Safety Analysis: Rooftop PV System Training Equipment

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Abstract

The implementation of PV Rooftop Power Plant systems as an alternative energy source has become increasingly widespread. The growing use of these systems is accompanied by the need for skilled workers with competencies in their installation. To support the development of such competencies, various training equipment designs have been created to enhance workers' skills in rooftop PV installation.

This article aims to evaluate Occupational Health and Safety (OHS) aspects in the designed rooftop PV training equipment. The methodology used in this research includes risk analysis through hazard identification, risk assessment, and mitigation recommendations. Data collection was conducted through a literature review related to OHS standards, direct observation of the equipment's use, and interviews with instructors and technicians involved. The research results show that the main risks include Falling Hazards, Electrical Hazards, Mechanical Hazards, Tripping or Snagging Hazards, and Ergonomic Hazards. Risk control measures were implemented by ensuring that the trainees understood work-related risks, using Personal Protective Equipment (PPE), and monitoring the condition of the work area and equipment.

Keywords *— Renewable Energy, Risk Management, Hazard Control*

1. INTRODUCTION

The implementation of renewable energy has become a global priority in efforts to reduce dependence on fossil fuel sources and address climate change[1][2][3][4]. PV Rooftop Solar Power Plants, as one of the rapidly growing renewable energy technologies, offer an effective solution for generating clean and sustainable electricity[5][6][7][8]. In this context, the increased utilization of PV Rooftop Solar Power Plants system not only involves the installation of efficient systems but also the development of a skilled and competent workforce.

Training equipment plays a crucial role in supporting the growing need for renewable energy applications, one of which is the use of rooftop PV systems[9][10][11]. This support comes in the form of educational tools that enable installation workers to gain the practical skills required for the installation and maintenance of rooftop PV systems. By using training equipment, trainees can practice in a controlled environment, allowing them to develop a deep understanding of the various technical and operational aspects of rooftop PV systems, including system component management and troubleshooting.

In the educational context, training equipment designed to support learning about rooftop PV systems is intended to provide practical experiences that closely mimic real-world field conditions[12]. However, the success of the learning process does not only depend on the functional design of the training equipment but also on the effective application of Occupational Health and Safety (OHS) principles[13][14]. Evaluating OHS aspects in the design of training equipment is essential to identify and mitigate risks that may arise during the use of such equipment. Effective training equipment can help develop a workforce that not only understands the theory behind renewable energy technology but can also apply it safely and efficiently. Thus, training equipment serves as a bridge between academic knowledge and practical skills, facilitating the enhancement of workforce capacity to support the broader adoption of renewable energy.

Regarding the integration of the Internet of Things (IoT) into training equipment, this aspect will enhance both functionality and occupational safety. IoT-based equipment monitoring enables real-time data collection, allowing for more accurate system performance tracking, early fault detection, and immediate safety alerts to reduce the risk of accidents. From a computer science perspective, the implementation of IoT in renewable energy systems can include information from the working conditions of the training equipment, which is then regulated to ensure safe usage and scheduled maintenance. By implementing IoT, potential hazards such as electrical faults, overheating, and system failures can be identified before they pose a risk.

This article aims to evaluate OHS aspects in the design of rooftop PV training equipment. This evaluation includes hazard identification, risk assessment, and the formulation of mitigation recommendations to reduce potential hazards. Using a methodology that involves literature review, direct observation, and interviews with instructors and technicians, this article is expected to provide valuable insights into improving the safety and effectiveness of rooftop PV training equipment.

2. RESEARCH METHOD

This research adopts a qualitative approach, focusing on evaluation based on literature review, direct observation, and interviews. The literature review was conducted to understand relevant Occupational Health and Safety (OHS) standards and guidelines related to the design of rooftop Solar Power Plant (PV) training equipment. The reviewed literature includes standard documents, scientific articles, and other documents related to work safety in the context of PV installation, which were then compared to the designed training equipment. The purpose of this study was to identify the OHS principles that should be applied to the training equipment and to compare the existing practices with the established standards.

Direct observation was conducted to evaluate the use of the existing rooftop PV training equipment. During the observation, the researcher identified potential hazards and risks associated with the use of the equipment. The observation covered the physical condition of the training equipment, compliance with OHS standards, and potential risks that may arise during the learning process. Data collected from the observation provided an overview of the technical and operational aspects of the training equipment, as well as the interaction between users and the equipment. Furthermore, interviews were conducted with instructors and technicians involved in the training on the use of the training equipment. The interviews aimed to gather information regarding their practical experience, the challenges they faced, and their assessment of the OHS aspects of the training equipment design. These interviews provided additional perspectives on the effectiveness of the training equipment in supporting learning and ensuring workplace safety.

The data collected from the literature review, observations, and interviews were then analyzed to identify potential hazards and risks related to the design of the rooftop PV training equipment. This analysis included an assessment of compliance with OHS standards and the development of mitigation recommendations to reduce the identified risks. The findings from data analysis were used to recommend practical processes and the implementation of Personal Protective Equipment (PPE) to improve safety and effectiveness in the learning process. To ensure the accuracy and reliability of the research results, validation was performed by comparing the findings from observations and interviews with relevant OHS guidelines and standards. Verification of the results was carried out by reviewing the collected data to ensure the consistency and relevance of the information.

3. RESEARCH RESULTS AND DISCUSSION

3.1. Description of Equipment Design

Figure 1 provides a detailed illustration of the design of the rooftop Solar Power Plant (PV) installation training equipment, which was created to support the learning process. This equipment consists of two main components: the rooftop installation block and the load simulation model block. The rooftop installation block includes various elements designed to resemble real conditions in the installation of solar panels on rooftops, such as a detachable roof frame, roofing materials installed according to actual standards, and marked footpaths related to occupational safety. The roof frame is designed with a slope of 30°-35°, consistent with common residential roof angles, to provide a realistic experience for trainees when installing solar panels.

The load simulation model block functions to simulate the electrical power flow process that occurs after the solar panels are installed. This block is equipped with various components such as an inverter, a kWh meter for power measurement, and electrical protection devices like DC breakers and AC breakers. The model is designed as a vertical wall, allowing trainees to practice installing electrical components on a vertical surface, which is a critical part of the rooftop PV system installation process.

Figure 1. Design of rooftop PV system training equipment

These two blocks are designed to facilitate a deep and practical understanding of PV rooftop Solar Power Plant installation, allowing trainees to acquire the necessary competencies more easily and effectively. The detachable design also enables the use of this equipment both indoors and outdoors, providing flexibility in the learning process and load simulation that closely resembles real conditions.

The equipment is initially designed for indoor use, allowing trainees to receive hands-on training under the supervision of instructors. Indoor usage ensures that the exchange of information between trainees and instructors can occur more effectively, allowing each step in the installation process to be studied carefully and systematically. Once the trainees have gained sufficient understanding, the equipment is then disassembled and reassembled outdoors. Outside, the equipment is used for a more realistic simulation process, utilizing direct sunlight exposure to simulate the actual operational conditions of the rooftop PV system.

3.2. Hazard Identification and Risk Assessment

The following are the results of hazard identification and risk assessment for the use of the Rooftop PV System Training Equipment.

a. Initial Information Gathering on Hazards in the Object and Workplace
   The initial information gathering focuses on potential hazards in the area where the Rooftop PV System Training Equipment is used. This information includes manual

guides for the equipment components and observable risks during its use. Physical and electrical hazards are identified as the two primary risks in the training area. Physical hazards are mainly related to the risk of slipping or falling when using the rooftop installation block, as the equipment design mimics an actual roof with a slope of approximately 30°-35°. The risk of falling or slipping increases when participants must stand or move on the sloped surface. Another physical hazard involves the risk of being pinched or struck by the equipment, which has a significant mass and could cause physical injury if it falls or traps someone. Additionally, electrical hazards stem from the various electrical components installed in the load simulation block. When participants perform installation or simulation tasks, the risk of electric shock may occur if electrical components are not handled properly. This risk can lead to serious injury or even death if proper precautions are not in place.

b. Hazard Inspection in the Object and Workplace

The inspection aims to identify hazards that may not have been apparent during the initial stage or those that may arise from changes in the work area. In the context of the Rooftop PV System Training Equipment, thorough inspections are conducted on all components, including electrical devices, the roof structure, and the surrounding work area. Hazards such as the risk of falling from a height, electrical contact, and other dangers are identified and documented. The inspection includes a detailed examination of the physical structure of the equipment, such as the stability of the roof frame and the condition of the roofing materials used. Failure to ensure that all components are properly and safely installed can increase the risk of accidents, such as falling from a height or injury due to equipment collapse. Additionally, the condition of the work area, including cleanliness and orderliness, is inspected to prevent incidents like tripping or slipping. Beyond physical aspects, the inspection also assesses electrical hazards from components such as inverters, solar panels, and electrical protection systems. Any identified electrical hazard requires careful handling, as the risk of electric shock can result in serious injury or even death.

c. Identification of Occupational Health Hazards

Occupational health hazards identified in the use of the Rooftop PV System Training Equipment include electrical exposure and potential harmful material exposure. Electric shock is a significant health risk, as it can cause burns, internal organ damage, or even death. This exposure could occur if participants are not adequately protected or if there is a mistake in the installation of electrical components. Moreover, practice sessions are often conducted outdoors, where excessive exposure to sunlight can harm the eyes. Therefore, it is important to ensure that health protection measures are taken, such as using appropriate personal protective equipment (PPE).

d. Investigation of Incidents

Any incident that occurs during the use of the Rooftop PV System Training Equipment is thoroughly investigated to identify root causes and implement preventive actions to avoid similar incidents in the future. Potential incidents, such as falls from height, electric shocks, or equipment structure collapses, are documented and analyzed to understand their causes. Detailed documentation and timely reporting are crucial for evaluating existing safety measures and making necessary improvements to the safety system. These investigations also provide valuable insights for updating safety procedures and ensuring the equipment is used safely and effectively in the future.

e. Identification of Hazards Related to Emergencies and Non-Routine Activities
Emergency situations and non-routine activities, such as equipment maintenance or outdoor simulations, may present different hazards from everyday activities. In the context of the Rooftop PV System Training Equipment, hazards that may arise during non-routine activities are identified, such as the risk of fire when working with electrical devices or the risk of falling while moving equipment outdoors. Developing appropriate emergency response procedures and preparing control measures for these situations is key to reducing potential risks.

f. Grouping of Identified Hazard Characteristics, Temporary Control Measures, and Prioritization of Hazards for Permanent Control
The final step is to group the identified hazards based on severity and likelihood of occurrence. These hazards are evaluated to determine temporary control measures, such as the use of personal protective equipment, until a permanent control program is implemented. In this study, high-risk hazards are prioritized for control, such as adding additional safety measures in areas with a high risk of falls. This evaluation ensures that all hazards that could cause serious harm are effectively and sustainably controlled. Table 1 presents the results of the risk identification.

Table 1. Risk Identification Results

No.	Hazard Identification	Risk Assessment	Control Measures	Monitoring
1	**Fall Hazard:** Since this tool resembles a roof with a slope of 30°-35°, there is a risk that trainees may slip and fall.	**Fall Risk:** **Likelihood:** Medium, especially if trainees are inexperienced. **Severity:** High, as a fall from height can cause serious injury. **Risk Category:** High.	**Fall Risk Control:** Use safety harnesses and ensure that the designated walking areas are clearly marked.	Regular monitoring is conducted to ensure effectiveness. Additionally, periodic reviews are performed to identify new hazards that may arise over time.
2	**Electrical Hazard:** The presence of electrical flow in the PV system, especially in the load simulation model block, poses a risk of electric shock.	**Electric Shock Risk:** **Likelihood:** Medium, especially when working with electrical systems operating at 220V AC. **Severity:** Very High, as electric shock can be fatal. **Risk Category:** Very High.	**Electrical Risk Control:** Ensure all trainees have a basic understanding of electrical safety and use personal protective equipment (PPE) such as insulated gloves and safety shoes.	
3	**Mechanical Hazard:** The process of installing solar panels, including the use of end clamps, middle clamps, and mounting brackets, can cause injury if the tools are not installed correctly or if there is a structural failure.	**Mechanical Injury Risk:** **Likelihood:** Low, if installation is performed according to procedures. **Severity:** Medium, may cause mild to moderate injuries. **Risk Category:** Medium.	**Mechanical Risk Control:** Ensure all mechanical components are installed according to standards and conduct routine inspections.	

No.	Hazard Identification	Risk Assessment	Control Measures	Monitoring
4	**Tripping or Snagging Hazard:** The shape of the tool and the use of cables placed in the practice area create a risk of tripping or snagging.	**Tripping or Snagging Risk:** **Likelihood:** Medium, depending on the trainees' attention to marked walking areas. **Severity:** Medium, may cause mild injuries. **Risk Category:** Medium.	**Tripping or Snagging Risk Control:** Double-check the walking areas and ensure all trainees follow the instructions correctly.	
5	**Ergonomic Hazard:** Incorrect body positioning while working on an incline or vertical surface can lead to muscle or bone injuries.	**Ergonomic Injury Risk:** **Likelihood:** Medium, especially if working posture is not observed. **Severity:** Medium, can cause muscle or joint injuries. **Risk Category:** Medium.	**Ergonomic Risk Control:** Ensure trainees are taught about correct working posture and safe lifting techniques.	

3.3. Recommendations for Practical Procedures Based on Safety Review of Rooftop PV System Training Equipment

There are six sections of Recommendations for Practical Procedures Based on Safety Review of Rooftop PV System Training Equipment:

a. Safety Introduction Before Practice
Before starting the practical sessions, all participants must attend a safety training session covering general safety procedures, specific hazards that may arise when using the Rooftop PV System Training Equipment, and emergency actions to be taken in case of an accident. Additionally, it is essential for every participant to wear appropriate Personal Protective Equipment (PPE), such as helmets, insulated gloves, safety shoes, and safety harnesses, especially when working at heights or with electrical components.

b. Installation and Practice Procedures for the Rooftop Installation Block
Before installation begins, the workspace must be prepared by ensuring cleanliness and that it is free of any objects that could cause accidents, such as tripping. The footing area markings should be clear and free of obstacles and must be followed by participants to reduce the risk of falling. During the solar panel installation process, participants must strictly follow instructions, ensuring that components such as rail mounting brackets, end clamps, and middle clamps are in good condition without any damage. During the practice session, supervision from an experienced instructor is crucial to provide guidance and handle emergencies if necessary.

c. Practice Procedures in the Load Simulation Block
Before connecting the simulation block to the power source, the electrical system must be tested to ensure all electrical components function properly and safely. In addition, participants should understand the lockout and tagout procedures for electrical components before performing any repairs or adjustments, to avoid the risk of electric shock. During the load simulation, electrical power flow should be monitored to ensure

the system operates within safe limits. Instructors should also ensure participants understand how to read and interpret data from measuring instruments. If any additional loads are used through outlets, it must be ensured that these loads do not exceed the designed system capacity, preventing the risk of overheating or fire.

d. Emergency Procedures and Follow-Up
Participants must be familiar with emergency procedures, including the location of fire extinguishers, emergency gathering points, and how to shut off the main power source in the event of an accident. If an accident occurs, such as a fall or electric shock, first aid should be administered immediately, and the victim should be taken to the nearest medical facility. Every incident, no matter how minor, must be recorded and reported to management for further analysis with the aim of improving future safety procedures.

e. Maintenance and Regular Inspections
The training equipment must undergo routine inspections to ensure there is no damage or wear on components. Frequently used components, such as clamps and mounting brackets, require more frequent checks. In addition, measuring instruments should be regularly checked to ensure accuracy and safety during use. Through regular maintenance and inspections, potential risks during practical sessions can be minimized, supporting a safer and more effective learning process.

4. CONCLUSION

Based on the research findings, several conclusions can be drawn regarding the hazard identification of the Rooftop PV System Training Equipment. First, the risk of falling can be controlled by using a safety harness and ensuring that the footing area is clearly marked. Second, the risk of electric shock can be minimized by ensuring that participants have basic knowledge of electrical safety and by using personal protective equipment (PPE) such as insulated gloves and safety shoes. Third, the risk of mechanical injury can be avoided by ensuring that all mechanical components are installed according to standards and by conducting regular inspections. Fourth, the risk of tripping or entanglement can be controlled by rechecking the condition of the footing area and ensuring that all participants follow instructions correctly. Lastly, the risk of ergonomic injury can be reduced by providing training to participants on proper working posture and safe lifting techniques.

5. SUGGESTED

Further research can be conducted to assess the fatigue levels of participants during the installation of rooftop PV system training equipment. The assessment of fatigue during the practice process can be considered from the perspective of both the participants and the mentors overseeing the practice. This section can recommend appropriate rest periods during the work process.

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