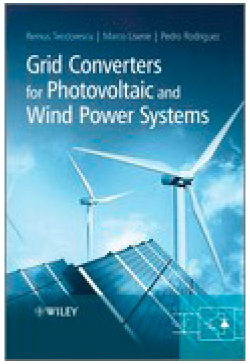

Grid Converters for Photovoltaic and Wind Power Systems

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Chapter 3

Grid Requirements for PV

International Regulations

Grid connection requirements

- IEEE 1547-2003 Standard for Interconnecting Distributed Resources with Electric Power Systems
- IEEE 1547.1- 2005 Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
- IEEE 929-2000, Recommended Practice for Utility Interface of Photovoltaic (PV) Systems – incorporated in IEEE 1547
- UL 1741, Standard for Inverters, Converters, and Controllers for Use in Independent Power Systems - elaborated by Underwriters Laboratories Inc. – compatibilzed with IEEE 1547
- IEC61727 [6] Photovoltaic (PV) systems - Characteristics of the utility interface - December 2004
- IEC 62116 Ed.1 2005: Testing procedure of islanding prevention measures for utility interactive photovoltaic inverter (describes the tests for IEC 61727) – approved in 2007
- VDE0126-1-1 2006 Automatic disconnection device between a generator and the public low-voltage grid" – Safety issues- applied on German Market

EMC

- IEC 61000-3-2, Ed. 3.0 – "Electromagnetic compatibility (EMC) –Part 3-2: Limits –Limits for harmonic current emissions (equipment input current ≤16 A per phase)", ISBN 2-8318-8353-9, November 2005
- EN 61000-3-3, Ed. 1.2 —"Electromagnetic compatibility (EMC) –Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection", ISBN 2-8318-8209-5, November 2005
- IEC 61000-3-12, Ed. 1 – "Electromagnetic compatibility (EMC) –Part 3-12:Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase" , November 2004
- IEC 61000-3-11, Ed. 1 —" Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤75 A and subject to conditional connection" , August 2000Standard EN 50160 – "Voltage Characteristics of Public Distribution System", CENELEC: European Committee for Electrotechnical Standardization, Brussels, Belgium, November 1999

Utility Voltage Quality

- Standard EN 50160 – "Voltage Characteristics of Public Distribution System", CENELEC: European Committee for Electrotechnical Standardization, Brussels, Belgium, November 1999

Public Voltage Quality – EN50160

- Voltage unbalance for three phase inverters. Max unbalance is 3%
- Voltage amplitude variations: max +/-10%
- Frequency variations: max +/-1%
- Voltage dips: duration < 1 sec, deep < 60%
- Voltage harmonic levels. Max voltage THD is 8%

Odd harmonics				Even harmonics	
Not multiple of 3		Multiple of 3			
Order *h*	Relative voltage (%)	Order *h*	Relative voltage (%)	Order *h*	Relative voltage (%)
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.5	6..24	0.5
13	3	21	0.5		
17	2				
19	1.5				
23	1.5				
25	1.5				

Response to abnormal grid conditions

- Voltage deviations

IEEE 1547		IEC61727		VDE0126-1-1	
Voltage range (%)	Disconnection time (s)	Voltage range (%)	Disconnection time (s)	Voltage range (%)	Disconnection time (s)
V < 50	0.16	V < 50	0.10	110 ≤ V < 85	0.2
50 ≤ V < 88	2.00	50 ≤ V < 85	2.00		
110 < V < 120	1.00	110 < V < 135	2.00		
V ≥ 120	0.16	V ≥ 135	0.05		

Obs. The purpose of the allowed time delay is to ride through short-term disturbances to avoid excessive nuisance tripping

- Frequency deviations

IEEE 1547		IEC61727		VDE0126-1-1	
Frequency range (Hz)	Disconnection time (s)	Frequency range (Hz)	Disconnection time (s)	Frequency range (Hz)	Disconnection time (s)
59.3 < f < 60.5*	0.16	fn-1 < f < fn+1	0.2	47.5 < f < 50.2	0.2

* for systems with power < 30 kW the lower limit can be adjusted in order to allow participation in the frequency control

Obs. The VDE0126-1-1 allow much lower frequency limit and thus frequency adaptive synchronization is required

- Reconnection after trip

IEEE 1547	IEC61727	VDE0126-1-1
88 < V < 110 [%] AND 59.3 < f < 60.5 [Hz]	85 < V < 110 [%] AND fn-1 < f < fn+1 [Hz] AND Min. delay of 3 minutes	N/A

Power Quality

- DC Current Injection

IEEE 1574	IEC61727	VDE0126-1-1
Idc < 0.5 [%] of the rated RMS current	Idc < 1 [%] of the rated RMS current	Idc < 1A Max Trip Time 0.2 s

Obs. For IEEE 1574 and IEC61727 the dc component of the current should be measured by using harmonic analysis (FFT) and there is no maximum trip time condition

- Current harmonics

IEEE 1547 and IEC 61727						
Individual harmonic order (odd)*	h < 11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h < 35	35 ≤ h	Total harmonic distortion THD (%)
(%)	4.0	2.0	1.5	0.6	0.3	5.0

Obs. The test voltage for IEEE1574/IEC61727 should be produced by an electronic power source with a voltage THD < 2.5% (typically ideal sources)

IEC 61000-3-2 for class A equipments apply also

Odd harmonics		Even harmonics	
Order *h*	Current (A)	Order *h*	Current (A)
3	2.30	2	1.08
5	1.14	4	0.43
7	0.77	6	0.30
9	0.40	8 ≤ *h* ≤ 40	0.23 x 8/*h*
11	0.33		
13	0.21		
13 ≤ *h* ≤ 39	0.15 x 15/*h*		

Obs. The current limits in IEC61000-3-2 are given in amperes and are in general higher than the ones in IEC61727. For equipments with a higher current than 16 A but lower than 75A another similar standard IEEE 61000 3-12 [12] applies

Power Quality

Average Power Factor

- Only in IEC61727 it is stated that the PV inverter shall have an average lagging power factor greater than 0,9 when the output is greater than 50%. Most PV inverters designed for utility-interconnected service operate close to unity power factor
- In IEEE1574 as this a general standard that should allow also distributed generation of reactive power there is no requirement for the power factor
- No power factor requirements are mentioned in VDE0126-1-1
- Obs. Usually the power factor requirement for PV inverters should be interpreted now as a requirement to operate at quasi-unity power factor without the possibility of regulating the voltage by exchanging reactive power with the grid. For high power PV installations connected directly to the distribution level local grid requirements apply as they may participate in the grid control. For low power installations it is also expected that in the near future the utilities will allow them to exchange reactive power but new regulations are still expected

Anti-Islanding Requirements

What is islanding?

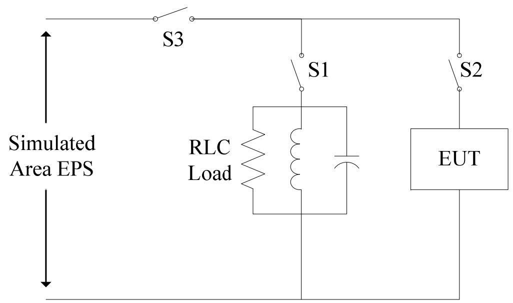
Islanding for grid connected PV systems takes place when the PV inverter does not disconnect very short time after the grid is tripped, i.e. it is continuing to operate with local load. In the typical case of residential electrical system co-supplied by a roof-top PV system, the grid disconnection can occur as a result of a local equipment failure detected by the ground fault protection, or of an intentional disconnection of the line for servicing. In both situations if the PV inverter does not disconnect the following consequences can occur:

- Retripping the line or connected equipment damaging due to of out-of-phase closure
- Safety hazard for utility line workers that assume de-energized lines during islanding

In order to avoid these serious consequences safety measures called anti-islanding (AI) requirements have been issued and embodied in standards

Anti-Islanding Requirements – IEEE 1574

In IEEE 1574 the requirement is that after an unintentional islanding where the distributed resources (DR) continues to energize a portion of the power system (island) through the PCC, the DR shall detect the islanding and cease to energize the area within 2 sec.



NOTES
1 – Switch S1 may be replaced with individual switches on each of the RLC load components
2 – Unless the EUT has a unity output p.f., the receiver power component of the EUT is considered to be a part of the islanding load circuit in the figure.

Adjustable RLC load should be connected in parallel between the PV inverter and the grid. The resonant LC circuit should be adjusted to resonate at the rated grid frequency and to have a quality factor of 1 or in other words the reactive power generated by [VAR] should equal the reactive power absorbed by [VAR] and should equal the power dissipated in [W]
The parameters of the RLC load should be fine tuned until the grid current through S3 should be lower than 2% of the rated value on a steady-state base. In this balanced condition, the S3 should be open and the time before disconnection should be measured and should be lower than 2 sec.
The UL 1741 standard in US has been harmonized with AI req stated in IEEE 1547

Anti-Islanding Requirements – IEC52116

In IEC 62116-2006 similar AI requirements as the IEEE1547 is proposed. The test can also be utilized by other inverter interconnected DER. In the normative reference IEC 61727-2004 the ratings of the system valid in this standard has a rating of 10 kVA or less, the standard is though subject to revision. The test circuit is the same as in the IEEE1547.1test (Figure 4.1) power balance is required before the island detection test. The requirement for passing the test contains more test cases but the conditions for confirming island detection do not have a significant deviation compared to the IEEE1547.1 test.

The inverter is tested at three levels of output power (A 100-105%, B 50-66% and C 25-33% of inverters output power). Case A is tested under maximum allowable inverter input power, case C at minimum allowable inverter output power if > 33 %.

The voltage at the input of the inverter also has specific conditions (see [8]). All conditions are to be tested at no deviation in real and reactive load power consumption then for condition A in a step of 5% both real and reactive power iterated deviation from -10% to 10% from operating output power of inverter.

Condition B and C are evaluated by deviate the reactive load in an interval of ±5 % in a step of 1 % of inverter output power.

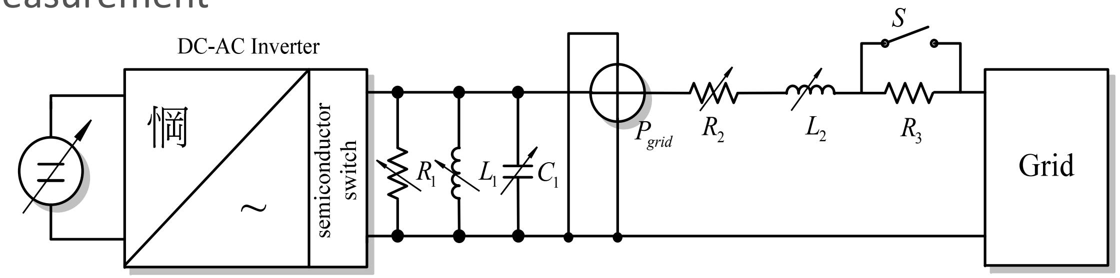
The maximum trip time is the same as in IEEE 1547.1 standards 2 sec.

In IEC61727, there is no specific description of the anti-islanding requirements. Instead reference to IEC62116 is done.

Anti-Islanding Requirements – VDE-0126-1

The VDE0126-1-1 allows the compliance with one of the following anti-islanding methods:

A. Impedance measurement



B. Disconnection detection with RLC resonant load

The test circuit is the same with the one from IEEE1547.1 depicted in Figure 4.1 and the test conditions are that the RLC resonant circuit parameters should be calculated for a quality factor of using (4.1)

With balanced power the inverter should disconnect after the disconnection of S2 in maximum 5 seconds for the following power levels: 25%, 50% and 100%

C. Voltage monitoring

For three-phase PV inverters a passive anti-islanding method is accepted by monitoring all three phases voltage with respect to the neutral. This method is conditioned by having individual current control in each of the three phases.

Finding an software based anti-islanding method has been a very challenging task resulting in a large number of research work and publications

Conclusions – grid requirements

- In this chapter an overview of the most relevant standards related to the grid connection requirements of PV inverters is given.
- High efforts are done by the international standard bodies in order to “harmonize” the grid requirements for PV inverters worldwide.
- Recently the IEEE1574 standard has done a big step in the direction of issuing a standard that includes grid requirements not only for PV inverters but for all distributed resources under 10 MVA.
- Underwriters Laboratories in US has revised this year the UL 1471 by accepting the grid requirements of IEEE1574 and also IEC62116 was revised to harmonize with the requirements of IEEE1574 in the anti-islanding requirements.
- Even the very specific German standard VDE0126-1-1 was revised in 2006 where the grid impedance measurement has become optional and an alternative requirement very similar to IEEE1574 was included. All these positive actions needs to be followed by adoption in different countries that still use their own local regulations.
- The most relevant conditions from these standards are highlighted in order to envisage the impact on the control strategies. For designing purposes, the readers are strongly recommended to access the complete texts of the standards and deal with all the related details.
- For large MW PV parks, grid-connection requirements are inlined with wind power connected to the distribution levels (see chapter 7)

Standards Overview

[1] Dugan, R.C.; Key, T.S.; Ball, G.J., "Distributed resources standards," Industry Applications Magazine, IEEE , vol.12, no.1, pp. 27-34, Jan.-Feb. 2006

[2] IEEE Std 929-2000 – “IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems,", ISBN 0-7381-1934-2 SH94811, April 2000.

[3] UL standard 1741, “Inverters, Converters, and controllers for Use in Independent Power Systems”, Underwriters Laboratories Inc. US, 2001

[4] IEEE Std 1547-2003 – “Standard for Interconnecting Distributed Resources with Electric Power Systems," ISBN 0-7381-3720-0 SH95144, IEEE, June 2003

[5] IEEE Std 1547.1-2005 – “Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems” ISBN 0-7381-4736-2 SH95346, IEEE, July 2005

[6] IEC 61727 Ed.2 – “Photovoltaic (PV) Systems - Characteristics of the Utility Interface”, December, 2004

[7] IEC 62116 CDV Ed. 1 – “Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters”, IEC 82/402/CD:2005

[8] VDE V 0126-1-1 “Automatic disconnection device between a generator and the public low-voltage grid”, VDE Verlag, Doc nr. 0126003, 2006

[9] IEC 61000-3-2, Ed. 3.0 – “Electromagnetic compatibility (EMC) –Part 3-2: Limits –Limits for harmonic current emissions (equipment input current ≤16 A per phase)”, ISBN 2-8318-8353-9, November 2005

[10] EN 61000-3-3, Ed. 1.2 —“Electromagnetic compatibility (EMC) –Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection”, ISBN 2-8318-8209-5, November 2005

[11] Standard EN 50160 – “Voltage Characteristics of Public Distribution System”, CENELEC: European Committee for Electrotechnical Standardization, Brussels, Belgium, November 1999 .

[12] IEC 61000-3-12, Ed. 1 – “Electromagnetic compatibility (EMC) –Part 3-12:Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase” , November 2004

[13] IEC 61000-3-11, Ed. 1 —“ Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤75 A and subject to conditional connection” , August 2000