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Real Problems in Utility High Voltage Network due to Grid Connected Photovoltaic Power Generation. The experience of Endesa.

Javier de la Cruz[1] & Pedro Gómez[2]

[1] Endesa Distribución Eléctrica S.L.U.
Escudo del Carmen 31, 18009-Granada, España
francisco.javier.delacruz@endesa.es

[2] Grupo de Investigación IDEA,
Escuela Politécnica Superior, Universidad de Jaén,
Campus de las Lagunillas 23071 - Jaén, España
pvidal@ujaen.es

Abstract. Photovoltaic (PV) systems require connection to a utility power grid to work effectively as energy sources. Numerous problems and unusual configurations have been detected in those connections: Some problems are due to a dysfunction of the faulted-phase relay protection on Substations (Sub.) not originated in all cases by phase imbalance of the PV inverters, other problems are related to an abnormal stationary (resonant) state of generation just after islanding of the plant, where frequency and amplitude of the power signal are in a corrupted stable state caused by the inverters. The final problem to be discussed is related to switch-on sequencing and associated starting inverter's problems.

Key words

Power inverter; Substation; switch-on sequence; faulted-phase relay; harmonics

1. Introduction

Due to the increasing demand of Photovoltaic (PV) power generation in the general amount of power generation within the network grid, connection problems have occurred as a result of these installations and have become greater than ever. In addition, a greater degree of custom engineering of the utility-PV interface and inverter's technology is to be expected as the size of PV system grows in relation to utility system capacity [1]. In order to avoid the increasing amount of power quality problems related to the interconnection of PV plants and utility grid, we understand that a close study of these problems is needed [2] [3] [4]. Based in our long experience [5] since the PV technology was born, in the connection of large PV plants to our power grids, we will discuss these issues like support of future massive implantation of this kind of technologies. Furthermore, no scientific literature about the real problems of these connections has been found. Endesa is one of the largest electric companies in the world and leader in PV Generation and Technology.

2. Problems in the HV power network

A. *Substations (Sub.) and their PV connected systems*

We based this study on our experience with problems involving the following plants, connected with our power grids:

- Type I: a 10 MW PV plant, three-phase inverters and solar tracking panels
- Type II: a 10 MW PV plant, three-phase inverters and solar tracking panels, same as Type I but with a dedicated Sub.
- Type III: a 4 MW PV plant, mono-phase inverters and fixed panels
- Type IV: a 30 MW PV plant, mono-phase inverters and solar tracking panels
- Type V: a 2 MW PV plant, three-phase inverters and fixed panels

3. PV & Sub's Protection Problems

A. *Description*

A 20Kv. power line is connected to a Type I installation. Endesa had a frontier automatic remote recloser (RECTEL) in the PV-utility interface and an old electromechanic Sub. Protection switch at the end.

Due to problems of untimely release of the Sub. switch, we decided to install a new one. It was clear that there was a misunderstanding of the 2 switchers because the Sub. switch protection fires too as same as RECTEL when the problem were downstream.

After that, the problems still happened, so we were forced to install measuring equipments to analyze the problem on RECTEL.

We observed numerous faults of faulted-phase protection relays and overcurrent protections. We compared the interruption events in the network grid between the faults, observing that part of the faults were resistive faults as no faults in the Sub HV power bars were detected. The rest were associated to HV gaps and originated the fault of the two protections: faulted-phase and overcurrent, so there was no clue about the origin of the problem.

After a long investigation, we observed that the overcurrent relay release's problem were associated with a bad isolation of a toroidal transformer in the Sub. that made the false resistive faults. But not all problems were solved. Why was the faulted-phase firing?

After the measuring results, we did not observe a real imbalance phase problem in normal operation. In order to maintain the service, we decided to eliminate faulted-phase relay of the Sub. switch in this case. This protection operates when an open phase is detected, due to a wiring break of one of the 3 wires during normal operation. Several imbalances such as that to the relay appear but they were not real imbalances.

Type I, II and V installations have three-phase inverters, so a phase imbalance could not be expected as in mono-phase inverters (Type III and IV) and the measuring results confirm that. However, the protection was making fault release, so the problem should be inside the inverter, as initial line of investigation.

In a Type II plant with the same problem, we made a programmed malfunction of the PANTAM Sub. transformer's voltage regulator, lowering it from 17 Kv. to 15 Kv. No problems were observed, but when we increased the value, by turning up the voltage to its normal level (17 Kv.) the inverter got into in a stable state point with significant imbalances between phases and currents modulated at low and high frequencies (Fig. 5,6,7 & 8).

The manufacturer's engineering team thought that the problem was due to the 8th and 10th harmonic produced by the inverter (Fig.6). But after a change in the programming of the internal logic to solve that, the problem was still occurring.

Further detailed analysis was required. After time in the manufacturer's central laboratories, they concluded that there was a problem when setting up the electrical impedance in the internal control software of the inverters, not observed before.

This equipment malfunction resembled a resonant state, and only was visible when the equipment, conditions and factors were the right, just as in the case of this installation, so the result is not extensive either Type I plant previously described because have different inverter's manufacturer, or the other PV plants explained, because the different conditions. After a new programming of the inverter, the problem disappeared. The manufacturer made the changes to equipment with same problem in a plant not described in the paper with the same good result

The Type V was another special case: The faulted-phase protection relay was an old model that operated only with the real value of measured intensity imbalance, not with the calculated inverse sequence's absolute value, so at very low ranges of intensity, a little imbalance could be greater than 100% of the current value, but not calculating their inverse sequence in absolute value. Modern relays use this kind of calculation.

The whole switch was replaced for a new one, including its faulted-phase relay, but the new relay needed to be eliminated as well, for continuous interruptions of the Sub switch.

B. *Measuring Equipment Results*

After installing measuring Class A equipments in RECTEL and inverters HV outputs in Type I and II plants, we obtained the following graphics:

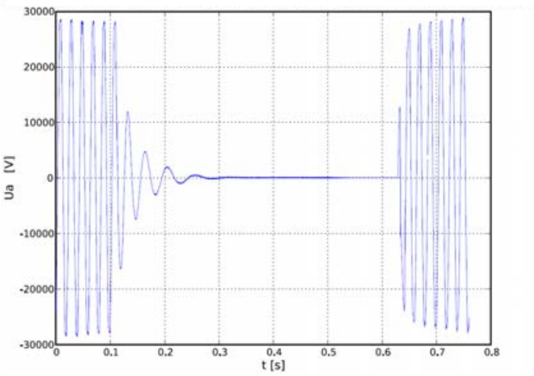

Figure 1. Waveform of the signal in the fault and reclosing in Type I plant

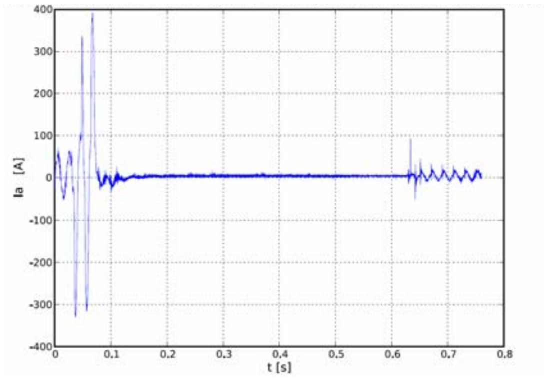

Figure 2. Current level (similar in the 3 phases) in the fault and reclosing in Type I plant

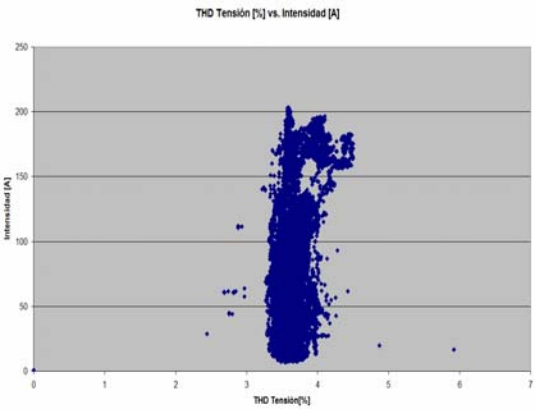

Figure 3. THD vs. current in Type I plant. The value is around 4%, very high compares to the normal Sub value (1.5%) but under the recommended 5% [5].

This is an important indicator of the quality and good design of the inverter: High cost inverters offers low THD values

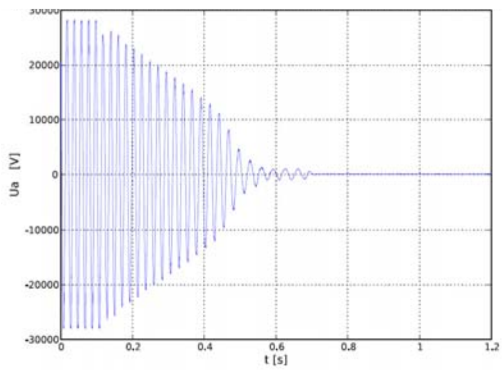

Figure 4. Type I plant. Example of a normal switch off. Abnormal 40Hz. generation state after islanding of the plant

We couldn't see any abnormal behaviour in this graphic with the exception of the strange pure 40Hz. generation (less than the 50 Hz. standard in Europe) with a constant slope ratio between voltage and time, just after the islanding of the PV installation and subsequent switch off of the generation power when the real value is under 20%-25% of nominal power. This situation holds up for around 0.5 sec.

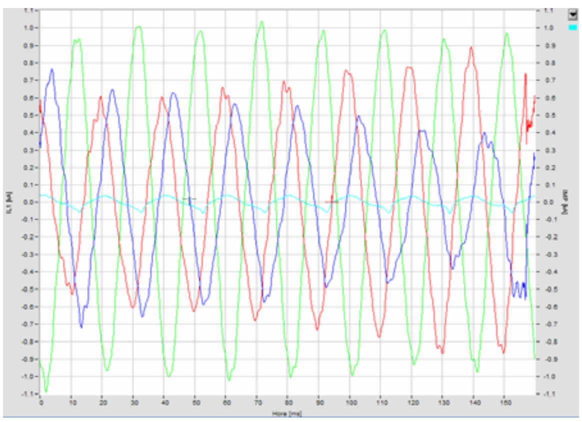

Figure 5. Type II plant: Waveforms of current and voltage.

We can see the irregular generation described in the resonant state. Obviously these problems could flow to our power grid making our quality parameters get worse

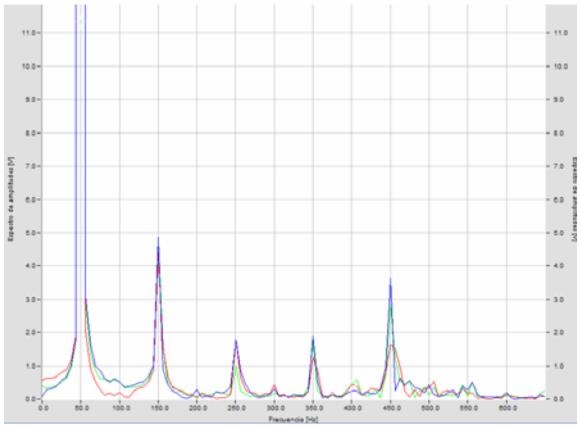

Figure 6. Voltage Phase & Neutral Harmonics in Type II plant

It's relevant the unique out of bounds value at 50 Hz. The other harmonic multiples, including the 8th and the 10th commented before by the manufacturer as origin of the problem, have low values in this case.

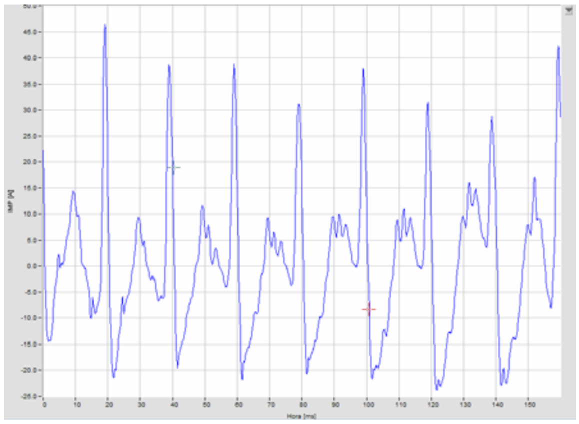

Figure 7. Type II plant: Neutral Intensity waveform with a peak over 45 A in the abnormal stable state.

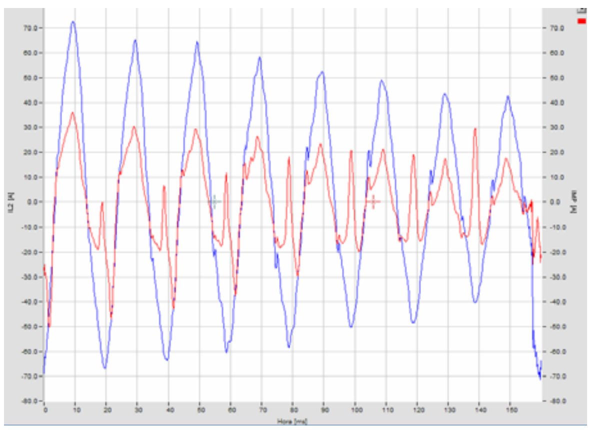

Figure 8. Phase & Neutral current waveform in the Type II plant during resonant state.

4 Mono-phase Inverters Switch-on Sequence & Starting Problems

A. *Description*

In Type III plant we have an unusual configuration of fixed panels with mono-phase inverters. In fixed panels, it is not necessary a predefined sequence order of the switch-on (starting) process, because all panels are equally illuminated, but in this specific PV plant have a determinate sequence.

The panels have a rack of 9 or 12 mono-phase inverters of 3 Kw. power. When the generation begins in the morning, the inverter with less hours of operation starts. Once the first 3 Kw. limit is reached, the next inverter starts too and finally the third one when the 6 Kw. limit it has passed, and so on for the 12 Kw. configuration. The rest of the inverters start by triples after this point.

This "exotic" configuration of the manufacturer causes a great degradation of the signal at low power levels (less than 22% or 18% of the nominal value) in the initial moments previously described. This state is defined also by a big imbalance of the phase values. One time the real power exceed the low nominal values, generation is well balanced.

B. *Measuring Equipment Results*

In order to analyze the problem, we installed our measuring equipments in the PV plant inverters, obtaining the following graphics:

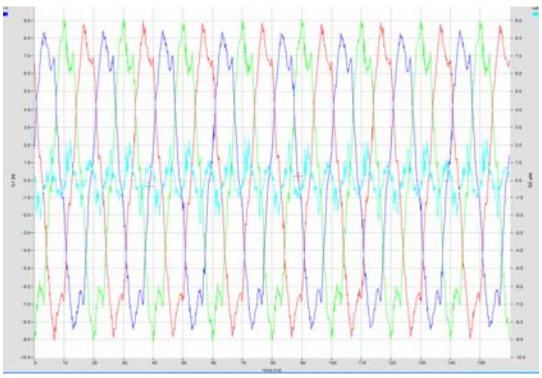

Figure 9. Current waveform in the starting process in Type III plant. The degradation of the signal values is evident

5 Distribution Transformer Degradation by Harmonics?

A. *Description*

In this case, we have a type IV plant. Each solar tracking panel has 3 mono-phase 5.5 Kw power inverter. We found that distribution transformers were inflating their heat sinks and finally got broken down. The manufacturer informed us that this effect originated by the distortions and harmonics introduced by the PV plant.

In the measure results we found that the harmonic emission in the low and high frequency LV band was negligible. In the initial instant of the connection the distortion was important, but this effect was so quick in time and cannot have caused great damage observed in the machines. Another relevant issue in the measurements is a neutral current with a dominant 3^{th} harmonic, but this current is negligible as well, like just a 5% of nominal value.

The PV system electrical output should comply with Clause 10 of IEEE Std 519-1992 [6]. The key requirement determines that the total harmonic current distortion shall be less than 5% of the fundamental frequency current at rated inverted output.

Another factor to discard the harmonic effect was the transform machines thermometer, which marked only 65ºC. of maximum temperature. If harmonic peaks were the principal cause, the main damage would have been overheating.

Finally, the clue was totally independent of the PV system. After a transformer's oil gases analysis, we discovered there may be internal problems of partial discharges or electric arcs in the transformer's core. After measuring partial discharges, we found that it was occurring. So, after all, this problem is not related to the PV plant and affected only the transformer's equipment.

B. *Measuring Equipment Results*

After the consequent installation of the measuring equipment, we obtain absolutely normal values in the inverter response as we can see below:

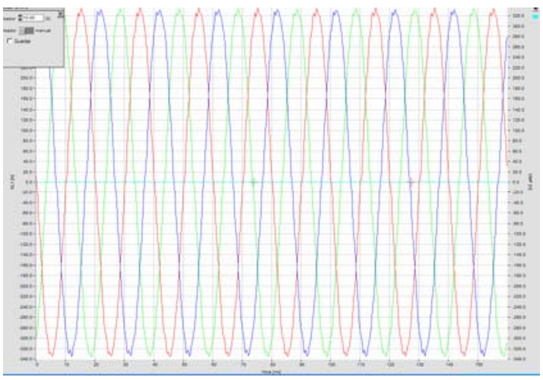

Figure 10. Type IV plant: Initial voltages in a serial panel starting

No abnormal behavior could be detected in this measurement discarding the harmonic effects

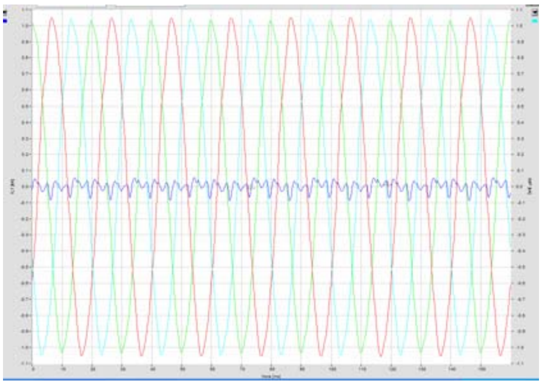

Figure 11. Currents at normal operation in Type IV plant. All values are in normal range.

6 Conclusion

After this study based in years of experience in this kind of connections described, we observe some conclusions and future lines of investigation:

- The faulted-phase relay causes the major number of interruptions and power HV lines reclosing. This behaviour is independent of technologies, topologies and manufacturer's fabrication and is present in ALL cases studied. Surprisingly it is not related to real phase imbalance. The solution in all cases was to disconnect the relay in lines connected to PV plants except in Type II plant, where manufacturer changed the software with success. In the rest of power lines not connected to PV plants, the relay works effectively. The clue could be in the parameters (response curves and software programming) of the relay when is connected to PV plants. This can be a future line of investigation for manufacturer's engineering.

- Harmonics only show significant problems at the starting of some kind of PV plants, but do not create relevant problems to Endesa power grid in normal conditions [5].

- The islanding effect is not regulated properly by all PV plants. Some of them show strange behaviour at the moment of the islanding but only for an instant. Fortunately its influence in the general amount of generation and quality values of Endesa power grid is currently negligible.

- The inverter is the most important element in a PV plant, observing quality parameters and signal balance. Taking into account that inverters are a very small part of the high economic inversion of this kind of plants, it is not recommended the use of cheap or not well-tested models. Furthermore, a more specific legal and technical regulation [5] [7] [8] [9] [10] by International Organizations and Governments of these equipments will be welcome.

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