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Assessment of the safe operation and maintenance of photovoltaic systems

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ABSTRACT

Nowadays although PVs (photovoltaics) have been a major energy source, there are limited publications focused on the risks regarding the operation and maintenance of PV systems. This subject is crucial especially by taking into account the number of additional installations due, also, to the favorable European policy. In addition, there are limited data worldwide regarding mishaps related to the operation/maintenance of installed PV. Thus, it is difficult to establish a safety policy roadmap for PV operations/maintenance projects, especially the large ones. In order to accomplish that, an operational risk management methodology is suggested to be adopted. The scope of this paper is: (i) to clarify the importance of safety at PV systems during normal operation/maintenance; (ii) to establish a baseline holistic risk assessment for installed PV working environment; (iii) to identify probable hazards incorporated to the operation/maintenance of PV systems; and (iv) to assess the associated hazards. The proposed methodology and findings should be considered as a baseline for further research in the future.

1. Introduction

As it is well known PVs (photovoltaics) have very limited environmental implications in comparison to the conventional energy sources [1]. However, although the installation, operation and maintenance of a PV system have some hazardous and risky elements, the amount of research regarding safe procedures is considering inadequate. The life cycle of a PV system includes [2] the following phases (Fig. 1): (i) Raw material Mining and Processing; (ii) Construction and Assembling; (iii) Installation/Operation/Maintenance; (iv) End of Life Cycle and recycling.

The primary attempts for the description of solar electricity technology risks were established in the beginnings of '90s. Most in the existing literature the researchers do not provide a quantitative and thoroughly investigation of technological risk factors related to different hazards categories.

Bezdek [3] described the environmental, health and safety implications of solar energy in central stations production. He compared relative risks of different energy sources (i.e. coal oil, nuclear, natural gas, hydroelectricity, wind, methanol, solar space heating, solar thermal electric, photovoltaic systems, and ocean thermal energy conversion).

Ramanathan [4] examined the diverse characteristics of eight different technologies (solar PV, biomass, windmills, hydroelectric, oil, natural gas, coal, and nuclear) using Data Envelopment Analysis. He utilized Comparative Risk Assessment as the balancing of the benefit-cost-risk estimates of all compared alternatives for accomplishing the same end purpose using as measurement tools the loss or gain of life expectancy, the land use, and the CO_2 emissions.

Johansson [5] analyzed the energy security aspects of renewable energy systems (including PV systems) and acknowledged three types of risk factors associated with renewable energy systems: economic & political, technological and environmental risk factors.

Sovacool et al. [6] assessed the risks of energy accidents of eleven energy systems (including solar PV) using original historical dataset over the period 1874–2014. In this analysis a subset of accidents-from1990 to 2013- was normalized to units of energy produced, in order to normalize fatalities and property damage to energy output.

The current analysis has put emphasis on a risk assessment during the operation and maintenance period of a PV system, which is estimated more than 20 years.

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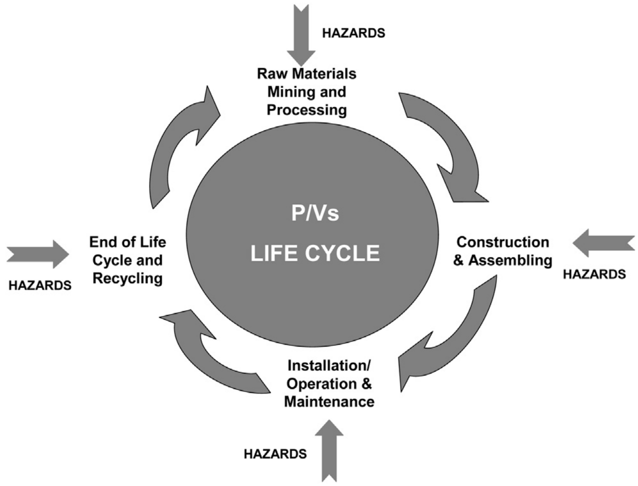

Fig. 1. Life cycle of a PV system.

The scope of this paper is: (i) to clarify the importance of safety at PV systems during normal operation/maintenance; (ii) to establish a baseline holistic risk assessment for installed PV working environment; (iii) to identify and to assess probable hazards incorporated to the operation/maintenance of PV systems.

2. Methodology

2.1. ORM (operational risk management)[1]

The ORM was chosen for the PV risk[2] management due to the following reasons:

(i) PV systems are working continuously (i.e. power generation) in coincidence with the sunlight. Similarly, the ORM tool is a dynamic tool with the help of which someone may continuously provide essential risk management procedures;
(ii) due to the global lack of statistical data regarding PV operational mishaps, the ORM tool is considered as an essential tool to build a qualitative baseline assessment of related hazards.

In order to better understand the methodology followed in this particular paper several definitions from different sources are given. The five steps of ORM are the following (Fig. 2) [8]:

(i) identify hazards/hazard[3] sources;
(ii) assess the hazards;
(iii) make risk decisions;
(iv) implement controls;
(v) supervise and watch for change

[1] For the purposes of this analysis it was defined as ORM (Operational Risk Management) the process of dealing with risk associated with any type of operations, which includes risk assessment, risk decision making, and implementation of effective risk controls and may involve five steps The four principles of ORM are: (i) accept risk when benefits outweigh the cost; (ii) accept no unnecessary risk; (iii) anticipate and manage risk by planning; (iv) make risk decisions at the right level.

[2] As risk it is considered the "measure of the probability and severity of adverse effects" [7].

[3] *Hazard* is defined as "*any dangerous condition that can cause an interruption or interference with the expected orderly progress of an activity*" [9]. The *Hazard Source* is considering as "*the intrinsic property of a component or skill (e.g. work materials, equipment, work methods and practices) that may cause damage*" [10].

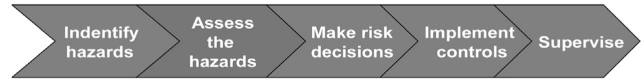

Fig. 2. The five steps of operational risk management.

Although the ORM tool was designed mainly for military operations, it may be utilized for any other types of operations which may involve risks.

The identification of hazards should identically present the conditions that may result into a potential mishap, and the existence of energy sources such as electricity or chemicals. Also, a review of mishap statistics to identify hazards that resulted in mishaps is strongly recommended. The risk assessment is the process which describes the likelihood that something could go wrong and the worst thing that could happen in terms of probability and severity. The decision making step is targeting the manageable risk: in this step, the level of risk is determined whether it is acceptable or not acceptable. The decision maker performs an evaluation of the risk and he/she has the opportunity to decide what tasks may be decreasing the level of risk.

It is very important to remember that not all risks are manageable, and sometimes the best decision is not to perform a task. The fourth step incorporates the implementation of control measures, i.e. to decrease the risk or eliminate it by applying engineering and/or administrative controls. When engineering or administrative controls are not practicable, PPE (Personal Protective Equipment) shall be used to reduce hazards. The final step of ORM involves the supervision process, where it should be ensured that the assessment was accurate and checked if the controls are effective. Due to the absence of a real case situation and the lack of sufficient statistical data related to PV Systems, for the purposes of this paper we only engaged with the two first steps of ORM (hazards identification and hazards assessment). The RACs (Risk Assessment Codes) can assist in the ranking of the control priorities putting values in the level of risk as follows:

(i) Negligible
(ii) Minor
(iii) Moderate
(iv) Serious
(v) Critical

For the purposes of this paper it is considered the Hazard Severity as an assessment of the worst potential consequence, defined by degree of injury, occupational illness or property damage. Four levels are used to assess Hazard Severity:

(I) Catastrophic: May cause death or loss of PVP facility
(II) Critical: May cause severe injury, occupational illness or PVP damage
(III) Marginal: May cause minor injury, occupational illness or PVP damage
(IV) Negligible: Probably would not affect personal safety or health but is a violation of a safety standard

The Mishap Probability is defined as the likelihood that a hazard will result in a mishap, based on an assessment of location, exposure in terms of numbers of people and frequency or duration of an operation. Four levels are used to assess Mishap Probability:

(A) Likely to occur immediately or within a short period;
(B) Probably will occur in time;
(C) May occur in time;