicle permit and could use sirens also while mobile.

Shifting column post: Risk can be controlled by providing training to the workers for safe material handling and using proper PPE's.

Handling cement bags: Risk severity is very high and only solution is to train the workers for safe handling of cement and using proper PPE's specially Masks.

Handling of templates: Risk can be controlled by providing training to the workers for safe material handling and using proper PPE's.

Handling of bolts, tools: Risk can be reduced by providing training to the workers for safe material handling and using proper PPE's.

Dehydration: Risk can be reduced by training the workers for consuming more and more water, taking rest in shelters when the temperature is more than 42 degree.

Analysis of EHS Performance Metrics

To validate the theoretical effectiveness of the HIRA controls, an empirical analysis of the project's real-time EHS tracking records was conducted. The project meticulously tracks both proactive (leading) indicators—which represent efforts to prevent incidents—and reactive (lagging) indicators—which record incidents that have occurred.

325MW BOS Package Solar Project	
	KPI TILL Date
SAFE MAN DAY	260388
SAFE MAN HOURS	2343492
EHS Leading Indicator	
	Data
PoWRA	2517
Observation card	3957
Tool Box meetings	12712
EHS Training	1028
Pre Medical Examinati	2298
Safety Meeting	55
Near Miss	21
SOV	9
Safety Induction	2325
EHS Lagging Indicators	
	Data
First Aid	5
Lost time accident	0
Fatlity	0

325MW BOS Package Solar Project	
	KPI this FY 25-26
SAFE MAN DAY	63760
SAFE MAN HOURS	573840
EHS Leading Indicator	
	Data
PoWRA	0
Observation card	26
Tool Box meetings	49
EHS Training	68
Pre Medical Examination	0
Safety Meeting	1
Near Miss	0
Safety Induction	0
SOV	0
EHS Lagging Indicators	
	Data
First Aid	0
Lost time accident	0
Fatlity	0

Table 6.2: Safe Man day and Hours Jan 2026

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
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325MW BOS Package Solar Project		325MW BOS Package Solar Project	
KPI TILL Date		KPI this FY 25-26	
SAFE MAN DAY	261751	SAFE MAN DAY	63760
SAFE MAN HOURS	2355759	SAFE MAN HOURS	573840
EHS Leading Indicator		EHS Leading Indicator	
	Data		Data
PoWRA	2517	PoWRA	0
Observation card	3993	Observation card	21
Tool Box meetings	12767	Tool Box meetings	45
EHS Training	1039	EHS Training	65
Pre Medical Examinati	2298	Pre Medical Examination	0
Safety Meeting	54	Safety Meeting	0
Near Miss	21	Near Miss	0
SOV	9	Safety Induction	0
Safety Induction	2325	SOV	0
EHS Lagging Indicators		EHS Lagging Indicators	
	Data		Data
First Aid	5	First Aid	0
Lost time accident	0	Lost time accident	0
Fatlity	0	Fatlity	0

Table 6.3: Safe Man day and Hours Feb 2026

325MW BOS Package Solar Project		325MW BOS Package Solar Project	
KPI TILL Date		KPI this FY 25-26	
SAFE MAN DAY	263437	SAFE MAN DAY	63760
SAFE MAN HOURS	2370933	SAFE MAN HOURS	573840
EHS Leading Indicator		EHS Leading Indicator	
	Data		Data
PoWRA	2517	PoWRA	0
Observation card	3994	Observation card	21
Tool Box meetings	12770	Tool Box meetings	45
EHS Training	1035	EHS Training	65
Pre Medical Examinati	2298	Pre Medical Examination	0
Safety Meeting	54	Safety Meeting	0
Near Miss	21	Near Miss	0
SOV	9	Safety Induction	0
Safety Induction	2325	SOV	0
EHS Lagging Indicators		EHS Lagging Indicators	
	Data		Data
First Aid	5	First Aid	0
Lost time accident	0	Lost time accident	0
Fatlity	0	Fatlity	0

Table 6.4: Safe Man day and Hours March 2026

VII. CONCLUSION, RECOMMENDATIONS & FUTURE SCOPE

7.1 Conclusion

The construction of utility-scale solar photovoltaic plants is often mischaracterized as a low-risk subset of the energy sector when compared to thermal or nuclear power. However, this study empirically proves that the sprawling geographical footprint, harsh micro-climatic exposure, and complex intersection of civil, mechanical, and electrical activities present severe occupational hazards. Through a rigorous Hazard Identification and Risk Assessment (HIRA) mapping of the given project, it was observed that unmitigated baseline risks frequently scored in the "High" to "Extreme" categories, particularly concerning heavy lifting under high wind loads, trenching in unstable soil, and high-voltage grid synchronization.

The empirical data unequivocally demonstrates that high baseline risks can be effectively suppressed through systemic administrative and engineering controls. The achievement of over 2.37 million safe man-hours is not a product of chance, but the direct result of nearly 13,000 documented toolbox talks and rigorous incident reporting systems. The

HIRA matrix acts not merely as a theoretical compliance document, but as an active, daily blueprint for safeguarding human life

Now a days solar power will play a crucial role in nation building and therefore it becomes very necessary to complete each and every project of solar power quite efficiently and safely. Hazards in Solar power plant project can be eliminated if we follow proper techniques to identify the hazards and also the risk of accident/incident can be reduced. Hazards are the agents which are having the potential to cause harm those who are exposed to it. There were so many activities found during project phase of solar power plant during the site inspection. The hazards found on the site has been recorded and informed to the company. Due to the activity which are coming under risk (person/property/business) has been reported to the company and risk matrix and hierarchy of control techniques are being studied to eliminate the hazard and control the risks associated with the hazards.

Some main points of conclusions are summarized as follows:

Maximum employees are young which indicate that physical manpower of the industry is very strong resulting more productivity.

Maximum employees are under matric.

Maximum workers are skilled. So quality of the work will be good.

Maximum employees are getting lesser emoluments. So the cost of the manpower will be less.

Maximum employees are married .So psychologically they stable which is good for the factory.

Management is more aware with hazards, which indicate the concern of the management for safety of its employees.

Maximum hazards are identified by the management which saves the time of employees.

Management is more safety conscious. So provides the safety of the appliances.

Maximum employees require light fitting clothing for working due to temperature.

A major concern during the project is handling of cement bags since due to dry air the particulate can spread very rapidly.

Mobile crane, concrete mixtures and many more heavy construction vehicles are operating at project site for which proper movement path should be identified.

For providing electrical supply from the solar power plant heavy cables will be installed which comes wrapped in heavy drums, during shifting of these drums a major concern is required.

7.2 Recommendations for the Solar Industry

Based on the findings of this thesis, the following strategic recommendations are proposed for project developers and EPC contractors operating within the Indian renewable energy sector:

Mandatory Dynamic Risk Assessments: Traditional HIRAs are often static documents prepared before project commencement. It is recommended that EPC contractors adopt a dynamic HIRA model (such as the Point of Work Risk Assessment), which updates in real-time based on fluctuating weather conditions (e.g., wind speed sensors tied directly to lifting permits) and changing topographical realities.

Centralization of the Fragmented Workforce: The disparity in safety culture among various sub-contractors remains the weakest link in solar site safety. Principal developers must mandate centralized, unified EHS training gateways, ensuring that the lowest-tier unskilled migrant laborer receives the same caliber of hazard communication as direct EPC staff.

Digitization of Observation Systems: Transitioning from paper-based observation cards to mobile-based EHS application tracking will drastically reduce the reaction time to correct unsafe conditions in sprawling solar parks that span hundreds of acres.

Heat Stress and Environmental Engineering: Given the rising ambient temperatures in India's primary solar belts (Rajasthan, Gujarat, and Madhya Pradesh), standard administrative controls for heat stress (water breaks) are insufficient. Future projects must integrate engineered shading structures for critical assembly nodes and explore climate-controlled wearable PPE for high-exposure tasks.

7.3 Scope for Future Research

While this study comprehensively addressed the physical construction and commissioning phases of fixed-tilt and single-axis solar plants, the industry is rapidly evolving. Future academic research should expand the HIRA framework to investigate the specific hazards associated with Battery Energy Storage Systems (BESS), notably the extreme risks of lithium-ion thermal runaway and chemical exposure. Additionally, assessing the long-term occupational health impacts of continuous crystalline silica dust exposure on solar workers presents a critical area for longitudinal study.

In conclusion, the aggressive pursuit of India's ambitious renewable energy targets must not come at the cost of occupational safety. The findings of this thesis affirm that with uncompromising adherence to a structured risk assessment framework, zero-harm construction in utility-scale solar infrastructure is a highly attainable reality.

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