Electrotechnical Requirements for PV on Buildings

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World-wide the number of grid-connected PV systems is growing fast, especially in the built environment. In order to assure the quality and energy output of these systems, a number of electrotechnical requirements need to be fulfilled, at both component and system levels. In addition requirements with respect to electrical safety need to be met. Part of these requirements are covered by international standards, especially with respect to the PV modules. A number of standards is still under development. In the area of systems and utility interfacing local codes are still in use. These local codes differ significantly from country to country. Copyright © 2004 John Wiley & Sons, Ltd.

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INTRODUCTION

Grid-connected PV systems are being used more and more in the built environment. The peak power ranges from a few hundred Wp to about 5 kWp for systems on houses, up to a few hundred kWp and higher for systems on larger buildings. A wide variety of system designs is applied. Small systems up to about 500 Wp comprise a number of modules and a small inverter, or a number of modules each having an integrated inverter (AC modules). In systems in the range 0.5–5.0 kWp, string inverters are frequently used. Large systems contain either a central inverter or a number of smaller inverters. In most cases the energy output of these systems is the most important property.

The energy output of PV systems is mainly determined by the local irradiation conditions, the peak power installed, the system design and the characteristics of the components used (i.e., PV modules and inverters). In order to guarantee the energy output, quality assurance of both the system and the components is crucial. In addition proper installation of the system must be assured. Furthermore adequate maintenance schedules are required.

In order to assure the quality of the system and the components, a number of technical requirements must be met. In addition a number of requirements have to be fulfilled with respect to grid-interfacing, safety, EMC (electromagnetic compatibility) and lightning protection. In many areas of trade and industry standards play an important role in assuring the quality of products and services. In the case of PV, the fact that components and systems meet certain standards enhances confidence of end users and utilities. Meeting standards can also imply that technical risks are being reduced, both for the end user and the supplier. In addition standards describe agreed methods for the determination of the performance of components, e.g., the peak power of PV modules and the efficiency of inverters. Originally PV standards focused on PV components. In the course of time standards for various other aspects of PV systems have also been developed. In this paper the requirements
at both component level and system levels will be highlighted. Furthermore attention will be paid to existing PV standards and new standards under development.

**MODULES**

Today it is common practice to use certified modules meeting international design qualification and type approval standards. These standards have a long history. The original standards were developed in the 1970s and were based, among others, on a number of IEC 68 (today IEC 60068) accelerated lifetime tests. These IEC 68 tests had been used for a long time for electronic components and systems. Comprehensive experience gained from many PV projects in the field and during qualification tests of PV modules was used to adapt and improve these standards over time. In this way the JPL Block I–V standards were developed successively in the USA, whereas in Europe this led to specifications 501, 502 and 503. This has resulted in the present ‘design and type approval’ standards for ‘crystalline silicon’ (IEC 61215) and ‘thin-film’ (IEC 61646) modules. These standards contain a number of accelerated lifetime tests such as thermal cycling tests, a high-humidity, high-temperature exposure test, a mechanical loading test and a hail impact test. These tests can be carried out in a relatively short period of time (typically 3 months) and the results are used to judge the design of the module. It is not the aim of the test to make a firm judgement of the real lifetime of the module.

The procedure for the determination of the electrical performance of modules, amongst others at Standard Test Conditions (1000 W/m² irradiance, AM1.5 spectrum and 25°C cell temperature) is described in standard IEC 60904. The energy output of grid-connected PV systems, however, is determined by the power output of the modules under actual operation conditions. The latter is, apart from the irradiance level, also determined by the cell temperature, the cell efficiency (which among others depends on the irradiance level) and the spectrum and angle of incidence of the incoming irradiance. At present an international standard (IEC 61853) for both the power and energy rating of modules is under development.

Above a certain system voltage, modules meeting electrical safety class II need to be used. In many countries this voltage is 120 V. Because there is still no international standard for safety class II of PV modules, modules meeting and certified according to the German ‘Safety Class II’ requirements are used in many countries. In the USA modules must meet the module safety standard UL 1703. An international standard (IEC 61730) for the safety of modules, including electrical safety is under development. In order to meet a module safety standard a number of safety tests need to be passed, such as an impulse voltage test, a dielectrical breakdown test and a scratch test, in addition to the design and type approval tests.

**INVERTERS**

Inverters play a vital role in grid-connected systems. Inverters provide both DC to AC conversion and maximum power point tracking. Important aspects are the efficiency, the reliability and the safety of the inverters used.

A good DC to AC conversion efficiency is crucial in order to obtain a good overall system efficiency. The use of new inverter concepts, optimised circuit designs and modern solid state devices have contributed to the improvement of the inverter efficiency over the last 20 years. Today, the typical average yearly inverter efficiency amounts to 90–95%. An international standard for the measurement of the inverter efficiency (IEC 61683) does exist. In order to cope with inverter losses at low DC input power the inverter nominal power should be less than the peak power of the PV array for an optimal system energy output. Typical undersizing ratios are between 0.7 and 1.0, depending on the local irradiation conditions. A good operating maximum power point tracking system is also essential. Though various procedures are being used to determine the proper functioning of a maximum power point tracker, no international standard exists yet.

In the past serious inverter problems have occurred. During the course of time the reliability has been improved significantly by adapted circuit designs, selection of more reliable components and the use of protective devices.
Inverters must meet EMC standards both with respect to immunity and emission. Until recently EN generic standards, FCC regulations and JIS standards were used in Europe, the USA and Japan respectively. These standards have been replaced by international EMC standards (IEC 61000 series) to a great extent. Meeting EMC emission standards implies that radio frequency emission both by direct radiation and via the public grid needs to be limited. The emission of undesired harmonics of the grid frequency needs to comply certain requirements also. In addition the inverters need to be sufficiently immune against external disturbances, especially from the public grid. The EMC standards concerning immunity against fast transients (IEC 61000-4-4) and surges (IEC 61000-4-5) are highlighted explicitly here. An insufficient immunity against pulses from the grid can cause failure of the inverter. Examples of these pulses are fast transients caused by switching actions in the medium- and high-voltage network and surges induced by lightning in the low-voltage network. No applicable EMC standard for the DC side of PV inverters exists yet. An EMC procedure has been proposed, however.

With respect to safety standards of inverters, it is important to mention that in the European Union inverters must meet the Low Voltage Directive. In the USA standard UL 1741 must be met. An international standard for the safety of inverters (IEC 62109) is under development.

**PV SYSTEM UTILITY INTERFACE**

A new version of standard IEC 61627 regarding the PV system utility interface is under development. This standard contains both requirements with respect to power quality and safety.

An important issue is the protection of a grid-connected PV system against islanding. In almost all countries island operation of these systems is not allowed. Islanding might occur if the connection with the public grid is disrupted and the power delivered by the PV system is more or less equal to the local load. An example of such a disruption is the break down of the connection between the house connection and the local distribution transformer.

In most countries a protection based on both measurement of voltage and frequency (and in some cases frequency shift) is considered to be sufficient to detect an island situation. In Germany however, a measurement of the grid impedance is mandatory. The voltage and frequency windows, allowed for safe operation, differ significantly from country to country. In addition the requirements with respect to disconnection and reconnection times differ as well. This implies that the local codes need to be followed and that factory inverter settings must be adapted accordingly.

A relatively low value for the upper voltage of the voltage window might cause problems, especially in the case of a relatively high grid resistance between the inverter output and the local distribution transformer. The voltage at the inverter terminal might be driven up by the inverter current, such that the inverter switches off unintentionally. This implies that the local grid conditions, including the tap setting of the distribution transformer need to be looked at. In difficult cases adaptation of the distribution transformer tap setting might solve the problem. In case of injection of relatively high amounts of PV power an analysis of the voltage at various points in the public grid has to be carried out.

**SYSTEM DESIGN CONSIDERATIONS AND REQUIREMENTS**

For a specific range of array peak powers several system design solutions exist and are being used. In small systems or subsystems up to about 500 Wp there is a tendency, for cost reasons, to use a number of modules with a single inverter instead of a number of AC modules. With a single inverter either one or two strings of modules are used or all modules are put in parallel. In the last case the system has a safe low system voltage, e.g., 12 or 24 V, implying that there is no need to use safety class II modules. Originally in systems in the power range 0.5–5 kWp the combination of a larger number of short strings and a DC coupling box has been used, resulting in a typical system voltage between 60 and 200 V DC. In order to eliminate the need for a DC coupling
box the string inverter concept has been developed, in which the number of strings is limited to at most three. In
the course of time the system voltage and the power of these systems have been increased to about 400 V and
5 kWp, respectively. The high DC voltage implies that safety class II modules need to be used and that the high
DC voltage has to be taken into account during system design and installation. In the case of large systems
(above 5 kWp) with a central inverter typical system voltages are in the range 400–800 V DC.
An optimum array tilt angle exists for a maximum energy output. This tilt angle depends especially on the
latitude and the distribution of the irradiation over a year. The energy yield can, however, strongly be reduced by
shading, caused both by blocking of direct and diffuse irradiation. In some cases a reduction of the tilt angle is
favourable to reduce the effect of shading. Also on the system level a number of measures can be taken. In the
case of application of long strings, the routing of strings becomes very important, because shading of part of
the string will influence the total string yield. A reduction of the string length, which implies a lower system
voltage, might be favourable. In complex situations the use of AC modules or splitting the system into smaller
subsystems, each with its own inverter can offer a solution.
Recently, a new system concept has been presented, called the ‘PV wirefree’ concept. In this concept
modules are clamped directly onto two metallic bars, serving both as the mechanical support and the electrical
interface with an inverter. In addition to the cost advantage that can be obtained, the concept is also very tolerant
with respect to partial shading.
Today, a number of countries still have their own guidelines for the layout and the execution of grid-
connected PV systems. The focus in these guidelines is safety rather than energy yield. The fact that a PV array
is a DC system sets specific requirements with respect to the selection of components such as DC switches,
DC fuses and DC overvoltage protection devices. These guidelines include requirements concerning wiring
and earthing as well. On IEC level IEC 60364-7-712 covering the safety of grid-connected PV systems will
become available.

LIGHTNING PROTECTION

Lightning can damage grid-connected PV systems, either by direct lightning strikes or by induced voltages. PV systems can be protected by an external lightning protection system, among others consisting of an air-
termination network, a number of down-conductors and an earth-termination network. The decision whether
to apply such a protection system is not easy and has to be based on the local probability of direct lightning
strikes and the acceptable financial risk. In many cases no external protection system is applied.

During lightning, high voltages can be induced both in the PV array and in the public grid. These voltages can
damage the inverter. On the PV array side it is important to avoid any wiring loops which might cause high
induced voltages. Residual induced voltages at a DC coupling box or at the DC input of the inverter can
be reduced further by the use of (thermally controlled) varistors. In many cases, however, lightning-induced
voltage pulses from the public grid represent a more severe risk. Good immunity of the inverter against these
pulses is therefore extremely important.

CONCLUDING REMARKS

Grid-connected PV systems need to meet a number of electrotechnical requirements. These requirements con-
cern both the components used and the PV system as a whole. An overview of the most important standards
discussed here is given in Table I. International design qualification and type approval standards for modules
have existed for a long time. International module standards for safety and quality assurance are under develop-
ment. Dedicated standards for PV inverters hardly exist yet, but are desirable. For safety of PV inverters an
international standard is under development. On the PV system level and the utility interface many local guide-
lines still exist. Especially the requirements with respect to islanding detection and the local requirements with
respect to corresponding inverter settings still differ markedly.
Table I. Overview of some of the most important electrotechnical standards for PV on buildings

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<tr>
<th>Application area</th>
<th>Subject</th>
<th>Standard</th>
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<tbody>
<tr>
<td>PV modules</td>
<td>Design qualification and type approval</td>
<td>IEC 61215 (Crystalline silicon modules)</td>
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<td>IEC 61646 (Thin-film modules)</td>
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<td>Performance</td>
<td>IEC 60904 (Performance measurement, at Standard Test Condition)</td>
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<td>IEC 61853 (Energy and power rating, under development)</td>
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<td>UL 1703 (USA)</td>
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<td>TÜV Safety Class II (Germany)</td>
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<td>IEC 61730 (Under development)</td>
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<td></td>
<td>Safety</td>
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<tr>
<td>PV inverters</td>
<td>Performance</td>
<td>IEC 61683 (Efficiency measurement)</td>
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<td></td>
<td>Safety</td>
<td>UL 1741 (USA)</td>
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<td>IEC 62109 (under development)</td>
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<td>IEC 61000 series</td>
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<td>Utility interface</td>
<td>Power quality and safety</td>
<td>IEC 61727 (new version under development)</td>
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<td>PV systems</td>
<td>Safety</td>
<td>Local codes</td>
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<td></td>
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<td>IEC 60364-7-712</td>
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REFERENCES

15. 73/23/EEC. *Low Voltage Directive,* including amendment 93/68/EEC.

