SAFETY OF A PV PLANT
ZERO RISK AS STATED GOAL

1. INTRODUCTION

Per today by far more than 400GW PV systems are installed worldwide. These PV systems are proven to be safe. Despite this fact there are still rumors that spread unsubstantiated safety concerns. These rumors are about firefighters who reportedly can not extinguish fires in houses where a PV system is installed. This has turned out to be a false message. PV systems are safe, and there are many reasons for this. This white paper shows what these are and how fires can be prevented and what to do in the event of a fire.

Major institutes like TÜV and Fraunhofer report that less than 0,006 percent of all PV plants have caused a fire (Dr. Wirth, H., 2018). Statistic of the German fire brigade and TÜV lead to the conclusion that most fires (>99,9 percent) have other root causes. According to the TÜV Rheinland „PV systems do not pose health, safety, or environmental risks under normal operating conditions if properly installed and maintained by trained personnel as required by electrical codes (Sepanski et al., 2015). Above studies show that traditional PV systems are safe. TÜV Rheinland even came to the following conclusion: „The greater objectivity in reasoning has led fire departments to shift away from the general demand for a shutdown on the grounds that theoretically any switch-off device can fail "(page 240) (Sepanski et al., 2015).

On top the fire brigade associations are well aware that according to DIN VDE 0132 the recommended extinguishing distances are 5 m at full jet and 1 m with spray jet. Up to these distances no hazardous leakage currents occur (DGUV, 2008). (Sepanski et al., 2015).

2. FIRE PREVENTION

First it must be recognized that traditional PV systems are already safe. Here some facts:
A Fraunhofer ISE study reports that less than 0,006% of all PV plants have caused a fire (Dr. Wirth, H., 2018). According to an official statistic of the German fire brigade there are about 190.000 fires each year . A TÜV study reported that 210 PV plants have been the cause of a fire in Germany. This means more than 99,9% of fires in Germany had different root causes than PV systems. The risk of fire by a PV system is thus neglectable.

Why are these PV systems so safe? Since the introduction of PV systems around 1990 several measures have been introduced to increase the fire safety of a PV system:

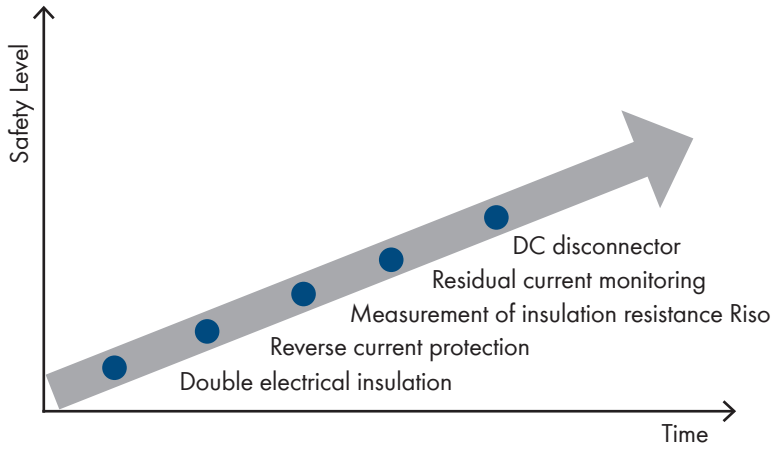


Figure 2.1Measures to improve safety of a PV systems

In order to find measures that improve fire safety even further the root cause of fire incidents have been analyzed. As a main source the TÜV study identified the following aspects:

1. **Installation mistake:** bad connection of DC connectors, insufficiently crimped connectors, missing strain relief etc.
2. **Product failure:** relate to failures of the modules and inverters
3. **External influence:** animal bite, lightnings etc.
4. **Planning failure:** wrong mechanical and electrical installation

[1]Deutscher Feuerwehrverband; Feuerwehrstatistik; www.feuerwehrverband.de/statistik.html

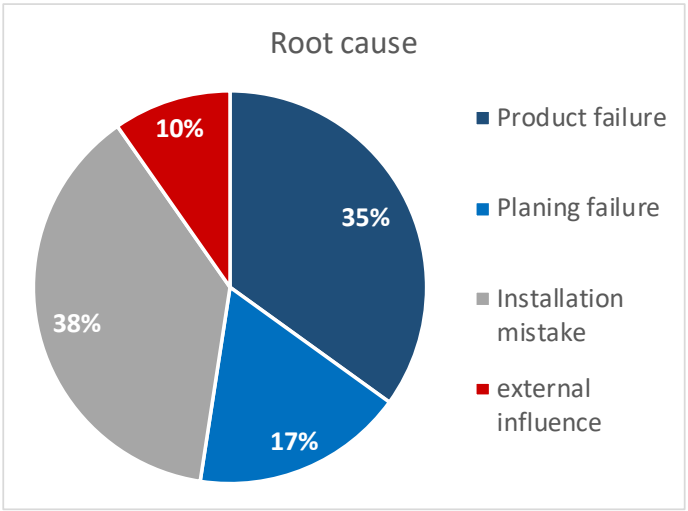


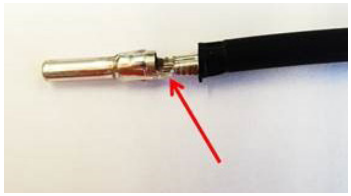
Figure 2.2 Figure 2.2 Root cause analysis fires by PV systems

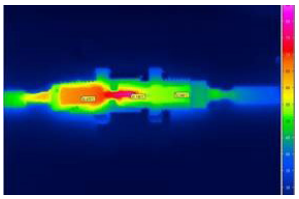
EXAMPLES OF BAD CONNECTION OF DC CONNECTORS:

Cross connectors: Contacts are proven to be very robust when connectors from the same manufacturer are used. This is the case for direct contacts from module to module. They are very robust and have a lifelong safety as field tests have proven. Concerning cross connectors, even if good contact connection exists at the time of installation, it may not be assumed that pairs of contacts from different manufacturers will attain a service life of 25 years (page 63) (Sepanski et al., 2015)

According to a surveil of University of Bern 48% of the installer reported that they have used cross connectors (Muntwyler et al., 2016). Why does this happen: in standard situations, modules and thus connectors from the same manufacturer are used, however, when introducing additional module electronic the chance of cross connectors increases significantly.

Crimped connector: Crimped connectors are sometimes used as an alternative for cross connectors. However also these can heat up if not crimped professional. Some suppliers propose to introduce thermal measurements in the panel level electronic to shut down the system in case of emergency, but these don't work reliably e.g. when connectors are crimped. The thinner crimped part of the connection increases the thermal resistance.





In summary the TÜV report identified as a main source of faults the "human factor". The proposed improvement measures therefore lie mainly in the realm of quality assurance pertaining to the components as well as to the planning and construction of the systems. Regular inspections by independent third parties were considered very useful; however, the financial cost must stand in a reasonable relationship to the revenue from the system. Additional safety components can further reduce the risk but were mentioned in the TÜV study only in second place, following professional planning and construction of the systems with high-quality components.

To further enhance the safety level, the focus must be on the most significant root causes for failures in PV plants:

- Contact failures
- Product failures
- Training and qualified personnel

The request for mandatory module level shut down equipment in contrast increases the number of DC connectors and the overall number of electronic components in the PV system and therefore increases the risk of fire.

Example: 10 kWp plant (40 modules à 250 Wp)

	String Technology	MLPE
Additional number of electrical components	0	40
Number of DC connectors	n	2*n

With introduction of module level shut-down the number of DC connectors would double and significantly increase the overall number of electrical components which also increases the risk of a failure in the whole PV system

Conclusion: To further enhance the safety level, the focus should be on the most significant root causes for failures in PV plants: Contact failures & Product failures. Increasing quality and define test standards are key to reduce vulnerability wrt. safety. Else module level shut-down equipment increases the risk of fire of a PV system and therefore should not be mandated for fire prevention.

3. FIRE FIGHTING

In case of a fire inside a building, the fire brigade may need to make a hole in the roof so that the smoke can escape the house. There are multiple guidelines from fire brigades that show how to make a PV system safe for fire-fighter in case of an emergency.
However, there are still some players in the market that request module level shut-down even though the chapter above has shown that the risk of fires increases by adding electronic and connectors to the roof. According to them the module level shut-down equipment would be required if PV modules must be removed and DC wire to be cut in an emergency.
But would there be sufficient time for fire-fighter to remove these in case of fire? No, fire-fighter will not work on a burning roof and remove the PV modules!
A TÜV report says: „Often safety components like fuses and switches are integrated in the DC part of PV systems. In the individual case it must then always be checked whether this measure is really necessary ". (page204) (Sepanski et al., 2015)
Alternatively, fire brigade associations as well as other experts e.g. from TÜV Rheinland and Fraunhofer ISE have come to the conclusion that several other measures which ensure the safety of a fire fighter in case of emergency.

1. CONSIDER EMERGENCY CASE ALREADY DURING THE PLANNING PHASE

PV installation rules for several roof types are defined by (DGS, 2011) :

- Inclined roof:

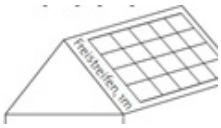


Figure 3.1Create access to the roof truss over a free strip

- Flat roof without any ingress route such as windows or skylights:

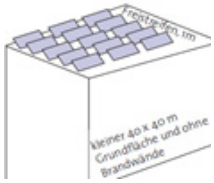


Figure 3.2 Create access to the roof truss for smaller flat roofs without via free strip on the longer side

- Large flat roofs:

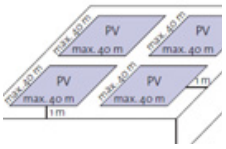


Figure 3.3For large roof access should be given for every fire section (usually 40m x 40m) around the generators. Width should not be less than 1m

2. DOCUMENTATION OF THE PV PLANT AND TRAINING OF THE FIRE BRIGADE

Provide information for fire fighters like installation layout diagrams showing the premises, conductors and other components of the PV system.

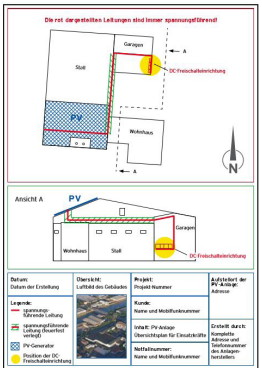


Figure 3.4 gives an example of a map of the PV system contains important information about the location of wire with voltage, DC disconnect switches etc. as recommended by the German fire brigade association (Feuerwehrverband, 2010). These maps should be located at the junction boxes or the electrical distribution boards.

3. IN CASE OF FIRE, FIRE-FIGHTERS CAN RELY ON THE PROVEN RULES AND SAFE DISTANCES

Given compliance with the recommended extinguishing distances of 5 m at full jet and 1 m with spray jet as per DIN VDE 0132, no leakage currents hazardous to rescue workers occurred when the water was used as the extinguishing agent. (page 131) (Sepanski et al., 2015)

Figure 3.5Measurement of leakage currents, extinguishing with foam under spray setting (Sepanski et al., 2015)

Conclusion: Experience has shown, that conventional PV systems with string technology are safe and can be managed in an emergency. Planning the PV system according to safety aspect right from the beginning, transparent documentation of the PV system and trained personnel are key to ensure the safety of a fire fighter.

4. SUMMARY AND CONCLUSION

In summary the TÜV report identifies as a main source of faults the "human factor". The proposed improvement measures therefore lie mainly in the realm of quality assurance pertaining to the components as well as to the planning and construction of the systems. Regular inspections by independent third parties were considered very useful. (page 106) (Sepanski et al., 2015)

- Experience has shown, that conventional PV systems with string technology are safe
- To further enhance the safety level, the focus should be on the most significant root causes for failures in PV plants:
  > Reduce the number of electric components and contacts in your system (fire prevention)
- Module level shut-down equipment increases the risk of fire of a PV system and therefore should not be mandated
- PV systems can be managed in an emergency
  > Apply constructive measures (fire prevention and fighting)
  > Apply proven rules of safe distances (firefighting)

Module level power electronic can add new functions like Optimization and monitoring, however **less is more**.

„The greater objectivity in reasoning has led fire departments to shift away from the general demand for a shutdown on the grounds that theoretically any switch-off device can fail ". (page236) (Sepanski et al., 2015)

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APPENDIX - CITATIONS:

„Components of photovoltaic (PV) systems undergo rigorous safety and reliability testing protocols during manufacturing and fulfill the electrical safety requirements established by various codes and standards. These systems do not pose health, safety, or environmental risks under normal operating conditions if properly installed and maintained by trained personnel as required by electrical codes" (page2) (IEA PVPS Task 12, 2017)

As a main source of faults the TÜV report recognized the "human factor". The proposed improvement measures therefore lie mainly in the realm of quality assurance pertaining to the components as well as to the planning and construction of the systems.
Regular inspections by independent third parties were considered very useful, however the financial cost must stand in a reasonable relationship to the revenue from the system. (page 106) (Sepanski et al., 2015)

„Using qualified skilled workers to ensure that existing regulations are adhered to is the best form of fire protection. To date, 0.006 percent of all PV plants have caused a fire resulting in serious damage" (page 70) (Dr. Wirth, H., 2018)

„PV plants do not present a greater fire risk than other technical facilities. Sufficient regu-lations are in place that ensure the electrical safety of PV systems and it is imperative that these are followed. Fires often start when systems are fitted by inexperienced pieceworkers. Weak points are inevitable when solar module connectors are installed using combination pliers instead of tools designed especially for this purpose or when incompatible connectors are used, and system operators should not cut costs in the wrong places" (page 71) (Dr. Wirth, H., 2018)

Even if good contact connection exists at the time of installation, we may not assume that pairs of contacts from different manufacturers will attain a service life of 25 years (page 63) (Sepanski et al., 2015)

„Electric arcs in a PV system typically do not occur abruptly and without previous indications, but are usually triggered by aging phenomena (degradation). Signs are already apparent in advance. Regular maintenance (e.g. every 2 years) can identify critical points in due time and rectify the causes of faults" (page 208). (Sepanski et al., 2015)

„Given compliance with the recommended extinguishing distances of 5 m at full jet and 1 m with spray jet as per DIN VDE 0132, no leakage currents hazardous to rescue workers occurred when the water was used as the extinguishing agent".(page 131) (Sepanski et al., 2015)

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„To improve safety, future additional hazard reduction and mitigation technologies need to be demonstrated to be effective and to perform as designed. Creating standards that demonstrate that the new hardware is reliable, fail-safe, and can function as designed over the life of the PV system is a challenge that requires ongoing testing. International cooperation between standards experts, firefighters, and technologists and other stakeholders will be crucial in successfully deploying these technologies"(page 2) (IEA PVPS Task 12, 2017)

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