Testing and anti-islanding protections for grid-connected inverters

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***Abstract* – Nowadays, almost all photovoltaic and grid-connected inverters, have internal protections against islanding. Usually, these protections perform a disconnection from the grid when parameters go beyond over-voltage or under-voltage thresholds, as well as over-frequency or under-frequency thresholds. Furthermore, other methods are often added to the previous ones.**

In spite of the importance of anti-islanding protections, it is not easy to test on field thresholds, reliability and performances of these devices.

CESI RICERCA undertook the study and the development of a system that simulates a grid whose parameters may vary in a suitable way to cause the protections trip and memorise results. From this activity a first prototype has been assembled.

The testing system may verify the four main thresholds of anti-islanding protections (under-voltage, over-voltage, under-frequency and over-frequency) and their times of intervention. Furthermore, a suitable methodology is used to assess and measure parameters of the frequency-derive protection.

Index terms – Unintentional islanding, Photovoltaic inverters, Main-loss protections, Anti-islanding protections

I. Introduction

Basically, the protections inserted downstream photovoltaic plants have the aim of protecting these plants from those disturbs that should occur in the grid and, at the same time to safeguard the grid itself from possible failures of generation plants.

For this purpose, the Italian standard CEI 11-20 prescribes 3 different protection levels (FIG. 1):

– Generator device

– Interface device

– General device

The interface device is specifically conceived for power generators connected to the LV and MV grids. Its operating capacity is viewed as particularly important by electric utilities in order not to worsen the conditions of a line put temporarily out of service.

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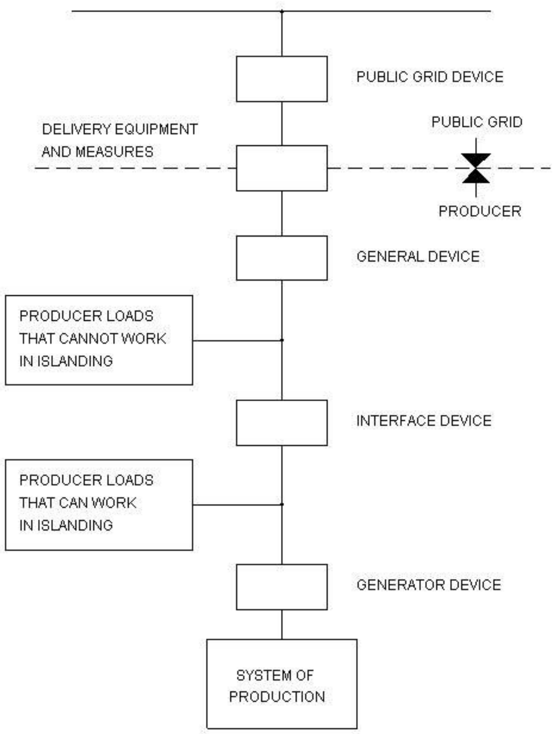

Fig. 1 – Levels of protection according to the standard CEI 11-20

The interface device along with its set of protections is used world-wide for the same purposes and they are usually referred as anti-islanding protections, main-loss protections or grid-loss protections. Further in the text they will be referred as anti-islanding protections.

Further than the Italian standard CEI 11-20 the prescriptions issued by electric utilities are most important because they contain all the technical details needed for a proper grid connection. In particular, the documents DK 5940 (for LV grids) and DK 5740 (for MV grids) issued by Enel refer to the most part of the national grid and they are usually considered as guidelines by other utilities.

In spite of its importance, a full test of the anti-islanding protections embedded in inverters is not easy to perform from outside. Most commercial inverters have an internal auto-check function that is certainly useful but cannot reproduce any real critical conditions on the field.

This paper takes into account only anti-islanding protections incorporated in small inverter, i.e. suitable for LV grid. Therefore only the documents CEI 11-20 and DK 5940 will be taken into account.

II. Main characteristics of anti-islanding protections

The aim of an anti-islanding protection is to detect grid failures and disconnect generators in order to avoid that the grid is energised in an uncontrolled way.

To obtain this result, in Italy is considered the following set of protections[1]:

- Low and high frequency
- Low and high voltage
- Frequency derive (only in special cases)

The figure 2 shows the basic circuit that uses these protections in photovoltaic applications. Note that the contactor is normally open.

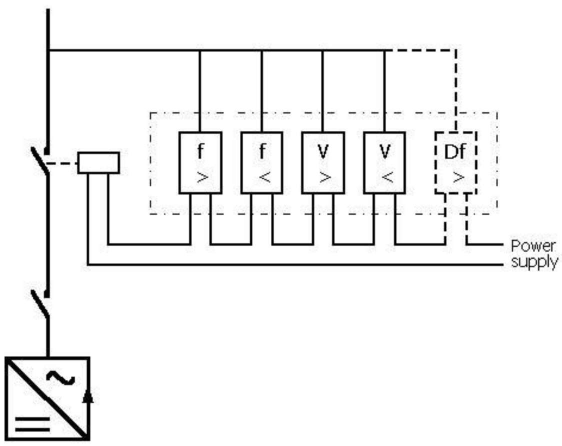

Fig. 2 – Basic circuit for interface protections

The table 1 reports the thresholds prescribed for the above mentioned protections.

Table 1 – Threholds for anti-islanding protections

Protection	Threshold value	Error
High voltage	1,2 × Vn = 276 V	≤ 5 %
Low voltage	0,8 × Vn = 184 V	≤ 5 %
High frequency	50,3 or 51 Hz[2]	≤ 20 mHz
Low frequency	49,7 or 49 Hz	≤ 20 mHz
df/dt	0.5 Hz/s (0.1÷1 Hz/s)	≤ 50 mHz/s

Table 2 – Max delays for anti-islanding protections

Protection	Delay of intervention
High voltage	≤ 0.1 s
Low voltage	≤ 0.2 s
High frequency	Without intentional delay
Low frequency	Without intentional delay
df/dt	Without intentional delay

III. Methodology

Tests on protections are performed by measurements of each threshold and the proper intervention of the disconnecting device (contactor). Furthermore, delays of intervention shall also be measured. Basically, results shall not exceed those reported in tables 1 and 2.

The figure 3 shows the general architecture of the test system. The functional requirements refer mainly to the voltage and frequency generator (reference generator) as well to the variable load.

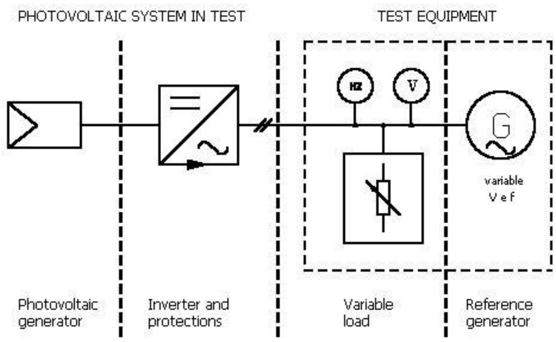

Fig. 3 – General architecture of the test system

[1] Further protections like impedence test, frequency shift, etc. may be used, but the paper considers only those mentioned in the documents taken into account

[2] Threshold of 51 Hz and 49 are allowed by Enel in particular conditions

With reference to the figure 4, thresholds shall be measured by varying continuously the voltage and frequency of the reference generator. The test begins from the central point (230 V, 50 Hz), then moving toward the first target until the device trips or a limit is reach. This action is then repeated for each protection.

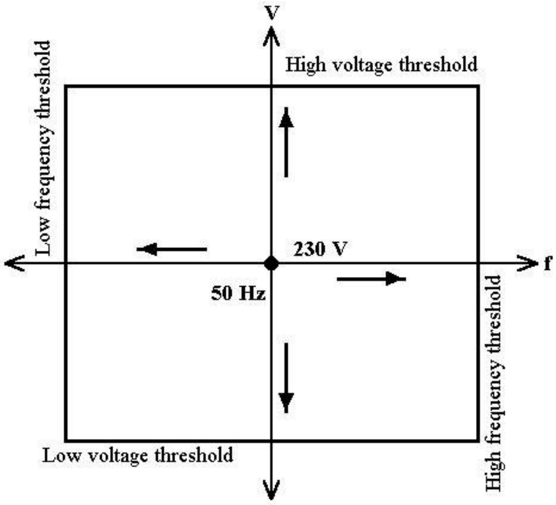

Fig. 4 – Test method

The test of frequency derive protection, when required, is also represented by the figure 4, considering the horizontal arrows. The acknowledgement of this intervention requires a trip before reaching a frequency threshold.

IV Measurement of voltage and frequency thresholds

Measurement must take into account tolerances on thresholds as indicated in table 1. Therefore for the testing system an error ≤ 10% of these tolerances has been stated. This means that measurement errors shall be kept under the following values:

High voltage: $\varepsilon \leq 0{,}1 \times 0.05 \times 276$ V thus $\varepsilon \leq 1.38$ V

Low voltage: $\varepsilon \leq 0{,}1 \times 0.05 \times 184$ V thus $\varepsilon \leq 0.92$ V

High frequency: $\varepsilon \leq 0{,}1 \times 0.02$ Hz thus $\varepsilon \leq 0.002$ Hz

Low frequency: $\varepsilon \leq 0{,}1 \times 0.02$ Hz thus $\varepsilon \leq 0.002$ Hz

The high precision needed for frequency measurements in many cases might be reconsidered, because they are difficult to obtain in practice.

A further source of error rises from the test dynamic. In fact, the measurement of thresholds implies a continuous variation of the parameter under test (voltage or frequency), from the starting point to the device trip. But the trip always occur with a specific late and thus the velocity or gradient of the measured parameter must be kept under a proper value, in order to consider this effect as negligible.

Therefore, considering this new error $\varepsilon_d \leq 0{,}1\ \varepsilon$, we obtain:

High voltage: $\varepsilon_d \leq 0.1 \times 1.38$ V thus $\varepsilon_d \leq 0.138$ V

Low voltage: $\varepsilon_d \leq 0.1 \times 0.92$ V thus $\varepsilon_d \leq 0.092$ V

High freq.: $\varepsilon_d \leq 0.1 \times 0.002$ Hz thus $\varepsilon_d \leq 0.0002$ Hz

Low freq.: $\varepsilon_d \leq 0.1 \times 0.002$ Hz thus $\varepsilon_d \leq 0.0002$ Hz

However, these new constraint do not need a higher precision of instruments, because a reduction of ε_d requires only a different dynamic of the system, that is a slower variation of parameters during tests.

Considering the maximum delay in table 2 and assuming 0.1 s for those not specified, if we introduce an error margin of 10%, we obtain:

High voltage: $(dV/dt)_{Max} = 0{,}138 / 0{,}11 = 1{,}25$ V/s

Low voltage: $(dV/dt)_{Min} = 0{,}092 / 0{,}22 = 0{,}42$ V/s

High freq.: $(df/dt)_{Max} = 0{,}0005 / 0{,}11 = 4{,}55$ mHz/s

Low freq.: $(df/dt)_{Min} = 0{,}0005 / 0{,}11 = 4{,}55$ mHz/s

It is possible to note that the two gradients of the frequency are well below the minimum threshold for the frequency derive (0.1 Hz). This means that these measurements cannot interact.

Under the above assumptions, the times required for each test, using a uniform gradient, are the following:

Low and High frequency:	65.9 s
High voltage:	36.8 s
Low voltage:	109.5 s

Times increase if frequency thresholds are set at 49 Hz and 51 Hz. In this case each measure takes 219.8 s.

V Measurement of the frequency derive

The measure of the frequency derive needs a feasibility verification. This is needed because the protection must trip before a frequency threshold is reached. Should this condition not satisfied, it would be impossible to discriminate between a frequency derive intervention and a frequency intervention.

Considering the worst case (> 1 Hz/s + 10% of error margin) the time available is about twice the time needed (0.23 > 0.11) and thus the condition is verified.

However the measure of the frequency derive needs more than a test, i. e. two at least in order to verify the non-trip condition under 0.1 Hz/s and the trip condition above 1.1 Hz/s. Furthermore, if both directions (positive and negative) are investigated the minimum set is four.

VI Measurement of the intervention times

Differently from the measure of thresholds, which requires a ramp variation, the measure of the intervention times requires a step.

This is made by means of instantaneous variations from the start point toward each direction. Variations must be wide enough to carry the point outside the specific threshold. Then, a simple counter measures the time from the beginning to the device trip.

Concerning the frequency derive, the method is the same, but the shift must not go beyond the frequency thresholds.

VII. System analysis and requirements

If we consider the test of protections on field, the power produced by the inverter in quite unpredictable and furthermore, the behaviour of this component is similar to a current generator.

Therefore, the test circuit needs a stable generator, which may vary voltage an frequency, and a variable load, in order to absorb the power generated. The figure 5 shows the equivalent electric circuit of this system.

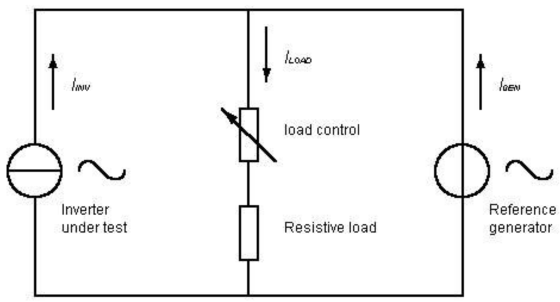

Fig. 5 – Equivalent circuit of the test system

The reference generator has a limited output power and so the load control must follow the power generated by the inverter in order to keep I_{GEN} positive and lower than its maximum value. This control is made by acting on the Duty-factor D of the PWM circuit referred as Load control. This modify the load resistance R_c as follows:

$$R_{eq} = \frac{R_c}{D}$$

Thus, the current supplied by the reference generator is:

$$I_{GEN} = I_{LOAD} - I_{INV} = \frac{V}{R_{eq}} - I_{INV} = \frac{V}{R_c} \cdot D - I_{INV}$$

Two different control circuits have been taken into account:

- Open-loop control
- Closed-loop control

Furthermore, the closed-loop control could be made by using independent measures of V and I or their product by means of a power transducer. In the project this last option has been chosen (figure 6).

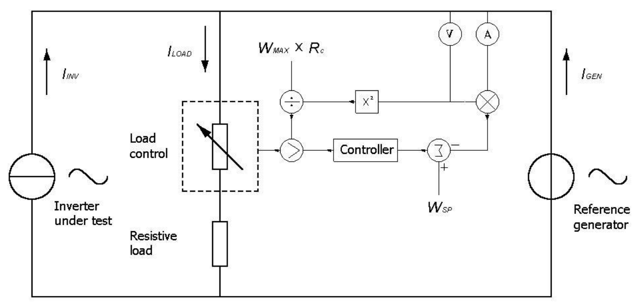

Fig. 6 – Closed-loop control with the power used as input

In the figure 6 it is possible to note a branch that introduce a limitation on power by comparing the signal generated by the controller with another proportional to V^2. This is for the safeguard of load that, under some circumstances should dissipate a power above its possibilities. Thus it must be verified the following:

$$\frac{V^2}{R_{eq}} \leq W_{MAX}$$

that in terms of the control variable D becomes:

$$D_{MAX} \leq \frac{R_c \cdot W_{MAX}}{V^2}$$

X Acknowledgements

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