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Methodology for renewable energy risk assessment applied to photovoltaic systems in Mexico

Metodología para evaluación de riesgos en energías renovables aplicada a sistemas fotovoltaicos en México

RUIZ-SÁNCHEZ, Teresa de Jesús[1]*†, SÁNCHEZ-JUÁREZ, Aarón[2], MESSINA-FERNÁNDEZ, Sarah Ruth[1] and HIDALGO-MILLÁN, Antonio[1]

[1]*Universidad Autónoma de Nayarit*
[2]*Universidad Nacional Autónoma de México*

ID 1st Author: *Teresa De Jesús, Ruiz-Sánchez* / **ORC ID**: 0000-0002-2904-5785

ID 1st Co-author: *Aarón, Sánchez-Juárez* / **ORC ID**: 0000-0002-4604-4581

ID 2nd Co-author: *Sarah Ruth, Messina-Fernández* / **ORC ID**: 0000-0002-6529-4818

ID 3rd Co-author: *Antonio, Hidalgo-Millán* / **ORC ID**: 0000-0002-0094-2861

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* Correspondence to Author (e-mail: tere.ruiz@uan.edu.mx)
† Researcher contributing first author.

Introduction

Due to the increase in demand for electricity, global warming and energy sustainability, there has been a significant increase in the use of renewable energy technologies. This can be seen in reports from the International Renewable Energy Agency (IRENA), which in 2018 reported a total world electricity generation capacity of 2,356,346 MW with technologies based on these energy sources. These data constitute a sustained annual growth over the last five years of between 8 and 9 % (IRENA, 2019, p. 2). Therefore, the use of these technologies is a strategy adopted worldwide to reduce both the dependence on fossil fuels and the environmental impact of electricity generation.

In addition, one of the parameters that should be considered within the sustainability of renewable energies is security. In 2013, the Paul Scherrer Institute (PSI) in Switzerland conducted and documented a comparative assessment of accident risks in the energy industry. Among the findings of this research, it was found that severe accidents have not yet been reported in some energy facilities with renewable technologies, such as photovoltaic plants. Therefore, expert judgement was used for their evaluation (Burgherr and Hirschberg, 2014, p.45-56). Subsequently, Sovacool and his group conducted an analysis of historical accident data from the energy sector from 1874 to 2014 and found that this sector had documented 1,085 accidents with 211,529 human fatalities and $344.4 billion in property damage losses. In this analysis, wind energy was found to top the list with the most frequent accidents per TWh generated. It is worth mentioning that the research team analysed archives, academic articles and web data, but found only a relatively small sample of accidents for solar and geothermal energy systems; 80% of the data found for these types of energy corresponded to accidents in Europe or North America (Sovacool et. al, 2015, p. 2016-2027).

Notwithstanding the above, in Mexico, the Ministry of Environment and Natural Resources (SEMARNAT) establishes as hazardous projects or facilities those that handle equal or higher quantities of one or more substances listed in the First or Second List of Highly Hazardous Activities, published in the Official Journal of the Federation on 28 March 1990 and 4 May 1992 respectively (SEMARNAT, 2016).

Thus, as can be seen, the Mexican regulatory basis excludes the hazardous conditions that are implicit in energy facilities.

Content

For the development of this section, subsections were established, which are presented below.

Methodology

Given the background of the limitations in the risk assessment of energy technologies in our country and the evidence that even in the absence of hazardous substances these installations can give rise to severe accidents, a methodological proposal is presented, which considers the risk aspects particular to the type of source or installation. That is to say, this proposal includes the identification of hazards, in order to subsequently evaluate the probabilistic aspects that lead to the occurrence of an accident situation due to system failure, human error or even external factors, such as climatological effects, in order to determine the impact of the consequences if these were to occur, even if their probability is small.

Therefore, in order to determine the risks inherent to this type of installation, it is proposed that assessments associated with the type of installation be included. Therefore, a preliminary identification of the hazard conditions that could occur according to the associated renewable energy technology was carried out. These conditions are presented below:

- Potential energy storage - hydro and wind.
- Kinetic energy enhancement - Wind and tidal.
- High voltages - Photovoltaic.
- High temperature - Geothermal, solar thermal and biofuels.
- Flash - Photovoltaics
- High pressures - Geothermal and biomass

The selection of the type of technology or energy source to be used to apply the risk methodology was made considering that this was a widely used technology.

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Thus, this methodology began to be applied in the assessment of electrical risks in Photovoltaic Systems (PVS), due to the fact that this is the fastest growing industry in our country given its versatility of use. This is because it can be used both for stand-alone applications (on-site power generation) or for interconnection to the conventional electricity grid with the sale of excess energy generated (SENER, 2017, p.80).

Similarly, in the world, IRENA reported that in the last five years it presented an increase in its use from 25 to 33% (IRENA, 2019, p. 48). On the other hand, the European Commission reported a 30% increase in PV industry production, reaching a global production volume of more than 80 GW of PV modules compared to 2015, and also documented a compound annual growth rate (CAGR) in the last 15 years of more than 40%, as shown in Figure 1 (Jäger-Waldau, 2017, p. 5). Furthermore, the costs of photovoltaic systems are currently affordable, which is why they are increasingly being installed in homes and shopping centres (mainly on roofs), as well as in public buildings (street lighting) (GIZ, 2018).

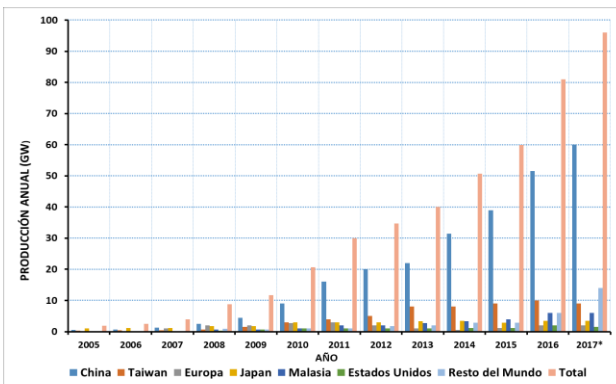

Figure 1 Annual PV module production from 2005 to 2017 [Adapted from (Jäger-Waldau, 2017, p. 5)]

As it could be assumed, SFVs having among their components many devices, as well as the generation of electric current, cause conditions that may represent a hazard, such as high voltage or high voltage, which is why the Swiss electricity sector is already evaluating the application of risk analysis in such facilities (Monja et. al., 2016, p. 1-6). Therefore, this work focused on identifying the hazards of SFVs interconnected to the grid, by means of retrospective and prospective analyses. These analyses are complementary, since retrospective analyses are based on the study of events that have already occurred, i.e., on the analysis of the causes of documented incident and accident reports.

On the other hand, prospective analysis is based on understanding the failure modes of a system that may lead to an incident before it occurs. In the literature review, it was found that, in Italy, following the increase in PV installations, more than 700 fires and 500 fires were documented in 2012 and 2014, respectively. Available data on such events range from fires generated in an electrical connection on one or a few PV modules to a large fire on the roof of a building (Fiorentini, 2015). Similarly, in the UK, in recent years, the Building Research Establishment Group was notified of eight incidents involving PV systems that required attention by the local fire service, however, as in our country, the actual number of fire incidents is unknown (Shipp, 2015).

Thus, a study was conducted from 2011-2013 at the Fraunhofer Institute in Germany, in which 420 SFV accidents that caused fires or temperature increase in SFVs were analysed. Of these, 48% were caused by a Balance of System (BOS) component, with the causes also found to be: installation errors (37%), defective products (35%), installation errors (18%) and others (19%). Likewise, it was reported that 2% of the incidents are generated by fires and 26% by overvoltage, which represented a loss in costs of 26% and 14%, respectively (Van de Velde, 2016).

Similarly, due to the absence of data, the assessment of consequences must be made based on empirical measurements or system-specific simulations, for example, for the flash condition and its effects, the US Federal Aviation Administration (FAA) started to require quantitative modelling for new projects and initiated work with Sandia National Laboratories (SNL) of the Department of Energy (DOE) (ACRP, 2014). These laboratories developed the -Solar Glare Hazard Analysis Tool‖ (SGHAT) software, which is already a requirement that, prior to SFV installation, a simulation with this software must be submitted to the FAA (SNL, 2020).

Thus, for the prospective analysis, it was considered to use a methodology that had already been used and that its application was simple and qualitative. Therefore, the What if? technique was used to identify situations of potential harm. This technique is widely used in chemistry (Ibarra-Hernández *et al.*, 2015, pp. 22-33).

It should be emphasised that proper hazard identification is the initial stage of risk analysis, and is the basis for the probabilistic assessment stages of failure events and their consequences. Therefore, given the absence of historical failure data for this type of installations, the estimation of the probabilities of undesired events must be carried out through the judgement of experts in the technologies considering the understanding of the failure modes and mechanisms of each system, i.e., a qualitative estimation.

Results

In addition to the Mexican regulations, which establish for this type of installations the requirements defined in the update of the PROY-NOM-SEDE-001-2018 standard, article 690, (DOF, 2018); practical improvements associated with this technology were sought. Thus, the following documents were found: "Catalogue of common failures and inadequate practices in the installation and maintenance of photovoltaic systems" issued by the European Photovoltaic Industry Association (EPIA), as well as another report on fire risks in PV systems documented by the International Energy Agency (EPIA, 2011; Sinha et. al., 2018).

Based on the information gathered, both from the retrospective and prospective analysis, the description of a FSS, the applicable national and international regulations and best practices, the What if? technique was applied with a group of experts. Among the electrical hazards found in these systems, the following stand out:

– Electrical discharges, whose identified and documented causes were: non-compliance with regulations (using inadequate components, lack of atmospheric discharge systems), design errors, loss of insulation due to rodent action.

Fires, due to arcing due to design flaws, loss of insulation, lack or failure of atmospheric discharge systems; heating of panels due to inadequate components (not certified), degradation due to dust accumulation, lack of maintenance or conditions that could generate hot spots on the solar panels.

Analysis of results

Given the results obtained, the analysis of causes and consequences, as well as the applicable regulations and best practices, a list of recommendations was issued in order to reduce the probability of occurrence of electrical accidents or their consequences. These recommendations were divided into three headings and are shown below:

1) Human factor:

– Employ qualified personnel for the installation and maintenance of the plant.
– Ensure the correct dimensioning and design of the lightning protection system.
– Comply with the installation of the devices and connections according to the torque specified by the manufacturer.

2) Reliability of components:

– Use certified PV modules and components.
– Maintain lightning protection and ground fault detection systems.
– Periodically check the state of connections, or have a system for continuous monitoring of current-voltage signals, power and electrical efficiency.
– Comply with the replacement of contactors according to the lifetime/number of interruptions defined by the manufacturer.
– Periodically check, either annually or between thermal cycles, the condition of the tightening torques of device connections, as well as the resistance/voltage drop on device contactors in order to prevent arcing.
– Periodic maintenance to remove dust and bird debris from the PV panels. Remember that this could not only reduce the lifetime of the component, but could also generate a hot spot and be the source of a fire.
– Periodically check the condition of the insulation. Remember that rodents and other insects can deteriorate it, which could be the cause of arcing, among others.

3) Consequence mitigation (fire)

– Develop and drill emergency response plans - fire response plans that include a plan with proper identification of disconnection points and those that continue to generate electrical current.
– Have fire extinguishers for type C fire.
– Avoid, as far as possible, placing the installation on roofs or combustible materials.

Conclusions

All energy technologies involve hazardous situations that must be assessed from their design and even in their modifications, since only economic and technical feasibility are evaluated. Risk analyses must consider climatological and geographical conditions, population density, affected areas, and include a multidisciplinary team that knows the mechanisms that could cause damage or failures, as well as the appropriate methodologies for hazard identification and risk assessment. All of this with the aim of preventing severe accidents before they occur and issuing regulations to control the impacts.

Thus, among the recommendations resulting from risk studies are the definition of exclusion zones associated with the development of emergency plans in accordance with the trajectory of different types or levels of uncontrolled events, as well as the design and introduction of mitigation or consequence control systems. In addition, given that each technology has its own particularities, it is necessary to make joint efforts for the development of regulations and predictive tools such as computer programmes.

Furthermore, photovoltaic systems are systems that are highly reliable when certified components are used and are designed and installed by qualified personnel. In addition, compliance with current regulations and standards related to system testing and maintenance activities must be incorporated. This would reduce the frequency of failures and the mechanisms that cause them, resulting in systems that are not only more reliable, but also safer.

In addition, the FSS should be evaluated considering the risks due to structural issues, given that in our country there are strong wind conditions in many areas and the effect of the height at which these systems are installed means that they can suffer damage and be launched as projectiles. However, given that it has been observed that climatic conditions have undergone variations with increases in natural disasters, these studies should be updated periodically.

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