

## Photovoltaic system behaviour with different loads.

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**Abstract.** This paper presents the analysis of influence of different loads, when these loads are connected to a small photovoltaic system. By means of tests, the interactions between the photovoltaic system and the different loads is visualized and analyzed. To achieve this goal, a sequence of starts and stops is established that are repeated with all the loads. Different parameters and wave forms have been registered to analyse the influence on the power quality. This process allows comparing the behaviour of each load in the electric network. In next future, the measured values will be used to contrast results obtained by means of simulations.

### Key words

Photovoltaic system, power quality, harmonic, flicker.

## 1. Introduction

Photovoltaic energy, is becoming one important way for obtaining energy. It consists on the conversion of solar radiation into electric power. This conversion is carried out in solar cells and, an energy with an almost null environmental impact is obtained. The systems require low maintenance and are easily monitored for their vigilance. The installations can be located near of the evacuation or consumption points and reduce transport distances.

One of the problems of this type of energy is the abrupt changes that occur in generation, because this depends on the existing solar radiation and a cloud can reduce the generation instantly. In winter the radiation decreases, and at night the production is zero. Therefore it is difficult to plan the amount of energy to be produced.

The photovoltaic modules can be operated isolated or connected to the grid but in both cases, to convert the solar radiation into electric power, different instruments are required. This new installed equipment, particularly the inverters, can introduce disturbances. These disturbances affect to the power quality and is necessary keep them in appropriate values.

The objective of this paper is to present the obtained results when analyzing different power quality parameters in an isolated photovoltaic system.

## 2. PV System Components.

The components in a system connected to the grid are:

- Solar Panels: Is the essential component that changes light into electricity. The solar cells can be "Single crystal silicon" or "Polycrystalline silicon". Polycrystalline silicon is cheaper than single crystal silicon but not as effective in energy conversion.
- Inverters: Is the component that transforms DC into AC. Has great influence on the power quality.

In a isolated system besides is necessary:

- Charge controller: Controls the energy flow to the battery and from the battery.
- Batteries. In solar energy systems a lead-acid deep cycle battery is used. This type of battery is designed to be more tolerant with the cycles of charging and discharging.

## 3. Tests.

To analyze the influence of photovoltaic systems in the power quality supply, different parameters are considered. Some of them are the following:

- Disturbances in amplitude: voltage dip, supply transient interruption, overvoltage, transient events, voltage fluctuations, flicker...
- Disturbances of the frequency.
- Disturbances in the wave form, harmonics
- Disturbances in the symmetry: voltage or current unbalances.

Besides the photovoltaic system components, (panels, batteries, regulator and inverter), different loads have been used in the developed tests. These loads are:

- 2 energy saving lamps.
- Set of 50 leds.
- Set of 8 fluorescents lamps.
- 1 small single-phase electrical motor.
- 1 low pressure sodium vapour lamp.
- 1 high pressure mercury lamp.

On the other hand, the power quality portable analyzer of Fluke 435 (CLASS A) is used as measurement equipment to register the different events. For the results analysis, the software "Power Log" of Fluke is used. The figure 1 shows the system used to perform the test.

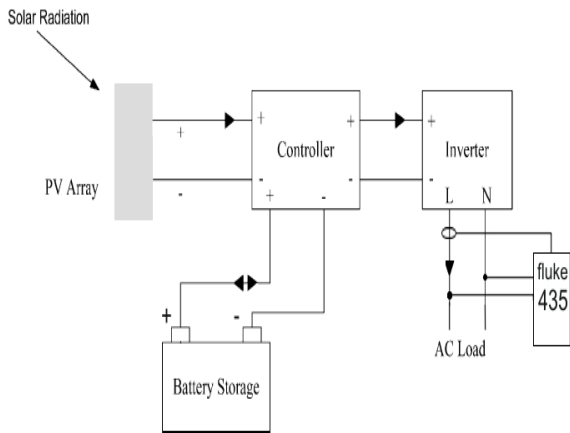


Fig. 1. Isolated system.

To analyse the behaviour of the photovoltaic system, different tests are performed. In these tests, the different loads are connected to the photovoltaic system and normal operation is emulated with starts and stops. A working protocol has been established. This protocol sets out the operating times and the starting and stopping (both hot and cold), for each load.

For the first four loads, the protocol times are the same. It starts with a cold-start up and the load stays connected for a minute until temperature is reached. The load turns off and then reconnects 30 seconds later, to make a hot start-up. After one minute a fault is simulated, and the inverter is turned off for 30 seconds. Finally the inverter with the load is connected for another 30 seconds.

The latest tests with discharge lamps have been done. The discharge lamps need a longer start-up time, and thus the sequence has been changed.

Moreover, the recording instrument is placed at the inverter output and is configured to capture the same parameters in all the tests.

#### 4. Results.

##### A. Energy saving lamps

At the inverter output (figure 1), 2 energy saving lamps (25 watts) and the portable analyzer are connected. The switching sequence takes 3 ½ minutes as follow:

1. The load is connected one minute.
2. The load is disconnected for 30 seconds.
3. The energy saving lamps are connects for 1 minute again.
4. The inverter is disconnected 30 seconds.
5. Inverter and load are connected 30 seconds.

In figure 2 the graph of the voltage and current obtained by the measuring instrument can be seen.

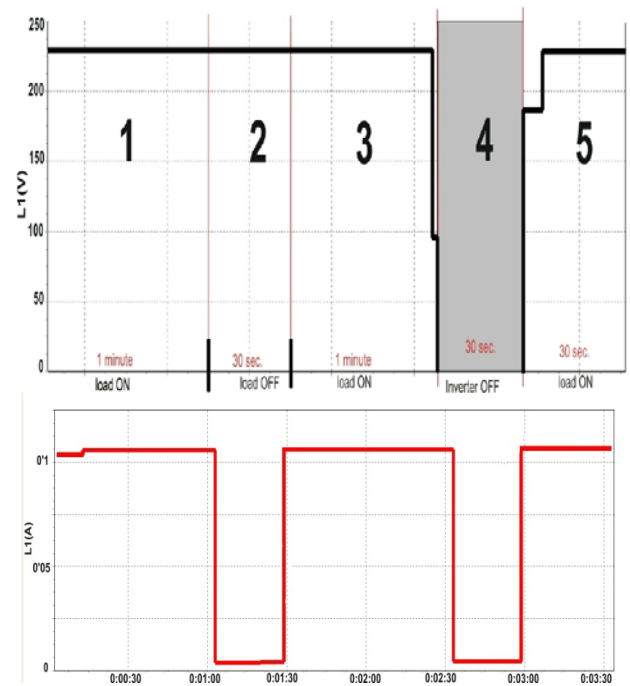


Fig. 2. Voltage and current signal at the inverter output.

The event recorder has captured 3 events: 1 voltage dip and two interruptions in this time interval (Fig. 3). But all of them related with the supply interruption when the inverter is disconnected. When the load is disconnected, signal the power quality is unaffected. A low power charge does not affect the signal of the inverter.

Eventos del registro				
START 09/01/10 15:37:06		EVENT 3 / 3		
0:03:31				
DATE	TIME	TYPE	LEVEL	DURATION
09/01/10	15:39:38:374	L1 DIP	0.0 U	0:00:31:892
09/01/10	15:39:38:394	L1 INT	0.1 U	0:00:00:050
09/01/10	15:39:38:484	L1 INT	0.0 U	0:00:30:929
09/01/10 15:40:38		230V 50Hz 1Ø		EN50160
		NORMAL		
		DETAIL		METER TREND

Fig. 3. Events of register.

It can be appreciated that the deformation in the waveform is high. The level of harmonics and the THD for voltage and current is showed in figure 4.

The THDi is produced by load. Although it is a very high value, the current magnitude is very small, and problems such as the risk of heating in the conductors are zero. THDv is produced by generator as a result of the distortion of the current.

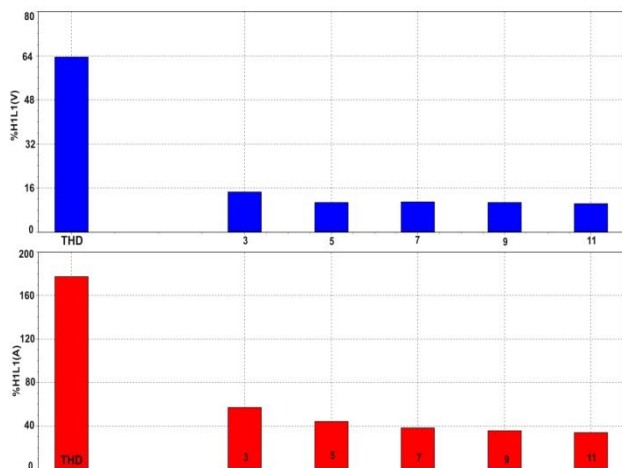


Fig. 4. THD and harmonics (V and I).

*B. Set of 50 leds.*

At the inverter output 50 LEDs (55 watts), and the Fluke 435 are conected (figure 1). The switching secuence is the same as for energy-saving lamps (section 4.A). The results obtained are equivalent to those obtained with low energy lamps. The event recorder has captured 3 events during the supply interruption, 2 voltage dip and 1 interruption when the inverter is disconnected. The THD values are lower than in the previus section but still high, as shown in Figure 5.

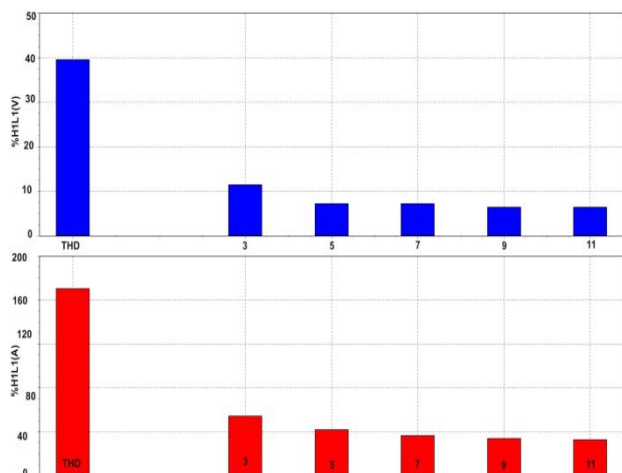


Fig. 5. THD and harmonics (V and I).

Since power and current magnitudes are very low, the importance of these values is limited since the generator and the conductors will support these values without problems.

*C. Set of 8 fluorescents lamps.*

At the inverter output 8 fluorescents lamps (144 watts) and the Fluke 435 are conected (figure 1). The switching sequence is 3 ½ minutes as in the previous cases. The event recorder has captured 7 events: 5 voltage dips (t < 100 ms.), 1 over voltage when the lamps are turned off and one interruption (with the inverter switched off).

THD values are in an acceptable range, below 10%. Figure 6 shows a time evolution of the harmonics. During normal operation of the system, the values are low. However, during the disconnection of the inverter, this electronic device generates higher values.

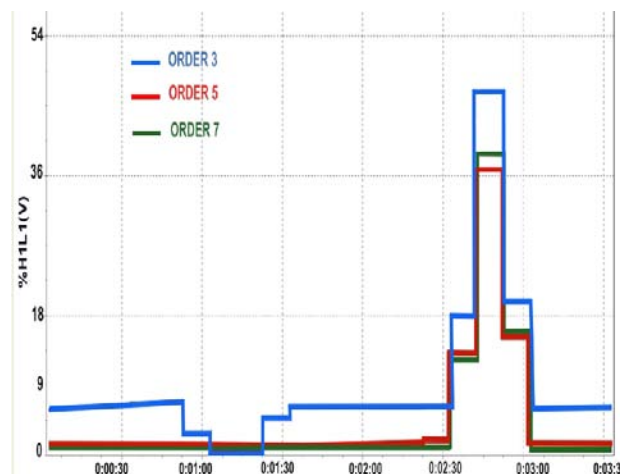


Fig.6. Temporal evolution of harmonics.

In this same interval, the recorder has captured eight transients as the result of the switching of the inverter. All of them have occurred when the inverter is starting after the interruption. The transients have an important effect on some types of load. They can produce deprogramming (PLC's...) or erratic behaviour caused by the interferences over a data bus for example but in this test the fluorescents lamps are not affected by transients. Figure 7 shows the first of the 8 captured.

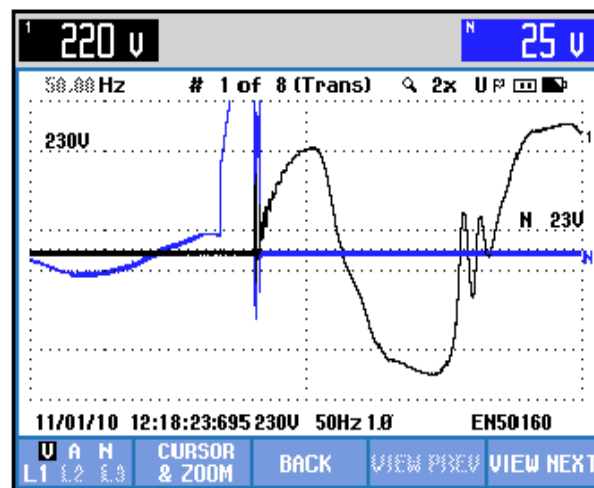


Fig.7. Captured transient.

*D. Small single-phase electrical motor.*

At the inverter output a small single-phase electrical motor (120 watts) and the Fluke 435 are conected (figure 1). The switching sequence is 3 ½ minutes as in the previous cases. During the first minute of operation, the motor is rotating in vacuum. In the second minute the motor is working with charge. In figure 8 current and voltage evolution for this time interval can be seen.

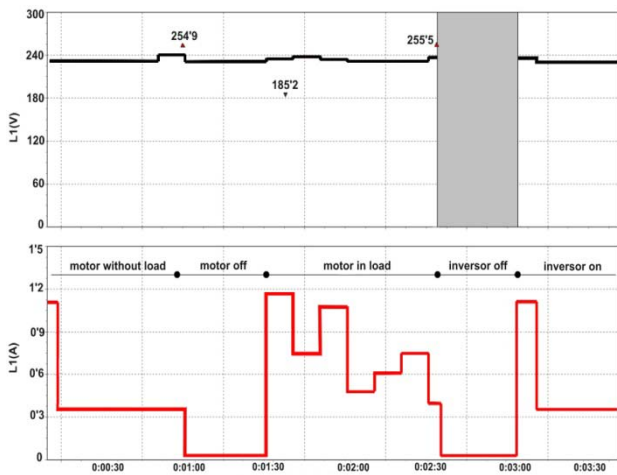


Fig.8. Voltage and current signal at the inverter output.

During the second interval of operation, the electrical motor has been forced by a non-constant load, (as seen in figure 8). Also, there is a voltage dip (185'2V) with a duration of 130 ms, as can be seen in figure 9. Probably it is due to an overload on the electrical motor. Its rated current takes a value of 0'6A and in that moment consumption is 1'2 A, (Fig. 8).

Fecha	Función	Duración	L1 Min	L1 Med	L1 Max
11/01/2010 12:29:45 663ms	THD V		1,68%	1,72%	1,77%
11/01/2010 12:29:45 663ms	THD A		167,11%	179,24%	189,96%
11/01/2010 12:29:45 663ms	THD W		1,29%	5,1%	64,26%
11/01/2010 12:29:45 663ms	Pf1			0	
11/01/2010 12:29:45 663ms	Pst			0	
11/01/2010 12:29:52 959ms	Hueco	0m. Os. 130ms.	185,2V		
11/01/2010 12:29:55 663ms	Tensión		209,29 V	229,46 V	233,94 V
11/01/2010 12:29:55 663ms	Corriente		0,024 A	0,572 A	1,168 A
11/01/2010 12:29:55 663ms	Peak Voltage		303,5 V	333,4 V	341,8 V
11/01/2010 12:29:55 663ms	Peak Current		0,03 A	0,446 A	1,594 A
11/01/2010 12:29:55 663ms	V Factor de Cresta		1,35	1,45	1,63
11/01/2010 12:29:55 663ms	A Factor de Cresta		1,36	327,67	327,67
11/01/2010 12:29:55 663ms	Half Cycle Voltage		185,17 V	229,44 V	237,99 V
11/01/2010 12:29:55 663ms	Half Cycle Current		0,022 A	0,572 A	1,171 A
11/01/2010 12:29:55 663ms	Potencia Activa		0 W	65,333 W	256,667 W
11/01/2010 12:29:55 663ms	Potencia Aparente		5,333 VA	73,333 VA	268 VA
11/01/2010 12:29:55 663ms	Potencia Reactiva		-6 VAR	24 VAR	116 VAR
11/01/2010 12:29:55 663ms	Factor de Potencia		-0,01	0,27	0,98

Fig.9. registered values.

Besides 2 over-voltages have been detected (figure 10). This situation is due to the fact that the motor (inductive load) causes a over-voltage at the time of disconnection.

Fecha	Función	Duración	L1 Min	L1 Med	L1 Max
11/01/2010 12:29:05 663ms	THD V		1,27%	1,28%	1,3%
11/01/2010 12:29:05 663ms	THD A		4,33%	4,39%	4,46%
11/01/2010 12:29:05 663ms	THD W		0,02%	0,03%	0,03%
11/01/2010 12:29:05 663ms	Pf1			0	
11/01/2010 12:29:05 663ms	Pst			0	
11/01/2010 12:29:14 910ms	Pico	0m. Os. 40ms.			254,9 V
11/01/2010 12:29:15 663ms	Tensión		227 V	229,98 V	239,23 V
11/01/2010 12:29:15 663ms	Corriente		0,024 A	0,335 A	0,358 A
11/01/2010 12:29:15 663ms	Peak Voltage		326,4 V	329,5 V	366,4 V
11/01/2010 12:29:15 663ms	Peak Current		0,03 A	0,512 A	0,566 A
11/01/2010 12:29:15 663ms	V Factor de Cresta		1,42	1,43	1,53

Fig.10. registered values.

The values of harmonics, as shown in figure 11, can be considered within the correct margins.

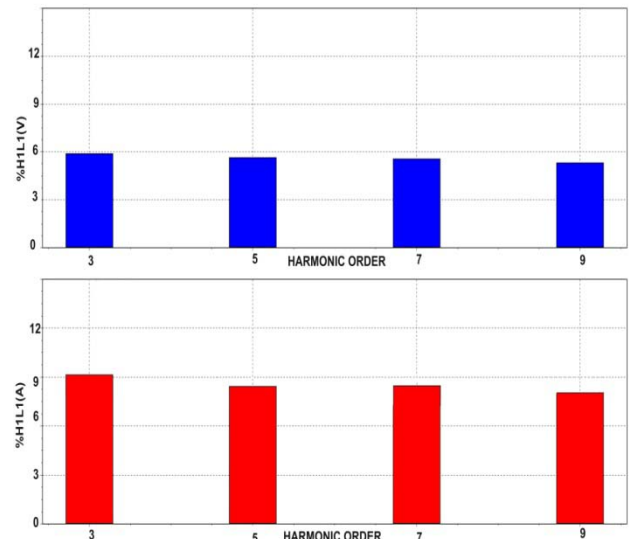


Fig. 11. Values of harmonics (V and I).

### E. Low pressure sodium vapor lamp.

At the inverter output, a low pressure sodium vapour lamp (55 watt) with his ballast and the Fluke 435 are connected (figure1).

The total starting time of a discharge lamp is longer that other lamps, therefore the working protocol has been changed:

1. The load is connected and stays until it stabilizes, about 12 minutes.
2. The inverter is disconnected for one minute.
3. It connected again and is maintained until stabilization, about 2 minutes.

In figure 12, voltage and current evolution for the last minutes of test can be seen.

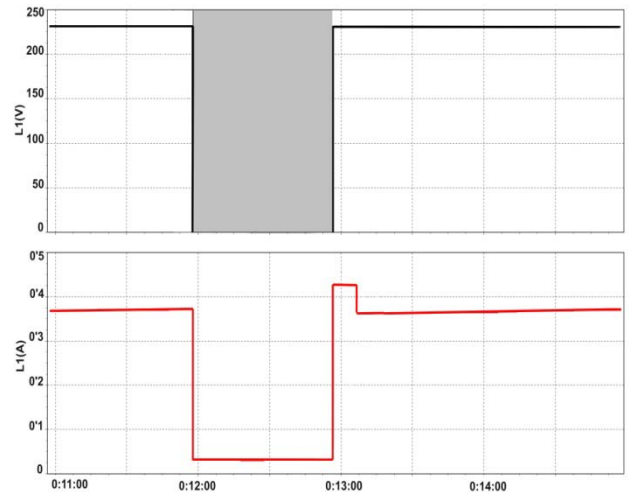


Fig.12. Voltage and current signal at the inverter output.

After disconnecting one minute, the inverter is reconnected and the lamp starts up normally. However, a small interval of time is needed to regain the previous state. The register does not detect any interruption.

The inverter has generated five transients during reconnection, such as that shown in figure 13.

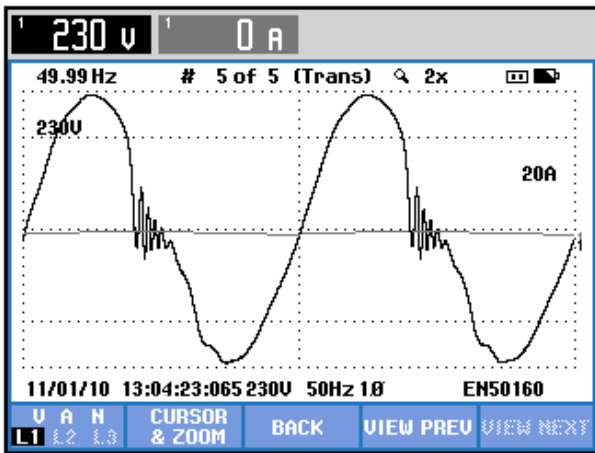


Fig.13. Captured transient.

*F. Low pressure sodium vapor lamp and the discharged battery.*

When batteries are discharged, the inverter tries to keep the load only with the energy produced in the PV array. If the energy generated is not enough, the inverter makes a connection attempt per second. In figure 14 can see as after about 30 seconds, the energy generated by the sun is enough, and the normal operation of the load is restored.

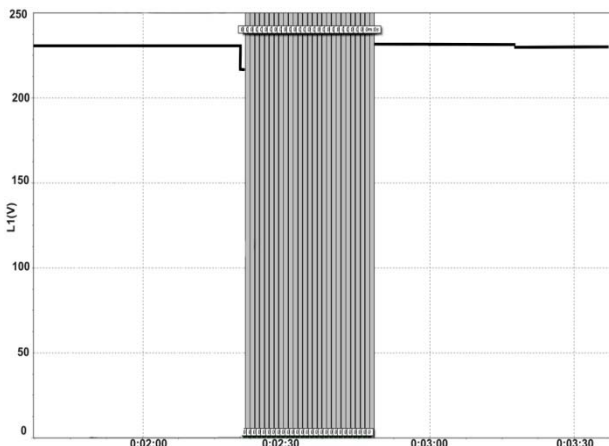


Fig.14. Voltage signal at the inverter output.

During this period, 29 voltage dips and 21 transients were identified.

In this situation, the inverter injects disturbances to the grid. These disturbances should be corrected if for example, there are sensitive loads connected or the system is connected to the grid.

*G. High pressure mercury lamp.*

At the inverter output, a high pressure mercury lamp (125 watt) with his ballast and the portable analyzer are connected (figure 1).

As with the low pressure sodium vapour lamp, the working protocol has been changed:

1. The load is connected and stays until it stabilizes, about 4 minutes.
2. The inverter is disconnected for 30 seconds.
3. The inverter is connected again, but the lamp needs more time to reconnect. It is necessary to wait for the mercury to condense. When this

happens, the arc is striking again and the lamp starts as can be seen in figure 15.

4. Is maintained until stabilization, about 2 minutes.

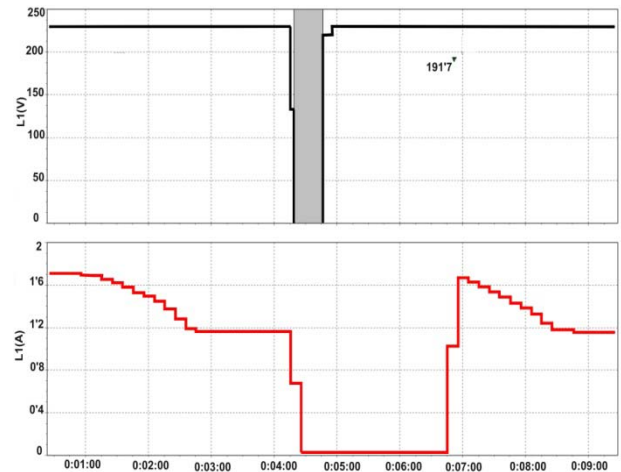


Fig.15. Voltage and current signal at the inverter output.

In this test, we must mention that only a voltage dip is generated at the time of reconnection, and as shown in figure 16 the harmonic level is good. The harmonic of order 3 is the most significant but all are within the correct margins.

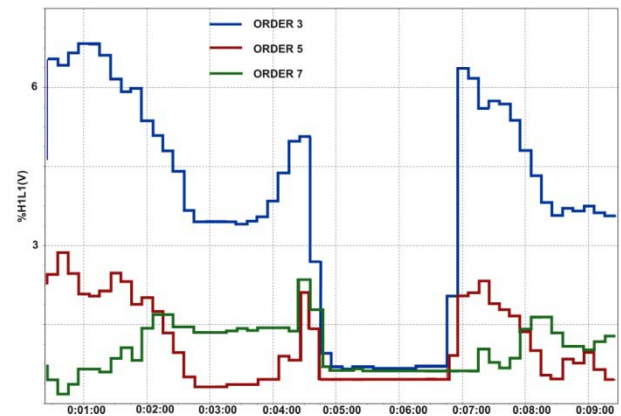


Fig.16. Temporal evolution of harmonics.

During reconnection, 6 transients as shown in figure 17 have been captured.

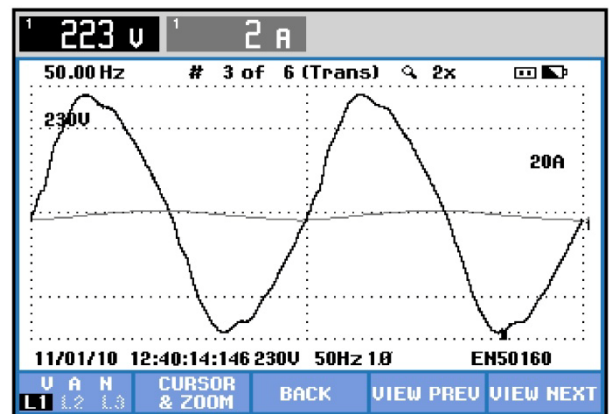


Fig.17. Captured transient.

With this type of load, the disturbances are less and with magnitude smaller that with other loads.

## 5. Conclusion

The system tested is a low power system. The loads were chosen in function of this system, but represent loads typically used. In summary, we conclude:

- With all different types of loads major disturbances occur.
- These perturbations are always associated to commutations of the load. Sometimes is the connection or disconnection of the load, sometimes it's the start of the inverter, but always important voltage dips occur.
- In some cases, the total harmonic distortion (THD) is too high.
- As is an isolated system has no significance in the grid. If has been connected, would be necessary to correct this situation.
- As is a low-power system, the inverter is a weak generator and is very sensitive to the type of load that feeds.
- It remains for later analysis test with a more powerful system and connected to the grid.

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