



Electrical safety and safety standards for PV installations represent a particular challenge for the operator

Operating photovoltaic installations safely and efficiently

Like every complex technical installation, a PV installation can also produce hazards. In addition, due to its nature a PV installation places high requirements on the system safety technology with its large voltage fluctuations. The often physically extensive PV installations are also subject to a heterogeneous range of climatic conditions such as UV radiation, heat, frost, moisture, salt and other environmental effects, e.g. rodent damage. As a consequence far-reaching safety standards apply to PV installations. This article addresses the requirements from the standards and how they can be implemented.



▶▶▶ In relation to "Protection against electric shock" the basic national safety standard DIN EN 61140 (VDE 0140-1):2007-03 or the international IEC 61140:2009 describes essential "Common aspects for installation and equipment [...] without limitation of the voltage" for these installations and equipment. A crucially important requirement for all electrical installations and equipment is:

"Hazardous-live-parts shall not be accessible and accessible conductive parts shall not be hazardous live either under normal conditions (operation in intended use and absence of a fault), or under single-fault conditions".

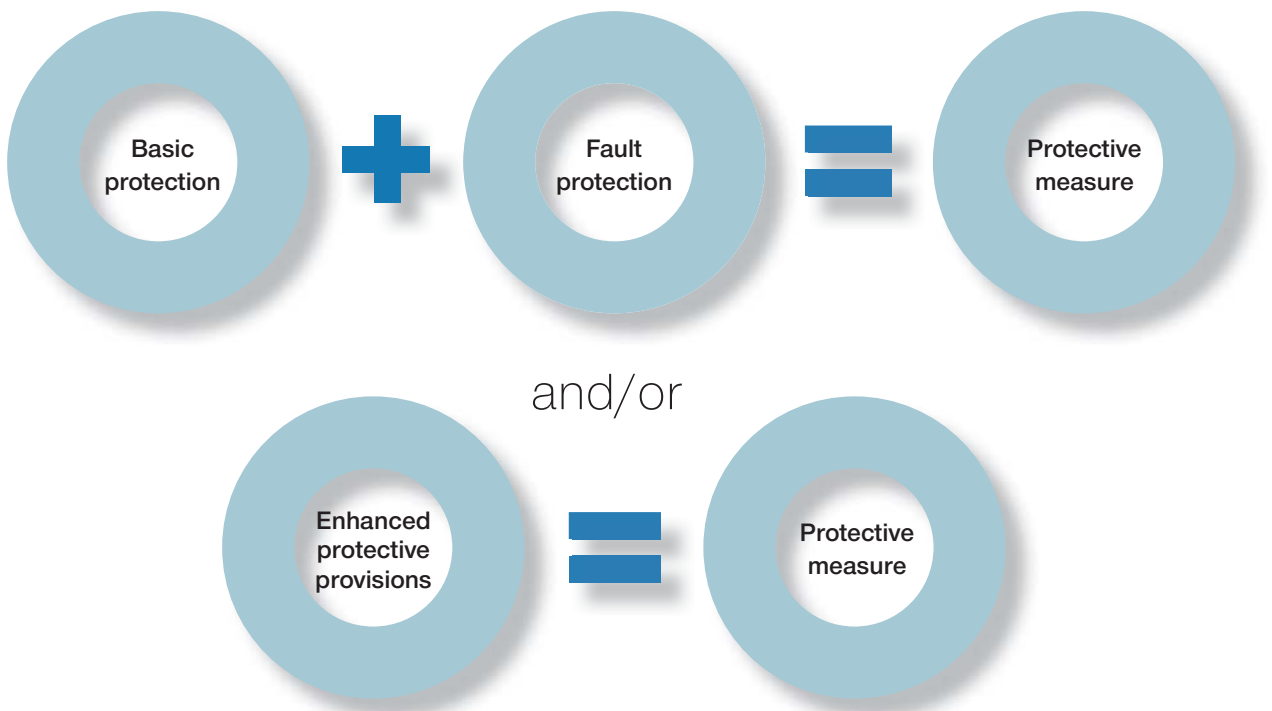
Here there is no differentiation between PV installations and other electrical installations.

An equivalent permissible implementation of a protective measure against electric shock in accordance with IEC 61140 comprises:

Detailed requirements in relation to the protective measures on erecting low-voltage electrical installations are described in the basic national safety standard DIN VDE 0100-410 (VDE 0100-410):2007-06 and the international IEC 60364-4-41:2005.

A harmonised European standard is also available, HD 60364-4-41:2007.

In section 411 of IEC 60364-4-41:2005 the "protective measure: automatic disconnection of supply" is described. This protective measure is widely used in most electrical installations and can be used for earthed systems and for unearthed systems (IT systems).



▶▶▶ Comprehensive protective measures are necessary



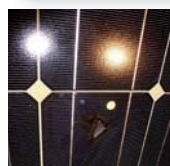
With the current state-of-the-art it is not possible to apply the protective measure "automatic disconnection of the supply" to the photovoltaic generators in PV installations, as an unpowered state in the normally physically extensive photovoltaic generator can only be achieved by covering the solar modules or in the dark at night. For this reason, in PV installations the "protective measure: double or reinforced insulation" is used as a minimum for the photovoltaic generator section. The requirements on the "protective measure: double or reinforced insulation" are described in part 412 of IEC 60364-4-41:2005. Particular attention is to be paid to section 412.1.3:

"Where this protective measure is to be used as the sole protective measure (e. g. where a whole installation or circuit intended to consist entirely of equipment with double insulation or reinforced installation), it shall be verified that the installation or circuit concerned will be under effective supervision in normal use so that no change is made that would impair the effectiveness of the protective measure. This protective measure shall not therefore be applied to any circuit that includes a socket-outlet or where a user may change items of equipment without authorisation."



Negligence can cost lives

This part currently applies to most photovoltaic generators in PV installations and means that the quality of the insulation, both during commissioning and during operation over decades, defines whether the "protective measure: double or reinforced insulation" is met. If there is a fault, compliance of the installation with the required insulation properties will decide on life or death, as negligence can cost lives.



The term insulation in PV installations refers, along with the insulation of cables and wires, air and creepage paths (e. g. in connectors and on terminals), also to the insulating films and insulating glass in the PV modules.

Standards for the prevention of electric shock and a fire risk

As these properties were already recognised as important long before the change in energy policy, as early as the start of the 90s there were extensive studies and assessments during which it was attempted to estimate which design measures in PV modules would result in safe behaviour over the long-term, both during fault-free operation and also after the first fault. Along with protection against electric shock, the fire risk was also considered.

The results of these studies and assessments were taken into account by the experts in the standards committees during the preparation of the standards on the design qualification and type approval of PV modules.

Currently these are for

- Terrestrial crystal silicon photovoltaic (PV) modules DIN EN 61215 (VDE 0126-31):2006-02 (intended replacement is E DIN EN 61215 (VDE 0126-31):2012-07)
- Terrestrial thin-film photovoltaic (PV) modules DIN EN 61646 (VDE 0126-32):2009-03.

Despite the numerous comprehensive tests during the type approval of PV modules and consideration of the requirements from the basic safety standards in the standard on erection DIN VDE 0100-712 (VDE 0100-712):2006-06 "Errichten von von Niederspannungsanlagen –Teil 7-712:



Anforderungen für Betriebsstätten, Räume und Anlagen besonderer Art – Solar-Photovoltaik-(PV)-Stromversorgungssysteme”(Low-voltage installations – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems” IEC 60364-7-712:2002, modified) time and again during the erection and the continuous operation of PV installations dangerous weak spots become apparent that have not been taken into account in the standards.

Example weak spots in PV installations:

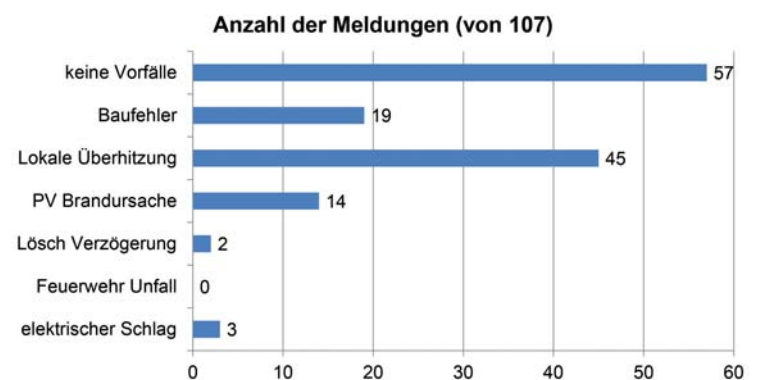
- Studies by the Fraunhofer Institute for Mechanics of Materials IWM on the "life expectancy of solar modules"
www.fraunhofer.de/de/presse/presseinformationen/2013/Okttober/lebenserwartung-von-solarmodulen-vorhersagen-7.html
"Using the simulation, we have learned for example that the brittleness caused by UV radiation plays a much greater role in material fatigue than has been assumed thus far."
- The results of the "Statistischen Schadensanalyse an deutschen PV Anlagen" (Statistical damage analysis on PV installations) from the Fraunhofer Institute for Solar Energy Systems ISE.
www.pv-brandsicherheit.de/fileadmin/WS_26-01-12/Stat.Schadensanalyse_an_dt._PV-Anlagen.pdf
 On slide 6 of the presentation => out of 107 responses 3 cases with the classification "electric shock".
- During the 3 1/2-year research project on "Brandschutz und Lichtbogenrisiko von PV-Anlagen" (Fire protection and arcing risk in PV installations), among other events, three workshops were held. From the third workshop on 03 April 2014 in Cologne (www.pv-brandsicherheit.de/koeln2014/) interesting information can be drawn from the papers presented by the participants.

– During a presentation by the GDV (Gesamtverband der Deutschen Versicherungswirtschaft e.V. Berlin - German Insurance Association) e.g., the following defects were highlighted (extract):

- Resistance to ammonia not taken into account. Comment: This means, e.g., the lasting chemical resistance of the insulating materials used in relation to liquid manure.
- Ambient conditions not taken into account (frost, atmospheric humidity, temperature drops, direct solar irradiation).
 Comment: *Condensation changes the creepage current behaviour in the extreme, this issue must be taken into account during the design of creepage paths.*
- Cable laying. Comment: A photograph was shown in which the insulation on a cable had been damaged by a sharp metal edge.



Fig. 1: Overview of the evaluation



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- ▶▶▶ – In numerous impressive photographs a large number of installation defects in PV installations were shown by the various participants to the workshop in the 15 presentations; these photographs demonstrate that the requirements and standards on the achievement of the protection objectives
 - Protection against electric shock
 - Fire protection
 are obviously often not met.

- TÜV Rheinland, e.g., stated: "At least 50 % of the defects are installation related"

- The quality of the maintenance of PV installations and the maintenance cycle were also the subject of numerous complaints.
 - There is a relationship between the frequency of damage and the time of year. There is more damage in the summer.
 - The significance of regular inspection is highlighted.



- In relation to "rodent damage" the following is stated in the book "Brandschutz in elektrischen Anlagen" by Herbert Schmolke: Such insulation damage is often not even detected by an insulation resistance measurement, as the remaining air gap between the bare conductors is very high impedance. As such the instrument sees intact insulation. Only on the addition of atmospheric humidity, soiling or the like do hazardous creepage currents occur.

Periodic testing not practical

The requirements on devices for insulation resistance measurement are described in the standard IEC 61557-2:2007. These devices normally operate at a measuring voltage of 500 V or even 1000 V, such that mostly the complete low voltage system with all its equipment and the protective and monitoring devices is not measured or tested, often only a cable. To undertake an insulation resistance measurement as a periodic test in a photovoltaic system a level of effort that should not be underestimated is required to configure the system for the measurement. As based on the current state-of-the-art the part of the installation related to the photovoltaic generators cannot be powered down, an insulation resistance measurement as periodic test in photovoltaic installations is not really practical.



Unauthorised people (family with children) are walking around in the solar field without knowing the dangers lurking around.



▶▶▶ Measuring without disconnecting

Conversely, insulation monitoring devices in accordance with IEC 61557-8:2007 are able to determine the total insulation resistance of an unearthed system (IT system) in operation without the need to disconnect equipment for this purpose. Measurement is made using low voltages such that no damage to equipment or protective and monitoring devices is to be expected. The determination of the total insulation resistance value by insulation monitoring devices functions correctly also on photovoltaic generators in the normal operating state without the need to specifically configure the system for the measurement and with the PV voltage present!

If the solar inverter is not operated as an IT system but has an earthed system, it is not possible to continuously monitor the photovoltaic generators in the operating state, as due to the electrical connection to the solar inverter necessary for normal operation there is already a low impedance path to earth. It is not possible to differentiate between the mostly higher parallel impedance insulation resistance values and this path.

Even though in the case of an earthed solar inverter complete continuous monitoring during 24-hour operation is not possible, the installation of an insulation monitoring device is definitely advantageous, as e.g. overnight the earthed solar inverter can be disconnected from the unearthed photovoltaic generator and at least the insulation resistance value for this part of the PV installation monitored by an insulation monitoring device for a few hours.

Continuous logging is prevention

In modern insulation monitoring devices the change in the level of insulation resistance over time can be recorded and displayed. If in this change over time, e.g., correlations are found between the level of insulation resistance and condensation overnight, and as a consequence fault location is started, the probability that rodent damage is found is much higher than during the mostly infrequently occurring periodic tests.

For other currently known defects in PV installations the continuous monitoring of the photovoltaic generator overnight also provides good chances of detecting states where there is a risk of fire in good time before damage occurs.

As an example of this issue reference is made to the article: "Warum kompatible PV-Steckverbinder gefährlich sind" (Why compatible PV connectors are dangerous) in ELEKTRONIKPRAXIS No.16 dated 26.8.2013. Here it is described that the necessary sealing of PV connectors had not been achieved due to installation errors during the erection of PV installations. Due to the ingress of dirt and moisture, the contact resistance in the related PV connector increases over time. In installation situations involving high currents there is a high probability of a fire due to the heating at the contact resistance.



At the same time there is a similar probability that the humidity and soiling in such an incorrectly installed PV connector will also cause a reduction in the level of insulation.

On the usage of an insulation monitoring device over a period as long as possible and on the display of a graphic curve of the level of insulation resistance as far as possible starting with the initial commissioning of the PV installation the detection of such critical defects also becomes more likely than via the infrequently undertaken periodic tests.



▶▶▶ Also the increasingly frequent requirement for the usage of arcing detectors does not always signal arcs with the expected reliability, as can be seen in the presentation by the Fraunhofer ISE on the following link

@ http://www.pv-brandsicherheit.de/fileadmin/WS_03-04-14/GRAB_Lichtbogendetektion_in_PV-Anlagen_K%C3%B6ln_2014-04-03.pdf

On the usage of an insulation monitoring device, the insulation resistance value is only an early indicator in this case. In conjunction with timely fault location to identify the cause of the reducing level of insulation resistance, this indication can lead to the actual problem of increased contact resistance. The higher impedance an insulation monitoring device can measure with system leakage capacitances present, the more likely such states will also be detected.

Advantage of unearthed IT system

In PV installations entirely designed as IT systems, the insulation resistance value can be monitored by an insulation monitoring device continuously and completely over all operating states. Insulation resistance values and even other system parameters are recorded with the assignment of the date and time in the insulation monitoring devices such that the specialist can correlate operating parameters and environmental parameters to critical states and initiate timely fault location.

For locating faults in PV installations there exist very varied methods, which in practice are more or less efficient. Very often the costs for a fully integrated fault location system are saved during the design of PV installations. Also the capabilities of a modern fault location system are unknown to the user or to the maintenance provider.

Arcing detectors tests according to UL 1699B at the Berner Fachhochschule
Measuring results: DUT (Device Under Test) 1

Short cable without resistance

Imp (A)	Electrode gap (mm)	Maximum response time permitted (s)	Tripping time 1 (s)	Tripping time 2 (s)	Tripping time 3 (s)	Passed yes - no
7	1,6	2	0.00	0.00	0.00	no
7	4,8	1,5	0.00	0.00	0.00	no
14	3,2	1,5	0.00	0.00	0.00	no
14	6,4	0,8	0.00	0.00	0.00	no

Long cable without resistance

Imp (A)	Electrode gap (mm)	Maximum response time permitted (s)	Tripping time 1 (s)	Tripping time 2 (s)	Tripping time 3 (s)	Passed yes - no
7	1,6	2	0.1	0.08		yes
7	4,8	1,5	no	0.06		no
14	3,2	1,2	0.07	0.08		yes
14	6,4	0,8	0.08	0.085		yes

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Arcing detectors tests according to UL 1699B at the Berner Fachhochschule
Measuring results: summary

Measurements with series resistance

DUT	Result
DUT	no
DUT 1	yes (17/17)
DUT	no (16/23)
DUT	yes (17/17)
DUT 4	no (7/16)

Success rate: 50% only!

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►►► Variety of methods for locating faults

Often simple methods are used, e.g. displacement voltage measurement, which has been used for over 70 years for locating earth faults in power systems. Here it is to be noted that symmetrical faults, which can cause fires, are not found.

For another method often used, parts of the PV installation, the strings, are very time consumingly taken out of operation to estimate, based on the changing the insulation resistance value, whether the string shut down is faulty. Here at least symmetrical faults are detected on the usage of an insulation monitoring device in accordance with IEC 61557-8 :2007.

The disadvantage of this method is in the very coarse identification of the faulty string, as it is not possible to detect the fault down to the module level. Locating faults based on this method is particularly disadvantageous if the insulation monitoring device used requires measuring times from 30 minutes to even hours due to large system leakage capacitances! As a consequence there are correspondingly high feed losses that reduce the efficiency of the PV installation to a significantly greater extent over the service life than any saving at the start due to the selection of a cheap, but ineffective insulation monitoring device.

Therefore, instead of locating faulty strings by means of expensive selective shut down, which itself involves hazards as it is necessary to switch manually, modern insulation fault location systems in accordance with IEC 61557-9:2009 are the instrument of choice. In special versions for PV installations, they offer the quick, reliable location of faults down to the PV module level, even in extremely large and physically extensive PV installations.



Increase in safety for man and machine

The insulation fault location systems are also available as portable systems. However, it is recommended to take into account fault location during the design of PV installations and preferably to select insulation monitoring devices that are already prepared for insulation fault location. In a system configured in this manner the electrician does not need to connect a portable measuring code generator in the field to locate the fault. The electrician is therefore no longer subjected to a hazard due to handling live parts of the photovoltaic generator.

Insulation fault location in the PV installation designed in this manner is straightforward and also possible at short maintenance intervals. Failures and downtimes are minimised. This situation benefits the safety and efficiency of the PV installation. ■

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