Islanding Detection for Photovoltaic Inverters Using the Sandia Frequency Shift Method

Marcos Vinicios Gomes dos Reis, Thais Gama Siqueira and Marcelo Gradella Villalva

***Abstract*—The connection of inverters for distributed generation photovoltaic systems to the distribution network creates situations of risk to the loads that are connected to the point of common coupling (PCC) and personals who maintain the power grid. A risk that should be avoided is the supply of electricity, by one or more inverters, to the distribution network after disconnecting the main power grid. The isolation of distributed generation systems that continue to supply the power required by the load at the PCC is known in the literature as islanding. The unintentional islanding can be avoided by using islanding detection techniques. This paper describes an anti-islanding detection method used for prevention against unintentional islanding of the distributed generator. The main focus is the study, implementation and analysis of the Sandia Frequency Shift method based on the IEEE 929-2000 standard.**

***Index Terms*—anti-islanding, islanding detection, distributed generation, photovoltaic, grid-tie inverter.**

I. INTRODUCTION

The inclusion of photovoltaic systems to the electricity distribution grid implies an improvement in the way in which the electrical power system was designed. Security measures need to be taken so that potential failures can possibly be avoided. A failure that may occur it is the islanding of the grid, which is powered by distributed generators. This situation is difficult to occur because it would require a power match between the distributed generator and the local load connected to the common coupling point. Some methods were created for the detection of islanding. They are classified mainly as remote and local. The local methods may be passive or active. Passive methods have large non detection zones (NDZ), and depending on the conditions will not be able to detect islanding. In addition, active methods have smaller NDZ, but may cause additional problems to the power quality due to the introduction of current harmonics. This paper focuses on the implementation of the Sandia Frequency Shift method for a single phase two-stage grid-tie photovoltaic system. The technique studied in this paper will have the performance evaluated according to the test criteria of the IEEE STD 929-2000 standard [8].

The paper starts with a brief description of the IEEE 929-2000 standard. Then the two stage grid-tie photovoltaic system used in the research. Next, the anti-islanding method used is explained in details. Finally, simulation results and conclusions are presented.

II. A BRIEF DESCRIPTION OF THE IEEE 929-2000 STANDARD

Standards determine the ideal operation of the distribution system. The IEEE 929-2000 standard was created to provide guidelines as to which frequency and voltage limits the distribution grid must have. Tables I and II show the voltage and frequency limits for the utility grid. When the main grid is operating in suitable way, the voltage and frequency are regulated by the electric power system according to these tables. However, when a fault occurs to the utility grid, these values are no longer established and they are strongly dependent to the local load connected to the PCC. The local distributed generator and its interaction with the local load on the other hand may cause dangerous situations not only to the equipment but to personnel.

The main scenario is related to the unceasing power injection by the distributed generator when the main grid is not present. This happens when the resonant frequency and the voltage limits coincide with those determined by the standard at the moment of islanding. Some techniques have been developed to speed up the islanding detection so as to meet the detection time of the standards.

TABLE I: Frequency limits for the IEEE STD 929-2000

Islanding detection time	
Frequency(Hz)	Detection time (in cycles)
frequency < 59.3	6
frequency > 60.5	6

TABLE II: Voltage limits for the IEEE STD 929-2000

Islanding detection time	
% of nominal voltage	Detection time (cycles)
Voltage < 50	6
$50 \leq$ Voltage < 88	120
$88 \leq$ Voltage < 110	Normal operation
$110 \leq$ Voltage > 137	120
$137 \leq$ Voltage	2

III. SINGLE PHASE TWO-STAGE GRID-TIE INVERTER

The single phase two-stage grid-tie inverter is composed of two conversion stages. The first stage is a DC-DC boost converter which is used to boost the PV (photovoltaic) module voltage and to control the PV voltage in order to regulate the operation of the module at the maximum power point. The output of the DC-DC converter is attached to the DC link, which is the input of the DC-AC converter. The DC-AC inverter is responsible for keeping the DC link voltage constant and to control the output current. This is done by controlling the energy stored in the DC link capacitor. When the first stage starts to inject power, the voltage at the DC link capacitor increases. The inverter then increases the power

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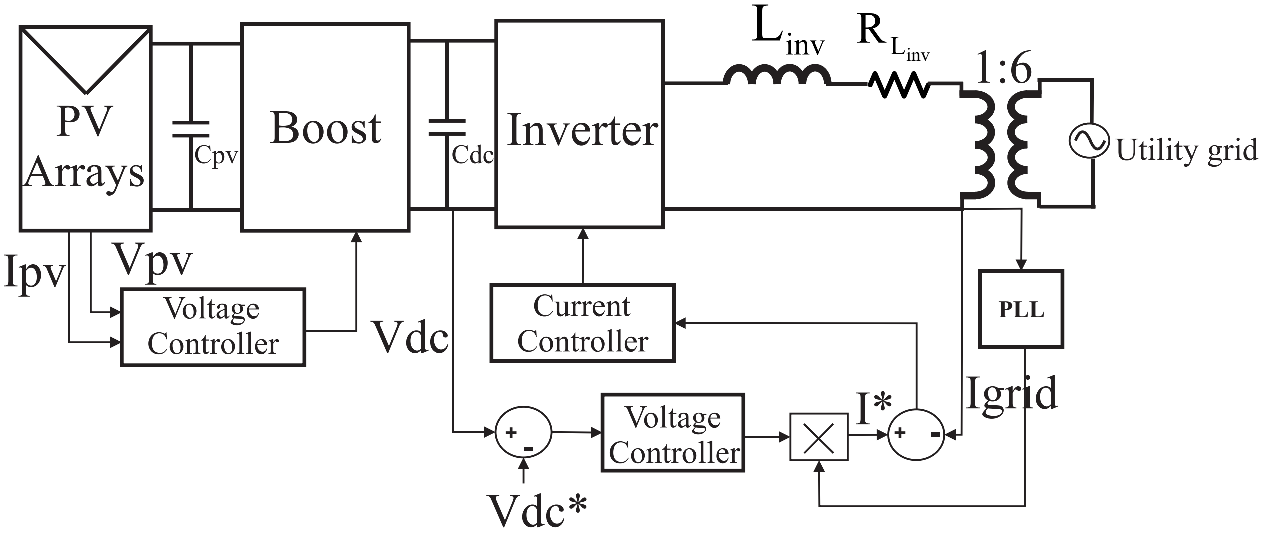

Fig. 1: Single-Phase two-stage grid-tie system.

injected into the grid to stabilize the inverter input voltage. If the power injected by the first stage is not enough to keep the capacitor charged the inverter draws energy from the grid to stabilize its input voltage [3], [6], [12], [16].

IV. ISLANDING DETECTION STRATEGIES

The main anti-islanding or islanding detection methods found in the literature are passive and active ones. Passive strategies are friendly to the grid while active ones cause disturbances to the grid. The inclusion of small perturbations in voltage levels and injected currents by the active methods increase the reliability of the detection system but reduces the quality of the power injected into the grid. In the following sections: a brief description of the nondetection zone of the over/under voltage (OUV) and over/under frequency (OUF) and the active method used in this paper.

A. Nondetection zone of OUV/OUF

The nondetection zone (NDZ) can be defined as the region in which the anti-islanding method fails to detect islanding conditions. The NDZ of reactive power is represented by the equation (1).

$$Q_f[1-(\frac{f_0}{f_{min}})^2] \leq \frac{\Delta Q}{P} \leq Q_f[1-(\frac{f_0}{f_{max}})^2] \quad (1)$$

Based on the standard IEEE 929-2000, $f_{max} = 60.5Hz$, $f_{min} = 59.3Hz$ and $Q_f = 2.5$ (quality factor) for a fundamental frequency f_0 of 60 Hz, the equation becomes:

$$-5,937\% \leq \frac{\Delta Q}{P} \leq 4.11\% \quad (2)$$

The NDZ of active power is represented by the equation (3).

$$(\frac{V}{V_{max}})^2 - 1 \leq \frac{\Delta P}{P} \leq (\frac{V}{V_min})^2 - 1 \quad (3)$$

Based on the standard IEEE 929-2000, $V_{max} = 110\%$ of nominal voltage, $V_{min} = 88$ % of nominal voltage and $Q_f = 2.5$ for a voltage V of 180 V, the equation becomes:

$$-17,35\% \leq \frac{\Delta P}{P} \leq 29,13\% \quad (4)$$

B. Active anti-islanding methods

Some active anti-islanding methods add small perturbations to the inverter output current so that islanding conditions may be detected in a faster way. Besides, this approach is known to decrease the non detection zone (NDZ) of the passive methods. If the utility grid is on, perturbations caused by the anti-islanding strategy are going to be ignored by the power system and no frequency or voltage changes will be noticed. When the grid power is off, the voltage and frequency of the local island will be disturbed until tripping occurs by OUV or OUF and the PV system is disconnected. Active techniques combined with passive ones can detect islanding conditions with neglectful NDZ [13], [20].

The main disadvantage of such active anti-islanding methods is the degradation of the quality power delivered to the grid because of the perturbations inflicted to the output current. When the number of distributed generators increases, the degradation is increased and the non detection zone of the active methods may increase as well [17], [19].

C. Sandia frequency shift

The method used in this paper was created by the Sandia National Laboratories, USA, and is known as the Sandia Frequency Shift (SFS) method for islanding detection. This method introduces small perturbations in the AC output current of the inverter, as shown in Fig. 2. These perturbations are characterized by the introduction of small blank intervals (T_Z) which cause an increase ($\delta f = 0.5 - 1.5$) in the current frequency when compared to the previous cycle. This frequency increase is increased by means of positive feedback of the grid voltage frequency until the over frequency protection is reached. It is limited by T_z (time of blank current). This limit is defined by the total harmonic distortion allowed by the IEEE 519-1992 standard [1]. Equation (6) describes the current of the inverter with the method.

When the grid is working properly there is a constant cf represented by cf_0. This small perturbation at the current will not have effect on the grid voltage frequency and the duration of T_Z will be kept small. When the grid is off cf_j starts increasing. The increase in frequency depends on the parameter k and its value is responsible for determining the speed of the islanding detection.

$$i_j^* = \sqrt{2}Isen[2\pi(f_{j-1} + \delta f)]t \tag{5}$$

$$cf_j = cf_0 + k(f_{j-1} - f_{grid}) \tag{6}$$

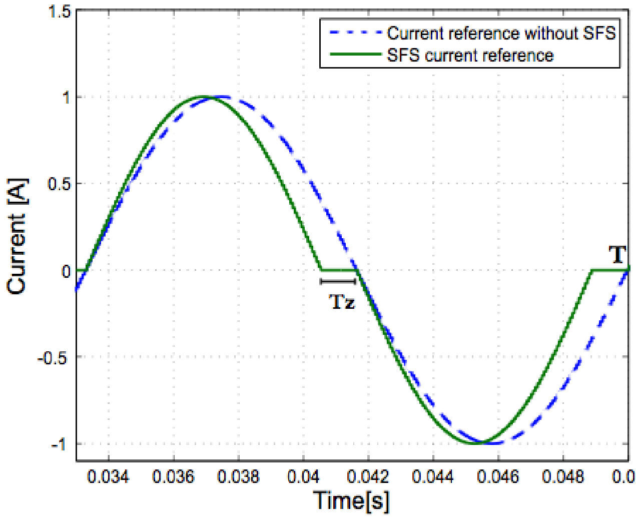

Fig. 2: Current disturbance imposed by the Sandia Frequency Shift Method.

V. ANTI-ISLANDING TESTING CONDITIONS

Testing of anti-islanding methods with inverters requires an RLC load tuned with certain criteria as shown in Fig. 3. The RLC load parameters are defined by the following equations, where P is the active power supplied by the inverter. When the grid is off the RLC load will create an island with constant voltage and frequency if the RLC was properly tuned. The resonance of the L and C components is set to the grid frequency and no reactive power will be supplied by the inverter.

The R component will dry the full active power. Ideally no frequency or voltage changes will be noticed at the output of the islanded inverter if these conditions are met. This is the worst case of islanding for an inverter. If there is no anti-islanding method to intentionally change the frequency or voltage the distributed generator will not stop injecting power into the islanded network [7].

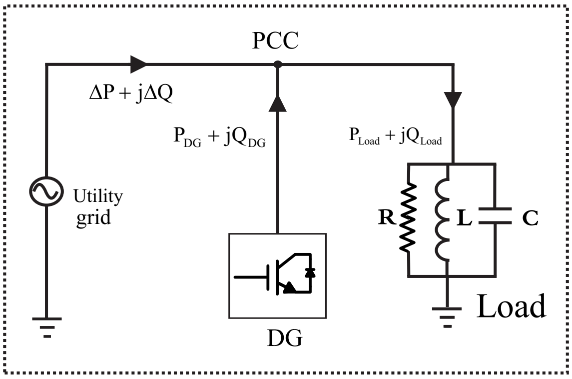

Fig. 3: Simplified diagram of a distributed generation system connected to the utility grid feeding a local charge on the point of common coupling.

$$R = \frac{V_{rms}}{P} \tag{7}$$

$$L = \frac{V_{rms}^2}{(2\pi f_0 Q_f P)} \tag{8}$$

$$C = \frac{Q_f P}{(2\pi f_0 V_{rms}^2)} \tag{9}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{10}$$

$$Q_f = R\sqrt{\frac{C}{L}} \tag{11}$$

VI. SIMULATION RESULTS

As it was described in the previous sections, it is necessary that the resonant frequency of the RLC load connected to the common coupling point coincides with the normal operation frequency of the main grid at the moment of islanding. The same has to happen to the acceptable operation values for the voltage magnitude according to the standard. Based on the power generated by the PV system and the equations described in section V, the values found for the resistance, inductor and capacitor of the RLC load are 67.5 Ω, 0.0716 H and 98.244 μF, respectively.

For the validation of the values found for the RLC load, the simulation of the system was run without the anti-islanding method. Fig. 4 shows that the PV system keeps injecting active power in the grid respecting the voltage values imposed by the standard, when the grid was off at $t = 1$ s. The islanding is not noticed.

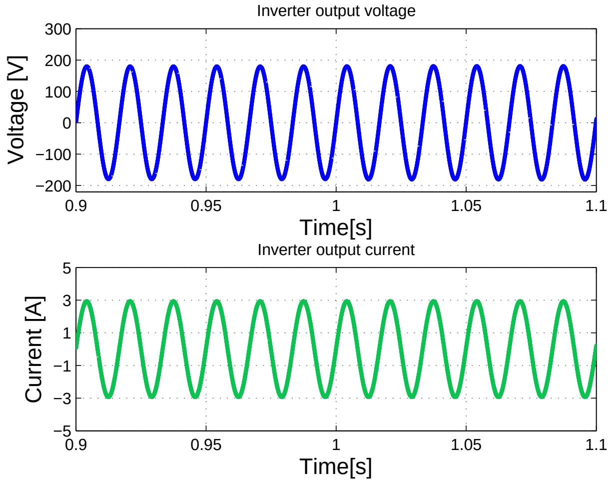

Fig. 4: Grid voltage and inverter output current during the simulation without anti-islanding detection.

The same happens to the frequency. Fig. 5 illustrates that the resonant frequency of the load coincides with the normal operation frequency of the grid. This situation represents the worst case scenario because passive methods fail to detect that a portion of the grid is islanded.

The active islanding detection method used in this work prevents such occurrence. Figs 6 and 7 show the inverter

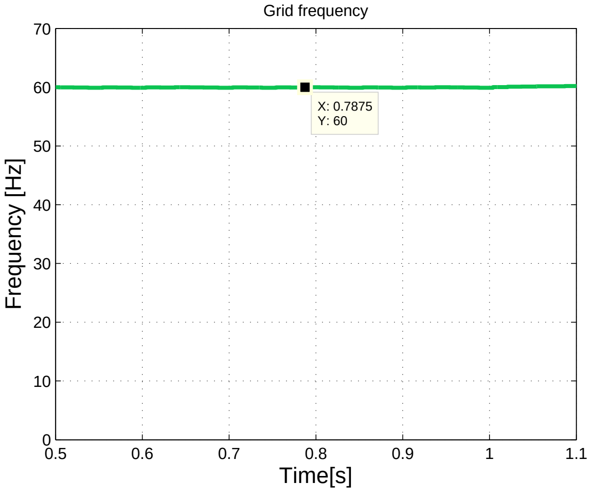

Fig. 5: Grid frequency measured by a PLL without the anti-islanding method.

output current reference and the actual output current with the implemented SFS anti-islanding method. When the grid is in full operation, the SFS method has a constant chopping factor that is represented by cf_0. Various values for δf were tested wherein for the presented results it is 0.9 and $k = 0.015$. This value is a good choice for the islanding detection.

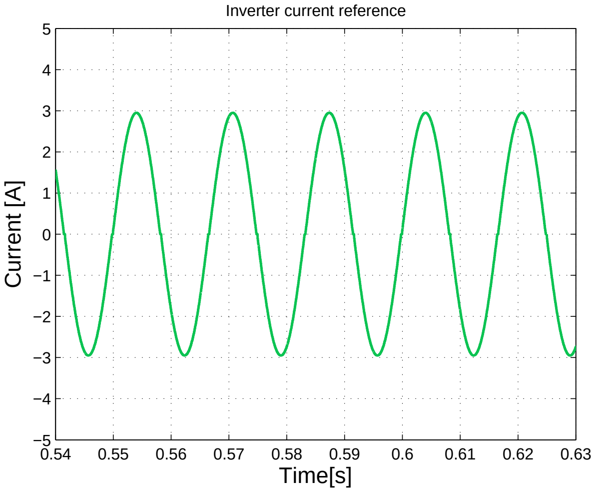

Fig. 6: Inverter output current reference with the SFS anti-islanding method.

Fig. 8 depicts the result obtained with the SFS method. It is possible to notice that the islanding was detected within 3.5 cycles of the grid voltage and it was able to meet the requirements of the IEEE standard. Depending on the factor k used the method can detect the islanding condition even faster. Fig. 9 illustrates the grid frequency measured by the PLL with the SFS method. There is a large frequency variation caused by it. When the utility grid is disconnected at $t = 1$ s the method forces the frequency to increase until it reaches the upper limit and trips the protection of the distributed generator.

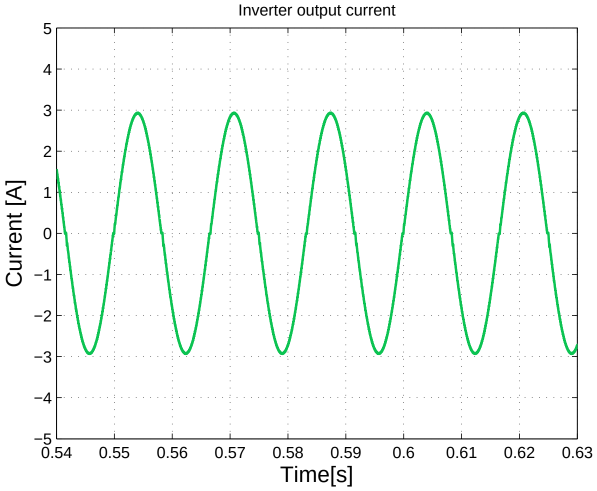

Fig. 7: Inverter output current with the SFS anti-islanding method.

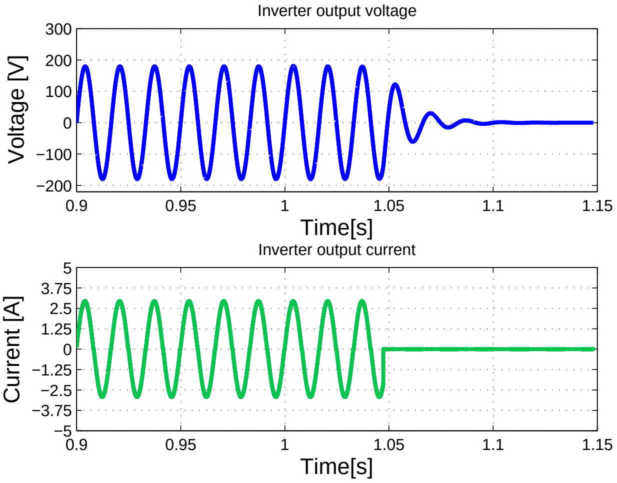

Fig. 8: Grid voltage and inverter output current during the simulation with the SFS method.

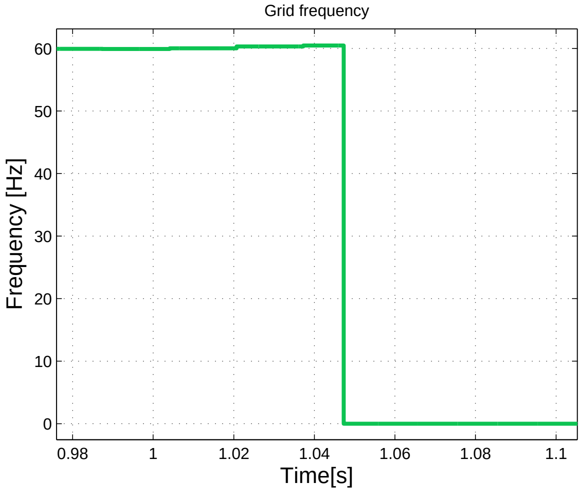

Fig. 9: Grid frequency measured by a PLL with the SFS method.

VII. CONCLUSION

The passive methods of UOF and UOV failed to detect the occurence of islanding. These methods are insufficiente when $\Delta P = 0$ and $\Delta Q = 0$. The inverter continued to power the islanded load. When the Sandia Frequency Shift method was used, the frequency of the PCC voltage was drifted by the injected current of the inverter and after 3.5 cycles the inverter stopped feeding the islanded part of the grid. The SFS method was able to detect islanding conditions within the 6 cycles required by the IEEE STD 929-2000 standard. Its time response could be improved using different values of k and cf_0.

VIII. ACKNOWLEDGEMENT

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