Islanding Detection Methods for Distributed PV Systems Overview and Experimental Study

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Abstract The current work presents an overview of islanding detection techniques, highlighting their advantages and disadvantages. Generally, all anti-islanding techniques detect the absence of utility-controlled generation and stop energy production. However, when the generation (from PVs) and loads within the island segment are well balanced—prior to the isolation event—it is difficult to detect the utility absence. The performed analysis indicates the fact that the islanding detection is a complicated procedure, which is affected by various parameters (load matching, quality factor, PV actual generation etc.). The islanding prevention techniques which are elaborated in this paper are limited to the case where the island segment belongs to the LV distribution grids, while remote islanding detection techniques are out of scope. Furthermore, this work presents an overview of the evaluation of the islanding detection techniques according to IEC 62116 and IEEE Std. 929-2000 standards. Finally, results from the experimental evaluation of various islanding detection techniques from different single phase inverters are presented too.

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1 Introduction

Nowadays renewable energy generation systems are developing rapidly on the way to meet future global energy demand, while reducing environmental pollution. The successful application of these systems requires efficient power converter topologies and also advanced control functions which assure the reliability, the safety and the power quality of the electrical grids. Although issues such as frequency deviation, voltage fluctuation and harmonic distortion are faced successfully under steady state operation, some others such as the Islanding detection and prevention are still pending, especially at LV distribution grids where grid-connected PV systems are the majority of renewable energy generation systems.

Islanding is the condition in which a portion of an electric power grid, containing both load and generation, is isolated (either intentionally or not) and continues to operate [1, 2]. The PV industry, in order to satisfy the apprehensiveness of electric power providers in case of islanding situations, has developed several islanding detection and prevention techniques (also called anti-islanding techniques) which can be divided into local and remote (or communication) techniques. Moreover, local techniques divided into passive, active and hybrid techniques are also introduced. Remote islanding detection techniques are based on the communication between the electric power providers and the renewable energy generation systems, through supervisory control, data acquisition and power-line carrier communication systems. These techniques may offer high reliability, but actually it is difficult to be applicable in LV distribution grids with large amount of distributed grid-connected PV systems, due to the system complexity, while in the meantime they are still very expensive to be implemented [2–6].

Generally, all anti-islanding techniques detect the absence of utility-controlled generation and stop energy production. However, when the generation (from PVs) and loads within the island segment are well balanced -prior to the isolation event-it is difficult to detect the utility absence; thus, customer and utility equipment can be damaged, since the generation units (PVs) are no longer under utility voltage and frequency control, or if the main grid re-closes into the island segment out of synchronisation. Last but not least there is danger of shock hazard to unsuspecting utility line-workers since the distribution lines within the island segment are energised.

Next paragraphs present the afore-mentioned islanding detection and prevention techniques, their advantages and disadvantages, as well as a test procedure to evaluate their effectiveness according to IEC 62116. The islanding prevention techniques which are elaborated in this paper are limited to the case where the island segment belongs to the LV distribution grids, while remote islanding detection techniques are out of scope.

2 Passive Islanding Detection Techniques

Passive islanding detection techniques typically monitor parameters such as voltage and frequency at the point of common coupling (PCC). The inverter ceases energising the grid if a remarkable change from normal voltage and frequency values occurs. The most popular passive techniques are the:

(a) Under/Over Voltage and Frequency (U/O-V&F) monitoring techniques,
(b) Voltage Phase Jump (VPJ), and
(c) Voltage Harmonics Detection (VHD).

Generally, all passive islanding detection techniques do not affect the inverter output power quality as well as their effectiveness is not affected by the parallel operation of other inverters [2–7].

2.1 The U/O-V&F Monitoring Technique

Nowadays all grid-connected PV inverters have to be equipped with U/O-V&F monitoring techniques that cease the PV energy production (even under utility-controlled generation) if voltage or frequency values at the PCC exceed the predefined thresholds. For example in Greece the voltage value at PCC (VPCC) should not exceed more than −20 or +15 % the grid voltage nominal value, while the frequency should not exceed more than ±0.5 Hz the frequency nominal value. Taking for granted that the inverter 'feeds' the grid with active power under unitary power factor (only the utility grid feeds the load reactive energy needs), the operation of U/O-V&F monitoring technique depends on real and reactive power flow balance at the PCC. In more details, if there is imbalance between the PV production and the load needs (the utility may feed the load with real or/and reactive energy), then the VPCC amplitude after the island segment "genesis" will change due to active energy unbalance and the frequency of the inverter output current will also change due to reactive energy unbalance (the load resonant frequency does not usually lie near the utility frequency). So the U/O-V&F monitoring technique detects the changes and prevents the islanding operation. On the other hand, in cases that active and reactive power balance exists within a network part, then there will not be any remarkable PCC voltage amplitude or frequency deviation after it is islanded and so the U/O-V&F monitoring technique will fail to detect the island operation.

Actually, taking into account that the U/O-V&F monitoring technique is activated only if PCC voltage amplitude and/or frequency take values outside the predefined thresholds, this implies that the afore-mentioned techniques will not detect any island operation for resistive load changes between 114 and 90 % of the pre-island segment "genesis" resistive load value (for the case of Greek utility voltage trip values). This load range is shown in Fig. 1 and is also called

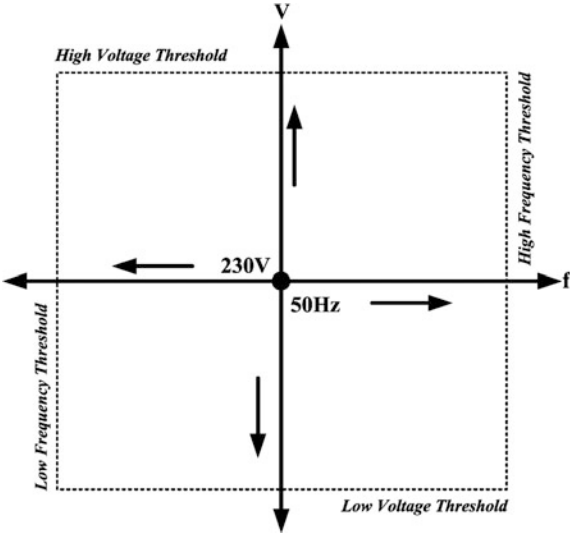


Fig. 1 Non-Detection Zone (NDZ) presentation

Non-Detection Zone (NDZ) for active energy unbalance and it varies according to each Distribution Operator thresholds. An additional NDZ for reactive energy unbalance can be also defined by using the appropriate reactive load equations. Nevertheless, the existence of a wide NDZ area makes U/O-V&F monitoring techniques to be considered as insufficient ones [2–7], although they can be easily implemented by software routines and so they are less expensive. It is worth mentioning that this situation worsens in cases where the Distribution Operation includes a Fault Ride Through scheme and/or Auxiliary Services (Voltage Support) for the interconnected PV systems—making so islanding detection much more complicated.

Last but not least, some others similar anti-islanding techniques [6] are based on the monitoring of the:

(a) Output power change (dP_{inv}/dt),
(b) Frequency change (df/dt), also known as the ROCOF method, and
(c) Ratio of frequency change over power (df/dP_{inv}),

where “P_{inv}” is the inverter output power and “t” is a certain duration of time (depending on the electric grid inertia).

2.2 The Voltage Phase Jump (VPJ) Monitoring Technique

The Voltage Phase Jump (VPJ) technique monitors the phase angle between the inverter output current and voltage waveforms at the point of common coupling, seeking for an unexpected phase jump; the grid-connected PV systems operate with current-source or voltage source current control inverters which synchronise their output current with the utility voltage by using zero crossing techniques and phase-locked loops (in order to detect either the VPCC rising or falling to zero value). Thus, the inverter output current follows a fixed waveform between two consecutive PCC voltage zero crossings. Consequently, an instant after the island segment “genesis”, the PCC voltage will not be under utility-control and so a sudden phase jump between the PCC current and voltage waveforms will be established. At the following PCC voltage zero crossing, if the phase divergence is higher than a predefined threshold value, the VPJ technique will command the inverter to cease energising the grid. The threshold values are difficult to be defined either if the inverter is allowed to operate under non-unitary power factor, or if among the local loads there are significant motor loads which may cause transient phase jumps (e.g. during start up). Due to the afore-mentioned thresholds there is also a Non-Detection Zone for this type of monitoring techniques. Similar islanding detection techniques can be found in literature either as Power Factor Detection, or Transient Phase Detection techniques [2–7].

2.3 The Voltage Harmonics Detection (VHD) Monitoring Technique

The Voltage Harmonics Detection (VHD) technique measures the voltage Total Harmonic Distortion (V_{THD}) at the point of common coupling and compares its THD_V value with a predefined threshold value. Before the utility disconnection the THD_V value is almost negligible, due to the presence of the strong distribution network; after the island segment “genesis” the inverter output current harmonics are feeding the load (which impedance is usually higher than the grid one) and so voltage harmonics are produced [8]. For example, the grid-connected PV inverters limit their output current THD_I value below 5 % at full rated power (although higher THD_I values emerge under partial generation conditions). So, the absence of the utility grid causes at least an equivalent for the case of pure resistive loads. The generated voltage harmonics or the THD_V value changes are detected by the VHD technique and so the inverter ceases energising the islanded segment. Unfortunately, the structure of the island segment (it is usually modelled as a parallel RLC circuit) may lead at lower THD_V values, depending on the quality factor (QF) of the equivalent circuit. Thus, the appropriate selection of the trip threshold for successful islanding detection is difficult to be defined. Additionally, for non-linear loads, the THD_V value may become too high causing faulty island detection under the electric power grid presence, while for linear loads (under island operation) the THD_V value may become too low to be detected, especially for modern PV inverters with very low THD_I. Similar islanding detection techniques can be found in the literature as Current Harmonics Detection techniques, while some of them measure only the third and the fifth current or voltage harmonics [2–7, 9].

3 Active Islanding Detection Techniques

Active islanding detection techniques are sensing the absence of utility-controlled generation by causing small scale intentional disturbances at the PCC and monitoring the network response. If a small perturbation is able distract grid operation from its normal conditions, the inverter ceases energising the grid. Active islanding detection techniques usually contain an active circuit that forces voltage, frequency or network impedance change, through positive feedback control perturbation techniques. Generally, the active techniques reduce remarkably (or even eliminate) the Non-Detection Zone. However, they may produce serious deterioration of the power quality or even cause instability problems. The most popular active techniques are the:

(a) Impedance Measurement,
(b) Impedance Detection at Specific Frequency (IDSF),
(c) Slip-mode Frequency Shift (SMFS),
(d) Active Frequency Drift (AFD),
(e) Sandia Frequency Shift (SFS), and
(f) Sandia Voltage Shift (SVS).

3.1 Impedance Measurement Monitoring Technique

The Impedance Measurement technique imposes variations at the inverter output current waveform (either at the amplitude, the phase angle or the frequency) and detects any impedance deviations at the inverter output stage. Thus, this technique is known as Output Variation, and Current Notching, as well as Power Shift technique. The current perturbation is usually performed through amplitude variation and the corresponding voltage perturbation depends on the utility impedance (which is supposed to be very small under grid-tied operation) and the power nominal values. If the electric power grid is disconnected, a remarkable change in PCC voltage rms value will happen due to the island segment higher impedance. The grid impedance deviations are monitored by calculating the ratio dV_{PCC}/dI_{inv}, where "I_{inv}" is the inverter rms output current. Moreover, by considering the Distribution Operator allowable voltage threshold values, it is obvious that the minimum current amplitude deviation has to be equal to the U/O-V monitoring technique full window size for successful island detection. For example in Greece the minimum current amplitude deviation has to be higher than 35 %.

The effectiveness of the Impedance Measurement technique decreases in case of parallel operation of many inverters—unless all inverters' output current perturbation are synchronised—as well on high-impedance (weak) grids. Moreover, in order to sense the utility disconnection, it is necessary to pre-estimate the utility impedance and use it as a threshold value. Last but not least, this islanding detection technique may cause grid voltage flicker and stability issues [2–7, 9].

3.2 The Impedance Detection at a Specific Frequency (IDSF) Monitoring Technique

The Impedance Detection at a Specific Frequency (IDSF) technique relies on the same operation principals with the VHD technique and so it is characterised by the same general advantages and disadvantages. Its main difference is that a specific current harmonic component is intentionally injected by the inverter to the PCC and the generated voltage harmonic value is measured. Considering that the grid impedance at the specific harmonic order is significantly lower than the islanded segment one, the amplitude of the generated voltage harmonic component depends on the presence of the utility grid as well as of the island segment impedance at the specific harmonic order. The effectiveness of the IDSF technique increases if the inverter injects to the grid a sub-harmonic current component instead of a high order one. However, if the sub-harmonic component amplitude has to remain very limited in order to avoid saturation issues to the distribution transformers [2–7].

3.3 The Slip-Mode Frequency Shift (SMFS) Monitoring Technique

Although the grid connected PV systems feed the electrical grid under (almost) unitary power factor, the Slip-mode Frequency Shift (SMFS) technique forces the phase angle between the inverter output current and the PCC voltage to change as a function of the PCC frequency, while a positive feedback technique is used in order to destabilise the PV system operation even under well balanced island conditions. The equation which describes the connection between the phase angle and the PCC frequency is given is [6]. The inverter phase angle response curve is chosen in such a way so that the inverter phase angle increases faster than the load phase angle. An instant before the island segment “genesis” the electric power grid provides a stable frequency reference, leading so to a stable phase angle value (between the inverter output current and the PCC voltage phasors) which cannot affect the electrical grid frequency. On the other hand, after the island segment formation, the positive feedback will force the new operation point to become outside the U/O-F protection threshold values and so the inverter ceases energising the grid island segment. Moreover, according to the specific anti-islanding technique reasoning, a small PV output power quality degradation is inevitable, as well as transient phenomena are possible to emerge at electrical grids with high PV penetration level and inverters with high gain positive feedback loops. Moreover, the positive feedback loop causes problems in case of noise at the reference waveform. Contrariwise, the effectiveness of the SMFS technique is not affected in case of parallel operation of many inverters [2–7, 9].

3.4 The Active Frequency Drift Monitoring Technique

According to the Active Frequency Drift technique, a time interval with zero inverter output current is imposed at the end of each utility half-cycle, aiming to cause deviations at the electrical grid frequency. If the above current waveform is applied to an island segment with pure resistive characteristics, then at the end of the first line half cycle the generated voltage frequency will be slightly higher (or smaller) compared to the grid nominal frequency. In this case, the PV inverter (assuming grid-tied operation) will increase (or decrease) the inverter output current frequency in order to eliminate the phase error. At the end of the next half line cycle, the inverter will detect a new phase error and consequently it will increase (or decrease) the output current frequency again. The continuous frequency changing process will cause the Under/Over Voltage and Frequency monitoring technique activation and so the inverter will cease energising the grid. Moreover, according to the AFD technique, the duration of every two consecutively zero inverter output current intervals have to be dissimilar. Of course, in case of non island conditions the aforementioned changes are not possible to affect the utility frequency. Like in previous anti-islanding technique, a small PV output power quality degradation is inevitable. Moreover, the effectiveness of the AFD technique decreases in case of parallel operation of many inverters -unless all inverters are synchronised to increase or decrease the output current frequency simultaneously. Last but not least, the inverter output current waveform may generate even harmonic order components to the low voltage grids.

Finally, the AFD technique Non-Detection Zone depends on the ratio of the two dead time intervals to the voltage half line duration (also called chopping fraction). It is worth mentioning that the NDZ may be affected from the combination of strong capacitive and resistive loads, or light inductive and strong resistive loads (in other words by high quality factor loads).

Similar islanding detection techniques can be found in the literature either as Frequency Bias or Frequency Shift Up/Down techniques. A noteworthy modification of the AFD technique is the Frequency Jump (FJ) technique. According to the FJ the time intervals with zero inverter output current are inserted not at every line cycle, but less periodically (e.g. every third cycle) or at sophisticated selected cycles, in order to minimise the inverter output current distortion. The effectiveness of the FJ technique decreases in case of parallel operation of many inverters -unless all the inverters' output current perturbation is synchronised [2, 6, 9].

3.5 The Sandia Frequency Shift (SFS) Monitoring Technique

The Sandia Frequency Shift technique (SFS) relies on the same operation principals with the AFD technique, with an additional positive feedback loop being applied to the utility grid frequency measurement in order to destabilise the PV system operation under island conditions. The equation that describes the relation between the chopping fraction, he nominal voltage frequency and the generated voltage frequency deviation is given in [9]. The SFS technique detects any utility frequency deviation and tries to amplify the frequency error by applying a positive feedback. Before the island segment "genesis" the electric power grid prevents any voltage frequency alteration, while after the island segment "genesis" the SFS technique reinforces the frequency error, until the U/O-V&F monitoring technique activation. The Sandia Frequency Shift technique is characterised by the same general advantages and disadvantages of the AFD one, while the positive feedback reduces noticeably the NDZ spread. On the other hand the positive feedback causes problems in case of noise at the reference waveform. Similar islanding detection techniques can be found in the literature either as Accelerated Frequency Drift, Active Frequency Drift with Positive Feedback, or Follow the Herd techniques [2, 6, 9].

3.6 The Sandia Voltage Shift (SVS) Monitoring Technique

The Sandia Voltage Shift technique measures the PCC rms voltage value and applies a positive feedback loop to the measured value. According to this anti-islanding technique any rms voltage diviation causes an inverter output current decrease or increase according to the SVS operation principals. Thus, in case of island conditions (assuming island segment with strong resistive characteristics) a reduced (or increased) inverter output current will cause further VPCC reduction (or increase), leading finally to a remarkable PCC rms voltage value deviation that will cause the U/O-V&F monitoring technique activation. Of course, an inverter output current reduction due to a transient PCC rms voltage value decrease (under grid-tied operation) cannot affect the PCC rms voltage value. On the other hand in case of island segment, the positive feedback loop will accelerate the PCC rms voltage value reduction, leading to a very fast U/O-V&F monitoring technique activation. Although either increasing or decreasing output current operations are possible, the current reduction method is in favor in order to protect the electric installations from critical voltage levels. Moreover, many PV inverter manufactures use a combination of the two above anti-islanding techniques (SFS and SVS) in order to achieve an extremely narrow NDZ. Unluckily, the SFS technique causes a small PV output power quality degradation (that may be harmful at weak electrical grids), while it may also decrease the MPPT controller efficiency—and so the inverter electrical efficiency—due to the intentionally inverter output current reduction and the corresponding output power reduction in case of utility presence. Similar islanding detection techniques can be found in the literature either as Voltage Shift, Positive feedback on voltage, Follow the Herd or Variation of P and Q techniques [2, 6, 9].

4 Hybrid Islanding Detection Techniques

Nowadays, many PV inverter manufactures incorporate both active and passive techniques leading so to Hybrid techniques. According to these anti-islanding schemes, the active method is implemented only when the islanding mode is suspected by the passive method.

5 Islanding Detection Techniques Test Procedure According to IEC 62116

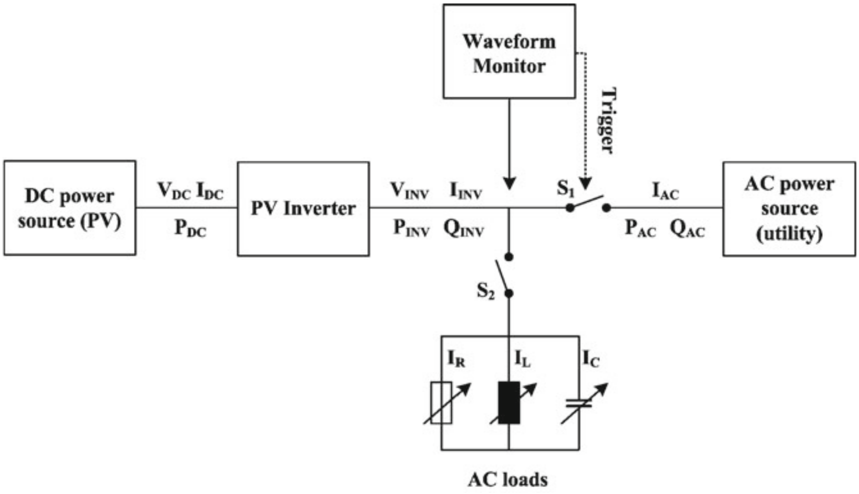
The scope of IEC 62116 standard is to provide a test procedure for the performance evaluation of the islanding prevention measures that are used in single or multi-phase utility-interconnected PV systems. Inverters that meet the requirements of this standard are considered to be non-islanding as defined in IEC 61727. According to IEC 62116 [1], a PV inverter is considered to be compatible with the anti-islanding protection demands if under any test condition—described in Table 1—the islanding detection is achieved in less than 2.0 s for over/under voltage and 1.0 s for over/under frequency (unless the Distribution Operator demands are different). The necessary test bench is shown in Fig. 2.

For test condition A, the real load and only one of the reactive load components should be adjusted to each of the load imbalance conditions shown in the shaded part of Table 2. Each cell corresponds to the active and reactive power (%) flow through S1 in Fig. 1, with positive value denoting a power flow from the Inverter to the AC power source. Actual load values should be within ±1 % of those specified. After each adjustment, an island test is being run and the run-on time is recorded. If any of the recorded run-on times is longer than the one recorded for the rated balance condition, then the non-shaded parameter combinations require also testing.

For test conditions B and C, the real load and only one of the reactive load components should be adjusted to each of the load imbalance conditions shown in Table 3. Actual load values should be within ±1 % of those specified.

Table 1 IEC 62116 test conditions

Inverter			
Condition	Inverter output power	Inverter input voltage	Inverter trip settings (Voltage—frequency)
A	Maximum	>90 % of rated	Manufacturer specified
B	50–66 % of the maximum rated	50 % ± 10 % of rated	Nominal
C	25–33 % of the maximum rated	<10 % of rated	Nominal



Parameters to be measured			
Symbol	Parameter	Symbol	Parameter
V_{DC}	DC voltage	I_R	Resistive load current
I_{DC}	DC current	I_L	Inductive load current
P_{DC}	DC power	I_C	Capacitive load current
V_{INV}	AC voltage	P_{AC}	Utility active power
I_{INV}	AC current	Q_{AC}	Utility reactive power
P_{INV}	Active power	I_{AC}	Utility current
Q_{INV}	Reactive power		

Fig. 2 Islanding detection techniques test bench according to IEC 62116

Table 2 IEC 62116 test condition A

Condition A				
% deviation in active and reactive load from nominal				
−10, +10	−5, +10	0, +10	+5, +10	+10, +10
−10, +5	−5, +5	0, +5	+5, +5	+10, +5
−10, 0	−5, 0		+5, 0	+10, 0
−10, −5	−5, −5	0, −5	+5, −5	+10, −5
−10, −10	−5, −10	0, −10	+5, −10	+10, −10

An additional anti-islanding frame that has to be discussed is the one that IEEE Std. 929-2000 describes [10]; according to this Standard, a PV inverter is able to pass through any islanding condition,

Table 3 IEC 62116 test condition B & C

Condition B & C
% deviation in active and reactive load from nominal
0, −5
0, −4
0, −3
0, −2
0, −1
0, 1
0, 2
0, 3
0, 4
0, 5

- if it disconnects in less than 10 line cycles in case of an islanded mode, where:
  - there is at least 50 % load—PV generation imbalance, or
  - the islanded load power factor is less than 95 % (either leading or lagging).
- if it disconnects in less than 2.0 s in case of an islanded mode, where:
  - there is up to 50 % load—PV generation imbalance, and
  - the islanded load power factor is greater than 95 % (either leading or lagging), and
  - the islanded network quality factor is less than 2.5.

6 Experimental Evaluation of Islanding Detection Techniques

In the following paragraphs the performance of several anti-islanding techniques—as they are applied in commercial PV inverters—will be experimentally studied, according to the test bench in Fig. 2. A typical example that highlights the U/O-V&F monitoring technique operation is shown in Figs. 3 and 4 for the case of a 3.0 kW commercial single phase transformerless inverter. Initially, the voltage is slowly increased and the value that causes the trip is registered. After the initial conditions restoration step voltage variation takes place from the same central point to a value above the measured high-voltage threshold. The time between the voltage step and the intervention of the protection is measured. The above procedure is inversely repeated by decreasing the voltage in order to obtain the low-voltage threshold. The same procedure is repeated to determine the high-frequency and low frequency thresholds and the time between the frequency step and the intervention of the protection is measured.

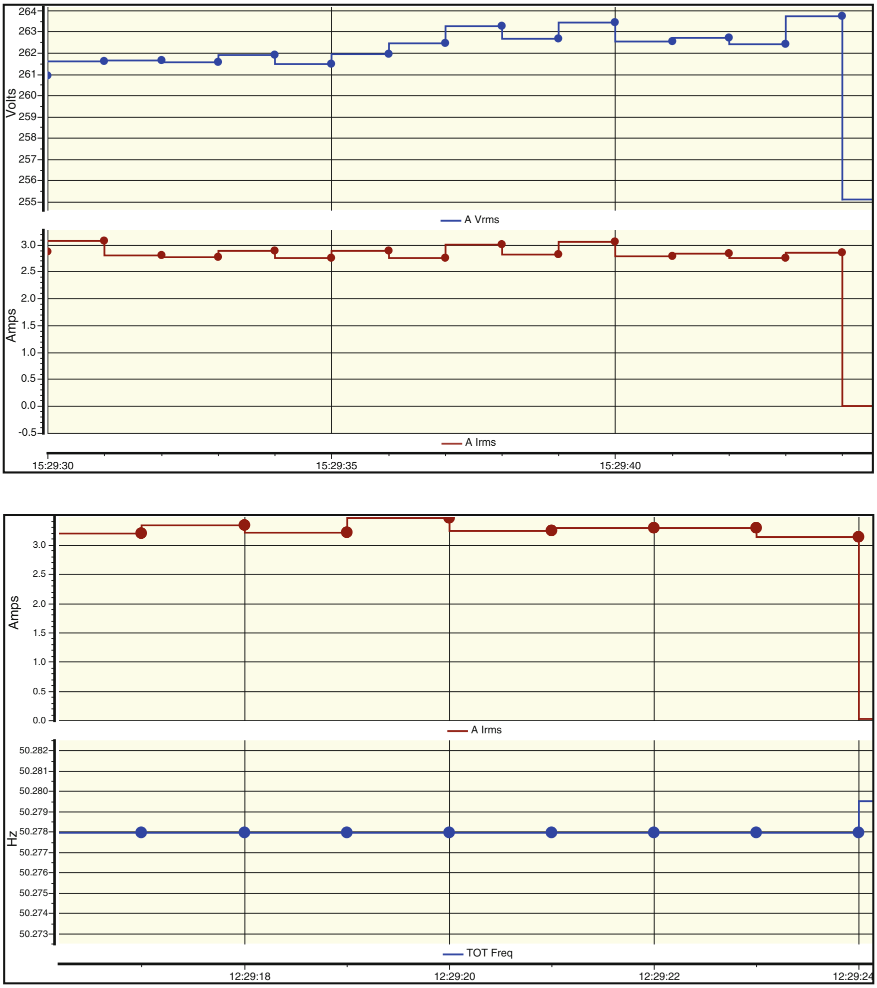


Fig. 3 The U/O-V&F monitoring technique; determination of over voltage and frequency thresholds (3.0 kW commercial single phase inverter). The *purple colour* represents the VINV and the *green colour* represents the I_{INV}

Additionally, Fig. 5 exhibits the inverter response in case of islanded mode under generation—consumption match and pure Ohmic load (the network quality factor is zero). This situation shows clearly the weakness of this passive monitoring technique to disconnect the inverter, due to the fact that the islanded network rms voltage remains within the Distribution Operation thresholds. It is worth mentioning that the alternative use of the passive VHD monitoring technique could be more effective—due to the distorted waveform of the islanded network voltage; however, under realistic quality factor values (between 0.05–0.25) even this monitoring technique would become ambiguous.

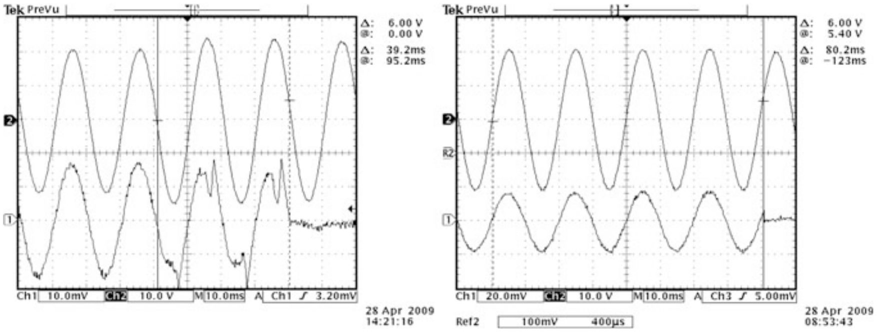


Fig. 4 The U/O-V&F monitoring technique; measuring the time interval between the voltage or frequency step and the intervention of the protection (3.0 kW commercial single phase inverter). The *purple colour* represents the V_{INV} and the *green colour* represents the I_{INV}

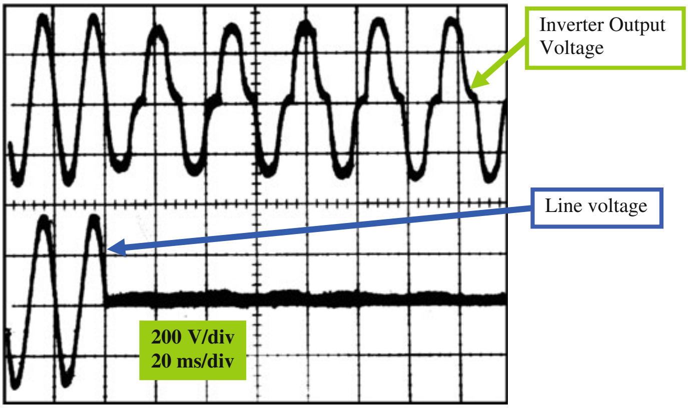


Fig. 5 The U/O-V&F monitoring technique; islanding operation under generation—consumption balance and pure Ohmic load (testing at a 4.0 kW commercial single phase inverter)

A typical example that highlights the effectiveness of active over passive islanding detection techniques in the aforementioned case of load match and realistic QF values is shown in Fig. 6; in this test a 2.0 kW single phase inverter is examined under load match and for QF = 0.125. The inverter implements the AFD monitoring technique, which manages to achieve disconnection at 380 ms. This is a satisfying response according to both the above mentioned international standards—which demand for the specific network condition a disconnection time of less than 2.0 s.

Moreover, Fig. 7 shows the implementation of the active impedance monitoring technique, performed by a 700 W single phase inverter unit; here the impedance measurement comes through a periodical current pulse injection which duration is about 2.3 ms and its peak value is comparable to the inverter nominal current

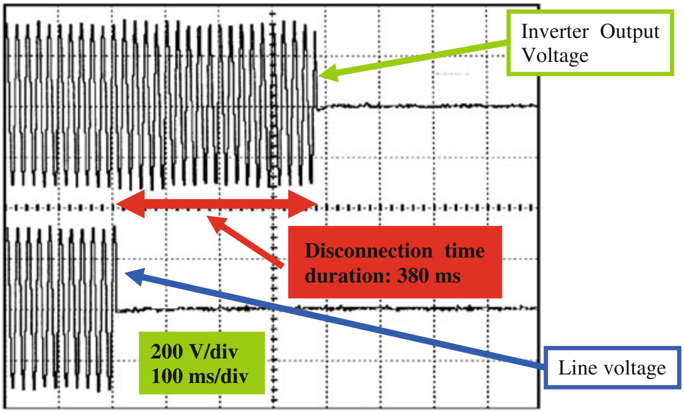


Fig. 6 The AFD monitoring technique; islanding operation under generation—consumption balance, QF = 0.125 (testing at a 2.0 kW commercial single phase inverter)

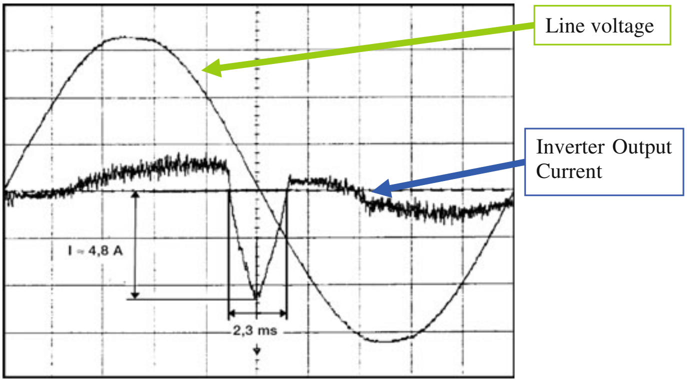


Fig. 7 The impedance monitoring technique implemented by a 0.7 kW commercial single phase inverter

amplitude. Although this method is very efficient for the detection of any islanding condition, it is obviously less attractive for high power PV systems due to the network voltage quality as well as the protection issues that it raises.

An improved impedance monitoring implementation that limits the voltage quality effects is discussed in Fig. 8; here the current pulse takes place after a dead time of 2.5 line cycles, which is enough for the detection of islanded operation (through voltage and/or frequency drop) under normal network/operation conditions. Thus, in this algorithm the current pulse is the second islanding detection stage (for cases of unusual high QF values).

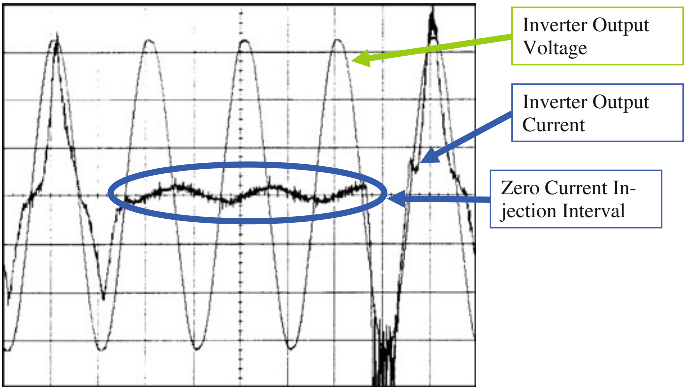


Fig. 8 The improved impedance monitoring technique implemented by a 1.0 kW commercial single phase inverter

7 Conclusions

A detailed overview along with an experimental evaluation process has been presented in this work, highlighting the fact that the islanding detection is a rather complicated work which depends on numerous factors (e.g. load matching, quality factor, PV actual generation). Moreover, this work encumbers as distributed PV generation penetration level increases due to its impact on the power quality of the supply. The experimental procedure that has been presented shows that the use of active islanding detection techniques based on positive feedback loops is the best way for PV inverters to become compatible with the IEC 62116 and the IEEE Std. 929-2000 standards and with small impact on distribution power quality. Nevertheless, it is foreseen that as penetration level increases the combination of local active and remote monitoring techniques will become obligatory—a step forward on the way to smart distribution integration.

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