SOLAR INVERTER TESTING PER IEC 61000-3-15

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ABSTRACT

Within the context of the development of IEC61000-3-15, a series of tests were conducted on solar inverters in the popular power range from 3 -5 kWatt/kVA. This paper discusses the test method and some of the result, mainly concentrating on the effects that grid tied inverters may have on power quality, i.e. emissions, and how inverters respond to less than ideal power quality of the grid itself i.e. immunity.

INTRODUCTION

The IEC61000-3-15[1] Project Team decided to use existing IEC and/or other international standards, such as UL-1741[2] and IEEE-Std-1547[3] as much as possible in the development of IEC61000-3-15[4], titled; **Limits - Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network.** Since some of the actual limits are still under consideration at the time of this writing, this paper will mainly concentrate on the test methodology and the obtained test results. The test methodology closely emulates the actual operating conditions that grid tied inverter are subjected to in typical "consumer" installations.

TEST METHODOLOGY

The testing method the project team decided on, involves a combination of a simulated public supply (AC source), a reference impedance unit, and a load unit that can produce linear as well as non-linear loads. This combination is then supplemented with a power quality measuring and data acquisition system that can record the data in any of the power legs, as illustrated in Figure-1 below. The AC power source is capable of producing near ideal power quality, distorted voltages – both harmonic and inter-harmonic type distortion per IEC61000-4-13[4]. It also produces voltage dips and interrupts per IEC61000-4-11[4] and 61000-4-34[4]. In addition, the AC source is preferred to be regenerative, i.e. accept negative power flow – coming from the inverter, just like the actual public supply grid does. The load presents user defined combinations of linear and non-linear current flow, which in turn can produce specific voltage distortions at the inverter terminals. The impedance unit is set to implement either the IEC 60725[4] Reference Impedance values, or the Z-test values as given in IEC61000-3-11[4]. This **system test** methodology therefore, allows the inverter to be tested under a variety of operating conditions, similar to those that can exist in actual customer installations.

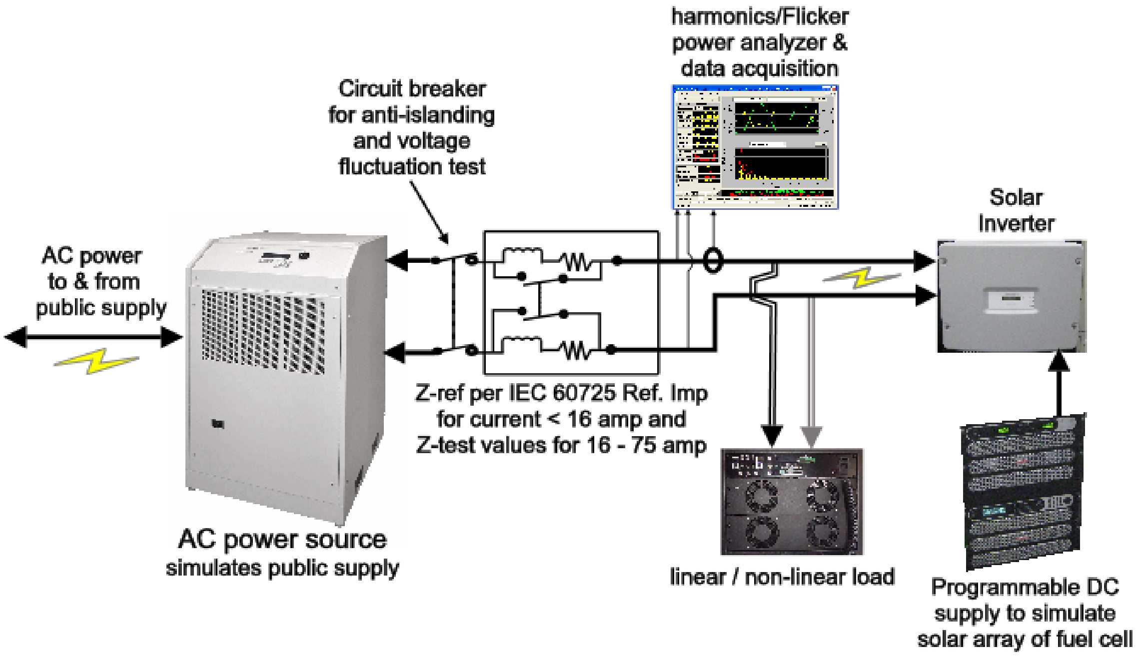

Figure- 1 Inverter test setup

EMISSION TESTS

The emission tests are designed to verify that the inverter does not inject excessive harmonic currents into the public supply, nor causes voltage fluctuations that could affect other electrical equipment, operated in parallel in either the premise where the inverter is located, or in adjacent electricity consumer's premises. Several test conditions are defined, with very low distortion conditions of the simulated public supply, but also with distorted supply voltages. Inverter emissions are evaluated under two types of distorted supply voltages, those caused by the public supply, and voltage distortion due to local non-linear loads.

Figure 2 below shows the public supply producing a clean sine wave, and the load set to a linear plus non-linear level of 1274.9 Watt having a current distortion of 7.8 % I-THD (load current is the red line in the bottom graph).

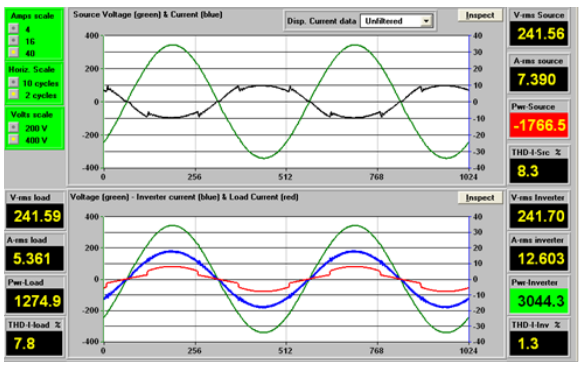

Figure 2 Illustration of test with partially distorted load

The inverter current remains nearly sinusoidal, with just 1.3 % distortion. The current distortion of the power being supplied back into the public supply is 8.3 %. Thus, the inverter produces 3044 Watt, feeds 1275 Watt into the load, and feeds the rest back into the public supply, less about 3 Watt being consumed in wiring and measuring circuits. Obviously, this excellent inverter behaviour is highly desired. Generally, the inverter control circuitry is optimized for operation at the mid-to-full power range.

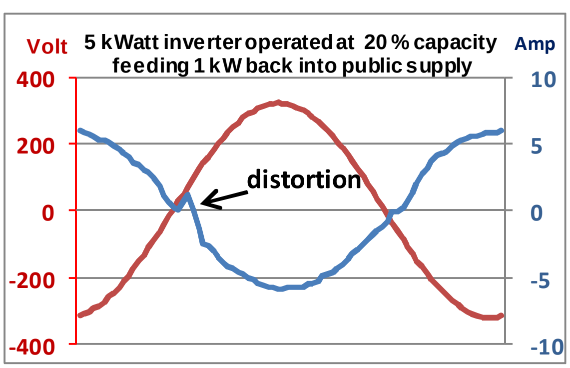

Figure-3 Inverter operated at 20 % showing distortion

At fractional power, this can lead to less than optimum behavior. This is illustrated in figures 3 and 4, for an inverter that is rated for max. 5 kWatt, but is operated at approximately 1 kWatt, as is likely to happen during cloudy days, or during morning or late afternoon hours, when solar irradiation patterns are of limited intensity. As is clearly shown in Figure 3, there is significant current distortion around the negative zero crossing. This is also illustrated in the current spectrum, with many harmonics at levels between 5 and 10 % of the 4.2 amp rms fundamental, thus resulting in about 28 % I-THD. Fortunately, the absolute current levels are low to moderate, and thus the resulting voltage distortion remains low at less than 0.5 %.

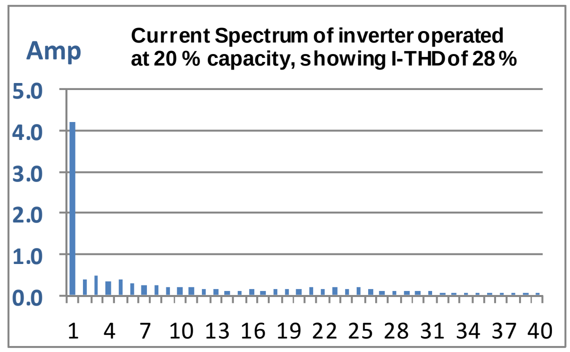

Figure-4 Current spectrum for inverter operated at 20 %

Figure-5 illustrates a test scenario where the simulated public supply is distorted, and the resulting inverter behavior is evaluated. The voltage distortion is 7 % for the 9th harmonic. The load is linear in this case. The current distortion into the load is partly compensated by the inverter current, but the current distortion that is fed back into the public supply is cumulative, and thus results in an I-THD of 13.1 %. This is clearly illustrated by the relatively bigger ripple on the current signal in the top graph (black line).

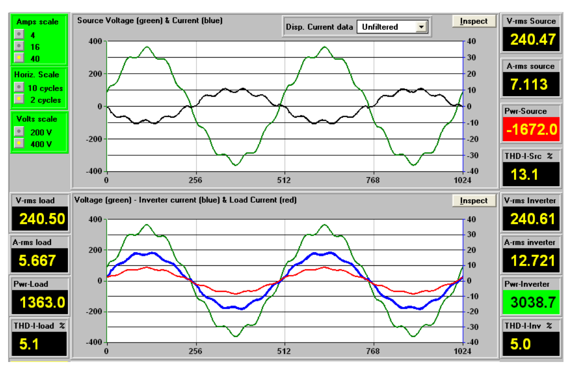

Figure 5 Inverter behavior with distorted supply voltage

Depending on the public supply impedance, the voltage distortion may increase by this type of inverter behaviour. Therefore, the IEC61000-3-15 project team decided to add a **system level test**, where this distortion contribution is evaluated when the IEC60725 impedance is in line.

The system level voltage distortion tests are performed in two modes, similar to current emission tests. One test mode is with a linear load and the public supply distorted, while the other mode is with a non-linear load, which produces the voltage distortion when the IEC60725 Ref. impedance is in line. The latter is illustrated in figure 6 for an inverter test in so called stinger mode (delta operation with inverter connected between 2 phases @ 208 Volt/60 Hz in the US). The distortion pattern is initially generated with the inverter off-line, i.e. with just the load connected through the impedance. Then, the inverter is brought on-line, and the change is voltage distortion is evaluated, the intent being that the inverter may add only small fractions to the distortion that is present before the unit comes on-line.

Test setup with IEC60725 Ref. Impedance in line

Combined linear and non-linear load - values for 208 V

Controlled load conduction angle from 45° - 135° (225° - 315°)

Voltage waveform shown has 5.5 % V-THD

Distortion V-THD - %	Linear Load Ω	Controlled Load Ω	Total Power - Watt	Total Current A-rms
2,0	84	84	910	4,5
4,0	84	41	1300	6,8
5,5	84	28	1700	8,9
7,3	84	18	2100	11,0
10,5	84	14	2800	15,1

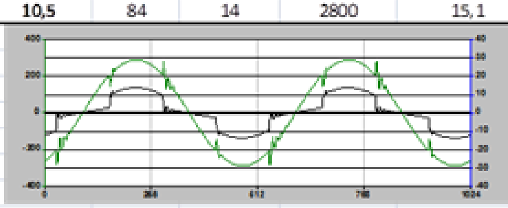

Figure 6 suggested values to produce distortion@ 208 V

The voltage behavior (green line) is of course due to the inductance of the Reference Impedance, which is 796 µH. In Europe, about 95 % of all consumers are connected to the public supply with an impedance at or below the values given in IEC 60725. For points where the impedance is lower, the distortion will generally be lower as well, so these system level tests represent a worst case scenario.

Load	DG Supply	Reference impedance	Pre-distortion level < 5%
linear	100 %	Z-ref or Z-test	4.0 ± 0.2 % set by source
50% linear 50% not linear	100 %	Z-ref or Z-test	4.0 ± 0.2 % caused by load
25% linear 25% not linear	100 %	Z-ref or Z-test	2.5 ± 0.2 % caused by load
For DG > 16 /phase	100 %	Z-test	4.0 ± 0.2 % set by source

Table-1 System level tests

In addition to the voltage distortion and current emissions, the Flicker contribution from the inverter is also evaluated, in accordance with the requirements of IEC61000-3-3[4].

IMMUNITY TESTS

In addition to the “normal” distortion levels, the inverter may also be subjected to a number of abnormal disturbances on the public supply, and must be able to survive these disturbances without impairing subsequent operation, after the public supply returns to normal. The most common disturbances are voltage dips and interruptions. Figure 7 illustrates the behaviour of the inverter when the public supply is interrupted, either at a neighbourhood level, or due to a circuit breaker trip at the premise.

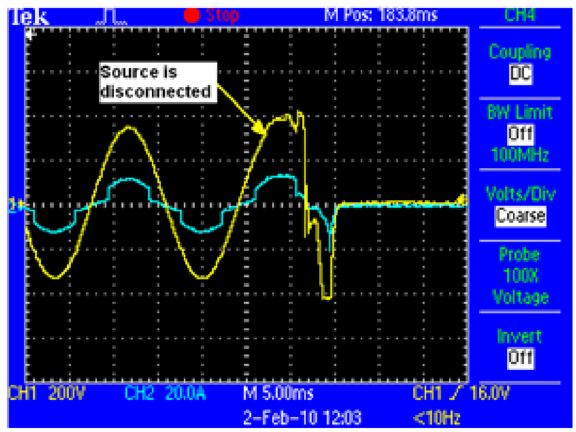

Figure 7 Inverter response due to power interruption

For this type of power interruption test, three criteria are to be observed. First, the inverter must disconnect itself within a pre-determined maximum time. Secondly, the inverter must remain functional of course, and re-connect after the power is restored. Third, the inverter must not cause excessive voltages when it disconnects, as this could damage other electrical products operated at the premise. As shown in the above figure 7, the inverter voltage briefly “swings up” and reaches ~ 430 Volt peak, vs. the normal 340 V-pk (for a 240 Volt rms nominal connection in the US as in this test). Although this is a 26 % increase, it lasts only milliseconds, and thus generally causes no problems for other electrical equipment.

If the load and inverter output power are balanced, it may take longer for the inverter’s circuitry to detect that the power has been disconnected. This situation is illustrated in Figure 8, where the 3 kWatt inverter is feeding a load that is set to 3 kWatt as well (at 240 V/60 Hz nominal). As the public supply voltage is disconnected, the voltage gradually “swings up” with the peak level increasing to 375 volt (~ 265 V-rms) before it disconnects itself – due to overvoltage being detected by its internal circuitry. Thus, the inverter disconnects at ~ 10 % above nominal, which is acceptable.

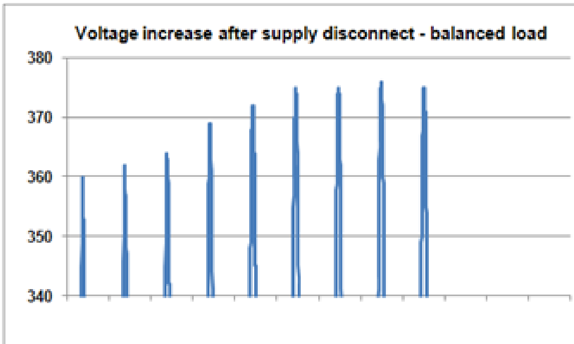

Figure 8 Inverter response with balanced load

The tests shown in Figure 7 and 8 concern interrupts. IEC61000-4-11 specifies a series of "dips" where the inverter is subjected to brief decreases in voltage. There is currently a grey area in inverter testing. In most countries, the inverter is required to separate itself from the network within 1 to 2 seconds, depending on the percentage of the voltage drop. The dip percentages specified in IEC61000-4-11 start with a 20 % voltage reduction, and virtually all inverter manufacturers have internal settings that cause the inverter to disconnect from the public supply when voltage dips exceed 10 %. Thus, the inverter is likely to "add to the dip" by disconnecting, which is not the desired result. It would be better, if the inverter is permitted stay on-line under these circumstances, but it is difficult to reconcile this with anti-islanding requirements.

A second set of voltage immunity tests, is to subject the inverter to slower voltage variations, in accordance with IEC61000-4-14[4]. This test standard defines excursions to at least plus and minus 10 % vs. nominal. These types of voltage variations can and will occur during normal operation of the public supply. Depending on the inverter settings, it may separate itself from the public supply, if the voltage excursions exceed the trip points of the internal monitoring circuitry.

Another immunity test is to subject the inverter to harmonics and inter-harmonic test patterns per IEC61000-4-13[4]. It is common for utilities to inject inter-harmonic voltages on the network to control distribution equipment, and tariff metering through so-called ripple control signals. Of course, the inverter must be able to handle these ripple control signals, just like all other electrical equipment that is connected to the public supply can handle them.

Also, small frequency variations may occur on the public supply, as defined in IEC 61000-4-28[4]. Figure 9 shows a test patterns with frequency steps increasing to a deviation of 0.6 Hz (at 60 Hz nominal), and figure 10 shows how the inverter responds. At 10 seconds into the test, the first frequency change occurs, and the inverter's output power

No.	Type	Time (s)	Voltage	Freq.	Repeat	Waveform
1	VF Step	5.000	240.0	60.00	0	SINEWAVE
2	VF Step	5.000	240.0	59.80	0	SINEWAVE
3	VF Step	5.000	240.0	60.20	0	SINEWAVE
4	VF Step	5.000	240.0	59.60	0	SINEWAVE
5	VF Step	5.000	240.0	60.40	0	SINEWAVE
6	VF Step	5.000	240.0	60.60	0	SINEWAVE

Figure 9 Frequency variation test pattern

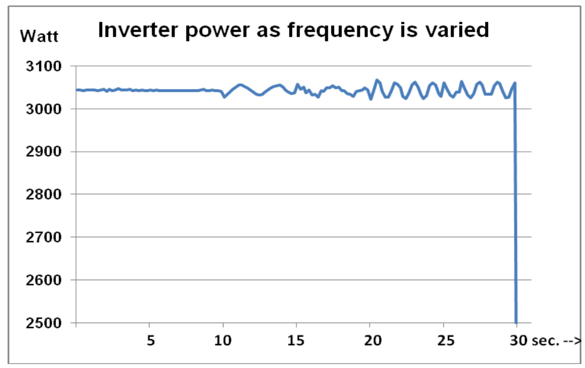

Figure 10 Inverter response to freq. variations per Fig. 9

shows a slight perturbation. The variations remain well within reason, until the frequency changes to 60.6 Hz (+ 1 %) at which time the inverter separates itself from the supply – as set by its internal monitoring circuit.

CONCLUSIONS

A substantial series of test criteria and standards exist, which can readily be applied for the purpose to evaluate dispersed generators, such as solar inverters. In addition to these existing test methods, new **system level tests** have been defined for IEC 61000-3-15. Test limits are most likely agreed upon by the time this paper is published, and thus the test methods can help to establish uniform testing procedures, to assure that inverters can be connected to the public system without immunity or emission problems.

REFERENCES

[1] IEC 61000-3-15 Draft version October 2010

[2] UL-1741 Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources – Feb. 2010

[3] IEEE-Std-1547 Standard for interconnecting distributed resources with electric power systems – July 2003

[3] Various IEC immunity and emission standards, such as IEC61000-3-2, 61000-3-3, 61000-4-11, 61000-4-13, 61000-4-14, 61000-4-28.